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TRANSLATION

SCIENTIFIC PRINCIPLES FOR ENGINEERING AUTOMATIC CONTROL EQUIPMENT

By Various Authors

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FOREWORD

A special session of the Academy of Sciences of the U.S.S.R. dealing with scientific problems of industrial automation was held October 15 - 20, 1956.

The Trudy sessii [Proceedings of the Session] were published by the Publishing House of the Soviet Academy of Sciences. Altogether, seven volumes containing the materials of the plenary session and the work of the various section have been published as follows:

1. Plenary session (general problems).
2. Basic problems in automatic regulation and control.
3. Scientific principles for engineering automatic control equipment.
4. Scientific problems in remote control of industrial processes.
5. Scientific and technical problems in automated electric drives.
6. Theory and design calculation methods for automatic machines and automatic lines.
7. Complete automation of industrial processes.

The present (third) volume of Trudy contains the reports and discussions of the section on the scientific principles for engineering automatic control equipment.

The section considered ten reports on the most significant and promising trends in the development of the latest types of automatic control devices.

The reports made by B. S. Sotskov, N. N. Shumilovskiy and B. S. Sinitsin dealt with the general problems of developing the technical means of automatic control. The reports of L. I. Gutenmakher, B. I. Kolomiyits, V. M. Tuchkevich, D. V. Zernov, M. I. Yelinson and A. M. Kharchenko concerned the outlook for developing new types of electronic, semiconductor, magnetic, and dielectric noncontact devices.

The present state and prospects for the application of radioactivity for controlling industrial processes were discussed by B. I. Verkhovskiy, N. N. Shumilovskiy and G. G. Iordan. The report by L. D. Rozenberg was devoted to acoustic and ultrasonic devices.

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Problems in the industrial application of radio-frequency and mass spectroscopy were analyzed by A. M. Prokhorov, V. L. Tal'roze, N. N. Shumilovskiy and R. I. Stakrovskiy. The problems posed in the various reports were thoroughly discussed.

These reports and the discussions on them indicate the basic scientific tasks in developing the latest types of automatic control devices.

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MAIN TRENDS IN THE DEVELOPMENT OF THE THEORY AND PRINCIPLES FOR THE DESIGN AND CONSTRUCTION OF AUTOMATIC AND REMOTE CONTROL ELEMENTS

By

B. S. Sotskov

The present report seeks to examine the most significant and general problems in developing the theory and principles for engineering the elements and systems of automatic control, guidance, protection and regulation.

The work of designing and perfecting new types of devices and systems of automatic and remote control is proceeding at present on a wide scale. Still, many problems of industrial automation cannot yet be solved because of the absence of elements necessary for controlling a number of important technological parameters. Higher parameters -- mechanical (pressures, velocities), thermal (temperatures and thermal capacities), and electric (voltages, power)-- in new technological processes, and their rapid rate of change call for new types of pickups, amplifiers, and final control elements, which must possess quick response and greater limits and precision of sensing and transformation.

The importance and complexity of operations performed by automatic systems demand a high degree of stability of characteristics and performance reliability in these systems and their components.

The requirements for longer life and efficiency of individual components and complete systems are constantly on the rise. The great need of automatic and remote control elements requires the standardization of the basic types of such elements so as to make their mass production possible. Finally, the necessity of selecting components and devices for systems of automatic control, guidance and regulation, requires the adoption of criteria for the evaluation of their properties, performance and parameters.

The above factors will determine the main trends and tasks of research and development in this field for the next 10 to 15 years.

The basic theoretical task is the elaboration of a theory of transformations

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in elements and devices of automatic control, guidance, and regulation, and a theory of performance reliability of elements considered singly and in systems.

The development of a general theory of transformations must comprise a systematic examination of every possible physical transformation, whether direct or indirect (intermediary), so as to determine the possible relationships between varied input and output values. At the same time, the effect of all other values and factors must be shown so as to establish the constant value and possible error of the basic transformation selected for building the element.

The mathematical aspect of the theory of transformations should enable us to determine (by mathematical analysis) or derive (by mathematical synthesis) the required functional correlations between the values of input and output on the basis of known correlations of the individual elements and their components (parts). The theory of transformation accuracy should also be developed, taking into account the effect of internal and external factors on the characteristics and parameters of the transducer. It is necessary to work out both the static and dynamic problems of transformation precision of elements, devices, circuits and systems. This is an immense task in itself and is of basic importance to measurement technology as a whole. The study of dynamic accuracy is linked closely with the analysis of the dynamics of complex systems of elements having a different physical nature and a complex relationship.

Finally, we must solve mathematically the problem of obtaining constant value (autonomicity) of the required transformation by setting up a suitable structural scheme of the transducer -- differential, logometric, or compensatory.

We still find ourselves in the stage of individual (sometimes quite interesting) studies dealing with particular problems of the general theory of transformations. Preliminary work is now being done toward formulating the basic elements. It is necessary to accelerate this maturing process because of the immense importance of this basic theoretical foundation for the further development of the means of automatic and remote control.

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The development of the theory of performance reliability of components and systems of automatic and remote control is another very important problem. Here we must investigate the effect of external factors and specific operational, mechanical, thermal and electric loads on the stability of the performance and lift of the elements. We must clarify and define the problems of the reliability of performance of components with continuous transformation (failure, excessive deviation of characteristics) and with discrete transformation (failure, faulty action). Of paramount importance is the development of methods of determining the general (resultant) reliability of complex systems and devices under conditions of series, parallel and compound connections of the various elements in the functional chain, and when the reliability of these elements differs. In evaluating the general performance reliability of a system consisting of a whole series of functional chains varying in their bearing on the operation of the entire system, we must introduce the necessary corrective factors which make it possible to evaluate the real effect of the failure of an element in each chain on the operation of the system as a whole. Finally, we must develop the methods of selecting elements (or subassemblies of the device) and their operating conditions for a given degree of performance reliability of the elements and of the system as a whole.

At present we have at our disposal only scattered studies dealing with specific problems; there has been no programmed and intensive work laying the theoretical foundations for determining the performance reliability of automatic and remote control equipment.

Equal in importance to the foregoing general questions of theory is the research and development of new principles for building the elements and systems used in automatic control, guidance, and regulation, as well as the further development of analysis and design methods for known types of elements and systems. Several large groups of problems that call for research might be mentioned at this point.

The first group consists of problems growing out of the utilization of the physical properties of conducting, semiconducting and dielectric materials needed for building the components of automatic and remote control elements.

Utilization of these properties makes it possible to obtain elements with a direct functional connection between changes in the various actuating physical quantities and the electric and magnetic properties and parameters of the element. Studies on this group of problems should include the following:

The investigation of changes in the electric and magnetic properties and parameters of metals and their alloys, combinations and compositions resulting from the action of various physical (electrical, magnetic, luminous, mechanical, thermal, etc.) and physico-chemical factors;

The investigation of changes in the electric properties of semiconductors (whether one-, two-, or multicomponent types) resulting from the action of various physical factors;

The investigation of changes of electric and magnetic properties of dielectrics brought about by the action of various physical factors;

The development of automatic and remote control elements and systems by the utilization of changes in the electric and magnetic properties of metals, semiconductors and dielectrics resulting from the action of various physical factors.

The second group of problems relates to research and development in the field of elements with a number of intermediary transformations. Use must be made of such elements when the elements of the preceding group - those with a direct functional transformation - are not available or cannot be used (for reasons of constant value, range of sensitivity or the degree of transformation accuracy).

This group of elements was the first historically and is the most widespread. However, modern requirements with respect to precision, working range, sensitivity and quick action, call for further research in this field. The emergence of new materials with superior mechanical, magnetic, electric, thermal and chemical properties is substantially modifying the design of known elements and calls for new design and analysis methods.

Recently there has been a number of new ideas with regard to engineering elements of this group; for instance, the replacement of gyroscopes by gyrotrons in measuring angular displacements in space, angular velocities and accelerations; further, using gyroscopic devices to measure the velocity of fluids; and finally, electromagnetic flowmeters, etc.

Research in this field should include:

The development of general methods of analyzing and designing mechanical and electromechanical systems with given terminal static and dynamic parameters and characteristics;

The development of more precise and suitable methods for computing complex magnetic and electromagnetic systems for constant, impulsive, and alternating field conditions and the development of new structural arrangements for the devices;

The development of more precise and suitable methods for computing complex thermal systems of various types and the development of new structural arrangements for the devices;

The development of precise and suitable methods for computing mechanical measuring systems used in determining mechanical parameters and the parameters of gaseous and fluid media, and the development of new structural arrangements for the devices.

The diversity of operating conditions, range of measurement and the required precision and speed of operation of the components of automatic and remote control equipment make it necessary to seek more and more new principles for their construction. This is particularly true in the case of the primary elements of automatic systems, the pickups, which detect changes in the controlled quantities.

Here, the development of new types of components makes use, among other things, of various auxiliary physical processes and chemical reactions for purposes of processing and control.

Progress has been reported recently in a number of lines in the application of auxiliary physical processes, mainly in connection with the utilization of the absorption and reflection properties of various radiations: acoustic, optical and

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electromagnetic, radioactive, etc. Positive results have been achieved in these lines and should substantially influence further developments there.

Here, work must be done in the following areas:

In the field of acoustic radiations as related to the design of automatic control and regulation equipment, it will be necessary:

To investigate selective and integral reflection and absorption of media, mixtures, and compounds for the various ranges of acoustic oscillations;

To study the characteristics of the radiators and receivers upon changes in the composition and physical properties of the surrounding medium;

To develop new design principles and arrangements for devices for the control of the composition or physical properties of media by utilizing changes in the characteristics of radiation, reflection and absorption.

In the field of optical and electromagnetic radiations, it will be necessary:

To investigate the absorptive and reflective capacities of various media and of their mixtures and compounds with respect to visible and invisible electromagnetic radiations under conditions of changed physical quantities (temperature, humidity, pressure, etc.);

To develop new design principles and arrangements for devices with direct or indirect utilization of visible or invisible electromagnetic radiations for controlling the composition of media or physical quantities;

To develop new indicators of visible or invisible electromagnetic radiations utilizing changes (during irradiation) of the properties and parameters of conducting, semiconducting and dielectric materials; further, to develop and improve existing principles of engineering radiation indicators.

Radioactivity has found wide application in recent years in the engineering of various devices of automatic control and regulation. In order to further develop equipment utilizing α-, β-, γ- and neutron radiation, it will be necessary:

To investigate selective reflection, absorption and transformation of α-, β-, γ- and neutron radiations by various media and their mixtures and

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compounds (in order to develop new methods of analyzing the composition or the changes of physical parameters of a substance);

To elaborate new principles for the direct or indirect utilization of α-, β-, γ- and neutron radiations in building devices for controlling changes in the composition of a substance or its physical parameters;

To develop new indicators of radioactivity utilizing changes in the electric parameters of conductors, semiconductors or dielectrics produced by α-, β-, γ- and neutron radiations.

A group closely related to the preceding groups consists of devices using principles of spectroscopy, radio-frequency spectroscopy, gamma- and neutronoscopy, and mass-spectroscopy. In order to develop these principles for building control devices, it is necessary:

To investigate the spectral characteristics of various media, their mixtures and compounds;

To develop new engineering principles and arrangements for automatic devices with direct or indirect utilization of the principles of spectroscopy, radio-frequency spectroscopy, gamma- and neutronoscopy and mass-spectroscopy to control the composition of complex media;

To develop indicators and computing elements for various spectroscopic devices for automatic recording, processing of results and conversion of results to the kind of material suitable for further use.

A special group of elements and systems of automatic control and regulation consists of devices which make use of auxiliary chemical reactions resulting in modified optical, electrical or other physical properties of the medium being analyzed or of special indicators (whether solid, fluid or gaseous). Modification of the indicated physical properties is utilized by the device for further functional transformation and analysis.

The elaboration of the above principles for building devices requires:

The investigation of the effect of the chemical composition of various substances on the physical (optical, electrical, etc.) properties of the substances themselves and on special indicator substances;

The development of new principles and arrangements for automatic devices for controlling the composition of substances utilizing changes in the physical properties of the controlled media and special indicator substances.

While the elements (pickups) used to detect the changes in the parameters of the controlled phenomenon or medium, must by their design and purpose be quite diverse, the reverse is true of the elements of automatic systems that are next in sequence - the intermediary and final control elements. It is preferable that these elements used to further amplify, distribute and transform the value and form of the impulse detected by the pickup be, whenever possible, partly or fully standardized.

Depending on the type of energy used for internal transformations in the automatic system, there are electrical, pneumatic, hydraulic and mechanical intermediary and final control elements.

The most developed electrical group of intermediary and final control elements has undergone in the course of recent decades a transition from contact and electromechanical types of elements to electronic and noncontact magnetic, semiconductor and dielectric elements (amplifiers, stabilizers, distributors, storage and computing devices,etc.). This does not mean, naturally, that contact and electromechanical elements have become less important and are no longer in use. Far from it. What has happened is that their field of application has been somewhat narrowed, while the most efficient of these devices are still being used in the transformation of electrical energy into mechanical energy.

However, the mushrooming development of electronic elements - amplifiers, stabilizers, distributors, computing devices, and the recent noncontact magnetic, semiconductor and dielectric elements - has changed radically the engineering of intermediary and final control elements of automatic systems.

We are witnessing at present a clearly-crystallized trend toward the creation of automatic systems by a schematic combination of standard electronic or, whenever

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called for, magnetic, semiconductor or dielectric components. This method has become prevalent in the development of modern systems, and only in cases where this method results in the construction of extremely complex and consequently not fully dependable systems or fails for some reason to bring the expected results, has it been necessary to build special electronic or electromechanical devices. Suffice it to say that in modern automatic control systems for large bombers the number of electron tubes reaches 7 or 8 thousand and in the case of electronic computing machines the number ranges between 500 and 18,000. With such great numbers of electron tubes in use, their main defects become readily apparent, namely their short life and undependability. This compels us to search for other solutions of the problem based on special electronic and electromechanical devices.

Magnetic elements of control systems are being developed along two major lines: magnetic components devised to utilize changes in the magnetic permeability of ferromagnetic materials due to an alternating magnetic field in the presence of a magnetizing constant magnetic field of a different magnitude, and magnetic components devised to utilize a large residual induction and a sharply defined differential in the magnetic permeabilities of separate segments of the curve of hysteresis cycle. The first principle is embodied in amplifiers, stabilizers, regulators, distributors and generators. The second principle is used in distributors and impulse storage devices.

Analogous elements (amplifiers, current stabilizers of voltage and power, distributors, impulse storage devices) may be built of materials with nonlinear resistance (the varistor type) or with nonlinear dielectric properties. Both of these groups of elements are finding application at the present time. Each of these (with nonlinear ρ, μ and ε) has its special characteristics as regards properties and application, and hence they complement each other well as control system elements.

The following are the principal tasks confronting the engineers of the above types of intermediary elements.

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As regards electronic elements of automatic control, it will be necessary:

To develop long-lived (with service of 30,000 - 60,000 hours) and stable electronic (and ionic) tubes, particularly multi-electrode and multiple-unit tubes, and also electron tubes with radioactive cathodes;

To develop special types of electronic and ionic devices: distributors (commutators), functional transducers, counting tubes, electronic and ionic converters of magnetic, electric, mechanical and other quantities.

In the field of nonlinear magnetic, semiconductor and dielectric elements, it will be necessary:

To develop new magnetic, semiconductor and dielectric materials with sharply pronounced nonlinear characteristics, and to investigate their properties;

To develop types of elements and methods for their design and analysis; to analyze their static and dynamic characteristics and parameters; to develop methods for analyzing complex systems containing nonlinear controlled elements;

To develop methods for engineering simple and complex systems with nonlinear elements for given terminal static and dynamic characteristics.

In addition to the development of noncontact components mentioned above, the search for new types of elements is continuing.

This search is directed especially toward the following types:

Elements capable of utilizing the Hall effect. Application of various semiconductors such as InSb, InAs, HgSe makes it possible to obtain electromotive forces of the order of tens of millivolts for values of flux density up to 10,000 gauss. This will permit a wide use of such semi-conductors for the construction of amplifying and computing devices;

Elements based on the galvanomagnetic effect, i.e., the effect of the change of electric resistance in a magnetic field. This effect, observable in bismuth, was formerly applied only in the construction of devices for measuring magnetic fields. In a number of new semiconductors, InSb, InAs, etc., this effect is very pronounced, and amplifiers, computing elements and pickups may be built which utilize the

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galvanomagnetic effect of these semiconductors;

Elements based on the utilization of the phenomenon of superconductivity (i.e, the stepwise drop of the electric resistance of a whole group of materials when temperature is lowered almost to absolute zero, or more precisely, to a few degrees on the Kelvin scale) and on the effect of the external magnetic field on the temperature at which the phenomenon occurs. Components of this type may be used as current and power amplifiers and as components of distributing and computing devices.

The above are but isolated examples of the great,still unused opportunities latent in the achievements of our physicists and chemists.

In analyzing output (final control) elements one should mention first of all the appearance of a whole series of high-powered controlled electronic devices (of the ignitron type or similar to it) and of controlled saturable reactors (high-powered magnetic amplifiers) for the purpose of controlling the flux of electric energy.

Numerous types of final control units are being devised for the control of mechanical displacements and speed. These may be divided into two basic groups. The units of the first group have controlled electric motors or electromagnetic circuits for alternating or direct current. We should note at this point the recent development of various types of two-phase electric motors for increased alternating current frequencies and stepwise electromagnetic final control units controlled by discrete inputs of current.

The second group is comprised of final control units with controlled clutches. The largest group of controlled clutches consists of electromagnetic clutches: friction, magnetic-coupling and asynchronous types. Here, particular mention should be made of electromagnetic clutches with a ferromagnetic filler which are new both in design and principle of operation and in their characteristics and the possibilities of using them for the construction of final control units. For the proper development of these clutches, it will be necessary to carry out a series of serious investigations of the physical and chemical properties of ferromagnetic fillers.

Mention should also be made of clutches with magnetic coupling. Under conditions of controlled magnetic flux they make possible final control units with controlled starting and stopping. In constant magnetic flux (e.g. that around a permanent magnet), these clutches represent a convenient component for various devices whenever it is necessary to transmit force or moment through some immobile nonmagnetic partition.

A significant role is played at present and will continue to be played in the future by pneumatic and hydraulic equipment of automatic control and regulation. It is not generally known that pneumatic and hydraulic devices have in the past 10 to 15 years kept abreast of electronic devices in their rate of development and practical applications.

Significant changes have occurred in the last few years in the design of these devices; the compensation principle for simple and complex systems of pneumatic and hydraulic equipment has been applied on a large scale. And a number of problems have come to the fore in the field of hydraulics. Unless solved, these problems will impede further progress in the development of this class of equipment.

The following are the main problems facing us in the field of pneumatic and hydraulic mechanisms:

The investigation of problems of the flow of fluids and gases through narrow apertures of various lengths and forms; the investigation of flow around various surfaces, etc.;

The investigation of the dynamics of operation of complex systems of pneumatic and hydraulic equipment and the development of methods for increasing their speed of operation;

The development of methods of synthesizing complex pneumatic and hydraulic systems for given conditions and characteristics;

The search for new methods for controlling the flow of fluids in hydraulic equipment for control and regulation.

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Here, attention should be drawn to recent efforts to find new working fluids for hydraulic systems, in particular, fluids with high electric or magnetic conductivity. This would permit the application of electromagnetic pumps for regulating the flow of liquids; by changing the current or the magnetic flux within these pumps, it is possible to vary the working pressure within the hydraulic system.

These, then, are the principal problems facing us in engineering the basic intermediary and final control elements of automatic systems.

Reference has already been made in the first part of the report to the principal and basic scientific problems bearing on the engineering systems of automatic control, guidance and regulation. We shall now turn our attention to still other important technical problems.

The principal problem facing us here is the problem of standardizing the construction of automatic and remote control systems. This question hinges on the development of system arrangements which would permit the combination of various input elements with standardized intermediary and final control elements. Such standardization will require extensive preliminary work in adapting the characteristics and parameters of the various input elements to standardized intermediary and final control elements, but the effort will be repaid by the great gain stemming from mass production of the technical means of automatic control.

The second problem has to do with setting up criteria for evaluating the properties, characteristics and parameters of elements and complete systems of automatic control, guidance and regulation. Unfortunately, this highly important problem has not, so far, attracted the attention it deserves; as a result, we lack the required criteria for a correct evaluation of the different variants of devices and systems needed for automatic installations.

We have outlined the main problems in the development of elements of automatic and remote control mechanics; the solution of these problems will require a great, concerted effort on the part of mathematicians, physicists, chemists, and specialists in the technical means of automatic and remote control. It is hoped that such cooperative and concerted effort will result from the present meeting.

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N. N. Shumilovskiy and B. S. Sinitsin

THE BASIC PROBLEMS OF THE THEORY OF AUTOMATIC MEASUREMENTS

Introduction

The rapid development of modern production, the intensification of technological processes, and the growth of procuction objectives are inconceivable without the increasing application of measuring devices.

Those automated measuring devices referred to as automatic control devices, are finding particularly wide use in varying degrees. It must be observed that the term "autocontrol" is often used in a larger sense. In using this word, we shall, however, confine ourselves to that part of its definition which implies the idea of autocontrol and automated measurements.

The use of autocontrol devices and even of entire "systems" gave rise to many important problems which are still far from solved. Thus, for example, great difficulties arise from the excessive increase in size of panelboards, which carry hundreds of pieces of devices. It is felt that indicating instruments should be replaced wherever possible with recording instruments. Attempts are being made to use devices for automatic control and computing installations, etc., concurrently /1, 2, 3, 4, 5, 6, 7, 8/.

In the present communication, we are examining in particular a group of questions concerned with the error theory of automated measurements and the methods for obtaining greater accuracy in automated measuring installations.

During the long years of development of accurate laboratory devices for manual control, sufficiently thorough methods of measurement were developed and a theory of errors for such measurements was worked out and solidly grounded.

The characteristic features of accurate measurement methods were in most cases the assumption of the stability of the value of the measured quantity and of the external conditions of the measurements. It has always been the aim to insure these conditions and to eliminate at times unavoidable variations.

The industrial indicating devices, representing strictly speaking the first step

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in the transition to the modern systems of control, were so crude in the original period of their application that no special measurement methods were required in these cases.

However, the developing technology demanded, on one hand, greater accuracy in the measurements of continuously varying quantities under operating conditions; on the other hand, laboratory devices for manual control more and more often did not satisfy the experimenters, from the physicists and astronomers to the engineers in the plant laboratories. By their very nature these devices were not suitable for the measurement of varying quantities; at the same time, however, such measurements were urgently needed. The solution was found in the automation of the measuring processes and the development of devices for autocontrol.

Their introduction and wide use in production and in the laboratory were launched not so long ago and are still continuing.

Of course, the old "classical" measurement methods, proceeding in most cases from the "static" conditions and assuming the presence of a relatively small number of devices, were found, to say the least, to be inadequate for the new conditions in the presence of modern measuring installations. In fact, with the conversion to the automated measuring arrangements, the field of physical phenomena utilized for measurements grew tremendously, the layout and the construction of measuring installations became more complicated, and new sources of static errors arose; finally, the systems of autocontrol, having automated the measuring process and made possible the measurement of variable quantitites, required the consideration of dynamic errors which developed as a result of the variation of the variable quantity itself and as a result of the variation of the external influence, i.e., the interferences.

It must also be pointed out that the simultaneous use of a larger number of devices, their use in combination with the systems of automatic regulation and control, particularly in connection with calculating and telemechanical arrangements, gave rise to a number of additional requirements for the operation of the autocontrol apparatuses and, above all, again required improvement of their accuracy.

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Though somewhat late in regard to the measuring practice, the theory of automatic measurements originated and began to develop as a result of these conditions.

The objectives of this theory must obviously be the development of the theory for independent concrete measurements, performed with the aid of autocontrol systems, as well as the establishment of the general theoretical foundations for automatic measurements.

The most important part of the theory of automatic measurements must be the theory of errors.

Now the question naturally arises as to whether this new trend is an isolated development or whether there are similar trends in other fields of knowledge. We accept the latter possibility; this, however, does not exclude the presence of many original independent questions, as well as the possibility of an indirect influence being exerted by the theory of automatic measurements on the related disciplines.

As an example for the latter case, we can point to the "classical" theory of errors and the mathematical treatment of the results of measurements; as an example of the direct influence on the development of the theory of automatic measurements we may cite the general theory of communications, the theory of automatic regulation, and the theory of calculating devices.

The aims and the problems of automatic measurements are closely related to and are the result of the development of problems previously solved with the aid of precise laboratory instruments. The novel aspect of all this, the things taking place under the operating conditions of the autocontrol systems and, above all, the presence of the continuously varying measured quantities--which create actions and interferences--are all very closely related to operating conditions in the field of communications as well as in the system of the automatic regulation.

Questions of Terminology

The complication of measuring layouts and the increase in their new functions require a more accurate and complete terminology. We shall not attempt, in this s

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paper, to examine this rather large number of terms; we shall only touch upon the basic definition of measurement and the closely related terms "measured quantity" and "result of measurement."

The definition given by M. F. Malikov states: "We call measurement the perceptual process consisting in the comparison, by means of a physical experiment, of a given quantity with its certain magnitude taken as the unity of comparison" ([9], page 18).

This definition does not stress the admissibility of continuously varying quantity, which is, as we have indicated, one of the most important operating requirements in the automated measuring installations. It is true that, by interpreting the concept of "quantity," M. F. Malikov on the same page 18 [9] writes: "In the abstract meaning, the word 'quantity' in general denotes a 'property' to which can be applied the concept of more or less..."; this in itself apparently permits the examination of the measurements of variable "quantities." However, further referring to the result of the measurement ([9], page 30), he states that "...the result of the measurement is always a concrete number" (underlined by M. F. Malikov). This last statement apparently presupposes the stability of the measured quantity during the measurement.

In automated measurements of continuously varying quantities, the knowledge of even an entire series of values of the varying quantity cannot be considered as the result of the measurement. It is necessary for us to be able, either directly or through some intermediary variable, to correlate the values of the measured "quantity" with the values of time.

Under term of the results of measurement of the continuously varying measured "quantity" we must therefore understand the definition of its values as a simple or complex function of time. The basic definition of measurement can be formulated as follows.

We call measurement the perceptual process, consisting in the comparison (by means of a physical experiment) of magnitudes of a given quantity (which in general

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[redacted]

is a function of time) with its certain magnitude, taken as the unit of comparison.

We can use the previous formulation too, but we will have to define more accurately what we mean by the measured "quantity" and the result of measurement /10/.

General Questions of the Investigation of Static Errors in the Systems of Automatic Control

The special features of the automatic control systems--as compared to the manual control devices and, in particular, as compared to the laboratory decade-type /sic/ compensators and bridges--are the great complexities of their structural arrangements, including, at times, a considerable number of links and the presence of a number of additional sources of errors, among them, the external interferences.

In examining the static errors, it is expedient and allowable in the majority of cases to divide them into two groups, depending upon whether or not the magnitudes of error are functions of the measured quantity /11/. For the systems of autocontrol, comprising a large number of sections with lumped parameters, it is expedient, on the basis of the method of superposition, to work out expressions for the total error of the entire system, caused by the variations of the parameters of separate sections.

Such complete expressions permit the evaluation of the error for the entire measuring system and the determination of the degree of influence of the variations of the separate parameters upon the magnitude of the error, the dependence of this error upon the "coordinates" of the point of application of the disturbing interference, as well as the degree of the mutual compensation of the separate errors. Besides, they permit the establishment of the relationship between the errors and the sensitivities, with respect to the measured quantity as well as with respect to the disturbing action. All this, in its final result, considerably facilitates the investigations of the automatic control systems.

For some systems, whose structural arrangements differ only as to the number of sections in this or that branch, it is expedient to make up the expression for the error by assuming the presence of an arbitrary but finite number of sections in each branch. This allows the formulation of sufficiently general rules, characterizing

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the given group of the system. We obtained such expressions for some of the most often encountered groups earlier [12, 13].

In connection with the requirements for greater accuracy in autocontrol systems, the investigation of static error of a system having not only sections with lumped but also with distributed parameters is quite interesting. On the basis of the examination of certain particular cases, we have established sufficient conditions whose presence permits the consideration of the general error of the autocontrol system as an additive function of a multitude of points of the system.

Let us stress that the requirements set forth for the static accuracy of the automatic control systems are often quite rigid; this means that it is necessary to consider a large number of influences which could appear to be of secondary significance. There is no reason to consider the influence of their variations when investigating the dynamics of the automatic control systems; however, their significance must be carefully taken into account in the statics.

Because of this, the need for common examination of statics or dynamics in various degrees does not mean that the first is only a special case of the second.

Let us note that many questions of the statics of automatic control systems are still awaiting solution; here we have, for example, the problems of synthesis, which have not been solved; the examination of the questions of statics does not sufficiently tie in with the problems of dynamics, and so forth.

Dynamic Errors of Systems of Automatic Control

Passing now to the examination of the questions of dynamics, we must mention that the questions of stability have a lesser significance here than in automatic regulation [14]. The problems of quality and particularly of dynamics errors occupy an important place in the theory of automatic measurements.

Among many characteristic features of the operation of these measuring devices, the problem of the accuracy of the measurements of continuously varying quantities forms the most important group of questions, which differentiate the theory of the

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of the automated measuring arrangements from the "classical" theory of measurements by means of devices with manual control.

As a matter of fact, the automation of measuring installations allowed the conversion to the measurement of continuously varying quantities, and because of that, this new, this most important property of automatic devices brought about its own, perhaps its most important and most difficult problem, i.e., the problem of accuracy.

It may appear at first glance that the investigation of the dynamic systems of automatic control cannot produce anything new in comparison with the theory of automatic regulation. However, this is not the case. Let us point out, first of all, that there exists a range of physical phenomena, subject to control, but not requiring or even not susceptible to automatic regulation. Therefore, questions naturally arise in the theory of automatic measurements which do not arise in the theory of automatic regulation.

Second, considerably greater requirements are set forth for the static as well as the dynamic accuracy of the systems of automatic control, than for the systems of automatic regulation. (As a characteristic example, let us point to the newest automatic bridges with multiple scanning of the scale for temperature measurement in the assembly with the platinum thermometer whose static error consists of several thousandths of one percent; in this way, the accuracy of these instruments approaches the accuracy of the meteorological instruments /15, 16/.)

It is natural that these quite rigid requirements for the accuracy of automatic control require a corresponding theoretical generalization.

Third, let us point to the following important circumstance. In the design of the automatic regulation systems, it is to a great extent necessary to take into account the properties of the objective of the regulation, which to a considerable degree determine the construction of the system.

In the measuring supervision systems (if the supervision principle is at the basis of the automatic arrangement), the objective consists in the movable system of the device--the registering member and the indicator which supervises the variatio STAT of the measured quantity. It is hardly necessary to prove that the variations in the characteristics of these sections of the autocontrol system can be achieved a lot easier than the variation of the characteristics of the objective in the automatic regulation systems. On the contrary, the inertia of the pickup (primary converter), which in the majority of cases has a small influence upon the dynamics of the automatic regulation systems, has primary significance in this operation of automatic control systems. And, finally, let us point out that the autocontrol systems are in general open systems [14].

Many essential problems of the theory of automatic measurements have already been solved. Let us mention here the problem of finding the errors of devices with arbitrary variations of measured quantity [17]; the methods for calculations of high-speed automatic compensators [18, 19, 20], which made possible the construction of apparatuses with an indicator scanning the scale in about 0.3 sec; the general theory of the linear amplifiers [21]; the extensive treatment of questions of the dynamics of magnetoelectrical devices [22]; and, finally, the construction of measuring devices of scanning converters [23].

Certain studies on the theory of automatic regulation are of great significance to automatic control; these studies deal with the operation of automatic regulation systems which appear to be particular cases of automatic regulation in many systems [24].

In investigating the dynamics of systems of automatic control, it is possible in many cases to limit the examination to the questions of quality. This is true, for example, with respect to multipoint devices when they are used for the measurement of comparatively slowly varying quantities. However, in an even larger number of cases--when the problems of the measuring installations consist in more exact measurements of continuously varying quantities--it is necessary to proceed to the investigation of the dynamic errors with random variations of measured quantities.

There are many ways to increase the dynamic accuracy of the automatic measuring installations.

Sometimes the errors can be reduced considerably only by a radical improvement in the properties of the elements in the autocontrol systems through the use of the latest inertialess methods of measurements.

It appears that great possibilities exist for the application of the principle of the scanning converter in the construction of high-speed instruments.

It is very desirable to design and to manufacture a limited series of such instruments so that they may be tested thoroughly under laboratory and plant conditions.

However, it is far from possible always to use any kind of inertialess methods of measurements under certain conditions. In automatic control systems, it is necessary to use measuring elements possessing inertia. In such a case--when elements possessing inertia are present--a great role must be played by the methods of the correction of dynamic properties for the entire system. It must be noted that the correction methods developed by the theory of automatic regulation are very insufficiently used in the measuring practice.

The basis for the theoretical investigation of the questions of the dynamic accuracy of automatic systems is, as we know, the mathematical theory of probability, and, in particular, the theory of random functions. (We shall not dwell in this work on several other methods for the solution of these problems [25, Chapter XXIV].) Under these conditions the measured quantity (master action) is most often considered as a fixed function of time [26, 27]. Such an examination presupposes, first of all, very small dimensions of the sensing element in practice and the absence of distortion of the field of the measured quantity in the vicinity of the sensing element and, second, a given fixed position of the sensing element in space.

The specifics of the automatic measurements and, above all, the great accuracy required in automatic measuring installations as compared to the automatic regulation systems, in certain cases demand a somewhat different statement of the problem.

Thus, it becomes necessary at times to take into account the dimensions of the

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sensing elements (for example, in measurements dealing with the investigations of turbulence [28, 29]).

No lesser interest, in the case of autocontrol of the parameters of continuous processes, is presented by the possibility of displacement of the sensing element. Let us examine this question in greater detail. The measured "quantity" must be considered in this case as a function of two independent variables: time and space coordinates of the sensing element (Figure 1).

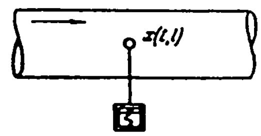

Figure 1. Simplified diagram of the system of the automatic control with one sensing element.

Considering the presence of the fundamental, predominant direction of propagation of the perturbation in continuous industrial processes, it is possible to assert that there exists a correlation between the values of the measured "quantity" at the given moment of time at a certain point in space, with the coordinate l and the value of the same measured quantity at the point with the coordinate $l + \Delta l$ at a certain future moment of time. The calculation of such a relationship permits the supplementation of the usual methods of "time" correction, used in the theory of automatic regulation, with the additional "space-time" correction. To realize this, it appears necessary to supply the system with several sensing elements. One of them--the primary one--must be located at a point in the process at which we want to measure the parameter we are interested in, while the others--the corrective ones--must be placed ahead of the main sensing element (i.e., forward toward the propagation of the perturbation of the measured quantity). It must be noted that such forward location of a single correcting sensing element is already employed in automatic regulation, not to increase the accuracy of the measurement, but for the correction of the dynamic properties of the system as a whole, including the object itself [30, 31]. However, the theory of errors of similar automatic regulation systems (taking into account the forward location of the corrective sensing element) has not been developed as far as we know.

We have not encountered the application of a system with the corrective sensin STAT elements scattered in space to increase the accuracy of the measurement in the dynamic regime.

Let us cite some of the results of the experimental investigation of autocontrol systems with the corrective sensing elements located in space away from the primary element.

The measured quantity is the temperature of the air stream within the pipe of an experimental setup.

The temperature was varied by means of changes of current in heaters, located at the origin of the pipe.

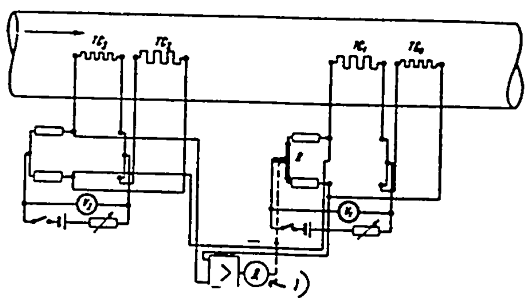

Figure 2. Basic diagram for the determination of errors of the system of temperature autocontrol with a correcting thermometer.

Resistance thermometers: TC_0 - reference (low inertia); TC_1 - primary (inertia); parts of the correcting thermometer: TC_2 - inertia part; TC_3 - high-speed part.

Legend: 1) dynode

The simplified basic diagram is shown in Figure 2. The graph of the temperature variation in the region of the primary inertia thermometer TC_1 and the reference thermometer TC_0 located next to it is shown in Figure 3. In producing such a variation of the measured quantity, we strove to obtain the characteristics of the variation close to the shape of a jump. The graph of the momentary values of errors is shown in Figure 4. As we can see, the forward location of the correcting thermometer insures a substantial decrease in error.

A similar measuring arrangement, but with a different array of sensing elements, was tried with the variation of the measured quantity, which approximated a short

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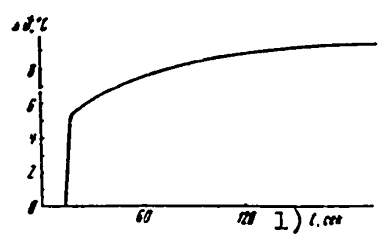

Figure 3. Graph of the variation of the measured temperature

Legend: 1) t, sec.

impulse. The graph showing the variations of the measured quantity is shown in Figure 5 and the curve of the variations in often momentary values of errors is shown in Figure 6. We notice that in this case also the forward location of the correcting sensing device insures the decrease in the error. Many experiments conducted under similar conditions showed that the forward location of the correcting sensing device results in a reduction in the dynamic error of the systems.

Experiments also showed that the introduction of two additional correcting sensing assemblies produces additional decrease in error.

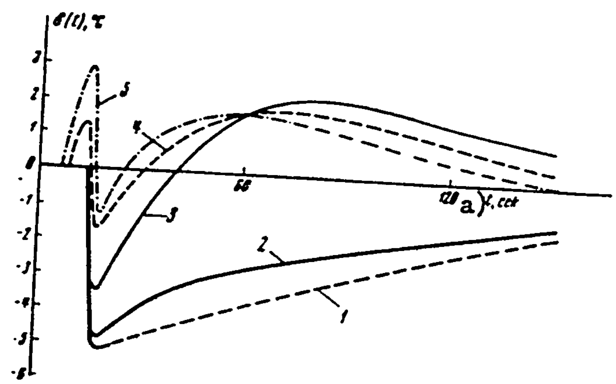

Figure 4. Graph showing the error for the system of temperature autocontrol.

In case of: 1 - single TC_1; 2 - single TC_2; 3 - all three thermometers, TC_1, TC_2, TC_3, but without the forward location of correcting thermometer; 4 - all three thermometers and with the forward location of the corrective thermometer at 9 m; 5 - same as 4, but with a forward location at 12 m.

Legend: a) t, sec.

The system with the correcting sensing devices--even if it is linear by itself--cannot be considered strictly speaking as linear in the presence of random correlating couplings. Final judgment concerning such systems can evidently be made on the basis of their tests in the presence of random variations of the measured "quantity."

We tested some of the autocontrol systems similar to the arrangement in Figure 2, with random variations of temperature. For this purpose, additional resistances were introduced into the heater circuit, which produced random variations in the heater power around a constant average value, according to a normal law. To obtain random variations, a special generator was designed and built for the random oscillations, based on the use of the known demonstration apparatus of Galton [9, 32].

