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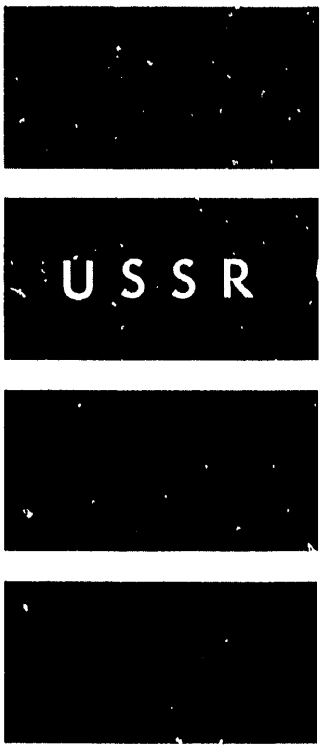

TRANSLATIONS ON USSR SCIENCE AND TECHNOLOGY

PHYSICAL SCIENCES AND TECHNOLOGY

(FOUO 27/79)

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TRANSLATIONS ON USSR SCIENCE AND TECHNOLOGY
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CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

UDC 681.324

THE MOST IMPORTANT METHODS OF INCREASING THE EFFECTIVENESS OF UTILIZING COMPUTER TECHNOLOGY

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 2, Mar/Apr 79 signed to press 3 Jan 79 pp 1-2

[Article by B. N. Petrov]

[Text] The development of computer networks and collective-use systems is the most important step on the path of solving the problem of increasing the effectiveness of utilizing computer equipment, posed by the 25th CPSU Congress.

The use of computers at the USSR Academy of Sciences and of the academies of sciences of the union republics is related to a significant degree to automation of scientific research. Investigations to develop systems for automation of scientific research are now being conducted on a broad front. It should be emphasized that scientists of the academies will be involved for a number of years with problems of developing fundamental research in the field of computer technology, instrument building and control equipment in the interests of increasing labor efficiency. Development of collective-use computer systems and computer networks within the USSR Academy of Sciences and of the academies of sciences of the union republics must be regarded as the next step related to automation of scientific research.

Problems of coordinating the indicated investigations and of integrating efforts in solution of the problem of automation of scientific research acquire primary significance. A special meeting of the presidents of the academies of sciences of CEMA countries was devoted to this. Taking into account the importance of effective coordination of investigations on computer technology within the system of the academies of sciences of our country, the Presidium of the USSR Academy of Sciences decided to create a Coordinating Committee on Computer Technology. Its main task will be coordination of investigations on fundamental problems of modern science and technology, related to development of highly productive computers, computer networks and the technical base of computer equipment.

There are definite successes in the direction of developing collective-use computer systems. Computer centers equipped with both highly productive computers and small machines have been created at many academic institutes. There is good experience of collective use of computer equipment at the USSR Academy of Sciences, the Siberian Department of the USSR Academy of Sciences, at the Ukrainian SSR Academy of Sciences, the Latvian SSR Academy of Sciences and so on.

To discuss the coordination problems which we face and the information about the experience available in this direction, a coordinating meeting of the representative delegations of the USSR Academy of Sciences and of the academies of sciences of the union republics, with the general designers of YeS and SM computer systems and of the El'brus computer complex being invited, was held in 1978 at the Institute of Electronics and Computer Technology of the Latvian SSR Academy of Sciences. Reports on the experience of constructing collective-use computer systems in the leading organizations of the academies of sciences and about the latest YeS and SM computer equipment and the equipment of the El'brus computer complex were heard at the conference. Among them were reports of the leading scientists in this field -- academicians G. I. Marchuk and V. M. Glushkov, Academician of the Latvian SSR Academy of Sciences E. A. Yakubaytis, general designer of the El'brus computer complex V. S. Brutsev, general designer of the YeS EVM [Unified computer system] V. V. Przhiyalkovskiy and deputy chief designer of the SM EVM [International Small Computer System] Y. N. Filinov. A report containing a survey of the advances of foreign scientists in this field (project manager of the International Institute of Applied Systems Analysis A. V. Butrimenko) was also heard.

Materials of part of the reports and communications presented at the conference are published in the given issue of the journal AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA.

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CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

UDC 681.324

PROBLEMS OF COMPUTER TECHNOLOGY AND FUNDAMENTAL RESEARCH

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 2, Mar/Apr 79
signed to press 21 Apr 78 pp 3-14

[Article by G. I. Marchuk and V. Ye. Kotov]

[Text] Within the very short time that has passed since the first Soviet electronic computer MESM [Small Electronic Computer] was developed under the supervision of S. A. Lebedev, computer technology has undergone a vigorous jump, being transformed from laboratory experiment to a branch of industry and has become an important component of the scientific-technical revolution. A new stage in its development has now begun. The needs of our country for data processing and automation equipment are increasing with each year, which requires a qualitatively new approach to planning the development of computer technology and to methods of development, production and application of computers. The basis of this approach should be scientific justification of all the decisions made on the basis of extensive fundamental investigations of the mathematical, systems-engineering and physical bases of data processing.

The general trend in the development of computer technology is characterized by a qualitative increase in the level of its production and application and includes:

a radical increase of the total productivity of computers by improving the engineering and technological base and of essentially new architectural concepts;

development of more effective forms and methods of man-machine interaction due to a significant increase in the level of programming languages and developed communications software and hardware;

conversion from powerful and medium monolithic machines of traditional structure to an optimum combination of "individual" computers with limited or special capabilities and of computer complexes of various configurations, wide range of capacities and designations.

The succession of computer generations is primarily initiated by the progress of the physics and technology of the component base, which improves such technical parameters of machines as speed, dependability, compactness and economy and thus permits embodiment of the ideas of engineers and programmers in machine designs which could not be realized by using previous technology. Along with improving the physical-technological parameters of the component base, the development of software was the main means of increasing the total computer utilization efficiency up to the present time. But in the final analysis the decisive factor which determines the capabilities of computer technology is the configuration of machines and systems.

The progress of microelectronics, the prospects for developing new physical principles of data storage and processing and the advances of programming and theoretical research in the field of computer structures have now laid the basis for practical postulation of the problem of working our new principles of organizing computer systems and processes. This task becomes especially timely because the range of problems which require qualitatively new methods of data processing and storage will increase rapidly and the fraction of complex problems will increase.

The component base of computer technology. The current state of development and production of computer logic elements is characterized by production of a series of integrated systems with signal distribution delay measured in units of nanoseconds. A further increase in the speed of logic components requires solution of the problem of intercomponent coupling, i.e., an increase in the level of integration with a simultaneous decrease of the mean consumed power to the gate.

Semiconductor storage devices are developing at rapid rates: from superhigh-speed storage devices based on logic elements to massive storage devices based on the simplest structures.

The most promising of the new physical-technological principles of developing the computer component base are opto-electronics and integrated optics. Opto-electronic components and devices will find ever greater application in computer technology, for example: in superlarge-capacity storage devices, in specialized analog and hybrid (analog-digital) processors for image processing, fast integral transformations and so on, and in using data input and imaging devices and multichannel data-image transmission devices.

The problem of developing an opto-electronic internal storage, for which there are now no appropriate information carriers despite the fact that a search for them is being carried out in many directions, is interesting and complex.

Development and improvement of computer devices based on integrated circuits, including optical data processing and transmission systems, require the creation of new technological equipment and the development of production processes, specifically, electronic and X-ray lithography and the technology of growing superthin semiconductor structures by the molecular-beam epitaxy

method, which leads to a significant increase in the level of integration and to stabilization of component characteristics.

Investigations and introduction of a new type of group memory -- magnetic domain storage devices, specifically, bubble domains -- are being carried out intensively. This memory should replace magnetic disks and drums, but there are still difficulties in the path of its development, overcoming of which also requires essentially new technology.

The problem of utilizing cryogenic effects in computer technology is of interest. On the one hand, cryogenic technology is now a unique technology where there are no essential physical restrictions for a significant increase of speed, dependability and the number of components. On the other hand, many specialists are carefully evaluating the possibility of bringing this principle up to practical introduction; in any case, any predictions in this field are difficult and this problem requires additional study.

Finally, the possibility of utilizing biological principles of data storage and processing, which may be promising due to the high viability, adaptability and energy economy of biological systems, should be noted.

It is anticipated that the realization of scientific programs in the field of the computer component base and introduction of the results of investigations will make it possible to develop by 1990 processes with productivity from 10^7 operations/second (universal) to 10^9 operations/second (superhigh-speed and specialized), superfast internal stores (OZU) with access time of 10 ns (capacity up to 10^4 bytes) and superlarge OZU with capacity of 10^8 bytes (access time of 1 microsecond) and external stores with capacity of 10^{10}-10^{12} bytes.

But the main effect of microminiaturization is those qualitative changes in the concept of "computer component" itself, which lead to radical expansion of its functional capabilities and fundamentally alter the methods of logical design of machines and their structure, rather than new quantitative parameter of devices. The appearance of microprocessors and their application as baseline design elements of computer devices and complexes is the first indicator of these changes and the first step on the path to development of an essentially new technique of the production and use of computer technology.

The architecture of computer complexes. A new jump in the qualitative increase of the component base alters the established concepts on the architecture of computers. The classical structure of computers is maintained in micro- and mini-machines. Any other functionally closed structural unit of future computer technology may be arbitrary, suitable for a given application or configuration and made up from diverse computer equipment. The range of these configurations is very wide: from individual machines at operator's positions to a network of powerful computer subassemblies dispersed throughout the country. Their range of possible applications and specialization is even broader. As an example one can name the following

computer complexes which have already been designed and developed: large information-computer complexes (state, regional and specialized computer networks and collective-use computer centers), integrated real-time systems (object and process control systems, scientific research automation systems and so on) and powerful universal and specialized computer systems (including those based on mini-computers and microprocessors).

The characteristic factures of future computer complexes must be noted: their functional and structural complexity, the large number of diverse components with complex interactions between them, increased requirements on the dependability of equipment and software, long lifetime and consequently special requirements on the compatibility of devices and programs and the capability of reconfiguration and adaptability to problem areas and changes in the modes of use.

The increasing complexity of the architecture of computer complexes requires an increase in the periods of working out the designs and volumes of material expenditures and recruitment of large collectives of highly qualified specialists. Successful implementation of these requirements is possible only with organization of a wide range of leading fundamental research in the field of the architecture and baseline software of complexes and of the computer equipment contained in them.

The classical architectural problem is development of baseline principles of constructing the main components of computers -- processors, memory, exchange devices and means of communicating with the machine. The main goals of research are an increase in the productivity of these devices and expansion of their functional capabilities with a simultaneous reduction of cost.

New principles of designing highly productive processors -- conveyor (mainline), associative, parallel matrix and so on -- are investigated most actively. These processes provide acceleration of calculations and present new functional capabilities both for organization of intrasystems processors (working with a virtual memory, processing interruptions; the protective mechanism, process planning and so on) and for applied problems (matrix calculations, solution of differential equations, linear programming, sorting and information retrieval and so on). The developers of these processors are now oriented toward microprocessor equipment, which permits realization of ever more complex structures. Another promising trend is the development of hybrid, analog-digital processors, including opto-electronic processors, which are very useful in processing two-dimensional data and image structures, for making rapid integral transformations and so on. The variety in the types of processors oriented both toward specific problems of users and toward special intrasystems operations: exchanges, control of resources, process planning, translation and so on, will increase as the new technology of the component base is developed, as the sphere of computer application expands and as the configurations of complexes become more complicated. It becomes necessary in this regard to develop special "machine arithmetics" and methods of converting algorithms and data to a form suitable for processing in special processors.

An increase in the capacity of storage devices forces new postulation of the problem on methods of reducing storage access time. On the one hand, the sharpness of competition is weakened due to storage resources, the possibility of data duplication and storage of copies of them at different points of the system appear. On the other hand, a sharp increase in storage capacities increases the necessary data retrieval time; therefore, investigating the methods of organizing a deeply and flexibly structured storage, introduction of parallel and associative access and apparatus methods of data distribution and protection are required.

An increase in the dependability and speed of information exchange, especially in distributed computer complexes, requires solution of diverse problems related to development of switching subassemblies and transmission lines: integration of various types of apparatus, reception and transmission of data arriving at different speeds, support and monitoring of message authenticity, organization of a flexible topology of dynamic communications and so on.

The forms of user contact with computer complexes will become more and more diverse and adequate to the spheres of application; they will be strengthened by development of intellectual terminals, data input-output visualization devices and other hardware (photocollecting devices, speech information input-output devices, recording and monitoring apparatus, means of coupling to telegraph and television channels and so on). The use of built-in microcomputers essentially reduces the problem of intellectual terminals to one of specialized machines oriented toward the process of communications. Problems whose nature is determined by the specifics of these devices arise for other devices.

The problem of a radical increase in the total productivity of computer complexes requires investigation and development of new principles of their structural organization. The basis of these principles should be rational combination and nonparallel functioning of all components, activation or "intellectualization," primarily of passive devices -- storage, communications channels, external equipment and so on, and decentralization of information flows and optimum separation of labor between special subsystems and processors.

Microelectronics imparts a new nature to the problem of the dependability of calculations. It can be solved with the simultaneous use of a large arsenal of methods and procedures, including sufficiently linear methods. Special processors built-in at different points of the systems will carry out the majority of operations related to checking, statistics and correction of the calculation process.

The stable trend toward increasing the level of machine languages and operating systems while retaining the effectiveness of calculations must be strengthened by investigation and development of methods of determining adequate virtual levels and improving methods of mapping onto each other and onto physical resources.

A timely problem is study of the architectural variants of complexes oriented toward different modes of application -- time-sharing, real-time operation, information retrieval and so on.

Providing specialization and adaptability to problem areas requires the development of a rich nomenclature of specialized data processing and storage devices, "programmability" of subsystems and devices for specific operating conditions and algorithms due to microprocessor equipment and development of the principle of dynamic rearrangement of the configuration of the complex as a whole. Problems related to automation of algorithm and program "translation" to equipment with regard to special requirements on the optimality and correctness of selected decisions arise at the juncture of systems programming and computer design.

The basis of all the applied architectural investigations should be the developed mathematical theory of analysis and synthesis of computer structures. The development of formal methods of describing the structures and data processing processes occurring in them is primarily required; languages of structural specification and methods of justification and automation of the synthesis of promising machines and complexes should become the applied result.

The role of modeling and optimization of computer structures and processes, specifically, modeling of large distributed complexes -- computer networks and collective-use computer centers -- is increasing. Conducting theoretical investigations is a necessary condition for further development of methods of complex automation of designing computer equipment at all levels. The problem of experiment, mockup and instrumental equipping of scientific research work in the field of architecture must be sharply brought to light due to the increasing complexity of projects.

As a whole, investigations of architectural problems should lead to development of well-founded methods of designing diverse computer complexes in which the equipment and software are efficiently utilized and in which high total efficiency in each of the fields of application is achieved.

Programming. Active investigations begun in the 1950's in the field of programming automation terminated in development of high-level algorithmic languages which considerably increase the labor productivity of programmers. In the 1960's, programming took on itself the problem of increasing the efficiency of computer use by organization of multiprogramming, resource and exchange management and coordination of the functioning of various computer components. The attention of programmers is now concentrated on increasing the quality of software, its efficiency and dependability, and in improving the program production technology. Investigations are continuing to increase the level of languages for communicating with the computer, including development of problem-oriented and systems programming languages. The effect of ideas and experience accumulated in programming on the architecture of equipment is becoming intensified and programmers interact actively with the developers of computers.

Investigations on the mathematical theory of machine calculations -- from individual problems of programming automation and optimization solved by methods of the theory of algorithms, automatons, algebra and logic theory -- have achieved considerable development, an independent scientific discipline was formed and Soviet scientists made an important contribution to establishing it. (However, attention to theoretical programming problems has recently decreased somewhat in our country, which is especially discernible on the background of the quantitative and qualitative growth of these investigations abroad).

The development of computer technology evoked vigorous progress of computer mathematics. Unique algorithms and methods of solving important applied problems have been developed and justified. This makes it possible to successfully pose and solve large and complex problems which require considerable storage capacities and solution time with more linear approaches.

Among the general trends in development of computer technology and spheres and methods of using it mentioned above should be noted those which primarily determine the main trends of investigations in the field of programming.

1. A significant increase in the output of computer systems, speed of calculations and storage capacities and the multicomponent nature and parallelism in large information-computer complexes -- centralized and dispersed multiprocessor systems, computer networks and collective-use computer centers.

2. The complex nature of problems in integrated data processing systems which include large volumes of calculations, information retrieval in large data bases and complex logic derivation. These integrated systems may include automated control systems, including control systems for production complexes and complex objects, scientific research automation systems, models of complex multicomponent dynamic systems and economics, meteorology, geophysics and so on.

3. Development of special data processing and storage equipment -- matrix and hybrid processors for processing two-dimensional data and image structures, associative memories and so on.

4. General expansion of the spheres of applications of computer technology and as a result a sharp increase in the number of users which cannot be related to the category of professional programmers.

Having added to this the internal trends of programming, one can formulate the main scientific problems in this area.

One must primarily develop programming theory in the direction of creating effective methods of describing interacting parallel processes. The applied results of this theory should be languages of the specifics and programming of complex dynamic discrete systems (for example, computer and operating

systems and production models) and parallel languages for multiprocessor computers which provide effective and dependable programming.

The boundaries of further increasing the effectiveness of programs depend significantly on the level of those theoretical investigations of the structural and semantic properties of programs and programming languages which are aimed toward optimization of machine calculations, global and dynamic dispersion, automation of debugging and program synthesis. These sections of programming theory have already become classical and it is important not to reduce the rates of investigations, harmonically combining their fundamental and applied directions.

Computer methods should be developed with regard to new capabilities offered by promising computer technology. A timely problem is development of parallel algorithms, methods of processing multidimensional data and image structures and methods of hybrid calculations.

The achievement of new positions in programming automation is related to the development of languages and superhigh-level systems based on abstract data structures, control structures and generalized operators. They become the basis for the software of "intellectual" operating systems and problem-oriented packets of applied programs, including packets with elements of artificial intellect and verbal means of communicating with computers on the basis of natural languages. The problem of packets is extremely timely and complex; it is an essentially complex problem and coordinated efforts of systems and applied programmers and also of specialists in problem areas are necessary to solve it, but the decisive factor is still the systems base of packets.

The difficulties in the path of developing large programs have already reached such dimensions that problems of programming technology require the most careful attention. This problem is also complex and touches all steps of programming -- from the rules of specification of assignments to debugging methods -- and taking into account all aspects of programming -- theoretical, language, methodological and organizing -- is required to solve it. The first steps in this direction have already been made within the framework of investigations on systems for constructing translators and checking the correctness of programs and methodologies of structured, systematic and collective programming. A complex program of investigations is necessary which would permit practical realization of the problem of "industrialization" of program design within the shortest possible periods.

The structures of computer systems. The component base of machines has changed twice qualitatively during development of computer technology, the methods of communicating with computers have changed significantly, peripheral equipment has become considerably more abundant and diverse, but the structure of the nucleus of the machine (processor, internal storage and control) has changed to a lesser extent, which, however, does not mean that new principles of organizing computers and calculations have not been advanced during this period. Thus, beginning with the second half of the 1950's, the idea of

parallel data processing began to be discussed and studied and powerful fourth-generation multiprocessor computers were designed and constructed. Two groups of systems -- universal large computers with small number of powerful processors and specialized "giants" with parallel matrix processors -- can be distinguished among the multiprocessor computers. However, neither one nor the other exhausts all the variety of forms of parallelism inherent to the problems solved and to the process of machine calculations itself. Systems of the first type mainly realize the concept of parallel processes arising in operating multiprogramming systems. Systems of the second type are constructed on the principle of vector or matrix parallelism, i.e., simple parallelism of completely independent calculations.

Until quite recently, there was no generally accepted concept of the architecture of a promising universal computer system in which the already known principles of parallel calculations would be sufficiently fully realized. The situation has now changed. First, a large volume of theoretical investigations of parallel methods of data processing has been conducted. A "critical mass" of investigations was formulated in which both general problems of organizing multiprocessor systems and specific variants of structures are considered. Second, some practical experience in achieving parallelism at different levels of calculations has been accumulated: at the level of microoperations, at the level of parallel processes in operating systems, in simulation problems and so on. And, finally, the progress of microelectronics, which assimilates serial production of large integrated circuits and microprocessors based on them, permit one to realize many concepts, previously seeming hardly realizable, new ideas are advanced and one is forced to reconsider the established concept of the principles of machine data processing. Moreover, microelectronic equipment provides transition to broad experiments in the field of computer system structures.

The outlines of future computers are being drawn more clearly. Transition to the new architecture is occurring not as a result of an unexpected jump, but will be an evolutionary development of those principles which already play an appreciable role in late-generation machines. The combination and interaction of these principles leads to qualitative changes in architecture. Rather than making a survey of existing and predicted variants of systems or of classifying them in a specific manner, let us formulate the main principles which determine the characteristics of the structures of future systems and the nature of the calculating processes in them. Justification of these principles is investigations of the last few years and analysis of plans for future computers and trends of development of computer technology and programming.

The parallel nature of data processing devices and processes. This principle is fundamental for computer systems, especially with regard to processors and calculations. Parallelism in systems is being developed in two directions. First, control devices and processes (for example, dispersed control), data storage devices and access to data (dispersed memories, multiaccess memory and so on) will become ever more parallel. Second, the variety of types of parallelism and the methods of optimum combination of them will increase. The

significance of dispersing data storage and optimum location in the system is especially acute, since a simple increase in the number of parallel processors rapidly exhausts the reserves for increasing productivity and access to data becomes a critical factor.

System decentralization and dispersion of processes, data flows and control. All components of a system will participate to a greater degree than now in control of processes and will store and autonomously process data. In the general case they will become more universal and homogeneous in their capabilities (an example of a device of this type is the processor-storage).

Specialization and the "programmability" of individual components and subsystems. Simple standard subprocessors for data processing may be realized by using microprogram equipment and more complex or specific subprocesses can be realized by using special processors and devices. Finally, complex or readjustable processing functions can be turned over to microprocessors or to programmable subsystems. Specialization touches both user processors and intrasystems operations. The latter is of special interest from the architectural point of view and supplements the principle of decentralization.

Asynchronism of control and exchange of information in a system, which permits similar and effective means of dynamic adjustment for special cases of organizing the computer process, including for sequential, synchronous and other calculations. The essence of asynchronous control consists in the fact that all processes and devices are regarded as a priori independent (they have their own "internal clocks") and cannot directly control the functioning of each other. Control interactions between them are carried out by their altering the states of some common control medium (general memory, channels and so on), individual tracking of the states of this medium and individual response to changes of states.

Hierarchical virtuality of system structure. A computer system is an aggregate of the equipment, programs and data. They interact with each other and as a result of this interaction form a unified whole -- a system. The complexity of the system requires decomposition of it into simpler components. The principle of virtuality assumes the design of a system as a series of enclosed concentric levels. Each level, besides the innermost, is a virtual system whose components and processes are mapped (by a program or by apparatus) onto the resources and processes of the more internal levels.

The principle of virtuality is already realized extensively in modern operating systems and machines. The tendency consists in making the images of levels more regular, increasing the fraction of apparatus-realized images and in shifting of (virtual) devices which control memory toward more internal levels. The latter is related to the relative increase of storage capacities in equipment and the volumes of information in programs, which provides the basis for many authors to regard the memory and processors which control access to data rather than processor-computers as the core of future systems.

Self-identification of data, which includes the fact that data are accompanied by tags -- information which indicates their type, properties or status. This information is decoded by apparatus and is used to control devices and the process of calculations. Tags may assume diverse forms and may indicate the degree of readiness of data to participate in calculations, the type of data for selecting the type of device or processing, data on sources, destination points or routes of data for organization of communications and exchanges, debugging information and information required to readjust the structure of the system or its individual components. Self-identification of data using tags replaces the principle of Neyman background, dominant in the traditional architecture of computers, which depersonalizes the data and gives the right of their identification to the program exclusively. Tagging of data permits great opportunities for organization of a flexible structure of systems and simplifies control of the process of calculations, but requires careful handling of the problems of the effectiveness of calculations.

The modular nature and reconstructability of virtual and physical levels and of the computer system as a whole. These principles developed on the basis of previously enumerated principles; they simplify the design and development of systems, increase their total effectiveness and permit one to adapt the system to the structures of the problems being solved, to resource capabilities and to the specifics of the area of application.

Uncontradictory and effective realization of these principles in a unified architectural concept is the main trend of investigations in the field of the structures of computer systems. Taking into account the already mentioned enormous material expenditures on development and creation of new computers and of especially powerful systems, one should emphasize the extreme importance of developed methodology of scientific research and experimental-design work on structures. One may recall that many "supergiants," beginning with the STRETCH and SOLOMON systems and ending with fourth-generation matrix and conveyer machines, were not put into serial production since they did not achieve the anticipated productivity or were more specialized than the developers assumed. The main reason for these failures was the absence of a real complex approach to design of these systems and as a result difficulties in matching the structures of the problems to the structure of the system. Another reason was systems engineering errors due to inadequate understanding of the overall properties and laws of computer processes. Computer design based only on intrasystems criteria and the technical tasks of the customer is now impermissible. Representation of user problem areas into the machine equipment should have no interruptions and white spots either in theory or in design practice. But this is a difficult task, although the first approaches to solving it have been made in programming, which for the time being is almost completely responsible for organization of this representation. Postulation of the problem itself must primarily be refined, namely development of formal means of specifying the calculating structures, processes and problems to develop and justify methods of transforming problems into processes and of processes into structure. The experience of similar investigations in programming, especially in the

theory of semantics and translation of programming languages, may be useful here. Methods of experiments, modeling and model realizations of computer systems must be developed parallel with this. Accompanying investigations in the field of computer methods and in modeling and optimization play an important role.

Let us describe in general outlines the concept of a modular computer system based on microprocessors which may be regarded as an instrument system for developing and checking methods of compatible realization of the principles enumerated above and for modeling various versions of future computer structures and as a prototype of an expanded system with rearranged structure.

The basis of the discussed concept of the system is understanding the computer module -- a structural element from which the systems and programs are designed. The comput module is a functionally closed device or fragment of a program in which four parts (zones) are determined: the processor zone, the memory zone, the control zone and the identification zone.

In the general case each of the zones of the module is an aggregate of submodules, i.e., lower-level modules. The memory zone is related to information storage, the processor zone is related to processing the information, the control zone fixes the module configuration, organizing internal communications and exchanges and establishes and monitors the modes of submodule functioning and the identification contains information about the conditions of module readiness for operation, about the type of module, about context relationships and so on.

Let us define a computer system as a maximum module in the hierarchy of enclosed systems modules and let us define the program as a maximum module in a similar hierarchy of program modules. At the lower level of the hierarchy are the elementary modules (microprocessors, special devices, instructions and standard procedures). Each module in the system or program has zones of different "capacity" as a function of the zone of the encompassing module to which it belongs. For example, the memory zone module of the system may have a developed internal memory zone and simpler processor and control zones. The recursive nature of the module concept of systems and programs facilitates the problem of formal description and analysis of them. However, the principle of a hierarchical modular structure interests us primarily as a method of designing systems from "large-block" elements based on microprocessors and of designing programs from program modules.

There are many examples of system classifications and most of them take into account the topology of intrasystem communications and control modes. Selection of a flexible, readjusted and at the same time efficient control module is one of the most timely problems in the field of the configuration of computer systems. Theoretical investigations indicate the advantage of asynchronous control with exchange of control information through the general memory: most of the other control methods can be simulated by asynchronous control. The asynchronous principle of control dominates in the new parallel programming languages. To give the programmer the opportunity to select or design

simpler, "explicit" methods of control convenient for his program (or different fragments of the program), it is suggested that the concept of the type of control be introduced into the programming languages. The programmer can describe the types of required control similar to how the types of data in languages with expanded data structures are described and can then use the described types of control mission in the program modules.

The concept of a closed module with clear determination of zones, especially of the identification and programmed control zones, lies within the channel of the ideology of structuring calculations, standardizes the design of programs and systems and permits automation of the process of matching their structures. It essentially relies on the ideas advanced and justified in a number of papers on the structures of future systems, including papers devoted to recursive machines, asynchronous systems and systems with rearranged structure.

Collective-use computer centers. The process of differentiating the stock of computers into powerful computer systems oriented toward solving a wide range of problems and into mini-computers designed to fulfill specialized data processing algorithms is now underway. In this case an important feature of scientific-technical progress is combining of these two trends into a unified trend of developing collective-use computer centers, the nucleus of which become powerful computers, while their intellectual terminals are mini-computers. The main means of man communicating with these centers becomes displays which depict various types of information on a screen, important to the user, and which ensure the work of subscribers with the computer in the dialogue mode. An important means of communication is also the remote-packet mode based on terminal stations capable of recovery of information in the form of a packet, feeding it into the computer system and deriving the necessary results of solving the problem in the required form.

Since high-capacity computer complexes are becoming ever more expensive and since this trend will be maintained in the future and the problems which require solution continually become more complicated, collective use of the higher-capacity computer equipment is essentially a common matter. It is for this reason that orientation toward regional collective-use computer centers with subsequent combination of them into a common network is a primary problem. A number of collective-use centers is being formed in the Academy of Sciences and a number of collective-use computer center designs is being formed in the branch ministries and agencies. All this is part of an overall program confirmed by GKNT [State Committee for Science and Technology] on development of a unified country-wide computer center network.

An important matter for institutions of the Academy of Sciences is now combining forces for total realization of collective-use computer centers based on the organizations indicated above.

Recommendations for institutions of the USSR Academy of Sciences and of the academies of sciences of the union republics to combine the highest-capacity computer equipment for collective use must be further developed and given.

It is important to carry out work to create problem-oriented data banks, accompanied and supplemented by the corresponding head institutes. These first collective-use data banks have already appeared in the USSR Academy of Sciences.

The problem of communications is of exceptional significance for development of computer networks and collective-use computer centers. Telephone-telegraph communications cannot satisfy these requirements at present. The main problem here is to create special communications channels and to use communications satellites; therefore, this problem must be prepared and it must be posed to the appropriate organizations. Positive solution of the problem of communications on this basis will permit organization of work on interaction of collective-use computer centers and their use in science and in the national economy.

Finally, the need has come to organize an experimental computer center network of the USSR Academy of Sciences based on combining regional academy computer centers with regard to the principles advanced above. This would be an important step on the path of forming a common methodology of developing a unified country-wide computer center network.

Conclusions. An active scientific search which prepares a qualitatively new step in development of computer affairs is now being conducted in all fields of computer technology, programming and computer application. Extensive work has been carried out on critical analysis of the results of theoretical investigations and the derived conclusions are being compared to the predicted trends and possibilities of practical realization. New approaches to solution of the main problem -- a sharp increase in the level of production and use of computer equipment -- are being formed on this basis. Total substantiation and introduction of these approaches requires intensification of fundamental and applied research both in special and in related scientific disciplines. The most timely problems are:

improving the technology of equipment miniaturization, specifically of the component base, founded on new physical principles;

development and introduction of new, substantiated principles of the structural organization of highly productive computers adapted to problem areas;

improvement of the principles of organizing computer processes in large information-computer complexes, specifically in networks and collective-use computer centers;

development of highly efficient superhigh-level programming systems, specifically, intellectual applied program packets based on natural and problem languages and large data bases;

complex automation of the design of computer systems and software.

This scientific program can be accomplished only by close cooperation of scientific and production collectives of the USSR Academy of Sciences, the academies of sciences of the union republics and of branch organizations in support and control of interagency organizations.

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CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

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THE EXPERIMENTAL COMPUTER NETWORK OF THE LATVIAN SSR ACADEMY OF SCIENCES

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 2, Mar/Apr 79
signed to press 24 May 78 pp 15-19

[Article by E. A. Yakubaytis]

[Text] The experience of automating scientific research indicates the importance of converting from the use of individual machines to development of multimachine hierarchical computer networks of scientific centers. Computer networks make it possible to combine control of experiments and generation, storage, transmission, processing and printing of information into a unified process. Networks have high economic efficiency, high viability and the capability for improvement and growth. Fusion of local computer networks of the scientific centers into a unified computer network will make it possible to combine the efforts of investigators and available information-computer resources for effective solution of important complex scientific problems.

The Experimental Computer Network (EVS) of the Latvian SSR Academy of Sciences is a multimachine hierarchical computer association [1], which combines structurally and program-specialized machines into a unified complex which makes available hardware and software for collective use by all scientific workers of the academy.

Development of a packet-switching computer network follows two main goals: conducting scientific investigations in the field of the configuration of computer networks and constructing a base of a general academy scientific research automation system.

The logic structure of the EVS is shown in Figure 1. As follows from the figure, a single-node computer network based on the use of six types of logic modules, was developed. The main module in the network is the working module, which makes available information-computer resources for collective use by their many investigators.

In contrast to the working module, the terminal module with terminals connected to it is a user of information-computer resources from the viewpoint

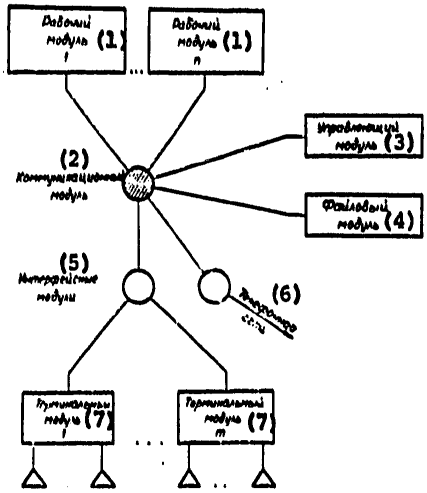

Figure 1. Logic Structure of EVS

KEY:

1. Working module
2. Communication module
3. Control Module
4. File module
5. Interface modules
6. Telephone network
7. Terminal module

of the network. At the same time, this module also makes available its own limited resources for its own terminals.

The task of the interface module is to process formats and codes and to perform a number of other transformations related to the need to match the characteristics and parameters of the working and terminal modules.

The communication module switches the packet flows among the working and terminal modules and also between the terminal modules. The file module makes available its own (disk) memory for storage of tasks by the working modules, decisions made and also to store any other information transmitted by investigators from the terminal modules.

The control module performs functions related to control of the network: control of the tasks, observation of the load of working modules, dumping of malfunctioning channels, recording the packet flows through all channels, providing local input-output from punch cards and punch takes and issuing lists on the course of tasks to all investigators.

Because of the structure indicated in Figure 1, the EVS makes available the following service to the investigators located near the terminals:

the possibility of assigning a task to any working module;

the possibility of preparing these tasks or programs in the dialogue mode and of editing them;

of generating lists on the course of tasks in the network;

of controlling the banks of their own tasks and of decisions made;

of generating lists on the tasks prepared in the terminal modules and of decisions made;

of storing the derived decisions in the file module "until demand";

of automatically recoding and reformatting the information prepared by different working and terminal modules;

of storing its own programs or data in the file module;

of automatically translating (or combining) information located on the carriers of some modules (punch cards, punch tapes, magnetic disks, magnetic tapes and paper printout) to the carriers of other modules.

One or several logic modules can be realized in an electronic machine as a function of its size and structure. A diagram of the layout of the modules shown in Figure 1 in the EVS is given in the table. As a result, the physical structure of the EVS is found which, according to the status for May 1978, is presented in Figure 2. The network consists of three main parts: a Central Computer Complex, the Terminal Complexes of the institutes and Communications Channels.

Realization of Logic Modules in Electronic Machines of EVS

(1) № пп.	(2) Тип машины	(3) Модули, реализуемые машиной
1	EC-1030	(4) Рабочий
2	M-4030	(4) Рабочий
3	M-4030	(5) Управляющий, файловый, коммуникационный, интерфейсный
4	M-400	(6) Интерфейсный
5	EC-1010	(7) Терминальный
6	M-400	(7) Терминальный
7	WANG-2200	(7) Терминальный

KEY:

1. No. of item
2. Type of machine
3. Modules realized by machine
4. Working
5. Control, file, communication and interface
6. Interface
7. Terminal

The central computer complex (TsVK) includes working and dispatcher machines. Three working machines (YeS-1030[1], YeS-1030[2] and M-4030[1]) perform the main information-computer operations. These machines are controlled by the OS 4.1 operating system. Moreover, subscriber stations interact with working machine YeS-1030[2]. The displays established here (YeS-7066 screen consoles) are controlled by the DUVZ (Remote Task Dialogue Input-Output) program system and perform the following functions in the dialogue mode:

editing the set of data;

creating new sets of data;

making available the tasks to the operating system of the working machine and issuing tasks on the displays or printout;

controlling the operation of the display users.

The dispatcher machine realizes functions determined by the version of the OSD 1.2 special operating system:

control of the information flows passing through the local input-output device (perforating and printing devices);

accepting tasks from the users of terminal machines;

transforming formats and codes;

checking the correctness of the information used and making a second request for receipt of it in the case of error;

buffering messages in the external magnetic disk memory;

selecting the working machine on which the next task will be performed and transmitting the task to it;

conducting a dialogue with working machines to check the priorities and to determine the volume of free buffers in the internal storage;

storing tasks and the results of completing them in the external storage;

transmitting the results to users of terminal machines in modes of urgent and immediate derivation of results;

checking the communications channels and switching off malfunctioning channels;

gathering statistical information on the operation of the computer system.

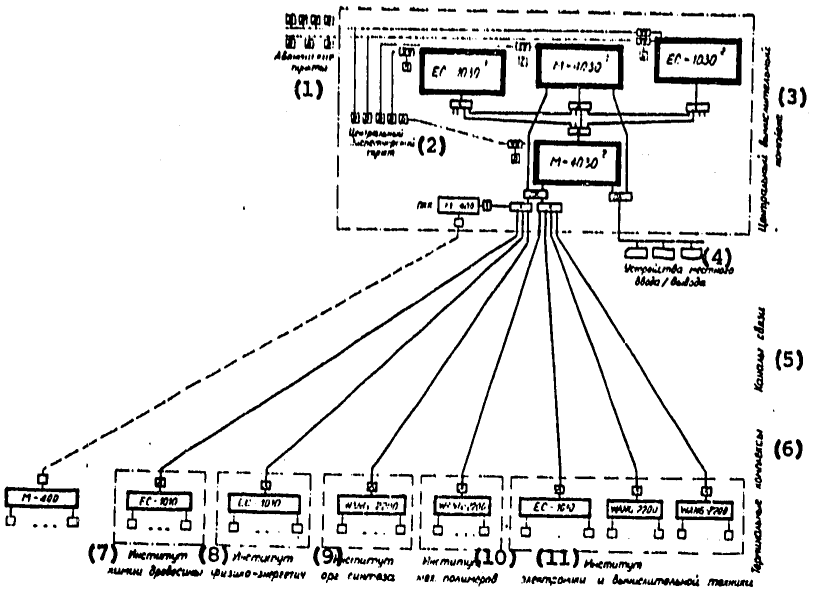

Figure 2. Physical Structure of EVS as of May 1978

KEY:

1. Subscriber stations
2. Central dispatcher station
3. Central computer complex
4. Local input-output devices
5. Communications channels
6. Terminal complexes
7. Institute of Wood Chemistry
8. Physics and Power Engineering Institute
9. Institute of Organic Synthesis
10. Institute of Mechanical Polymers
11. Institute of Electronics and Computer Technology

Various machines of the YeS EVM and SM EVM can be used as the dispatcher machine in the computer network. The M-4030[2] machine, operating in the YeS EVM mode, was selected as the dispatcher machine to make it possible not only to work with the OS D 1.2 operating system, but also to conduct investigations with various system control programs. In case of repair of the machine or of an emergency, its functions are transferred to the M-4030[1] machine.

The programmable communication controller (PKK) is designed to provide interaction of the TsVK with the terminal machines through a telephone network.

The important element of the TsVK is the central dispatcher station. It has a group of displays which duplicate the input and output information of the operator consoles of the user machines and displays. The presence of this station permits the chief of the shift (the mathematician controlling the computer network) to monitor the operators and users and to correct their work in necessary cases.

The terminal complexes of the institutes were developed on the basis of terminal machines of types M-400, YeS-1010 and WANG-2200. The systems software developed for these machines permits preparation (including editing) of tasks in algorithmic languages in the dialogue mode and permits remote input of tasks and output of results to the external devices of both the working and terminal machines. Transmission of tasks and reception of results are accomplished in packets (blocks) into which the messages are divided automatically without user participation.

The communications channels in the EVS are subdivided into parallel (high-speed) and series. Parallel channels are formed in groups of 28 twisted pairs of telephone cables each. The machines are connected to these channels by means of adapters (A) which provide parallel (nine-bit) symmetrical semi-duplex asynchronous information exchange between the machines at speeds from 0.2 Mbits/s (at distance of 2,000 m) to 1.5 Mbits/s (at distance of 50 m).

A telephone network is used for series (bit-by-bit) communications. Information is transmitted over these channels at a speed up to 2,400 bits/s.

The interaction of machines in the EVS is determined by the five-level software system of the computer network [1] whose characteristics are regulated by the corresponding hierarchy of protocols.

1. The physical interface (method of integrating the machine with the communications channel).

2. Channel control (procedure of data transmission over the communications channel).

3. Packet control (structure of packets and rules of routing them).

4. Transmission control (methods of delivering packets from the process in one machine to the process in another machine).

5. Process-process (forms of interaction of processes in the terminal and working machines).

The information transferred between the machines is clear for any types of texts and methods of coding them.

Development of computer networks permits:

a) achievement of computer capacities not achievable in a single machine by combining machines;

b) a significant increase of their functioning efficiency due to collective use and specialization of machines;

c) an increase of viability due to dynamic variation of the structure of the system;

d) high speed of preparation and fulfillment of tasks by means of multilevel conveyer processing of information;

e) making available to the investigator convenient forms of communicating with machines due to remote processing and dialogue modes.

The computer network permits a significant reduction in the volume of routine operations and a reduction of the periods of performing theoretical operations and applied developments. The real possibility appears of transferring scientific investigations to a qualitatively new level.

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THE CONFIGURATION OF OPEN NETWORK REMOTE DATA PROCESSING SYSTEMS OF THE YES EVM

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 2, Mar/Apr 79 signed to press 30 May 78 pp 20-26

[Article by V. V. Przhiyalkovskiy and V. S. Lapin]

[Text] One of the most effective methods of satisfying the systems requirements of the user at present is the use of a family of program-compatible computers with a wide range of productivity, supported by remote data processing facilities. Universal use of remote data processing is a characteristic feature of the modern development of information-computer and control systems.

The YeS EVM has high capabilities in the field of satisfying systems requirements compared to the computers previously produced in socialist countries.

Several hundred automated control systems and automated data processing systems of different level and designation now function on the basis of YeS EVM models. The experience of utilizing the YeS [Unified system] hardware and software made it possible to determine the weak and strong aspects of its development and to note the principles for further development of the system upon transition to solving new problems of fourth-generation computer equipment.

One of the central problems in realizing the scientific-technical program of the YeS EVM is that of developing hardware and software of remote data processing systems and networks which provide the capability of dispersed data processing; in this case the development of these facilities in the unified configuration of open network remote processing systems is provided.

In this regard we should dwell on analysis of the capabilities of YeS EVM equipment for organization of collective-use systems.

The remote data processing system of YeS EVM. The goals and tasks of the scientific-technical program for developing the first unit of the YeS EVM remote data processing system are:

organization of collective-use computer systems for remote subscribers;

work of remote subscribers with the computer over telephone and telegraph communications channels;

organization of computer-computer intermachine information exchange;

development of standard remote processing hardware: data transmission multiplexors, data transmission apparatus and man-machine communicating equipment -- remote subscriber stations;

development of standard remote processing software and data transmission.

The complex program for development of the YeS EVM unified remote data processing system provides for realization of dialogue operation of the subscriber, packet data processing and data gathering and transmission. The possibilities of constructing data bases and banks with remote access and also of computer-computer information exchange are provided. A wide nomenclature of YeS EVM remote data processing hardware which combine a common system, unified interfaces in the structure, unified procedures and control algorithms has been developed.

YeS EVM remote data processing hardware in the USSR includes 3 data transmission mulitplexors, 5 remote subscriber stations, and 13 nomenclatures of data processing apparatus and auxiliary apparatus. The hardware has been put into production and tested under real automated data processing systems. Complex work has been carried out to ensure functioning of the apparatus under noisy conditions and interruptions in the communications channels and also functioning with provision of information concealment.

The YeS EVM remote data processing software system contains the required facilities for outfitting collective-use computer centers:

a) software at the level of access methods for construction of specialized systems, including subscriber stations and local displays;

b) components of operating systems which provide simultaneous operation of a large number of users for remote verbal input of tasks and interactive problem-solving;

c) applied program packets which provide development of data bases, access to them by a large number of users and modification of data bases and contact of the user with the applied programs which utilize these bases.

The operating system (OS) of YeS, edition 4.1, contains software for remote communicating and graphical methods of access. By using macroinstructions of the general remote communicating method of access, it is simple to construct a specific message control program in the remote data processing system of the computer which provides switching of messages, priority of their passage in the internal storage and on magnetic disk, priority

processing and editing of messages and communications of the subscriber station operator with an arbitrary applied program.

The OS YeS has DUVZ (remote verbal input of tasks) components which permits the programmer working at the subscriber station to enter programs, data and task control language operators over the communications channel into the computer, to edit programs and to fulfill them in the packet mode with derivation of the results to the subscriber station.

Development of the program components of a time-sharing system has been completed which provides interactive solution of user problems, the use of verbal programming languages with expanded debugging capabilities and a set of service programs operating in the time-sharing mode.

The KAMA and OKA applied program packets have been developed which ensure the work of users with data bases and access to data from local displays and subscriber stations. Standard YeS EVM remote data processing equipment was the basis of existing automated data processing systems and management systems of the national economy.

The YeS EVM remote processing equipment was tested in the experiment recently conducted by GKNT [State Committee for Science and Technology] on exchange of data in the network between Moscow, Kiev, Tomsk and Tashkent.

One can state that the complex of YeS EVM equipment now provides the required completeness of the set of hardware and software required not only to construct collective-use computer systems, but also computer networks. Possible configurations of the computer systems are presented in Figures 1 and 2.

The main problems today are to train user personnel, to increase production of remote processing equipment, to solve problems of system design and to ensure deliveries of equipment complexes -- data processing systems -- to the user, to develop new YeS EVM equipment and to efficiently utilize the capabilities offered by the programming system.

The problem of the incompatibility of remote communications equipment being developed in the country by several agencies (MRP [Ministry of the Radiotechnical Industry], MPSS [Ministry of the Communications Equipment Industry, USSR], Minpribor [Ministry of Instrument Making, Automation Equipment and Control Systems], Minsvyaz' [Ministry of Communications] and so on) now requires serious attention and resolution. Ninety-nine percent of the communications processors, multiplexors and terminals in the United States now operate by using a control procedure -- BSC protocol. New HDLC and SDLC telecommunications protocols are being introduced which have the properties of code independence, high dependability and capabilities of operating by satellite networks.

A unified principle of a complex approach to organization of a data processing system, whether it be a collective-use system, computer network or data transmission system or network, must be developed. This principle should reflect the unanimity of three main parties: the user (a list of services available to the user), communications administration (how to construct the

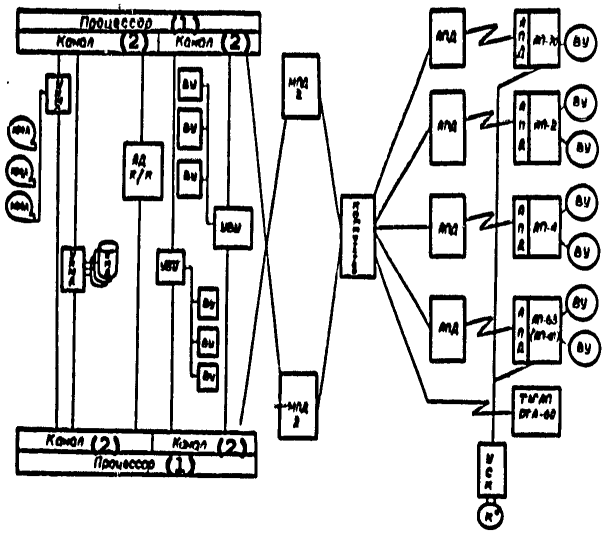

Figure 1. Two-Machine Remote Processing System With Computer and MPD Standby

KEY:

1. Processor
2. Channel

communications and data transmission subsystem to satisfy the requirements of network remote processing) and developers of the computer equipment (the equipment should be compatible and should be combined with each other at all levels of the structure).

Development of the problems discussed above led us to the problem of the configuration of open network remote processing systems.

Investigations are now being conducted on problems of the configuration of network remote data processing and development of the ideology, hardware and software -- components of open network remote processing systems and computer networks, according to a plan of NIR MPK [expansion unknown] on computer technology of the Council of Chief Designers of the YeS EVM with participation of organizations of the academies of sciences of socialist countries. The problem of an open system is formulated as "providing an opportunity for the user or program of one computer system to interact with the user or program of another computer system." Hence, it is clear that this problem is related to providing general systems compatibility in computer networks and data transmission networks. Open remote network processing systems (OSST) are an important step in development of computer technology and its systems use in CEMA countries; it is anticipated that they will contribute to a significant expansion of the spheres of computer application.

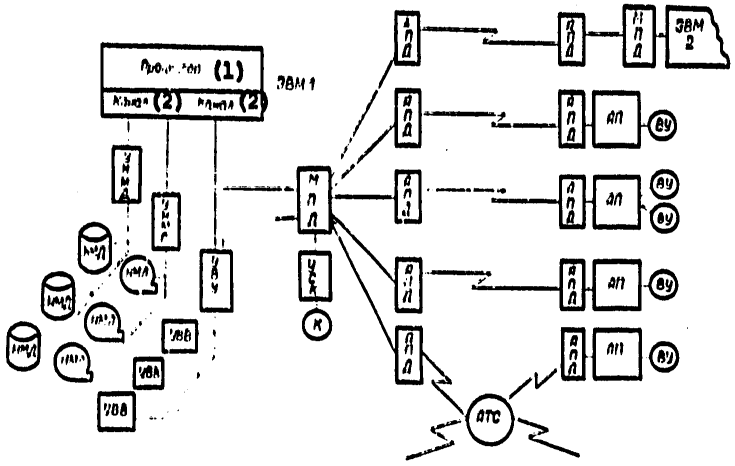

Figure 2. Remote Processing System With Intermachine Exchange

KEY:

1. Processor
2. Channel

Development of the OSST includes creation and improvement of a global logic model of system configuration provided by formal description of the functioning logic of the devices in the open system configuration, distribution of functions at functional levels between the two final users according to formalized description of the configuration and development of protocols of interaction of dispersed components of one level and representation of the language of description of functions and interaction in the open system.

There is now a unanimous opinion of most workers in this field that information systems should be represented according to multilevel configuration of the type (Figure 3) whose physical realization is presented in Figure 4.

The network in the systems plan of OSST is logically constructed from sequentially arranged functional levels. The lower levels correspond to remote communications devices of the data transmission subsystem, while the upper levels correspond to standard data processing application and to users (computers, subscriber stations and applied programs of the user).

This preliminary composition of the functional levels of network remote processing with regard to the proposals considered by international organizations on standardization (ISO and ECMA) includes:

user control;

control of standard applications;

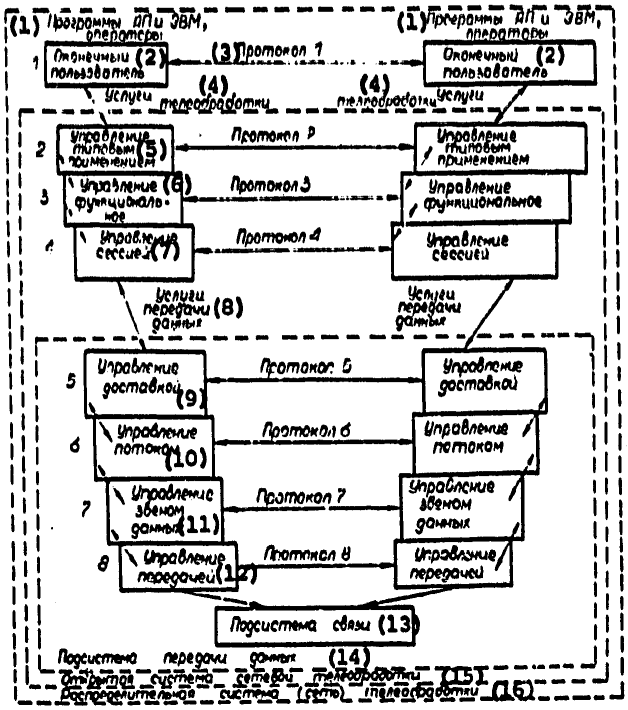

Figure 3. Configuration of Open Remote Network Processing Systems

KEY:

1. AP and EVM programs and operators
2. Final user
3. Protocol
4. Remote processing services
5. Control of standard application
6. Functional control
7. Session control
8. Data transmission services
9. Delivery control
10. Flow control
11. Data link control
12. Transmission control
13. Communications subsystem
14. Data transmission subsystem
15. Open remote network processing system
16. Distributing remote processing system (network)

control of functional processing and representation of data and formats;

control of logical joining of users (session control);

delivery control;

data flow control;

data link control;

transmission control.

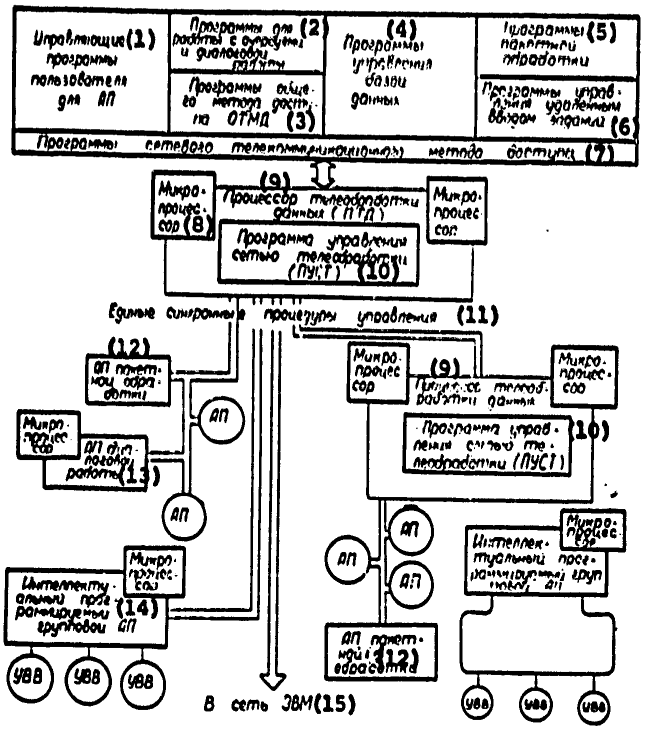

Figure 4. Network Remote Processing. Hardware and software configuration

KEY:

1. User control programs for AP
2. Programs for working with queues and dialogue work
3. Programs of general access method OTMD
4. Data base control programs
5. Packet processing programs
6. Remote task input control programs
7. Programs for network telecommunications method of access
8. Microprocessor
9. Remote data processing processor (PTD)
10. Network remote processing control program (PUST)
11. Unified synchronous control procedures
12. Packet processing AP
13. Dialogue working AP
14. Intellectual programmable group AP
15. To computer network

The last four levels form the data transmission subsystem. By providing the requirement of general compatibility and interaction of data transmission

apparatus and remote processing apparatus when working through the data transmission subsystem network, one must realize the indicated levels in a logically unified manner.

Together with the data transmission subsystem, the first four levels, which perform functions of data conversion and processing, form the architectural model of an open network remote processing system.

International organizations on standardization feel that standards on data transmission and communications should be developed, conforming to the global systems model of architecture of an open remote processing system.

Communications between dispersed components of one level of OSST architecture requires precise determination of the format, content and sequence of exchange between these components of the level. These rules are formalized by standard protocols. Within the framework of investigations conducted on development of the architecture of open YeS EVM systems, the object of standardization should primarily be a protocol of international final exchange (user-user, user-computer and computer-computer) and a functional control protocol related to representation of data, data formats and types of control for a specific class of subscriber stations.

An important application and use of the principle of an open network remote processing system are general state data transmission and remote processing systems (OGSPD and GSVTs). These systems (networks) are inhomogeneous in the general case and, therefore, the indicated principle of organization is most applicable to them.

The following program for working on the topic of OSST of YeS EVM has been adopted:

1) determination of areas of standardization in the sphere of YeS EVM open systems;

2) development of OSST architecture in the form of formalized description of the functioning logic of the components of architecture;

3) determination and development of proposals for standard interaction protocols and interfaces of architecture components;

4) development of network remote processing hardware and software in the architecture of open YeS EVM systems in CEMA countries.

Development of data OSST should be regarded as the main trend of investigation for many years; therefore, the required actions must be undertaken for effective development of investigations in this field.

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CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

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INVESTIGATION OF THE INSTITUTE OF AUTOMATICS AND CONTROL PROCESSES ON DEVELOPING A COLLECTIVE-USE COMPUTER CENTER

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 2, Mar/Apr 79
signed to press 29 May 78 pp 36-37

[Article by A. A. Voronov]

[Text] Preparatory work is now being carried out at the Institute of Automatics and Control Processes (IAPU) of the Far Eastern Scientific Center (DVNTs) of the USSR Academy of Sciences at Vladivostok to develop a collective-use computer center oriented mainly toward automation of scientific research at institutes of DVNTs, but whose users have also expressed the desire that there be more than 20 institutions and enterprises of Primorskiy Kray.

Initially, according to the plan of development of DVNTs, the computer center was created at the Institute of Automatics and Control Processes with regard to the need of fulfilling the orders of other institutes of DVNTs as well. In summer of 1977, a committee consisting of representatives of the Council of Ministers and of the State Committee on Science and Technology arrived at Vladivostok, which familiarized itself with preparation for organization of the collective-use computer center in the kray and with the work of the computer centers of a number of institutions and recommended that this center be developed on the basis of the IAPU computer center, which at that time had at its disposal modern computer technology and highly qualified personnel, including systems programmers who were temporarily attached to the Institute of Cybernetics of the Ukrainian SSR Academy of Sciences for several years in the composition of the IAPU laboratory.

It has been proposed that new highly productive machines be installed at the future center and that a collective be formed, the staff for which will be allocated by GKNT [State Committee for Science and Technology]. It is planned to use machines of class YeS-1060 and the El'brus-1, linking them into a complex, and also alphanumeric and graphical displays, plotters and drum graph plotters, graphical information input devices and so on. Terminals will be installed at institutes of DVNTs and terminal processors for SM-1, SM-2, SM-3 and SM-4 will also be installed at some institutes. Gradual connection of a number of organizations of other agencies over communications channels, both those who have and those who do not have their own computer

centers, has been proposed for the future, which will essentially become the basis for a regional computer network. Taking this into account, the kray committee of the CPSU decided to accelerate construction of the new building of the Institute of Automatics and Control Processes with the computer center and ATS [Automatic telephone exchange] and of putting them into operation in 1981.

The main systems programming complex for the given configuration is being developed by a collective of systems programmers of the institute on the basis of the M-4030 and YeS-1033 computers already available at the institute and also on the basis of the M-400 and SM-1 computers. Eight magnetic disk stores, six YeS-7064 and A-5433 graphical displays and alphanumeric displays 7906 have been connected to the M-4030 computer (storage capacity up to 1 Mbyte). The basis of the design of the unified machine complex is the idea of maximum use of domestic serial connecting devices, the main part of which -- the USVM [Unified computer system] communications device, modems and so on -- is already operating at the institute.