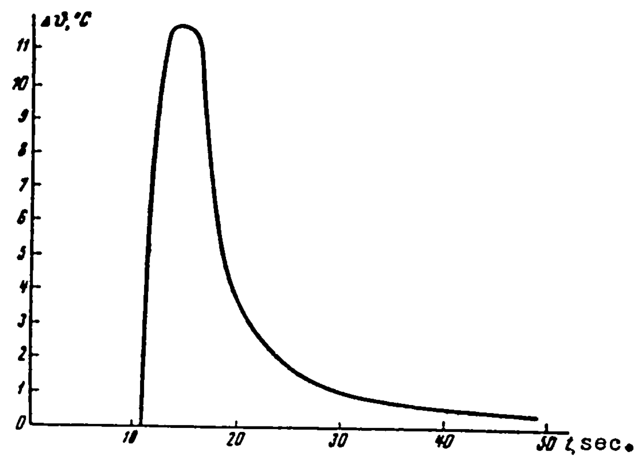

Figure 5. Curve of the impulse variation of the measured temperature.

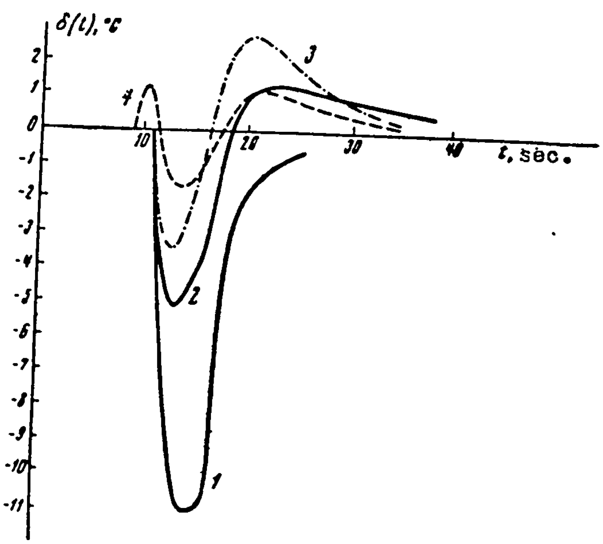

Figure 6. Error curves of the system of autocontrol with impulse variation of measured quantity.

In case of: 1 - single TC_1; 2 - single TC_2; 3 - all three thermometers, TC_1, TC_2, TC_3 but without the forward-located thermometer; 4 - same as 3, but with forward distance of 1.5 m.

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The results of the investigation of the system with random variation of the measured quantity also confirmed that the forward location of the correcting sensing device insures a decrease in dynamic errors.

The variation of the stream velocity in general has an influence on the quality of the correction. At the present time work is being conducted on building a system involving the introduction of the correction for the speed of propagation.

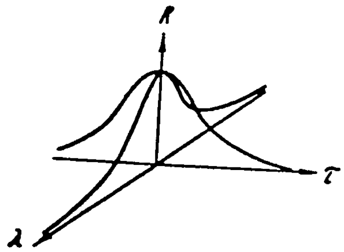

Figure 7. Three-dimensional graph of the correlating function of the homogeneous random field.

To investigate theoretically the questions concerning the accuracy of the auto-control system with forward-located correcting sensing devices in the presence of random variation of the measured "quantity," it is necessary to know its average value $M\xi(P)$ and its correlating function $M\xi(P)\xi(P')$.

The correlating function can be represented graphically as a surface

$$R(\vec{\rho}) = R(\tau, \lambda),$$

where $\vec{\rho}$ is the vector with components τ and λ (Figure 7).

With this information and the knowledge of the characteristics of the system, it is possible to find the values of the root-mean-square of the error. The solution of the problems of systhesis is also possible.

In conclusion, let us say that the methods for the decrease of dynamic errors described above do not exclude each other by any means but rather complement each other and are often used simultaneously.

The improvement in the dynamic characteristics of systems often finds itself in contradiction to the requirements set forth for their accuracy in the static method of operation.

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This circumstance must without doubt be taken into account in the design of the automated measuring installations.

Some Modern Development Trends in the Field of Automatic Measuring Apparatus

The diversity of measurement methods and of problems involved in automatic control gave rise to many arrangements and constructions of measuring apparatus. In addition to the dial-type apparatuses with increased rotation moment, automatic compensators, and automatic bridges, we can begin to note the wide use of the coordinate type of registers (with polar or right-angle system of coordinates), of the previously mentioned instruments with scanning converters, and of various versions of digital devices in autocontrol systems built on the aggregate principle, etc.

Some of these products are not yet being manufactured by the domestic industry or they are being manufactured in such small quantities that it is difficult to arrive at any conclusion about their operating qualities.

Let us consider in this connection some of the development trends in automatic measuring installations and in problems arising in this connection in the theory of the automatic measurements.

The expansion of the field of measured quantities, the ever increasing use of methods of electric measurements for nonelectric quantities, and the expansion of the limits of measurements require the development of new types of sensing devices and all kinds of improvements in the existing ones. In many cases, good results were obtained in the design of sensing devices using semiconductors, radioactive isotopes, etc. The problem of the improvement of sensing devices is one of the most important in the field of automatic control.

Of great importance also is the improvement in the subassemblies of the devices used in automatic control, since many of them have weak spots. Thus, for example, the slide wires of the automatic compensators and the bridges introduce errors because of their individuality, the nonuniformity of the resistance winding along its length, sliding wear, etc.

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The sources of working current of the autocompensators of direct current vary their emf with time and with the ambient temperature. The sources for feeding the compensators of alternating current also are lacking in stability. The standard elements require particularly careful handling; due to their imperfection, the errors of the apparatuses are also increased.

We do not have reliable information about the characteristics of the automatic compensators without sliding wires and of standard and dry cells manufactured by some foreign firms, while the development, conducted by local design and scientific organizations, is progressing very slowly in this direction.

Much can be done to improve assemblies not only in the field of automatic compensators and bridges but also in any other region of automatic control.

One must particularly call attention to the need for the improvement of the process of recording measurement results, especially, better paper for photorecording in daylight.

Let us now examine some general tendencies in the development of automatic measuring apparatus and above all in the problem of digital devices.

Digital devices have for a long time been used along with continuous-operation instruments in measuring practice. Decade-type laboratory bridges and compensators are examples of this, though they are completely nonautomated.

The following factors have been responsible for this in recent years: first, in many cases the measurement itself has a different, separate character and consequently the digital devices, due to their very nature, are better suited for making the measurements, than are the devices with continuous operation; second, the digital devices allow the direct feeding of the data into the computers and thus become one of the important elements of the next, more developed stage of automation; third, digital devices are more convenient for telecommunication of the measured results and, finally, these devices are devoid of certain errors that are inherent in continuous-operation devices (reading errors caused by the parallax, the nonuniformity of the scale, and so on).

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The rapid development of digital devices was made possible after the introduction of electronics into measuring practice; however, even now the solutions for the construction and arrangement, which are at the basis of these devices, are quite diverse. There exist electromechanical and purely electronic variations.

We consider that one of the most important problems of the near future is the development, mastery, and manufacture, by the local instrument plants, of digital indicating and recording devices, while the scientific research organizations must develop the theory of digital devices, taking into account their application in the measurements of varying quantities.

It must be noted that, because of certain drawbacks of the digital devices and above all because of the nongraphic aspect of digital recording, there is no basis to think that these devices will completely displace the devices with continuous action.

In our opinion, there is a great future for the multiple scanning of the scale, which represents an original combination of digital and continuous-action devices /15, 16, 33/. Combining the high accuracy of the digital devices with the graphic recording obtained from the devices with continuous registration, these devices are destined to replace to a great extent the accurate laboratory measuring arrangement using manual setting during experimental investigations. The use of the multiple scanning of the scale also makes it possible to somewhat increase, by quite simple means, the accuracy of the existing instruments manufactured by the local plants. It appears desirable to us to manufacture in the nearest future a moderate number of instruments with multiple scanning of the scale.

Measuring practice is in many cases greatly facilitated by the so-called coordinate-type recorders which make it possible to record one quantity as a function of another. However, too few of these devices are being produced and they are not available in sufficiently different models for use in the laboratory and in the plant; it is therefore practically impossible to use them extensively. Their theory is also very insufficiently developed.

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Recently a demand arose for the construction of automatic compensators and bridges for alternating current. In balancing such measuring devices, two interdependent parameters must be made to vary automatically. The theory of such devices is not yet sufficiently developed.

Another important problem consists in the creation of automatic measuring devices for indirect measurements, i.e., the building of groups of devices and computer-installations which would automatically measure several parameters and would automatically compute the measurement results on the basis of certain given direct measurements. Not so long ago, only isolated examples existed of such complex measuring installations. But, the rapid development of computer installations has stimulated considerable progress in this field. Let us note that, in addition to their use for the mathematical treatment of the measurement results, the computer installations can be used for the design of the measuring installations, which automatically vary their own characteristics, when variations occur affecting any of the conditions of measurements. Such measuring installations can be considered as selfadjusting measuring systems. The important questions of the theory of such devices are also insufficiently developed.

Finally, let us examine the question of checking the automated measuring installations. We will hardly be wrong in stating that little has been done in this field. In fact, the existing system for the checking of these devices provides mainly for the testing of these devices under static conditions. Proper attention is not being devoted to the problem of determining the dynamic errors; the methods for their determination are quite imperfect, while the checking facilities--reference standards and instruments--are often lacking.

Much work remains to be done in the creation of facilities for the checking of automated measuring installations under the conditions of measurements of variable quantities and for the development of checking methods.

Particularly great difficulties are encountered, of course, in working out the standard measurement methods.

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In conclusion let us state that the successful solution of the enumerated problems, as well as of those we could not mention in this short report, is only possible under the proper combination of conditions of the development of new technical means for automatic control and of the solution of problems of the theory of automated measuring installations.

Many special features and, above all, the consideration of the continuous variations of measured quantities make the theory of automatic measurements different from the error theory and from the calculation methods for accurate laboratory devices. The specifics of the automated measuring installations and, in particular, their high accuracy--which at times, under static conditions, approaches meteorological accuracy--excludes the possibility of considering this new field of knowledge as the simple application of the theory of automatic regulation to the concrete problems of measuring practice.

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B. T. Kolomiyets

SEMICONDUCTORS AND THEIR APPLICATION IN AUTOMATION

As is known, semiconductors are distinguished by the ability to change their electric conductivity under the influence of many external factors. These include light, temperature, magnitude of electric and magnetic fields, direction of current, pressure, etc. Previous experiments in the field of electric properties of semiconductors made it possible to find materials in which one of the enumerated factors assumes the major role in controlling the conductivity and to determine ways for control by means of some other properties in many semiconductor materials. Both of these circumstances resulted in the creation of new electric circuit and cells, with the parameters and the characteristics differing by the second or third order from the previously known ones. By way of example, we can mention such general characteristics as sensitivity, power dissipation, length of service, weight, volume, etc.; each of these characteristics differs from the characteristics of previously existing devices by 100 to 1,000 times and more.

The abovementioned features of the semiconductor devices and many other properties are interesting for industry in general and for automation and telemechanics in particular. On their basis we can make simply-constructed and reliably operating equipment for the control, signaling, and regulation of technological processes in many branches of industry.

The prospects for the application of semiconductor equipment in automation and telemechanics are very great. Such equipment can be used and is being used as sensing elements and as intermediate elements in various automatic and telemechanical installations. In all known cases, the semiconductor products proved themselves to be reliable elements, completely satisfying the strict requirements of industrial operations. However, the many existing semiconductor devices are not yet being used to a great extent in automation practice.

The present paper is intended as a review of the present state of the art in the creation and utilization of semiconductor equipment in the Soviet Union and abroad

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and as an examination of the prospects of their development. Below are described groups of semiconductor devices whose application considerably widens the potentialities of automation and telemechanics.

Photoelectric Devices

The extensive research on photoelectric porperties of semiconductors in the Soviet Union resulted in the creation of many original photocells. Here we find, first of all, silver sulfide photocells produced by the Physics Institute of the Academy of Sciences Ukrainian SSR. The present photocells, which were developed as far back as 1938, possess a sensitivity as high as 10,000 μa per lumen as compared with 500 μa for the selenium photocells. It must be stressed that these photocells are being used extensively in Soviet industry but are not known abroad.

We find even greater sensitivity in (also completely original) photoresistors made from powdered cadmium sulfide developed by LFTI of the Academy of Sciences USSR and NII MRTP. These photoresistors, manufactured industrially since 1954, have a sensitivity reaching 3,000,000 μa per lumen.

The appearance of semiconductor photoresistors led to a new stage in the development of industrial photoelectric automation: the creation of simple, reliable, and long-lasting equipment. The example of the use of photoresistors in automation can be considered as characteristic for all semiconductor products. Because of this, we shall examine them somewhat in greater detail. Let us also note that in the field of photoresistors our achievements exceed those abroad.

Among many advantages brought to automation by semiconductor photoresistors, as compared with the photocells when activated by an external photoelectric effect, we can mention the following.

1. High sensitivity. As we said before, the sensitivity of the photoresistors attains 3 amp per lumen, that is, the sensitivity of the photoresistors is higher than the sensitivity of ordinary antimony-cesium vacuum photocells by 30,000 times.

2. High allowable power dissipation. Under illumination, photoresistors can control electric circuits requiring several watts of power; this cannot be achieved

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with photoelectric devices built on the basis of the external photoeffect.

3. Small dimensions and weight. The photoresistors do not require for their operation a vacuum or gas medium; this makes it possible for them to have very small dimensions. For use in the laboratory, we have photoresistors with a light-sensitive area from 1 to 400 mm^2 in the shape of squares, rectangles, disks, sectors and washers. The possibility of giving the light receivers any shape considerably expands the range of their application in automation.

The operating stability of photoresistors is very high. There are industrial installations where the photoresistors have operated without interruption and replacement for more than two years.

Among the shortcomings of the photoresistors must be mentioned their sluggishness, which limits their application to problems where their operating time is of the same order as that of the electromagnetic relays. Table 1 shows the time constants for all of the photoresistors manufactured by industry. It shows that the lead sulfide photoresistor of the type FS-A1 has a very small time constant.

Table 1

Type of Photoresistor	Time Constant, sec.
FS-A1	$4 \cdot 10^{-5}$
FS-B2	$1 \cdot 10^{-3}$
FS-K1	$25 \cdot 10^{-3}$
FS-K2	$30 \cdot 10^{-3}$

For applications where a rapid response from the light is required, it is necessary to use the new type of semiconductor photocells: germanium photodiode developed by LFTI of the Academy of Sciences USSR. This type of photocell combines to a remarkable degree the best properties of vacuum photocells and photoresistors. From the former it borrows the rapid response and the proportionality between the photocurrent and the light beam and from the latter the high sensitivity.

Table 2 compares the main characteristics of photocells, photoresistors, and photodiodes.

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The construction of the photoresistors manufactured by industry and their dimensions are shown in Figure 1, those of the photodiodes developed by LFTI are shown in Figure 2. These figures show that the dimensions of both types of products are small but this is their great advantage in the construction of automated installations.

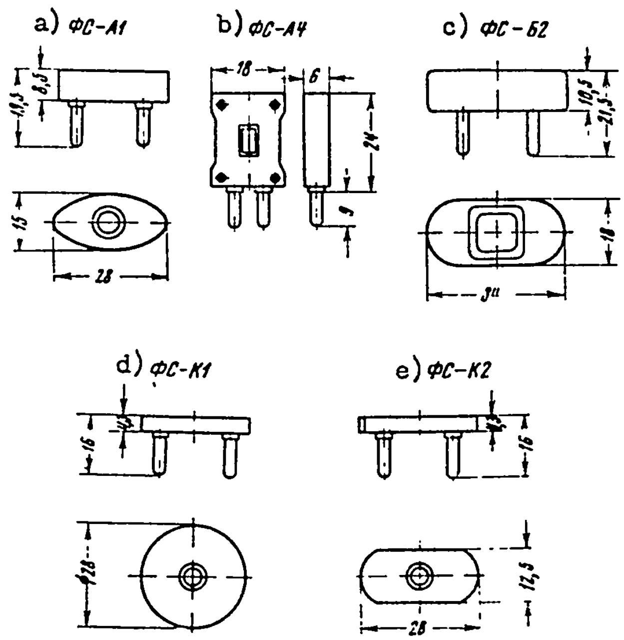

Figure 1. Construction of main types of resistors (dimensions in millimeters).

Legend: a) FS-A1 b) FS-A4 c) FS-B2 d) FS-K1 e) FS-K2

The semiconductor photocells--that is, rectifier photocells, photodiodes, and photoresistors taken as a whole--embrace a very large span of radiations, from gamma rays to the medium infrared wave lengths. This makes it possible to design control and automatic instrumentation in those regions of radiation which increasingly enter into engineering practice. Figure 3 shows the spectrum sensitivity of germanium photodiodes and photoresistors manufactured by industry. It must be also mentioned that the photoresistors made from the multicrystals of cadmium sulfide, manufactured by the Physics Institute of the Academy of Sciences Ukrainian SSR, have sensitivities in the ultraviolet region of the spectrum and in the x-ray region.

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Table 2

Types of Photocells	Type Designation	Sensitivity μa per lumen	Maximum Photocurrent
Vacuum antimony-cesium	STsV-3	100	0.1
Gas-filled cesium	TsG-4	500	0.1
Germanium photodiode	FD-1	30,000	3.0
Lead-sulfide photoresistor	FS-A1	10,000	0.2
Cadmium sulfide photoresistor	FS-K1	3,000,000	50
Photoelectronic multipliers	FEU-19	10,000,000	0.1

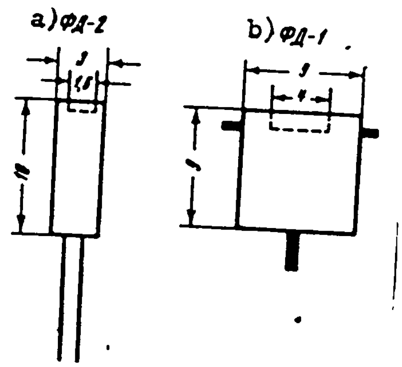

Figure 2. Outline dimensions of LFTI germanium photodiodes.

Legend: a) FD-2
b) FD-1

The existence of an extensive variety of photoresistors led to the production of many types of controlling and automatic instrumentation of industrial value. There are already a considerable number of examples illustrating that the use of various installations incorporating the new techniques employing semiconductor photoresistors saves hundreds of thousands of rubles in industry per year and frees manual labor by replacing the labor of man with the work of automatic machines. These examples have to do with the metallurgical industry (Uralmetallurgavtomatika), printing industry (Moscow, Leningrad), food industry (Karpov plant and K. Tsetkin tobacco factory in Leningrad), and others. However, the above-mentioned facts are only isolated applications and are not widespread. The reason for this, in our opinion, is the insufficient level of production of photoresistors, insufficient information, and, above all, the absence of a specialized production center for the development and manufactuing of photoelectric automatic equipment to satisfy the numerous requirements of all branches of industry.

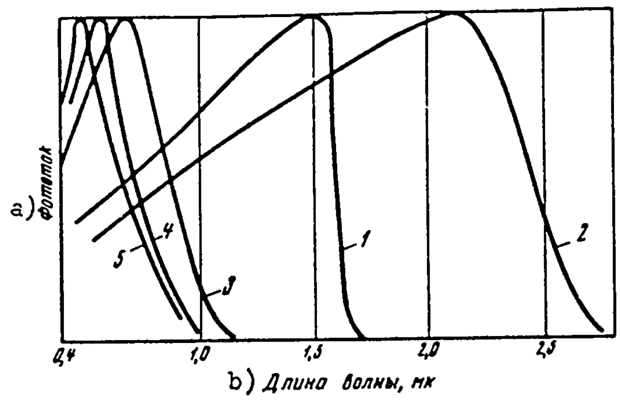

Figure 3. Spectrum sensitivity:

1 - of germanium diode; of photoresistor: 2 - FS-A1, 3 - FS-B2, 4 - FS-K1, 5 - FS-K2.

Legend: a) photocurrent
b) wavelength, μ.

One of the factors hindering the wide use of photoresistors in industry is the small amount of work in the creation of new types and designs. The Ministry of the Radiotechnical Industry has only one small laboratory working along these lines and is therefore not capable of satisfying all requirements. There is a series of important problems whose solution is impossible because of the small size of the laboratory at NII of the Ministry of the Radiotechnical Industry.

The main problem in the field of photoelectric automation is the creation of a strong developmental and production foundation. It is necessary to organize the production of automatic equipment which uses semiconductor photocells, as well as considerably to expand the production of photoresistors and increase the amount of scientific and developmental work in the investigation of new types and designs. These measures must be undertaken as soon as possible, not only because it is necessary to supply our industry with the new technique, but also because the investigations now being conducted on the photoelectric properties of the semiconductors promise to give

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industry new and more valuable types of photocells. The new properties of photocells naturally will lead to the creation of new instruments which then must be introduced into industry on a large scale. In order to shorten this process, a physical base is required in the form of strong branch laboratories and industrial production.

In the nearest future, our industry must produce a new kind of photoresistor from cadmium selenide. According to the preliminary results, these photoresistors, whose spectrum sensitivity is shown in Figure 4, have a sensitivity 10 times larger than the photoresistors of cadmium sulfide, with considerably less sluggishness. These properties, combined with their spectrum sensitivity will undoubtedly make it possible to develop new devices and new automatic equipment for industry.

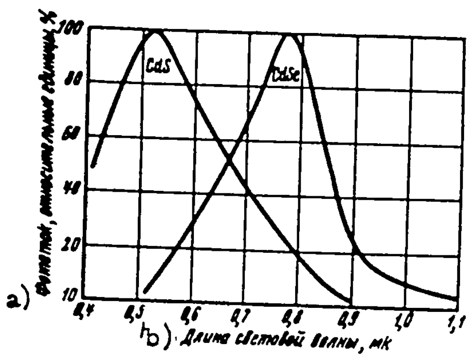

Figure 4. Frequency characteristic of photoresistors of cadmium selenide and cadmium sulfide.

Legend: a) photocurrent, relative units, %
b) wavelength of light, μ.

In addition to the photoresistors of cadmium selenide, one must expect in about two years the appearance of lead selenide photoresistors. As we can see from Figure 5, these photoresistors are particularly interesting because of their high sensitivity in the infrared region of the spectrum which extends to 6 μ.

As we said before, the germanium photodiodes are a very interesting kind of semiconductor photocell. It is expected that they will soon be produced industrially. However, it is necessary to call popular attention to this fact because, from 1954 to the present time, the organization of such production has not been successful. STAT

It is necessary to ask the Ministry of the Radiotechnical Industry to organize the production of germanium diodes in order to guarantee progress in many technical trends. including automation.

The group of photodiodes is a very promising kind of semiconductor photocell. Their spectrum sensitivity extends from the gamma rays to the far infrared region of the spectrum (10-12 μ). There are already indications in the literature on the subject to the effect that it is possible to make photodiodes from a series of new semi-

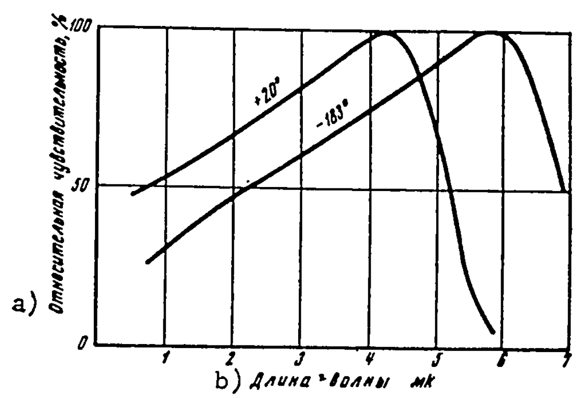

Figure 5. Spectrum distribution of the internal photoeffect in PbSe.

Legend: a) relative sensitivity, %;
b) wavelength, μ.

conductor materials; some of their first new properties are described there too. Because of the low sluggishness and high sensitivity, this kind of photocell merits serious consideration for use in automation. To push the development in this direction it is necessary to create the required conditions, first of all, by securing the requisite pure chemical products.

To satisfy some of the requirements of automation, considerable interest is presented by the rectifier semiconductor photocells of the silver sulfide type, mentioned above, and of the selenium type. Both of these photocells found in our country are used extensively. However, foreign industry is apparently making wide use of rectifier photocells, made of single-crystal germanium, silicon, or cadmium sulfide, which are called solar batteries. All of these photocells have a very high sensitivity and their coefficients of conversion of light energy into electricity, according to STAT the published data, is 10% and more.

In the manufacturing and design of photoresistors, our industry is ahead of foreign industry, but in the field of rectifier photocells just mentioned, we are apparently considerably behind. Information about them began to appear in foreign literature two years ago. In our country, however, we did not begin to receive the first specimens with very modest parameters until this year.

The rectifier photocells are bound to be of considerable interest in automation because they can be used as sensing elements of the automatic instrumentation and as sources of energy. The volume and level of theoretical experimentation in the field of photoelectric phenomena in the Soviet Union does not lag in its scope behind efforts abroad. It is only necessary to consolidate the material-technical bases.

Thermal Resistors

The semiconductors have a negative temperature coefficient of ohmic resistance. The conductivity of the semiconductors varies greatly with the change in temperature, according to the exponential law $\sigma = Ae - \frac{B}{kT}$ which applies to a very large number of semiconductors. The type of variations for metals and semiconductors is shown in Figure 6.

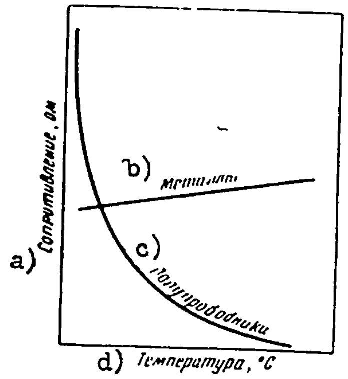

Figure 6. Type of relationship between resistance and temperature.

Legend: a) resistance, ohms
b) metals
c) semiconductors
d) temperature, ^{o}C

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The great dependence of conductivity of semiconductors upon temperature has been used and at the present time, on the basis of this, industry developed and is now manufacturing various types of semiconductor-type thermal resistors (thermistors).

The semiconductor thermal resistors in our country are used extensively in the solution of such important problems as the automation and control of industrial processes in the most varied branches of industry. With the aid of the thermal resistors we can measure control, and regulate temperature, stabilize the potential, temperature compensation, fire alarm, and other types of signals, and measure humidity, pressure velocity of gas streams, and many others. The majority of these problems are successfully solved by means of thermal resistors manufactured by the plants. The thermal resistors of NII of the Ministry of the Radiotechnical Industry, developed together with LFTI of the Academy of Sciences USSR, are shown in Figures 7 and 8.

The interest in semiconductor thermal resistors is caused by the general features of the semiconductor devices: their small weight and volume, stability in operation, and excellent electric properties. As an example showing the advantages of the semiconductor resistance thermometer over the metallic thermometer, we can cite the following facts. The thermal resistor of the type KMT-5 used as resistance thermometer has a volume hundreds of times smaller than that of the metallic resistance thermometers, and for the same temperature difference produces a change of resistance many thousands of times larger.

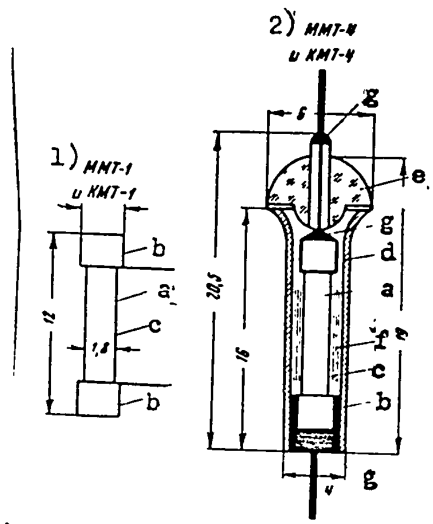

Figure 7. Construction details of thermal resistors MMT-1, KMT-1, MMT-4, and KMT-4.

a - body of thermal resistor; b - contact caps; c - layer of enamel paint; d - protective metallic case; e - glass insulator; f - metallic foil; g - layer of tin.

Legend: 1) MMT-1 and KMT-1
2) MMT-4 and KMT-4

It can be asserted that in the field of semiconductor thermal resistors and

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their application, the development work in the Soviet Union is on the same level with the work abroad. However, the general use of these resistors cannot be considered satisfactory because not even the current requirements of industry are being met due to the low volume of production.

The appearance of thermal resistors led to the conception in industry of a series of interesting ideas, which require the development of new designs of thermal resistors with new electric parameters. Among them can be cited resistors for automatic starting of electric motors without rheostats, resistors for control and regulation of cooling of automobile engines, charging of batteries, and so on. These problems and other similar ones, in spite of their great significance to the national economy, cannot be solved due to the low production volume of devices for experimental-design and development purposes.

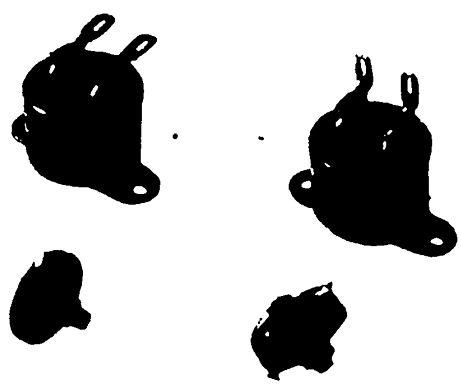

Figure 8. Thermal resistors for temperature compensation.

A drastic increase is required in the volume of work on semiconductor thermal resistors and the necessary materials must be made available for this effort.

The investigations dealing with the temperature effects of the semiconductors are proceeding in two directions. One has for its aim the creation of new designs for thermal resistors. During the current year, our industry will produce thermal resistors of the type KMT-10 (Figure 9), intended for the thermal control equipment developed by the Electrotechnical Institute of the Academy of Sciences Ukrainian SSR. These thermal resistors, together with the electromagnetic relays, make possible the STAT

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construction of automatic equipment which signals the increase above the preset temperature within the limits of +20 to +100°C. The accuracy of operation at any temperature within the above interval is within one degree.

Next year, our industry will receive another one of the new types of the semiconductor devices which are of considerable interest for automation; they are called bolometers. Semiconductor bolometers represent one of the variations of the thermal resistors, made in the shape of a thin film of semiconductor which changes its ohmic resistance as a result of absorption of heat radiations.

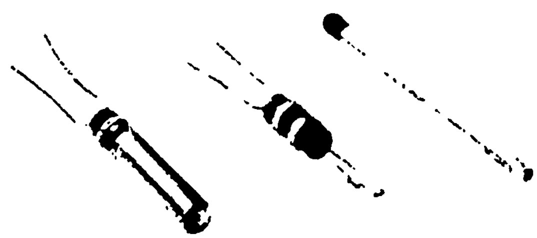

Figure 9. Thermal resistors of type KMT-10 for heat control.

The second investigation trend is aimed at the discovery of new semiconductor materials, combining high temperature dependence with high conductivity and stability when operating at high temperatures. In the conduct of these experiments, a series of interesting results were obtained which ensure further progress in the development of this group of semiconductor devices.

Amplifiers and Rectifiers

The investigations of the phenomena at the boundary between metals and semiconductors led to the development of rectifiers from alternating to direct current. Similar investigations with semiconductors of different carrier polarity and with high mobility very recently were crowned with remarkable success in our century, namely, the development of semiconductor amplifiers. The absence of a vacuum, the small dimensions, and other qualities of these semiconductor devices have brought about a revolution in the radio industry and those branches of industry which use it. Automation is also included in this, since it utilizes radio devices extensively.

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We are not going to examine the details of construction and the characteristics of germanium and silicon diodes, triodes, and other devices, since they are well known. Also, their value to automation is well understood, due to the long life, reliability of operation, small volume, and weight, etc. In examining the uses of these devices in automation, we must recognize first of all the small scale of practical use, which is due to the general unsatisfactory conditions within the group of semiconductor devices under examination.

In earlier semiconductor devices, our thermal and photoresistors were on the same level with foreign technology and even surpassed it; in the field of germanium and, particularly, silicon triodes and diodes, we are considerably behind.

This lag exists in the field of the creation of industrial models and the engineering of their industrial production, as well as in the volume of production and in the application of types already developed. In our opinion, the first situation is linked to the insufficient amount of activity in all stages of experimental work, from the Academy of Sciences to the plant laboratories. The second situation is due to the lack of industry's serious consideration of the production of germanium diodes and triodes. Only recently, after three years of the design work on the first models, was the production of germanium devices entrusted to a competent plant.

The absence of an organized and sufficient volume of production of semiconductor devices made of germanium and silicon impedes the progress of industry at the present time and threatens the development of industry in the future. At the present time, interesting research work is being done on new semiconductors with large drift mobility. This research, in which Soviet science is not lagging behind foreign science, will undoubtedly soon result in the discovery of new, more perfect semiconductor devices. In industry, in general, and in automation, in particular, the lack of production or a small volume of production will naturally hinder the rapid transmission, to industry, of the expected results of scientific research.

A great event in the field of semiconductor rectifiers is the development of powerful germanium rectifiers by the group of scientific workers of LFTI of the

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Academy of Sciences USSR. The new contribution brought to industry by these rectifiers may be judged by the data shown in Table 3.

Table 3

Type of Rectifier	Allowable current density ma/cm^2	Value of Inverse voltage, v
Selenium.	50	26
Germanium	100,000	200

The table shows that the current density in the new rectifiers is 2,000 times larger than that of the best existing selenium rectifiers. This circumstance and the large value of inverse voltage make it possible to design rectifiers which are hundreds and thousands of times smaller in volume but have the same value of rectified current.

When large-capacity germanium rectifiers came into existence, we were not lagging behind foreign technology. However, judging by the degree of their use in practice, the gap widened with time to our disadvantage. The reason for this lies again in the absence of organized production of semiconductor equipment.

The outlook in the field of semiconductor rectifiers is excellent. Thus, technology will in the nearest future receive large-capacity silicon rectifiers.

According to the available information, industrial production of silicon rectifiers has been started abroad, with parameters two times larger than those of germanium rectifiers.

The investigations of electric properties of new semiconductors with large drift mobility must also open the way for the development of new rectifiers that will be even more perfect with respect to some of their parameters.

It is appropriate to say that, concurrently with the work on the new types of rectifier, intensive research with considerable results is being conducted in our country to improve the properties and the preparation techniques of the existing copper oxide and selenium rectifiers. In view of its economic importance, this work is still overshadowing the work being done on the newest rectifiers. This, however, does not bespeak the happy state of affairs in the field of selenium rectifiers. The volume of their production and their quality is below the requirements of this country and the standards of the foreign samples. This is one of the causes for insufficient development of automatic instrumentation.

Varistors

Among many remarkable features of semiconductors, there is one which has not found sufficient application in Soviet industry and which is bound to be of considerable interest to automation and telemechanics. Many semiconductors exhibit a considerable deviation from the Ohmic Law; in silicon carbide, for instance, the conductivity is proportional to the third and even fourth power of the applied potential $(J \sim V^n)$. Such a relationship between conductivity and potential makes it possible to create nonlinear electric resistances that are very valuable to industry. Abroad, such resistances are called varistors and, according to the foreign press, they are manufactured by a number of firms for the most diverse purposes and for varied potentials. Such resistances are made in the form of discs with diameters ranging from one to several centimeters; their thickness varies from 1 to 10 mm and even more.

This type of semiconductor devices practically does not exist in the Soviet Union. A report on the last work done on them was published in the magazine Avtomatika i telemekhanika /Automation and Telemechanics/ in the year 1951.

Recently some progress has been noticed in the work with this group of semiconductor devices. Thus, LETI is doing very successful work on the study of nonlinear relationship between the semiconductors and the strength of the electromagnetic field and on the development of industrial models. However, the volume of this work corresponds neither to the importance of this research trend to industry, nor to the possible large-scale use of varistors. It is important to resume and expand this research in the Academy of Sciences (Semiconductor Institute) as well as in the branch institutes. In the first place, it is important to reestablish the development work

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on the industrial types of varistors and on the technology of their industrial production at VEI, where work in the past has been on a very high level; at the same time, developmental work on these automation elements should be included in the activities of the Institute of Refractory Materials of the Ministry of Ferrous Metallurgy.

New Semiconductor Devices

The number of semiconductor devices described above, which are extensively used in industry and particularly in automation and telemechanics, was recently increased by the addition of new original devices. The large values of the thermoelectromotive force of semiconductors made possible the development of new types of sources of electric energy, e.g., thermogenerators or, as they are also called, thermal batteries. The honor for the development of the theory and of the industrial models of the thermal battery belongs to the Semiconductor Institute of the Academy of Sciences. This institute also developed an electric refrigerator using semiconductors. Both of these types of semiconductor devices will be manufactured in the near future in sufficiently large industrial quantities to allow them to find their proper place in automatic apparatus, first of all, as power sources, and to act as thermostats for automation elements.

The conductance of semiconductors depends also on the magnetic field and the pressure. The first property recently led to the development of another new semiconductor device, which is very useful for rapid and accurate measurement of a magnetic field. This device, which as yet has not received an official name, was constructed for the first time in one of the laboratories of the Semiconductor Institute of the Academy of Sciences.

The second property of semiconductors--the change in conductance with pressure--is at present time in the preliminary stages of investigation. Using this feature of semiconductors, it is possible, in principle, to develop elements which can be utilized to measure pressure.

Of interest among the new semiconductor devices is an electric light modulator

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which consists of a thin plate of germanium, through which passes a light beam whose value changes depending upon the strength of the current flowing in the plate.

Outlook for the Development of Semiconductor Devices

The number of semiconductor devices described above is based upon the utilization of many physical properties of previously known semiconductors. The great successes achieved in amplifiers, rectifiers, and photocells are related to the qualitatively new developmental stages in the field of solid states--the study of electric properties of the purest substances and the manner in which the addition of individual elements of the periodic chart affects these properties. This investigative approach led to the discovery of new qualitative properties of materials (large values of drift mobility, changes of sign, etc.) and to a conscious control of these properties. On this basis are constructed the above-described diodes, triodes, photodiodes, solar batteries, and powerful rectifiers. A new illustration of the production and use of the qualitatively new properties of semiconductors is the recently produced LFTI semiconductor device which, by virtue of its characteristics, is analogous to a gas-filled rectifier tube.

The study of materials of maximum purity is now the leading trend in semiconductor physics. This trend, which in many ways depends upon our chemical industry, without any doubt is the reason for the improvement of the existing semiconductor devices and for the development of new ones.

In addition to this trend, which ensures scientific and industrial progress in the field of semiconductors, two new areas of research are noticeable at present.

The first of these arose as the result of endeavors to expand the number of substances having large drift mobility in order to supplement the group comprising only two substances: silicon and germanium. On the basis of the crystallin-chemical resemblance, LFTI forecast the resemblance of the physical properties of silicon and germanium to the binary combinations of elements of the third and the fifth group of the periodic chart of elements. This was confirmed experimentally by obtaining large

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drift mobilities in the new group of substances. As an example, we can cite the following figures.

The drift mobility in germanium is 3,800 $\frac{cm^2}{v. sec}$; however, in one of the new substances, InSb, the drift mobility, according to the latest data, is as high as 80,000 $\frac{cm^2}{v. sec}$. The difference between these numbers illustrates perfectly well the possibilities for the development of such semiconductor devices as amplifiers, rectifiers, photocells, and photodiodes.

Investigations of the semiconductor group with large drift mobility are now being conducted here, in the Soviet Union, as well as abroad. The practical results of these efforts will depend to a considerable degree upon the chemical industry because the problem of purity and admixtures is here decisive.

Within this new group of semiconductor substances, which has received in literature the name of the metallic group $A^{III}B^{V}$ the most interesting at the present time are InSb, InAs, InP, and GaAs. Information appears in literature concerning production, using the above substances, of first models of photocells, photodiodes, and equipment for magnetic field measurement. The transistor effect lying at the basis of semiconductor amplifiers also has been observed.

The second area of investigation directed toward the production of new semiconductor substances is developing in the direction of the synthesis of complex compounds formed by three or more elements, and the study of their electric, physical, and general physicochemical properties. This area of research has as its goal the determination of general laws that bind electrical properties of a semiconductor to its chemical properties and structure and has begun to produce useful results.