Development of software for working on mini-computers of type M-400 is now being completed. A so-called "program factory" for working on the M-400 is being developed in the YeS EVM [Unified Electronic Computer System] operating system. Work on a dialogue program debugger-interpreter of the M-400 in the YeS EVM is now in the stage of completion. Work has been completed on development of a cross-assembler on the YeS EVM for the M-400. This approach facilitates development of the corresponding support for the mini-computer. The baseline software for mid-level automation of scientific research, specifically, the DISGRAF graph packet for YeS-7064 and A-5433 graph displays, the DISFORT packet for working with SID-1000 and YeS-7906 alphanumeric displays from FORTRAN language and a multilanguage programming system for realization of problem-oriented user languages, has mainly been developed and is operating. Several information systems of a problem nature is being developed on the basis of the KAMA remote control system operating at the institute. Investigations are being conducted on development of software for construction of information reference systems for automation of scientific research and software for exchange of data distributed in different computer classes between bases on mini-computers.

Investigations to develop applied program packets which utilize the dialogue and machine graphics mode will be coordinated with the Siberian Department of the USSR Academy of Sciences. The following packets are in the stage of development: for geophysical regionalization of territory by pattern recognition methods, for geophysical modeling of geological structures, for synoptic-statistical analysis and forecasting in the atmosphere and ocean, for investigating electromagnetic fields in the atmosphere and ocean.

In solving personnel problems, we have been oriented toward the base of the Moscow Physicotechnical Institute, created at DVNTs, which has regularly made personnel available to the institute beginning in 1971.

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CSO: 1870

CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

UDC 681.324

THE MULTIPLE-USER COMPUTER SYSTEM AND THE DATA BANK OF THE NAUKA ASU OF THE ARMENIAN SSR ACADEMY OF SCIENCES

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 2, Mar/Apr 79
signed to press 24 May 78 pp 38-40

[Article by B. B. Melik-Shakhnazarov]

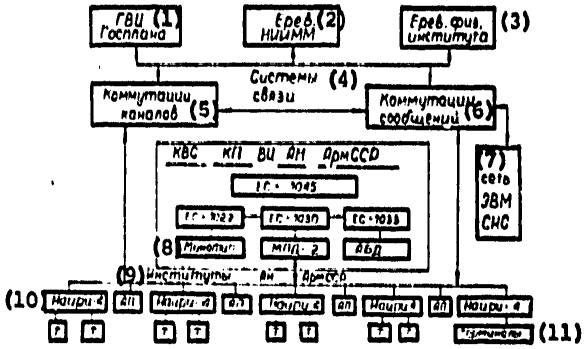
[Text] The multiple-user collective-use computer system (KVS KP) of the Armenian SSR Academy of Sciences is an aggregate of hardware used for data gathering, transmission, processing, storage, retrieval and display during investigation and management in the scientific institutions of the republic. In the first step, the KVS will service primarily academic institutions. This is an open three-level system having a number of interconnected high-speed computers or processors in the first rank, working machines specialized to carry out infrastructure problems at the second level and simple or intelligent user terminals at the third level.

The indispensable parts of the KVS are an open, i.e., increasable data transmission system and interconnected operating systems of the network separate computers and an automated data bank. The main calculating capacity in the system is provided by the YeS-1045 computer, which is capable of meeting the needs of users at the given stage and during the 2-3 years of development of the KVS KP. The reserve for it may be two BESM-6 computers of the computer system of the Yerevan Institute of Physics (see figure).

The second level of the system has the following infrastructure functions:

1. Communications between computers of the named level, essentially between those which form the multiple-user computer system, to service users with calculating capabilities of median productivity.

2. Special infrastructure servicing of users in issuance of information to them from the automated data bank (ABD KVS KP and of dispersed ABD), making available to them the external storage capacities, connecting users to specialized calculating capabilities for accomplishing technical design and calculations, processing photographic negatives, editing texts and printing them on the "Monotype" to accomplish printout and so on.



Computer Systems of Armenian SSR

KEY:

1. Main computer center of Gosplan
2. Yerevan Scientific Research Institute of Mathematics and Mechanics
3. Yerevan Institute of Physics
4. Communications systems
5. Channel switches
6. Message switches
7. SKS computer network
8. Monotype
9. Institutes of the Armenian SSR Academy of Sciences
10. Nairi-4
11. Terminals

3. Accomplishing communications with a wide network of third-level subscriber-users through data transmission multiplexors (MPD-2 or MPD-3).

Simpler user terminals and intelligent terminals are available at the third level of the system. Intelligent terminals are small and medium computers which service users on the spot and which in turn have their own terminal network in subdivisions of the scientific institution and which operate as connecting processors during interaction with the data transmission system (which is now caused by the poor quality of communications channels). The main type of computer which will be used as an intelligent terminal is the Nairi-4. These computers have software which permits working together with computers of YeS type and of connecting them to 64 local displays.

The computer capacities and subscribers of the KVS KP will be linked to each other by channels of three types. A message switching system, which, servicing telegraph channels, is loaded by 8-10 percent, has been introduced in the republic. It contains three YeS-1030 computers which can expand the sphere of its own services in the oblast: a) development of general-use ABD for servicing users while providing work in the dialogue mode; b) processing regular systems problems with reserve capacities which will first be introduced to users of type: wage calculation, material-technical support, monitoring fulfillment of directive and agency decisions and so on; and c) transmission of circular instructions to all or to a number of users

by lists and providing gathering of report information of the same type, reduction of it to summary data and issuance to the corresponding organizations who manage or analyze these data. Installation of a 200-600 baud channel switching system with provision of terminal devices of the main information users was also begun. The third type of data transmission encompasses only large information users: computer centers, information banks and managing organizations which can be connected to each other by direct data transmission channels. These channels will link to each other at least five computer systems formed in the republic: 1) the network of the Institute of Physics (nine computers); 2) the Ministry of Communications (six computers); 3) the Computer Center of the Armenian SSR Academy of Sciences (four computers); 4) the Yerevan NIIMM [Scientific Research Institute of Mathematics and Mechanics] (five computers); and 5) the Computer Center of Gosplan of the Armenian SSR (three computers) (see figure).

We are devoting a great deal of attention to problems of information support of the institutes of the Academy of Sciences and of other users. Whereas 10-15 years are required to develop a computer system and its software, decades are required to form an ABD having sufficiently complete data files in different areas of knowledge with a programming system and legal and information support. Many years of tedious labor are required to determine the features for describing objects of the studied area of knowledge, for developing methods and even the mode of interaction of many research groups to form permanent data files of the studied field and to provide dependability and timeliness of these indicators for any moment of time. The clear interest of user-subscribers in this type of information plays a great role if, of course, the process of hardware and software formation of these banks is provided. The Academic Institutes of Ethnography and Arts now have many thousand prepared machine-oriented questionnaires for formation of files, while the Institutes of Microbiology and Geology and the fundamental library could make available similar materials at any moment. There are experimental data files in the computer center on scientific workers, scientific topics, institutes, historical memorials and completed developments.

A number of the formed ABD is directly related to the work of regional scientific institutions and cannot be created without the assistance of the latter. Work in this field includes problems of the national characteristics of the people who populate the region, their history, ethnography and language; purely territorial problems concern landscape, soils, flora, fauna, geology, economics, population and others. These data should become the nucleus of solving complex regional problems of environmental protection, regionalization of economics, efficient use of resources, natural-landscape transformations and so on.

The second type of ABD is related to development of part of the all-union distributed banks in the case when the scientific potential of regional institutions is adequate to form its own bank. Data files on pharmaceutical and microbiological preparations and crystals and data files in the field of astronomy, medicine, organic chemistry and so on may be created in the Armenian SSR Academy of Sciences.

The third type of ABD is data files selected from other, main banks for their use as scientific-technical reference or permanent standard information required to conduct investigations in specific areas of knowledge within a given region.

Whereas development of the KVS KP requires specific initial investments which will be returned by acceleration of technical progress, formation of an ABD does not require large expenditures since it is organically included in the structure of research institutions, considerably facilitating their work and freeing personnel for a wider range of investigations. The external storage of large computer complexes is adequate to create a wide class of ABD.

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CSO: 1870

CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

UDC 681.324

THE COLLECTIVE-USE COMPUTER SYSTEM OF THE LITHUANIAN SSR ACADEMY OF SCIENCES

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 2, Mar/Apr 79
signed to press 16 May 78 pp 41-43

[Article by L. Tel'ksnis]

[Text] Computer technology plays a significant role in conducting fundamental and applied scientific research in the Lithuanian SSR Academy of Sciences, which has 12 institutes. It occupies a special place in investigations of random processes in technical and biological systems, the properties of semiconductor materials, thermophysical and electrochemical processes, atomic and ion spectra, photometry of celestial bodies, information received from spectral devices, the characteristics of biological molecules, the mechanisms of chemical reactions, the dynamics of environmental pollution and purification, dendroclimatochronology, the activity of nerve cells and insect behavior and cardiac rhythmograms.

When conducting these investigations, one must utilize complex mathematical models and problem-solving methods and must process large files of experimental data. Large computer capacities, developed problem-oriented software, problem-oriented data banks and the dialogue mode of problem-solving are required for effective completion of this work. The Collective-Use (KP) Computer System of the Lithuanian SSR Academy of Sciences has been created to meet these requirements.

High-capacity computers and mini-computers comprise the technical base of the KP system. High-capacity computers are used in solving problems of different complexity in packet and terminal modes. Mini-computers are used to process data and calculations on simple algorithms and also to manage experiments. The SAMAS apparatus is used in the system. It is planned to use a micro-computer in the near future. Data transmission to a distance up to 1 km is accomplished through special channels. Standard telephone and telegraph communications channels will be used to transmit data over greater distances. It is planned to transmit large information files between computers, when data transmission delay by 1-2 hours is permissible, by transfer of data recordings made on the magnetic tape of storage devices of type YeS or Hewlett-Packard.

The KP Computer Center of the Lithuanian SSR Academy of Sciences, shown by the diagram in the figure, is planned to be constructed by the end of 1980. The existing components of the system (as of April 1978) are cross-hatched in the diagram.

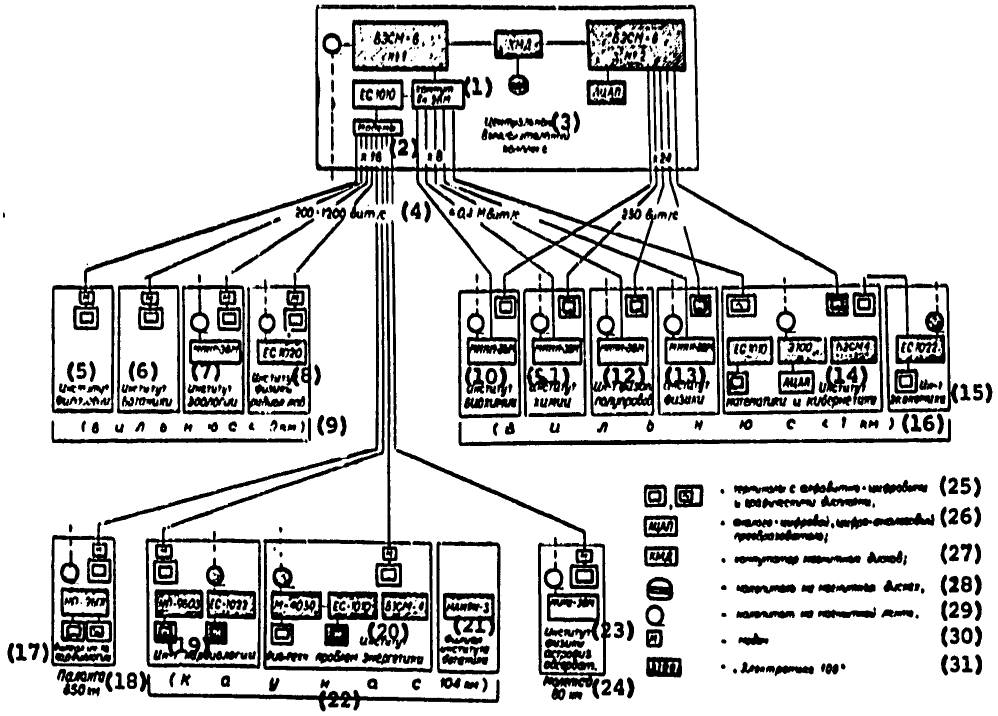

Diagram of Collective-Use Computer System of the Lithuanian SSR Academy of Sciences

KEY:

1. External computer switch
2. Modems
3. Central computer complex
4. bits/s
5. Institute of Philosophy
6. Institute of Botany
7. Institute of Zoology
8. Institute of Physics of the Radiological Laboratory
9. Vil'nyus less than 0 km
10. Institute of Biochemistry
11. Institute of Chemistry
12. Institute of Semiconductor Physics
13. Institute of Physics
14. Institute of Mathematics and Cybernetics
15. Institute of Economics
16. Vil'nyus less than 1 km
17. Branch of Institute of Cardiology

(Key continued on following page)

18. Palanga 350 km
19. Institute of Cardiology
20. Institute of Physicotechnical Problems of Power Engineering
21. Branch of Institute of Botany
22. Kaunas 104 km
23. Institute of Physics of the Astrophysical Observatory
24. Moletay 80 km
25. Terminals with alphanumeric and graphical displays
26. Analog-digital, digital-analog converter
27. Magnetic disk commutator
28. Magnetic disk store
29. Magnetic tape store
30. Modem
31. Electronics 100

Main attention is being concentrated in development of the software for the KP computer system on development of problem-oriented program packets, data banks and dialogue problem-solving systems. Specifically, a program packet for statistical analysis of random processes in the dialogue mode, a system for management of thermophysical experiment, a dialogue system for identification of the functional condition of the heart and of vegetative regulation from rhythmograms, a dialogue system for synthesis of classifiers of random observations and an information retrieval system for rarely corrected data are being developed. Program packets are being created for solving nonlinear differential equations by numerical methods, for solving multiextremal problems and for calculating atomic and ion spectra.

It is planned to carry out development of the KP Computer System of the Lithuanian SSR Academy of Sciences on the basis of the El'brus multiprocessor computer complex. It is assumed that users from higher educational institutions and branch scientific and production organizations who will require large computer capacities will also be connected to the system.

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CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

THE THEORY OF FINITE AUTOMATONS AND ITS APPLICATIONS

Riga AVTOMATIKA I VYCHISLITEL'NAYA TEKHNIKA in Russian No 2, Mar/Apr 79 p 92

[Review article]

[Text] A total of nine issues of the collection have been published at Izdatel'stvo "Zinatne" during the period from 1973 through 1978. Reports read at the seminar of the section "Finite Automatons" of the Scientific Council on Automation of Scientific Research and on Problems of Cybernetics attached to the Presidium of the Latvian SSR Academy of Sciences are presented in these collections. The main problems discussed at the seminar are related to the theory of finite automatons, methods and algorithms of analysis and synthesis, characteristics of constructing discrete devices and systems based on modern microelectronic components, problems of technical diagnosis of these systems and automatic methods of investigating computer networks. Materials on the principles of organization and construction of design and monitoring automation systems, realized on the basis of modern computers, can be found in the collections. The collections are intended for scientific workers, engineers and post-graduate students working on problems of logic design of discrete automation systems.

Orders to acquire the collections by COD can be sent to the Scientific Secretary of the Institute of Electronics and Computer Technology of the Latvian SSR Academy of Sciences at the address: 226006 Riga, ul. Akademiyas, 14.

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CSO: 1870

ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 621.371.4:551.463.7

THE RESOLUTION OF A SYNTHESIZED APERTURE RADAR WHEN OBSERVING THE SEA SURFACE

Gor'kiy IZVESTIYA VUZ RADIOFIZIKA in Russian Vol 21 No 12, 1978 pp 1750-1760

[Article A.V. Ivanov, Institute of Radio Engineering and Electronics of the USSR Academy of Sciences, manuscript received 12 December, 1977]

[Text] The limitations on the azimuthal resolving power of a side-looking, synthesized aperture radar (RSA), which are related to the mobility of the sea surface, are analyzed. The solution of the problem is based on a two-dimensional model for radio wave scattering in the VHF band by an agitated sea surface. Quantitative estimates are given for the azimuthal resolution of an RSA as a function of the radar and wave agitation parameters.

1. Introduction

It was thought for a long time that it was impossible to obtain an image of a sea surface using a side-looking radar with a synthesized aperture (RSA). The experimental results published in recent years [1-4] demonstrate the falseness of this opinion. Wind waves, ship waves, wind shadow sections on the sea surface, etc., are clearly visible in the images presented in these papers. However, the process of synthesizing the image of a sea surface has almost not been treated up to now in a theoretical sense.

An attempt is made in this paper to find the limitations, related to surface mobility, on the azimuthal resolving power of centimeter and short decimeter band RSA's. The following procedure is used in this case: the process of generating the image is considered for the case of small surface perturbations (much less than the radio wavelength λ) employing the known results obtained for a field scattered by such a weakly distrubed surface [5, 6]; thereafter, final conclusions concerning the resolution of RSA's are made by working from a two-dimensional model for the scattering of VHF band radio waves by an agitated sea surface [6, 7].

2. The Influence of Small Surface Oscillations

An idea can be gained of the specific features of the synthesis of an image of a moving surface in the case where surface deviations from the center position are small, by means of the following simple arguments.

Any realization of a stationary random surface can be represented in the form of a set of infinite sinusoids, corresponding to a certain spectral density $\tilde{R}(K_x, K_y)$. The y axis here and in the following is assumed to be directed along the course of the RSA vehicle. If each of these sinusoids moves at its own phase velocity, corresponding to the dispersion relationship $\omega = \Omega(K_x, K_y)$, remaining absolutely regular in this case, then the following spectral density will correspond to such a surface:

$$\tilde{R}(K_x, K_y)\,\delta[\omega - \Omega(K_x, K_y)]. \tag{1}$$

A certain three-dimensional spectral density, which can always be written approximately in the following form, will correspond to the actual oscillations of the liquid surface:

$$\tilde{R}(K_x, K_y)\,f[\omega - \Omega(K_x, K_y), \gamma(K_x, K_y)], \tag{2}$$

where f is some function with a maximum at the point $\omega = \Omega$ and a width γ. When $\gamma \to 0$, $f \to \delta(\omega - \Omega)$. It is obvious that the surface oscillations with a spectral density of the form (2) can be compared with a set of sinusoids of finite length - wave trains with a random independent phase, moving at a phase velocity of $v_f(K_x, K_y)$ and existing on the average for a time $\tau_0 = \gamma^{-1}(K_x, K_y)$.

We shall treat the scattering at the surface in a first approximation using the method of small perturbations. Then, if each train contains even a few periods and the width of the actual directional pattern of the antenna in the azimuthal plane is small, then one can consider only those trains with wave numbers falling in a small range of values $K_x = 2k\cos\theta$, $K_y = 0$ ($k = 2\pi/\lambda$, θ is the grazing angle; $\theta < 60°$); the remaining ones will make practically no contribution to back scattering [5, 6]. The amplitude of the field scattered by each train is directly proportional to the amplitude of the latter, and depends in a complex manner on θ. The frequency of the signal reflected to the radar is shifted by the amount $\pm\Omega(2k\cos\theta, 0)$ (the sign depends on the direction of the phase velocity of the train: to the radar or away from it).

In the case of uniform motion of the RSA vehicle, the dependence of the frequency shift of the signal reflected from the stationary concentrated target on the coordinate y is linear, while the signal processing system in the RSA, as is well known, can be treated as a spatial filter, matched to a linear FM signal [8]. An additional constant frequency shift in the linear FM signal leads to a shift, in this case a spatial one, of the compressed signal [9], i.e., to a displacement of the train image with respect to y. The size of the shift will amount $[r/V]v_f(2k\cos\theta, 0)\cos\theta$, where r is the oblique range to the target and V is the velocity of the vehicle.

It is apparent that coherent storage of the signals reflected from a given train can take place only as long as this train exists with its own constant or linearly changing phase. Correspondingly, the azimuthal dimension of the train image will be determined by the synthesis time t_c when $t_c < t_0$ and the time t_0 in the opposite case:

$$\Delta y \approx \frac{r}{V} \frac{\lambda}{\min\{t_c; \tau_0\}}$$

(with respect to the resolution as a function of the synthesis time, see, for example, [8]).

At all appearances, the quantity t_0 is not less than the attenuation time of the oscillation with an absolute value of the wave vector equal to $2k\cos\theta$. If it is assumed that wave attenuation is determined by the molecular viscosity of the liquid, then [10]:

$$\tau = \frac{2\mu K^2}{\rho},$$

where μ is the dynamic molecular viscosity of the liquid, ρ is its density, and the condition $t_c < t_0$ is met with a considerable safety margin for actual centimeter and short decimeter band systems with a parameter $r/V \approx 100$ s (this value is characteristic of radars intended for operation from a satellite with an intermediate orbit). In the case of actual wind wave agitation, the upper layer of the sea becomes turbulent, and the quantity t_0 can change, however, as before we shall assume that no degredation occurs in the resolution due to the finite "coherency" time of the resonant component of the ripple.

Thus, we obtain an image of each train with a resolution of

$$\Delta y_0 = \frac{r}{V} \frac{\lambda}{t_c}$$

and shifted with respect to y by the amount $\frac{r}{V} v_\phi(2k\cos\theta, 0)\cos\theta$. Experiment shows [11] that surface oscillations with a wavelength on the order of 10 cm, with a wind velocity of as little 1 m/s and more, i.e., practically always, are isotropic. Consequently, the intensity of the trains moving

towards the radar and away from it, are identical on the average, and instead of each of the sections of the surface with a different ripple amplitude (oil spots, wind shadows), we obtain two images, shifted with respect to y by the amount $[r/V]|v_f|\cos\theta$ in different directions from the true position.

Thus, splitting of the image of the surface is possible. The manifestation of the splitting effect can be observed when the following conditions are met:

$\Delta y' < \frac{r}{V} | v_\phi | \cos\theta$, where $\Delta y'$ is the resolution of the radar due to the effects of large waves (see below) and the inherent instabilities of the radar (Δy_0);

the size of the object being observed is less than the quantity $[r/V]|v_f|\cos\theta$.

If we add to this the fact that the quantity $[r/V]|v_f|\cos\theta$ in the best (and rather rare) situations can exceed $\Delta y'$ by only few times, then it becomes understandable that practically the main effect is to be considered the degradation of theresolution which will amount to:

$$\Delta y_1 = 2\frac{r}{V} | v_\phi(2k\cos\theta, 0) | \cos\theta =$$

$$= \frac{r\cos\theta}{V}\sqrt{\frac{2g}{k\cos\theta}\left(1+\frac{4\alpha k^2\cos^2\theta}{\rho g}\right)}. \qquad (3)$$

here α is the surface tension factor of the liquid.

The quantity $\Delta y_1 V/r\cos\theta$ is shown in Figure 1 as a function of $\lambda/\cos\theta$ (curve 1). The degradation of the resolution will be minimal at $\lambda/\cos\theta$ = = 3.4 cm and will amount to 45 m at $r\cos\theta/V$ = 100 s.

The anisotropy of the spatial spectral density of wave agitation is rapidly amplified with an increase in the wavelength [11, 12]. Because of this, when λ is on the order of a few meters, splitting will be actually absent if only the wind direction is not very close to the line of flight.

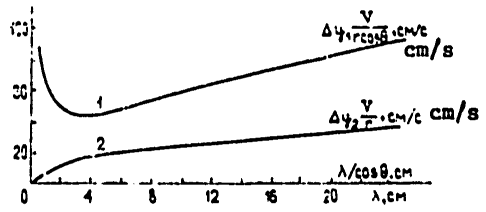

Рис. 1. Figure 1.

A more rigourous derivation of the results of this section is given in the Appendix.

3. The Influence of Large-Scale Wave Agitation

As was shown in paper [7], the spectrum of actual wave agitation can be broken down into two parts, so that the following conditions are met: the mean square value of the height of the surface points is much less than λ and the mean square values of the slope angles of the surface are much less than unity in the high frequency portion; the mean square value of the radius of curvature of the surface is much greater than λ in the low frequency portion. The breakdown frequency, naturally, depnds on λ. This means that scattering at the surface can be computed in a first approximation using the method of small perturbations, taking as the zero approximation the field scattered at the surface corresponding to the low frequency portion of the wave agitation spectrum, which in turn, can be found by the method of tangential planes. In other words, one can assume that large scale low frequency wave agitation influences the back scattering through the slow modulation of the parameters which determine the scattering for the case of very small roughness (θ, the amplitude of the ripple, etc.).

In accordance with this, one can propose that the results obtained in the preceeding section will also remain justifed for the images of sections of the sea surface with dimensions on the order of the shortest wavelength in the low frequency portion of the wave agitation spectrum. The larger waves will vary the intensity of the resonance component of the ripple and the local grazing angle, at which the given section is visible from the radar, from section to section, because of which, the large waves become visible to any side-looking radar. Another form of their action on the ripple will be considered here: the change in the phase velocity of the scattering trains with respect to the radar by the orbital motion in large waves.

In an RSA, the image of a uniformly moving point is shifted with respect to y by the amount $(r/V)u$, where u is the projection of the velocity of the point on the direction to the radar. The quantity u depends on the coordinates $u = u(x, y)$. The dependence of u on y leads to the distortion of the image (see [3]): the dimensions of the object or the width of the boundary in the image can become both larger and smaller than the true values. The dependence of u on x leads to other results. An azimuthal shift of an image, for example, of the straight-line boundary of any object, directed perpendicular to the course of the vehicle, will be different for different values of x, and as a consequence of averaging over x, within the limits of a range resolution element there will occur a washing out of the image of the boundary in azimuth (besides a distortion of its shapedue to the change in the shift from element to element). The amount of washing out will on the average by equal to $\Delta y_2 = (r/V)\Delta u_c$, where Δu_c is the mean square value of the velocities of the points in a range resolution element with respect

to the point lying in the center of this element, in which case, the averaging should be carried out wtih respect to the realizations of the surface and with respect to range.

We shall assume that the values u are distributed in accordance with a normal law having a dispersion σ_u and a normalized correlation function $R_u(x)$. Then the dispersion of the difference of the velocities of the points spaced a distance x from each other, is equal to the following on the average over the realization:

$$\sigma^2_{\Delta u} = 2\sigma^2_u [1 - R_u(x)] \tag{4}$$

and on an average with respect to x within the limits of a range resolution element Δx_0

$$\Delta u^2_c = \frac{1}{\Delta x_0} \int_{-\Delta x_0/2}^{\Delta x_0/2} \sigma^2_{\Delta u}(x)\, dx = 2 \int_{-\infty}^{\infty} \tilde{R}_u(K) \left[1 - \operatorname{sinc} \frac{K \Delta x_0}{2}\right] dK, \tag{5}$$

where $\tilde{R}_u(K)$ is the spectral density of the process; sinc x = sin x/x.

We shall assume that the wave agitation is cylindrical: the heights of the surface points do not depend on y. The instantaneous vertical velocities of the points are equal to the derivative of the height with respect to time, and the time spectral density $\omega^2 S(\omega)$ corresponds to them, where $S(\omega)$ is the spectral density of the values of the height of a surface point for a fixed value x. We shall assume that the same spectral density $\omega^2 S(\omega)$ corresponds to the projections of the velocity of the points "floating" on the surface onto any direction falling within the plane of the orbital motion. Then, again by virtue of the proposed cylindrical nature of the large scale wave agitation:

$$\tilde{R}_u(K) = \omega^2 S(\omega) \left.\frac{d\omega}{dK}\right|_{\omega=\omega(K)}.$$

Here, and in the following we shall use an expression for $S(\omega)$ of the form of a Phillips spectrum:

$$S(\omega) = \begin{cases} bg^2\omega^{-5} & (\omega > \omega_0) \\ 0 & (0<\omega<\omega_0) \end{cases}, \tag{6}$$

and we shall assume that ω_0 is equal to the frequency of the maximum of the Pearson-Moscowitz spectrum, for which a function of the force of the wind W of the form [12] is adopted:

$$\omega_0 = Cg W^{-1}, \qquad C \approx 0{,}88, \qquad b \approx 4{,}1 \cdot 10^{-3}.$$

The spectrum in (6) is considered to be even and defined for ω from $-\infty$ to $+\infty$. As a result, $\tilde{R}_u(K) = \frac{1}{2} bg K^{-2}$ when $|K| > K_0$, $K_0 = C^2 g W^{-2}$,

$$\Delta u_c = bg \Delta x_0 \int_{K_0 \Delta x_0/2}^{\infty} (1 - \operatorname{sinc} x) \frac{dx}{x^2}. \qquad (7)$$

The approximate form of $\Delta y_2(V/r)$ as a function of W for several values of Δx_0 is shown in Figure 2. In the limiting cases:

$$\Delta u_c \approx \left(\frac{2b}{C^2}\right)^{1/2} W \quad \text{при when} \quad W \to 0 \quad \text{или or} \quad \Delta x_0 \to \infty,$$

$$\Delta u_c \approx \frac{1}{2} (\pi bg \Delta x_0)^{1/2} \quad \text{при when} \quad W \to \infty \quad \text{или or} \quad \Delta x_0 \to 0.$$

4. Accounting for Nonlinearity in the Motion of the Surface Elements

Each individual reflecting element of the model considered here, a resonance wave train, moves in space in a complex fashion due to the orbital motion in large waves, and consequently, the signal reflected from it as a function of the radar coordinate y_0 will contain not just linear frequency modulation alone. In order to assess the limitations on the resolving power related to this, we shall replace the actual spectrum of large waves with a single sinusoidal cylindrical wave having the same value of the mean square height of the surface points as does the real wave agitation:

$$A = \sqrt{2}\sigma, \qquad \sigma^2 = \int_{-\infty}^{\infty} S(\omega)\, d\omega,$$

where A is the amplitude of the sinusoid. We shall also assume that its wave number is $K = K_0$ ($\omega^2 = \omega_0^2 = K_0 g$). Then, $A = ag\omega_0^{-2}$, where $a = \sqrt{b} \approx 6.3 \cdot 10^{-2}$. If a point "lies" at the surface of the described wave, then this point moves in a circle (radius A, period $2\pi/\omega_0$). When $v_f \ll v$, where v_f is the inherent velocity of the point or the phase velocity of the train, and v is the phase velocity of a large wave, the inherent motion of the point is taken into account by a supplemental linear displacement in the horizontal plane, which in this case can be neglected. If the circle falls in the (x, z) plane, then the motion of the train in a projection onto the direction to the radar will be described as

$$r_1 = A \cos \omega_0 t$$

regardless of the angle θ.