Thus, for example, several new tricomponent chemical compounds were obtained (in the systems Te-Sb-Se and Te-Sb-S); means of uninterrupted and significant variation of conductance were established, etc.

Triple and more complex compounds in the systems of the group $A^{III}B^{V}$ open the way for securing a range of semiconductor substances with smoothly varying properties and of materials with even larger drift mobility.

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An original result of the investigation of complex compounds was the discovery of a new and large group of semiconductor substances, i.e., vitreous semiconductors. Due to their electrical properties, these substances--obtained by fusing such elements as arsenic, selenium, tellurium, sulfur, tallium, antimony, and others--are typical semiconductors. Because of a number of their physical and chemical properties, they can be considered as ordinary glass.

The current detailed investigation of vitreous semiconductors will in time determine their place and signficance among semiconductor devices. However, judging from the results of optical investigations, they can find their application even now as optical filters for the infrared portion of the spectrum.

It follows from the above that the outlook of our semiconductor industry is great.

Conclusion

The above review of the present state and future prospects for the development of semiconductor devices, as well as a general acquaintence with the conditions of affairs concerning their immediate utilization in the automation and telemechanics, leads to the following deductions.

1. Semiconductor devices open wide vistas for the development of industrial automation and telemechanics. However, at the present time there is a considerable gap between the potential for using semiconductor devices and the extent of their practical application.

The following semiconductor devices are being developed for industry: diodes, triodes, photodiodes, large-capacity rectifiers, photoresistors, thermal resistors, magnetic field measuring instruments (magnetometers), thermal batteries, and refrigerators.

None of these types of semiconductor has as yet found sufficiently large application in practice.

The basic reasons for this state of affairs are the very insufficient level of

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industrial production of semiconductor devices and the lack of specialized organization for the development and manufacturing of automatic instrumentation for industry (photorelay, thermal relay, and others).

2. We are lagging considerably behind foreign industry in some semiconductor devices, for example, varistors, germanium and silicon photocells, and some others.

The theoretical level of work on semiconductors in our country is basically the same as abroad.

The lag behind foreign industry is due to the insufficient amount of scientific investigation, particularly in experimental and construction work. It must be stressed that our chemical industry is falling far short of meeting our research needs in the field of semiconductors.

To ensure the most rapid increase in the use of semiconductor devices and further progress in their development, it is necessary:

a) To intensify the volume of scientific research and experimental and construction work on semiconductors at the Academy institutes and, in particular, in plant laboratories and branch institutes, by creating the necessary conditions.

b) To require the chemical industry to organize industrial production of superpure elements. It is recommended that an Institute of Pure Elements be organized for this purpose.

c) To develop in every way the work in the field of semiconductor materials, aimed at obtaining new semiconductors with the best properties for industry.

c) To expand the production of semiconductor devices, and in particular of diodes, triodes, large-capacity rectifiers, photoresistors, and thermal resistors. To organize the production of new devices, such as photodiodes, photocells, etc.

e) To organize a number of centralized production centers for manufacturing the simplest automatic instrumentation utilizing semiconductor devices.

Comment

by Doctor of Physical and Mathematical Sciences V. M. Tuchkevich

The list of semiconductor devices which can now be found in the laboratories c be increased over the number mentioned in the report of B. T. Kolomiyets.

It is necessary to approach the problem of semiconductor equipment for automation from a somewhat different point of view: not simply by describing the properties of certain pieces of equipment, but also by asking the question as to which instruments are necessary for the automation and what requirements must be made of this equipment.

Semiconductor devices can be divided into two major groups: devices utilizing properties of materials and devices utilizing contact properties. Each group of these devices finds its own field of application.

Semiconductor devices at the present time have a number of shortcomings. As we know, the parameters of the semiconductor devices are dependent upon temperature. This property in certain cases is used to build corresponding sensing elements, but in other devices this dependence upon temperature presents a condition which can be a great oostacle, considerably limiting their field of application. Many of the semiconductor devices do not now possess sufficient stability and their parameters change with time and perhaps are also dependent upon other factors.

The parameters of semiconductor devices cannot as yet be reproduced with sufficient accuracy. The low level of production results in a large scatter of parameters in those devices which are manufactured.

These are the main shortcomings of the devices, which require a special approach in their application.

The dependence upon temperature, which is practically absent in certain devices of the nonsemiconductor type now in use, can be compensated for in the majority of semiconductor devices at the expense of the reserve sensitivity or some other parameters. It seems to me that the construction of various automatic equipment requires a somewhat different approach on the part of the specialists in the field of technical facilities for automation, than the simple presentation of definite, concrete requirements in these devices. It is necessary in many cases to construct this equipment on a new basis, on new principles, taking into account such specific features as are possessed by the semiconductor devices.

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Because certain groups of semiconductor devices have been distributed only recently and that the industrial production of these devices is insufficient, not all of their properties are known.

The semiconductor devices have new properties different from the properties of the amplifier vacuum tubes, and the problem consists, not in the replacement of the vacuum tubes by the semiconductor amplifying devices, but in the development of completely new schemes which cannot be accomplished with the vacuum tubes. This problem, it appears to me, has not been sufficiently discussed, probably because of insufficient knowledge of these semiconductor devices.

On the other hand, a number of semiconductor devices, particularly germanium and silicon amplifier-rectifiers for possible use in automatic installations, are already being manufactured by our industry, though in an insufficient quantity.

These devices are produced without regard to the operating conditions and the specific requirements of the automatic systems, primarily for use in the radio industry. When they are used in computer installations, it thus becomes necessary in these machines to take into account entirely special requirements which are not considered when these devices are used in ordinary radio installations.

As a parameter of this kind, it is possible to point to the magnitude of current within the closed circuit in a semiconductor device. This parameter is of no special significance in the radio amplifying installations, but is exceedingly important in the mathematical machines. If one is to consider the development of equipment for automatic purposes, it is necessary to state the problem of the development of special semiconductor devices for automatic installations, just as the problem is stated here for the development of vacuum tubes for automatic installations.

It appears to me that, in planning our future work, it is necessary to examine the semiconductor devices also from this point of view. It is necessary to formulate the requirements which must be fulfilled by these new semiconductor devices that are designed for use in the automatic systems.

The aim of the present session is not only to state that we have such devices

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at the present time and that they are still being produced in an insufficient quantity, but also to outline the aims of our work in the future. I would like to mention the new principles of construction of semiconductor devices which are projected now and which, it seems, will represent an important area of research in the future. The construction of the thyratron type devices can be considered as belonging to this area.

Extensive application in a number of automatic installations will obviously be found by a device based on a property, i.e., the modulation of a light beam by electric current.

It appears that, by passing a modulated current through a germanium plate, it is possible to modulate a light beam. This device will make it possible to obtain a modulated beam of infrared rays.

Address

of Candidate in Technical Sciences N. P. Udalov

Information concerning the properties of semiconductor elements, the methods of their design, and the experimental characteristics necessary for the design, is not sufficient. Often the designers refuse to use semiconductor thermal resistors only because they are not sufficiently familiar with the properties of these resistors. The first attempt to utilize these devices in their designs--when not grounded on proper calculations and experimental data--usually ends in failure; this discredits the notion and people cease to occupy themselves with these problems for a long time.

Because of this, I have a recommendation: in the resolution of our session to record the need for the Automation Institute to conduct, at the beginning of 1957, a conference on the problems of the application of semiconductors in automation, with the wide participation of the representatives of various scientific developmental institutions.

Semiconductor thermal resistors have great prospects of employment if such thermistors can be made to operate on strong current. Unfortunately, our industry, which makes stable thermal resistors, does not manufacture them in a sufficient

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number of models. Fifteen years ago, excellent thermal resistors, called "urdox," were manufactured abroad. They were made to carry currents up to 30 amp. It is necessary to manufacture heater-type thermal resistors capable of handling the currents of motors to be used as starting rheostats for electric movers, thermal resistors with sharply falling characteristics for installations requiring large time delay, from 1 msec to tens of minutes.

D. V. Zernov, M. I. Yelinson, and A. M. Kharchenko

PROSPECTS FOR THE DEVELOPMENT OF NEW TYPES OF ELECTRONIC EQUIPMENT FOR AUTOMATIC AND TELEMECHANICAL INSTALLATIONS

Introduction

Modern automatic and telemechanical installations are unthinkable without the extensive use of electronic equipment. As we know, large-scale replacement of mechanical and relay elements and systems with electronic equipment was started a long time ago (15-20 years back) and this triggered the considerable progress in automation and telemechanics because of the sharp increase in the speed, sensitivity, and accuracy of the automatic installation. As the use of electronic equipment increased, the number of such devices grew considerably.

The last decade is further characterized by a large increase in the use of automatic installations of various types of gas discharge equipment (thyratrons of various types, glow discharge tubes, decatrons, plasmatrons, ignitrons, etc.), Finally, during recent years, the semiconductor elements began to assume particularly varied and growing importance because of their advantages.

Naturally, it is impossible to discuss completely in this short presentation the entire subject of the use of all the above-mentioned equipment in automation and telemechanics. Because of this, we shall limit ourselves to the analysis of the present-day status and future prospects for the use of only the vacuum electronic equipment, restricting ourselves in addition to the special types.

As is well known, the widest application in automation and telemechanics as well as in the radio industry is enjoyed by the electron tube with the grid controlling the intensity (density) of the electron beam. During the period of vigorous mastery of the electron tubes, automation and telemechanics accepted them in the form they were developed for radio needs. It is evident, however, that we need additional requirements here for the reliability, durability, stability under external influences, fidelity of reproduction of the electron tubes, as well as for some of the others of their electrical parameters. Unfortunately, the industry, as a rule, is presently

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not manufacturing electron tubes especially made for use in automation and telemechanical installations. This problem must be considered in the near future.

One hears opinions from time to time that further improvement in the electron tubes is not warranted since they will soon be replaced by semiconductor devices. But this, like any other extreme point of view, is a rather one-sided way of looking at this. In reality, this discussion will concern most probably only the partial replacement. Very indicative in this respect is the evaluation of the prospective use of electron tubes and semiconductor devices in U.S. aviation equipment.

According to information from 19 American firms, at the present time an average of 22% of the tubes in aviation equipment have so far been replaced with semiconductor devices. It is estimated that in the equipment being developed 38% of the tubes will be replaced in 1956 and 50% in 1957. In many cases the replacement becomes unprofitable because of the increased complexity of the equipment. Thus it is considered that about 40% of the electron tubes will be replaced with semiconductor devices.

The appearance and the vigorous development of semiconductor devices considerably narrowed the prospects for the use of the electron tubes in many areas of automation.

Side by side with the electron tubes, a large number of electronic devices has been developed up to the present time.

The fact is that the electron tubes, first of all, cannot perform all the necessary functions required by the automatic cycle. Thus, for example, electron tubes in many cases cannot be directly used as sensing elements for various quantities (displacement, acceleration, pressure, magnetic field, radiation, etc.) and cannot perform many functional transformations, etc.

Second, the complexity of modern automatic and telemechanical installations (for example, multiplicity and variety of modulation forms in telemechanical systems or computing machines) requires a very large number of electron tubes. This threatens the reliability of the operation of the system.

Apparently, the problem of greater reliability can be solved by two methods:

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either we sharply increase the reliability of each element of the system (electron tubes), or we sharply reduce the number of elements making up the system.

The second method is tied up with the development of special electronic equipment, capable of replacing a whole series of electron tubes and of corresponding radio engineering arrangements. With this in mind, it is necessary to single out the typical and most frequently used blocks of tubes and to attempt to find the operating principles and to construct simple electronic equipment capable of performing the functions of these blocks. Experience shows that such solutions are found in many cases and, as we shall show below, that they are very efficient.

The physical basis for the creation of the described special electronic equipment is the great flexibility of the electron beam which, when concentrated by some means, is capable of changing not only its intensity but also its position in space under the influence of electric and magnetic fields.

The entire exposition below will be mainly devoted to the analysis of the present-day status and prospects for future improvement and creation of new specialized electronic equipment. The authors of the present paper participated in the development of many types of such equipment while on the staff of the former IAT Electronics Laboratory of the Academy of Sciences USSR and, subsequently, on the staff of IRE of the Academy of Sciences USSR.

Below we shall examine the use of special electronic devices, such as sensing devices, amplifiers, distributors, converters, functional tubes, and memory elements.

Sensors

Among all the types of electronic sensors let us examine only the radiation sensors and the magnetic field sensors.

1. Radiation Sensors

Photoelectronic methods of radiation indication have found a wide acceptance in automation and telemechanics; they are extensively used as photocells with external photo action and as photoresistors and rectifying photocells.

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Photoresistors and rectifying photocells are very simple devices, possessing a very large integral sensitivity (up to 10 a/lumen).

Their characteristic deficiencies are the poor threshold properties and large inertia which narrows their field of applications. It is important to note that the operating stability of these devices is still unsatisfactory (instability of the output signal, aging, sensitivity toward temperature, humidity etc.).

The vacuum photocells are made at the present time with several types of photoelectronic cathodes: antimony-cesium, cesium oxide, bismuth-cesium. So-called multialkaline cathodes are now being developed, i.e., cathodes which contain, in addition to cesium, other alkaline metals (potassium, sodium, etc.). These types of photocells are designed for the visible and the nearest region of the infrared spectrum.

For the ultraviolet part of the spectrum, photocells are being developed with pure metallic cathodes (magnesium, beryllium, cesium, etc.); however, the optimum type of cathode has not been found yet. Magnesium photocells are now being manufactured.

The sensitivity of the vacuum photocells does not exceed 40-200 μa/lumen. Therefore, the use of these photocells for automation naturally requires an additional amplifying system.

In contrast with photoresistors and rectifying photocells, the vacuum photocells have practically no inertial and are more stable; these properties assure them of a sufficiently large area of application.

Particularly promising is the use of photomultipliers (and of electronic multipliers in general). As we know, the photomultipliers use the secondary emission for the amplification of the electronic current; this enables them greatly to improve their threshold properties. Modern multipliers, without cathode cooling, are capable of registering light beams up to 10^{-12} and 10^{-13} lumens. Photomultipliers are now manufactured with cesium-oxide, antimony-cesium, and purely metallic photocathodes, having different types of construction depending upon their purpose.

An antimony-cesium layer, as well as oxygen activated copper-magnesium and

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[redacted]

aluminum-magnesium alloys are used as secondary electron emitters.

Thirteen-stage multipliers requiring a supply of 1,000-4,000 v and few-stage, miniature, vibration-proof multipliers requiring 600 v are being manufactured. The integral sensitivity of multipliers is very high; it attains 30-40 a/lumen.

The average output currents of the new types of multipliers using alloy-type emitters attain several milliamperes; under pulse operation, they attain several amperes.

With the aid of the electronic multipliers, it is possible to register not only electromagnetic radiations within a wide range of wavelengths (from infrared to γ-rays) but also the corpuscular radiations of various types (electrons, α-particles, ions, etc.).

There are many uses for photomultipliers. One must mention here, first of all, the automation of the atomic industry and of atomic power, the automatic installations of experimental nuclear physics, and also the automatic installations in many branches of industry using radioactive isotopes.

Photomultipliers are very valuable in automatic control and regulation installations in the metallurgical, metalworking, chemical, and other branches of industry and also in space navigation.

Thus, a further improvement and development of new photomultipliers and of electronic multipliers in general is warranted in order to create specimens of high stability and sensitivity that have definite kinds of spectrum characteristics. It is also important to produce multipliers having a large power output, and also "low" natural pulse duration, i.e., a small spread of electron transit times.

2. Sensors of the Magnetic Field.

In automated and telemechanical installations, a growing place is being assumed by the magnetic recording of signals with their subsequent reproduction, transformation, etc.

As we know the reproduction of signals is being accomplished at the present time with the aid of electromagnetic heads in an imperfect manner because of the

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special frequency characteristic of these heads (the output signal increases with the increase in frequency) and their low sensitivity.

It is practically impossible to reproduce a time constant signal, while the frequency correction within the limits of the sound range requires cumbersome equipment.

The same problem of signal reproduction on the magnetic tape without drawbacks inherent in the electromagnetic head, can be easily accomplished by means of a very simple electron-beam device (see Figure 1a).

The device consists of an electron gun producing an electron beam. This beam can be deflected by the magnetic field under investigation; for this purpose, the

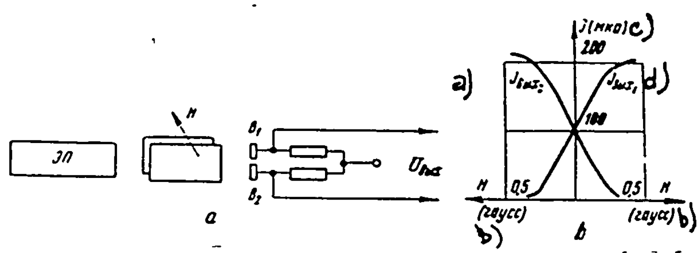

Figure 1. Electron-beam device for measuring a magnetic field.

a - schematic diagram; b - output characteristics; ЭП electron gun.

Legend: a) output 2; b) Gauss; c) μa; d) output 1.

device is inserted into a magnetic circuit the same as the coil of the electromagnetic head. To increase the magnetic induction in the region of the deflection of the beam, permalloy poles are used inside the device. The output arrangement of the tube consists of two split metallic plates. When there is no signal (deflecting magnetic field), the electron beam falls on both plates equally, so that there is no signal in the differential output of the tube.

The presence of the signal deflects the beam, depending upon its magnitude and sign, toward one of the output plates, with the result that an output signal appears. In contrast to the electromagnetic head, the signal is proportional to the magnetic

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field itself, and not to the speed of its variations with time. Figure 1b shows the relationship between the magnetic field and the output current for a device developed by IRE of the Academy of Sciences USSR, in 1955.

The curves show that there is linearity within the limits of ±0.3 Gauss, which considerably exceeds the values of the signal registered on tape. The sensitivity of the device with a load resistor of 100,000 ohms is 10 v/Gauss; this is about 100 times higher than the sensitivity of the electromagnetic heads.

The frequency characteristic is independent of the signal frequency within the limits of 0 to 10^4 which in many cases is an invaluable property of the tube. Apparently, it will be possible in the future, to make similar electronic devices, capable of even larger output currents, possessing an even higher sensitivity toward the magnetic field, and suitable for the reproduction of magnetic tape signals as well as for other applications related to the reaction to the weak magnetic field.

Unfortunately, the sample tubes developed by the laboratories are not yet sufficiently used by industry. It appears to us that in the future a wider use of these tubes should be urged upon industry.

Amplifiers

Signal amplifiers are the key part of the automatic cycle. The electron tube was until recently the undisputed master in the electronic equipment for the amplification of weak signals. (We naturally do not consider here the magnetic amplifiers.) The semiconductor amplifier is now becoming a powerful competitor of the electron tube.

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But, as we mentioned in the introduction, the electron tubes are still very important. Interchangeable long-life tubes, unaffected by external conditions, must be developed. It is desirable to improve the parameters of the electron tubes. Thus, for example, it is very important to develop tubes with high transconductance. It is rewarding to note the appearance of tubes, such as 6Zh11P with transconductance of S = 28 ma/v with anode current of 26 ma and anode potential of 150 v (C_{in} = 13 $\mu\mu f$) and of the output tube 6E5P with the transconductance of S = 27 ma/v, with anode

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current of 45 ma and potential of 160 v (C_{in} = 16 $\mu\mu f$).

There seems to be good prospects for the use of secondary emission to increase the transconductance, which becomes possible as the development progresses in the efficient and current stable secondary emission emitters. The principal advantage of such tubes lies in the possibility of increasing their transconductance without an increase in the interelectrode capacity; this favors their use as wideband and impulse amplifiers. This results from the location of the secondary electron emitter (dynode) behind the control grids (Figure 2a).

Tubes with the secondary emission are suitable for use as triggers for the generation of short pulses etc.

A number of such tubes was developed abroad (EFP60, VX5038, Valmark tubes, and others). Thus, the EFP60 tube has a transconductance of S = 25 ma/v with anode current of 20 ma and input capacitance of 0.004 $\mu\mu f$. The same tube, operating in the regenerative circuit, may ensure the steepness of the pulse rise in several millimicroseconds. The resistance of the rising part of the characteristic operating under the above conditions (with 30 v dynode supply) is smaller than 0.5 ohms (Figure 2b).

Of great interest are tubes with secondary electron emission, which utilize the beam deflection instead of the grid control. In this case, it is possible to use the positive characteristic of the anode as well as the negative characteristics of the dynode (Figure 2c), and thus to make the quiescent current of the tube (in the absence of a signal) equal to zero. Such tubes (with current ~10 ma and transconductance of 1 to 2 ma/v) are successfully used for differential amplifiers, voltage regulators, multivibrators, binary storage elements, coincidence circuits, etc.

We consider the development of electron tubes with secondary emission very promising.

Amplifiers for small signals are very important in automation. The amplifier EMU-2, manufactured by our industry, uses tubes 2E2P and is employed under special operating conditions, amplifies a current as weak as 10^{-14}.

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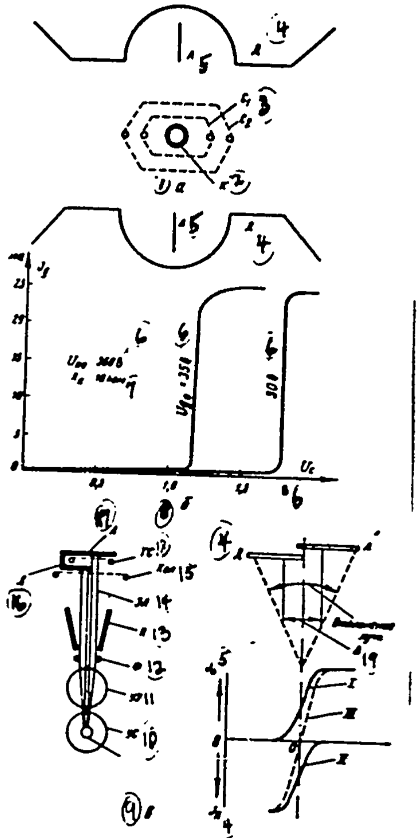

Figure 2. 1-a- Cross-section of a tube with grid control utilizing secondary emission

2 - cathode; 3 - grids; 4 - dynode; 5 - anode; 6 - v; 7 - kilohm;

8-b- Characteristic curves of tube EFP60;

9-c- tube with beam deflection and utilization of secondary emission:

10 - controlling grid; 11 - accelerating electrode; 12 - focusing system; 13 - deflecting plates; 14 - electron beam; 15 - collector; 16 - dynode; 17 - anode; 18 - restraining grid; 19 - width of beam; 20 - beam deflection.

Characteristic curves: I - anode; II - dynode; III - total output.

As further development of amplifiers for weak currents, it is desirable to make special electron tubes with grid currents of 10^{-16} to 10^{-17} a (electrometer tube 2E2P has a grid current of about 10^{-15} a).

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Distributors

In modern automatic practice, and particularly in telemechanics and computer technology, many different electronic pulse circuits are used in addition to the usual amplifying systems. These circuits perform the functions of generation, shaping, conversion, distribution, delay, counting of electronic pulses, and so on.

These systems consist in the main of ordinary receiving-amplifying tubes and semiconductor devices; in many cases the number of tubes and semiconductors in these installations becomes very large, amounting to hundreds and even thousands of pieces. the limited life span of electron tubes and the lack of identity in the parameters of tubes and in particular of semiconductor devices, impedes the full utilization of installations employing these devices and makes them insufficiently reliable.

In this connection, as we said in the introduction, a need arises for the development of special electronic equipment, which will combine the functions of more or less complex tube blocks and which will considerably decrease the total number of electronic and semiconductor devices, utilized in this or another complex system. By this means, of course, it will be possible to achieve an improvement in the reliability of the entire installation, even though the service life of each device is relatively of short duration. From this point of view, the electron beam devices of the commutator type become very promising; they control the current in the output circuits not only by means of the density of the electron beam, but also by changing the position of the beam with respect of the system of output electrodes. It is relatively easy to combine in these devices a large number of inputs and outputs and to obtain arbitrary forms of dependence of the output currents on the input potentials. This gives them great flexibility and universality and makes possible the construction of equipment for the most diverse practical objectives. One of the pioneers in the development of such types of equipment is the large IAT Electronics Laboratory of the Academy of Sciences USSR, which produced several new types of electron-beam commutating devices, some of which have already found application in industry.

A new type of electron-beam commutating device has been developed and has passed

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the tests this year at the IRE of the Academy of Sciences USSR. It is a ten-cell ring trochotron, possessing considerable advantages over earlier types of linear trochotrons, namely: simplicity of construction, large output currents (up to 10-20 ma), and independence of output circuits from control and commutating circuits.

The principle of operation of the trochotron, as we know, consists in that the electron beam of a given magnitude emitted by a cathode is formed into a ribbon-shaped beam by the intersecting and approximately homogeneous electric and magnetic fields and follows the equipotentials of the electric field.

By changing the electrode potential, it is possible to direct the beam in the desired direction and to lock the position of the beam.

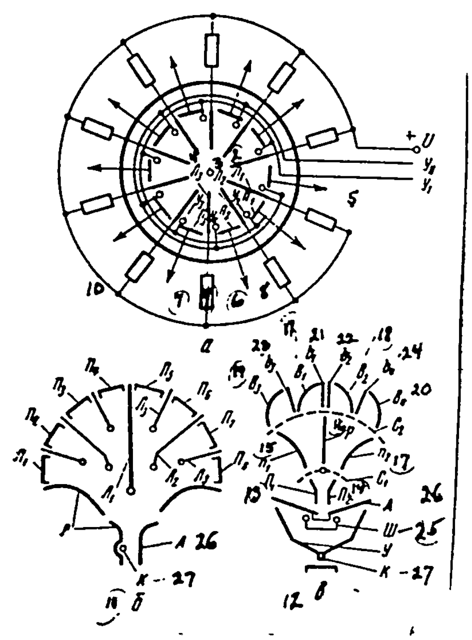

Figure 3.

1 -a- schematic arrangement of construction and switching of the binary trochotron:

2,3,4- L_1, L_2, L_3 - switching electrodes, blades; 5,6,7 - P_1, P_2, P_3 - receiving electrodes, plates; 8,9,10 - U_1, U_2, U_3 - control electrodes;

11 - b - binary trochotron type KL-6;

12 - c - double switch;

13,14 - P_1 and P_2 electrodes of the first deflecting system; 15,16,17 - n_1, P, n_2, electrodes of the second deflecting system; 17,18,19,20 - B_1 to B_4 -

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output electrodes, possessing secondary emission capability; 21, 22,23,24 - b_1 to b_4 - output (trap) electrodes; 25 - stubs, focusing electrodes.

The cross-section of the ring trochotron with some of the arrangement elements is shown in Figure 3a. The magnetic field is directed perpendicularly to the drawing.

As the figure shows, around the cathode are symmetrically located 10 cells formed by 10 switching electrodes (blades) and 10 receiving electrodes (plates). A control electrode is located in each cell.

If a resistance is inserted in the circuit of each corresponding blade, and connected to the positive pole of potential source (smaller than the magnetron cutoff for a given construction); the device will have 10 working, stable beam positions when the beam is locked in one of the cells, and one stable position when the beam is "extinguished" (cutoff condition of the magnetron). When a negative pulse is applied to one of the blades, the beam is locked in the corresponding cell because a small portion of the beam current (about 1 ma) produces a potential drop in the resistor of the blade circuit, which ensures a low potential of the blade. The major portion of the beam falls on the plate of the given cell.

If a negative pulse is applied to the control electrode of this cell, the beam will be transferred to the blade of the next cell in the direction of switching. The beam current reaching this blade produces a potential drop in the resistor of its circuit, and the beam is locked in this next cell.

In this manner, by applying negative pulses to the control electrodes, it is possible to switch the beam from one cell to the next one consecutively.

To increase the operating reliability of the trochotron and to decrease the requirements imposed upon the counting pulses, the control electrodes are connected in two interlacing groups, and the negative pulse potentials are consecutively applied in each group. It is advisable for this purpose to install in front of the trochotron a trigger and connect the anodes of its tubes to the controlling electrodes.

A unit containing a trochotron can be used as a counting decade (the resolving time of this decade is 0.2 μsec).

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If the plates of the trochotron are borught out of the tube envelope, they can then be used as the large capacity output electrodes with large output current (10 to 20 ma).

The ring trochotron can be used as a multichannel distributor because it is possible to connect in series several trochotrons and thus increase the number of commutating circuits.

The trochotron can operate with small potential supply (24 v) together with semiconductor amplifiers.

The new type of trochotron, according to the information from abroad, has found many uses, e.g., pulse counting, frequency divider, distribution in systems with modulation of one carrier frequency simultaneously by several independent audio channels, gate systems, matrix systems, coding, time measurement, etc.

The ring trochotron can also be used as a component part in telemetering, telecontrol, radiolocation, homing systems, automatic control, etc.

In spite of the fact that we started the development of trochotrons earlier than other countries, the trochotrons are already being massproduced in Sweden and in the U.S.

According to the foreign information, because of the optimum operating conditions of the cathode in the ring trochotron, its service life is very long, i.e., 50,000 hours. We find it very worthwhile to organize the widespread application in industry of the several models of ring trochotrons as fast as possible.

Electronic digital calculating machine represents one of the most accomplished automatic arrangements. At the present time they are constructed with electron tubes. It appears that in the near future semiconductor devices will be widely used. However, it is worthwhile to examine the problem of utilizing, in the special purpose digital computers of the nonstationary type, specially developed electronic equipment, capable of replacing an entire system requiring a large number of ordinary elements. This will greatly simplify the computer and will make it more reliable. [redacted] worthwhile because in portable computers, oper- STAT ating under variable ambient conditions, the semiconductor elements are not stable; their stabilization would require cumbersome arrangements. The economic factor may also prove to be important.

Foreign literature describes several types of special electron tubes, combining in one device the functions of several elements of calculating arrangements.

The former IAT Electronics Laboratory of the Academy of Sciences USSR built a universal digital logical element; in 1955 the IRE of the Academy of Sciences USSR built a special electron-beam device--a binary switch, operating according to a logical scheme with two inputs and four outputs (Figure 3c) and with an output current of about 5 ma at 350 v of potential supply. Two devices within a single enclosure

Inputs		Outputs			
1	2	1	2	3	4
0	0	1	0	0	0
0	1	0	1	0	0
1	0	0	0	1	0
1	1	0	0	0	1

can operate as a complex summation unit. These devices are operating directly from one another without intermediary elements. The results of the pulse testing of the binary switch can be summarized as follows: with 100,000 ohms in the load circuit of the output electrode and a capacity of 30 $\mu\mu$f, the time for the appearance of the output voltage is equal to 1.5 to 3 μsec with a potential gradient of 100 to 150 v.

Further improvement and the search for the new types of electronic devices of the commutating type that perform the distribution function should be undertaken without a doubt.

Converters

The problem of signal conversion from one kind into another is often encountered in the automatic and particularly in the telemechanical installations (different types of modulation of signals coming from sensing elements, conversion of one type of modulation into another to increase interference-killing features or to increase

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the ease of reception, conversion of a constant signal into a pulsating one and conversely, etc.). The flexibility of the electron-beam devices, permitting performance of the most diverse types of conversions, is strikingly illustrated in the solution of these problems. A number of special devices of this type have been developed up to the present time. Lack of space does not allow us here to describe all existing types of devices; hence, we shall examine only the coding and electronic contact tubes.

The problem of coding the transmission, i.e., the conversion of any level of a constant signal or of a signal varying with time into a series of pulses, set up according to some rule, can be realized with the aid of several types of electronic devices.

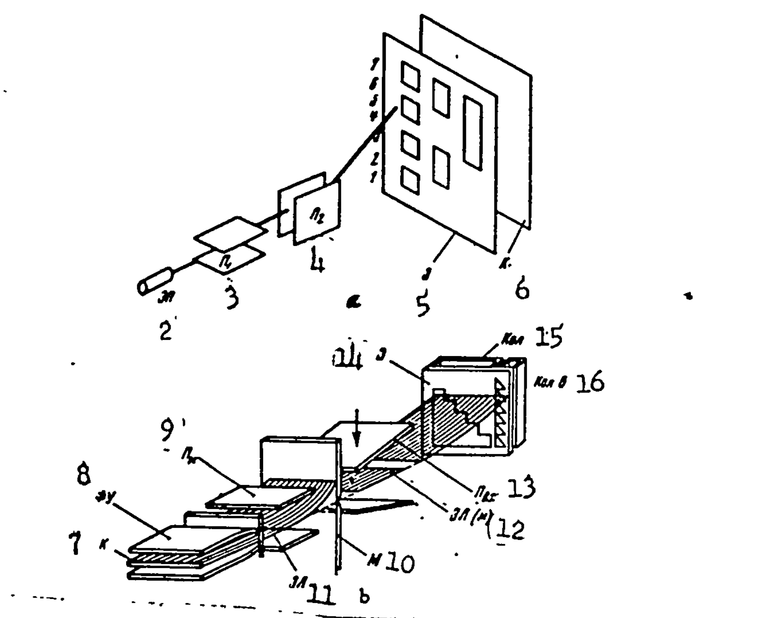

Figure 4. Coding tubes.

a - pulse coding tube:

2 - electron gun; deflecting plates; 3-P_1 - first, 4-P_2 - second, 5 - screen with openings; 6 - collector;

b - tube with pulse-time modulation and quantization of amplitude:

7 - cathode, 8 - focusing arrangments; 9 - plates for pulse time modulation; 10 - screen with a slot; electron beam; 11 - nonmodulated; 12 - modulated; 13 - input plate; 14 - screen with openings; collectors; 15 - output; 16 - auxiliary.

One of these is an electron-beam tube having two pairs of deflecting plates with electrode openings and with receiving collector (Figure 4a). The signal to be coded is applied to the horizontal deflecting plates and the short pulses are applied to the vertical ones.

The arrangement of openings in the screen is chosen in accordance with the necessary coding requirements. It is evident that the coded combination in the output of the tube, set up on the output screen by the horizontal pulsating deflection of the beam, will directly correspond to the given level of the coded signal. The speed of operation of such a tube is low due to the weak current of the beam, but it can be greatly increased through the use, for example, of the secondary electron emission. To narrow down the necessary frequency band or to transmit additional information with a given frequency band it is expeditious to use "quantization," i.e., splitting into separate levels of signal amplitudes in common with the pulse modulation.

The construction of the tube capable of pulse modulation and quantization of amplitudes is shown in Figure 4b. The flat-shaped beam passes through the first deflecting system, which is supplied with an auxiliary variable potential. As a result, this beam passes through the second pair of deflecting plates, supplied with the signal, and reaches the output arrangement consisting of a plate with openings of special shape and of the collector electrode. If the beam has a constant density along its width, we will obtain a pulse-modulated quantized signal on the output collector. The tube gives good results with the frequency of the alternating potential on the first pair of deflecting plates equal to 5 mc and with a microsecond sawtooth signal on the signal deflecting plates.

Extensive use in automated and telemechanical installations, as well as in telephony, can be made of special electron contact tubes, utilizing secondary electron emission and functioning as converters of a constant signal into an alternating one, as contactors, switches, etc., and differing by the fact that they possess a very small internal resistance ($\sim$1 kilohm). The appearance of these tubes for the first

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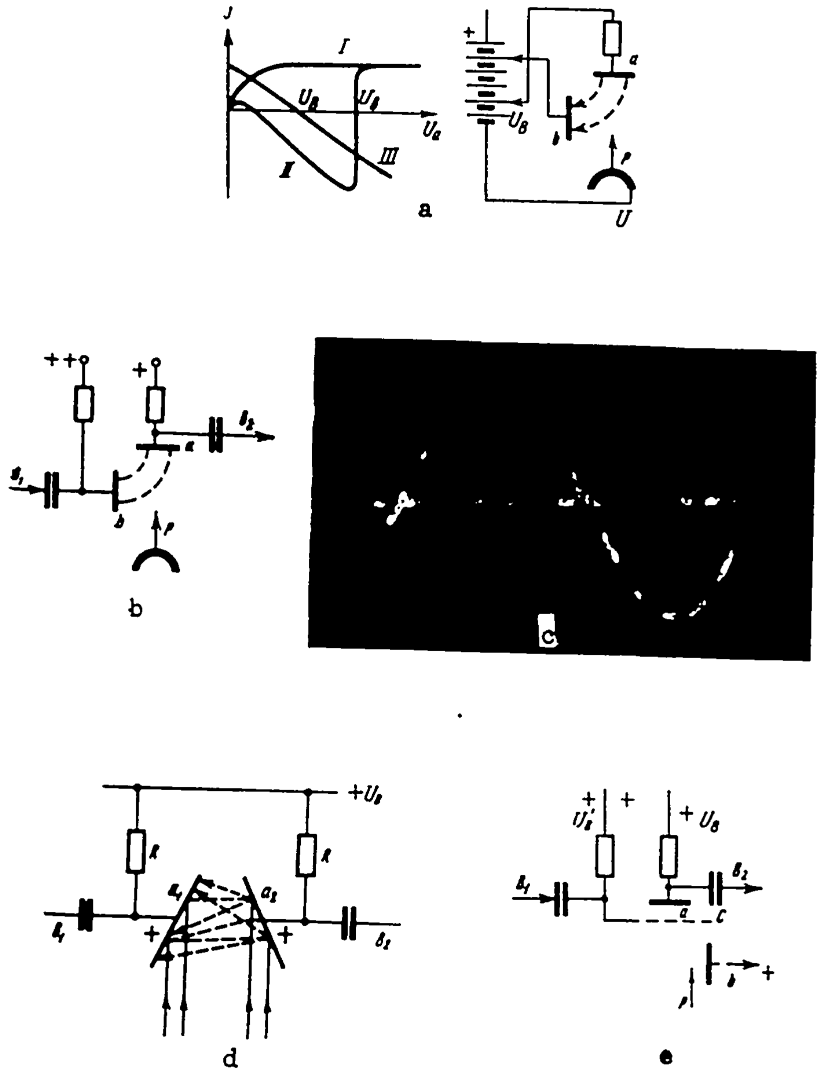

Figure 5. Contact tubes utilizing secondary emission.

a- unidirectional contact; b- arrangement for transmission of an alternating signal through the contact; c- oscillogram of the modulated signal; d- two-way contact; e- contact with grid control.

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time made possible the actual replacement of mechanical contacts with electronic ones in a number of new cases; this will make it possible to increase considerably the operating speed and the reliability of contacts, and sharply to reduce the power required for the contact control.

In these tubes, a flat electron beam is formed by the electron-optical system and is directed toward the secondary emission contact. The principle of operation of the contact is illustrated in Figure 5a. The primary electrons p strike the electrode a which is at the positive potential. If the secondary emission from the electrode a is absent, the current at this electrode, depending upon its potential, will vary according to the curve I. However, if the electrode a is an efficient emitter of secondary electrons and if the nearest electrode b has a higher potential ($U_b > U_a$), then the volt-ampere characteristic of electrode a will correspond to curve II. If, further, a resistance is inserted into the circuit of the electrode a, then, having supply voltage U_b, the stable equilibrium potential (U_a) will be determined by the point of intersection of the straight line III and the volt-ampere characteristic II. Potential (U_a) is approximately equal to potential U_b, which amounts to a closing of contacts between electrodes a and b. It is evident that the potential of electrode a will follow the variations of the potential of electrode b. The closing and the opening of contacts can be accomplished by the deflection or the blanking of the beam. The arrangement for closing of the electronic contacts for the transmission of alternating potential is shown in Figure 5b.

The modulation of the signal (U = 20 v, f = 80 c) by means of the interruption of the beam by the modulating potential (U = 60 v, f = 600 c) is shown in Figure 5c.

The described contact is unidirectional, i.e., the potential U_a follows U_b, but U_a follows U_b only within narrow limits.

To obtain a two-way contact, the contact arrangement of the tube is made symmetrical, i.e., both electrodes (a and b) are efficient secondary-electron emitters (Figure 5d). In this case, each one of the electrodes can operate either as an anode or as an emitter.

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Several contact arrangements can be installed within one enclosure, and the commutation of several circuits can be accomplished through their use.

The electronic contacts of the described simple type can be connected in a series of no more than 3-5 units. In order to connect a large number of contacts in series, it is necessary to separate the functions of the controlling electrode from the electrode collecting the secondary emission electrons, as is shown in Figure 5e.

Input electrode c has the form of a grid and collecting electrode b, with a high potential, is placed on the side. The main part of the secondary electrodes strikes the collecting electrode. The current of the control grid can be made approximately equal to zero, if it is made of a material with the coefficient of secondary emission $\sigma = 1$.

Ten contacts can be connected in series with this type of construction.

The upper limit of the signal frequency which can be transmitted through the contact is determined by the time constant of the contact which, when R = 1,000 ohms and C = 3 $\mu\mu$f, gives us $t = 3 \cdot 10\ \text{sec}^{-9}$.

The tubes developed at IRE of the Academy of Sciences USSR, R = 3,000 ohms, C = 5 to 10 $\mu\mu$f, $t = 1.5$ to $3 \cdot 10^{-8}$, have a noise level of 200 to 500 μv in the band up to 1 Mc. The minimum input signal at the frequency of 10 kc can possibly be lowered to several microvolts.

By analogy with the contact tubes, so-called signal tubes can be made, which at their output produce pulses of a specific amplitude, with input pulses varying in amplitude within very large specific limits.

The possible development will be electronic contact tubes with low level input signal and small number of contacts in one enclosure and multichannel tubes with average level of input signal (10-100μv).

There is no doubt that the new problems arising in automation and telemechanics will require the creation of new electronic equipment, performing the functions of varied signal conversions. As has been pointed out, the special electron-beam devices are the most suitable elements; in many cases, nothing can compete with them,

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even when they are compared to semiconductor devices.

Multipliers and Functional Tubes

During recent years, special electronic tubes have been being developed for use in analog computers (computing machines with continuous action).

Let us examine several types of multiplier tubes.

One of these consists of an electron-beam tube, with two pairs of mutually perpendicular plates for electrostatic deflection, and of a second pair of plates surrounded with a coil which produces the axial magnetic field (Figure 6a). The potential proportional to the first factor is applied to the first pair of plates. The current proportional to the second factor is put through the coil. It is easy to show that the resulting deflection of the electrons, after passing through the first pair of plates and the magnetic coil (due to the acquisition of the transverse component of velocity), is proportional to the product of the factors.

The receiving system of the tube consists of two plates insulated from each other. If the beam is located on the separation line, the output signal, in the differentially connected curcuit is equal to zero. The amplified output signal is applied to the second pair of the deflecting plates, which in this manner compensate for the total deflection. The magnitude of this potential constitutes the output value, proportional to the product. A laboratory model of such a device was at one time constructed in the former IAT Electronics Laboratory of the Academy of Sciences USSR. The accuracy of this multiplier, as demonstrated by theoretical calculations and experimental investigations, is within 2 to 3%.

In the other type of multiplier, also consisting of an electron-beam tube with two pairs of deflecting plates, the electron beam with a large circular cross-section is aimed at a metallic screen, made of four quadrants and insulated from one another (Figure 6b). If the currents in the first and third quadrants are positive, and in the second and the fourth negative, it is easy to show that the algebraic summation of currents will be proportional to the product of deflections x and y, and, in the

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presence of a linear system of deflection, proportional to the product of the positive and the negative plate potentials. The accuracy of the multiplication ranges within 2%; the speed is approximately 100 kc.

The third type of the multiplier which we would like to mention also consists of an electron-beam tube whose basic feature is a deflection system which produces a hyperbolic field. The construction of this multiplier is shown in Figure 6c. A first deflection system (deflecting in the x direction) is located in front of the electron gun; a deflection potential U_1 is applied to this system. The first system

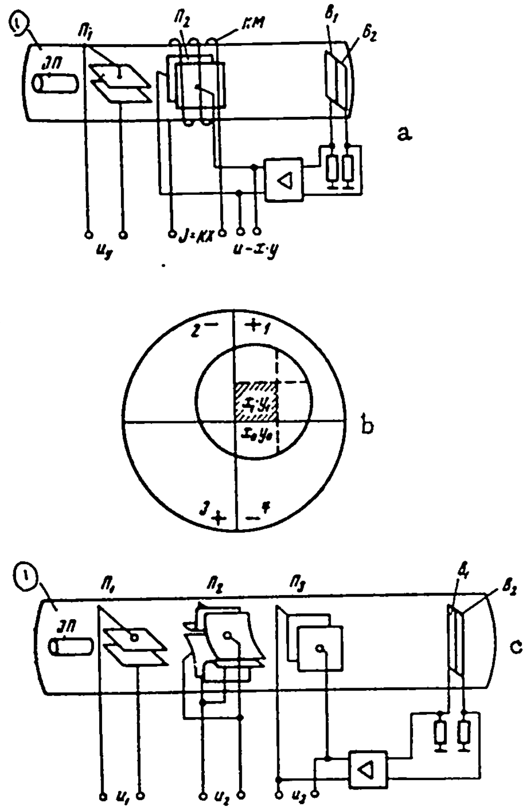

Figure 6. Electron-beam multipliers:

a- with a magnetic coil; b- with a wide beam; c- with a hyperbolic field; 1 - electron gun.

of deflection is followed by the second one, which consists of four electrodes, producing a hyperbolic field in the cross-sectional plane xy. This field is such that the electric field intensity in the y direction increases linearly with the increase of x, and is negative for $x > 0$, and positive for $x < 0$. In this manner the beam deflected by the first system by a value x gets into a hyperbolic field which is proportional to the deflecting potential u_1. It is obvious that in such a field the electron beam is deflected in the y direction proportionally to $u_1 \cdot u_2$ with the sign, which takes into account the signs of u_1 and u_2. As in the first type of the multiplier we examined, a third deflecting system is provided; it is connected with output plates through a feedback circuit. The potential on the third deflecting system will be proportional to the product $u_1 \cdot u_2$.

The accuracy of this arrangement is high, with an error of about 0.5%. The limiting frequency is approximately 200 kc.

We must consider the long-range development and use of the examined types of electron-beam multipliers, as well as their improvement, in order to simplify the construction, to boost the accuracy, and to increase the operating speed noticeably.

There is a very good outlook for the development of electronic devices in which the output current is any predetermined function of the input quantity, i.e., of

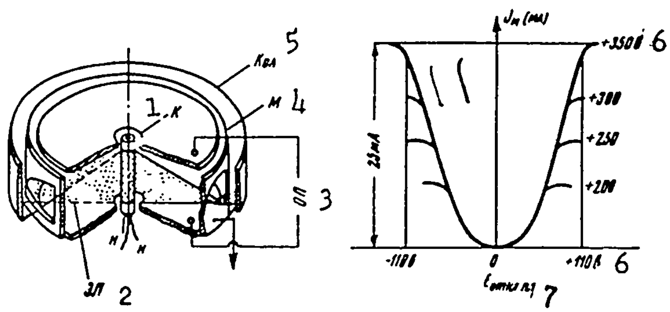

Figure 7. Quadrature tube--internal construction and output characteristics.

1 - cathode; 2 - electron beam; 3 - deflecting plates; 4 - mask; 5 - collector; 6 - v; 7 - $E_{deflecting\ plate}$

function data units (formatrons). The operating principle of these devices consists in the fact that the output current is the assigned function of the position of the flat or round electron beam. The form of the output function is determined by the shape of the output electrode (mask). It is apparent that only such devices can en-

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sure most simply and most accurately and reliably the analog of the required functional dependence.

An example of such a function tube is the quadratron, massproduced in the U.S. (type QK 256) (Figure 7). The tube has a very simple construction and has the dimension of the receiver-amplifier tube. The electron beam, emitted by a cylindrical cathode, is formed by special electrodes into a disc-shaped beam, which is focused on the mask. This mask consists of a cylinder with several cutout parabolic openings. Behind the mask is placed the electron collector. The same figure shows the characteristics of the output current, which approximates very closely the relationship $i_{out} = KU_{in}^2$. The total tube current is about 40 ma, which ensures practically any speed of operation. The accuracy is close to 99%. The formatrons can find extensive application as amplifiers, mixers, quadrature detectors, phase and frequency modulators, limiters, automatic regulators, frequency multipliers, discriminators of amplitude, modulated waves, etc.

Of considerable interest to calculating technique are the so-called matrix tubes, which are also functional data units.

Memory Elements

The tendency to complicate the functions performed by the automatic installations calls for the emergence of new technical means for preserving the applied signals with the possibility for subsequent reading and erasing, i.e., in preparation for the new act of retention. To perform this function of memory, a number of special electron-beam apparatuses can be proposed, all of which use thin dielectric layers as retention elements, with an electron beam as the recording and reading agent, capable of producing local positive or negative charges on the surface of the dielectric layer.

During recent years several such types of apparatuses have been developed (potential scopes with barrier grid, with dielectric grid, graphectrons, selectrons, tubes with retention of illumination, etc).

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Memory electron-beam tubes which, with approximately 2,048 elements give about 2,000 rotations at a speed of 4 μsec, were put into massproduction for the electronic calculating machines here in the USSR in 1956. According to the published information, the American firm IBM in 1954 developed a tube with a barrier grid which, with 3,000 elements, is capable of 2,000 rotations; the same tube with 10,000 elements is capable of 100 rotations. The Bell System describes a tube (1955) which with 16,000 elements is capable of more than 100 rotations at a speed of 2 μsec.

The current requirements for tubes working in the operating unit of memory machines consist of 4,000 rotations with 4,000 elements and a speed of 1 μsec. It is hoped that these parameters will be attained in the near future.

Conclusion

The material presented in this article shows that a number of problems in the field of the construction of automation and telemechanical equipment can be successfully solved by using special electronic equipment, in particular, through the use of equipment employing the principle of the control of the output current by the control of the location of the electron beam with respect to the output electrodes.

Many types of such equipment have already been developed abroad as well as here in the Soviet Union.

There is no doubt that the equipment which has already been developed here or which is known from publications would find extensive use if it were manufactured by our industry.

As we know, automatic and telemechanical equipment is being developed by a large number of scientific research establishments, design bureaus, and industrial laboratories. An unusual situation resulted in the process of these developments. In many cases the systems development personnel recognized that the best solution can be secured through the use of special electronic equipment for which they can formulate technical specifications. But past experience shows that, if they decide on such an approach, they will as a rule not be able to complete their development on time. Thus,

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they were forced to use existing elements, although this often resulted in complicated and unreliable solutions.

The USSR has a very inadequate variety of special electronic equipment capable of successfully solving many problems confronting automation and telemechanics. The development and, in particular, the acceptance of such equipment by industry is progressing very slowly and this undermines the confidence of the users of the developed products. It appears, for example, that there is a need to set up in the MRTP system a special construction office with a good production base and an experienced plant which could manufacture products from development models, adapt them to industrial needs, and manufacture small quantities of new electronic equipment as ordered by the users. This equipment must in all respects be usable in current automatic and telemechanical systems.

We believe that the creation and its efficient operation of such an establishment will considerably help the development of industrial automation and telemechanical facilities in our country.

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L. I. Gutenmakher

PROSPECTS FOR THE APPLICATION OF MAGNETIC AND CAPACITIVE UNITS AND ELEMENTS IN THE AUTOMATIC SYSTEMS

The existing automatic systems are built essentially with the relay-contact equipment. As an example it is sufficient to cite the automatic telephone stations (ATS), railroad signalling systems, centralized control, automatic block control (STsB), telegraph stations, telemechanics of the energy producing systems, of the gas pipelines, of the oil pipelines, and production lines of machines and of automatic factories in industry.

The number of operating pairs of contacts is very large (more than 10 billion).

The drawbacks of relay-contact equipment are known: impacts, jolts, and vibrations can produce displacement and faulty closing of contacts; jamming of shafts, dampers, and other movable parts can change the characteristics of elements and at times make them inoperative. The sparking of contacts can be the cause of fires and explosions. The operation of this equipment requires frequent checking, adjusting, and contact cleaning (for example, it is necessary in ATS to clean and adjust 1.5% of the relays daily); it is necessary to provide access to the relays; thus, they are placed on flat structures with an aisle between them (on racks).

Great hopes were placed in the use of electronic tubes and electron-beam tubes instead of relay contact equipment. Rapid operation of the electron-tube equipment made possible the construction of high-speed digital computers, electron-tube integrators, models and trainers, and controlling machines. However, the short service life of tubes, their low efficiency, and the presence of delicate mechanical parts (cathode, grid) do not permit the construction and sufficiently reliable use of complicated automatic equipment which contains tube components.

The drawbacks of relay and tube equipment for a long time hindered the development of automatic systems and the expansion of its field of application. It became necessary to discover new principles for the construction of contactless and tubeless elements and systems of automation that would be free of the above-mentioned defects.

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The way to the solution of this problem lies in the use of semiconductor elements (crystal diodes, triodes), nonlinear resistances, magnetic elements (transformer and impedance relays and amplifiers, storage devices, commutators, logical switches), and capacitance elements.

The automatic systems built with these elements will exhibit some characteristic properties: static operation (i.e., they will consist of permanently connected electrical networks made of mechanically nonmoving elements and units), vibration stability, and moisture proofness; they will not be affected by the pressure of the ambient atmosphere and they will operate with equal reliability in different positions in space and when subjected to rapid accelerations.

Because of their great reliability, automatic systems can be constructed from these elements, which can perform more complicated functions than can presently be performed with many thousands and millions of separate elements in one network.

As a result of the design work on magnetic contactless and tubeless elements* and assemblies for automatic systems, it now appears that it is possible to place more than 100,000 relay cells in 1 cu m. The construction of units, in contrast to the surface arrangement of contact and tube systems, can be of a volumetric nature. At the end of the assembly and testing, the units are filled with a viscous isolating material, are hermetically sealed, and possess a great mechanical and electrical stability. All elements are very durable. Their high-speed operation is close to the speed of the electron tube equipment.

The mass use of these new industrial automatic facilities will bring about great changes in the national economy of our country. The great reliability of the contactless magnetic, capacitive, and semiconductor elements, as compared to the presently existing elements in the relay contacting equipment, makes it possible to assume that in 10-15 years the quantity of similar contactless equipment will increase by 100 to 1,000 times. This will result, not only in the increase of automatic telephone stations, mathematical machines, railroad automatic signalling and other complicated

* This report does not separately examine crystal-triodes (transistors), which also are of great importance in the creation of reliable miniature equipment for the automatic systems. The possibility of the construction of such systems, using mainly magnetic elements, is stressed on purpose. It is feasible to combine them with crystal amplifiers and relays.

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systems known to us now, but also to the appearance of qualitatively new automatic systems. In this connection it is necessary to plan for the corresponding scientific investigations and technical developments.

In examining the development of new systems of automation in the light of the coming five-year plans, we must await the appearance of the new undertakings and institutions with new operating systems.

It is possible to see, for example, within this persepective a dense single network of automatic information and control stations in our country, which will include equipment of automatic telephone and telegraph stations of the new type. They will include high-speed digital computing and controlling machines and statistical and information machines.

Part of the stations--branch stations for information and control--will be tied into a single system network of enterprises belonging to one combine and one ministry; some of them will be located directly in the individual large enterprises and establishments.

Automatic Contactless Telephone Stations (ATS) of the New Type

The replacement of the contact telephone relay and step switches with the new, contactless relays and commutators is within the realm of possibility in the very near future. The realization of the new type of ATS represent one of the most important problems because this will result in the mass production of all the basic elements of the contactless systems which are also necessary for other innumerable uses in the national economy. In using the crystal and magnetic amplifiers for the amplification of the intensity of the sound vibrations and with the use of high-speed ferrite impulse relays, registers, and commutators, it is wise to plan for the application of the digital interference-proof method of modulation. In this manner, the entire commutation scheme and the ATS memory are reduced to the already tested arrangement of units and elements of the contactless systems. Even now the ferrite magnetic relay elements operate at a frequency larger than 300,000 operations per second and by virture of their speed of operation they are suitable for the construction of the new ATS.

The possibility of using new long-lasting capacitive and ferrite operative memory installations will result in new interesting variations in the work of the ATS. Thus, for example, in order to call any phone number busy at the time, it will only be necessary to dial the number once. This number is then transferred into the operative memory of the ATS, with the result that the automatic arrangements of the ATS watch that the connection with the dialing telephone will be made as soon as the busy phone becomes available again. It will also be possible to install, for added convenience, a signal on each telephone to indicate, during the conversation with another telephone, that a third phone is awaiting the connection (signal "someone is waiting for you").

The great speed of commutation and the presence of memory and controlling computing installations will permit in the new ATS more efficient schemes of telephone connections in each separate case.

Telegraph communications using the ATS system of the new type will be greatly facilitated by the introduction of the pulse methods of transmission of telegraphic signals and by the installation of amplifiers in the output networks of the ATS. The present-day telegraphic equipment, by virture of its principle of operation and construction, represents complicated electromechanical instruments consisting of a great number of relays and contacts.

In order to bring the number of telegraphic sets, for example, on a par with the number of telephones, it is necessary to develop and massproduce small-size contactless systems of telegraphic equipment.

It is necessary to develop complex telephone-telegraph portable apparatus.

The introduction into the cities and districts of a single telephone-telegraph network through the ATS will give us new ways for the construction of control systems used in the national economy. The entire correspondence among different establishments, combines, ministries, and other organizations can be organized and conducted

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with the aid of telegraphic equipment and memory machines which receive the information. This will result in a sharp reduction in time required for the transmission and the processing of business papers.

Automatic Statistical and Information Machines

The pulse systems for the transmission of various types of information will permit the introduction of new forms of machines for statistical data processing concerning the working of industry, the national economy, and transportation. Data pertaining to the operation of establishments--receipt and use of materials, money resources, distribution and utilization of work force, and tens of thousands of other items of information--can be fed in parallel into the memory of high-speed, digital statistical machines. This will make it possible to process with extreme speed the material according to preset programs and to work out the necessary data required for correct planning and control. This will result in an increase in the productivity of the employees of the state institutions and in an increase of the part played by each worker who is using machine technology for the registration, classification, and processing of all incoming and outgoing materials of the establishments.

It is necessary to add to this system the automatic reference machines* which must contain reference material registered in long-lasting machine memory and pertaining to science, industry, and the national economy. The reference machines will make possible the process of utilization, in the national economy, of all the accomplishments of science and industry and will result in the better use of all presently known results of research and technical development in the future. They will also improve the work of planning and controlling the national economy.

The need for the analysis and synthesis of the content of the world is scientific

* 1. Bystrodeystvuyushchiye nauchno-spravochnyye i statisticheskiye machiny /High-speed Scientific Reference and Statistical Machines/, Publishing House of the Academy of Sciences USSR, 1954.

2. Puti postroyeniya informatsionnyich i statisticheskikh mashin novogo tipa, L. I. Gutenmakher, /Ways to Construct Information and Statistical Machines of the New Type/, Publishing House of the Academy of Sciences USSR, 1955.

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and technical literature is now being felt by millions of workers in all branches of the national economy. The uninterrupted growth of the number of books (up to 200,000 titles per year) does not permit even the most highly qualified workers to follow the publications in detail and to remember the needed information. It is well known that, due to insufficient information, a substantial amount of effort and money is being spent in vain by many establishments and enterprises. Figure 1 shows a block diagram of such automatic reference machine.

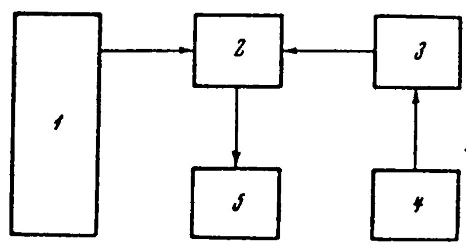

Figure 1. Block diagram of the scientific reference information machine.

1 - machine "memory" (storage of the information units); 2 - reading mechanism; 3 - converter of the ordinary information text and interrogation into the machine text (pulse code), and conversely; 4 - input mechanism (introduction of information and interrogation into the machine); 5 - output mechanism (printing of answers or transmission of worked-out results (answers) through the telegraph apparatus.

To solve this problem we need methods for text recording which will allow the reproduction of the material with great speed as many times, as necessary, for 50 to 100 years and without damage to the material (until the content becomes obsolete). To record, for instance, only the existing reference magazines accumulated up to the present time, a memory machine is necessary with a capacity of about a billion letters (25,000 printed sheets), filled with telegraphic signs. In addition, it is required that the size of the machine memory be relatively small. The memory of the machine of a billion letters must occupy a space similar to the book storage of an ordinary library. Present-day technology allows the reading of 250,000 pages of text in one hour. A person can only study several pages of scientific text in one

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hour. A person often reads to sort out the information he needs and partially remembers interesting data he encounters on his way. These functions of sorting out of information can be performed by the machines. Let us examine their possibilities and the outlook for their development.

The machine can find and select in the memory the material which has given qualitative characteristics. The entire material recorded in the machine memory is thus reviewed for this purpose and is compared at all times with a certain number of characteristics established by the interrogating person. As soon as the characteristics of the material and of the request coincide, the selected article, reference, or report is printed by the machine and is telegraphically communicated to the subscriber. In the simplest case, the answer can contain the enumeration of the selected items as a list of their numbers in the bibliographic yearbooks.

It must be noted in this case that the machine can select material according to the combination of such concepts which cannot be foreseen with the aid of any system of classification. Considering the great number of separate elementary characteristics, the number of their possible combinations in response to an interrogation is unusually large and practically cannot be exhausted. The theory of combinations permits an easy determination of such "astronomical" numbers, which can be obtained in counting the possible number of combinations to a question. Even with modest original data, this number will be larger than $10^{1,000}$.

The comparison can be performed not only according to the qualitative characteristics but also according to the quantitative data. For example, one can ask for the data concerning the magnetic material which possesses certain given properties within the current frequency of 1 million to 10 million c, and which lies within the given limits of magnetic permeability, induction, coercive force, mechanical strength, and so forth. One can ask for information about the materials which possess maximum or minimum values of given qualities.

The machine reading can be conducted also selectively according to the given addresses. With the aid of an electric network, it is possible to send out currents

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in accordance with a given program, in order to select any element of information (reference, word sentence, formula, diagram, etc.). In the same way as such elements of information are identified in the books by their "address"--book numbers, pages, lines--so each element of information within the system circuit of the machine has its address. Just as subscribers of the telephone ATS can be reached by dialing their numbers, so the information elements in the machine memory can be connected by the commutator ("called out") to the mechanism for the analysis of their content. The existence of the addresses makes it possible to conduct a search for the new material using the literature references which are usually present in the scientific articles, reports, etc. Such a process of searching for the material within the internal circuits reminds one of the search through the association of ideas when a person recollects more and more details of some question which interests him.

It is also possible to imagine the organization of a search for the required information, using various tables previously introduced into the machine, which relate the particular concepts with more and more general ones. Thus, the machine will permit the obtaining of newer and newer properties of the concepts within the inquiry which interests us, replacing the particular concepts with more general ones.

Consequently, the machine "reading" as assigned does not represent, in this case, a simple sorting out of information according to the characteristics of the inquiry. The internal networks and the search program permit a rapid and intelligent selection of the needed information, a comparison of different data, and their analysis. In many cases the inquirer may be interested, not in the bibliography, but in the analysis of the content of the articles. If one just imagines the tremendous amount of information which can be examined by machine means, the need for and the prospective uses of such machine reading becomes apparent.

The creation of such "reading" machines possessing a vast and stable memory can radically change the methods for the use of the vast and inexhaustible potential wealth which has been accumulated by human genius*. The development of such machines

* See the article by Academician A. N. Nesmeyanov, "Looking into the Future of Science," Pravda /Truth/, 31 December 1955.

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is one of the most important problems.

Translating Machines

The information machine cannot be constructed for the literature of only one language. Its memory must accumulate the material of foreign literature. It is apparent that, in order to utilize such literature, translating machines are needed which would automatically translate the foreign text into the Russian language.

Preliminary calculations showed that, using static durable memory and contactless magnetic relays and commutators, it is possible to construct such a translating machine which will serve simultaneously about 1,000 subscribers connected to the machine, through the systems of the city automatic telephone stations. Let us add, for example, another 1,000 numbers of the translation machine to the numbers of the future ATS of the new type; by dialing, for instance, on the ordinary telephone the number 901, one will be connected through the subscriber's instrument to the translating machine. Let each subscriber have a special automatic typewriter. The keyboard of this typewriter transmits, by means of telegraphic code, the letters of the foreign text which are manually assembled by the subscriber, while the machine types the Russian letters of the translated text, received from the translating station in response to the assembled text.

With what speed can the subscriber work who is assembling the letters of the foreign text on the keyboard? Let us assume that his speed consists on the average of 100 letters per minute (about two letters per second). Thus, the assembly by the subscriber of a sentence containing 20 words of 10 letters each (on the average) will require 120 sec, while the future machine will be able to make a translation of more than 10 such sentences in one sec.

There will be within the instrument of each subscriber a memory mechanism (made of magnetic registers) for the receipt and transmission of coded signals of one sentence.

The address system for the search of the address of a vocabulary unit in response

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to an assigned word can be constructed from a system of two-coordinate ferrite grids.

Statistical Machines

The statistical machines, located in the automatic stations of information and control, will receive, through the telegraph lines from establishments and organizations such data, such information as is needed for durable safekeeping and for processing as the need arises for planning and control.

The simplest of them can be used for planning and control in commerce. Thus, for example, information about the sales progress and the results of receipts due to the sale of various merchandise items can be fed directly into statistical machines through the improved cash registers of department stores and shops. By automatically processing this information according to given program, the machine itself will be able to send out the necessary orders to the commercial bases for the delivery of various other merchandise items from the trading points.

For example, the statistical machines of a main administration of the metal processing industry will be able to receive the complete information concerning the progress of production. It will be possible to obtain information, for example, about the following indicators of the operation of the enterprise: staff, number of workers and their breakdown according to categories, production per worker, execution of plan, production cost, electric energy used, number of orders and their characteristics, raw materials, and parts in stock, etc. The study of these materials can be conducted according to "different profiles."

With the existing techniques for processing these data in the accounting offices, even a relatively narrow processing of records requires a large amount of time and resources. If the data on each record are automatically recorded through the new type of the ATS as a unit of information on the leaves of the machine memory, the machine review of all the records of the enterprises of the combine will require several seconds with a speed of about 30,000 units of information (leaves) per second.

The processing and the computation of the data according to any profile in accordance with an indicator will only require several seconds.

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The construction and use of such statistical machines will make it possible to analyze the operation of enterprises from all angles through the most varied profiles.

Application of the Controlling Machines

The feasibility of reproduction, in accordance with a given address, of any kind of curve makes it possible to propose a new system of program control of various machines, machine tools, and other objects.

In the U.S. and in the USSR, work is being done on the automatic control of metal-processing machine tools with the aid of perforated cards and magnetic tape, on which is recorded the program for the process of the machining of the product. Higher speed and more reliable static memory can be utilized instead of the perforated cards and the magnetic tapes. The high-speed reproduction of the program for the operating process permits the control of a large number of machines and machine tools (more than 100) with the aid of a single memory installation.

The application of reliable contactless magnetic commutators, accumulators, and interpolators in conjunction with the new programming facilities will without a doubt result in a control system which will be very productive and profitable.

Let us briefly recall that in the case of program control the machine tools operate automatically according to the schedule indicated by the tables of numbers. The program indicates the exact trajectory of the instrument (cutter, knife), the sequence of transitions from one kind of operation to another, as well as the control signals for switching the operation off and on, the change in the number of revolutions of the spindle, the supply of the cooling liquid, etc. The accuracy of numerical programming is not limited: it depends practically only upon the accuracy of the mechanisms and the wear of the instrument.

This case of the use of contactless commutators and memory for program control can be extended to the other types of program control of complicated equipment, with a large number of elements linked together into one common system. Such equipment can be found in chemical, metallurgical, oil, textile, and other industries.

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Application in Calculating Practice

The new memory devices can be successfully used in the analog computors and in the universal digital computers.

Analog stands for the testing of the devices for automatic control and regulation are becoming more and more important. It sufficies to cite examples of the use of these models for testing the dynamic operation of autopilots and other types of aircraft equipment. The most complicated flight and combat conditions can with sufficient approximation be imitated in these analog stands.

Increasing importance is also being assumed by trainers, which are electrical analogs used to train people for the control of moving objects.

These analog installations can assume great significance as a result of the new type of memory equipment.

It can reproduce disturbances of various types, variable and constant coefficients, tables of functions, and other data.

It is possible to introduce into the universal calculating machines one program of operation after another, registered on static memory units. The gradual accumulation of programs of different types in the machine, always ready for action, will increase the scope of the machines.

It is possible to compile a large system of programs and subprograms, which in various combinations will be able to perform the majority of problems encountered in practice.

Figuratively speaking, these machines possess a "short" memory (good for one problem) at the present time.

By using large-capacity, high-speed, and always-ready memory program units, the efficiency of the machine will gradually grow.

The original data for the solution of different problems can also be registered outside the machine on memory leaves. The units made with these leaves can then be instantly put into operation at the same rate as the operative and arithmetical units of the machine (at the same speed).

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The above-mentioned examples of utilization can be realized already in the near future. To confirm this statement let us examine the state of the corresponding development in the Laboratory of Electrical Analog Computers of the Academy of Sciences USSR. We will at the same time point out also the data expected in the near future.

Durable Capacitive-Type Memory Device

Figure 2 shows in a schematic form the electrical arrangement of a large-capacity unit whose construction is shown in Figure 3.

To simplify Figure 2, all elements located on one leaf of paper are shown on one vertical line (T_1-L_1, T_2-L_2,..., T_n-L_n).

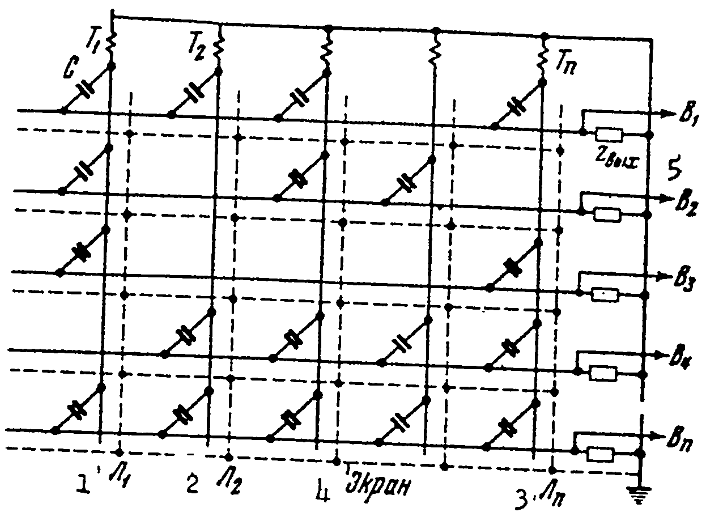

Figure 2. Schematic diagram of a durable capacity-type memory device.

C - capacity; T - transformer windings of the address system.

Legend: 1) L_1 4) screen
2) L_2 5) Z_{output}
3) L_n

One unit contains up to 1,000 leaves.

Each leaf has the electrodes of small condensers C with 3 $\mu\mu$f capacity. The recording of information is accomplished by leaving in or switching off the circuit of condensers C. To accomplish this, it is possible to omit the printing of separate condenser electrodes on the designated places. It is also possible at first to pri

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sheets with all connections and then, as the need arises, to punch out the connections of the electrodes with the buses.

The method of punching out completely printed arrangements is used in the laboratory. When a large number of identical sheets is needed, it is reasonable to print the sheets only with the necessary connections (without performations).

On the sheets L shown in Figure 2 are recorded the following codes of binary numbers: L_1-1110[1]; L_2-1001[1]; L_3- 1101[1]; $L_4$0101[1];..., L_n-1011[1].

The presence of condenser C is shown here with the unit ("1"); the absence of condenser C is shown with zero ("0"); the recording is done from top to bottom along vertical buses (L).

The reading of the recorded information is done with the aid of voltage pulses, induced in the secondary winding of transformers T_1, T_2,..., T_n(see Figure 2).

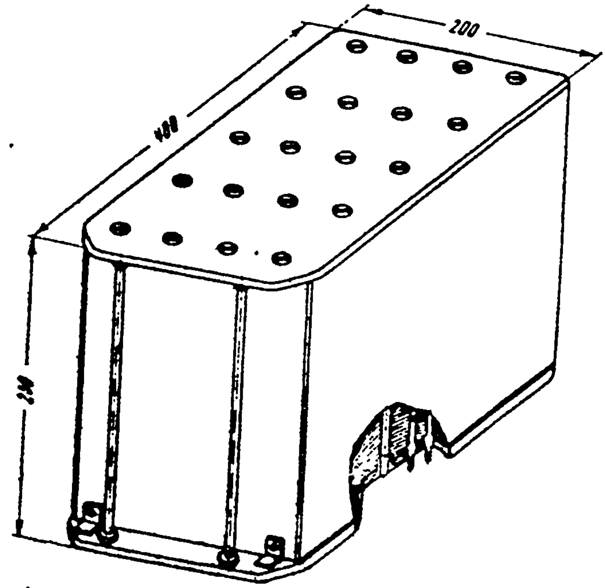

Figure 3. General view of a unit of the capacitive registering device.

When one of the transformers is excited, for example T_3, the voltage will act on the common electrode of the sheet L_3. The capacitive current will pass through condensers to the horizontal buses B_1, B_2, B_4,..., B_n. As we can see in the diagram, there is no condenser C between bus L_3 and bus B_3; therefore, the capacitive current will not flow directly from bus L_3 to bus B_3.

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Consequently, when T_3 is pulsed, the capacitive current will flow only to the buses B_1, B_2, B_4,..., B_n and will produce the corresponding voltage pulses across the output resistances. If the distribution of these output pulses on buses B is recorded in the form of the binary number, the code 11011 is obtained.

The presence of a pulse is denoted here by the unit ("1"), while the absence of the pulse is denoted by zero ("0").

In this manner, the action of one pulse, applied to a bus of one sheet, produces, in parallel on the output buses, the pulses of the code previously registered by the condensers C. The parallel reading of the code of the binary numbers from buses B can be done in any sequence and as many times as necessary without disturbing the record.

The secondary windings of T are placed on the ferromagnetic cores of the two coordinate address grids.

The two numbers of the coded address x and y produce the conditions of the excitation of one of the transformers of the address grid. The voltage of the secondary winding of the transformer acts on the buses of the sheet and the code of the binary numbers registered on the sheet is reproduced on the output buses.

The sheets, when assembled into a unit, are subjected to a pressure of 50 to 100 kg/cm^2. Under this pressure, electrodes A and B of the through holes form current--conducting zinc columns (the sheets consist of metallized zinc). The resistance of such a column is very small.

Investigations were conducted to determine how reliable the contact connections were made in the zinc collars of the openings.

The resistance R falls with the increase of pressure up to 200 kg/cm^2; when the pressure P decreases from 200 to 120 kg/cm^2, the resistance remains constant. Further, a decrease in pressure produces a gradual increase in resistance R. The curve $R = f_1(P)$ has the shape of a hysteresis curve. The curve $H = f_2(P)$, where H is the thickness of the unit, has the same shape.

If, after removing the pressure, one tries to separate such a unit into separate

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sheets, one finds that the zinc contacts forming the column are so solidly bound together that one can only disassemble the unit by tearing away the paper. After compression, the pressure is maintained with compression bolts.

At the end of the assembly, the unit can be completely hermetically sealed.

The following experiment was conducted to test the reliability of the bonding of the contacts of the individual collers on the sheets within a unit: the compressed unit was immersed in transformer oil for 2 months. The resistance of the contact columns was checked after 14, 30, and 60 days. All these measurements did not show any change in the magnitude of the resistance. This proves the reliability of the binding of the contacts.

The cross-sections of the unit made after the compression showed that the compressed metallized sheets formed a structure similar to the structure of the laminated compressed isolating material.

A system of automatic contact soldering was developed by the laboratory for the reliable connection of the electrical circuits of separate units.

It is possible to replace the condensers on the sheets by ferromagnetic cores or by resistors in the circuit similar to that of Figure 2.

Circuits with printed resistors and inductors can also be used for the recording and the reading of information.

To commutate the output signals of the condenser units, magnetic commutators were developed and used, consisting of cores saturated with currents flowing in the coils of the control network. The principle of operation of these magnetic commutators is very simple. The ability to vary the saturation of the reactive resistance of reactors or of the coefficient of transformer ratio by means of the ampere turns is used for the commutation of currents.

Thus, for example, a model of a "scanning" device was developed which connects, in succession, the registers of the condenser memory equipment to the output circuits of the bus B. The commutation is also performed according to the signals of the binary code of some address system.

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The technology of the preparation of the sheets determines the dimensions of the electrodes and size of the units. In the products of the years 1953-1955, the thickness of the paper was 125 μ.

The capacity of the condenser is inversely proportional to the thickness of the sheet. If the thickness of the sheet is reduced 10 times, which is possible in the near future, it will be possible to reduce 10 times the dimensions of the electrodes C for the same value of capacitance.

If the size of the sheets remains the same, the dimensions of the unit reduces 10 times, and the capacity of the sheet in the binary notations is greatly increased due to the reduction of the electrode dimensions.

The smaller the capacity of the elementary condenser, the smaller is the power required from the elements of the address grid.

The technology of electrode printing practically determines the magnitude of the assumed capacity of the elementary condenser (3 pf). From the point of view of actual practice, it is desirable to make the electrodes on the sheets and the capacities as small as possible.

For rough calculations it is possible to use the following formula to determine the power:

$$P_{in} = \frac{\alpha m}{X_C} U_{in}^{2},$$

where P_{in} is the reactive power of the input bus (one the electrode L of the sheet); m is the number of the binary digits of the information element, which corresponds to the number of condensers, connected to the electrode L of the sheet: X_C is the reactive resistance of the condenser; α is the coefficient which takes into account the screen capacity. In practice α has a value from 2 to 3.

With U_{in} = 100 v, $X_C = 5 \cdot 10^5$ ohms (C = 3 pf), m = 500, and $\alpha = 3$, a power of 30 va is required. With a tenfold decrease in the capacity C, power of only 3 va is needed.

With the decrease in capacity, the magnitude of interference, arising from the parasitic couplings between buses through these capacities, also decreases.

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The action of this interference is roughly approximated by the formula

$$\beta = \frac{U(«1»)}{U(«0»)} = \frac{2X_C}{mZ_{out}},$$

where U ("1") is the voltage of the signal "1"; U ("0") is the voltage of the signal "0" (i.e., of the interference); Z_{out} is the impedance of the output circuit of the saturated transformers of the address grid; β is the ratio of U (1) to the interference U (0).

As we can see, the larger X_c gets when we have constant values of m and Z_{out}, the smaller will be the influence of the interference, i.e., the larger will be the signal in relation to the voltage of the interference.

Let us cite an example. Let m = 500; Z_{out} = 50 ohms; and $X_c = 5 \cdot 10^5$ ohms (with C = 3 pf). Then

$$\beta = \frac{2.5 \cdot 10^6}{5 \cdot 10^2 \cdot 5 \cdot 10} = 40.$$

The signal "1" is 40 times larger than the signal "0."

If the capacity is reduced 10 times, the reactance X_c will increase 10 times, and this will result in the increase of β from 40 to 400.

Thus, it is possible to deduce that the main problem in the further development consists in the devising of a better technology for the printing of the electrodes on thin sheets of paper or on sheets on some other insulating material (film).

One of the facets of this problem is similar to the problem of the production of radio-type condensers which is being solved by the radio industry. The other facet of this problem is the special case of the general problem of the development of the technology for the manufacturing of printed electrical circuits.