The nonlinear phase shift will be maximal for trains which lie in the circle of the cosine maximum or minimum. At these points, assuming $t_c < 2\pi/\omega_0$

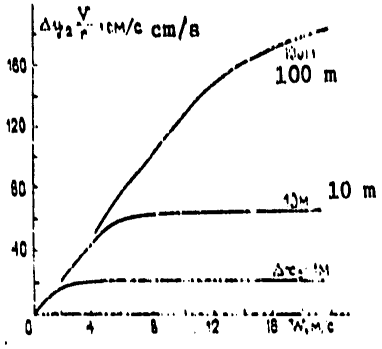

Figure 2.

$$r_1 \approx \pm A\left(1 - \frac{\omega_0^2 t^2}{2}\right).$$

The nonlinear phase shift has practically no influence on the synthesis efficiency, if the amount of the phase shift at the edges of the actual antenna directional pattern does not exceed $\pi/4$ with respect the the center [8]:

$$2\pi \frac{\Delta r_1}{\lambda} < \frac{\pi}{4}, \qquad (8)$$

where $\Delta r_1 \approx \frac{A\omega_0^2}{2}\left(\frac{t_c}{2}\right)^2$.

From this:

$$t_c < \sqrt{\frac{\lambda}{ag}} \quad \text{или or} \quad \Delta y_3 = \frac{r}{V}\frac{\lambda}{t_c} > \frac{r}{V}\sqrt{ag\lambda}. \qquad (9)$$

In Figure 1 (curve 2), $\Delta y_3(V/r)$ is shown as a function of λ. It is apparent that the arguments cited above will be justified if the amplitude of the wave agitation is rather large:

$$2\pi \frac{A}{\lambda} > \frac{\pi}{4},$$

Otherwise, the problem is completely solved within the framework of the small perturbation procedure. Making use of the functions $A(\omega_0)$ and $\omega_0(W)$, this condition can be written for the wind velocity:

$$W > \sqrt{\frac{\lambda g}{8a}}, \qquad (10)$$

which corresponds to values of 0.5--2 m/s for λ = 1--20 cm.

It is likewise easy to show that when condition (10) is met, the condition $t_c < 2\pi/\omega_0$ is practically always met automatically.

The estimates presented in this section are extremely approximate ones. We will note that although the assumption of the sinusoidality of large waves is quite a rough one, the important factors for use were only the circular motion of the point at the surface and the linear relationship between A and V , and both are justified within the framework of trochoidal wind wave theory [13].

It was assumed in sections 3 and 4 that the direction to the radar falls in the plane of the orgital motion in large waves, i.e., the results obtained correspond to the maximum values of the degradation of the resolution, which in practice will be realized wither in the case of wave agitation with

sharply pronounced cylindricity when flying along the wave front or when observing at grazing angles approaching $\pi/2$, regardless of the angular structure of the wave agitation. In all the remaining cases, it is necessary to calculate by working from a specific form of the two-dimensional (in x and y) spectral density of the wave agitation and a specific value of the grazing θ.

5. Conclusion

To estimate the degradation of the resolving power of an RSA, we broke the sea surface down into elementary reflectors: trains of resonance Bragg waves. The presence of constant phase velocity of the trains leads to a shift in the image, and since the velocities of the different trains are not the same, the resulting image is washed out, where this image has the character of the superposition of a set of images shifted with respect to each other. The cause of the scatter in the train with respect to the velocities is the isotropicity of the surface oscillations (the degradation in the resolution related to this is designated as Δy_1, formula (3), Figure 1, curve 1) and the orbital motion in large waves (Δy_2, formula (7), Figure 2). Moreover, the orbital motion causes a timewise change in the velocity of each individual reflector, and thereby, limits the permissible time for the coherent accumulation of the signals reflected from it. This in turn means that the minimum size fo the image of an individual reflector is limited (Δy_3, formula (9), Figure 1, curve 2). The resulting resolution will be equal to:

$$\Delta y \approx \max\{\Delta y_0;\ \Delta y_3\} + \Delta y_1 + \Delta y_2,$$

where Δy_0 is determined by the limitations on the synthesis time inherent in the radar itself.

All three factors are of a statistical nature. The degradation of the resolution which is related to each of them can run from several tens to several hundreds of meters depending on the radio wavelength λ, the wind velocity W, the range resolution Δx_0 and the grazing angle θ (when the ratio of the slope to the target to the velocity of the vehicle is on the order of 100 s).

Unfortunately, there is little experimental data published at the present time, but it does not contradict the results obtained.

In conclusion, the author would like to express his deep gratitude to A.Ye. Basharinov and A.A. Kalinkevich for discussing the work.

Appendix

The input signal of a radar for the case of scattering from a segment with center coordinates of x_0 and y_0 is written as [6]:

$$E(x_0, y_0) \sim \int_S e^{2ikr'} z(x, y, t)\, dxdy,$$

where r' is the range from the radar with coordinates of 0, y_0 to any surface point, z(x, y, t) is the shape of the surface.

If the antenna directional pattern is sufficiently narrow, then

$$r' \approx r + (x - x_0)\cos\theta + \frac{(y - y_0)^2}{2r},$$

where r is the range from the radar to the center of the segment.

For each horizontal line of the primary image with respect to range x_0 = = const., $y_0 = Vt$, where V is the velocity of the vehicle:

$$E(x_0, y_0) \sim \int_{-\infty}^{\infty} u(x_0 - x)\,dx \int_{y_0 - Y_1/2}^{y_0 + Y_1/2} \exp\left\{2ikx\cos\theta + \right.$$
$$\left. + \frac{ik}{r}(y - y_0)^2\right\} z\left(x, y, \frac{y_0}{V}\right) dy,$$

where u(x) is the spread function of the radar with respect to range, and Y_1 is the size of the illuminated segment with respect to y.

The pulse response of the input filter has the form

$$E_\phi(y_0) \sim \begin{cases} \exp\left\{\frac{ik}{r}y_0^2\right\} & (|y_0| < Y/2) \\ 0 & (|y_0| > Y/2) \end{cases},$$

where the dimensions of a coherently processed segment of the primary image Y are usually substantially less than Y_1, and for this reason, one can set $Y_1 = \infty$; this will affect only the far side lobes of the spread function with respect to y.

From this, it is easy to derive the fact [8] that the resolution or width of the spread function with respect to the zeroes for a stationary target or surface is

$$\Delta y_0 = \frac{\lambda r}{Y} = \frac{r}{V}\frac{\lambda}{t_c},$$

where t_c is the synthesis time and $Y = Vt_c$.

For a moving reflecting surface, the output signal of the filter is

$$E_{вых}(x_0, y_0) = \int_{-\infty}^{\infty} E(x_0, y_0 + \xi)\,E_\phi^*(\xi)\,d\xi \sim \iint_{-\infty}^{\infty} dx\,dy \int_{-Y/2}^{Y/2} d\xi\,u(x_0 - x) \times$$
$$\times \exp\{2ikx\cos\theta\} \exp\left\{\frac{ik}{r}(y - y_0)^2\right\} \exp\left\{\frac{2ik}{r}\xi(y_0 - y)\right\} z\left(x, y, \frac{y_0 + \xi}{V}\right).$$

We shall assume that:

$$\langle z(x_1, y_1, t_1) z(x_2, y_2, t_2) \rangle = \sigma(x_1, y_1) \sigma(x_2, y_2) \times$$
$$\times R(x_1 - x_2, y_1 - y_2, t_1 - t_2).$$

The average "power" of the ripple $\sigma(x, y)$, which does not depend on time, plays the part of the object, with respect to the image of which the resolution will be defined; $R(x, y, y)$ is the normalized correlation function.

Then for the output power averge with respect to the set of realizations or for the average with respect to several images of the given object $\sigma(x, y)$ of the image tracing density, we obtain:

$$\langle P(x_0, y_0) \rangle \sim \int u(x_0 - x_1) u(x_0 - x_2) \exp\{2ik(x_1 - x_2)\cos\theta\} \times$$
$$\times \exp\left\{\frac{ik}{r}[(y_0 - y_1)^2 - (y_0 - y_2)^2]\right\} \exp\left\{\frac{2ik}{r}[\xi_1(y_0 - y_1) - \xi_2(y_0 - y_2)]\right\} \times$$
$$\times \sigma(x_1, y_1) \sigma(x_2, y_2) R\left(x_1 - x_2, y_1 - y_2, \frac{\xi_1 - \xi_2}{V}\right) dx_1 dx_2 dy_1 dy_2 d\xi_1 d\xi_2.$$

The argument of the exponent with the square terms can be written in the form:

$$\frac{ik}{r}[(y_0 - y_1)^2 - (y_0 - y_2)^2] = -\frac{ik}{r}[(y_1 - y_2)^2 + 2(y_0 - y_1)(y_1 - y_2)].$$

The function $R\left(x_1 - x_2, y_1 - y_2, \frac{\xi_1 - \xi_2}{V}\right)$ when $|y_1 - y_2| > l_y$ where l_y is the correlation length, can be considered equal to zero. Further, integration with respect to ξ_1 and ξ_2 will yield a certain function of $(x_1 - x_2)$, $(y_1 - y_2)$, $(y_0 - y_2)$ and $(y_0 - y_1)$, which should differ neglibly from zero when $|y_0 - y_1| > L$, where L is a certain quantity which falls within limits of from Δy_0 to Y_1, depending on the properties of the function R.. Consequently, if the following conditions are met:

$$\frac{kl_y^2}{r} \ll 1, \qquad \frac{2kl_y L}{r} \ll 1$$

(and they are practically always met), the indicated exponents can be replaced by unity.

We shall write $t_i = \xi_i/V$ and $\alpha = V/r$, and substitute the variables:

$$t_1 - t_2 = \tau, \qquad y_1 - y_2 = \eta, \qquad x_1 - x_2 = \chi,$$
$$t_1 = t, \qquad y_1 = y, \qquad x_1 = x.$$

Then $$\langle P(x_0, y_0)\rangle \sim \int \exp\{2ik\chi\cos\theta\}\, u(x_0 - x)\, u(x_0 - x + \chi)\times$$

$$\times \exp\{2ik\alpha(\tau y_0 - \tau y - t\eta + \tau\eta)\}\, \sigma(x, y)\, \sigma(x - \chi, y - \eta)\times$$
$$\times R(\chi, \eta, \tau)\, dx\, dy\, dt\, d\chi\, d\eta\, d\tau.$$

The limits of integration with respect to τ are: from $-t_c/2 + t$ to $t_c/2 + t$; with respect to t: from $-t_c/2$ to $t_c/2$. With respect to the remaining variables, the limits of integration are infinite.

We shall assume that $R(\chi, \nu, \tau)$ falls to zero faster with respect to χ and ν than u and σ vary with respect to the same variables. Then, by integrating with respect to χ and ν, one can assume $u(\chi) \approx u(0)$, $\sigma(\chi, \eta) \approx \sigma(0, 0)$,

$$\langle P(x_0, y_0)\rangle \sim \int u^2(x_0 - x) \exp\{2ik\alpha\tau(y_0 - y)\}\times$$
$$\times \tilde{R}_{12}\{2k\cos\theta, 2k\alpha(t - \tau), \tau\}\, \sigma^2(x, y)\, dx\, dy\, d\tau\, dt. \qquad (11)$$

The subscripts 1 and 2 on $\tilde{R}$ mean that the Fourier transform is taken with respect to the first and second variables.

The characteristic range of variation of $\tilde{R}_{12}$ with respect to the second argument is of the order of $1/l_y$. Consequently, if the condition $k\alpha t_c \ll 1/l_y$ or $kl_yY/r \ll 1$ is met, then the second argument can be replaced by zero throught the integration range. The indicated inequality is observed because of the fact that $kl_y \simeq 1$ and $Y/r \ll 1$.

The width of the function $\tilde{R}_{12}(2k\cos\theta, 0, \tau)$ with respect to τ is equal to $\tau = \gamma^{-1}2k\cos\theta, 0)$. If $\tau_0 \gg t_c$, then since the maximum value of τ in the integration range is $|\tau| = t_c$, one can assume $\tau_0 = \infty$, and

$$\tilde{R}(K_x, K_y, \omega) = \tilde{R}(K_x, K_y)\,\delta[\omega - \Omega(K_x, K_y)],$$

$$\langle P(x_0, y_0)\rangle \sim \tilde{R}(2k\cos\theta, 0)\int u^2(x_0 - x)\,\mathrm{sinc}^2\left[\frac{kY}{r}(y_0 - y + \right.$$

$$\left. + \Omega/2k\alpha)\right]\sigma^2(x, y)\, dx\, dy,$$

where $\Omega = \Omega(2k\cos\theta, 0)$.

Thus, the spread function with respect to y has a width of Δy_0, but the entire image is shifted by the amount:

$$\delta y = \frac{\Omega}{2k\alpha} = \frac{r}{V} \left| v_\phi (2k \cos\theta, 0) \right| \cos\theta. \tag{12}$$

Now let $\tilde{R}(2k\cos\theta, 0, \omega) = \tilde{R}(2k\cos\theta, 0) f(\omega - \Omega, \gamma)$ amd $\tau_0 = \gamma^{-1} << t_c$. Now, the function $\tilde{R}_{12}$ with respect to τ in (11) is much narrower than the integration range, and the limits of integration with respect to τ can be considered infinite. By substituting the following in (11)

$$\tilde{R}_{12}(2k\cos\theta, 0, \tau) = \int \tilde{R}(2k\cos\theta, 0) f(\omega - \Omega, \gamma) \exp|i\omega\tau| \, d\omega,$$

we obtain:

$$\langle P(x_0, y_0) \rangle \sim \tilde{R}(2k\cos\theta, 0) \int u^2(x_0 - x) f[2k\alpha(y_0 - y) + \Omega, \gamma] a^2(x, y) dx dy,$$

from which it can be seen that the spread function with respect to y is:

$$v^2(y) \sim f(2k\alpha y - \Omega, \gamma),$$

The shift of the image, as before, corresponds to formula (12), while the width $v^2(y)$ is equal to

$$\Delta y = \frac{\gamma(2k\cos\theta, 0)}{2k\alpha} \sim \frac{r}{V} \frac{\lambda}{\tau_0},$$

Q.E.D.

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PRINCIPAL RESULTS OF SEISMIC INVESTIGATIONS IN THE FRUNZE PROGNOSTIC TEST SITE

Moscow IZVESTIYA AKADEMII NAUK SSSR, FIZIKA ZEMLI in Russian No 11, 1978 pp 42-53

[Article by V. P. Grin, B. Il'yasov, N. I. Kim, L. R. Kriger, T. A. Lopatina, Z. A. Medzhitova, and T. Ya. Serebryanskaya, Institute of Seismology, Kirgiz SSR Academy of Sciences]

Abstract. A brief examination is made of the seismicity of the region of the Chuyskiy basin and its surrounding mountains, and data are given on the spatial-temporal laws governing the manifestation of seismicity. A conclusion is drawn on the periodicity of the seismic process that consists of an interchange of periods of seismic activity and calm. Studies are made on the spatial and temporal variations in the ratio V_p/V_s. The mechanisms for the foci of earthquakes are investigated. The findings are discussed from the viewpoint of finding the prognostic signs.

[Text] The territory of the test site includes the Chuyskiy basin and its surrounding mountains. Since the seismicity and the system of observations of the area of study have been previously described [1] we will dwell only on the principal laws governing the spatial-temporal distribution of earthquakes.

Analysis of the experimental material showed that for the examined territory one should consider earthquakes representative that belong to the energy class $K \geq 11$ from 1929, $K \geq 9$ from 1951, $K \geq 8$ from 1958, and $K \geq 7$ in the period of detailed seismic observations (1967-1975). The maps for the epicenters of earthquakes given in figures 1 and 2 provide an idea about the seismicity of the region. The first of them presents earthquakes with $K \geq 9$ for 1885-1967 in accordance with the aforementioned representativeness of earthquakes, and the second--the materials of detailed seismic observations from 1967 through 1975 ($K \geq 7$).

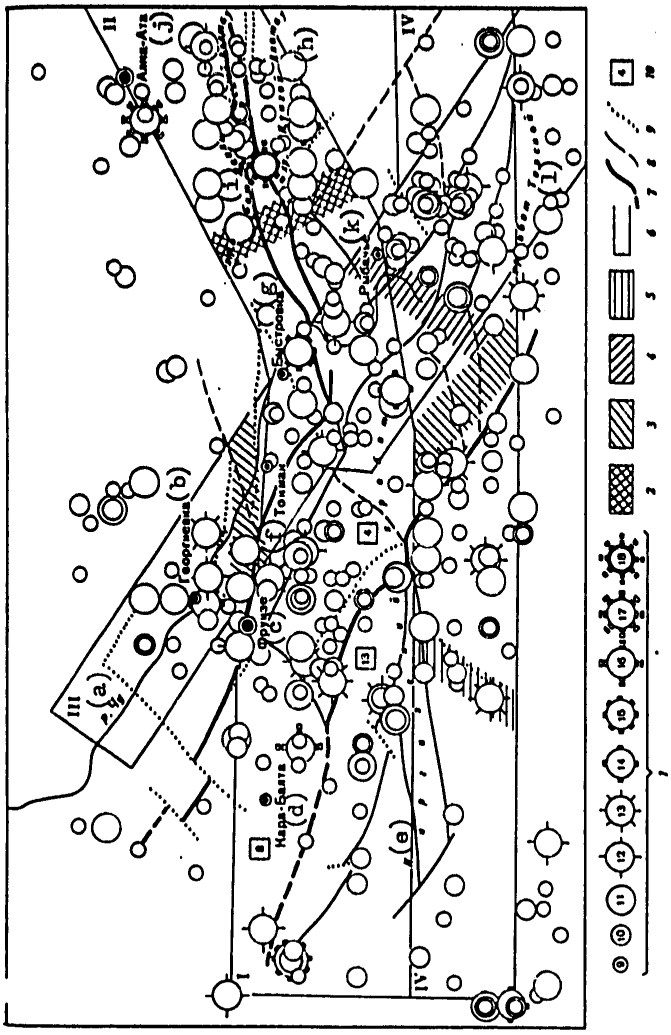

Figure 1. Map of Epicenters of Earthquakes in Chuyskiy Basin and Its Surrounding Mountains for the Period from 1885 through 1967

Key:
1. epicenters of earthquakes with K=9-18. Boundaries of regions isolated according to spatial-temporal laws governing seismicity:
2. first order
3. second order

[Key continued on next page]

4. third order
5. boundary whose order has not been established
6. boundaries of seismogenic zones

Faults:

7. interclod
8. interblock
9. intrablock
10. numbers of tectonic blocks

For numbering of other blocks see figure 4.

a. Chu River
b. Georgiyevka
c. Frunze
d. Kara-Balta
e. Kirgiz ridge
f. Tokmak
g. Bystrovka
h. Kungey Alatau ridge
i. Zailiyskiy Alatau ridge
j. Alma-Ata
k. Rybach'ye
l. Terskey ridge

The maps fairly clearly isolate mainly two seismogenic zones, southern and northern. The southern seismogenic zone (designated on fig 1 by Roman numeral I) covers the the southern section of the surrounding mountains of the Chuyskiy basin with a fairly broad belt of epicenters, and stretches in a latitudinal direction along the foot of the Kirgiz ridge along its lower foothills. The northern seismogenic zone (designated by number III on fig 1) encompasses the entire northeastern section of the surrounding mountains of the Chuyskiy basin. The band of epicenters here begins to the north of Tokmak and stretches in a relatively narrow belt to Georgiyevka and further along the Chu River goes to the northwest.

On the territory of the Frunze polygon the southern seismic zone occupies a special place. It is the most seismically active and has a complex structure; it consists of individual blocks that differ in the manifestation of seismicity in them.

The level of activity from the set of all instrument data for the southern zone equals 0.1, and for the northern 0.045. One can judge the depths of the earthquakes only from the materials of detailed seismic observations, i.e., from the middle of 1967. The greatest number of earthquakes is confined to depths from 5 to 15 km. The maximum depth is 25 km. Within the limits of the northern zone the main mass of foci lies closer to the diurnal surface, 0-5 km, while in the southern zone--at depth 10-15 km.

Spatial-Temporal Laws Governing Seismicity

An investigation of the spatial-temporal laws governing the manifestation of seismicity in the Chuyskiy basin and its surrounding mountains was conducted by constructing and analyzing the spatial-temporal diagrams for different zones and sections of the territory designated by Roman numerals on fig 1. The technique for constructing the temporal diagrams is stated in [2].

The studied territory was divided into zones and sections according to the geology of the region, and with regard for the seismic data. Thus, zone I encompasses the entire southern seismic zone extending along the structures of the Kirgiz ridge. Zone II is associated with the system of ridges of

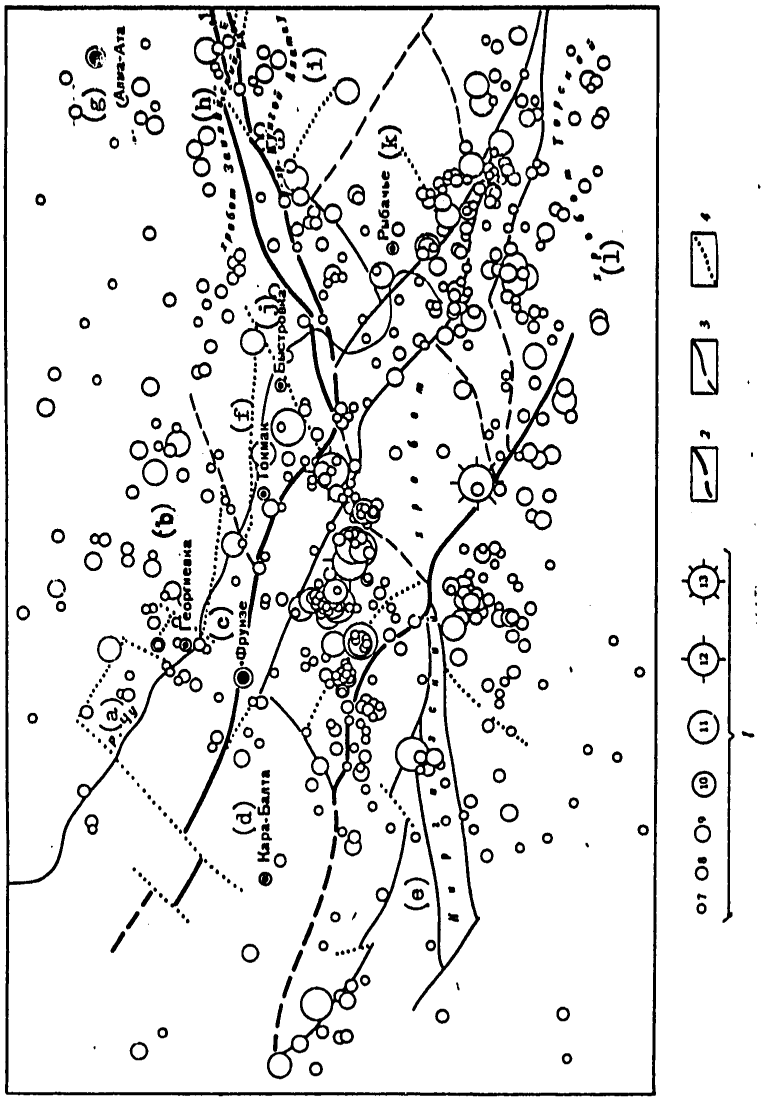

Figure 2. Map of Epicenters of Earthquakes of Chuyskiy Basin and Its Surrounding Mountains for the Period from 1967 through 1975 from Data of Detailed Seismic Observations

[Key on next page]

Key:

1. epicenters of earthquakes with K=7-13

Faults:

2. interclod
3. interblock
4. intrablock
a. Chu River
b. Georgiyevka
c. Frunze
d. Kara-Balta
e. Kirgiz ridge
f. Tokmak
g. Alma-Ata
h. Zailiyskiy Alatau ridge
i. Kungey Alatau ridge
j. Bystrovka
k. Rybach'ye
l. Terskey ridge

Zailiyskiy and Kungey Alatau ridges. Zone III includes in the north the northwest section of the northern seismogenic zone, in the center the eastern flank of the southern seismogenic zone, and in the southeast--the western branches of the Terskey alatau ridge. Finally, zone IV covers the southern branches of the Kirgiz ridge in the west, and the western section of the Terskey alatau ridge in the east.

From the viewpoint of both seismology and geology it is important to explain the question of whether the manifestations of the seismic process in all these zones are governed by the same time laws or if there exist differences between them. Analysis of the spatial-temporal diagram constructed for each of the indicated zones, as well as separately for the northwest, central and southeast sections of zone III showed the following.

Previously [2,3] it was found that in the manifestation of seismic activity of the southern zone there is a definite periodicity lasting 8-10 years. The periods of seismic activity are 1929-1938, 1947-1954 and 1968-1974. The time intervals between the named periods are characterized by relatively reduced seismicity. In the periods of activation of total length 26 years there were 26 earthquakes with $K \geq 11$, while in the periods of calm lasting 21 years--1. It is evident that such a distribution of relatively strong earthquakes in time cannot be random.

In zone II such alternations of periods of activation and calm are observed that differ, however, in their rhythm from zone I. The periods of calm and activation in these two zones do not coincide in time. Thus, for zone II the period of decline is observed in 1958-1960, in zone I in 1955; there is no observed correspondence in zone I to the sharp drop in seismic activity in 1968-1970 in zone II. These facts indicate that zones I and II "operate" completely independently of each other.

Of especial importance is an investigation of the seismic activity in zone III, or rather, its individual sections: northwest, southeast associated with different geological structures, and especially the central, located at the junction of the latter. Investigation of the development of the seismic process in this zone indicated that in the northwest and central sections the opposite tendencies occur: intensification of the activity in the central section (eastern flank of the southern zone) corresponds to its attenuation in the northwest, and vice versa. This indicates the

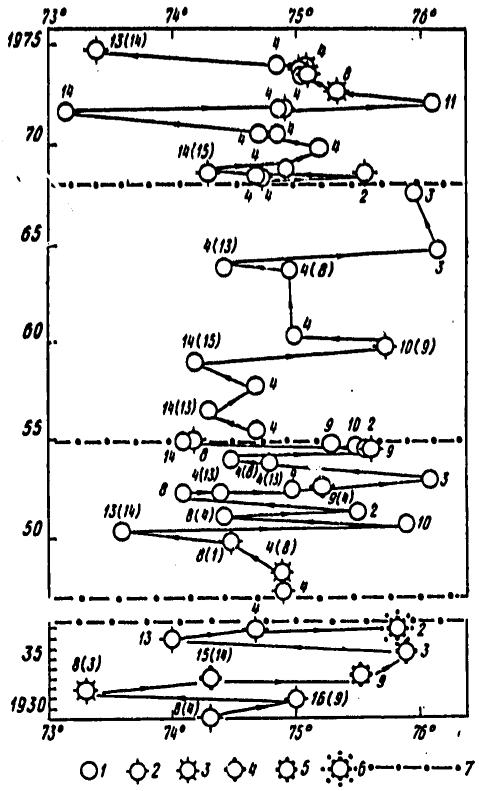

Figure 3. Summary Scheme of Migration of Earthquakes for Southern Sesimogenic Zone

Key:

1-6. K=10-15

7. lines separating the periods of activation and calm

Numbers at epicenters indicate the number of tectonic blocks, numbers in parentheses--less probable variant of the block.

existence of a definite interrelationship between these sections. Such interrelationships can be called local since sections of comparatively small dimensions are involved in them. There are published indications that the high intensity of local interrelationships testifies to the high tectonic loads on the territory of the sections, but at the same time it also testifies to the absence of stronger effects anticipating strong earthquakes [4]. If here in the given time interval (1967-1975 there had been preparation for a strong earthquake, then the action of powerful

tectonic stresses encompassing a much greater area, as it seems to us, would have suppressed these intensive short-period antiphase oscillations in seismicity on the indicated sections.

Finally, we will examine the epicentral zone IV that includes the southern slopes of the Kirgiz ridge and the western section of the Terskey-Alatau. Zone IV in the nature of its spatial-temporal laws is separated into three sections--eastern, central and western. Here the manifestations of seismicity in individual sections of the zone have their peculiarities. Thus, for example, an increase in the activity of one of the sections elicits a certain attenuation in the other sections.

All of these facts, as it seems to us, can serve as additional criteria for the establishment of the configuration of the boundaries of tectonic blocks possessing unified properties in an accumulation and the release of seismic energy. It is evident that such blocks possess their own seismic potential, i.e., can be areas responsible for the earthquake of a certain energy.

Thus, an investigation of the laws governing the seismicity make it possible to separate the studied territory into seismogenic zones and individual sections in accordance with the time laws in each of them. Depending on the similarity or difference in the spatial-temporal laws governing neighboring regions one can establish the degree of sharpness (order) of the boundaries between them. The sharpest boundary (of the first order) should be considered that which separates the regions with the most distinctive spatial-temporal laws--zones I and II. The weakest (second order) boundaries separate sections (regions) in which the development of the seismic process occurs in the antiphase: intensification of seismic activity in one section is accompanied by its drop in another. Such boundaries separate the northwest and central sections of zone III, and the eastern and central sections of zone IV. The weakest boundary (third order) is the boundary separating the central and southeast section of zone III whose time laws are very close (fig 1).

The examination of the manifestation of seismic activity in the southern zone on the level of earthquakes $K \geq 10$ reveals the migration of the foci of earthquakes. The summary scheme of migration is shown in fig 3. Here on the horizontal axis the longitude of the epicenters is plotted, and on the vertical--the time for the emergence of the earthquakes. It follows from an analysis of the given scheme that the migration of foci of earthquakes in time occurs according to the scheme west-east, east-west (oscillations of the wavy type). Another feature of the migration of earthquake foci is the fact that each time they begin in the central section of the zone (fourth block). Further the epicenters of the earthquakes migrate considerable distances--all the way to the edge sections of the zone.