During the last three years, the laboratory has acquired a certain experience in the manufacturing of sheets, in the construction of the units, and in the commutating arrangements (address grids, decoders, etc.).

On the basis of this experience it is possible to quote approximate figures for the general dimensions of the units for the case of arc metallization and vacuum metallization. The approximate cost calculations show that, with vacuum metallization of one coding sheet, the screen and lining will cost about 10 kopeks (for 512 digits). STAT

The sheet for one million binary digits will consequently cost 200 rubles; correspondingly, for 100 million digits the cost will be 20,000 rubles, and so on. With massproduction of sheets and mountings, the cost naturally will be greatly reduced, i.e., by about 5 to 10 times. However, the abovementioned figures show that in many cases they can even now be economically acceptable for the construction of a series of machines mentioned previously.

In 1955 the commission tested a model of a durable memory unit (unit "A") with parallel reading of cards.

The purpose of testing the model was to determine its possible use in computing equipment.

The model of unit "A" consisted of the following component parts.

(1) A unit, assembled from 256 cards. The capacity of each card was 128 binary digits, this constitutes one information.

(2) Magnetic scanning for 256 cards with a reading speed of 30,000 cards per second.

(3) Output amplifiers (equal to the number of digits read simultaneously).

The testing of the model took a long time, more than one month. The stability of unit operation (correctness of reading of code) was tested.

The code under examination (obtained through the selective method, for example) was:

On the tenth output (during the scanning of the 256 cards):

010111 11111 111 1010101 10001 100011 110011 1100111 1001 10111001 101 11101101 11
11010101 10001111 111111 11 1111111 11001011 1100011 10011001 101101 10001 1010101
1110101 111 10001 11011.

The correctness of the code being read was directly checked at the card output and also after the output amplifiers.

The average voltage of the output signal of the card was 60 mv, with the average voltage of the scanning signal being 20 v.

After the output amplifiers, the signals from the cards were strong enough for the triggering of the standard magnetic storage cell of the register (i.e., not less than 15-30 ma, 6-8 v).

The ratio of the maximum interference to the minimum signal while reading 256 cards was less than 15%.

The results of the tests of the unit of the durable memory arrangement with parallel reading show that the unit developed in the laboratory makes it possible to obtain more than 3 million pulses per second (for a card capacity of 128 binary digits). The number of delivered pulses per second is determined by the operating speed of scanning and the number of the parallel outputs (by the number of digits on the card).

It is important to note that the accepted speed of reading can even now be increased 10 times, i.e., brought up to 300,000 informations (cards) per second.

In practice, the speed can be taken as 30,000, or 100,000 cards per second, for the initial operation.

Magnetic Elements and Units

The laboratory developed magnetic storage units for signals, logical switches, registers, triggers, counters, commutators, as well as arithmetical devices (multiplying and adding devices, functional converters, etc.). All these elements and circuits were tested in the system where circuits were interconnected according to a predetermined scheme.

1. Magnetic Storage Unit for Signals

The storage device developed in 1952 consists of an arrangement which stores in its cells electric signals which are fed in succession (one by one) into the first cell, The capacity of the storage is determined by the number of cells.

The speed of storing is determined by the speed of the cyclic pulses from the internal source of current, which serves for the transfer of the accumulated information from one row of elements to the other.

In contrast to the known systems of storage units, in which cores with rectangular shape of the hysteresis loop are used, the operating principle of the developed storage device permits the use of cores with a nonrectangular hysteresis loop, in particular, the use of the ferrocart cores.

The transformers used in the storage device of 1952 have an outside diameter of 7.2 mm, an internal diameter of 3.9 mm, and a torus height of 2.2 mm; the weight of one core is 0.32 g. The windings of the transformer are made with a conductor 0.1 mm in diameter. The weight of one winding is 0.51 g. The selenium discs have a diameter of 7.2 mm. The weight of the disc is 0.1 g.

The speed of storing during the tests was equal to 30,000 storage pulses per second. The active power used by the storage devices in the circuit of cyclic pulses with 200 cells was about 20 w. The total power was of the order of 26 w. The tests showed the operating stability of the storage device when the voltage was increased by +20%(over the minimum allowable value), which supplied the output tubes of the generator of the cyclic pulse current. The tests for the checking of the stability under vibration showed that the storage device is stable when subjected to vibrations with a frequency from 20 to 40 c and accelerations from 1.5 to 10 g.

The storage device unit (containing 50 cells) continued to operate in a stable manner while the ambient medium temperature varied within the limits of + 56 and -39° C. The signal amplitude in the output cells changed under these variations by ±20% with relation to the amplitude at a temperature of +20° C. The amplitude decreased as the temperature rose and increased as the temperature fell.

At the present time, under laboratory conditions, the manufacturing of one cell costs about 11 rubles. With further improvement in manufacturing technology, the cost of one cell will be several rubles.

At the end of 1952 and in the beginning of 1953 the laboratory prepared and issued 10 standard storage units (10 x 200 = 2,000 storage cells). Besides, from 1953 to 1955 the laboratory prepared more than 10,000 storage cells made out of ferrocart and ferrite with the rectangular hysteresis loop.

2. Logical Circuits (Switches)

On the basis of the storage relay cell made with hysteresis relays, logical switches were developed which, in combination with the storage, permitted cells the realization of complicated arithmetical and logical equipment.

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Generating Triad. The storage cell, which has a circuit feeding back from the output element to the input of the first element and which possesses an additional coding winding on the first element, is called the generating triad "T." When the coding signal is applied to the first coding winding, a corresponding signal appears on the output of the cell. If a signal "1" is supplied, this signal is again applied to the input of the cell because of the presence of the feedback circuit. In this manner, the unit signal will appear on the output of the cell with each cyclic pulse of the current source. There results a dynamic memory (circulation) of the signal, appearing at the output of the cell. The second coding winding serves for the "erasing" of the registered signal. When the signal "1" is applied to this winding, a compensation of the circulating signal takes place and output of the signal to the external circuit stops. If the pulses at the output of the generating triad are smoothed out and shaped, it is possible to obtain a pulse of constant current.

Coincidence Circuit "AND-AND." The storage cell with two output windings, cumulatively wound, is called coincidence circuit "AND-AND" or switch "AND."

Only when two signals "1" appear together on the inputs of the coding windings will the signal "1" appear on the output of this cell.

Comparison or Noncoincidence Circuit "OR-OR." The storage cell with two input coding windings is called logical circuit of comparison or noncoincidence (switch "OR").

When the coded signal "1" is applied to one of the coding windings, a signal "1" appears on the output of the cell.

When the coded signal "1" is applied simultaneously to both coding windings, a signal "0" appears on the output of the cell.

Prohibiting Circuit "NO." The prohibiting circuit (switch "NO") consists of a storage cell with an additional coding winding. When a coded signal is applied to the first main coding winding, a corresponding code appears on the output of this cell.

The prohibiting circuit brings about a selective "erasing" of the signals "1" in the code which passes through this cell.

3. Registers, Triggers, Counters, and Commutators

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The register consists of the signal storage device having a feedback circuit from the output of the last cell to the input of the first cell. The feedback circuit is realized through the switches of the circulation "AND" and "NO."

The information entering the register is "memorized" and is circulated within it as long as it is required by the program. If it is necessary to issue the information, the control pulse is applied to switch "AND." If it is necessary to "erase" the recorded information or part of it, the control pulse is applied to the key "NO."

Trigger. The combination of the logical switches "AND" and "NO" with the storage cells produces a triggering circuit from hysteresis relays.

Counters and Division Links. To count the pulses in the binary system, a circuit for a binary counter was developed.

The circuit uses switches "I" and "NO" and simple storage cells. The counter consists of division cells with each link performing the function of the division by two of the binary code applied to its input. All division cells are of the same type and are interchangeable.

A series-connection of these cells permits the division of the coded signals applied to the input of the first cell by 2n, where n is the number of the dividing links.

The counter can serve for the control of any circuit according to the given number of the pulse.

The manufactured binary counter permits division by 2^{15}.

For the counting of pulses in the decimal system, a circuit was developed for the decimal counter with the transfer of the tens.

The decimal counter made with triads can be used as a commutator and as a distributor.

Magnetic Synchronous Commutator. A magnetic field rotating in space can be used for changing the magnetic permeability of the ferromagnetic material, located in the path of the magnetic field. Under these conditions a sequential variation of the magnetic state of the elements takes place with time.

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Investigations conducted in the laboratory have shown that such a magnetic commutator can be used as a synchronous distributor, as well as for the phase modulation of current pulses, for the production of pulses displaced in time, and for the conversion of codes, etc.

Multicoordinate Contactless Relay Grids. Systems with two coordinate grids which contain magnetic nonlinear elements permit the construction of high-speed "tables of multiplication," "tables of addition," and other tables of various functions. A larger number of coordinates can be used for other purposes.

4. Summation and Multiplication Devices

Arithmetical devices were developed which perform the functions of adding and multiplying the binary numbers.

With the selected speed of admission of the cyclic pulses at the rate of 30,000 pulses per second, the summation device can perform the addition of two numbers of the 32nd rank with a speed of 1,000 additions per second. The speed of addition is determined by n cycles, where n is the rank of the numbers to be added.

The summation device consists of the logical "AND" "OR" and simple storage cells. The typical unit of the summation device for the addition of the number of the 64th rank contains 17 switches "AND" and "OR" and about 130 simple storage cells. It is placed in one typical box (see 3 in Figure 6).

The laboratory has manufactured six summation devices, out of which three were of the storage type (integrating).

The developed multiplying devices perform the multiplication of the binary numbers with a speed of 2n cycles, where n is the number of ranks of the multipliers (the multiplication of two numbers of the 32nd rank is performed with a speed of about 500 multiplications per second). For the multiplication of numbers, the principle of consecutive parallel subranking addition is applied. For example, the multiplying device for the multiplication of numbers of the 8th rank contains about 55 switches of the type "AND" "OR" and "T," and 50 simple storage cells.

5. Device for the Comparison of Numbers, Converters, Decoders

The device for the setting of the coordinates in the three-dimensional region and for the comparison of numbers ("UZK") adds consecutively the numbers

$$x = x_1 + \kappa_1 \Delta x$$
$$y = y_1 + \kappa_2 \Delta y$$
$$z = z_1 + \kappa_3 \Delta z$$

x, y, and z are the coordinates of a certain given region: Δx, Δy, and Δz are their increments, and $k_{1,2,3}$ are whole numbers (1, 2,...64).

Simultaneously with the summation there takes place the comparison of the current values of the coordinates x, y, and z with their boundary values.

The comparison principle means that the number which is compared is subtracted from the one which is given. When the number which is compared becomes larger than the given one, the summation process stops and the addition of the increment Δ to other coordinates takes place.

This device makes it possible to change the coordinates of the region x, y, and z by 1 within the limits of 0 to 127. It contains about 45 switches of different types and 243 simple storage cells.

The nonlinear functional converter (table of sines and cosines; devices for the selection from the tables) represents a device which permits the obtaining of the values of $\sin \alpha$ and $\cos \alpha$ simultaneously for the given value of α.

The device consists of a grid, assembled as a table of sines and cosines, and of a decoder with logical switches.

The device for the selection from the tables consists of about 60 logical switches and of about 200 simple storage cells.

The decoder, which converts the code from the binary system into the binary-decimal system, consists of summation links, connected among themselves with registers and switches. This device converts the binary code of the 32nd rank into binary-decimal, which is necessary for printing the output data in decimal numbers.

The decoder consists of 60 logical switches and of 400 storage cells.

6. Magnetic Operative Memory Device "MOZU"

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As we mentioned previously, circulating registers made from simple storage cells are used to memorize the information.

In these registers, the number of digits of the memorized information is determined by the number of memory cells connected in series.

It is evident that to memorize an information containing a large number of digits, a large number of storage cells is required. The laboratory has developed a new magnetic operative memory device "MOZU" which uses bipolar current pulses, produced by the pulse current transformers, for the recording and the reading of information.

Figure 4 shows the schematic diagram of connections of windings (or buses) which thread through the toroids of one plate of the memory device.

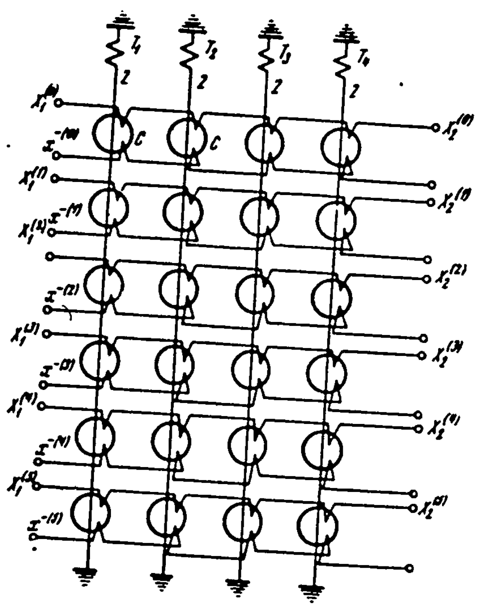

Figure 4. Schematic diagram of the magnetic operative memory device (MOZU).

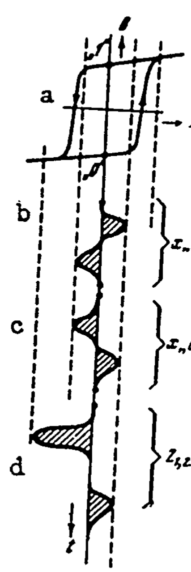

Figure 5. The hysteresis loop and the diagram of the ampere-turns of the element of (MOZU).

The number of toroids mounted along a single bus Z is determined by the rank of the information or of the number (Figure 4 shows 6 ranks).

The number of stacks of toroids in the X coordinate of the plate is determined by the required capacity of the memory device. Figure 4 shows four stacks; conse-

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quently, on this plate we can record and read four numbers, each of which can contain six ranks of the binary system.

In practice it is possible to install along the stack Z, 20, 40, 80, and more numbers of toroids, and the number of stacks along the X coordinate can be taken as equal, for example, to 16, 32, 64, and more.

To increase the capacity of the device, it is possible to introduce one more coordinate "Y," i.e., to connect several plates into one system.

Each torus of the plate has three windings: $X^{-(k)}$ for the reading of signals, $X^{-(k)}$ for the registering of signals, and Z for the setting up of the address of reading and of recording, i.e., for the selection of one number out of many.

Figure 5 shows the hysteresis loop of the toroid (Figure 5a), as well as the distribution of the ampere-turns of the signal currents for the recording of unity (Figure 5b), of zero (Figure 5c), and of the ampere-turns of the address system (Figure 5d).

The pulses of current are passed into one of the stacks along the bus Z with the aid of the pulse transformers of the address system.

At the end of the first pulse, all the toroids of a given stack will have negative values of induction ("0").

To register "1," it is necessary to supply a current pulse in accordance with Figure 5b; to register zero it is necessary to supply a current pulse in accordance with Figure 5c.

In this manner there are two pairs of current pulses (from the address system and from the recording bus) acting in each cycle on the toroids of one stack. Depending upon whether the ampere-turns of the signal currents add or subtract, a record of unity or zero is produced in the given toroid.

A two-coordinate address system is applied in "MOZU" similar to the address system used in the units of the capacitive memory devices.

In June 1955 a model of the magnetic operative memory device was tested by the commission and approved for production.

Model of a System Made of Magnetic Elements and Links

In order to test the feasibility of common operation within a system of arithmetical and logical units, and of the units of the capacitive memory device, a model of the system was developed in 1954 which permitted the combination for common operation of a capacitive memory device with different arithmetical and logical units.

Each arithmetical unit, included in this system has its input and output leads, connected through plug-in arrangements.

All incoming and outgoing leads of the units are connected to a common switchboard, where they can be externally connected according to a given plan.

Figure 6 shows the general view of the model of the system.

The right stand contains the units of the capacitive memory equipment (1) and the magnetic decoders of the address system (2).

The left stand contains the arithmetical and logical units, and the register units (3).

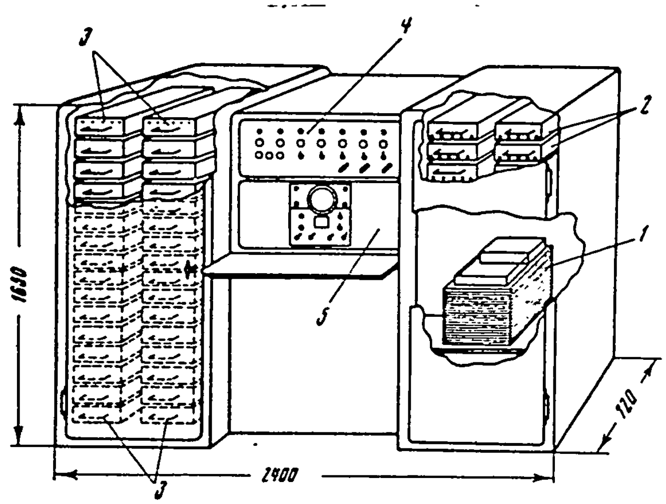

Figure 6. General view of the model of the system consisting of the capacitive memory devices, arithmetical units, registers, and other links.

The center part contains an arrangement for the setting of the coordinates of the region and for the comparison of numbers "UZK" (4) and the control board with the indicating unit (5).

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Each unit has an internal program of control and can operate independently outside of the system.

The magnetic elements, links, and units were tested. The observations, conducted for 10 8-hour days of uninterrupted work, showed that they operated in a stable manner with the variations of the anode potential in the source of the cycle pulses within the limits of 280 to 440 v (the upper value is limited by the source). The supply originated at the source with a frequency of 30 kc.

The arithmetical and logical units (multiplying, adding, device for the setting of the coordinates "UZK," device for the selection from the tables "VT," binary counter of 15 cells with the division of the 30-kc frequency by 2^{15} and the converter of the binary numbers into the binary-decimal ones) were tested during joint operation in the system.

The results of observations during the three days of the uninterrupted (nonstop) operation of the units showed their working stability.

As the drawbacks of the magnetic elements, one can mention their upper temperature limit (50-70°), the necessity for the use of rectifiers, and the frequency limitations.

The elements, links, and units of the hysteresis relays have been approved for production.

The work on the ferrite elements is conducted in the direction of the frequency increase (high-speed operation). The electrocomputing laboratory in 1955 conducted research and investigation on all types of relay elements and storage and logical switches for the frequency of 330,000 operations per second. The magnetic operative memory device was designed for the selection and recording of numbers in 8 μsec.

The increase in the speed may within the nearest future reach 1 million operations per second. However, this is related to the growth of the minimum power value of the relaying magnetic element. To decrease this threshold of power, we need new technological developments to decrease the size of the cores and to introduce the machining or printing of their windings. As current sources for the supply of con- STAT

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tactless magnetic systems we can use electrical machinery (motor-generators and static converters of alternating current), tube rectifiers, and crystal (semiconductor) current generators.

The principle and the most important property of the magnetic contactless systems is their operating reliability and their long life.

Together with the large amount of work being done on the crystal triodes here in the USSR and in the U.S., work is being done on an increasing scale on the magnetic relays and amplifiers. For example, the firm of Remington-Rand, Division of Sperry Rand Corp., reports about a new, cheap, high-speed calculating machine without electronic tubes; built with miniture magnetic elements called "microferractors." Mass-production of these machines is expected to start at the beginning of 1957. In the U.S. an increasing number of publications* are dealing with magnetic elements. There is a general opinion that where very great operating speed is not required (more than 300,000 operations per second), a magnetic contactless system must be used.

To insure the greater reliability of these systems, work is being done in the USSR and in the U.S. on the construction of standard units which could be manufactured by means of a printing process. Investigations are being carried out on the multi-circuit magnetic network on one common core having printed windings. The aim is to create mechanically sturdy units with a very large number of elements. While, for example, in the electron tube of calculating machines a separate plug-in unit is represented by a tube trigger, we find even now in the experimental magnetic systems within one plug-in unit more than 100 magnetic triggers; and within one unit of the magnetic memory there are more than 3,000 elements. In the future it is possible to expect the production of units with the number of elements larger by 1 or 2 orders.

Deductions

The reliability of operation, long service life, small size, processing, comparative cheapness, and other qualities of contactless equipment lead us to expect that

* Detailed bibliography can be found in the article, Karnaugh Proc., JRE, May 1955, page 570.

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this type of equipment will in the future receive wide application:

(1) for the creation of the new type of ATS by replacing contact relays and selectors, introduction of the operative memory and computing-solving equipment for the selection of the optimum circuit connections in each individual case: it will be possible to include in the ATS the telegraphic network for the transmission of numerical material and text;

(2) for the construction of new high-speed automatic systems and information, statistical, and translating machines which cannot be realized in practice with the old means of automation; only because of the introduction of durable high-speed memory with a very large capacity can we plan the design of these machines and their inclusion in the general system of the future common service of information and control;

(3) for the programming of automatic control of industrial objectives, where we need a memory for the registering of the program, very sturdy and reliable calculating-solving equipment, and commutators for the communication between the central point of control and the numerous objectives;

(4) for automatic signalling and control of railroad traffic, of gas pipes and oil pipes.

(5) for the remote-controlled systems of automation of atomic electric stations and atomic power installations and other types of production with difficult and harmful operating conditions for the personnel;

(6) for the construction of computing devices for popular use (arithmometers, tabulators, special accounting machines), digital computers for testing the equipment for automatic control and regulation, and digital trainers for the instruction of flyers.

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OUTLOOK FOR THE UTILIZATION OF RADIOACTIVE ISOTOPES IN THE AUTOMATION OF INDUSTRIAL PROCESSES

One of the most important problems facing us in the field of industrial automation is the task of building accurate and dependable devices for controlling parameters that must either remain unchanged during the production process or follow a set pattern of change. The constantly increasing speed of technological processes and high expectations of accuracy of measurements compel the designers of automatic devices constantly to improve the old methods of control while searching for new methods. Some of these new methods employ the radiations of radioactive isotopes. The experience gained in the past several years in designing and operating such devices underscores the growing importance of radioactive isotopes among the tools of measurement technology. Apparatus equipped with radioactive devices is being used very effectively both in laboratory work and in controlling various industrial processes. In many instances, both in our country and abroad, devices of this type are being used or are slated to be used as transducers in automatic systems for the regulation of industrial processes.

The present report does not purport to present a detailed survey of the work being done to apply radioactive isotopes in the field of automation. The paragraphs that follow describe briefly the basic paths along which this applied work is being developed, and the possibilities of their expansion. At the conclusion we have formulated a number of scientific-methodological and organizational problems whose solution is vital to our success in this field.

I. In evaluating the prospects of utilization of radioactive isotopes in the field of automation, attention has been centered in the main on the application of these elements in devices for automatic control and guidance of industrial processes. Let us therefore consider, first, some advantages common to the metering methods based on the application of radioactive isotopes.

(1) A characteristic feature of such metering techniques is the noncontact

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nature of control and, as a corollary of this, the absence of a reverse reaction of the device on the measured parameter. It thus becomes possible to exercise control without interference in the industrial process and without changing the properties of the object of measurement. On the other hand, such procedures protect the device from any possible damage, and in many cases make possible the exercise of control when the application of other methods proves impossible.

(2) As is well known, a change in external conditions, such as temperature, pressure, humidity, etc., affects neither the action of the preparation nor the energy of the radiation it emits. This fact serves to differentiate radically such radioactive sources from all other components used in building the mechanisms. The high stability of the radioactive flux permits the carrying out of precise measurements under the most difficult industrial conditions. Moreover, this characteristic of the radioactive isotopes permits their use as gauging or calibrating devices and a material lessening, through the setting up of various differential and balancing systems, of errors introduced into the final metered data by changes in the parameters of the other components of the device.

(3) Devices and mechanisms that make use of radioactive isotopes also manifest a low degree of inertia. This fact is very important in the control and automatic regulation of technological processes proceeding at high speeds.

(4) The long period of half-life of some radioactive isotopes (some of these periods last years or decades) opens up prospects of building devices with very long terms of service.

(5) In the case of numerous parameters, such as, for example, thickness, density, humidity, flow, level altitude, etc., devices of the same type may be used in the most diverse branches of industry. It thus becomes possible to devise standard measuring systems and devices, or at least the basic assemblies for such devices, that are capable of serving industry as a whole; this fact, naturally, facilitates the use of such mechanisms in automatic regulating systems.

(6) In devices based on the use of radioactive isotopes, changes of the cont- STAT

led magnitude are converted directly into an electric signal. This fact, likewise, serves to simplify materially the problem of combining such devices with systems of automatic regulation and with computing mechanisms.

II. The use of radioactive isotopes in metering technology is developing along the basic paths of the utilization of the penetrating capacity of the ray and of the measurement of the degree of its absorption by the substance, of the utilization of the phenomenon of the dispersion of radiation, as well as the process of ionization of the substance as a result of the radioactive emission. Considerable interest also centers on the utilization of neutron sources. As is well known, neutrons are never emitted directly by radioactive isotopes, but can be readily produced with their aid.

(1) Measurement of the degree of absorption of a radioactive emission by a substance supplies the basic principle in the operation of a large number of devices. Such devices are used effectively in metallurgy for measuring the thickness of the rolled metals, in the paper industry for measuring the thickness of paper, and in the building industry for measuring the mud density in mudpumping machines, etc. The penetrating capacity of the radioactive ray is utilized in a number of instruments used to measure the level altitudes of liquid and free-flowing dry substances in closed reservoirs, in devices used for signalling the reaching of a predetermined point by the level, and in other signalling devices.

Further refinement of the degree of accuracy in measuring the thickness in each specific instance (depending on the chemical composition and the density of the material in question) is achieved by the use of an isotope that emits a ray with a given amount of energy. A substantial broadening of the possible avenues of application of such devices may be attained by the utilization of a "soft" gamma ray (with energy on the order of 100 kev) as well as of a braking and characteristic x-ray radiation resulting from the absorption of fast beta particles. Somewhat further down on the agenda is the possible utilization also of the "hard" gamma rays with energy of 6 to 8 Mev that appear in certain nuclear reactions.

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Measurement of the extent of radioactive emissions is used, as is well known, in the detection of flaws in products and materials. The development of flaw-detecting methods not based on the photographic recording of radiation is a most urgent problem. Such methods may be used as a basis for evolving systems of complete automatic control of manufactured products under conditions of mass production. The solution of this problem depends on the further refinement of methods of fast and accurate measurement characterized by highly effective recording of the flow of radioactive emissions, and of gamma rays in particular.

The degree of absorption of a "soft" gamma ray bears a very close relation to the atomic number of the absorber. This fact provides the basis for developing a whole series of devices to be used in determining and controlling the chemical composition of various materials used in technology. The degree of absorption of a "hard" gamma ray (with an energy of from ~ 0.5 Mev to ~ 2 to 3 Mev) and of a beta ray depends on the number of electrons per unit of weight of the absorber. For this reason, the absorption of such radiation is sensitive to the hydrogen content of the absorber; this fact can be used in building devices for measuring the moisture content or, for example, the ratio of C to H in hydrocarbons.

In the case of signalling devices, a radiation detector is generally used as a part of a relaying system, i.e., under conditions when, at one position of the measured object, the magnitude of the recorded flow is virtually zero, while at another position of the same object it has the maximal value. In such cases, an accurate measurement of the radioactive flow is not required.

It should be noted at this point that the development of methods permitting an accurate metering of the measured parameter without calling at the same time for high accuracy in the measurement of the radioactive flow (whether frequency, phase, based on utilizing modulated radioactive emissions, etc.) holds great promise. Such methods will enable us to simplify materially the apparatus and instruments presently in use, and in a number of cases to attain a degree of accuracy beyond our reach when using other methods.

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The Geiger-Mueller counter--a simple, yet highly sensitive device--is used most frequently as a radiation receiver in signalling systems. However, two factors tend to limit their use--the large amount of dead time and their brief lifetime. The lessening of the dead time and an increase in the length of service and in the stability of the Geiger-Mueller counters will bring about a marked increase of their application in controlling and measuring devices. This, in turn, will improve the prospects of a wide adoption of such devices by the most diverse branches of industry.

(2) The intensity of dispersion, or, as it is often called, of the reflection of a radioactive ray, depends on the thickness, chemical composition, and density of the reflector. This fact is utilized in devices used for determining the thickness of electro-deposited coatings and the composition of alloys and mixtures.

The measurement of the thickness of electro-deposited coatings by means of radioactive isotopes is often the only possible method of measurement that does not result in the destruction of the controlled coating. The field of possible applications of this method is extremely large and is not limited, inter alia, by the presence or absence of certain electric or magnetic properties in the measured material. The methodological potentialities of measuring the thickness of electro-deposited coatings by means of radioactive isotopes are far from being exhausted. A severely limiting factor in the application of this method in many branches of industry is the fact that, with the aid of devices presently in use, the determination of the coating's thickness must be made over a wide area. Development of devices permitting the measurement of the thickness of an electro-deposited coating over a small area and possessing a low degree of sensitivity to changes in the spatial relationships between the device and the object to be measured will permit a manifold increase in the application of radioactive isotopes in this field.

In measuring thicknesses, whenever the measured object may be reached from only one direction, we may utilize the well-known interdependence of the intensity of dispersed radiation and of the thickness of the object. In devices of this type, considerable difficulties are presented by the need for protecting the radiation re- STAT

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ceiver from the effect of the radiation flow coming directly from the source; this problem is particularly acute in the case of gamma rays. The use of lead collimators and of protective screens to eliminate this difficulty calls for an increase in the intensity of the radioactive source, leads to an increase in the size and weight of the device and very often precludes the attainment of the required accuracy of measurement, particularly in the case of small areas. It is possible, however, without making use of protective screens, to record dispersed radiation only, by using the methods of gamma-spectroscopy, since the energy of gamma rays, when dispersed backward, differs markedly from the energy of gamma rays emitted directly by the source. This method permits an increase in the accuracy of measurement as well as a material decrease in the required intensity of the radiation sources and in the weight and size of the instrument. Further refinement of such devices must await improvements in gamma-spectroscopic methods, above all, in scintillation methods. It is possible, by the use of a set of radiation sources with differing energies, to determine simultaneously the content of the separate components of multicomponent systems. The building of automatic devices of this type will require, in all likelihood, the enlisting of the methods and resources of computing technology.

(3) Metering technology utilizes the ionizing capacity of radioactive emissions very extensively. The functional dependence of the degree of ionization on the density and composition of the gas provides the basis for the operation of devices for the measuring of pressures as well as for determining the contents of certain admixtures in gases. The increase in the range of measured densities and the construction of gas analyzers capable of detecting the various admixtures will make possible a substantial expansion of the field of application of such devices for the purposes of industrial automation.

The phenomenon of the ionization of a gas by a radioactive ray is also utilized in devices that measure the speeds of gas fluxes and the flow of gas. Refinement of the temporal, frequency, and phase methods of measuring these parameters (methods that are based on the use of modulated radiation and do not depend on a precise measurement of the degree of ionization) will permit an increase in the range of the measured velocities, particularly of low and supersonic velocities, as well as improve the accuracy of measurement; the possible fields of application of these devices will be correspondingly broadened.

Measurement of the spectral composition and of the intensity of luminescence caused by a radioactive emission may be used in determining chemical compositions, as, for example, in determining the degree of purity of certain organic combinations.

(4) We shall consider next the prospects of utilization of neutron flows in metering technology and in automation. It should be noted at this point that the scale and volume of the work presently done in this field is utterly inadequate. Yet, the areas of possible application of devices incorporating neutron sources are extremely broad. Just as in the case of the use of radioactive emissions for determining the various properties of a substance, we can make use in this field, too, of the functional relationships that mark the processes of absorption and dispersion of neutrons by various media. Furthermore, the so-called activational analysis represents another distinct field that utilizes the neutron flows and will, no doubt, contribute significantly to the automation of industrial processes.

Effective retardation of fast neutrons by hydrogenous media provides the physical basis for instruments used to measure the moisture content of various materials. Many branches of industry are interested in such instruments; among these may be mentioned ferrous and nonferrous metallurgy, coal mining, the building industry, and other leading branches of the national economy. The construction and wide adoption of such instruments and devices would be greatly aided by the further refinement of industrial methods of measuring the flow of fast and thermal neutrons.

The measurement of the degree of absorption of neutrons by various media may be used to determine the content of elements with a large cross-section for absorbing neutrons, such as, e.g., boron, cadmium, and a number of others.

Neutron radiations may also be used in flaw-detection of products with large thicknesses when the penetrating capacity of gamma rays proves inadequate, and in

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certain other cases.

Neutron sources may be utilized in devices used for measuring the levels of hydrogenous media. A great merit of such devices is the fact that they may be used in cases where the object to be measured can only be reached from one direction.

As the methods and the apparatus of neutron spectroscopy are improved and refined and made ready to meet the exacting standards set for industrial devices, neutron sources will probably also find application in the field of temperature measurement.

Neutron sources are already being used in the petroleum industry as well as in other geologic exploration. With further development of methods of neutron and neutron-gamma core-sampling, the application of these sources in geologic exploration work will, no doubt, steadily increase.

The methods of activational analysis, i.e., the measurement of the content of various elements by an analysis of radioactivity resulting from their exposure to neutron rays, are of considerable value and interest to people concerned with automation of the processing of ores. It is well known that many chemical analyses--indispensable in the work of controlling metallurgical processes--require considerable time for their completion; this is true even in cases where high-speed methods are used. A reduction of this time could be achieved in many cases by the use of methods of activational analysis and of radioactive indicators, and would benefit the industry greatly. Should these methods be improved in the reasonably near future to the point where it would become possible to exercise automatic control (directly in the industrial process) over the content of at least some elements, the automation of metallurgical processes will be materially advanced.

To achieve success in this field, it will be necessary to improve still further the present methods of recording radioactive rays, of the measurement of low intensities, and of the analysis of the composition of rays emitted by a mixture of several radioactive isotopes. In the work of automation, and especially in the determination of the chemical composition and of the measurement data of the individual elements, interest attaches not only to nuclear reactions that result in the form-

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ation of radioactive isotopes, but to certain other nuclear reactions as well. Among such reactions may be included the reaction $(n:\gamma)$ regardless of whether the resulting isotope is radioactive or stable. Determination of content of the individual elements in this case may be made by analyzing the specter of the gamma ray emitted at the moment of the entrapment of neutrons. This method will, in many instances, require considerably lower densities of neutron flows, since the gamma ray is emitted within an infinitely small interval of time after the entrapment of the neutron. To get a gamma ray flow of equal intensity by the use of methods of activational analysis (these methods may be used if the resulting isotope is radioactive), will require either a considerable span of time--equal approximately to three half-lives of the formed isotope--or considerably stronger neutron flows. The main difficulty encountered in using this method of measurement stems from the fact that the emitted gamma rays generally show a complex spectral composition, and the energy of this radiation by the various elements lies, as a rule, in one part of the specter, the only points of difference being the varying intensities of the separate lines.

Both the methods of activational analysis and the methods based on nuclear reactions are closely linked with the measurement and analysis of complex radioactive emissions. For this reason, the building of devices for automatic control and especially of transmitter devices for automatic regulation systems will involve, also in this case, the enlisting of the resources of computing technology.

The use of computing apparatus will also make possible the creation of a whole series of devices for simultaneous automatic measurement of several different parameters and will increase the potentialities of mechanisms used to measure one parameter at a time. The building of such devices will permit a substantial broadening of the field of application of radioactive isotopes in the automation of industrial processes. The use of radioactive isotopes in determining the composition of multicomponent mixtures has been referred to previously. Examples of other possible applications of this method of measuring several parameters at the same time are the following. The simultaneous determination of the moisture content of metallurgical STAT pulp by means of neutrons and the measurement of the degree of absorption of a soft gamma ray will enable us to define both the content of the hard component in the pulp and the content of elements with high atomic numbers in this hard component (ore). The measurement of the degree of absorption of soft and hard gamma rays by coal permits the determination of its ash content. At the same time, changes--inevitable in the process of production--in the thickness of the radiation-absorbing layers of coal will introduce no error into the measurement data. In a device using only one source of gamma rays, such changes would introduce errors far in excess of allowed tolerances.

The method of using radioactive indicators for chemical analysis, may, in addition to the aforementioned possible application, find other, though limited, fields of application in the control and regulation of industrial processes. Limitations of the method stem mainly from the undesirability of contaminating manufactured products and factory space by any substantial amounts of radioactive substances or wastes. However, improvements in the methods of measuring low intensities, and the use of radioactive isotopes with a brief half-life will, in all likelihood, permit in some cases the application of radioactive indicators for the purposes of automation; at present this method is used widely in research work. This method may be used, for instance, in measuring the velocity of flow and flux of various technological mixtures and solutions. A radioactive isotope may be either introduced into the system from the outside or be obtained as a result of the exposure of some segment of a mixture or a solution to neutron rays. For measuring velocities, it is most convenient to build separate "packets," each containing a radioactive isotope. Such packets may be built, for instance, by the application of a time-modulated flux of neutrons. The measurement of velocity and flux may then be accomplished by counting the number of "packets" that pass the radiation detector in a given period of time.

In our examination of the prospects of application of radioactive isotopes in the field of automation, we have limited ourselves up to this point to a review of their use in controlling and measuring operations. However, the work of automation STAT

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very often calls for modifications and improvements of technological processes. In this field, too, radioactive isotopes present considerable interest and definite promise. One of such possible areas of application of radioactive isotopes is their use for the removal of electrostatic charges. Application of radioactive isotopes for this purpose often presents the simplest and at times the only possible solution of the problem, and in many cases permits a considerable increase of the speed of technological processes.

Another possible field of application of radioactive isotopes in the area defined above is the use of their radiation for increasing the speed of certain chemical processes and for changing the properties of certain materials, e.g., semiconductors. This application of radioactive rays constitutes a large, independent field by itself, and it would not be feasible to go into it in great detail in the present report. However, the fact that this field of application of radioactive isotopes is of interest and value to the cause of automation should not be lost sight of.

III. Let us now consider some questions of scientific and methodological character whose solution, in our opinion, is of general interest to all areas of application of radioactive isotopes in controlling and measuring devices and in systems of automatic regulation.

(1) The problem of increasing the accuracy of data on the measured parameters obtained by the use of devices incorporating radioactive isotopes is linked, as a rule, with the need for increasing the accuracy of measurement of the flux of radioactive rays. This task encounters considerable difficulties, particularly in cases involving time-consuming measurements under industrial conditions. For this reason, parallel to the development of methods that do not require accurate measurement of the radiation flux, there must be a continual refinement of methods of protracted, continuous, and precise measurements of the fluxes of radioactive and neutron radiations. And in the process, special consideration should be given to methods of measurement characterized by high efficiency in recording, particularly to the methods of scintillation.

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(2) Development of spectroscopic methods for radioactive and neutron radiations.

(3) Development of methods of complex simultaneous measurement of a group of parameters. Application of computing devices in the instruments.

(4) Improvement of radiation receivers, particularly the development and preparation of scintillating plastic materials and of liquid scintillators, as well as of crystal scintillators of large dimensions; improvement of photoelectronic multipliers and the development of new types of this device with a higher stability of parameters; lengthening of the lifetime of Geiger-Mueller counters.

(5) Increase of the lifetime of devices to a period comparable with a half-life period of isotopes with a long lifetime (about a year or longer) and an increase of their reliability. This task will require the development and application, in the devices, of measuring systems built of semiconductor elements and an investigation of the possibilities of constructing radiation receivers of such elements.

(6) An enlargement of the scale of application of devices incorporating sources of radioactive rays and the securing of safe conditions of work both for the personnel servicing the instrument and for personnel tending the technical equipment on which the instrument is mounted; these will require the adoption of special measures and the drafting of appropriate regulations. Let us note in passing that the present Pravila raboty s radioaktirnymi izotopami /Instructions for Working with Radioactive Isotopes/ make no reference whatsoever to possibilities of working with such instruments.