The map of epicenters of weak earthquakes in the period of detailed sesimic observations (fig 2) shows that in the course of a lengthy period the earthquakes develop in individual places in groups, not imposed on each other, but adjoining the regions where a group of epicenters has already occurred. With time these groups of epicenters expand, encompassing ever greater areas.

A comparison of the sequence of manifestations of seismicity of different sections of the southern zone finds a logical explanation from the viewpoint of the block structure. Figure 4 shows the sequence of manifestation of seismicity in different time intervals for individual blocks. The time intervals were selected according to the periods of activation and calm of individual blocks or their sets. The hatched areas indicate the relative level of activity of each interval for the mean value for the entire period of detailed observations (1968-1974).

It follows from the scheme that an obvious sequence is observed in the manifestation of seismicity of individual blocks. This can be related to the periods of intensive release of seismic energy--activation of the seismic activity, or its accumulation--calm, which for different blocks may not coincide in time. The dimensions of the blocks are roughly equal between themselves, which indicates the possible equality of their seismic potentials. One can also speak of the equal probability of the emergence of a fairly strong earthquake in any of the isolated block systems. However the nature of the manifestation of seismicity in the fourth block to a certain degree can serve as an indicator for the detection of the activity of the others. It follows from figure 4 that the underestimated value of seismicity of this block must correspond to the overestimated value in one or several of the others.

Ratio of Velocities V_p/V_s

Recently considerable interest has developed in the study of the ratios of velocities of longitudinal and transverse waves of weak earthquakes as a possible forerunner of strong ones. In the Soviet Union the principal results have been obtained in the comprehensive seismic expedition of the Institute of Earth Physics of the USSR Academy of Sciences [5], and abroad--in the main Japanese and American research.

A study of the spatial-temporal distribution of the ratios of velocities of longitudinal and transverse waves by the technique developed in Garm [5] made it possible to zone the territory of the test site according to this parameter. Without dwelling in detail on the research technique since it has been covered in detail in [6] we will note the principal results. The mean value for the ratio V_p/V_s for the entire region is 1.72 ± 0.02. According to this the values $V_p/V_s \leq 1.70$ are viewed as underestimated, $V_p/V_s > 1.74$ as overestimated. Research has shown that on the test site territory on the background of normal ratios $V_p/V_s = 1.72 \pm 0.02$ anomalous volumes of underestimated and overestimated ratios are isolated to whose boundaries strong earthquakes have been confined.

During the period of detail seismic observations on the test site territory 2 earthquakes of the 12th energy class were the strongest: Shamsinskiy on 27 October 1972 and Issyk-Atinskiy on 1 September 1973. We have attempted to examine the behavior of the ratios V_p/V_s in the process of preparation of these earthquakes. In both cases on the graphs of the time course of

dynamic parameters of the foci of weak earthquakes in the Chuyskiy basin and its surrounding mountains in the period of detailed seismic observations (1967-1973) indicate that there exists a fairly distinct spatial separation of the three types of mechanisms of the foci.

a) The dependent wings of the faults are elevated (deformations of the type upthrust, upthrust-strike-slip fault). The orientation of the axes of the main stresses is such: compression (i)--close to horizontal ($0° < e_i < 30°$)*, extension (k)--closer to vertical ($30° < e_k < 90°$), intermediate (x)--closer to horizontal ($0° < e_x < 60°$). The shoves in one plane have small angles with level ($0° < e_I < 45°$), for the other--medium angles ($15° < e_{II} < 75°$).

b) The dependent wings of the faults are lowered (deformations of the type normal gravity fault, normal gravity-strike slip fault). The stresses of stretch are close to horizontal ($0° < e_k < 30°$), compression--closer to the vertical ($30° < e_i < 90°$), intermediate--closer to the horizontal ($0° < e_x < 60°$). The shoves, as in the first case, on one plane are close to the level ($0° < e_I < 45°$), and for the other--have mean angles with them ($15° < e_{II} < 75°$).

c) The dependent wings of the faults either are eleveated or lowered, whereby the shoves in both cases for one plane are almost horizontal ($0° < e_I < 15°$), and for the other--close to the vertical ($60° < e_{II} < 90°$). The stresses of stretch and compression have angles of slope to the horizon close to 45° ($30° < e_{k,i} < 60°$). The intermediate stresses are close to the horizontal ($0° < e_x < 45°$). For convenience of presentation we will call positive and designate by the sign (+) such shoves where the dependent wings of the faults are elevated; and negative (-)--if the dependent wings are lowered.

Research has shown that on the territory of the Chuyskiy basin and its surrounding mountains in the foci of earthquakes dislocations dominate that correspond to deformations of the type upthrust-strike slip and normal gravity-strike slip. The upthrusts and normal gravity faults (without the strike slip fault components) are few. There are practically no pure strike slip faults. In the foci directly surrounding the Chuyskiy basin the positive movements are directed towards the latter, i.e., overthrust of the mountain structures on the valley occurs. The stresses of stretch in the region of research do not have a dominant course, the stresses of compression are oriented primarily transverese to the main faults, and the intermediate stresses most often are close to the horizontal and directed parallel to the faults.

It is apparent from figure 5 that the foci with different signs of movements are grouped in a quite definite manner, and one can separate regions with a different nature of the movements in the foci. The epicenters of the strong ($K \geq 12$) of earthquakes of past years (up to 1967) plotted on this same figure, are located near the indicated boundaries, i.e., one can speak of the confinement of strong earthquakes to the boundaries of the change in movements in the foci of weak earthquakes.

*Angle of the corresponding parameter with horizontal plane.

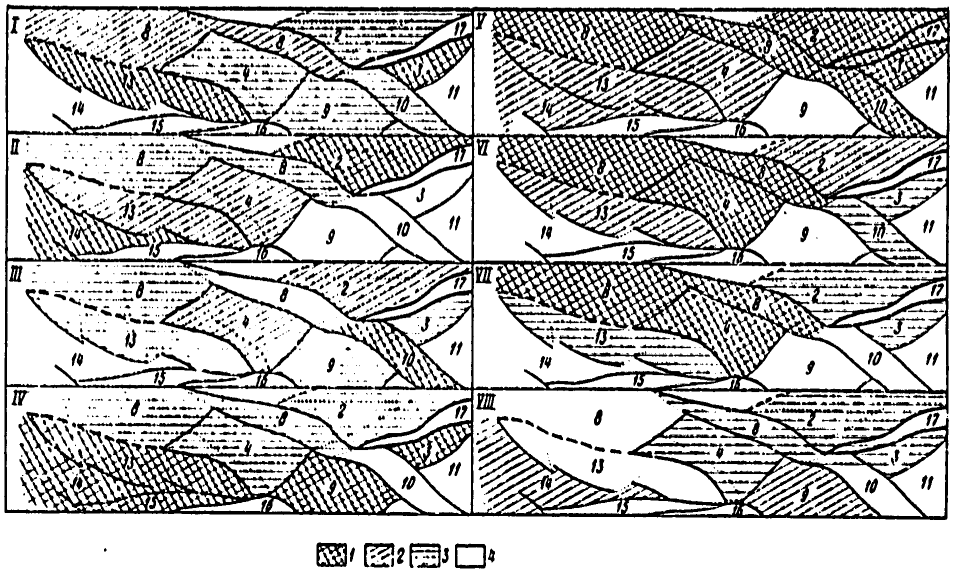

Figure 4. Sequence in Manifestation of Seismicity in Individual Blocks of Southern Sesimogenic Zone

Key:

Relative number of earthquakes:

1. more than 1
2. equal to 1
3. less than 1
4. no earthquakes observed

The Roman numerals correspond to the number of the time interval. The designations of the faults are the same as in fig 1. The numbers inside the circle correspond to the number of the block.

velocity ratios "bays" were noted that have an asymmetrical nature [6]. However, the depth and shape of the "bay" were not the same. For the deeper Issyk-Atinskiy earthquake (h=10 km) the depth of the "bay" was somewhat greater. It is possible that this is associated with the fact that the earthquakes occurred at different depths (depth of the focus of the Shamsinskiy earthquake h=5 km), and the sizes of the zones of preparation varied. The duration of the "bay" in both cases is 9-10 months, which, apparently, can be taken as the period of preparation of the given earthquakes.

Mechanism of Foci of Weak Earthquakes

A study of the mechanisms of the foci was carried out according to the technique of A. V. Vvedenskaya. The results of the investigation of the

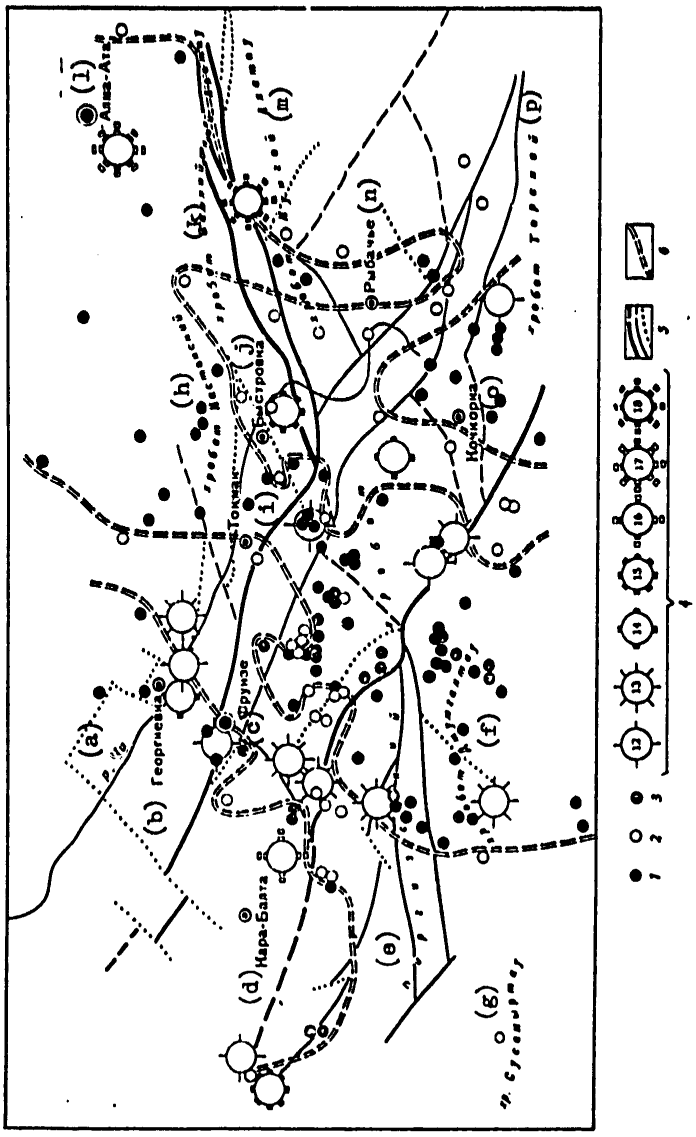

Figure 5. Dynamic Parameters of Foci and Strong Earthquakes

Key:

Epicenters of earthquakes with movement of dependent wings of faults in foci:
1. upwards (upthrust and upthrust-strike slip fault)
2. downwards (normal gravity and normal gravity-strike slip fault)
3. horizontal (strike-slip fault)

[Key continued on next page]

4. earthquakes of energy class K= 12-18
5. faults
6. boundaries separating regions with different signs of movements of dependent wings of faults

a. Chu River
b. Georgiyevka
c. Frunze
d. Kara-Balta
e. Kirgiz ridge
f. Dzhumgaltau ridge
g. Susamyrtau ridge
h. Kastenskiy ridge
i. Tokmak
j. Bystrovka
k. Zailiyskiy Alatau ridge
l. Alma-Ata
m. Kungey Alatau ridge
n. Rybach'ye
o. Kochkorka
p. Terskey ridge

The attempt to trace the process of preparation of earthquakes with $K \geq 12$ from the changes in the mechanisms of the foci of the preceeding weak jolts did not produce results. It is possible that this is explained by the absence of the necessary volume of information on the foci of weak earthquakes preceeding the strong.

Some Other Dynamic Characteristics of Earthquakes

In the period of detailed seismic observations (1967-1973) the distribution of signs of the first shifts in the P-waves recorded at a number of stations, and the ratio of amplitudes A_s/A_p for earthquakes in the Chuyskiy basin were also studied.

Analysis of the distribution of signs of the first shifts of longitudinal waves from the data of individual stations and their set indicated that a fairly clear and fairly stable spatial separation is observed in the epicentral zones with different signs of the first shifts. Here the regions of change in the signs are correlated to the anomalous sizes of the underestimated ratios V_p/V_s [7]. Almost all the known strong earthquakes ($K \geq 12$) of the research region are confined to the boundaries separating the zones with different signs of shift.

In order to study the ratio of the amplitudes of transverse and longitudinal waves of earthquakes in the Chuyskiy basin and its surrounding mountains in the period of detailed seismic observations we processed 318 earthquakes with $K \geq 8$. Of the 11 seismic stations operating on the test site territory seismic stations 1,5 and 8 were selected whose stations were not altered during the entire research period. Measurements of the maximum amplitudes of P- and S-waves were made only for the first trains of oscillations.

The histograms for the distribution of A_s/A_p (fig 6) for different stations indicate that for the majority of earthquakes values dominate of ratios lying in limits from 1 to 5 (70-80% of the total number of cases), although for different stations the distribution somewhat varies.

Mapping of this parameter for the test site territory carried out by constructing maps for individual stations 1, 5 and 8 and their subsequent unification showed that in the given region the foci with values $A_s/A_p \leq 5$

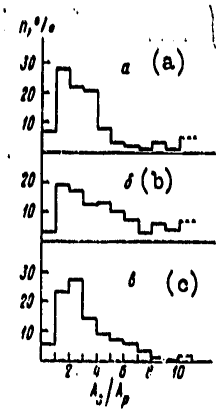

Figure 6. Histograms of Distribution of Values A_s/A_p

Key:
Data of seismic stations:
a. No 1
b. No 5
c. No 8

and $A_s/A_p > 5$ are separated fairly clearly in space. Figure 7 has hatched and outlined the regions in which earthquakes were observed with $1 \leq A_s/A_p \leq 5$: the solid lines--boundaries made confidently, the dotted lines--less confidently. It is apparent from the summary scheme of the spatial distribution of ratios that the regions with $1 \leq A_s/A_p \leq 5$, obtained from materials of different stations overlap. They also coincide with the anomalous volumes of underestimated ratios V_p/V_s [6].

In examining the changes in the ratios of ampltidues of transverse and longitudinal waves in time one should bear in mind that A_s/A_p is governed by both the source and the medium, and at the given stage of study they cannot be separated. The ratios of the amplitudes (in all cases where there are the necessary data) in the southern zone are usually altered according to the time laws governing seismicity previously noted, and precisely: by the end of the period of activation relatively low values of ratios are observed. An analogous phenomenon occurred also before the strong earthquakes, although in a number of cases an underestimated value of amplitude ratios was observed that was not accompanied by an earthquake.

Conclusions

1. Studies were made of the spatial-temporal laws governing the manifestation of seismicity on the territory of the Chuyskiy basin and its surrounding mountains for the period 1929-1973. A cyclicity was found

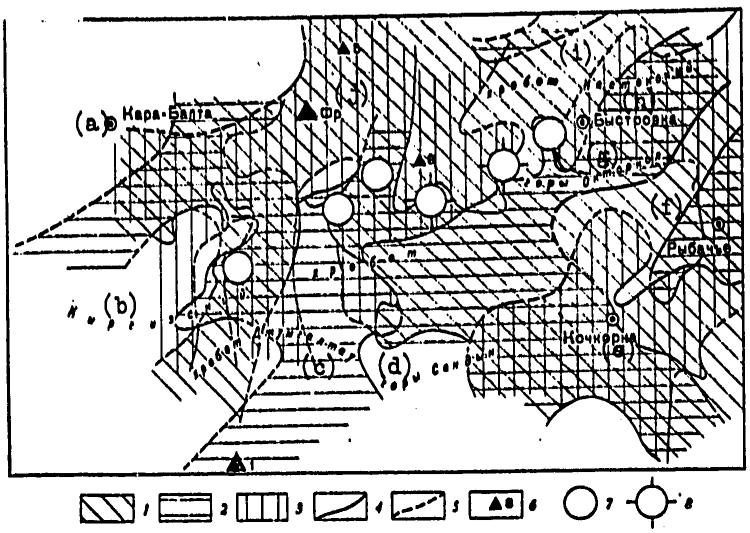

Figure 7. Spatial Distribution of Ratios A_s/A_p and Strong Earthquakes

Key:

Regions of values $1<A_s/A_p<5$ from data of stations:
1. No 1
2. No 5
3. No 8

Boundaries of regions $1<A_s/A_p<5$
4. positive
5. less positive
6. seismic stations

epicenters of earthquakes
7. K=11
8. K=12

a. Kara-Balta
b. Kirgiz ridge
c. Dzhumgaltau ridge
d. Sandyk mountains
e. Kochkorka
f. Rybach'ye
g. Oktorkol mountains
h. Bystrovka
i. Nasteksiy ridge
j. Frunze

in the seismic process that is manifest in the alternation of periods of activation with periods of relative seismic calm. The length of these periods is altered in small limits and equals 8-10 years. A study of the spatial-temporal distribution of earthquakes can serve as an additional criterion for the establishment of boundaries of the tectonic blocks linked to the general tectonic pattern.

2. Time variations have been examined in the ratio of velocities V_p/V_s before strong earthquakes, and the spatial distribution of this parameter on the studied territory. A bay-like change was noted in the parameter V_p/V_s before all earthquakes of the 11th and 12th energy classes occurring in

the test site region during the period of observations. Regions have been isolated in which the values V_p/V_s are above or below the normal. It is shown that strong earthquakes are confined to the boundaries of these regions.

3. The mechanisms have been studied for the foci of weak earthquakes in the period of detailed seismic observations (1967-1973). It has been found that in the test-site region deformations dominate of the type upthrust-strike slip fault and normal gravity-strike slip fault; the upthrusts and normal gravity faults (without the strike slip fault components) are rare; pure strike slip faults are almost completely lacking. It has been shown that the earthquakes with different nature of movement in the foci are spatially separated. All the relatively strong earthquakes ($K \geq 12$) are confined to the boundaries of change in the signs of movements of the dependent wings of the faults in the foci of weak earthquakes.

4. A fairly clear and fairly stable spatial separation has been noted in the epicentral zones with different signs of the first shifts in the P-waves.

5. A grouping has been found of earthquakes with relatively low values of A_s/A_p (1-5) that spatially coincides with the anomalous volumes of underestimated ratios V_p/V_s.

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PHYSICS

OPTICAL SCIENCE IN BELORUSSIA

Minsk ZHURNAL PRIKLADNOY SPEKTROSKOPII in Russian Vol 29, No 6, Dec 1978 pp 965-986

[Article by B. I. Stepanov]

[Text] On 1 January 1979 the Belorussian people marks a great holiday -- the 60th anniversary of the proclamation of the formation of the Belorussian Soviet Socialist Republic and the creation of the Communist Party of Belorussia. At present Belorussia is a highly developed republic with a large industrial capacity, rapidly developing agriculture, and many scientific and cultural institutions. The Belorussian people is bound by close ties of friendship and cooperation with all other sister peoples of the great Union of Soviet Socialist Republics. The Belorussian republic approaches its illustrious anniversary in the flowering of its creative abilities, filled to overflowing with a feeling of well deserved pride in its achievements and accomplishments over the years of Soviet power.

But until 1917 Belorussia was one of the backward, impoverished outlying regions of the tsarist empire. The majority of the rural population was illiterate. There were almost no books among the population. The autocracy was not interested in the cultural development of the people, and indeed hindered it at every opportunity. Until the great October socialist revolution Belorussia did not have a single institution of higher learning. The Goretskiy Agricultural Institute, founded in 1848, did not endure long. No scientific research was performed. In 1863 it was closed as a result of the intensification of the democratic student movement. In all of Belorussia there were three experiment stations, at which only 10-12 specialists worked.

This has now all changed, and changed radically. The present industrial make-up of the Belorussian SSR includes modern machine building and instrument making, petrochemistry and radio engineering, and many other branches of industry at the

forefront of scientific and technical progress. There have been remarkable successes in increasing the material well-being of the people, in public health, in the development of secondary and higher education, and in science and culture.

Fifty years ago, on 1 January 1929, the Academy of Sciences of the Belorussian SSR (AS BSSR) was formed. This was preceded by the organization of a commission on scientific terminology (1921), which was converted into the Institute of Belorussian Culture, the first rapidly developing scientific institution in the republic. The Institute steadily incorporated an ever growing number of branches of knowledge. Already by 1926 it had nine working sections, including one for natural science (subsections: geology and soil science, chemistry, physics, mathematics and meteorology, zoology, botany, and geography).

But physics at first developed extraordinarily slowly. In 1922 a physics and mathematics division was organized in the pedagogical school of the Belorussian State University. However, there was then as yet no scientific staff. Only in 1936 did the first candidate of sciences appear. The organization of departments took place in 1938. In the physics division of the school of physics and mathematics, four departments were formed: general physics, theoretical physics, x-ray physics, and electromagnetic oscillations.

At the time of the fascist occupation in Belorussia all institutions of science and higher learning were destroyed. After World War II everything had to start anew: buildings were erected, libraries and equipment were assembled, pedagogical and scientific staff were trained.

The history of Belorussian optics, and indeed of all physical sciences, begins in 1945 with the work done at the University of Belorussia by F. I. Fedorov. It was then that a new path of scientific investigation was taken, which even to the present is one of the fundamental paths of Belorussian physics, and which has deservedly received universal recognition.

This new field is the optics of anisotropic media, with new methods for solving the most difficult problems in phenomenological optics. After the organization of the sector of physics and mathematics (1953), later converted into the Institute of Physics and Mathematics (1955), this scientific field began to be developed principally in the AS BSSR by F. I. Fedorov and his students.

Since there have not yet been any review articles devoted to this problem in our journal, we will dwell on it in somewhat greater detail.

Physical optics

By the beginning of the 20th century it seemed to many that phenomenological optics was already basically complete. The laws governing the propagation of electromagnetic waves in isotropic media, and also their behavior at the boundary of two isotropic media, were in fact known, and solutions to Maxwell's equations for all the most important special cases had been carefully analyzed. The electromagnetic theory of the propagation of light in transparent inorganic crystals had been worked out. It seemed that there were no limitations in principle to extending it to more complex cases as well, for example, to absorbing crystals of all the known classes. However, the situation proved to be much more complex: in essence, until the work of Fedorov crystal optics had stagnated for 40 years.

Problems in the optics of anisotropic media were solved at the beginning of the 20th century by applying the tensor of permittivity to the system of three principal tensor axes. However, even in these coordinates the solution of the systems of equations obtained presented enormous and in most cases insurmountable difficulties for electromagnetic theory. Further, for absorbing and magnetic crystals no single system of principal axes exists; the previous theory was entirely useless. Serious difficulties arose also in describing the optical properties of absorbing substances. Earlier it was considered that in this case it was sufficient to find solutions of Maxwell's equations for isotropic media and in place of the actual value of the permittivity substitute its complex value. This procedure even acquired a special name: the transfer principle. As shown by exact solutions of the equations obtained several decades later, for many anisotropic media this principle is incorrect and may not even be viewed as a first approximation. At that time no theory of magnetic crystals existed at all.

F. I. Fedorov at the outset refused to use any chosen coordinate axes and developed a direct vector-tensor method for solving the equations of electromagnetic theory that was completely adequate for the assigned purpose. Of course, vector-tensor methods had long been known in mathematics, but their application to the solution of optical problems required considerable further development and specific adaptation. We cannot dwell here on the details. It is important to note only that all the relations of phenomenological optics took on a very simple form in the new theory and were not bound to the choice of a particular system of coordinates.

We will present a few examples. The use of covariant methods required, for example, the violation of the usual criteria for the polarization of light. In that treatment the complex vectors E and H of the electromagnetic wave were as a matter of course projected onto a phase plane, defining thereafter the relationship between two components of a vector. This procedure is the result of the choice of a particular rectangular coordinate system, one of whose axes coincides with the normal to the wave. In place of this, in the covariant theory wave polarization is determined directly from the vectors E and H. Thus, for example, the condition for linear polarization is of the form $[EE^*]=0$, and the condition for circular polarization is $E^2=0$.

In analyzing the optical properties of magnetic crystals, it was possible to prove that they are defined not by the tensors of ε and μ separately, but by a certain single tensor. If the tensors of ε and μ are proportional to each other, then in the crystal only one wave propagates, its speed depending on the direction of propagation. Thus, contrary to existing views, birefringence is due not to the anisotropy of electrical properties but to the difference in the anisotropies of ε and μ.

In the study of absorbing crystals many qualitatively new features were revealed. While it was known earlier that in absorbing crystals of lower systems there may exist rotational optical axes along which light propagates with only circular polarization, in the covariant theory it was established that "isotropic" optical axes are also possible. Light propagating along these axes may have any polarization.

According to the theory based on the transfer principle, absorbing crystals may in the number and character of their optical axes be of only three types: those which are isotropic, those with a single isotropic optical axis, and those with four circular optical axes. In fact, 16 forms of absorbing crystals may exist in nature, differing in the type and number of optical axes.

In the covariant theory the processes of reflection and refraction may easily be analyzed at the boundaries of transparent and absorbing media having any type of anisotropy. Earlier, many of these cases were insoluble in practice; one of the coordinate axes was naturally fixed to the normal to the boundary, so that the expressions for the tensor of ε and all other theoretical relations became excessively ponderous. Covariant methods made it possible to find simple, general expressions for the Fresnel formulae. On this basis an

experimental method was also proposed for determining all the optical parameters of a crystal by studying the properties of light reflected by one of the randomly oriented portions of its surface.

The rejection of coordinate methods for solving the equations made it possible to construct a general theory of plane, inhomogeneous waves. Inhomogeneous waves are encountered very frequently in nature, but their properties were earlier studied hardly at all. Inhomogeneous waves arise in transparent media with total reflection, in an absorbing medium with oblique light incidence, and sometimes also at the boundaries between a crystal and any medium. The properties of inhomogeneous waves are entirely specific. In this case, for example, the E and H vectors usually describe curves differing in form and lying in different planes. The process of energy transfer is just as unusual. The direction of energy translation at any point in the medium changes continuously, describing a conical surface.

One unusual property of inhomogeneous waves is associated with the violation of the generally accepted law of the reflection of light (the incident beam, the reflected beam, and the normal to the plane of incidence lie in the same plane). In fact, for example in total reflection, the light beam is displaced perpendicular to the plane of incidence. The existence of this phenomenon was predicted in Belorussia in 1954. It was discovered experimentally by the French scientist Humbert in 1969 and was entitled the Fedorov shift. Since that time it has been studied intensively.

Most recently a new problem has arisen -- the study of the reflection of light from amplifying media. The first experiments and calculations showed that the reflected beam may be more intense than the incident beam.

In Belorussia there is both theoretical and experimental development of still another important field associated with the study of the behavior of electromagnetic waves at the boundary of different media under conditions of total reflection: integrated optics. The waveguide is becoming a basic element in many modern devices in optical electronics. The simplest such waveguide is a thin dielectric plate. Light is transmitted along it, undergoing total reflection from the inner surfaces of the plate. Outside the plate the light field exists as an inhomogeneous wave. Only for a discrete set of angles of incidence and wave polarization outside and within the plate is a coupled system formed, transmitting light energy along the plate. On this basis using fibers it is possible

to transmit energy over great distances (light guides). Covariant methods have made it possible additionally to study in detail the properties of waveguides formed by semiconductor diodes with p-n junctions, multilayer and absorbing waveguides, waveguides with anisotropic dielectric and magnetic properties, etc.

With covariant methods it has been possible also to work out the basis for the sequential theory of optical activity and to classify gyrotropic crystals. All crystals must be considered gyrotropic whose symmetry admits the existence of a non-zero optical activity pseudotensor of the second rank. Gyrotropy must be exhibited by 18 classes of crystals (not 15, as held previously). In the analysis it was revealed that in the previously existing theory the law of conservation of energy for bounded optically active media was not satisfied. The contradiction was resolved by the formulation of new material equations for the electrodynamics of a gyrotropic medium. Based on them, the laws governing the propagation of light and its reflection and refraction at the boundary of absorbing gyrotropic crystals were examined.

In summary it may be said that in this period in Belorussia a complete phenomenological theory has been constructed for the optical properties of anisotropic, magnetic, absorbing, and gyrotropic media. Its conclusions are beginning to be applied widely in a number of fields of science and technology: solid state physics, quantum electronics, integrated optics, optoelectronics, optoacoustics, information transfer, etc.

Within the framework of this article it is possible only to mention the many other problems in physical optics investigated by Belorussian scientists. Among them are the detailed study of the reflection of light from absorbing isotropic substances, based on the use of the Fresnel formulae and the completed compilation of detailed tables and nomograms making it possible to find values of n and $\varkappa$ according to characteristics of the reflected flux determined by experiment. In the early 1960's at the Institute of Physics of the AS BSSR and the Belorussian State University imeni V. I. Lenin (BSU) a number of theoretical studies were performed of the optical properties of crystalline plates and an assemply of systems of thin isotropic (transparent, absorbing, and amplifying) layers. The methods developed served additionally for solving a large number of problems in quantum electronics, the investigation of the effect of boundary conditions on the intensity of generation of a plane-parallel amplifying layer, the effect of losses and the thickness of the layer, and its anisotropy. Development must also be noted of a number of branches of the molecular theory of the propagation, reflection, and refraction of light.

The creation of a new class of optical filters for the infrared spectral region must be considered one of the greatest accomplishments made by Belorussian physicists. Such filters are thin plates formed by compressing two-component powders whose dispersion curves intersect at a single point (at one wavelength). The filters transmit radiation at that wavelength and at nearby wavelengths. For other wavelengths the plate is opaque. At present a series of filters has been developed covering a wide spectral region from 1.2 to 100 μm. In the process of developing and studying the properties of filters a detailed analysis was performed of features of the scattering of light by two-component systems (dependence on the type and dimensions of the particles, closeness of packing, thickness of the layer, etc.). Dispersion filters have many valuable properties: high mechanical strength, temperature independence, temporal stability, and a comparatively narrow spectral passband. For further narrowing of the passband in the future, dispersion-interference filters have been developed. In this case a small number of thin films is deposited on a dispersion filter, creating an interference effect. For a long time now series production of dispersion filters has been organized in the Central Design Bureau of the AS BSSR. The filters have been successfully applied to the solution of many scientific and technological problems.

Beginning in 1953 studies have been performed in the AS BSSR of the optical properties of scattering objects. In the first stage they were devoted to the development of methods for determining the optical constants of weakly absorbing and luminescing powder-like materials by measuring their reflection and transmission spectra. The scattering layer was then modeled by a stack of plane-parallel plates, and this gave entirely satisfactory results.

Later, at the Institute of Physics of the AS BSSR, special subelements were created to study problems in the optics of scattering media. Taking into account the backwardness of this field of knowledge at that time, it was necessary to examine not only applied problems, but also basic, fundamental problems: the scattering of light by individual transparent and absorbing, spherical and nonspherical particles (for example, in aerosols), the multiple scattering of light, the formation of a deep scattering mode in media with arbitrary scattering index, the determination of the optical parameters of weakly and strongly scattering media (water, the atmosphere, aerosols, photographic materials, luminescent screens, blood, etc.), using the theory

of the transfer of beam energy and the theory of similitude to explain the characteristics of scattered radiation, and the modeling of real scattering objects in laboratory conditions.[1]

With the advent of high-power laser light sources it became necessary to study the laws of propagation of directed fluxes in a real scattering medium and the dependence of the optical parameters of this medium on the density of the incident radiation, and also on the degree of its coherence.

The appearance of pulsed lasers with short pulse length made it possible also to develop a qualitatively new field -- the study of features of the non-steady-state scattering of light. If the radiation flux is of short duration, the signal from scattering objects located at varying distances from the light source reaches the observer at different times. The investigation of the temporal characteristics of the scattered radiation made it possible to formulate basic principles of laser (rapid) probing of the atmosphere and ocean, the creation of systems for optical radar, range-finding, vision, and information transfer in scattering media. This entire cycle of work was completed by the development of engineering methods for calculating light fields in real scattering objects.

Theoretical investigations were performed simultaneously with experiment. In the Institute of Physics an entire series of instruments was created for studying the attenuation and scattering of light in water, the atmosphere, and other media.[2] A number of hydrooptical instruments were produced in small series. Note should be made also of instruments developed in the Mogilev division of the Institute of Physics of the AS BSSR for estimating the quality of strongly scattering media for practical use (screens, paper, powders, etc.). One of the most recent instruments of the Institute of Physics, called the lidar, has particularly valuable properties. It makes it possible to investigate properties of the atmosphere using a pulsed laser light source (pulse length approximately 10^{-8} s) with tunable wavelength. The capability for varying the wavelength makes it possible to increase by many times the amount of information about the object. The instrument records not only the intensity but also the polarization of the scattered radiation. Use has

[1]In the Institute of Physics a special 50-meter water basin was created for simulating the passage of light in specific conditions.

[2]The successful development of apparatus for probing the atmosphere using lasers is now also being conducted at the Scientific Research Institute of Applied Physical Problems of the BSU.

also begun of light sources with picosecond durations (pulse length approximately 10^{-11} s). The creation of hydrooptical apparatus was stimulated by experimental investigations under natural conditions (Lakes Svityaz' and Naroch', the Black Sea, the Sea of Japan, and the Atlantic Ocean).

Ever greater importance attaches also to the solution of the inverse problem of the optics of scattering media: the determination of characteristics of the medium according to the intensity, polarization, and frequency of the scattered radiation. It has been shown through experiment that the optical properties of the medium may be determined rapidly at great distances with high spatial resolution. It is possible also to probe highly inhomogeneous media (for example, clouds) using lasers. Not long ago one of the first optical studies of the process of cloud formation was performed.

Methods applied in the optics of scattering media have been improved constantly. In the propagation of modulated radiation in a scattering medium the phase is shifted and the depth of modulation is varied. These parameters may be used to describe properties of the medium (for example, its attenuation index). The use of interference phenomena occurring through the superposition of the scattered radiation and a given reference beam makes it possible to improve greatly the spatial resolution of radar systems. The method is particularly effective in the investigation of dense scattering objects (paper, plant tissue, blood, show, etc.). Consideration of the Doppler shift in radiation frequency is very effective in solving certain problems in the optics of scattering media.

Results of the theoretical investigation of the light field within the particle have been applied unexpectedly in an entirely different field. They may be used to study heat production within massive objects irradiated with long-wavelength millimeter-wave radiation. Based on this, methods have been proposed for bringing out of storage transplant organs that have been preserved at low temperatures.

One important direction for research in physical optics was started at the Physico-technical Institute (1950) and then developed at the Institute of Physics and the Institute of Solid State and Semiconductor Physics. This was initially the study of the distribution of stimulated optical anisotropy arising in a medium during irreversible plastic deformation. As is well known, the optical method of studying stresses arising in elastic solids produced by an external effect of some sort was in wide practical use even before the time of Brewster. However, the application of a similar method to

the plastic flow of material always encountered serious difficulties. These were overcome only recently. First, materials were found experimentally which were suitable for modeling the corresponding processes. In the second stage a detailed theoretical and experimental investigation was made of optical anisotropy arising in the flow of viscous and viscously elastic media. This included development of the fundamentals of the phenomenological and molecular theory of the phenomenon of stimulated optical anisotropy produced by the flow of the medium, the creation of special apparatus, and the study of flow processes under the most varied conditions of deformation. This polarization-optical method has become very fruitful in the study of the behavior of solutions and melts of polymers and many free-flowing substances.

Starting in the mid-1960's at the Institute of Physics of the AS BSSR and the BSU, systematic investigations using covariant methods were begun into the effect of stimulated anisotropy and gyrotropy occurring under the influence of external electrical and magnetic fields.

Control of a laser beam in space (its focusing and deflection) is an important scientific and technical problem, arising immediately upon the advent of lasers. Interesting results have been obtained in Belorussia, as well as other places. In the Institute of Heat and Mass Transfer imeni A. V. Lykov of the AS BSSR gas lenses are under development which may be used to focus high-power laser radiation. In the Institute of Physics laser flux is controlled using inhomogeneous electrical fields.

Modern experimental practice required the theoretical investigation of the laws of propagation of real light beams. The usual description using infinite plane waves is not always applicable. In many cases it is necessary to take into account limitations of light beams (especially in studying anisotropic and inhomogeneous media). In the Mogilev division of the Institute of Physics and at the BSU a detailed analysis has been performed of the properties of Gaussian beams, providing a good description of many actual phenomena. In addition to Gaussian beams with ordinary circular symmetry, elliptical light beams were examined. Also studied was the effect of laser resonators on the properties of Gaussian beams formed during generation.

The advent of lasers caused an intensification of interest in the problems of statistical optics and the theory of coherence. Systematic theoretical investigations of coherent properties of optical fields have shown, in particular, the effect of coherent

properties of the light source on the intensity distribution of diffracted or scattered radiation. A clear form has been found for the multidimensional distribution function of electromagnetic fields which are coherent in the first order. In the investigation of single-mode optical fields it was possible to explain successfully the role of correlations of the intensities of the electromagnetic field of higher orders. Also examined was the problem of the formation of radiation with given statistical parameters, extremely important for a number of experimental situations. Considerable attention was given to establishing the link between the entropy of optical fields and their coherent properties.

Spectroscopy and luminescence

Until the mid-1950's there was no research in the field of spectroscopy and luminescence in Belorussia. Only in the laboratories of four industrial plants were spectral analytic methods used.

In the past 26 years the situation has changed substantially. Scientific research at the Institute of Physics of the AS BSSR was strictly planned from the outset, and spectroscopy and luminescence have played a leading role in it. Development of these same fields was started in the newly organized schools of optics of the university, and later also in the Scientific Research Institute of Applied Physical Problems of the BSU. In addition, spectral-luminescent methods are now widely applied in many other institutes of the AS BSSR: those of Photobiology, General and Inorganic Chemistry, Physical and Organic Chemistry, Electronics, and the Mogilev division of the Institute of Physics. Characteristic of the Belorussian school of spectroscopy are the combination of experimental and theoretical research and the comprehensive development of theoretical spectroscopy.

One of the first works in this field (1956) was the classification of various types of secondary emission by methods of quantum electrodynamics. In studying the laws of light conversion (the intensities and shapes of lines and bands, polarization, the laws governing the extinction of after-emission) by atoms and molecules taking into account the surrounding medium, it became clear that luminescence differs from other types of secondary emission principally in the occurrence of intermediate processes between the acts of absorption and emission. For the classification of emission it is impossible to use only one indicator, for example that of the duration of emission.

The calculations described are correct for comparatively small intensities of the light interacting with matter. It has recently been discovered that at very large radiation intensities and with strictly resonant excitation a new, additional effect occurs, characterizing the interaction of light and matter; each level is split in two, and in the emission spectrum three lines appear in place of one.

In quantum electrodynamics the harmonic oscillator is widely used as a model for matter. However, its optical properties were insufficiently studied. In the literature it was erroneously asserted that the absorption coefficient of an oscillator is dependent on temperature. In detailed analysis it was discovered that for a harmonic oscillator the laws of linear optics are correct at any intensity. All the results of quantum and classical theory pertaining to the optical properties of a harmonic oscillator are in complete agreement.

In any other objects at particular (not always high) intensities of irradiation saturation effects inevitably occur: the Bouguer law is violated, absorption and emission powers tend to a limit, polarization of luminescence decreases, and stimulated dichroism occurs. The radiation density necessary for the occurrence of saturation effects is determined by the parameter of nonlinearity, which is unambiguously linked to the probabilities of transitions between levels. As shown still later (1961), this same parameter of nonlineariy determines at the same time very important characteristics of laser systems.

In studying features of the absorption and emission of light by atomic systems it became necessary to describe quantitatively the population of levels, the absorption coefficient, the power, the quantum yield, the duration and polarization of luminescence, and stimulated dichroism as functions of internal parameters of the objects under study. The methods of quantum mechanics, based on the second approximation, were clearly not suitable, and exact solutions to the equations are in practice impossible. It was for this reason that there was developed in the Institute of Physics an approximate but extremely simple probabilistic method for calculating the functions under investigation. It was at that time that the limits of applicability of the method were evaluated. It made it possible to solve spectroscopic problems for systems with discrete and continuous levels, for atoms, complex molecules, and semiconductors; to describe, explain, and predict a considerable number of experimental facts.

A large body of research by Belorussian scientists was devoted to the luminescence of complex molecules. Characteristic of these molecules are an abundance of strongly interacting

vibrational degrees of freedom and the rapid redistribution of vibrational energy within the excited molecule. As became clear, this causes a loss of the individual properties of distinct degrees of freedom; only average values of transition probabilities are revealed through experiment. As a result of the rapid exchange of energy with the solvent, the individuality of separate molecules is also lost. A group of molecules behaves as a single collective. It is for this reason that the law of luminescence quenching for solutions of complex organic substances is exponential, and the quantum yield and spectrum of the luminescence are independent of the method of excitation.[3]

Study of the absorption and luminescence of vapors of complex molecules has assumed particular importance. In this case the individual properties of the molecules are evident. The change in stored vibrational energy of the excited molecule during a change in the frequency of irradiating radiation, an increase in concentration, or the addition of a foreign gas, may be studied successfully in detail. These changes lead in turn to a change in all the optical characteristics of the substance. The phenomenon of the strengthening and weakening of vapor fluorescence produced by admixtures of gases, revealed by B. S. Neporent and N. A. Borisevich, was registered recently as a discovery. On the basis of this it was possible to establish features of the exchange of energy within and outside the molecule and of many other processes occurring in molecules after excitation, and to develop a great range of methods for determining the optical parameters of complex molecules.

Studying the optical properties of vapors of complex compounds as the pressure of a gaseous admixture is increased makes it possible to approach correctly an understanding of the properties of solutions and the effect of intermolecular interactions. Subjected to particularly thorough experimental investigation were the temperature dependence of absorption and luminescence spectra of solutions, the temporal behavior of the luminescence process, the effect of the solvent on the formation of spectra, and along with this the orientation interactions of excited molecules with solvent molecules. Whole classes of substances

[3]As explained in recent work at the Institute of Physics, this is true if thermodynamic equilibrium of the complex molecules and the solvent molecules can be established over the lifetime of the excited state of the complex molecules. If the excited molecule has a dipole moment and the solvent is polar, then the fluorescence spectrum depends to a considerable extent on the frequency of the exciting radiation.

were studied specially: porphyrins, phthalimides, phthalocyanines, rhodamines, polymethine dyes, etc. The electronic spectra of cellulose were studied for the purpose of spectral analysis.

Specific problems arose in the comprehensive investigation of the optical properties of porphyrins, and most importantly chlorophyll. Strnage as it may seem, the interpretation of the spectra of these most important substances was long in error. A reliable interpretation was reached only based on the successive application of all contemporary spectroscopic methods: study of the polarization of luminescence, flash photolysis, quasilinear spectra, and infrared and Raman spectra. Currently occupying the center of attention of Belorussian scientists working on problems in photosynthesis are processes in the molecule after the absorption of light, intramolecular transfer of excitation energy, deactivation of excited molecules, vibrational relaxation in excited molecules, features of molecules in the triplet state, fundamental details of the initial stage of the photosynthetic process, and features of the ionization, complex-formation, and association of chlorophyll-like molecules. Construction of the energy and probability diagrams of the chlorophyll molecule has already been completed.

In the Institute of Photobiology of the AS BSSR, which is actively working on problems of photosynthesis, methods of molecular spectroscopy are successfully being used to study the processes of aggregation of plant pigments and the transfer of energy between them in early stages of the formation of photosynthetic apparatus. Spectroscopic research has aided in developing new concepts of the formation of the photosynthetic pigment system in plants and in demonstrating the conservation of molecular organization of submembrane particles produced by chloroplasts of higher plants. Also at the Institute an oscillator model was constructed for the basic luminescence center of albumen -- the tryptophane molecule, and the albumen-like nature of ultraviolet fluorescence in cells was demonstrated. This research furthered the widespread application of luminescence analysis in the solution of problems in biophysics, biochemistry, cytology, immunology, and embryology. Discovered in particular was the capability of albumens in solution and in the cell to store the energy of electrical excitation for extended periods; many characteristic properties of biological membranes were also revealed.

Very convenient for studying the intramolecular transfer of excitation energy are organic complexes of rare-earth elements. Their spectral and luminescent characteristics are widely used

at the Institute of Physics to determine the mechanism, conditions, paths, and probability of transfer and deactivation of activation energy, and the connection between the structure and spectrum of the molecule. On the basis of this, rational guidelines have been proposed for synthesizing promising rare-earth luminophores, and very sensitive methods have been proposed for distinguishing rare-earth elements. Similar problems have been solved successfully at the BSU in research on the properties of uranyl compounds. Spectra of these compounds are exceptionally sensitive to changes in structure, external effects, and temperature, and therefore provide rich information on features of intramolecular and intermolecular processes.

Of substantial importance for the systemization and interpretation of experimental data was the derivation of the universal relationship linking the power of luminescence and the coefficient of absorption of complex molecules. It was shown that the ratio of these quantities is independent of the individual properties of particles. The universal relationship holds if an equilibrium distribution of excited molecules by vibrational levels can be established before light is emitted. Using this relationship, it is possible to simplify many experimental investigations. The degree of violation of equilibrium is now judged according to deviations from it.

In studying the optical properties of semiconductors it was noted that use could be made of the correspondence between the broad energy zones of these materials and the set of electron vibrational levels of complex molecules, and also the correspondence of resdistribution processes occurring in them between the acts of absorption and emission of light. As a result, an extended similarity was revealed both in the methods and in the results of calculations of the absorption coefficient, the emission power, and other optical parameters of complex molecules and semiconductors. For describing the distribution of complex molecules by electron vibrational levels it is possible to use, in particular, the concept of Fermi levels. Further, it turned out that the universal relationship between absorption and emission spectra, generalized to the case of high light intensities, is identical in form for both complex molecules and semiconductors.

In experimental research into the optical properties of semiconductor materials a large number of interesting properties were discovered. The use of frequency-tunable lasers made it possible for the first time to study luminescence excitation spectra in detail. There is also great interest in streamer luminescence in semiconductors, discovered in zinc sulfide and other substances. According to properties of streamer luminescence it is possible to determine crystallographic cleavage

planes. The spectrum of streamer luminescence depends substantially on the volume absorption of light in the crystal. Streamer luminescence may be quenched by irradiating the crystal with a sufficiently intense flux of light.

As early as 1922 S. I. Vavilov emphasized that all equilibrium optical processes, including luminescence, take place against a background of preceding thermal equilibrium. However, it became possible to take the thermal background into account quantitatively only on the basis of a probabilistic method of calculation. The initial formula for luminescence power was derived by Belorussian scientists jointly with scientists of the Physics Institute of the USSR Academy of Sciences. In the process of further developing the fundamentals of the theory of luminescence it was possible to explain the phenomenon whereby results of external effects on the quantum-mechanical system are dependent on temperature and on properties of the medium with which the system was in equilibrium. Analysis showed that the excitation of the system may be two-fold; in both cases the Boltzmann distribution is violated, though in one case the number of particles at higher levels is increased, and in the other -- decreased. For negative excitation it is sufficient to replace the usual light source with some sort of cooled body whose temperature is lower than that of the excited system. Negative excitation may arise in many cases also in the use of normal methods of irradiating systems. When equilibrium is violated, at some frequencies there is the usual positive luminescence, and at others -- negative luminescence. A negative luminescence power signifies that the light energy emitted by the system is less than the power of thermal radiation corresponding to the previous equilibrium state. In exactly the same way the existence of a negative photoelectric effect and a negative acoustooptical effect were established. The replacement of a hot light source by a cooled body is equivalent in all the formulae of theoretical optics (in the linear approximation) to irradiation of a system with a negative light flux. This last result was immediately confirmed experimentally at the BSU. The negative acoustooptical effect was observed by Leningrad physicists. Negative luminescence has not yet been discovered. It must be sought in the infrared portion of the spectrum, where thermal emission during radiative transitions between vibrational levels is especially great.

In the theoretical analysis of properties of multilevel systems, unexpected results came to light (1955, Institute of Physics of the AS BSSR, the BSU, and the Physics Institute of the USSR Academy of Sciences). It turned out that with some excitation methods the luminescent energy yield may be greater than unity.

The existence of such systems does not contradict the second law of thermodynamics; in nonequilibrium systems external effects may initiate the conversion of a portion of the thermal energy into luminescent energy, and the effect of light may be to cool the body.

In Belorussia methods of molecular spectral analysis associated with the study of vibrational spectra are constantly being developed. At the Institute of Physics a basic objective has become the study of various hydrocarbons (particularly cellulose), resins, and certain artificial polymers; at the BSU, peroxides are studied. In all cases a detailed study is conducted of the dependence of spectra on the composition and structure of molecules, and basic characteristic features are determined for bonds and bond groups. In the analysis of spectra particular attention is given to their dependence on the many possible conformations of the molecule. The spectra of hydrocarbons turned out to be highly sensitive to variations in structure; as a result of this, physicists and chemists jointly succeeded in completing a considerable number of technical projects aimed at the creation of new materials whose properties are specified in advance. The use of spectroscopy in the development of a new technology for processing plant fibers produced an economic savings of 42 million rubles. Recently a great deal of attention has been given (jointly with Tadzhik scientists) to the systemization of the spectra of various varieties of cotton, cotton cellulose, and products of their structural modification, and to chemical effects, deuterium exchange, and the explanation of the uniqueness of spectra of varieties of cotton plants infected with wilt.

Further increase in the efficiency of molecular spectral analysis, as with all other repeated experimental investigations, will result from its automation. In the center for the automation of spectroscopic measurements, which has been in operation for six years now at the Institute of Physics of the AS BSSR, development is being completed of an automatic system for determining the structure of organic molecules. Information obtained using spectrometers for the infrared, visible, and ultraviolet regions of the spectrum, and also mass and nuclear magnetic resonance spectrometers, goes into a computer in whose memory are stored characteristic features of the given class of organic compounds. The computer processes the structural information logically and constructs a set of possible molecular structures satisfying the initial spectra.

At the Mogilev division of the Institute of Physics of the AS BSSR original methods have been proposed for local infrared spectrophotometry of surface layers of fibers and films using the phenomenon of the disruption of total internal reflection. The anisotropy of optical and spectral characteristics is used to investigate the processes of crystalization and orientation

of many materials produced in the republic. At the Institute of Photobiology of the AS BSSR a simple and rapid luminescence method has been developed for determining the albumen and fat content of milk. A considerable number of similar spectro-analystical methods for solving a variety of applied problems has been developed as well in other institutes of the Academy of Sciences and in scientific institutions and departments of VUZ's in the republic.

Beginning in 1955 members of the Institute of Physics (and also the BSU and the Institute of General and Inorganic Chemistry of the AS BSSR) have started the mass introduction of methods of emission spectral analysis at Belorussian enterprises. Simultaneously specific methods were developed, light sources were studied and improved, and factory personnel were trained. At present the methods of atomic spectral analysis are being successfully applied in over 150 enterprises, in institutes, and in other institutions in the republic. In the last ten years there has been a systematic investigation of the spectroscopic properties of plasma obtained through the action of weak laser radiation on matter. On the basis of this, effective methods of laser spectral analysis have been developed, along with the corresponding apparatus, which has now been produced in small quantities. The basic advantages of laser spectral analysis include the capability for analyzing refractory and electrically non-conducting materials, the local nature of the analysis, the suppression of the effect of "third elements" and the structure of the specimen, and the sterility of the analysis.

In 1960 at the Institute of Physics spectroscopic research into the properties of plasma were begun. Work in this direction has expanded quickly as a result of the requirements of new technology. A series of plasmatrons of original design was created with a plasma temperature of up to 100,000°C and pressures from 0.1 to 100 atmospheres. The basic goal of the research is to develop spectral and laser diagnostic methods for various types of plasma and to study the interaction of plasma and high-power laser radiation. A number of successful methods and instruments have been developed for measuring the temperature of a plasma medium and the particles dispersed in it, for measuring the speed of movement of light-emitting particles in the plasma, and for measuring the spectral characteristics of radiation reflected from various objects. The accumulated experience has made it possible to find important industrial applications. Thus, for example, it was discovered that the use of plasma streams is economically sound not only for cutting and hardening metals, but for processing ceramics, silicates, and concretes in order to form protective and decorative coverings.

The experimental research of Belorussian spectroscopists is, as a rule, combined with theoretical analysis. Here it is desirable to note calculations of the properties of radiation in atomic gases not in vibrational equilibrium and the development of efficient methods for the approximate solution of integral and differential equations of radiation transfer taking into account the effect of scattering particles and the non-isothermal nature of the gas.

A number of problems of interest to Belorussian spectroscopists are associated with general problems of theoretical physics. Among them are the development of efficient methods for calculating the energy spectrum and wave functions of many-electron atoms, molecules, and crystals and the development of new analytical methods in steady-state and non-steady-state perturbation theory, making it possible to obtain closed and simple solutions to the Schrodinger equations for centrally symmetrical quantum systems with arbitrary perturbation potential and degree of degeneracy. It should be emphasized that on the basis of this it was possible to propose efficient methods for analyzing the single-photon and two-photon spectra of atoms, activated crystals, and dimers.

In the theoretical study of the luminescent and spectroscopic characteristics of a substance, its volume element is usually examined. However, before it can reach an instrument, the radiation is repeatedly reabsorbed. A comprehensive theoretical and experimental analysis of the effect of secondary processes of light absorption and emission was conducted as early as the 1950's

As the concentration of atoms or molecules is increased, substantial qualitative changes in their optical properties sometimes occur. Thus, for example, resonant emission by vapors at high pressures is converted to reflection and ceases to be quenched by gaseous admixtures. Interesting also is the occurrence of coherent spontaneous light emission. The study of collective effects of this type has become one of the major efforts in theoretical spectroscopy being expanded in Belorussia.

At the conclusion of this section the work of the Institute of Physics should be recalled in the field of quantum electrodynamics in the precise formulation of the most important equations of the theory of the interaction of light and matter. In this work for the first time is a detailed derivation from fundamental physical equations of concise equations for the density matrix of particles of matter in a radiation field, and a detailed examination of the effect of radiation on spectral and other optical characteristics of transparent and resonant media.

Quantum electronics, nonlinear optics, and laser spectroscopy

Scientific research in the field of quantum electronics and nonlinear optics, concentrated initially at the Institute of Physics of the AS BSSR, grew logically from previous work in the field of spectroscopy and luminescence and until now has been closely tied to it. It may be said that in Belorussia there has been a development predominantly of optical aspects of quantum electronics. Theoretical analysis of the process of interaction between light and matter, performed from the outset taking into account the stimulated emission of light, made it possible even in the period before the appearance of lasers (1958) to obtain analytical expressions which contained already at that time solutions to some problems in quantum electronics. We were already discussing nonlinear effects associated with the saturation of levels. In using the probabilistic method for calculating the populations of three-, four-, and multilevel systems, and also their dependence on the intensity of irradiation and parameters of the system it was immediately clear that in a number of cases there arises an inversion in the population of levels, and the absorption coefficient becomes negative. The formulae obtained made it possible to find the intensity threshold for the exciting radiation. In 1959 by a similar method it was shown that in the excitation of complex molecules the absorption coefficient in the anti-Stokes regions of the spectrum becomes negative.

In 1969, after the appearance of the first articles on ruby lasers, work on lasers began to develop quickly. Fundamental attention was given to establishing the connection between stimulated and spontaneous emission and the connection of the spectral and luminescent characteristics of a substance with features of its generation. Most quickly developed at first were theoretical methods of investigation -- the development of simple and reliable methods for calculating optical properties of solid state lasers. The goal of the work was the analysis of the mechanism of action of specific laser systems and the discovery of the limits of their capabilities, as well as the sources of energy losses, the interpretation of many continually recurring experimental facts, and principally the search for convenient analytic expressions determining the dependence of the power, threshold, and efficiency of generation on parameters of the active medium, pumping intensity, properties of the resonator, the temperature of the active element, and its form. In all cases particular attention was given to the optimization of the mode of generation. Important problems were associated with the study and elimination of energy losses in noise amplification, the study of the effect of heating of

the active element, and the study of the distribution of the pumping energy and the generated radiation within and outside this element. It was then that matting of the lateral surface of the active rod was recommended. Many difficulties had to be overcome in studying the process of the temporal development of generation and the construction of the theory of single-pulse generation, as well as the repetitively pulsed mode. Most results by far were obtained with the probabilistic method. At present this method is generally accepted, and the limits of its applicability are clearly defined.

The development of quantum electronics was inseparably linked, particularly in the first stage, to the search for new laser media with good output parameters. Theoretical work on this problem was conducted at the Institute of Physics of the AS BSSR jointly with the Institute of Crystallography of the USSR Academy of Sciences. Under consideration then was the rejection of the method of random tests requiring the growth of crystals of large size. It was necessary to find a quantitative link between the luminescent characteristics of a substance and its lasing capacity, and then to propose a specific procedure for measuring luminescence parameters and on this basis to predict in advance the effectiveness of the laser systems created. These methods were developed and used repeatedly. The most important result in this area was the discovery of a new class of lasing compounds -- the organic dyes.

In parallel with theoretical research, as early as 1962 the development of comprehensive experimental research was begun. Initially the formulae proposed by theoreticians for calculating the energy and temporal characteristics of solid state lasers were verified. Simultaneously, convenient methods were developed for determining the loss coefficient of the resonator, the most important parameter characterizing the properties of the laser system and as such a substantial influence on its output parameters.

In the same research cycle was a special examination of the optical properties of ruby and of neodymium:glass. The populations of their levels were measured at high excitation intensities both before and after lasing, and their nonlinear properties resulting from the saturation effect were described. Simultaneously the loss coefficient due to the amplification of noise radiation was measured. Particular attention was given to the properties of ruby in the triplet state. Study of the properties of this state in strong magnetic fields made it possible to explain features of the splitting of the R_1 and R_2 lines. In all cases the energy balance of the lasing system was formulated.

In the first stage of the development of gas lasers the physical processes occurring in a mixture of helium and neon and in a He-Ne laser were studied in detail, along with the mechanism for forming an inversion in the plasma of a gas discharge, the lasing mechanism, and the effect of temperature on lasing parameters. Simultaneously with this, numerical models of the active medium were proposed, reflecting basic features of the process and making it possible to estimate the dependence of properties of the generated radiation on gas pressure, discharge current, tube diameter, and properties of the resonator. Simple experimental methods were also proposed for measuring the gain and loss coefficients, as well as methods for frequency selection and for achieving single-frequency and controlled two-frequency lasing modes.

The amount of research performed at the Institute of Physics expanded quickly. All the research for the period from 1964 to 1978 may be divided into four categories. These are the creation of organic dye lasers; the development of a method for controlling the energy, time, frequency, and polarization characteristics of lasers and the development on that basis of new types of instruments and devices; the study of features of the interaction of high-power laser fluxes with matter, and, finally, the application of laser technology to solve varied and fundamentally new problems in spectroscopy, holography, and other areas of science, as well as the practical use of lasers in various branches of engineering.

As already noted, the systematic study of the connection between luminescent and lasing characteristics of a substance made it possible as early as 1964 to predict the achievement of lasing in solutions of complex molecules. It was established that the lasing efficiency of a number of molecules could be rather high. At the same time, all the basic unique features of the anticipated lasing were formulated in advance, starting with the capability for continuous variation of its frequency and spectral width. Two years later the lasing of dye solutions was in fact achieved by pumping both with radiation from solid state lasers and by radiation from ordinary flash lamps. Subsequently it was shown that there is a huge multitude of complex molecules with the capacity for lasing. Along with luminescence, lasing is one of their basic optical properties.