(7) As the application of instruments and devices incorporating radioactive isotopes grows in scale, the problems of decreasing the intensity of the emitter in each model of the instrument will come increasingly to the fore; the solution of these problems is important because it will help to lower the costs; even more important is the effect it will have in insuring safe conditions of work. The natural lowest limit of the required intensity of the emitter is represented by the level at which the accuracy of measurement is determined entirely by the statistical fluctuations of the recorded flux of radiation. The use of such instruments in systems of

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automatic regulation requires a theoretical and experimental examination of the questions of construction and behavior of such systems in the presence of a fluctuating input signal. Problems bearing on the accuracy of measurement and on the selection of optional parameters in connection with the development of measuring methods and the construction of instruments based on the application of radioactive isotopes likewise call for theoretical analysis.

IV. In conclusion, we deem it essential to consider in detail some organizational questions linked with the application of radioactive isotopes in the field of automation.

(1) The nature of problems facing us in this field requires for their solution the services of specialists of the most varied types--physicists, instrument designers, and specialists in automation. At the present time, parallel to the work of a number of other organizations in effectively applying radioactive isotopes in instrument design and automation, such work is also being done by the Laboratory of Isotopes and Radiation of the Academy of Sciences USSR; by the Laboratory of the Institute of Automation and Telemechanics, Academy of Sciences USSR; and by the laboratory of the NIITyeplopribor of the MPSA USSR. Incorporation of these laboratories into the complex of the above institutes can and should insure the carrying out of research and studies on a high scientific and methodological level, with the utilization of the most modern physical methods and means of instrument-designing technology and automation.

While reserving comment on the other shortcomings in the work of these laboratories, it is proper to point out that the scale and the tempo of research being done there can under no circumstances be termed satisfactory. The cause lies mainly in the poor and at times utterly inadequate supplying of these laboratories with scientific manpower, industrial quarters, and proper equipment. Without trying to anticipate the measures that should be taken to remedy the present situation, we feel that the end result of such measures should be a considerable increase in the capacity of the above laboratories and their conversion into basic and leading or- STAT ganizations in this field. The Academy of Sciences USSR should also take steps to establish and strengthen laboratories attached to the academies of sciences in the various republics.

(2) Fully congnizant of the fact that a number of problems linked with the application of radioactive isotopes is peculiar to each specific branch of industry and that the successful solution of these problems requires the closest possible liaison with the appropriate institutes and enterprises in the various branches of industry, we recommend the establishment of new laboratories as well as the expansion of the existing laboratories in this field; these laboratories are to be a part of the institutes engaged in the work of instrument design and automation for the basic branches of industry. It seems to us, in the meantime, that the Academy of Sciences should recommend an end to the present practice of the atomizing of resources by the creation of a large number of miniature laboratories; it should advise instead the concentration of effort in a comparatively small number of adequately powered laboratories capable of conducting research on a high level and at the proper tempo.

(3) Under existing conditions, when the work of applying radioactive isotopes in the fields of instrument design and automation is being done by a large number of organizations, it is vital to establish an appropriate scientific and coordinating center. Such a center could be set up in one of the branches of the Administration for the Utilization of Atomic Energy of the Council of Ministers USSR. It could be tentatively called the "Commission for the Application of Radioactive Isotopes in Instrument Design and Automation." Needless to say, every effort should be made to induce the leading specialists engaged directly in research in this field to join the commission's staff.

High on the agenda of such a commission would be the following tasks.

A study of the situation existing with regard to the application of radioactive isotopes in the field of automation; it should be noted that the number of instruments and installations now in use is considerably smaller than the number of instruments prepared by various organizations; a wide adoption of fully-evolved methods and devices could have a considerable effect on the national economy.

The drafting of recommendations for a long-term plan of scientific research in the field of application of radioactive isotopes in automation. In addition to the permanent members of the commission, specialists in the branches of industry most directly concerned with the development and dissemination of these methods could be drawn into this work.

(4) Considering the fact that a number of devices incorporating radioactive isotopes is of value to the industry generally and can be used without material changes in various branches of industry, the Academy of Sciences would be well advised to recommend the establishment, within the apparatus of the MPSA USSR, of a special design bureau and of a pilot plant for the design and manufacture of such instruments; such a step would tend to hasten the adoption of the newly-developed methods and instruments by the national economy.

(5) The Academy of Sciences should recommend appropriate measures for widening the range and improving the qualitative characteristics of radioactive isotopes produced at present. The need for sources of soft gamma rays and the necessity of increasing the specific intensity of the supplied preparations should be particularly borne in mind. It would be advisable, likewise, to consider the question of lowering prices for radioactive isotopes, especially for isotopes that may be used as sources of braking and characteristic x-rays, e.g., Strontium-90 isotopes whose present price precludes their use for these purposes.

Finally, a solution must be found for the problem of supplying interested organizations with radioactive isotopes made to fit their devices. The present situation, in which a multitude of organizations is engaged in preparation of such sources, is reducing this important activity to the level of a primitive handicraft. Technical shortcomings inevitable under such circumstances may entail dangerous contamination with radioactive isotopes of both laboratory and industrial buildings where such devices are being used.

(6) The Academy of Sciences must also raise the question of the need of manu-

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facturing special equipment for equipping laboratories engaged in reaearch in the field of application of radioactive isotopes. Furthermore, the problem of designing standardized laboratories must also be resolved.

(7) The wide adoption of instruments featuring radioactive isotopes requires even at this comparatively early stage the creation of an authoritative body with powers to police the manufacture and use of such devices in the interests of safety and security. The establishment of such a body will help to prevent accidents and will also help to dispel unfounded fears that arise occasionally upon the installation of such devices.

(8) And last but not least we have the question of the training of "cadres" or scientific and professional manpower. The Academy of Sciences should, in our opinion, take the initiative and recommend that the institutes, which at present graduate instrument-designing engineers, also train specialists in the fields of development, design, and operation of instruments with radioactive isotopes, or that at the very least the appropriate training courses be included in the programs of these institutes. It would likewise be advisable to include such courses in the programs of instrument-design technicums.

To insure competent and skilled handling of installed instruments, the ministries concerned should undertake the proper training of engineers and technicians at the plants and enterprises where instruments and devices based on the application of radioactive isotopes have been installed or are slated to be installed.

Statement
by Engineer Ye. A. Nekhayevskiy

The All-Union Scientific and Research Institute of the State Bureau of Engraving in the past two years, thanks mainly to the efforts of G. G. Iordan and B. I. Verkhovskiy, has developed, built, and tested a device for determining the weight of an area unit of a paper tape; this device will be used in automatic production controls of papermaking machinery.

The device is called a weightmeter and measures the weight of a moving tape STAT weighing from 5 to 25 mg/cm^2. The weightmeter consists of a measuring pulley with a differential system of ionization chambers with two thallium sources of 10 millicuries, and a specially designed dynamic condenser for transforming the measured ionized current into an alternating one; the latter is amplified in an electronic unit with an outlet to a standard recording device of an EPD type. Altogether, there are three stabilizing cascades or stages.

It has been established that the error in measurement does not exceed 2.5%; error in time measurement does not exceed 2 sec; the device is also characterized by high stability--no drift of the initial control is observed in a period of 24 hours.

This device has passed industrial and laboratory tests and is now being installed in an industrial enterprise for regular use.

The following are the distinguishing features of the above mechanism: linearity of the scale secured by a dividing device equipped with a compensating absorber; the scale divisions are uniform throughout because of the use of the dividing device; the measured data are completely independent of the shifts of the absorber within the specified tolerance; the effect of temperature fluctuations without the use of the compensator does not exceed 0.5% per 1°C; a capacity to accommodate simultaneously up to five indicators with an accuracy of ±5 mg/cm^2 of the specified value; the recording takes place in absolute units over the entire measuring range (up to 25 mg/cm^2).

A measuring pulley controls the moving tape with a width of up to 800 mm in its movement over a "path" with a width of 250 mm and can be set automatically over the tape within a given time after a tear or break of the tape has been repaired; the pulley can likewise be withdrawn automatically at the moment of the tape's break or tear. Remote control of the measuring pulley is now under consideration.

Plans are afoot to combine the described mechanism in the capacity of a transducer /transmitter/ with a regulating device. The use of an automatic weight regulator will permit the lowering of substandard production to 5%. The resulting economy will amount to about 1 million rubles per year per each papermaking machine

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in the Bureau of Engraving.

And now please permit me to say a few words in connection with the report by B. I. Verkhovskiy and others. The present method can lay no claim to freedom from effects of outside media and outside conditions on the results of measurements. The greatest trouble is caused by the effects of temperature changes. The low degree of inertia is a relative concept, since it is difficult to achieve a time constant of 1 sec.

On the questions of organization and methodology I would like to suggest the following: an immediate effort should be made to draft rules and regulations on the use of the instruments--the sanitary inspectors of the district will not permit us to use the completed instrument for a test run under industrial conditions because of the absence of such regulations.

A valuable suggestion has been made in the report with regard to the preparation of sources. There is no need to build expensive laboratories for the making of sources in each separate enterprise. Such sources are not prepared very often and are quite expensive as a result.

We support the proposal concerning the establishment of a coordinating scientific center for the application of radioactive isotopes; I would only add to the suggestion a list of organizations engaged in the design of instruments similar to the one I have just described; the Central Laboratory of Automation (measurement of the thickness of metallic tapes), the Central Scientific Research Institute of the Cotton Industry (measurement of the extra weight of substances coated or added to fabrics). LETI in Leningrad is designing a similar instrument for work on paper for the "Kommunar" paper factory. Nonferrous metallurgy, the textile industry, and the paper and building-materials industries are all active in this field.

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RADIO-FREQUENCY SPECTROSCOPY AND THE POSSIBILITY OF ITS USE IN THE FIELD OF ANALYSIS

by

A. M. Prokhorov

Radiospectroscopic methods are in wide use at the present time in physics and chemistry for the study of properties of nuclei, atoms, molecules, fluids and solids. But radiospectroscopy also has its practical uses. For example, the measurement of magnetic fields (with accuracy up to 10^{-6} oersteds) and their stabilization by the use of nuclear and electronic paramagnetic resonances is becoming increasingly widespread. A highly significant application of radiospectroscopy is represented by the utilization of spectral absorption lines for setting up standards of frequency (time). A large number of studies are concentrating at present on this problem.

Finally, the question arises as to the possibility of using radiospectroscopic methods for the purpose of analysis. However, in using such methods, a number of difficulties are encountered. For a clearer understanding of the use of radiospectroscopy for analytical purposes and the corollary use of radiospectroscopic methods for process control, it will be necessary to make a brief survey of radiospectroscopic methods and to go over the conditions that favor the appearance of absorption spectra for substances and materials we are interested in studying.

Radiospectroscopic methods fall into the following four categories:

1) Gas radiospectroscopy which is primarily concerned with rotational transitions.

2) Paramagnetic electronic resonance. This method is primarily concerned with transitions between energy levels resulting from the interaction of paramagnetic ions with an external magnetic field.

3) Nuclear paramagnetic resonance. In this method, observation centers on energy level transitions that result from the interaction of the magnetic moment of the nucleus with an external magnetic field.

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4) Pure quadrupole transitions; the phenomenona observed here are energy level transitions resulting from the interaction of the electric quadrupole moment of the nucleus with the electric field formed by charges arranged around the nucleus.

Let us examine each of these methods in closer detail.

1) Rotational molecular spectra are observed in centimeter and millimeter wave bands. The study of these spectra is effected by means of radiospectroscopy. Substances under study are generally in a gaseous (vapor) state, contained in an absorption cell with a total volume of about 1 liter, under pressure corresponding to 10^{-2} - 10^{-3} millimeters of mercury. Under such pressure, the collisions of the gas molecules are rather infrequent and the width of the line is obtained at about 1 megacycle; i.e., considerably below the value of electronic rearrangement of the klystron, which is of the order of 40 - 60 megacycles. Lessening of pressure leads to the lessening of the maximal volume of absorption without a narrowing of the line, since the width of the line under conditions of low pressure is determined in the main by the Doppler effect and by the collision of the molecule with the walls of the vessel.

Increase of pressure leads to the widening of the lines but the maximal volume of absorption does not change in the process. In order for the gas to have an observable absorption capacity it is necessary that its molecules possess a dipole moment. The greater the dipole moment, the larger the volume of absorption. Should we deal with an average molecule (in terms of geometry and molecular weight) with average dipole moment, we may be able to detect 0.1 - 1% of concentration of such molecules in a gas mixture. Moreover, the possibilities of isotopic analysis should not be lost sight of. Suppose we are given a mixture of isotopes and it is necessary to determine their percentage-wise content; the problem may be solved by the preparation of a suitable mixture for an analysis based on the fact that the lines of absorption of molecules with differing isotopes have differing frequencies.

2) Observation of an electronic paramagnetic resonance takes place mainly

in waves within the centimeter range. Free radicals and paramagnetic ions with an odd number of electrons have their lines of absorption on wave $\lambda = 3.2$ centimeters, with the volume of tension of the magnetic field H = 3,300 oersteds. It should be emphasized that both solutions and solids may be used for the observation of a paramagnetic resonance. In many cases, it is best to use monocrystals rather than polycrystalline substances in the observation of a paramagnetic resonance. Moreover, to take the typical case of the paramagnetic resonance of raré earth ions, measurements must be made at the temperature of liquid hydrogen; i.e., at 20° of the Kelvin scale. Worth noting is the fact that when gadolinium ions are present in a trivalent state, while the europium ions are bivalent, the paramagnetic resonance of these rare earth ions may be observed in polycrystalline substances at room temperature. Some idea of the effectiveness of this method may be gained from the fact that it may be used to detect an admixture of gadolinium when its concentration is as low as $10^{-2} - 10^{-3}$ %.

In order to observe an electronic paramagnetic resonance, the substance (with a volume < 1 cm^3) is placed in a volumetric resonator at the point of the maximum of a high-frequency magnetic field. Next, a constant magnetic field is impressed over the observed specimen in such a manner that the high-frequency and constant fields are perpendicular to each other.

To observe the absorption line, it is necessary to modulate the constant magnetic field rather than the frequency of the klystron; in other words, use is made of the modulation of the magnetic field.

3) Nuclear paramagnetic resonance may be observed in the case of nuclei whose spin I is not equal to zero. However, should the spin I of the nucleus be $> \frac{1}{2}$, the nucleus will be found to possess a quadruple moment. The presence of this moment in a nucleus brings about a rather strong interaction with the surrounding media; this, in turn, results in a pronounced widening of the lines, and may, in some instances, preclude the observation of a nuclear paramagnetic resonance. For this reason, conditions for observation are most favorable for the paramagnetic resonance

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of nuclei whose spin $I = \frac{1}{2}$, and of nuclei with a small quadrupole moment. We should bear in mind that the volume of the signal will be the stronger the greater the magnitude of the nucleus' magnetic moment.

Observations are generally made at frequencies on the order of tens of megacycles with the magnetic fields measured in thousands of oersteds.

When the strength of the outside magnetic field is indicated, the resonance frequency of a given nucleus changes very little in transitions from one combination to another. This fact provides us with a simple and effective method of detecting the various nuclei in a combination that is being analyzed. This method is used to conduct isotopic analysis. The effectiveness of the method may be illustrated by the following example. The volume of signals of deuterium nuclei in natural water exceeds the volume of noise tenfold. As is well known, the dispersion of deuterium is about 0.02%.

Methods of observing the nuclear resonance do not differ materially from the methods of electronic paramagnetic resonance; the only difference is that at the usual radio frequencies use is made not of volumetric resonators but of self-induction and capacitory coils.

Specimens for analysis may be used in either liquid or solid states. In some cases, it may be necessary to add some paramagnetic salts to the analyzed substances so as to shorten the relaxation time of the nuclei, and thus to assure an adequate observation of the nuclear paramagnetic resonance.

4) Pure quadrupole transitions are observed in a wide range of frequencies - from tens to hundreds of megacycles. Observations are made, as a rule, without the use of a magnetic field.

The frequency of the resonance lines depends both on the magnitude of the quadrupole moment of the nuclei and on the magnitude of the second derivative of the electrostatic potential caused by the surrounding charges at the locus of the nucleus. The magnitude of the electrostatic potential's second derivative depends closely on the type of the chemical combination; for this reason the location of the

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resonance frequency of a given nucleus will depend on the type of chemical combinations involved. The value of the ratio signal/noise will be rather small here. The method of observation is comparatively simple - one observes the absorption line at the given frequency of the generator.

It may be seen from this brief survey that radiospectroscopic methods may be used to solve only certain concrete analytical problems; accordingly, each specific case should be studied carefully before we decide to apply spectroscopic methods.

L. D. Rozenberg

ACOUSTICAL METHODS FOR MEASURING NONACOUSTICAL QUANTITIES

General Considerations

Modern measuring practice is characterized by the expansion of its technical foundations. Alongside with the direct methods of measurement of quantities, indirect methods are appearing; at the basis of the latter we find the measurement, not of quantities directly in question, but of some factors associated with them. Often these methods are more convenient than the direct ones because of the better availability of the measured factor, better sensitivity, and, what is particularly important, the possibility of an automatic measuring process.

Among others, methods based on variations of the parameters of a sound field, especially produced at the object of measurements, are beginning to be used now, In spite of the fact that there are only a few disconnected and unrelated acoustical methods of measurement of nonacoustical quantities, the technique as a whole apparently is quite promising and merits a further systematic investigation.

Because of their mechanical nature, elastic (sound) vibrations and waves appear to be the most adequate method for the investigation of the material objects and of the variations of their mechanical properties. The parameters of the sound waves, which are subject to variations, are the frequency of oscillations, amplitude, phase, time of propagation (for traveling wave), and the traveling wave ratio (for standing wave).

The knowledge of these parameters permits the determination of the speed of propagation of sound waves in the medium under investigation, their attenuation in the process of propagation, the coefficient of reflection from the boundary of two media, the coefficient of dispersion in a nonhomogeneous medium, and some other quantities.

The speed of sound, in its turn, is directly determined by the density of the medium and the corresponding modulus of elasticity or its inverse quantity, the compressibility.

Speed of propagation of sound waves

$$C = \sqrt{\frac{A}{\rho_0}},$$

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ρ_0 - density of the medium

A - modulus of elasticity

Gas: $A = \gamma P_0$,

γ - adiabatic constant

P_0 - constant pressure

Liquid: $A = \frac{1}{\beta}$,

β - compressibility

Solid body

longitudinal waves:

inside a bar $A = E$,

E - Young's Modulus;

in a continuous medium $$A = \frac{E(1 - \sigma)}{(1 - 2\sigma)(1 + \sigma)},$$

σ - Poisson's coefficient

Shearing waves: $A = G$,

G - shear modulus.

In this way, the knowledge of the speed of sound propagation makes possible the determination of the elastic constants of the medium with a known density or, inversely, the density of the medium with the knowledge of the constants of elasticity.

The coefficient of absorption of the sound waves is determined by the viscous and the relaxation losses with the sound propagating in homogeneous media, and also of the coefficient of sound dispersion in the case of nonhomogeneous media. Sound absorption is expressed by comparatively complicated formulas, which are not exactly known for all cases. However, the variations of the coefficient of absorption makes it possible in each concrete case to follow directly the variations of the properties of the medium, for example, viscosity.

In some cases it may be helpful to conduct the measurements at different frequencies. The coefficient of absorption is almost always dependent upon the frequen-STAT but the character of this dependency is different for different substances. Thus, by conducting measurements on several frequencies, it is possible to obtain the necessary data for the solution of a system of equations encompassing, for example, the losses in the multicomponent mixtures, etc.

The natural frequencies of bodies are determined by their geometrical dimensions and by the speed of propagation of sound waves. The simplest example is presented by the Helmoltz resonator for which the following equation is correct.

$$W_0 = C \sqrt{\frac{S}{lV}},$$

where: C is speed of sound propagation; S is the cross-section of throat; l is the length of throat; and V is the volume. Thus, when the speed of sound propagation is known, it is possible to use the variation of its frequencies to determine the geometrical dimensions of bodies. This, for instance, is being used in the resonance thickness gauge and cavity meter. The other method for the measurement of the geometric dimensions of a body consists in measuring the time required for the propagation of a sound pulse whose spatial length is considerably smaller than the dimension to be determined. This method, known as the echo method, is widely used in the hydroacoustics, in supersonic fault location, and for the measurement of liquid levels.

The acoustical methods may be divided into four main groups, depending upon the object of measurements: measurement of geometrical dimensions and volumes of bodies; measurements of parameters of a medium, observation of the state of a medium; location of internal defects and of nonhomogeneity of structure. The first group includes the thickness gauges, altimeters, level gauges, cavity meters, etc. The methods of the second group embrace the measurement of density, of all moduli of elasticity of volumetric and shearing viscosity (viscosimetry). The methods of the third group allow the control of the progress of the chemical reactions and of the physicochemical processes, as for example, the variation in the state of the aggregate, the hardening of concrete, such processes as crystallization, polymerization, etc. Here we can also mention the measurements of variations in the speed of flow of liquids and gases (consumption meters). The last group includes all types of supersonic fault locations and underwater location.

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Depending upon the method of measurements, one can distinguish the pulse method and the stationary method. In its turn, the pulse method can be divided into two groups. In the methods of the first group, the transit time of the pulse or the change of its amplitude is measured. If we know the speed of propagation, the transit time permits the determination of the length of the path of the traveling pulse (echo meters, liquid level gauges) and if we know the distance, we can determine the speed of propagation (consumption meters, measurement of elastic constants). The amplitude variation of the pulse determines the absorption in the process of propagation.

The schematic arrangement of such measurements is shown in Figure 1.

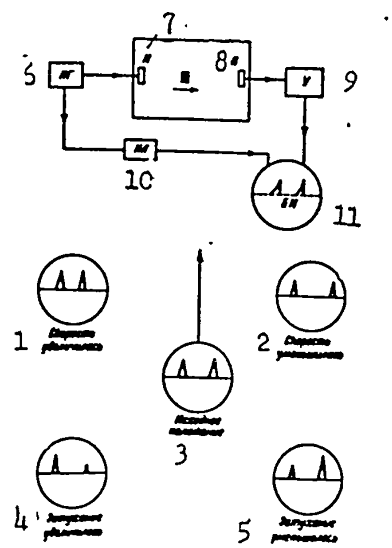

Figure 1. Diagram of the pulse method for measuring substance properties.

Legend: 1 - increase in speed; 2 - decrease in speed; 3 - original position; 4 - increase in attenuation; 5 - decrease in attenuation; 6 - generator IG; 7 - emitter I; 8 - receiver P; 9 - amplifier U; 10 - artificial line IL; 11 - beam indicator BI.

Let the medium to be investigated be located in some container (if it is a liquid or a gas). With the aid of emitter I, a supersonic pulse is introduced into the medium. This pulse, at the end of its travel, is received at the opposite end by receiver P. The output voltage is fed from the receiver amplifier to electron beam indicator BI. Simultaneously, the same indicator receives the original electrical pulse produced by generator IG which supplies the emitter. On its way, this control pulse passes through an artificial line IL which permits the regulation of its amplitude and introduces some time delay. In this manner, it is possible to observe simultaneously on the screen of the electron-beam indicator the fixed control pulse together with the examined pulse which appears after a short time. The variation in the speed of propagation or of attenuation during propagation produces the corresponding change in the observed picture. Figure

1 shows the simplest case. This principle is employed, for example, in the cavitation gauge developed by the Polytechnic Institute of Kharkov and used in hydraulic turbines; this equipment is being demonstrated at the All-Union Industrial Exhibit.

In the methods of the second group, the pulse is used as a means for the excitation of natural oscillations of a system. By investigating the process of attenuation of these oscillations, it is possible to measure, for example, the losses in this system. By analogy with the architectural acoustics, this method is also called the reverberation method. On this principle are based some viscosimeters and also devices for the determination of the internal friction in metals, plastics, rubber, etc.

The methods which use stationary sound waves can also be divided into two groups: those using traveling waves and those using standing waves. The first group of methods allows the determination of properties of a medium in which an elastic wave is propagating. The methods of the second group are more universal. Because the standing wave is the result of reflection of a traveling wave from the boundary between two media or from the boundary of an obstruction, the investigation of the parameters of this standing wave permits the establishment of the properties of the medium which lies on the other side of the boundary or of the properties of the obstruction, as well as the distance to the reflecting boundary or obstacle.

In the vast majority of cases, the primary sound field is produced externally; however, there are also cases where the field is produced by the examined process itself. In this sense, all acoustical methods are, as a rule, active, i.e., they require the presence of a source (emitter) of sound oscillations. The measurement of the sound field is accomplished with the aid of the sound receiver. In some cases the functions of the emitter and the receiver can be combined in one converter; in this way, particularly, is constructed almost all echo method equipment. At times the receiver is entirely absent: the results are judged by the reaction of the medium on the emitter. This reaction is measured at the electric side of the emitter. For example, when in the medium of finite length, connected to the sensing element of a STAT

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resonance thickness gauge, there is packed a whole number of half-waves, the loading of the emitter changes sharply and this reacts upon the magnitude of the current which supplies it. The change in the current strength is detected by means of a visual indicator. Sometimes, in order to produce the picture of the standing waves, a special reflector is used; such a method is used in the interferometers.

The selection of the working frequency can be determined by various considerations. In the resonance methods (cavity meters, resonance thickness gauges), the frequency is selected on the basis of the resonance frequency of the system to be measured. In the pulse methods, the selection of the frequency is determined on the one side by such considerations as these: with the increase of frequency, the resolving power and the accuracy of the method increase, while, on the other hand, we have the fact that, due to the increase in absorption, the received signal decreases in magnitude. In those cases where the magnitude which interests us is the absorption of sound during its propagation, the working frequency must be selected sufficiently large so that the absorption constitutes an appreciable magnitude.

As converters, the electromechanical systems have the monopoly; we have here electrodynamic, magnetostrictive, and piezoelectric converters. Hydrodynamic and aerodynamic emitters have not found acceptance in spite of the fact that they have a better efficiency and that the supersonic energy produced by them is considerably cheaper. This is explained by the fact that, on one hand, great power is usually not required for measurements, and, on the other hand, the aerodynamic and hydrodynamic emitters are considerably less stable in their frequency, amplitude, and phase and are difficult to handle. Besides the electromechanical converters are reversible; as we mentioned earlier, this property is used in many echo methods and also in the consumption meters.

The selection of the converter type is determined by the frequency range. With a frequency range from 0 to 10-15 kc, electrodynamic converters are the most convenient; for frequencies of 5-150 kc, it is better to use the magnetostriction type, and finally, the range of 100-15,000 kc is handled by the piezoelectric converters.

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Higher frequencies have not as yet been used; however, even here the only possible converters are likewise the piezoelectric ones.

In the piezoelectric emitters, quartz is used in the majority of cases; it possesses a high mechanical and electrical strength and has a small temperature coefficient. The ceramics of titanate of barium, which have recently become so popular for technological supersonic applications, are relatively rarely used for controlling and measuring purposes, in spite of the very great magnitude of the piezoelectric modulus. The point is that, along with their virtues, the ceramics of titanate of barium possess great shortcomings which restrict their application for measuring purposes: their piezoelectric modulus and specific inductive capacitance change considerably with temperature, and, when heated to 120° C, a complete depolarization takes place and the ceramics irreversibly lose their piezoelectric properties. Because of this, they are used only in those cases where the operating temperature does not exceed 70-80° C and when the absolute magnitude of the emitted and received signal does not have a tangible value. Examples of such an application are the probes of supersonic fault locators or the resonance thickness gauges.

Description of Certain Existing Equipment

The resonance thickness gauges are manufactured in the USSR by the Ministry of Aircraft Production and abroad by various firms in the U.S., West Germany, France, Belgium, Italy, and others. On the sheet whose thickness is to be measured, we placed a piezoelectric converter which is supplied with a voltage of continuously variable frequency. At the moment when the thickness of the sheet is equal to the even number of half-waves, the reaction on the converter changes sharply, and this acts on an indicator. Figure 2 shows one of these instruments. Four ranges of frequencies permit the measurement of thickness within the limits of 1 to 100 mm with an error of 2-3%. The advantage of acoustical thickness gauges consists in that it is not necessary to reach the measured part from two sides; this makes it possible to measure from the outside the thickness of pipe walls, of tanks, of closed volumes, and of

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parts with complicated configuration /1/.

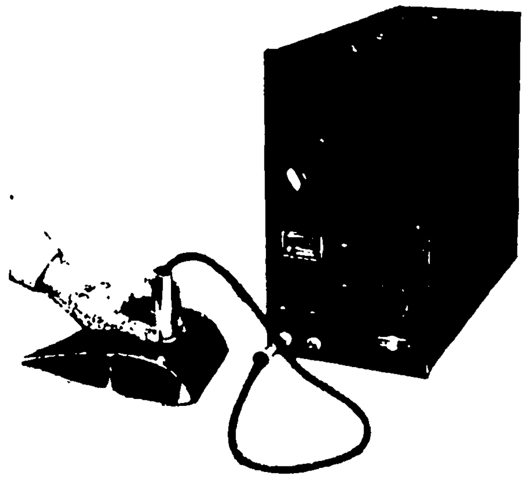

Figure 2. External view of a resonance frequency meter.

Viscosimeter. At the present time, we have several different viscosimeters which operate in the region of sound, as well as of supersonic frequencies. Let us examine in detail one of them, manufactured by the firm "Ultraviscoson" /2/. The

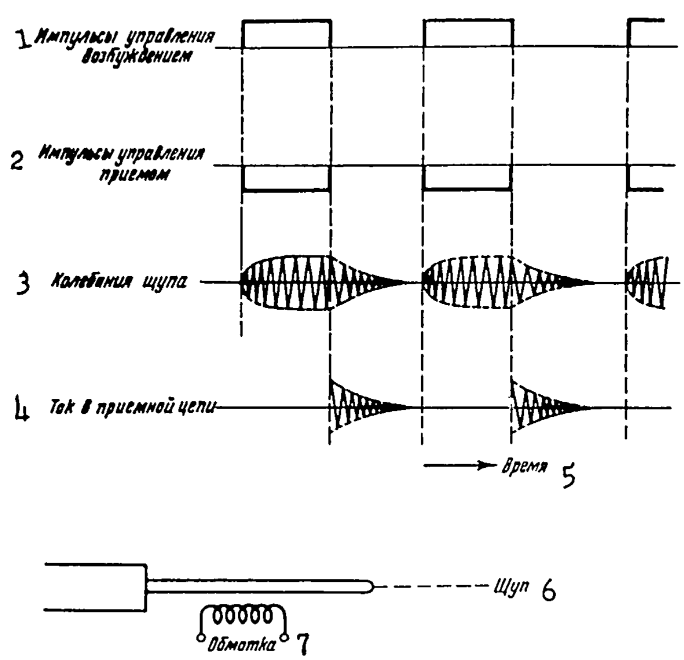

Figure 3. Principle of operation of a viscosimeter.

1 - pulses for the control of excitation; 2 - pulses for the control of reception; 3 - oscillation of the probe; 4 - current in the receiving circuit; 5 - time; 6 - probe; 7 - winding.

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operating principle of this viscosimeter is based on the fact that the attenuation of the natural oscillations of an elastic plate immersed in a liquid depends upon the viscosity of the latter. The magnetostriction plate (Figure 3) oscillating in the direction parallel to its surface, is excited to its natural frequency (20-100 kc) by the regularly repeated square pulses. At the end of the pulse action, the oscillations of the plate attenuate. This attenuation process induces within a winding an attenuating electrical pulse. A series of consecutive attenuating pulses is integrated with a large time constant. The variable quantity is the frequency of the sequence of the exciting pulses; it changes automatically so that the average current, produced by the attenuating oscillations of the plate, remains constant. The calculations show that the necessary sequence frequency of pulses is proportional to the product of the density of the liquid under investigation and its kinetic viscosity. Figure 4 shows the external view of such a viscosimeter. The magnetostriction probe is seen in front.

According to the company's information, the equipment is good for operation within the temperature range of -120° C to $+340^{\circ}$ C. The limits of measurements are from

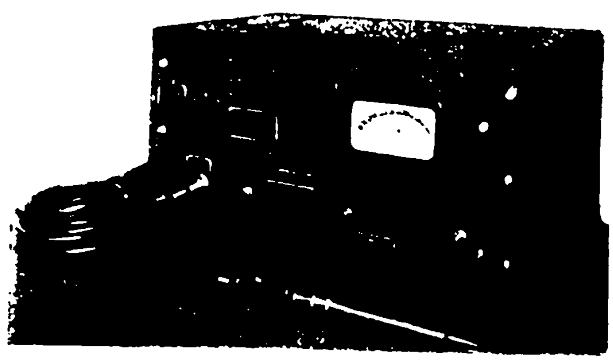

Figure 4. External view of the viscosimeter; the probe is in front.

0 to 5×10^4 centipause x g/cm^3. The minimum amount of liquid required for measurement is 2-4 cm^3; the error of measurement is 2-5%, the repetition error is 1%. The sensing element can be separated from the indicator by a distance of 1.5 to 2 km. Since the amplitude of oscillation of the device does not exceed 0.5 μ, it practically has no influence on the medium being measured. The time required for one measurement

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[redacted]

is about 1 sec. Later, an installation was described with 16 channels [3] and its external view is shown in Figure 5. It permits the observation of 16 points simultaneously with a recording of all results on one paper chart.

Figure 6 shows the arrangement of a sensing element of a viscosimeter, operating at a considerably lower frequency of about 800 c [4]. The active element is here the disc clearly seen in the figure, oscillating in the plane parallel to its surface. The coil of the exciting electromagnet can also be seen; it is supplied with a current of variable frequency. Figure 7 shows the calibration curve of this viscosimeter. The calibration was conducted in a liquid with a known standard viscosity. We can see that the scale of the device is practically linear within a very large variation of magnitudes.

The cavity meter, an instrument for the acoustical measurement of cavity volume, is described by Poole [5]. It is shown in Figure 8. The depression P to be measured (the diagram shows an example of measurement of the volume of the depression on the

Figure 5. The indicator unit of the viscosimeter with 16 channels.

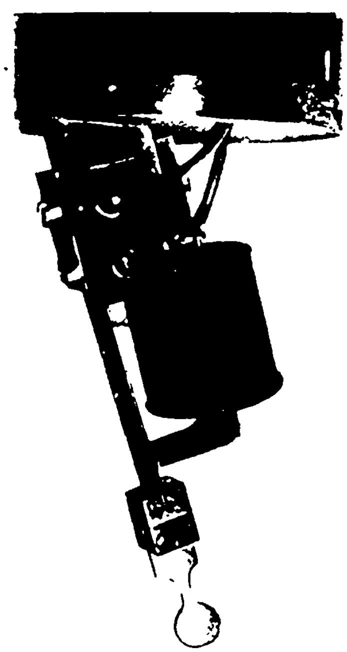

Figure 6. Sensing element of the low-frequency viscosimeter.

top of the block of an internal combustion engine) is closed with a cover Kp having an opening O. The sound waves from the sound source G can, through this opening, reach the cavity being measured. Another opening connects the cavity with the microphone M.

The output of the microphone is connected to the input of an amplifier U and the output of the amplifier feeds a loudspeaker. The stages are so selected that the system is excited to the frequency which is determined by the natural resonance of the acoustical resonator which is formed by the cavity, the cover, and the opening O. The frequency of self-excitation is compared, by means of comparator K, with the frequency obtained from an opening of standard dimensions. The amount of frequency deviation represents the amount of deviation of the volume from the required one.

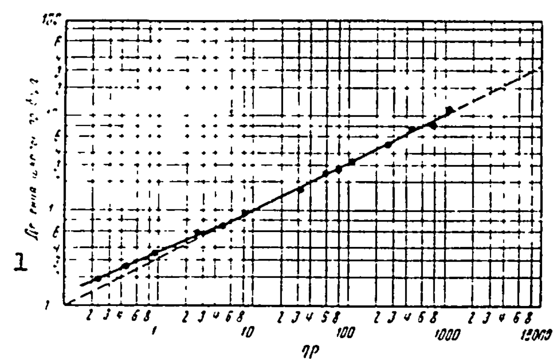

Figure 7. Calibration curve of a viscosimeter.

Legend: 1) divisions on the scale of the instrument.

The author shows that, in order to measure the volumes encountered in the ordinary construction of machines, a frequency range of 50-500 c is sufficient.

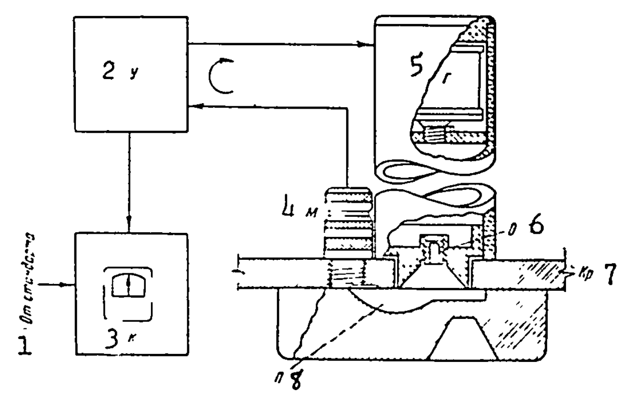

Figure 8. Diagram of operation of a cavity meter.

Legend: 1 - from the gauge; 2 - U; 3 - K; 4 - M; 5 - G; 6 - O; 7 - Kr; 8-P.

Consumption meter. The principle of a supersonic consumption meter has been described many times in literature. It is based on the fact that the sound speed within a medium is equal to c, while the speed of flow of this medium is v; the time of travel of the supersonic pulse from the stationary source to the stationary receiver will be $t_1 = \frac{d}{c+v}$ if the direction of propagation of the sound wave coincides with the direction of flow of the liquid or gas, and $t_2 = \frac{d}{c-v}$ in the case it is directly opposite; d is the distance between the source and the receiver. From

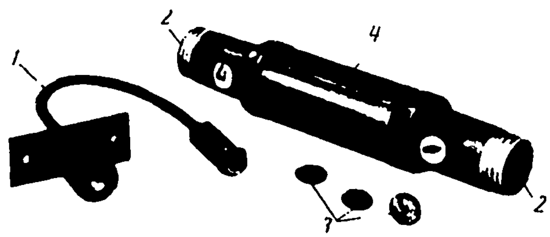

Figure 9. Sensing element of the NITTeplopribor consumption meter.

1 - plug; 2 - connecting pipes; 3 - piezoelectric plates of the vibrators; 4 - body of the vibrator.

the two obtained equations the simple values of the speed of motion of the medium, v, and the speed of propagation of sound are determined [6]. Such consumption meters were developed and are manufactured by many companies. Figure 9 shows the sensing elements of the consumption meter developed at NITTeplopribor [7]. Figure 10 shows the cross-section of the emitter-receiver, manufactured by one of the foreign firms for the measurement of large consumption of water. Figure 11 shows the photograph of its installation within the spiral of a hydraulic turbine with a power of 42,500 hp. In this last case the cross-section of the pipe is 5 x 7.5 m, the largest consumption of water is 56 m^3/sec, the distance between the sensing elements is 9 m, and the operating frequency is 25 kc [8]. The average error of the consumption meter of this type is about 2%.