The study of the link between the lasing properties of molecules and their structure made it possible to find molecules having favorable energy characteristics. Using 10 to 15 solutions it was not difficult to obtain high-intensity laser fluxes at any frequency in the region from 210 to 1100 nm, and to provide

continuous tuning of the radiation frequency. For controlling the frequency and bandwidth, use was made of diffraction gratings, interferometers, temperature variation, the electrochemical method, and the distributed feedback method. Theoretical analysis made it possible to explain the dependence of lasing parameters on internal properties of the system. The experience accumulated served as the basis for the development of a series of instruments intended for series production.

Among the most substantial results in this field should be included the discovery in 1973 of lasing by complex molecules in the gaseous phase. Lasing was achieved both in pure vapors of various complex molecules and in vapors with gaseous admixtures. The lasing has a number of very valuable qualities. Under study at present is the possibility of lasing vapors of complex molecules by collisional excitation using electrons.

For controlling the radiation frequency of a dye solution or a solid state laser (variation of the frequency according to a definite rule over the time of a single lasing pulse), a high-speed interferometer-selector was developed having piezoelectric control. This device may be used for modulating the frequency and transmitting information. Reliable stabilization of the radiation may be achieved as necessary by similar methods.

Among the problems associated with the control of the frequency of laser radiation should be included additionally a number of investigations in the field of nonlinear optics and the phenomenon of stimulated Raman scattering. By using the covariant methods developed at the Institute of Physics, a consistent theory was constructed for the conversion of laser radiation by nonlinear anisotropic crystals, a number of methods were proposed for optimizing this process, and several effective devices were created making it possible to double the frequency or mix (add or subtract) the frequencies of two laser fluxes, including those from dye solution lasers. Based on this, lasers were constructed with which it is possible to obtain intense, tunable laser radiation in the ultraviolet region of the spectrum.

For obtaining intense, tunable radiation in the near and far infrared region of the spectrum, the method of stimulated Raman scattering was successfully used. Recently several laser designs based on rotational transitions have been proposed and constructed, making it possible to obtain tunable laser radiation in the far infrared region. An inversion between rotational levels of excited vibrational states is produced by radiation from a CO_2 laser.

The frequencies, intensity, and polarization of laser radiation depend to a great extent on properties of the resonator. By applying various types of resonators and varying the loss coefficients, it is possible to obtain substantially different lasing parameters. To this end a special method was developed for calculating the polarization and frequency characteristics of complex resonators of various types and of regenerative amplifiers with arbitrary choice of anisotropic devices. Simultaneously, a theory of mode interaction was constructed, making it possible to analyze the mode structure of the field within the resonator and its effect on lasing characteristics. Analysis of the lasing stability of various modes and lasing channels made it possible to explain problems associated with the tuning of lasing channels and the occurrence of two-frequency lasing. Constructed for the first time were two-dimensional and three-dimensional resonators (mirrorless lasers), now known as waveguide resonators, and a number of other laser devices based on the use of the phenomenon of total reflection.

Particular attention was given to the development of the theory of ring lasers, the investigation of the polarization and frequency characteristics of ring lasers with various interacting devices, the construction of systems with various types of oscillations in opposite directions, and the development of a consistent quantum statistical theory of ring lasers taking into account collective properties of a system of active atoms. Based on this a new mixing mode was predicted (and later produced) with high stability of the difference frequency.

A large cycle of theoretical research was devoted to control of the temporal characteristics of lasing. One of the most promising control methods is the insertion into the laser resonator of nonlinear elements whose transmittance depends on the radiation density. Using them it is possible to obtain lasing not only in huge single pulses, but also in a form with continuously or periodically varying intensity. Passive (transmitting or attenuating) filters may be used as the nonlinear elements, as well as modulators which vary losses according to a given rule. Ruby (in a ruby laser) may also serve as a passive shutter. In recent years fundamental attention has been given to the study of high-frequency modulation of single pulses and their dependence on the switching speed of losses taking into account the transit time of radiation within the resonator and the properties of the mirrors and other resonator elements. Also analyzed theoretically and investigated experimentally were features of mode synchronization in ruby lasers resulting from high-frequency modulation of losses at intrinsic

resonator frequencies (mode locking). All this research cycle may also be considered one of the first foundations for effective methods of intracavity optics.

The experimental study of various types of shutters, including passive dye shutters, making it possible to generate single pulses of high energy, led to the creation of several successful designs for single-pulse lasers.

In the first stage of the development of laser systems, fundamental attention was usually given to their energy, temporal, and spectral characteristics. Recently attention has been turned to the practical value of their polarization parameters and to the development of convenient methods for calculating the polarization of various specific systems and methods for varying them in a controlled manner.

A steady expansion has begun in work which may be considered to come under laser spectroscopy. This is entirely consistent with the basic range of disciplines at the Institute of Physics of the AS BSSR. This work includes, in particular, the use of lasers to study optical properties of complex molecules and to study the fundamentals of a multitude of intra- and intermolecular processes occurring in the excited state following the absorption of light. Used earlier for this purpose was the study of features of absorption and luminescence, and now a new method has been added to them -- the study of features of lasing.

The development of methods of intraresonator spectroscopy must also be considered a major branch of laser spectroscopy. As already evident, the properties of a laser beam may be varied if objects of some sort are placed within the resonator. A small change in their parameters leads to a substantial change in radiation characteristics: intensity, polarization, frequency, and temporal behavior. This may be used not only for controlling laser flux, but for solving the reverse problem -- the study of the composition of a substance introduced into the resonator by measuring its spectrum and coefficient of absorption, its dimensions, form, and index of refraction. Since polarized radiation repeatedly passes through the object studied, the sensitivity of methods for determining, for example, the absorption coefficient, is increased by three to five orders of magnitude. Dye lasers with laser, lamp, and continuous pumping make it possible to measure the value of optical density to an accuracy of 10^{-3}, 10^{-5}, and 10^{-6}, respectively.

The methods of laser spectroscopy are a good complement to ordinary magnetooptical methods. If a substance placed inside the resonator is subjected to a longitudinal magnetic field,

the plane of polarization of the laser radiation is rotated. The magnitude of the roataion is a function of the optical density; the sensitivity with which the density may be determined can reach $1C^{-10}$, making it possible to determine the concentration of very small quantities of a substance (hundreds of atoms and fewer). The study of two-photon transitions in media placed in a longitudinal magnetic field has made it possible to propose mew methods of high-resolution intra-resonator spectroscopy and to resolve structures whose components are separated by distances less than the natural line width.

Many other methods developed at the Institute of Physics should also be considered to fall under laser spectroscopy: laser diagnostics of plasma, laser interferometry of plasma, laser spectral analysis, and laser spectroscopy of plasma. Using lasers it is possible to obtain plasma with a wide range of thermodynamic parameters: from rarified to super-dense, from low to thermonuclear temperatures. This has made it possible to obtain and study the spectra of multi-charged ions with a record number of electrons removed (as many as 30 to 50).

A considerable amount ow work at the Institute of Physics is devoted also to the study of properties of semiconductor laser systems. Included is first of all the development of effective methods for calculating the output characteristics of injection lasers, the search for optimum modes, and the determination of internal parameters of the semiconductor. A number of specific laser systems have also been developed, making it possible to reduce the energy lost in the amplification of luminescence, and specific features of optical pumping methods have been examined.

The study of molecular lasers began in Belorussia following the first publications on them. In theoretical work particular attention was given to spectral characteristics of the output radiation, to calculating the rotational structure of laser vibrational levels, to the redistribution of energy between them, and to calculating the population of levels. Gradually the primary concentration of theoretical research shifted to the study of optically pumped molecular lasers. Such systems are very promising since they may operate at very high gas pressures and are capable of being continuously tuned in frequency.

In the experimental study of properties of molecular lasers special attention was given to the kinetics of infrared luminescence of molecules under selective pulsed excitation of individual rotational levels and to the determination of deactivation rates of laser levels. Simultaneously a number of

new laser systems were created: a high-pressure CO_2 laser with preionization of the gaseous medium by ultraviolet radiation, a photoionization laser, lasers operating on rotational levels, and a cw CO_2 gas dynamic laser with nitrogen preheating by an electrodeless high-frequency discharge. Very promising are new types of gas dynamic lasers developed at the Institute of Heat and Mass Transfer of the AS BSSR. In these lasers there is selective excitation of components of the gas mixture and subsequent mixing in a supersonic flow. The output power of the lasers is 10^3 to 10^4 watts.

The development of quantum electronics was inevitably accompanied by the formation of a new science -- nonlinear optics. The laser itself is a nonlinear system. In the action of a high-power laser flux on matter the usual laws of nonlinear optics become unsuitable. The efforts of the Institute of Physics in the field of nonlinear optics were directed toward the systematic (and first of all theoretical) investigation of these phenomena. First to be developed was the mathematical apparatus suitable for describing nonlinear interactions of light and matter. As already noted, it was based on equations for the mean density matrix. Using the proposed method, expressions were found for the nonlinear polarization of various media in the field of high-power radiation, and laws were established governing variations in the spectral characteristics of matter produced by light. Results of the calculation of certain unique optical phenomena were compared with experiment and produced good results.

Among the nonlinear effects systematically investigated by Belorussian scientists both theoretically and experimentally are the doubling and shifting of frequencies, two-photon absorption, and stimulated Raman scattering.

Laser radiation of sufficient intensity is capable of melting and vaporizing a great variety of materials. This is the basis for many technological applications of lasers. Scientists in Belorussia, as in other USSR scientific centers, have conducted a detailed study of the features of laser erosion flares, their rate of formation, their gas dynamic structure, and the formation of shock waves in the flare. The interaction of radiation with metals and dielectrics was investigated. At present fundamental attention is being given to processes of the interaction of laser radiation with plasma flares formed under the action of the same radiation and to the study of air breakdown caused by CO_2 laser radiation near a target. The use of laser radiation to change the physical structure of polymers has become an independent direction for research.

The advent of a new direction for Belorussian research -- dynamic holography -- must be considered an important result. In contrast to ordinary holography, in this case nonlinear light-sensitive media are used to record non-steady-state wave fields. Inhomogeneities in the index of refraction or the absorption coefficient induced in them may be viewed as short-lived holograms of the incident light flux, and diffraction (or scattering) of light from them may be seen as the readout of information from the holograms. Light-induced diffraction may be used for the transfer of images from one flux to another. The advantages of nonlinear media as light-sensitive materials include their resolving power, the reversibility of the processes, and the high rate of operation. The basic distinguishing property of dynamic holography is the simultaneous recording and processing of non-steady-state wave fields. Both processes proceed as a single process of the interaction of light with matter. Recently at the Institute of Physics of the AS BSSR hologram image generators which amplify holograms have been constructed. The methods of dynamic holography have begun to be applied also for determining the rates of processes occurring in recording media, for determining the lifetimes of excited states, diffusion coefficients, thermophysical properties, damping rates for acoustic oscillations, and for the study of a new phenomenon -- wave front reflection.

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In approaching the 60th anniversary of the formation of the Belorussian Soviet Socialist Republic and the Communist Party of Belorussia, the scientists of the republic experience a feeling of well deserved pride in all that has been accomplished in the economy, in culture, and in science. As a result of the unusually rapid development of scientific research in the republic, the Academy of Sciences of the Belorussian SSR in a short time has become one of the leading scientific centers of the Soviet Union. In 1979 it marks the 50th anniversary of its founding.

Belorussian scientists understand clearly that before them now are new and still more complex and responsible tasks, and they are confident that they will prove equal to them.

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PHYSICS

THE DEVELOPMENT OF INTEGRATED OPTICS IN THE USSR

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[Article by A. M. Goncharenko, L. N. Deryugin, A. M. Prokhorov, and G. P. Shipulo]

[Text] Integrated optics has by now been conclusively confirmed as a most important and promising area of science and technology. This has taken place as a result of fundamental theoretical and experimental research performed in the last 10 to 15 years abroad and in the Soviet Union, in particular at the International Friendship University, the Institute of Physics, and the Institute of Radio Engineering and Electronics of the USSR Academy of Sciences, at the Academy of Sciences of the Belorussian SSR, the Siberian division of the USSR Academy of Sciences, and elsewhere. As is well known, integrated optics includes problems in the propagation, amplification, generation, and conversion of light in thin film waveguides. The ultimate technical goal of integrated optics is the creation of microminiature planar functional optical elements, assemblies, and circuits principally for the transmission, storage, and processing of information. Achievements in the field of the technology of optical fiber and thin film waveguides in recent years provide a basis for the hope that integrated optical devices in the next 5 to 10 years will be widely applied in fields of science and technology.

The present review generalizes basic results of research in integrated optics performed in the oscillations laboratory of the Physics Institute of the USSR Academy of Sciences, in the school of radio physics of the International Friendship University, and in the Mogilev division of the Institute of Physics of the Belorussian SSR, working in close cooperation. The review is not intended to include fully all the work on integrated optics in the USSR. The bibliography cited contains principally publications by these groups, with the results of work by other groups and foreign authors represented in monographs and reviews [1-7].

Thin film waveguides. The first experimental and theoretical investigations of thin film optical waveguides used in integrated optics were performed in the 1960's [7-14]. Basic properties of thin film dielectric waveguides in the optical region were studied in these works, and their promise for practical application was demonstrated. Additionally, a number of initial investigations of optical thin film waveguides were associated with the theory of injection lasers [15], since a waveguide channel may exist in p-n junctions. The 1970's saw a rapid growth of the number of publications on integrated optics [5-7], [16-18].

The estimation of thermal losses in metallic and dielectric waveguides showed that purely dielectric asymmetrical waveguides are the best basis for planar optics [8,10]. Dispersion equations were derived and solved for them, and the dependence of delay and extinction on parameters and thickness of the carrier layer was found [8,9]. With low relative waveguide thickness the number of intrinsic waves is small and may be reduced to a single wave. If the thickness of the waveguide is close to the critical thickness, the field of the corresponding intrinsic wave penetrates deeply into the substrate, possibly producing interference of these waves with those of the substrate [19].

Anisotropic waveguides. Integrated optical devices for controlling the parameters of a light beam (modulators, filters, deflectors, etc.) are constructed as a rule based on crystal waveguides. Therefore considerable attention has been given to the study of anisotropic thin film waveguides [12,20-27]. Properties of thin film anisotropic homogeneous waveguides and inhomogeneous optical waveguides have been studied in detail in the case in which the orientation of the axes of the permittivity tensor permits the separation of TE and TM waves [12,21-25]. Expressions were obtained for the indices of refraction and the gain coefficients of intrinsic waves. It was shown that anisotropic waveguides may be used for the separation and conversion of TE and TM waves.

Diffusion waveguides. In glasses and crystals optical waveguides are produced basically by the methods of diffusion or irradiation by charged particles. In this case the waveguide layers are inhomogeneous; that is, the transverse profile of the index of refraction is described by some continuous curve. Waveguides having various profiles have been studied. If the waveguide channel is at a certain depth in the substrate, then the most suitable profile for calculations is the so-called Ekkart profile [7,15,21], for which the field is represented by hypergeometric functions.

A theory was developed for optical waveguides with arbitrary inhomogeneously laminar transverse distribution of the index of refraction, in which the basic concepts are the effective index of refraction and the effective thickness of the waveguide [28,29].

A universal method was proposed for the calculational and experimental determination of the profile of the index of refraction and the transverse fields of waveguide modes [30] by approximating the profile with a combination of two or more distributions (parabolic, exponential, etc.), for which the solution of the waveguide equation consists of known functions. The method provides high precision for waveguides with arbitrary number of modes and profile [31-35]. On the basis of the measurement of mode spectra, experimentally obtained indices of refraction of waveguide layers were calculated [36,37].

For a multilayer waveguide with a sinusoidal distribution of the index of refraction the solutions of Maxwell's equations are expressed in terms of Mathieu's functions [38-40].

Stripline waveguides. In integrated optics waveguides in the form of narrow dielectric strips are often used. In waveguides which are wide in comparison with the transverse dimensions of the light beam no substantial differences from a plane waveguide are observed [41]. Narrow strips may be modeled by rectangular waveguides [42-45]. Stripline waveguides have been produced by ultraviolet irradiation of polymethylmethacrylate films, thus changing their solubility in certain organic solvents, and by the diffusion of metal oxides through a mask [46-48]. Various approximate methods have been developed for calculating stripline dielectric waveguides [44,45,49,50].

Nonlinear waveguides. If the waveguide medium is not linear, nonlinear transformations are observed: frequency multiplication and parametric light amplification [10,51-56]. In [10,52] for the first time frequency doubling in optical film waveguides was obtained in the radiation (Cherenkov) mode. In lithium niobate waveguides frequency doubling was achieved in the waveguide mode, as well as frequency shifting of the laser radiation [54,55].

The field distribution in lithium niobate diffusion waveguides was investigated by the method developed in [30,57], making it possible to optimize the overlapping of interacting fields in the generation of the second harmonic and to increase the efficiency of conversion to 16% [51].

Methods for producing thin film waveguides. The first waveguide films [10] were constructed by the method of vacuum thermal deposition of such materials as ZnS, CdS, ZnTe, Ge, Si [46], etc., on glass and quartz substrates. However, as a result of strong light scattering from the polycrystalline structure of the films, the effective length of the first waveguide samples was small. As a result of this a resonant method was proposed [11] and carried out [10] for measuring the parameters of waveguide films with short effective length, based on the determination of waveguide reflection coefficients in a prism coupling system. This method made it possible in the first stages of investigation, by choosing materials and technology and at the same time monitoring parameters of the waveguides obtained, to achieve a gradual increase in the effective length of the waveguides (up to 1 cm) [10]. Detailed investigations were conducted later of the properties of planar waveguides for the visible and near and mid-infrared regions, produced by various methods [58,59].

The method of high-frequency sputtering is widely used to construct thin film glass waveguides [60-62]. By this method, varying the composition of the targets, it is possible to obtain films with various values of the index of refraction. Properties of the waveguide layers depend on the hf power and the oxygen content of the working gas [61], which may be explained by the predominant deposition of certain components of the target in the hf discharge. A result of this is the observed difference in the composition of the film from that of the material of the sputtered target.

Methods for preparing thin film polymer waveguides have been mastered [63-67]. Of interest is the method of polymerizing organic monomers in a high-frequency discharge. Using this method a new class of organic compounds for waveguide films was found -- compounds of the aromatic series. Waveguides of toluene, xylene, cumene, and orthoxylene obtained using the polymerization method have indices of refraction in the range from 1.59 to 1.61 and are resistant to the effects of many chemically active substances. No change in their properties has been found in the course of 1.5 years. Thermal processing reduces the index of refraction and the thickness of waveguides and may be used to obtain required parameters.

By the deposition of oxides in an atmosphere of inert gas and also by direct oxidation of metals in deposition (chemical vapor deposition), thin film waveguides of tantalum pentoxide [68] and aluminum oxide [69] have been obtained having high (up to 2.5) indices of refraction.

For obtaining inhomogeneous waveguides, the method of solid state diffusion has been widely used [30,32-35,48,70-76]. But occasionally the diffusion of metals in glasses leads to their coloring, which is undesirable for waveguides [77]. Investigations attest to the complex mechanism for the diffusion of metals and the formation of waveguide layers in glasses [27,78].

Of particular note is the very simple method for obtaining waveguide layers in glasses by the effusion of certain of their components during thermal processing. By this method waveguides have been obtained in a group of optical glasses.

Inhomogeneous optical waveguides have also been created by the irradiation of substrates of KB quartz glass with 5 MeV protons. In this manner a waveguide layer is formed at a depth of 260 mm with a width of 20 μm [79]. Waveguides obtained through irradiation by deuterons with energies of 100 to 200 keV are located at the surface of the substrate [80]. Thermal processing of these waveguides improves their quality markedly as a result of the annealing of color centers.

Waveguide gratings. For exciting planar waveguides and extracting radiation, bevels, prisms, and also periodic structures on the surface or within the waveguide are used. Theoretical and experimental studies have been conducted of phenomena occurring in coupling devices: those employing prisms [81-88], bevels [89], and periodic structures [90-93]. The theory of optical waveguides with a periodically (sinusoidally) corrugated surface separating the media has been developed based on the concept of waves diffracted by a set of plane waves [94]. A similar method was applied also for theoretical analysis of waveguides with a sinusoidal volume grating [95-98]. In the case of sinusoidally corrugated waveguides, the final results were obtained in compact analytical form both for the diffraction of radiation and for excitation, as well as for various types of resonant conversion of surface waves [94-96].

The process of radiation, reflection, and transformation of waves in corrugated waveguides has been studied theoretically and experimentally [95,99-115], in particular by the method of transverse cross sections. Relations have been derived for determining the coefficients of extinction and reflection depending on parameters of the waveguide and the corrugation. Analysis of these relations, calculations, and experiments has established the strong influence of interference effects on the value of the extinction coefficient of TE and TM waves in thin film waveguides [99,105].

Studies of diffusion waveguides, for which interference effects are practically nonexistent, have made it possible to explain substantial differences in the radiation of TE and TM waves [100,101], produced by diffraction properties of the corrugated interface between waveguide media [105,116]. A strong asymmetry is observed, along with the appearance of a narrow region with essentially a zero value of the radiation coefficient for TM waves depending on the angle of radiation into the substrate (that is, on the corrugation period). These features explain the predominant generation of TM waves in waveguide lasers with distributed Bragg mirrors [102], and also may be considered the basis for polarized waveguide selector modes.

At present in semiconductor waveguide lasers with distributed Bragg mirrors there is wide use of a grating with a period equal to the wavelength in the waveguide [103], and therefore on the basis of [57,94], a method has been developed for calculating the radiation structure of distributed feedback with this period. In the proposal for a small amplitude corrugation and the absence of losses from absorption, analytical relations have been obtained for the coefficients of reflection R, radiation I, and transmission P of the light for basic [102,104] and hybrid modes [117], with a substantial role being played in this by the introduction of the effective thickness of the waveguide, determined by the amplitude of the wave field at the corrugated boundary [76,104]. The possibility was demonstrated of achieving a value of R≈1 with reasonably large grating lengths and with the occurrence of an optimum grating length at which the radiation power reaches a maximum value of 0.2 to 0.4 of that incident on the grating. For practical calculations of the radiation structure of distributed feedback a simplified method has been developed making it possible to obtain values of R, I, and P with sufficient precision [118,119].

Waveguide lasers. Amplification and generation of light are observed in active waveguides or in waveguides on an active substrate. Studies of thin film waveguides activated by dyes, as well as lasers created on their basis, are contained in [28,63,46,78,120-126]. It was also shown that logic elements may be constructed based on thin film lasers (127,128].

Methods were studied for the frequency tuning of waveguide lasers with distributed feedback, and a method has been proposed for the spatial modulation of the magnitude of feedback [65], as well as a method for frequency tuning using surface acoustic waves in a laser with a Bragg waveguide or distributed Bragg mirrors [64].

Integrated optical devices. Methods have been developed for creating various functional optical devices in planar configuration: lenses, prisms, gratings, resonators, modulators, filters, couplers, deflectors, etc. [70,71,129-149] Particular attention was given to the study of electrooptical and acoustooptical modulators [138-148,150-153]. Also created and studied have been waveguide electrooptical modulators and acoustooptical deflectors of the Bragg type in a lithium niobate crystal and in films of organic materials.

Optimum characteristics have been determined for a lithium niobate electrooptical modulator [135,147]. A device has been constructed with 100% modulation at a voltage of 5 V and a bandwidth greater than 1 GHz. The device was used successfully in a fiber optic communication line [148].

The fundamental limitations of optical electrooptic deflectors have been analyzed [137].

A new method has been proposed for transmitting images on fiber optic communication lines based on scanning of the image using optical spectrum analyzers [134,135], and the possibility of constructing spectrum analyzers based on thin film waveguides has been investigated [130-133].

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PHYSICS

SPECTROMETRIC ENVIRONMENTAL INVESTIGATIONS IN THE VISIBLE REGION FROM THE SALYUT-4 ORBITAL SCIENTIFIC STATION

Minsk ZHURNAL PRIKLADNOY SPEKTROSKOPII in Russian Vol 29, No 6, Dec 78 pp 1011-1017

[Article by B. I. Belyayev, G. M. Grechko, A. A. Gubarev, L. I. Kiselevskiy, P. I. Klimuk, V. Ye. Plyuta, and V. I. Sevast'yanov of the Center for Cosmonaut Training imeni Yu. A. Gagarin and the Institute of Physics of the Academy of Sciences of the Belorussian SSR]

[Text] The radiation field of the earth formed by the transformation of solar radiation in the geographical envelope of the planet contains broad information concerning the external and internal structure and the chemical and physical state of the environment. The study of radiation characteristics makes it possible to obtain important scientific and applied data by remote means.

The immediacy of such research has increased recently as a result of the involvement of mankind in economic activities over wide portions of the planet, embracing essentially all regions suitable for man's existence. In these circumstances it has become vitally important to create fundamentally new and highly efficient global methods for studying the earth's resources shows that to the fullest extent this task may be performed with complex equipment, including as a most important part means of recording the earth's radiation field from space. To be investigated in this manner are spatial and temporal, energy and spectral, angular, and polarization characteristics of the field.

The information received is multiparametric, and therefore in order to simplify recording apparatus and processing equipment, recourse is usually made to averaging the information on some parameters while preserving the maximum possible or useful resolution in the most important of them.

In the development of space-based spectral methods of studying the earth's resources, two approaches have been used, differing in the choice of the most important parameters. These are the methods of multizonal photographic and television recording, making it possible to obtain an image of the surface below the instrument in a few relatively narrow spectral regions, and spectrometric methods for recording the entire spectrum in a given spectral region, averaged over a certain portion of the underlying surface. The first methods have high spatial resolution with a large loss in spectral information, while the latter, on the other hand, have high spectral and low spatial resolution. Each of these approaches has its most advantageous areas of application. Their promise has been convincingly demonstrated in a number of space experiments.

In this article some results are presented of spectrometric measurements of the earth's surface and atmosphere made according to the flight program of the Salyut-4 orbital scientific station.

The most informative part of the optical spectrum is the visible region [1]; the majority of studies of natural formations by observation from space has therefore been conducted in the region from 0.4 to 0.5 and from 0.7 to 0.8 μm. The first object of study was the earth's twilight horizon, photographed by Ye. V. Khrunov in 1969 from the Soyuz-5 manned spacecraft [2]. For this purpose he used an RSS-1 hand-held spectrograph, which recorded radiation in the region from 0.43 to 0.69 μm. Spectral studies of the atmosphere were performed from a number of Soyuz spacecraft and Salyut orbital scientific stations. Thus, in 1973 spectrometric measurements of the brightness profile of the earth's daylight horizon were made from the Soyuz-13 spacecraft by P. I. Klimuk and V. V. Lebedev. [3].

The first spectral measurements of the earth's surface from satellite orbit were made from the Soyuz-7 spacecraft on 13 October 1969 by cosmonauts V. N. Volkov and V. V. Gorbatko. Data were collected in the portion of the trajectory from the Red Sea to the Aral Sea in the wavelength band from 0.43 to 0.69 μm with a spectral resolution of 0.05 to 0.1 μm [4]. More detailed spectral data were obtained in 1970 from the Soyuz-9 spacecraft by A. G. Nikolayev and V. I. Sevast'yanov [5]. A detailed description of the apparatus, measuring methods, and interpretation of the results of these experiments is given in [2,6].

In the first half of the 1970's spectrometric investigations of the earth's surface were made on board the Skylab orbiting scientific station. Measurements were performed with the S191 spectrometer [7] simultaneously in three spectral bands: 0.39-1.1 μm with a resolution of 11.5-18.5 nm; 1.1-2.5 μm (resolution 16.5-63 nm); and 5.8-15.99 μm (resolution 0.11-0.3 μm).

In 1975 from the Salyut-4 station a large number of spectrometric investigations of the atmosphere and surface of the earth were performed in the band from 0.4 to 0.8 μm with a spectral resolution of 7 nm using an MSS-2 automatic spectrometer [8]. As a result of these experiments, over 50 thousand spectra were obtained of all classes of natural features under various illuminating conditions with various orientations of the optical axis and the input slit of the instrument. In addition, the spectral brightnesses of the atmosphere at the earth's daylight horizon were recorded, the spectra of noctilucent clouds were obtained, and the change in spectral characteristics of a view port was studied over the course of a space flight.

The greatest quantity of spectral characteristics of the earth's surface was obtained in experiments with the orientation of the instrument's optical exis strictly along the local vertical. A number of experiments were conducted with observation at various angles to the earth's surface in order to study the angular structure of the radiation field of some portions of the surface and to obtain additional information on the spectral parameters of the atmosphere.

Processing of the spectrometric information obtained was performed on computers of the unified series. The processing took into account the amplitude characteristics of the instrument, the optical properties of the viewport, and statistical analysis of the spectra.

In the analysis of large masses of spectrometric information an important stage is the segregation of rational structural units of the earth's geographic envelope at a given level of detail of the elements of the geosphere. Known to physical geography is the concept of the natural territorial complex, a historically formed combination of mutually related natural objects and phenomena of the earth's geographic envelope or any of its parts [9]. Each natural territorial complex is relatively uniform and may include smaller taxonomic units, as for example a zone, province, or landscape, which in turn may be divided into separate structural elements.

It is important to emphasize that these concepts include all components of the geographic envelope, that is, the atmosphere, the lithosphere, the hydrosphere, and the biosphere. It is these components which participate in the formation of the earth's radiation field, and in measuring the characteristics of the field with exoatmospheric instruments, generalization of the image hinders the determination of the contribution made by any of the components individually. Normally reference is made to the predominant contribution of one of the components to the radiation recorded.

Most often the problem of separating the contribution of a component of the natural territorial complex such as the atmosphere is examined [2,10], since solar and reflected radiation are substantially transformed in passing through the atmosphere as a result of scattering, absorption, and intrinsic emission by the atmosphere. This distorts the optical field formed by other components of the natural territorial complex; that is, most importantly, by the underlying surface. It is possible to account for the distortions introduced by the atmosphere, calculating its transfer function, if the optical parameters of the atmosphere are known in the specific measurement conditions.