Analyzer of impurities. Since the acoustical methods permit indirect measurement of different impurities through the change of sound propagation or its absorption, they are, strictly speaking, not well adapted for the analysis in the full meaning of

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this word, since different impurities can produce similar effects. Because of this, acoustical methods are used either in those cases when the expected composition of impurities is known beforehand, or when it is only necessary to establish the fact of the presence of impurities regardless of their composition or quantity. As an example, one can cite an acoustical analyzer designed to monitor the appearance of harmful gases in the air, such as chlorine, carbon monoxide, or methane. This device is based on the change in the speed of sound propagation in the presence of impurities. The measurement itself is made with a small interferometer, shown in the cross-sectional view in Figure 12. Between the quartz emitting plate Q and the reflector R, a system of standing waves forms. By depressing the pushbutton K, the reflector is brought in contact with the surface of the emitting plate. When the pressure is released, an external spring F returns the reflector to the original position. If, between the surface of the quartz and the surface of the reflector, n half-waves can be accommodated, then, when the reflector moves, the reaction on the emitter will change n times, i.e., the magnitude of current in the circuit of the emitter will change n times. The resultant electric pulses are fed into a pulse counter. The presence of impurities change the speed of sound propagation, change the length of the wave and as a result the number n of the half-waves and correspondingly of the pulses which reach the counter. This permits not only signaling of the pollution of the gas, but also indicates the degree of this pollution

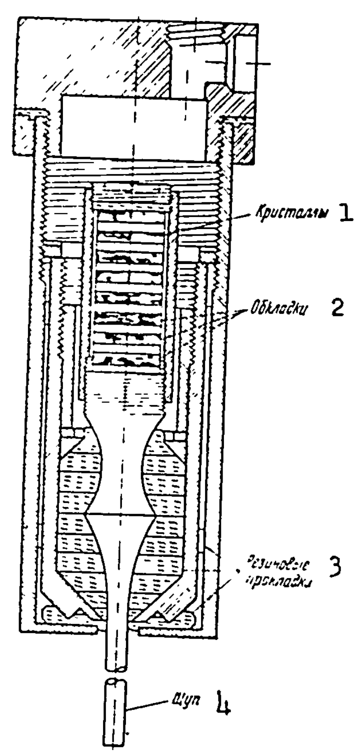

Figure 10. Antenna-type sensing element.

Legend: 1 - crystals; 2 - linings; 3 - rubber packing; 4 - probe.

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The devices described above are far from representing the only possible methods of acoustical measurements. In addition, the history of the appearance and of the development of devices described above compels one to state that the appearance of precisely such devices in the first place does not result from some general considerations, but has often been determined by accidental causes and local requirements. As yet the application of acoustical methods is very small, for the control of chemical reactions and physicochemical processes, where these methods can introduce large improvements.

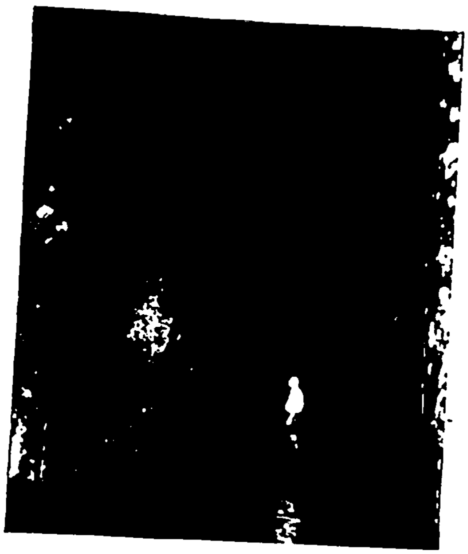

Figure 11. Installation of a sensing element in the spiral of a powerful hydraulic turbine.

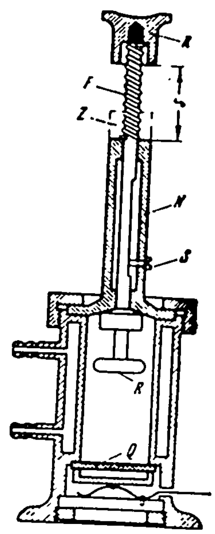

Figure 12. Construction of a high-speed interferometer.

Only very recently have acoustical methods begun to be applied here and abroad, for the control of quality and for the supervision of the hardening of cement.

It is necessary to initiate a large amount of technical development and construction efforts for the rapid growth of prospective methods of acoustical measurement, considering in particular the circumstance that these methods are characterized by high sensitivity and short time necessary for the performance of measurements; they permit a remote location of sensors and can be successfully used for automation and control.

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V. L. Tal'roze

MASS-SPECTROMETER AS AN INSTRUMENT FOR THE CONTROL OF INDUSTRIAL PROCESSES

Mass-spectrometer and the Principle of Mass-spectrometer Analysis of Mixtures

Mass-spectrometer analysis--used during the early stages of its development in a vast majority of cases to determine the masses of atoms and the isotope composition of elements--became during the last 15-20 years an efficient means for the investigation and determination of the chemical compositions of mixtures.

The modern mass-spectrometer represents an electric vacuum apparatus consisting of the following major parts: ion emitter, designed to convert the molecules of the substance to be analyzed into ions; analyzer, in which these ions by some means are grouped according to their masses (more exactly, according to the ratio of the mass to the charge); receiver, in which the ions reach a collector. The ion current is measured by electrical means.

In the case of the analysis of gases or of more or less easily vaporized substances, with which this article will be mainly concerned, a bombardment of molecules with electrons possessing an energy of several tens of ev is used in an ion source in order to obtain a beam of ions. Usually in this case, energies are used which result in maximum cross-sections of single charge ionization (40-100 ev). (Additional analytical potentialities can sometimes be obtained in determining the ionizing potentials or working near the ionizing potentials.)

The application of the mass-spectrometer for the analysis of mixtures of chemically different substances is based on the fact that, with constant energy and electron current, the ratio of ion currents of different materials is proportional to the ratio of concentration of these materials in the analyzed mixture. This coefficient of proportionality can be found by means of calibration. Besides, under a molecular type of supply of gas into the ion source, the ion currents of the components of the mixture are proportional to their partial pressures in the mixture. Under the elec-

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tronic bombardment of molecules by electrons with energies usually employed in mass-spectrometer analysis their dissociative ionization takes place, in addition to the simple ionization of molecules, with the result that each kind of molecule gives rise to ions with different masses; for example, the molecules C_2H_6 produce ions $C_2H_6^+$, $C_2H_5^+$, $C_2H_4^+$, ..., C_2^+, C^+, H^+. This produces a mass-spectrum with many lines. It is possible to assume that the spectra of different materials superimpose themselves upon each other additively. Thus, in the general cases, to find the composition of the mixture with components, one has to solve, depending upon the spectrum, a system of k linear equations*:

$$\begin{aligned}
a_{11}x_1 + a_{12}x_2 + \ldots + a_{1j}x_j + \ldots + a_{1k}x_k &= J_1 \\
a_{21}x_1 + a_{22}x_2 + \ldots + a_{2j}x_j + \ldots + a_{2k}x_k &= J_2 \\
\ldots \\
a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{ij}x_j + \ldots + a_{ik}x_k &= J_i \\
\ldots \\
a_{k1}x_1 + a_{k2}x_2 + \ldots + a_{kj}x_j + \ldots + a_{kk}x_k &= J_k
\end{aligned}$$

where x_i is the unknown partial component; a_{ij} is the calibration coefficient; and J_i is the intensity of the mass spectrometer lines in the spectrum of the analyzed mixture.

In order that the coefficient a may remain constant, it is necessary--in addition to a sufficiently low pressure within the source and a constant electron energy--to have a constant temperature in the region of ionization. The importance of this condition increases with the increase in the number of atoms in the analyzed molecules. However, the existing experience in the use of the mass-spectrometer gas analyzers shows that with the usually employed stabilization of electron emission during the analysis of little distinguishable mixtures, the temperature of the source remains practically stable, without the special stabilizers used in more complicated analytical mass-spectrometers.

* A more exact, but more difficult method is the use of the number of equations larger than k. In this case one has to use a method of the least squares (see the article in [13]).

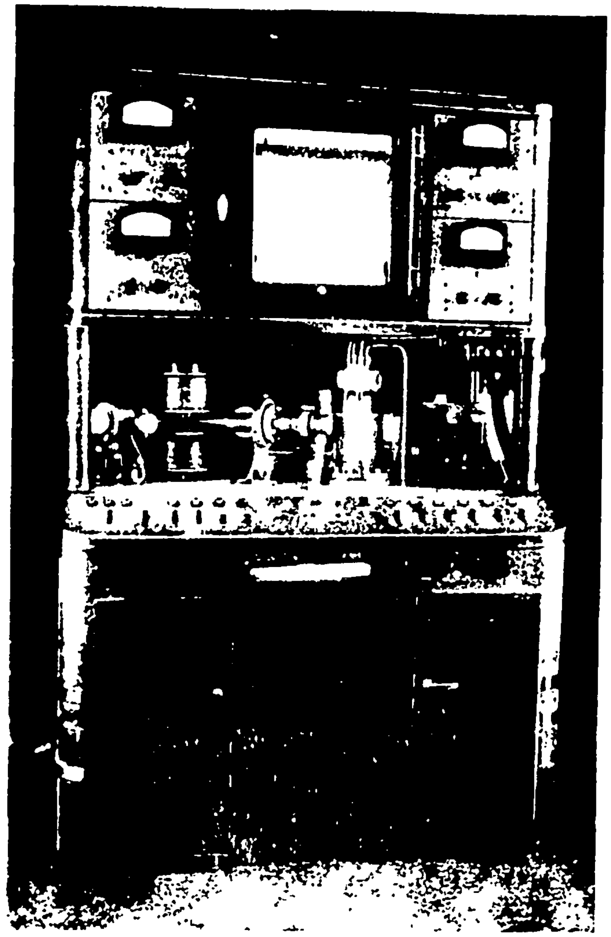

Figure 1. MAGS-2.

Another factor, which influences the reproducibility of the mass-spectrum and the sensitivity of the mass-spectrometer is the degree of cleanliness of the internal parts of the mass-spectrometer chamber. The author's experience shows, for example, that in making systematic analyses of hydrocarbon mixtures, sudden changes in the spectra are due to the contamination of walls of the analyzer tube (made of red copper), which appear after 2-3 months of operation. These variations are due to the formation of surface charges on the deposits, thus influencing the ion beam. These layers are easily removed by simple mechanical cleaning.

However, even with careful stabilization of electronic emission and temperature and using a carefully cleaned instrument of existing construction, one fails to achieve a stability of the mass-spectrometer sensitivity, corresponding to variations smaller than a few percent in several days. Many times better is the stability of the ratios of sensitivities toward various substances and the stability of the distribution of intensities in the spectra of individual matters /1/. As a result, the experimenter, attempting to obtain more exact results, often uses the method of "ratios," introducing at times a special internal standard.

Let us dwell briefly on the MAGS-2 apparatus to illustrate the operation of a mass-spectrometer gas analyzer. Its experimental models were issued by NII LRTP /2/.

The MAGS-2 apparatus (Figure 1) represents a construction unit containing a single-beam mass-spectrometer, in which a segmental magnetic field is used for the separation of the ion beam. It possesses a system of molecular supply of the analyzed mixture introduced into the source of ions and a system of automatic recording of mass-spectra. The diagram of t e instrument is shown in Figure 2. A small volume of the analyzed mixture ($\sim$ 8 cm^3)--after the measurement of its pressure by means of a mercury manometer, read through a microscope--is let into a supply vessel having a volume of about 8 lit. From this vessel the mixture gets into the ion source through an opening 10-15 μ in diameter, made in a thin ($\phi \sim 1 \mu$) aluminum foil which insures the molecular character of supply. The system of automatic recording of mass-spectra includes a wide-band scanning of the spectrum by changing the magnetic field. The recording of the spectra takes place on a strip of an autopotentiometer EPP-09, connected to the output of the electrometric amplifier with a full feedback circuit. The low level of background noise within the gas analyzer is guaranteed by the extensive use of stainless steel as a construction material, and the use of a vacuum valve which separates the instrument chamber from the pumping system. The resolving capability of the instrument is 1/80, the range of mass numbers is 1-80, the recording time of spectrum within the subrange 12-30 m.e. is 12 min. The stability of the relative sensitivity is characterized by the deviation of $\pm$ 1-$\pm$1.5% from the average value during several days.

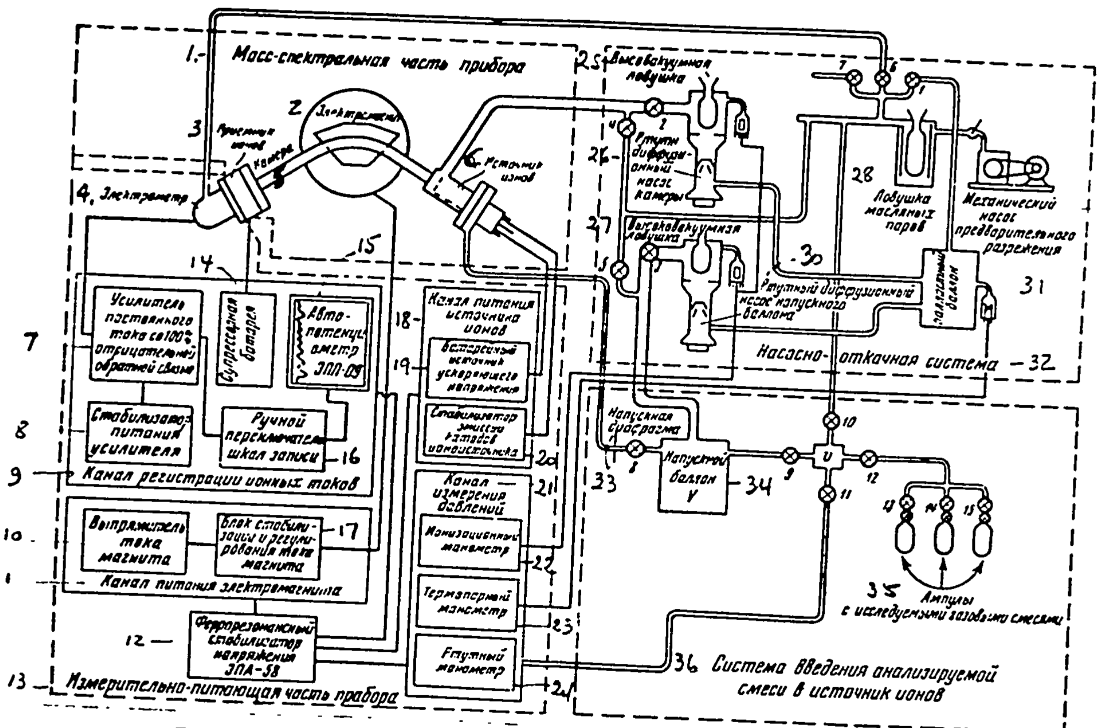

Figure 2. Schematic arrangement of apparatus MAGS-2

1-15 valves.

Legend: 1 - mass-spectrum part of the apparatus; 2 - electromagnet; 3 - ion receiver; 4 - electric meter; 5 - chamber; 6 - ion source; 7 - direct current amplifier with 100% negative feedback circuit; 8 - regulator for the power supply of the amplifier; 9 - section for the recording of ion currents; 10 - magnet current rectifier; 11 - section for the supply of the electromagnet; 12 - ferroresonance potential regulator EPA-58; 13 - measurement and power supply part of equipment; 14 - suppressor battery; 15 - autopotentiometer EPP-09; 16 - manual switch for recording scales; 17 - stabilization and regulation block for the magnet current; 18 - section for the supply of ion sources; 19 - battery source of accelerating potential; 20 - emission stabilizer for cathodes of ion source; 21 - section for the measurement of pressure; 22 - ionization gauge; 23 - thermocouple gauge; 24 - mercury gauge; 25 - high vacuum trap; 26 - mercury diffusion pump of the chamber; 27 - high vacuum trap; 28 - oil vapor trap; 29 - mechanical pump for the preliminary evacuation; 30 - mercury diffusion pump for the supply vessel; 31 - ballast vessel; 32 - evacuating system; 33 - supply diaphragm; 34 - supply vessel; 35 - flasks with investigated mixtures; 36 - system for the introduction of mixture to be analyzed into the ion source.

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Table 1

Mixture of Gas Hydrocarbons

Substances	Mixture Composition, Volume %		Deviation %	
	From dosage data	Found by mass-spectrometer method	Absolute	Relative
Acetylene	35,1	35,3	+0,2	+0,6
Ethylene	32,2	32,5	+0,3	+0,1
Ethane	14,6	15,2	+0,6	+3,9
Propane	18,3	18,7	+0,4	+2,1

Table 2

Mixture of Liquid Hydrocarbons

Substances	Mixture Composition, Mol %		Divergence %	
	From weight data	Found by mass-spectrometer method	Absolute	Relative
H-hexane	21,0	21,1	+0,1	+0,5
Cyclohexane	30,9	31,5	+0,6	+1,9
2,2,3-trimethylpenthane	22,1	22,1	0	0
H-decane	26,0	25,3	−0,7	−2,7

Table 3

Mixture of Oxygen-containing Organic Compounds

Substances	Mixture Composition, Mol %		Divergence %	
	From dosage data	Found by mass-spectrometer method	Absolute	Relative
H-butyl alcohol	16,1	15,9	−0,2	−0,8
Ethyl alcohol	26,6	26,4	−0,2	−0,7
Methyl alcohol	19,1	19,0	−0,1	−0,5
Acetone	20,6	21,0	+0,4	+1,9
Methyl acetate	17,6	17,6	0	0

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Table 4

Mixture of Chlorine Compounded Methane

Substances	Mixture Composition Mol %		Divergence, % Absolute
	From dosage data	Found by mass-spectrometer method	
CCl_4	13,6	14,3	+0,7
$CHCl_3$	20,9	18,4	−2,5
CH_2Cl_2	19,8	20,2	+0,4
CH_3Cl	26,7	27,4	+0,7
CH_4	19,0	19,7	+0,7

Substances Analyzed with the Aid of the Mass-spectrometer

As a result of investigations during the recent years, the range of substances which can be analyzed with the mass-spectrometer increased greatly. This range now includes apparently all or practically all substances entering into the raw materials or products of the oil and chemical industries. Among these substances can be found hydrocarbons and organic compounds, containing oxygen, sulfur, nitrogen, not to mention such comparatively simple materials for analysis as, for example, air gases, inert gases, etc.

It must be noted that in more complicated cases, for example, in the analysis of crude oil, of benzene and heavier fractions, the complete mixture analysis can only be made through the combination of the mass-spectrometer with other methods (adsorption separation, distillation, optical methods).

Tables 1-4 show examples of analysis made with domestic apparatus /1, 3/.

Application of Mass-spectrometer as a Control Instrument under Industrial Conditions

The application of the mass-spectrometer as a control device is due to its extensive analytical potentialities, its comparatively high speed of analysis, the

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high sensitivity in many applications, and the possibility of continuous control when connected to the stream.

It must be notod that in the U.S. mass-spectrometers have been widely used during the last three or four years for production control /4, 5, 6/. Let us point out some application areas of mass-spectrometer control.

1. Continuous control of raw material composition and products in the production of the acetylene and of the hydrocarbon gases. The special effectiveness of such a control is due to the particularly critical conditions for the optimum course of the process: the output of acetylene decreases by 40% with the temperature deviation of 5° C from the preset one.

2. The determination of harmful admixtures of ethylmercaptan (0.1%) and other substances in the derivation of methylmercaptan used in the production of methionine.

3. The analyses of gases, trapped in dirt extracted by borers, to determine the location of the oil layer (the mass-spectrometer is placed close to the well).

4. The analysis of waste gases for H_2S and SO_2 in the plants processing hydrogene sulfide into sulfur. It is claimed that the use of the mass-spectrometer increased the sulfur output from 91.5 to 94.5% or decreased the sulfur content in the waste gases by 35%.

5. The determination of the end point of water liberation in the treatment of metals with hydrogen (in vacuum welding).

In the Soviet Union, a series of investigations were also undertaken during the recent years. Let us mention some of them. In MRTP /7/, the mass-spectrometer analysis used experimentally for the control of industrial processes for the elimination of high vacuum equipment, gave rise to new opportunities for the determination of the best method of pumpout.

At the IKhF of the Academy of Sciences USSR, G. D. Tantsyrev and the author of this article were able to carry out a mass-spectrometer control of the purity of the inert gases for various technological problems.

M. V. Tikhomirov, A. I. Kasperovich, and C. Sh. Bykov /8/ performed experiments

[redacted]

for the determination of $C_3 H_6$ admixtures in the industrial gas mixtures, which has ethylene as their main component. The experiments were conducted under plant operating conditions and gave successful results.

NIVI MRIP has already developed and manufactured several years ago several models of the MAG-3 apparatus /9/, which has been used, in particular, for the purity control of ethylene mentioned above. The MAG-3 apparatus (Figure 3) is an example of a mass-spectrometer gas analyzer intended for continuous control. This apparatus

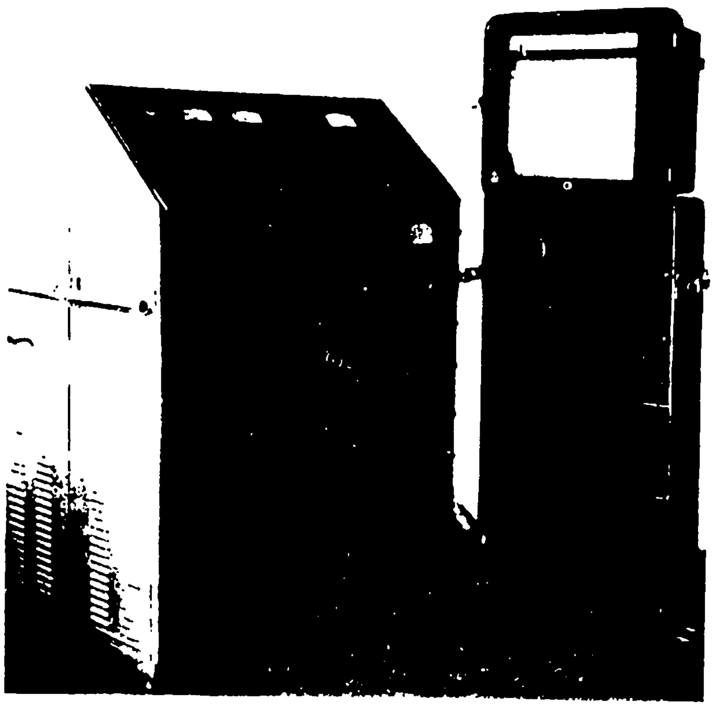

Figure 3. MAG-3 apparatus.

uses a 180° deflection of ions. The mass-range is 12-100, the resolution capability is 1/50. The apparatus uses a permanent magnet. The adjustment for the mass is accomplished by means of step variations of the ion accelerating potential according to a given program. A six-point electronic recording potentiometer can record six lines of spectrum in 30 sec.

Construction Problems of Mass-spectrometer Gas Analyzer for the Control of Production Processes

In the development of a mass-spectrometer for the control of industrial processes,

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many problems occur, which, in the case of mass-spectrometers intended for experimental work, either do not play a substantial role or are not very important.

Let us examine these problems in order.

1. Problems Connected with the Increased Speed of Analysis

The process of mass-spectrometer analysis is divided into four stages: (a) the establishment of fixed conditions after the introduction of the mixture into the apparatus; as the work experience at the IKhF of the Academy of Sciences USSR shows there occurs, in the system with molecular supply during this period, the establish-

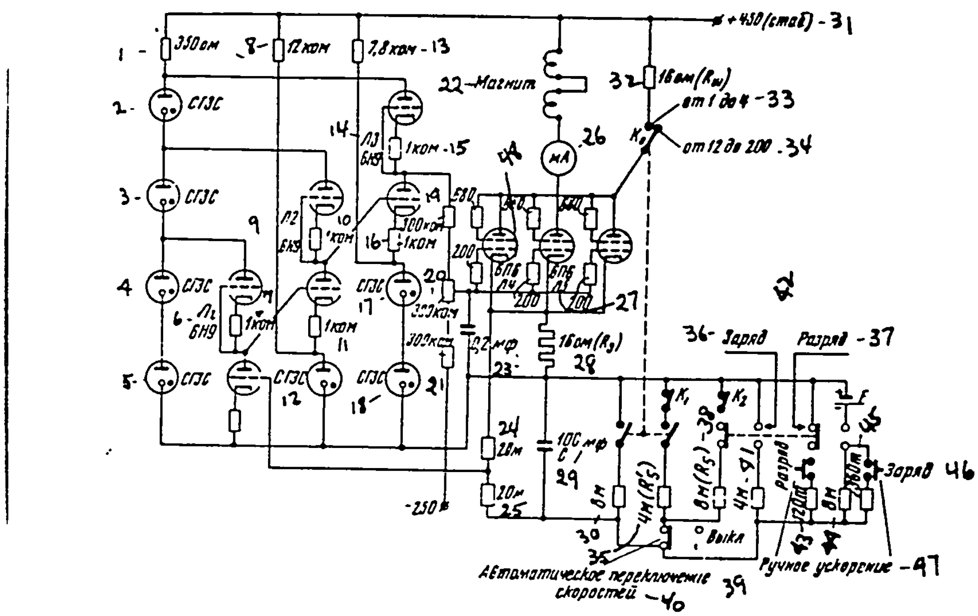

Figure 4. Schematic diagram by the IKhF of the Academy of Sciences USSR of magnetic-field exponential scanning of the mass-spectrum.

1 - 350 ohms; 2 - SG3S; 3 - SG3S; 4 - SG3S; 5 - SG3S- 6 - tube 1 6N9; 7 - 1 kilohm; 8 - 12 kilohms; 9 - tube 2, 6N9; 10 - 1 kilohm; 11 - 1 kilohm; 12 - SG3S; 13 - 7.8 kilohms; 14 - tube 3, 6N9; 15 - 1 kilohm; 16 - 1 kilohm; 17 - SG3S; 18 - SG3S; 19 - 300 kilohms; 20 - 300 kilohms; 21 - 300 kilohms; 22 - magnet; 23 - 0.2 mf; 24 - 20 megohms; 25 - 20 megohms; 26 - ma; 27 - tube 5, 6P6: 28 - 16 ohms; 29 - 100 mf; 30 - 8 megohms; 31 - +450 regulated; 32 - 16 ohms; 33 - from 1 to 4; 34 - from 12 to 200; 35 - 4 megohms (R'_5); 36,- charge; 37 - discharge; 38 - 8 megohms (R_5); 39 - switch; 40 - automatic switching of speeds; 41 - 4 megohms; 42 - discharge; 43 - 120,000; 44 - 8 megohms; 45 - 360,000; 46 - charge; 47 - manual acceleration; 48 - tube 4, 6PP.

ment of thermal equilibrium in the ion source and partly the establishment of the adsorption equilibrium; (b) the recording of the spectrum; (c) the pumping out of the analyzed mixture until the erasing of the absorption memory; (d) calculation of the mass composition from the mass-spectrum.

The first stage usually takes several minutes. The duration of the second stage, generally speaking, is different for different apparatuses. In the majority of our domestic apparatuses, the recording system consists of a direct current amplifier with full negative feedback and of an automatic potentiometer EPP-09; the inertia of this system, naturally, limits the speed of scanning. To obtain the maximum possible (with a given inertia) speed of spectrum recording--as has been indicated by the author [10]--the application of the optimum law of spectrum scanning is essential, which happens to be an exponential law.

The arrangement by means of which the exponential scanning of the magnetic field in the mass-spectrometer is accomplished, was developed by the IKhF of the Academy of Sciences USSR [11]. This arrangement, shown in Figure 4, also permits automatic variations in the speed of scanning by accelerating it in the areas between peaks. The MS-1A [1] apparatus makes it possible to record a spectrum in the range of 12-200 in 20 min. The duration of the third stage essentially is determined by the adsorption memory of the apparatus. This memory is considerably longer for substances with polar molecules (water, alcohol, ammonia, etc.). The literature indicates that the adsorption memory is related in the main to the region between the diaphragm-admitter and the ion source. By bringing the diaphragm right against the region of ionization, it is possible to decrease considerably the adsorption memory. Our experience shows that in such a case it is possible to reduce it to several minutes even in the case of the strongly adsorbing substances.

It is possible to point here to another possibility for a large decrease in the duration of the first and the third stages. This possibility consists in supplying the gas to the mass-spectrometer as a modulated molecule beam. The experiments conducted recently at the IKhF of the Academy of Sciences USSR indicate the possibility of this method. The arrangement of the supply to the mass-spectrometer, used in these tests, is shown in Figure 5. The analyzed gas is contained in volume 1 and is supplied to the ion source in the shape of a molecular beam through channel 3. Gate 2, which

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is opened and closed by means of magnet 4, modulates the beam. Inasmuch as the beam does not practically touch the walls of the source and the materials which are adsorbed by the walls of the vacuum part of the supply system are not introduced into the modulated component of the molecular beam, one can expect, by increasing the ion current in the modulated part of the molecular beam, a reduction to a minimum of the inertia of the mass-spectrometer due to the establishment of thermal equilibrium and of the adsorption memory. Our tests showed, in particular, that in this case it is possible to decrease many times the memory in comparison with apparatus without the molecular beam but with a diaphragm, located near the source.

Figure 6 shows a time variation curve of the intensity of the line 18 m.e. in the mass-spectrum of water after its supply to the ion source has stopped. The curves

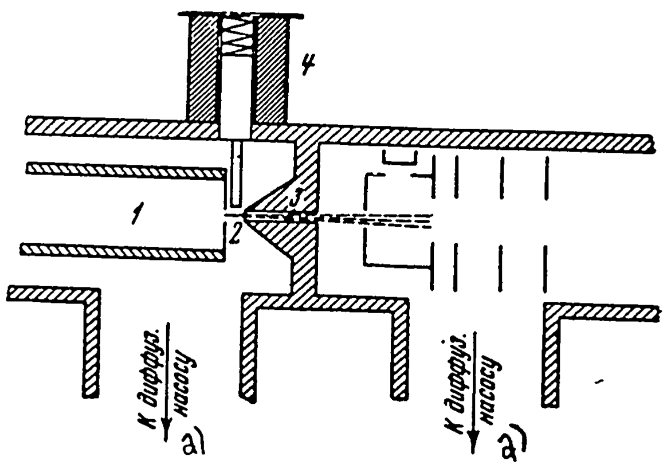

Figure 5. Arrangement of the supply part of the mass-spectrometer.

Legend: a) to diffusion pump.

were obtained at the IKhF of the Academy of Sciences USSR on three apparatuses: on the industrial isotope MS-2 apparatus, on the MS-1A [1] mass-spectrometer and on the experimental mass-spectrometer IKhF with a molecular beam.

On the abscissa axis is shown the time after the beginning of the pumpout of the supply volume; on the ordinate axis is shown the intensity of the line 18 m.e. in percent of the original.

As to the decrease in the duration of the recording of the mass-spectrum, the only way here is the introduction of the oscillograph registration with rapid scanning of the spectrum. Although the descriptions of individual apparatuses of this type STAT

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was published /12/, the real investigations of their capabilities were not made. In those cases where the graphical representation and the speed of registration is more important than the accuracy, this method can be very promising.

The calculation stage in the case of the multicomponent mixtures is found to be the most lengthy and takes at times 80 to 90% of the time required for the entire analysis. For these cases, the reduction of this stage through the use of computing

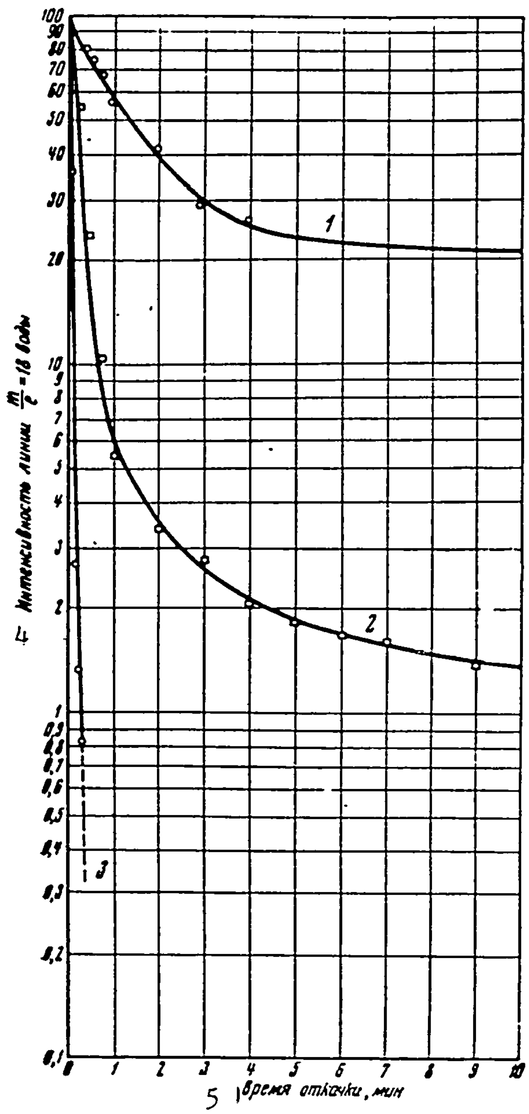

Figure 5. Adsorption "memory" in the case of water by mass-apectrometers with different supply systems.

1 - supply system MS-1 (needle valve); 2 - supply system MS-1A; 3 - supply system with modulated molecular beam (experimental mass-spectrometer of IKhF); 4 - intensity of the line $\frac{m}{e}$ = 18 of water; 5 - pumpout time, minutes.

machine technique becomes very great. For the solution of systems of first-order

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algebraic equations, relatively simple analog arrangements can be used. These are, however, not sufficiently accurate when the number of equations is great; the use of an electronic calculating machine becomes then very desirable.* With the preset programming, which can encompass practically all the cases one is interested in, the time which is required by one machine to calculate the results of one analysis apparently does not exceed several tens of seconds.

It is believed that, under present-day conditions, the use of computing technique in the mass-spectrometer applications is more of an organizational problem than a scientific one.

2. Problems Arising when it is Required to Connect the Mass-spectrometer to a Stream for Continuous Automatic Control

It is evident that with the use of mass-spectrometer for continuous controls, the problems connected with a more rapid analysis in certain cases preserve their urgency. However, these cases in chemical and oil production will not be very frequent at the beginning. These problems involve the various uses of the mass-spectrometer for the simultaneous control of many pipes or reactors with automatic consecutive switching of the supply system of the mass-spectrometer from one control object to another.

In the majority of cases, the control involves one or two objects with very slow possible variations of the composition of the mixture.

However, when the mass-spectrometer is connected to a stream, new problems arise, connected with the gas supply systems for the ion source, the recording of the spectrum, the automatic programming of the operation of the apparatus, and with the insurance of a prolonged and stable operation.

In principle two systems for supplying the gas from the plant piping into the ion source are possible: with one stage or with two stages of pressure reduction. In the system with one stage, the supply to the ion source must be accomplished pri-

* The problems of the use of calculating machine technique in the mass-spectrometer is described in detail in the monograph [13].

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marily according to the law of viscosity. In this case the quantitative charactoristics of the component content of this mixture are not the magnitudes themsolves of the mass-spectrometer peaks, but only their ratios*. Here we find the main drawback of this system: when we use the automatic calibration with a standard gas, which appears to be desirable, it is necessary to add a measured amount of this gas directly into the stream directed into the mass-spectrometer, i.e., to create an internal standard. The two-stage system is free from this drawback, where the gas is continuously eleiminated with a vacuum pump from the volume, with a resistance at the inlet, insuring a volume pressure of about 0.1 mm of the mercury column. This volume is connected to an ion source by means of a diaphragm, which insures a molecular supply of gas into the source. In this case the supply of the standard gas can be alternated with the supply of the mixture to be analyzed. Such an installation is used in the U.S. for the control of the gas products in the cracking plants /4/. In the Soviet Union a similar system has been used by IAT of the Academy of Sciences USSR, in developing a system of mass-spectrometer control for the products of underground gasification of coal /15/.

The other problem encountered in the continuous mass-spectrometer control is the stability of the calibrating characteristics. As all mass-spectrometer operators know and as we mentioned above, the relative sensitivities of a mass-spectrometer for different gases are more stable than the absolute sensitivities. Even in the case of a more careful preparation of ion sources, the mistakes in the analyses, performed with the "method of ratios" are two or three times smaller than with the use of absolute sensitivities. Because of this, it is desirable, in continuous analysis, to use a standard gas which is supplied automatically into the ion source alternatively with the mixture to be analyzed. The IAT of the Academy of Sciences USSR is working on the further development of this method: the use of the ion current of the standard gas for an automatic correction of the amplification factor of the mass-spectrometer amplifier /15/.

Two systems of spectrum recording are used in the mass-spectrometer for con-

* See, for example, the survey /14/.

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tinuous analysis: a continuous system with an automatic programming of the recording ranges and a dot system for the maximum values of the ion current in the mass-spectrometers (an example of the system of this last type is the recording system in the MAG-3 /9/ apparatus). The continuous system naturally insures a completely reliable recording of a maximum; the dot system requires for reliable recording, a special automatic arrangement which is now being worked out in particular by the authors of the MAG-3. With continuous control, the use of an electronic oscillograph appears particularly desirable.

In case when the problem requires the watching of only two or three spectrum lines, it is most convenient to use correspondingly two or three collector mass-spectrometers with a simultaneous recording of the ion current in each section (or the ratio of these currents) /16/.

In case of continuous automatic control, a substantial role is assumed by the system of automatic programming. In the general case, this system must perform the following tasks: select the mass-spectrum lines, which must be registered; establish the range of sensitivities, within which each line must be recorded; control by means of automatic valves the supply of the mixture for analysis, alternating the connection with various pipes and with the vessel containing the standard gas.

3. Problems of Simplicity and Small Dimensions of the Apparatus

One of the main courses, followed by physicists and designers who are attempting to simplify the apparatus, is the development of the new and the improvement of the ordinary methods for the distribution of ions according to their masses.

At the present time three systems based on this principle are being used.

In one of the systems, proposed by Bennett /17, 18/, the ions emitted by a source pass through several groups of grids, each containing three grids. The first and the third grid of each group have a constant potential; the second grid has an alternating potential, oscillating with a frequency of several megacycles; the ions which do not get into the proper phase are slowed down and, as they pass through each

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succeeding group, they are slowed more and more. The probability of an ion getting into phase depends upon the ion speed, which, with similar kinetic energy of ions W, depends upon their mass:

$$v = \sqrt{\frac{2W}{m}}.$$

The inhibiting field in front of the collector does not pass any ion with a kinetic energy smaller than a given magnitude.

The other system employed is similar to the linear accelerator (or retarder) in which the ions pass through a series of accelerating (or retarding) intervals formed by the grids which have potentials oscillating at high frequency. At the output of the tube we have an electrostatic analyzer which passes to the collector the ions which have accumulated (or lost) a definite energy.* According to the information found in literature /18, 6/, apparatuses of this type are being manufactured. The scanning in the first apparatus is achieved by the variation of the accelerating potential, and in the second one by the change in frequency.

The third system was developed in the Soviet Union at the FTI of the Academy of Sciences USSR /20, 23/. In this system the source emits pulses of ions with a given frequency which move toward the collector. In front of the collector there is located a grid to which is applied a shutoff potential pulse a certain time t after the source had emitted the ion pulse. To the different times correspond the groups of ions of different masses.

Another method used at the present time in the mass-spectrometry is the method of cyclotron resonance /21/. The apparatuses of this type are the miniature cyclotrons in which the collector receives ions with masses satisfying the equation

$$m = \frac{qH}{2\pi} T,$$

where T is the oscillation period of the accelerating potential, H is the intensity of the magnetic field in which is located the chamber, and q is the ion charge.

* It must be noted that the idea of using a linear accelerator as a mass-spectrometer was brought up by Alkhazov and Murin in 1941 /19/.

The scanning of the mass-spectrometer in this apparatus is achieved through the variation of T.

It is now generally accepted that all these apparatuses are related to the class of dynamic mass-spectrometers.

Among the industrial static instruments, a mass analyzer /18/ is beginning to be used, employing the intersection of magnetic and electric fields, and thus possessing a double focusing (for the direction and the speed) /24/. The operating principle of this apparatus is clear from Figure 7. The magnetic field is directed perpendicularly to the surface of the figure, the direction of the electric field is shown by the arrow. S_1 is the slot of the ion source, K is the collector. The substantial advantage of this analyzer with a cycloidal trajectory is also its capability of focusing ion beams with a large aperture.

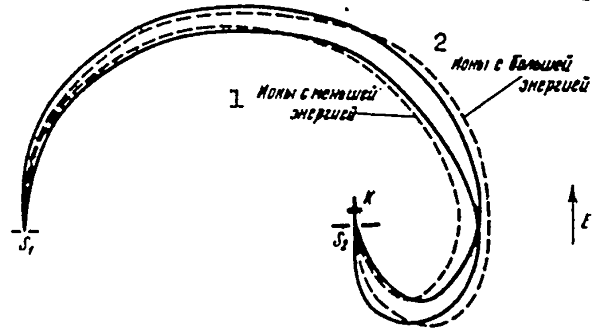

Figure 7. Principle of operation of the analyzer with double focusing.

Legend: 1 - ions with lower energy; 2 - ions with larger energy.

In the Soviet Union, N. Ye. Alekseyevskiy and his collaborators /22/ very effectively used a magnetic mass-spectrometer with a nonuniform field to increase the resolution power of the mass-spectrometer. One of the results of this work proved to be the possibility of obtaining an instrument with a smaller radius without the loss of the resolving power. An experimental model of the mass-spectrometer for the analysis of mixtures, using the focusing of N. Ye. Alekseyevskiy was demonstrated at the All-Union Industrial Exhibit in 1956 by the "Neftepribor" construction department.

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It must be noted, however, that in spite of the large scope of efforts expended on the new mass-spectrometers, each of it by itself does not result in the simplification and cost reduction of mass-spectrometers. The reduction in the dimensions of the analyzer part itself, obtained in certain cases, affects very little the overall dimensions because these are determined primarily by the vacuum pump and the electronic equipment. One cannot also say that this achieves a simplification of electronic equipment, since the replacement of the magnet, in particular of a permanent one, hardly constitutes a simplification of electronic circuits. It is more correct to consider that the main advantage of the new types of mass-spectrometers, resulting from the use of broad particle streams or beams with a large aperture, consists in the increase in the ion currents and consequently in the increase in sensitivity for the similar resolving power. Even this conclusion, at least with respect to dynamic instruments, must be reached with a certain caution. Thus, as has been reported, in particular all American dynamic instruments, mentioned in this paper, which have a resolving power of 1/100 to 1/120, produce ion currents of 10^{-10} to 10^{-11} a, i.e., practically the same as those of the ordinary static instruments.

The present state is such that, in the selection of the mass-spectrometer type for industrial production, it is not yet possible in many cases to make a flat decision in favor of one or the other type. The decisive reasons in such a selection can be considerations linked to the reliability of operation, based on a sufficiently extensive experience. A considerably larger area for simplification and reduction in the cost of mass-spectrometers is found, in the opinion of the author, in its vacuum and electronic parts. It suffices to say that semiconductor technique has not yet found its way into this field. It can also be stated that the use of atomic batteries for the acceleration of ions in the mass-spectrometer is very promising due to the comparatively low currents. Finally, of very great importance is the conversion in the mass-spectrometers, particularly intended for continuous control, from the mercury pumps and traps with liquid nitrogen to the oil pumps and efficient charcoal traps, used in many mass-spectrometers in the U.S.

In concluding this section let us note, that the use of the mass-spectrometer in industry can require its construction in an explosion-proof form.

Possibilities for the Use of the Mass-spectrometer Gas Analyzer for Automatic Control of Industrial Processes

Although the application of the mass-spectrometer for control has a long history, its application for automatic control, judging by the published information, is still somewhere off in the future. The most interesting subjects for regulation would be the chemical processes in the industrial reactors and columns. It would appear that the problem is clear: to supervise the concentration of several components and act upon the corresponding parameter (temperature, pressure, speed flow, mixture composition) so that these concentrations or their ratios may be optimum. However, when the problem is so stated, serious difficulties are immediately encountered. The point is that, at the start of any chemical production, the technician usually selects the best conditions which are then maintained constant. Thus, let us say, when the output of the product falls, it is usually due to some noncontrolled or poorly controlled factor, for example, the state of the catalyst. At first glance it is not clear how it is possible to apply here the principle of automatic control. However, the author thinks that there is one possibility which has not yet been examined. Let us illustrate it with an example in which the reason for the decrease in the output is due to the change in the state of the catalyst which must be replaced. Naturally, such a replacement is made when the output falls below some value of the allowable output previously determined, which lies, let us say, 5% below the maximum. The question now is whether during the entire period of the decrease in activity of the catalyst all other conditions were kept at their optimum values. Apparently, this is far from always the case. It is possible, for example, that during this period the largest possible product output with each given state of the catalyst is reached under somewhat different reactor temperature than when the catalyst retains its original activity. In such a case the application of the automatic temperature regulation of the reactor becomes justifiable with the aid of the mass-spectrometer which supervises the output of the product and maintains its concentration at its maximum. In another case such a parameter can be not the temperature but, let us say, the composition of the mixture, the speed of product flow, etc. In this case it is possible to obtain optimum conditions during the entire period of the decrease in the output--from the original to the "allowable." It seems that the possibility of such a control must exist and that the chemists, after making the corresponding investigations, and maybe on the basis of already existing experience, could point to the appropriate concrete examples. In examining these concrete examples, the decisive factor will apparently be the economics. It may happen, for example, that we will lose more if we maintain for a long time an output slightly higher than the allowable one, instead of changing the catalyst more often. In any case, the role is assumed by several percent of the product in a production with a large tonnage is clear, and in this connection the value of the examined approach is clear for the use of the mass-spectrometer for the automatic control of chemical processes.

Another, apparently more long-range use of the mass-spectrometer consists in the automatic control of a mixture composition, resulting from the mixing of the outflow from the two pipes. In the simplest case, the control can be accomplished by acting automatically on the valves in the pipes.

The designers of the MAG-3 apparatus in particular are now working on the development of a device for the solution of problems of this type.

It is possible to increase the number of similar examples; however, it is questionable whether it is necessary to do this in such a general manner. As to the formulation of concrete problems, the best way to examine them is through an extensive use of the mass-spectrometers, first of all, for automatic control, particularly in pilot installations.

In order to use the mass-spectrometer as an instrument for automatic control, it is necessary in the general case to employ a more or less complicated computing installation, which, depending on one or another relationship of the ion currents, will send a signal to the operating devices. The problems arising in such a case a STAT examined in the report by professor N. N. Shumilovskiy in this session.

Conclusion

Above were examined the problems related to the construction and the application of the mass spectrometer as an instrument for the control and automatic regulation of industrial processes.

In discussing the construction of the mass-spectrometer we have concentrated our attention only on the problems which are characteristic in its application for the control purposes, leaving aside, to a certain measure, the general problems pertaining to mass-spectrometry as a whole, the problems arising with the increase in the sensitivity of the devices, in the suppression of the background noise, etc.

We have not attempted to develop final recommendations for the possible types of devices, and have limited ourselves only to the obvious selection of the class of these devices for the continuous control. Different problems naturally require instruments of different types: it is useful to note that it is always possible to build the spectrometer in such a way that the different problem can be solved through the addition of the corresponding blocks and links to the main instrument. Such an approach, as is evident, makes the instrument cheaper when massproduced.

In conclusion, it is possible to state that the existing experience in the use of mass-spectrometers for control points to the great importance of the development in this field. In the Soviet Union, vast scientific and technical experience has already been accumulated in the area of mass-spectrometry. From this standpoint, there is practically nothing to prevent an extensive application of this new and progressive method for automatic control except the actual lack of industrial manufacturing of mass-spectrometers for the analysis of mixtures. All the domestic work, which we have mentioned, was done on the experimental models, constructed at times 3 to 4 years ago.

It appears to us that the present session must call the attention of the existing organization to the abnormality of the current situation.

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N. N. Shumilovskiy and R. I. Stakhovskiy

AUTOMATIC GAS ANALYZERS OF THE MASS-SPECTROMETER TYPE

General Considerations

In the automation of continuous industrial processes, a very important part must be played by the proper control of qualitative indicators of the principal manufactured product in the various stages of its processing through the use of automatic analyzing devices operating on one or another principle. Modern production requirements bring out more distinctly and more urgently the problem of analysis of multicomponent mixtures for all or at least for many of their component parts.

In this connection, mass-spectrometers have been becoming more and more widespread in recent years. They make possible the obtaining of a mass-spectrum of an analyzed product and, after the corresponding computations, permit the determination of the gas composition of the analyzed mixtures.

The great attention devoted to this field of measuring technique in recent years is explained by the advantages of the equipment of this type over other equipment for gas analysis. These advantages are:

possibility to analyze multicomponent mixtures for all components;

relative speed of analysis;

great sensitivity of instrument and accuracy of measurements;

possibility, in many cases, to perform the analyses of mixtures only with the aid of this equipment.

Equipment of the mass-spectrometer type unfortunately has many drawbacks, among which can be counted, first of all, bulkiness, complexity, high cost, and so far inadequate adaptation for automatic, continuous analysis of production under direct manufacturing conditions.

The presently known types of mass-spectrometers can be divided according to the method of analysis of ion beams into two groups: equipment of static and dynamic types.

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The first group (static type) comprises equipment in which the separation of ions is accomplished either in the electric or the magnetic, slowly varying field.

In the equipment of the second group, rapid variation of an electric field is used, in which the ionized particles separate either according to their transit time between the ionization source and the receiving collector, depending upon the mass of the particle (ratio of mass to charge), or upon their own frequency, also depending upon the mass.

At the present time, mass-spectrometers of the static type can be considered as having been mastered in the USSR. At GSKB /State Special Design Bureau/ for gas analyses of the MPSA, the industrial production of mass-spectrometers of types MS-2, MS-3, and MS-4 for isotope analysis has been set up. Simultaneously, other organizations have developed many designs for mass-spectrometers: MAGS-2 (NII-160), MAG-3 (NIZI MEP), mass-spectrometer for PGU (IAT of the Academy of Sciences USSR and VNIIPodzemgaz) and for the analysis of crude oil products (SKB-6 MNP).

Industrial models of the dynamic type of mass-spectrometers have not been produced as yet in the USSR, and only laboratory and developmental models are in existance. These are: the laboratory model of the transit time mass-spectrometer at the Physicotechnical Institute of the Academy of Sciences USSR, the developmental model of the radio-frequency mass-spectrometer with a parabolic field in the Department of Industrial Electronics of MEI, the developmental industrial specimen of a mass-spectrometer of the transit time type at GSKB for gas analysis of MPSA.

In the light of problems set forth by the resolution of the Twentieth Congress of the Communist Party of the Soviet Union in the field of automation of the national economy, the instrument of the mass-spectrometer type must receive wide application in the installations for automatic control, as well as in the installations of automatic regulation of industrial processes in accordance with qualitative characteristics of the manufactured products. It is therefore very important right now to determine correctly the directions which will be followed by the development of this type of equipment for their best adaptation to the demands of industry.

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Many characteristics (speed of analysis, smaller complexity, and smaller dimensions of the vacuum section) make equipment of the dynamic type more suitable for the above-mentioned aims. In the U.S. a series of such instruments have been produced for industrial purposes. Among them can be listed: the apparatus of the firm Philips Petroleum Company (of the Bennett type) for the analysis of gas mixtures (hydrogen, helium, methane, nitrogen, argon), the "omegatron" of the General Electric Esso Company for the analysis of hydrocarbons, the apparatus of the Beckman Instrument (of the Bennett type with stagnation feature) for the analysis of hydrocarbons.

In this connection, one of the actual problems is the development of new dynamic mass-spectrometers, intended for automatic control and regulation.

At the same time, extensive work must be undertaken for further development of equipment of the static mass-spectrometer type intended for automatic control as well as for automatic regulation, as well as their manufacturing for use as automatic continuous-action gas analyzers for direct determination of multicomponent composition of an analyzed mixture in industrial departments.

Industrial tests made with the mass-spectrometers MAG-3 (NIVI) and PGU (IAT of the Academy of Sciences USSR and VNIIPodzemgaz), with step scanning of the accelerating potential for the definite number of the most characteristic masses, gave positive results. The time required to perform the analysis of the six components with this type of scanning was only several minutes.

For the regulation of high-speed industrial processes (where this is required) in two or three components, it is possible to use a static mass-spectrometer with several collectors for the simultaneous automatic control or regulation of the investigated mixture for each characteristic component.

The direct analyses of complex mixtures and the determination of the components of such a mixture requires a long mathematical processing of the measurement results. This can be achieved in the equipment through the use of special computing arrangements, which will considerably decrease the expanded time for the interpreting of the records obtained in the instrument.

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Such a computing installation can consist of a separate computing desk with manual input of data obtained from the ordinary mass-spectrometer, or it can consist of an additional intermediary block within the instrument itself, which automatically receives the output pulses of the masses and which automatically process them in the form of pulses suitable for the typewriter which writes corresponding to the magnitude of components in the analyzed mixture.

In this last case, the mass-spectrometer directly assumes the functions of a multicomponent gas analyzer. In the manufacturing of such a gas analyzer of the mass-spectrometer type for automatic control and regulation of production processes, it is necessary to satisfy the following requirements:

provision for continuous automatic control;

suitability for operation under plant conditions in the presence of the plant's corrosive gases;

provision for automatic processing of primary results of measurement of masses, and for automatic recording on a receiver device of the composition of the analyzed mixture (automatic gas analyzer);

reception of signals at the output of the gas analyzer intended for automatic regulation;

insurance of stability, with time, of the sensitivity of the entire measuring installation as a whole.

In the majority of cases, the mass-spectrometer can insure only a periodic control of masses, with a subsequent automatic computation of the component parts of the analyzed mixtures. The time between individual measurements will determine the periodicity of control. The reduction of the time measurements for each individual cycle can be achieved through the step-type variations of the scanned fields (magnetic or electric). In addition, the instrument must have an automatic regulating arrangement, which allows for measurement taking according to a definite developed program.

The necessity for installation of this instrument near the analyzed product in the plant requires its protection from harmful external agents. At the same time the servicing of the measuring section of the installation requires its periodic inspection. In this connection one of the measures for combating the action of corrosive gases is the separation of the entire installation into two parts: the vacuum part, installed directly in the neighborhood of the control point and located in a hermetical enclosure and the measuring part of usual construction, located in one of the central locations. This last arrangement requires the installation of a remote-control automatic regulation for a coordinate operation of these parts in accordance with a preset program.

Instability of Ion Currents in Mass-spectrometer Gas Analyzer

The use of mass-spectrometers as automatic instruments of the industrial type creates as one of the basic problems the achievement of stability of its indication together with unchangeable overall sensitivity.

At the same time it is known that calibrating characteristics of mass-spectrometers vary with time and that repeated calibrations are necessary. In the case of automatic gas analysis, for well-understood reasons, the stability requirements of the sensitivity are considerably higher and additional corresponding measures must be taken.

One of the main reasons for the instability of a mass-spectrometer is the instability of ion currents caused by the physical processes which take place within the ionization chamber and the analyzing tube.

It is known [1] that the magnitude of the ion current depends upon the temperature of the ionizing chamber of the ion source. This is determined by the performance of the cathode of the electron gun, the external conditions, the composition of the analyzed gas, etc. In order to avoid this influence, it is necessary to control the chamber thermostatically.

The analysis of the operation of the chamber shows that its temperature instability is not the main reason for the instrument instability; at the same time, the required temperature stability (within the limits $\pm 1^{\circ}$ C) complicates the arrangement of the equipment. In this connection, the domestic mass-spectrometers of the indus-

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trial type do not use temperature stabilization of the ionization chamber.

With the passage of time, under the action of electron and ion bombardment, a semiconductor layer is formed on the metallic surfaces subjected to their actions. This phenomenon is connected with the recombination of ionized hydrocarbon molecules and their subsequent deposition on the nearest metallic surfaces [2]. The most favorable conditions for the appearance of such layers occur in the ionization chamber of the ion source and the analyzing tube. The hydrocarbon molecules can reach the vacuum system of the gas analyzer from the analyzed hydrocarbon, as well as from the oil vapors occurring when oil diffusion pumps are used.

The occurrence of semiconductor layers on the walls of the ionizing chamber can bring about a change in the effective potentials of electrodes, as compared with those which are set externally by the sources of supply. These variations can be as high as 10 v or more. As a result of this, a disruption of the focusing of the ion beam can take place.

As far as the analyzer tube is concerned, the semiconductor film formed on its surface will result, under the action of a prolonged ion bombardment, in erroneous potentials, but of somewhat lower magnitudes, because of significantly smaller densities of ion beams. However, it must be taken into account that the produced false potentials act on the ion beam along the entire length of the analyzer tube, and this increases their influence on the total instability of the output ion currents. As was shown by the experiments conducted at the Institute of Chemical Physics of the Academy of Sciences USSR, the film formed in the analyzer can result in the instability of the ion currents on the order of several percent.

The removal of the film can only be accomplished by mechanical or chemical means, and only at the time of the dismantling of the instrument. During the operation of the instrument, between the regular dismantling and cleaning, it is necessary to take into consideration the occurrence of a certain instability of the ion current due to the formation of this film.

The magnitude of the total ion current i^+ in the ionization chamber of the ion

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source is determined by the equation:

$$i^{+} = i_e^{-} p \cdot Q_i \cdot l, \qquad (1)$$

where i_e is the value of ionizing electrical current; p is the pressure inside the ionizing chamber; Q_i is the cross-section of the ionization of the investigated molecule, depending upon the energy of the electron; and l is the length of electron trajectory within the ionizing chamber.

Usually it is considered that the ionizing electrons are of the single-energy type and the magnitude of the ionizing current is measured by the anode current of the electron gun, which is stabilized by one or another means. In addition, it is considered that the negative space charge of the electron beam, although noticeably influencing the magnitude of the ion current, does not influence the stability of the ion current because it remains constant.

Actually the situation is complicated by the electron secondary emission, occurring at the walls of the ionization chamber and at the anode of the electron gun [3].

The results of experiments conducted at the IAT of the Academy of Sciences USSR established that the electron beam, inside the ionizing chamber is not of a single energy type because of the presence of the secondary emission from various surfaces of this chamber. The amount of slow secondary electrodes within the entire beam depends upon the magnitude of the magnetic field in the region of the source; in its absence this may be as high as 70%; when we have a magnetic field with an intensity of 200 oersteds, this amount decreases to 25%.

The presence of slow secondary electrons in the beam affects the magnitude of the cross-section of ionization and greatly increases the negative space potential, created by the electron beam. This leads to the disturbance of ion-optical properties of the source and from here leads to the variation of the magnitude of the ion current.

In this manner, under normal operating conditions of the ionizing chamber, there exists within the electron beam of the ion source a large amount of secondary electrons, which materially affect the magnitude of the ion current. With time, the properties

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of metallic surfaces of the ionizing chamber change as a result of the formation of various films and deposits. In addition, each time the instrument is operated, a slow degasification of the electrodes of the ion source takes place, with the result that the coefficient of the secondary emission changes. All this leads to the uncontrollable fluctuations of ion current which can reach a value of 20-30% and even more.

The magnitude of the ion current is proportional to the pressure within the ionizing chamber, which depends upon the speed of specimen supply into the ion source, on the aerodynamic resistance of the corresponding parts of the system for the supply of the specimen, and on the speed of elimination by the diffusion pump, which usually does not remain constant.

In this manner, the maintenance of a prolonged operating stability of the mass-spectrometer by preserving its sensitivity causes many material difficulties because of the impossibility of maintaining the stability of the ion current whose magnitude is substantially influenced by the uncontrollable processes which arise within the ion source and the analyzer tube.

The technical level in the area of mass-spectrometry is such at the present time that there is no hope for eliminating all these influences entirely. It is necessary to continue in the future the investigations of these phenomena in order to find further means for their complete suppression. Concurrently with this, in the design of an industrial type of an automatic gas analyzer, it is necessary to insure its stability by corresponding automatic correcting arrangements, intended for the compensation of all the detrimental phenomena, which interfere with the correct operation of the gas analyzer.

Methods for Periodic Automatic Calibration of a Mass-spectrometer

To adjust the indications of mass-spectrometers continuously and automatically, IAT of the Academy of Sciences USSR is developing a special system of periodic calibration for automatic gas analyzers of the mass-spectrometer type.

The method of automatic calibration of the instrument (standardization) is used

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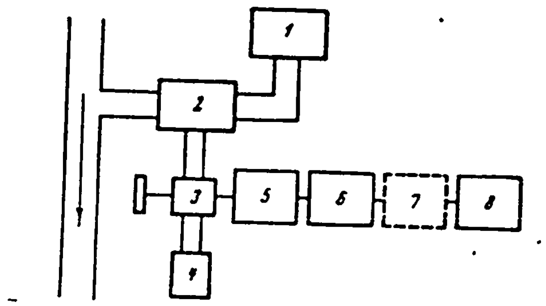

Figure 1. Block diagram of a gas analyzer with a periodic automatic calibration.

1 - vessel with comparing gas; 2 - three-way valve; 3 - supplier; 4 - pump; 5 - analyzer; 6 - ion current amplifier; 7 - automatic corrective arrangement; 8 - recording potentiometer.

very extensively in American practice; in the Soviet Union it has been used in isolated cases, where it gave definite positive results.

The method of a periodic calibration proposed by IAT of the Academy of Sciences USSR is shown in Figure 1. The gas analyzer is supplied with a vessel 1, containing a comparing gas of constant and known composition. At predetermined time intervals the gas analyzer is disconnected automatically, with the aid of an automatic valve 2, from the line of the controlled product of production and is connected to the vessel containing the comparing gas with a composition close to that of the controlled-product.

After the recording of the partial spectrum of the comparing gas, the instrument is reconnected for the control of the production product. The fixed initial recording of the composition of the comparing gas and of the controlled product makes it possible--each time during the interpretation of the records--to use the scale coefficients from the preceding recording of the comparing gas and thus eliminates the errors accumulating during the time between periodic calibrations.

During the comparative tests of the mass spectrometer for the five masses of PGU, using the calibration system with a standard gas, as well as without it, noteworthy positive results were obtained, as shown in Table 1. (The comparator gas was the PGU gas of known composition.)

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Table 1

Components	m/e	10 hours			11 hours			12 hours			15 hours			16 hours			17 hours			Average Coefficient, K_{av}
		Relative Error, %									Relative Error %									
		Without correction	With correction	K*	Without correction	With correction	K*	Without correction	With correction	K*	Without correction	With correction	K*	Without correction	With correction	K*	Without correction	With correction	K*	
H_2	2	0,75	0,75	1	6,3	1,6	4	24	5,8	4,1	3,6	1,45	2,5	7,7	3,07	2,5	13	2,9	4,5	3,5
N_2	14	4,8	4,8	1	5	0,84	6	3,65	0,66	5,5	10,0	1,44	4,7	7,7	3,65	2,1	1,67	0,33	5	4,7
CH_4	15	3,7	3,7	1	8,7	1,45	6	12	5,0	2,4	12,4	0,35	36	2,9	1,45	2,0	17,4	2,45	7,1	10,7
O_2	32	35	35	1	40	36	1,1	12	2,6	4,6	40,5	24,5	1,65	64	53	1,2	15,5	9,1	1,7	2,06
CO_2	44	9	9	1	10	9	1,12	8,5	1,7	5	7,4	2,28	3,25	6,6	2,2	3	2,85	5,7	5	3,45

* K – Coefficient of the decrease in error.

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As we can see from the table, the use of correction from the automatic calibration reduced the errors of each measurement by 7 times on the average.

The development of this method is due to the use of special schemes and arrangements, which insure an automatic correction of the instrument and maintain the scale coefficients (of sensitivity) constant at all times.

For this purpose, the device 7 is connected to the amplifier output of ion currents, which is able to change at the time of calibration the sensitivity of the entire measuring instrument sufficiently so that, independently of the instability of the ion current, the signal at the output of the analyzer tube, supplied to the input of the receiver of the measuring device, will remain constant and equal to the value preset beforehand. At the end of such a calibration, the preset sensitivity of the mass-spectrometer gas analyzer will remain unregulated for the entire time interval between the consecutive calibrations. As a result, the maintenance of the required scale constant in the given case is accomplished automatically.

It is difficult to determine in advance the time necessary for this automatic calibration, because the instability of the mass-spectrometer still possesses an individual character. This can be done only with the help of corresponding tests of the instrument by means of numerous recordings of the spectrum of the analyzed gas. The installation must, however, allow for the establishment of different spans of time for such a calibration.

Such an automatic correction consists in the automatic maintenance of a constant magnitude of the mass current of the comparing gas, which is supplied to the instrument at the time of the automatic calibration. To accomplish this, it is necessary to have an amplifier which is capable of automatically changing its sensitivity sufficiently so that its output signal will remain constant independently of the instability of the ion source. The sensitivity of the entire instrument established in this manner must be "remembered" until the next cycle of calibration.

The arrangement of such an installation is shown in Figure 2.

In order that the calibration of the instrument indications may be made compar-

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atively quickly, it is necessary to insure a rapid and complete changeover from the investigated gas to the comparing gas and conversely. This can be achieved by a special admitting system of sample selection, one variation of which is shown in Figure 1. The given arrangement provides only for the viscous supply of the gas into the ion source.

In the case under examination, the selection of the sample is carried out by an uninterrupted suction of the gas through the automatic three-way supply valve; a small amount of this sample is drawn into the ion source. The suction can be applied to the gas pipe with the controlled gas as well as to the vessel with the comparing gas. The required switching is done with the aid of special electromagnetic

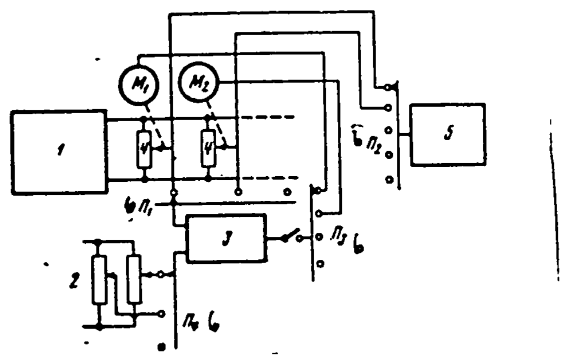

Figure 2. Amplifying arrangement of the mass-spectrometer gas analyzer.

1 - amplifier of ion currents; 2 - setting potentiometers; 3 - servoamplifier EU-18; 4 - calibrating potentiometers; 5 - recording potentiometers; 6 - P_{1-4} plates of the searcher ShI-50.

switching valves of the solenoid type having an operating time of 0.1 sec. The complete automatic switching of the instrument takes from 2 to 3 sec.

Figure 3 shows a variation of the input system with a small expenditure of the comparing-gas and with molecular feeding of the sample into the ion source. In the given arrangement the valves K_1, K_2, K_3, and K_4 are automatic small size of low-vacuum type, developed at the IAT of the Academy of Sciences USSR.

The system provides for a periodic picking of a portion of the gas from the pipe. When the valve K_1 is opened, the volume between valves K_1, K_2, and K_3 (a few cubic centimeters) is filled instantly with a pressure equal to that of the pipe, because

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the entire system, has been evacuated beforehand by the vacuum pump with K_1 and K_2 closed and K_3 and K_4 opened. When the vacuum is reached ($2\text{-}3 \cdot 10^{-2}$ mm of mercury column) K_3 and K_4 are closed. When the intercepted volume is filled, K_1 is closed and K_2 is opened; the volume thus intercepted now expands in the supply chamber from where the gas begins to enter the ion source. With this expansion the pressure of the gas drops to a value of a few millimeters of the mercury column, thus resulting in a molecular type of supply. To change the sample, the valves K_3 and K_4 are opened and the gas is pumped out by the vacuum pump. In order to admit the comparing gas into the instrument, valves K_1 and K_2 are interchanged. In constructing the admission

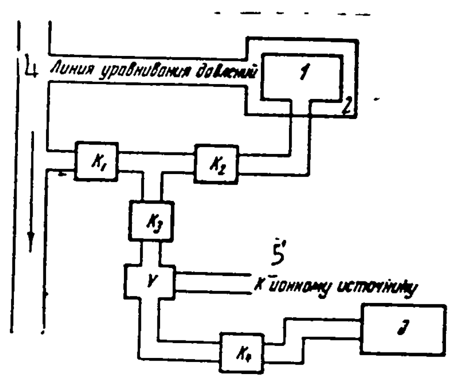

Figure 3. System for the admission of a picked sample.

1 - elastic container; 2 - hermetic container; 3 - vacuum pump; K_{1-4} - remote-controlled valves; V - supply volume; 4 - pipe for pressure equalization; 5 - to ion source.

system it is necessary to take into account the fact that, to insure a correct calibration of the mass-spectrometer, it is necessary to maintain the pressures of the analyzed and of the comparing gas equal. However, there is no necessity to have them constant all the time; but care should be taken that, during the calibration, the pressure does not change appreciably. If the maintenance of equal pressures for some reason becomes difficult, it is possible to maintain a constant ratio of these pressures.

As a comparing gas, it is desirable to select a gas which is close in composition to the analyzed gas and which has all the components of the latter. The comparing gas must be available in a sufficient quantity to insure periodic calibrations during a prolonged time. From this standpoint, the determination of the possible use of air as a comparing gas is of great interest. It is true that in this case limitations and certain difficulties arise; however, the convenience of such an application becomes very evident.

Computing Installation for the Determination of Component Parts of the Controlled Multicomponent Mixtures

The system of equations which must be solved in determining the component parts of the controlled mixtures by measuring their masses, is written in the following manner:

$$A_j = \sum_{i=1;\, j=1}^{i=n;\, j=n} a_{ji} x_i, \qquad (2)$$

where A_j is the directly measured peak of the mass, a_{ji} is the scale of each mass spectrum, determined at the time of calibration; x_j is the value of concentration of the j-th component of the controlled mixture. The solution of this system for the value of x_j results in the equality

$$x_j = \frac{\Delta j}{\Delta}, \qquad (3)$$

where

$$\Delta j = \begin{vmatrix} a_{11};\ a_{12}; \ldots\ldots A_1 \ldots a_{1n} \\ a_{21};\ a_{22}; \ldots\ldots A_2 \ldots a_{2n} \\ \cdots\cdots\cdots\cdots\cdots \\ a_{n1};\ a_{n2} \ldots\ldots A_n \ldots a_{nn} \end{vmatrix} \qquad (4)$$

$$\Delta = \begin{vmatrix} a_{11};\ a_{12};\ a_{13} \ldots\ldots a_{1n} \\ a_{21};\ a_{22};\ a_{23} \ldots\ldots a_{2n} \\ \cdots\cdots\cdots\cdots\cdots \\ a_{n1};\ a_{n2};\ a_{n3} \ldots\ldots a_{nn} \end{vmatrix} \qquad (5)$$

After carrying out the solution for all components of the multicomponent mixture, we obtain as a result the following system of equations

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$$\left.\begin{array}{l} x_1 = \sum_{j=1}^{n} C_{j1} A_j \\ x_2 = \sum_{j=1} C_{j2} A_j \\ \cdots\cdots \\ x_n = \sum_{j=1}^{n} C_{nj} A_j \end{array}\right\} \qquad (6)$$

where C_{ji} is the function of coefficients a_{ji}.

The solution of each equation is obtained from the computer through the use of a single summator (solver amplifier) with the use of variable resistors for the setting of coefficients. The switching of resistors going from one equation to another must be done automatically. If, in addition, a recording device is connected to the output of the summator, it will register on the diagram the values of x_1, $x_2, \ldots, x_n$ after a definite time interval.

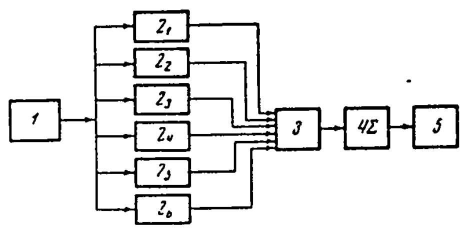

Figure 4. Blocks of computing installation with manual setting of input data.

1 - block for manual setting of data input; 2 - blocks for setting coefficients; 3 - solution transfer switch; 4 - summator; 5 - recording device.

This type of computer can be made in two versions.

1. Computing Device with Manual Setting of Input data.

This device consists of an individual stand on which are manually set the values of input potential resistors in accordance with the obtained records of the controlled masses from the mass-spectrometer (values of A_1, A_2, etc.).

The structural arrangement of such a computing device for the recording of six masses (six equations) is shown in Figure 4. Here blocks $2_{1,2,\ldots,6}$ are intended for the setting of resistances R, in accordance with coefficients C_{ji}, which are determined each time in accordance with the controlled gas mixture. The scale coefficients,

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in determining the resistances for the computer, are selected in such a way that any summation of potentials, appearing at the output of the solver amplifier (summator), will be within the allowable limits (in particular within the limits of 10-100 v). A recording device is installed at the output of the solver amplifier to measure the electric potential (specifically, EPP-09).

2. Automatic Computer Block, Built into the Automatic Gas Analyzer of the Mass-spectrometer Type

The computing arrangement with an automatic input of data in accordance with the value of the ion current, appearing at the output of the analyzer tube, differs from the manual computer by the presence of a special input block. This block includes a condenser memory device and a device for the synchronization of pulses.

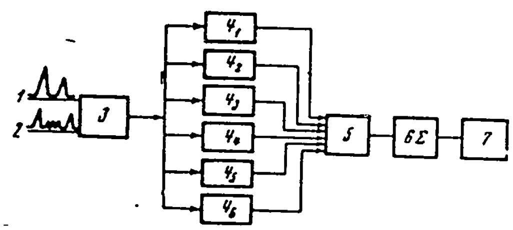

Figure 5. Blocks for setting coefficients and their signs in an automatic computer.

1 - input channel for peaks; 2 - channel for the synchronization of pulses; 3 - memory block; 4_{1-6} - blocks for setting of coefficients; 5 - solution transfer switch; 6 - summator; 7 - recording device.

Within the condenser memory device, the pulses which come from the intermediate amplifier as a series of individual peaks are sequentially remembered on individual condensers.

The synchronizing device distributes the received signals to the individual condensers according to a predetermined order. After the last, the sixth peak, has been memorized (the memorizing process is equivalent to the data setting in the manual computer), the solving process begins with the starting of the step-by-step switch. This process of solution does not differ in principle in any way from that of the computer with manual data setting. From this point on, the remaining part of the structural arrangement does not differ in any way from the corresponding part of the first version, as we can see from Figure 5.

Figure 6 shows the schematic arrangement of an automatic gas analyzer of the mass-spectrometer type, which incorporates all the above-mentioned considerations. The instrument is intended for the control of any six masses within the limits of 1 to 100 in accordance with the controlled multicomponent mixture.

The setting of the masses to be controlled is accomplished manually each time during the adjustment of the gas analyzer for the particular mixture to be controlled. A computer block can be included in this arrangement, the a recording device registers

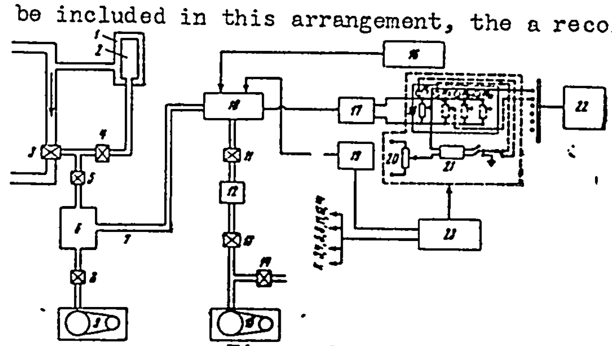

Figure 6.

1 - hermetical container; 2 - elastic container with comparing gas; 3, 4, 5, 8, 11, 13, 14 - remote-controlled valves; 6 - supply volume; 7 - diaphragm; 10 - analyzing tube with an electromagnet; 12 - diffusion pump with a trap; 9, 15 - vacuum pump; 16 - supply regulators; 17 - ion current amplifier; 18 - calibrating potentiometers; 19 - scanning arrangement; 20 - setting potentiometer; 21 - servoamplifier; 22 - recording potentiometer; 23 - controlling device.

directly the components of the gas mixture. It is also possible to disconnect this block from the instrument and to connect the recording device directly to the input of the intermediary amplifier.

In this case we obtain a record in the shape of a mass-spectrogram. The input system of the instrument is automated and provides for a periodic input into the instrument of the comparing gas under a pressure equal to the pressure in the controlled pipe. This is insured by placing the comparing gas into a soft container of the oxygen pillow type which is located in a hermetical compartment, connected with the inlet of the sample. The automatic picking of a portion of the analyzed gas is accomplished with the aid of small solenoid valves developed by the Institute of STAT

Automation and Telemechanics. The operating order of valves is shown above.

When a portion of the gas has been picked through a sudden change of the current in the electromagnet, the six selected masses are recorded, whereupon a smooth scanning takes place within the range of the single peak to determine its height accurately.

At the end of the recording of the last peak, the input system changes the sample by means of the already described means, and the control cycle repeats itself. After a predetermined number of control cycles, the comparing gas is admitted into the instrument by opening the valve K_2. This requires a negligible amount of the comparing gas, determined by the volume between the valves K_1, K_2, and K_3. Now, in order to adjust for the selected masses, it is necessary to set the sensitivity for each mass by means of the six rheostats with induction drives. For the automatic setting, the signal from the mass-spectrometer is memorized at its peak value. After this the slider on the rheostat changes its position with the aid of a servoamplifier until the potential on the rheostat becomes equal to the potential on the comparing potentiometer, manually set. At the end of the automatic setting of sensitivity for all masses, the instrument again admits a portion of the controlled sample in accordance with already described method and so on.

Inasmuch as the vacuum section of the instrument must be controlled remotely, IAT of the Academy of Sciences USSR undertook the development of automatic low-vacuum and high-vacuum valves. At the present time, IAT of the Academy of Sciences USSR has developed vacuum valves of the solenoid type with rubber packing; the through opening has a diameter of 7 mm which insures a reliable shutting-off of the system from the atmosphere.

High-vacuum automatic valves have also been developed and produced with an opening diameter of 30 mm in two versions: with metallic and with rubber packing.

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Address

by Comrade P. Ye. Rybchinskiy

Because of the high cost of mass-spectrometer analyzers (on the order of 30,000 rubles in massproduction), their use will be justifiable only in those industries where they will result in substantial savings, in particular in the production of artificial alcohol and in the manufacturing of ethylene oxide. In this last case, it will be possible to reduce the employed personnel from 100 to 30 persons.

Since the extent of such industries is compartively limited, it will be desirable, at least for the present, to design mass-spectrometers, not of the universal type, but for special applications, calculated for the control of definite types of production.

The accuracy of analysis, amounting to 2 to 3%, is suitable for present-day chemical production; thus the various complicated features introduced into the mass-spectrometer by IAT in order to increase the accuracy are, in my opinion, not justifiable. In addition, I do not consider desirable the division of the instrument into two parts: the analytical block and the electrical block.

Address

by Comrade R. I. Stakhovskiy

The present-day state of mass-spectrometer technique does not allow a long-time (weeks, months) stability of ion currents, required for an industrial instrument used in automatic control. It is possible to obtain 2 to 3% only for a few days. After this, a new calibration of the instrument is required. Because of this, the automatic calibration allows for the increase in reliability and accuracy of the instrument. Inasmuch as a mass-spectrometer is quite a large and cumbersome instrument, the addition of one block for the automatic correction does not change the

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structure of the instrument, and also does not change in a noticeable manner i[illegible] complexity and its dimensions. In addition, this block can be made removable and can be taken out if it is not needed.

For production cases, where a mass-spectrometer must be located immediately at the place where the sample is taken, it is wise to have two blocks; in addition, the electronic part of the instrument must be put in a binding where there are no corrosive media.

The vacuum part of the instrument can be controlled remotely.

* * *

In a concluding address, B. S. Sotskov, chairman of the session, informed the gathering of the content of the draft resolution, in particular, about the proposed organization of the Scientific Council on Automation attached to the Presidium of the Academy of Sciences USSR, which will be charged with the coordination of scientific investigations in the field of automation. B. S. Sotskov also announced that a series of special consultations will be conducted next year, concerning semiconductors, magnetic amplifiers, and contactless elements, and concerning the problems of regulation, etc.