Spectral information obtained was associated with specific objects in the earth's geographic envelope based on ballistic data and synchronous photography (with the KATE-140 camera). Photographic frames made it possible to determine the boundary of the region covered by spectrometry, the type of surface, and the state of cloud cover along the trajectory. On the basis of this information, along all the photographed tracks the spatial and temporal behavior of spectral brightness was constructed at several wavelengths. A sample of the data obtained is presented in fig. 1. Analysis of such types of dependence makes it possible to solve a broad range of problems: from choice of the most informative portions of the spectrum for spectrozonal studies to the recognition of natural formations by their spectral characteristics.

With further processing of the information, a detailed decipherment was made of individual, precisely identified spectra which represent typical spectral brightness distributions of all recorded classes and types of surface. Examples of such spectra obtained in identical illumination conditions for desert, plant cover, water surface, and dense cloud cover, are presented in fig. 2. Intense absorption bands of oxygen (0.63, 0.68, 0.76 μm), water vapor (0.59, 0.65, 0.72 μm), and ozone (0.57μm), which contribute fundamentally to selective absorption of solar radiation by the atmosphere in the visible portion of the spectrum, stand out clearly in spectra of reflected radiation. Solar absorption lines of Fe (0.43 μm), Mg (0.52 μm), and, in the most intense reflection spectra, Na (0.47 μm) and H (0.49 μm), are also observed. Analysis of atmospheric absorption bands has made it possible to obtain some information on the state of the atmosphere, for example, to determine the upper boundary of cloud cover from absorption of radiation in the 0.76 μm band [10].

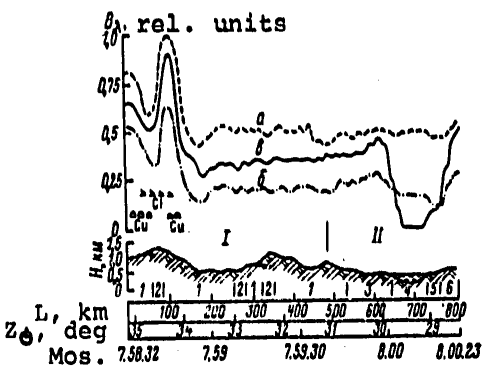

Fig. 1

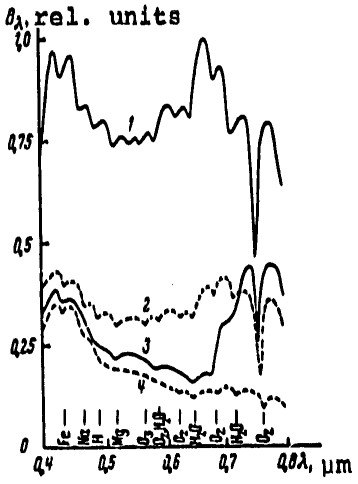

Fig. 2

Fig. 1. Geologic and geographic profile and spatial and temporal behavior of spectral brightnesses for three wavelengths above the steppe and semidesert zone of an area of low, rounded, isolated hills in Kazakhstan (I) and above the northwest part of the Zaysan basin (II): 1 -- an arid-denudation plain and an area of low, rounded, isolated hills with light chestnut-colored soils; 2 -- low mountain relief with chestnut-colored mountain souls; 3 -- alluvial lake plain with light chestnut-colored, sandy, and sandy-loam soils; 4 -- Lake Zaysan; 5 -- floodplain of Chernyy Irtysh River with alluvial soils under tugai vegetation; 6 -- plain of shifting sand; $Z_{\odot}$ -- solar zenith angle; Mos. -- Moscow time; Ci -- cirrus and Cu -- cumulus clouds. λ=0.42 (а), 0.55 (б) and 0.74 (в) μm

Fig. 2. Spectral brightnesses of four classes of surface in identical illumination conditions: 1 -- dense cloud cover; 2 -- desert; 3 -- vegetation; 4 -- water surface

The spectral brightnesses of the surface and atmosphere system depend substantially on illumination conditions, which are determined by the position of the sun in relation to the surface whose spectrum is to be measured. The experiments performed have made it possible to investigate the function $B_{\lambda}=f(Z_{\odot})$ over a fairly wide range of solar zenith angles $Z_{\odot}$.

Statistical analysis of the basic mass of data was performed for individual spectral regions, which served as reference wavelengths. Their values were chosen in the course of the detailed decipherment of spectra for typical, representative natural formations, taking into account recommendations as to the most informative zones of the spectrum. The reference wavelengths were chosen outside the spectral absorption bands for atmospheric gases. Processing of the results of measurements was performed for portions of the track from the largest and most uniform, such as cloud cover, deserts, plant cover, and water surfaces, to finer taxonomic units of the geographic envelope.

Statistical characteristics of reflection spectra were calculated for tracks of various lengths from tens to several thousands of kilometers. In fig. 3 are presented average values of spectral brightnesses of the surface and atmosphere system for certain physicogeographical zones, bodies of water, and cloud formations in various illumination conditions. A general feature of spectral brightnesses of all classes of surface is the increase in these characteristics in the blue region. Analysis of the spectra has shown that this increase is produced by radiation scattering in the atmosphere. Of interest is the fact that the maxima of spectral brightness curves in all spectra are shifted toward shorter wavelengths in comparison with the maximum of the distribution curve for solar radiation. This may also be explained by the effect of light scattering in the atmosphere.

The basic classes of surface are characterized by the following spectral parameters. Typical of deserts is a brightness minimum near 0.5 to 0.55 μm and an increase in brightness toward the red region with a maximum at approximately 0.7 μm. Plant-covered surfaces are characterized by a decrease in brightness from the blue portion of the spectrum (the atmospheric maximum) to 0.62-0.64 μm with an unpronounced maximum at 0.55 μm; then there is a considerable rise toward the red region with a broad maximum near 0.74 μm which becomes more pronounced as the percentage of projected plant cover on the soil along the measurement track increases. Water surfaces decrease more evenly from the blue toward the red region of the spectrum.

The spectral brightnesses obtained from Salyut-4, averaged over the great masses of data, were classified according to their spectral characteristics using the principle proposed by Ye. L. Krinov [11]. Analysis has shown that the classification of Ye. L. Krinov, expanded and refined by the authors of [2,6,12] according to results of the study of individual space spectrograms, is entirely applicable as well for statistically generalized spectrometric data.

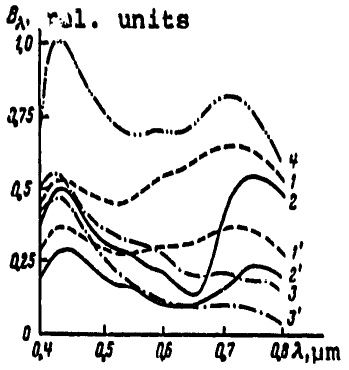

Fig. 3

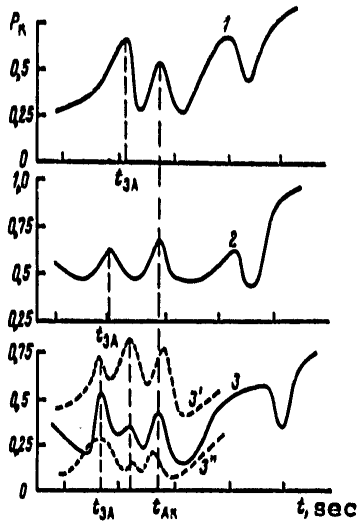

Fig. 4

Fig. 3. Average values of spectral brightnesses of natural formations. Desert (1, 1'); vegetation: forest zone (2), forest steppe zone (2'); water surfaces: Lake Zaysan (3), Mediterranean Sea (3'); dense cloud cover (4). $\bar{z}_\odot$=46° (1), 67° (1'), 42° (2), 59° (2'), 29.5° (3), 22° (3'), 62° (4).

Fig. 4. The function $P_k(t)$ in the first (1), second (2), and third (3) profiles of the earth's daylight horizon.

An important task performed using the MSS-2 instrument during the Salyut-4 mission was the spectrometric measurement of the earth's daylight horizon. These experiments were performed by the method of spatial scanning with a constant angular rate in a direction forming an angle δ from the vertical toward the horizon. The scanning plane coincided with the sagittal plane of the instrument.

In the course of the experiments spectra were obtained of vertical profiles of the atmosphere at the earth's daylight horizon. These have made it possible to establish in detail the optical characteristics of the atmosphere in the visible portion of the spectrum. Since the instrument's field of view was greater than the angular height of the atmosphere, a special method was developed for analyzing the data based on ideas from linear correlation analysis.

As an example we will consider the task of determining the optical height of the atmosphere. Serving as a criterion for the transition from one object which falls within the field of view of the instrument to another as the instrument's optical axis is shifted is the difference between the r_{kl} element of the normalized mutual correlation matrix of spectral brightness for the kth and lth spectra and the value determined by the geometry of the experiment. From the geometry of the experiment it follows that the time for total replacement of an object in the field of view of the instrument is 14 seconds; that is, each second 7.2% new area enters the field of view. Thus there should be a close and nearly linear correlation between recorded spectra.

The correlation coefficient in the conditions examined is the measure of dispersion or error of the associative relation between any two recorded spectra. Since the maximum change in information per second does not exceed 15%, the fractional linear dispersion of two compared spectra should be 85%; that is, the coefficient of determination r^2 is 0.85. On the other hand, this coefficient is determined from the matrix elements and for spectra numbered k and l equals r_{kl}^2. From this it follows that a reliable difference between any two compared spectra may be observed for $r_{kl} \leqslant \sqrt{0.85}$. Representing this quantity by r_o, we introduce a criterion characterizing the difference between spectra. As such a criterion we choose conditions producing a maximum of the quantity

$$P_k = \frac{1}{n} \sum_{l=1}^{n} P_{kl},$$

where $P_{kl}=0$ for $r_{kl}-r_o \geqslant 0$ and $P_{kl}=1$ for $r_{kl}-r_o<0$, and n is the number of spectra in the profile analyzed.

It should be noted that r_{kl} is a random quantity and does not characterize the assignment of two compared spectra to a linear function uniquely, but rather with a certain probability. Since the volume of choice in our case is small, for analysis of the presence of a statistically significant correlation between two spectra under study we used the zero hypothesis and a statistic having a Student distribution [13,14]. Calculations have shown that linear correlation analysis, used to study transition spectral characteristics, was chosen correctly.

In fig. 4 are shown values of P_k obtained by the method discussed above for three profiles of the daylight horizon. The analysis performed makes it possible to distinguish clearly the moments of transition of the instrument's field of view from one object to another (from the surface through the atmosphere into space or from some optical inhomogeneities to others). Maxima of the P_k function correspond to these moments.

In the figure the moment of transition across the optical boundary between the surface and the atmosphere is designated t_{3A}, and the moment at which the upper edge of the slit goes out into space is t_{AK}. From this it is possible to calculate the optical height of the atmosphere at the daylight horizon, determined by the product of the quantity $(t_{3A}-t_{AK})$ and the vertical linear scan rate $V=\omega L\cos\delta$, where L is the distance to the object recorded.

Numerical values of V varied for each of the profiles. This explains the lack of coincidence between t_{3A} moments in the figure. The following values were obtained for the optical height of the atmosphere: in the first profile 32±8 km, in the second 33±6 km, and in the third 31±4 km.

The precision of the calculations of the optical height of the atmosphere was greatest in the third profile, for which the vertical scan rate was lowest. Evidently this explains the appearance in this particular profile of an intermediate maximum of the P_k function between t_{3A} and t_{AK}, corresponding to an optical inhomogeneity in the atmosphere at an altitude of approximately 17 to 20 km (the Junge aerosol layer). For this profile a more detailed investigation was made of the P_k function in the spectral bands from 0.42 to 0.62 μm (fig. 4 curve 3') and from 0.62 to 0.78 μm (curve 3"). Comparison of the results shows that the optical height of the atmosphere is different in different portions of the spectrum. In particular, in the long-wavelength region it is 27±4 km, and in the short-wavelength region it is 36±4 km. This phenomenon may be explained by features of light scattering in the atmosphere. The lower boundary of the atmosphere is essentially independent of the choice of spectral zone, and the variation in the optical height of the atmosphere is associated primarily with its upper boundary.

The spectrometric research performed on Salyut-4 makes it possible to conclude that spectrometric methods of studying the environment from spacecraft have great promise. Automatic instruments with photoelectric recording of the MSS-2 type have the unquestionable advantage that a powerful arsenal of modern computing equipment may be used to process the huge masses of information obtained. Particularly promising is the comprehensive approach combining spectrometry with other methods of studying the earth's natural resources.

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PHYSICS

ATOMIC EMISSION SPECTRAL ANALYSIS USING LASERS

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[Article by M. L. Petukh and A. A. Yankovskiy of the Institute of Physics of the Academy of Sciences of the Belorussian SSR]

[Text] Lasers are used in atomic spectral analysis primarily because of the capability of high-power laser radiation to fuse, vaporize, and convert to plasma a great variety of solids. This feature of the effects of lasers has attracted the attention of many researchers. As early as 1962, two years after the creation of the first solid state lasers, works were published on their use for spectral analysis [1,2]. To the present over 300 works have been published on the use of lasers for spectral analysis. In 1966 the first monograph was published devoted to laser emission multispectral analysis [3] (Russian translation [4]). A large space in [5,6] is given to the examination of problems in laser multispectral analysis. In a number of works [7-20] there are chapters or paragraphs devoted to laser multispectral analysis. Many problems in laser multispectral analysis are examined in [21-23]. Short reviews of some research in the use of lasers for emission spectral analysis are contained also in publications [24-26]. Specialized seminars [27] have begun to be held.

Problems and topics examined in published works may be divided into two groups. To the first group belong topics in the investigation of physical processes fundamental to laser spectral analysis. Knowledge of the laws governing these processes makes it possible to conduct a well directed search for optimum conditions of laser spectral analysis. Such processes include first of all those of the breakdown and ejection of matter produced by lasers, temporal, spatial, and phase distribution of this process, and also the processes of excitation and radiation of atoms in the plasma formed. In

the second group are applied problems in laser spectral analysis, the search for its optimum applications, and the development of specific methods and instruments.

Laser erosion of matter. The effect of laser radiation with a flux density greater than 10^6 W/cm^2 on a test sample leads to the breakdown of the sample and the ejection of vaporized matter and condensate (fused droplets and solid particles).

When laser radiation is focused sharply on the surface of metals, depressions with fused walls are formed, most often conical in shape. The amount of matter ejected from various materials and the dimensions of the depressions formed depend on the conditions under which the laser radiation acts on the test sample (the generation mode, the energy and duration of the laser pulses, the focusing of the laser radiation) [4,19,22, 28-55] and the thermophysical properties of the materials [19,34-41,44,45,54]. Most authors consider that properties of the materials having the most substantial effect on the size of the depressions are such factors as the melting point [28,36-39, 42] and the coefficient of reflection of the laser radiation from the surface of the material [19,28,35,45,54]. Also of importance in the process of the destruction of materials is the boiling point [43,54]. As laser radiation in the free generation mode acts on the test object, the mass of the products of laser erosion of metals is proportional to the amount of energy absorbed and inversely proportional to the amount of energy required to melt a unit mass of the substance [20].

The temporal development of the action of laser radiation on metals and the ejection of matter have been studied by the method of fast photography of the ejection flare [38,46] and the deposition of erosion products on stationary and moving substrates [28,38]. When acted upon by laser radiation produced in the free generation mode and having an energy of a few joules and a duration on the order of milliseconds, matter goes into the vapor phase [38,46], and the emission of particles begins after a short time (80-150 μs). The solid angle of particle emission decreases as the depth of the depression increases. The proportion of vapor in products of the laser erosion of metals in the case of the use of the free generation mode constitutes approximately 0.1% [20]. For radiation effects in the semi-Q-switched pulsed mode (the duration of a pulse consisting of 15-20 beams was 30 μs, and the flux density was $7.8 \cdot 10^6$ W/cm^2) and in the Q-switched mode (energy 0.5 J, pulse length 50 ns) the proportion of vapor in erosion products is greater than in the use of the free generation mode [46].

The laser erosion of two-component alloys depends on their composition and structure [42,47]. For copper-zinc alloys a selective movement of zinc is observed. The ratio of the concentration of zinc to copper in the vapor is higher than in the initial alloy. This is true both for radiation effects in the free generation mode and in the single-pulse mode [44,48,49]. In [30] there is also observed an increased manganese content in vapor produced by the effect of laser radiation on iron alloys. On the whole, the chemical composition of the matter ejected in laser effects is essentially identical to the composition of the test sample studied, since the proportion of vapor in the erosion products is small [38,50].

The effect of the pressure of the surrounding atmosphere on the degree of erosion depends on experimental conditions. Some autors find [28,51] that the quantity of matter ejected by a laser pulse in the free generation mode is independent of the pressure of the surrounding atmosphere. In [22] it was revealed that at low laser radiation energies atmospheric pressure does not affect the quantity of matter ejected, but as the energy is increased and the depression becomes deeper, the quantity of matter ejected increases as the pressure decreases. In the case of the effect of a Q-switched pulse, at low pressures the erosion is greater than at atmospheric pressure [29]. This may result from the reduction in screening of the laser radiation by the plasma [54].

The data cited apply to the erosion of metals or the simplest alloys. In the literature there is little information on the erosion of electrically non-conducting materials. It is clear that for such materials the number of factors on which the degree of erosion depends is still greater. In [39] it is indicated that the laser damage of various materials, including ionic and covalent semiconductor crystals, depends on the bonding energy of atoms and the proportion of energy absorbed. For the transition metals of groups IV-VI and their carbon, boron, and nitrogen compounds an attempt was made to link the degree of erosion with the statistical weight of atoms having a stable configuration [47]. The authors of [56] show that for biological specimens the dimensions of the depressions are a nonlinear function of the power and energy of the laser.

Radiation from laser plasma. Radiation from plasma formed by the action of laser radiation on materials depends on the generation mode, the energy of the laser radiation, its focusing conditions, the laser pulse duration, properties of the irradiated sample, and the pressure and content of the surrounding atmosphere.

When metals are acted on by laser radiation both in the free generation [51,57] and Q-switched modes [29], two zones of intense emission are observed. The primary zone is at the very surface of the sample; the secondary zone is formed as a result of the interaction of the plasma stream with the surrounding air and is located a certain distance from the surface. This distance depends on the energy of the laser radiation, its degree of focusing, the reflection coefficient of the irradiated material, and its melting point [58,59]. At low laser radiation energies (0.1 J in the free generation mode) only a single intense emission zone has been observed [60]. The maximum intensity of lines with various excitation energies and atomic lines for various ionization states are observed in various parts of the zone of intense emission of the plasma cloud [57,61-63]. The lower the excitation energy of the lines, the greater is the distance from the surface of the sample at which its zone of maximum emission is located [43,46,58,62].

In plasma spectra obtained in the action of laser radiation in various pulsed generation modes -- Q-switched and semi-Q-switched pulses [46], free generation [46,64], quasi-steady-state radiation, and repetitively pulsed radiation [64], from a liquid laser [65] and a CO_2 laser [66] -- the intensity of the background and the width and shift of the spectral lines were greater than in spectra obtained using standard electrical generators for emission spectral analysis. In addition, in the spectra from a laser plasma there is observed a marked self-reversal of resonance lines [43,46,51,58,64,67-69]. The quality of the spectrum from a laser plasma is substantially improved by lowering the pressure of the atmosphere surrounding the test object [28,29,58,60,68-72]. In addition, as the background intensity decreases, the diffusion and reabsorption of spectral lines also decreases.

Study of the temporal behavior of the intensity of lines from plasma obtained by the action of laser radiation on a test object has shown that the duration of emission and the intensity of the lines depend on parameters of the laser radiation, properties of the object, the concentration of a given element, and the line excitation energy [19,43,46,62,66,73-75]. The duration of emission for lines with low excitation energy is greater than for those with high excitation energy. In a number of articles it is shown that lines of atoms which have lost more electrons appear at earlier stages in the development of the plasma cloud. However, in [74], using high temporal resolution, it was found that within 1 to 2 ns of initiation, there is emission on lines with a lower degree of ionization.

The discrepancy between the temporal and spatial emission of lines and the background and excitation energies may be used to increase the signal-to-noise ratio and the sensitivity of the analysis [62]. Temporal resolution makes it possible to increase the ratio of line intensity to background intensity in the case of single-peak modes [46]. In [61] an increase by a factor of two in sensitivity was obtained through spatial resolution.

The change in intensity of spectral lines in proportion to the action of repetitive laser pulses at the same spot on the test object (burning processes) was studied in [76-78]. As the number of laser pulses increases, the intensity of lines decreases, but the relative intensity remains constant. In all the indicated articles the change in line intensity is associated with the change in depth of the depression.

In the combined use of laser and electrical pulses the spectra constitute a superposition of the spectra from the two sources [43]. The nature of the resulting spectrum depends on the ratio of the energies of the laser and electrical pulses. Usually the energy of the electrical pulses used is higher by a factor of ten than that of the laser pulses [3,5,43,79]. Therefore the nature of the resulting spectrum is essentially determined entirely by the electrical light source used [79]. Further, to a considerable degree there is a reduction in reabsorption, spectral line spreading, and background intensity.

An increase in the pressure of the surrounding atmosphere increases the spreading, reabsorption, and shift of the lines [80-82]. Replacement of air by oxygen, nitrogen, argon, and helium leads to a change in the line intensity and the spatial distribution of line intensity in the plasma cloud [83-85]. The use of an argon atmosphere with a small admixture of oxygen lowers the threshold for detection of impurities in steel by a factor of 2 to 3 in comparison with air [81].

Methods of laser spectral analysis. Lasers used for spectral analysis are for the most part solid state lasers which generate in various pulsed modes; the possibility has also been demonstrated of using liquid [65] and CO_2 gas lasers [31,66,86,87].

There are two methods of spectral analysis using lasers. In the first method the source of spectral excitation is the plasma formed by the effect of laser radiation on the test object; that is, the intrinsic radiation of the laser plasma is used. This method was used for performing various analytical

tasks [34,59,73,88-100]. In a number of cases good results were obtained. For example, in [101] a threshold of 10^{-14} to 10^{-15} g was achieved for the detection of a number of elements.

At the same time, the quality of emission spectra in the case of the use of intrinsic radiation from a laser plasma is low. In addition, in this method of analysis the efficiency of use of the substance of the analyzed sample is low. The greater part of the laser erosion products, especially in the case of free generation, is ejected in the condensate phase [35,50,55] and does not participate in the formation of the spectrum. According to estimates made in [20], for various generation modes the portion of the substance converted to plasma constitutes from 0.05 to 1% of the laser erosion products.

In the second method lasers are used in combination with electric discharge generators. The matter ejected under the effect of laser radiation enters the interelectrode gap and is deposited on the electrodes. In the electric discharge, vaporization occurs and a portion of the substance in the condensate phase is excited. As a result of this the intensity of the spectrum is increased by 1 to 2 orders of magnitude in comparison with the intensity of the laser plasma spectrum, and the quality of the spectrum is improved [102-104]. A number of authors consider that in the case of the combined use of laser and electrical pulses, additional excitation of the laser plasma occurs in the electrical discharges [4,5].

At present the second method is most used in the practice of laser spectral analysis. In the majority of serially produced instruments for laser spectral analysis, additional electrical discharges are to be used. In the "Laser Microprobe" [6], LMA-1 [4], and MSL-2 [5] instruments the laser plasma directly initiates the electrical discharge. In the LMA-10 [105] instrument there is provision for delaying the electrical discharge for a given time interval after the beginning of the laser pulse. The electrical discharge in these instruments is a single pulse with an energy of up to tens of joules.

As distinct from these instruments, in the "Korall-1" instrument [106] use is made of the principle of removing the products of laser erosion and vaporizing them in electrical discharges. Laser removal of the sample may be made onto transparent films [107], onto specially prepared carbon cylinders [103] or electrodes with an opening through them [108], and also onto the end surface of two [109] or one [30] electrode. The best repetitive processing method for laser removal of the sample onto two electrodes is used in the "Korall-1" instrument. In this instrument the electric discharge need not correspond in

time with the laser pulse. Both processes may take place independently, and for obtaining a spectrum of the substance analyzed it is possible to use discharges from standard electrical generators for spectral analysis, and also any arc or spark discharges.

The sequential removal of the sample by laser and vaporization of the sample in electrical discharges makes it possible to choose the optimum conditions for each of these operations. In some cases this is of substantial importance in achieving the necessary analytical precision and sensitivity.

For efficient choice of the conditions for laser removal of the sample it is necessary to know the laws governing laser erosion of matter, spatial and temporal distribution of erosion products, and their distribution by phases depending on properties of the object analyzed, parameters of the laser radiation, its focusing, etc. These laws, as well as the processes of vaporization of the substance removed in electrical discharges and problems in the development of methods and instruments for spectral analysis using laser removal, have been studied systematically at the Institute of Physics of the Academy of Sciences of the Belorussian SSR [28,30,37,38,48, 50-52,57-60,64,65,77,79,94,103,104,109-117]. Some generalization of the results of this work is given in chapter eighteen of [20], and also in [22,23,27].

Practical questions in laser spectral analysis. Laser spectral analysis may be used for determining the chemical composition of a very broad range of objects. Much research has been performed in the use of lasers for analyzing metals and alloys [34,46,89,93,94,118-133], welding seams [134,135], laminar analysis and the analysis of thin coatings [99,127,136-145], microinclusions [102,146-152], small parts [152,153], powder samples and minerals [73,76,91,92,96,97,108,119,154-176], glasses and enamels [22,118,148,149], semiconductors [102, 177,178], ceramics and graphite [102,91,96,179,180], meteorites [171,181], single crystals [182,183], lubricating oil [184], biological samples [56,98,101,185-189], toxic and radioactive substances [190], and determination of content of rare-earth elements [95,191], carbon [192,193], and halogens and sulfur [194]. The capability for direct analysis of any solid material without substantial preparation makes it possible to simplify methods of spectral analysis and to accelerate the analysis of electrically non-conducting materials.

Sensitivity. The sensitivity of laser spectral analysis is approximately the same as for emission analysis using electrical discharges as the light source.

In the use of lasers in combination with electrical generators the sensitivity of the analysis is determined principally by the electrical light source. Taking into account the fact that the detection limit with electrical light sources is 10^{-10} g, in [20] it is shown that in using lasers in combination with electrical discharges, for detection approximately 10^{-9} g of the element to be determined are required. In the case of iron, the volume of substance is about 140 μm^3. The diameter of a conical depression of this volume is approximately 8 μm (with a depth of 8 μm). This quantity of substance is required for determining the element when it constitutes the basic part of the sample, that is, when its content is close to 100%. For determining admixtures it is necessary to increase the dimensions of the depressions and the quantity of substance removed from the sample. The author of [195] considers that in the case of the use of the LMA-1 for quantitative analysis the optimum diameter of the depression is 60 to 100 μm.

These estimates agree basically with data on the sensitivity of laser spectral analysis presented in [20,81,83,94,101,118, 162,177,195-202]. By specially choosing the conditions of analysis it is possible to identify even smaller quantities of a substance. In [200] by vaporizing the substance from a small portion of the surface (a few μm) and by reducing the duration of emission of the laser plasma the content of $6 \cdot 10^{-10}$g of iron in steel and $5 \cdot 10^{-13}$ g of magnesium in aluminum were determined.

In recording the intrinsic radiation of laser plasma the sensitivity of determination is of the same order of magnitude on average. In some cases by choosing optimum conditions greater results were obtained. By using the single-pulse mode of a ruby laser, photoelectric recording of the spectrum, and a certain delay and recording time for each spectral line, the detection limits obtained were $2 \cdot 10^{-15}$ g for magnesium and copper, $1 \cdot 10^{-14}$ g for calcium, $5 \cdot 10^{-14}$ g for zinc, and $3 \cdot 10^{-13}$ g for iron and mercury in biological specimens [101]. In [197] intensity of the magnesium line sufficient for recording was obtained through the action of single-pulse laser radiation on a single blood cell. It should be noted that even with non-laser light sources high sensitivity may be achieved if a small quantity of a substance is efficiently vaporized. For example, by the method of vaporizing an isolated droplet in a flame a detection threshold for sodium of 10^{-16} g was obtained [203].

The relative sensitivity of determining elements by laser spectral analysis is characterized by an average value of 10^{-3}%. In some cases even higher results were obtained, for

example $1 \cdot 10^{-4}$% for the determination of chrome [73]. By replacing air with an atmosphere of argon the relative sensitivity of determination of admixtures in aluminum was increased by a factor of 2 or 3 to $1 \cdot 10^{-4}$% for zinc and $3 \cdot 10^{-4}$% for magnesium [81].

In determining the content of elements near their detection threshold the background intensity considerably exceeds the intensity of the line. For quantitative spectral analysis it is desirable to work in conditions in which the background intensity is approximately an order of magnitude less than the line intensity. In this case satisfactory calibrated plots for determining the composition of elements in alloys using LMA-1 and "Korall-1" instruments in standard conditions may be obtained with an element content of 0.1% [22,195], and for some elements starting at 0.01%.

Precision. The precision of spectral analysis is determined by its reproducibility or the repeatability of its results, characterized by random errors in analysis, and by its accuracy, characterized by the absence of systematic errors.

Information on the reproducibility of the intensity of spectral lines and of analytic results is contained in [20,43,46,76,88, 94,96,110,118,155-157,177,196,197,204-207]. The reproducibility of analytic results depends both on parameters of the laser radiation and the electrical discharge and on properties of the material analyzed. Therefore it is natural that various authors in non-identical conditions have obtained dissimilar results.

In [43] it is shown that the reproducibility of laser spectral analysis depends on the cleanness of the sample surface and on the angle of incidence of the laser radiation. The author of [96] came to the conclusion that the reproducibility of analytic results is higher for an unpolished surface than for a polished surface as a result of fluctuations in the reflective capacity of a polished surface. In [207] it was noted that the reproducibility of the intensity of spectral lines is affected by nonuniformity in the distribution of elements in the sample and by inhomogeneities in the spatial distribution of vapors in the cloud, as well as by the lack of spatial and temporal coincidence of the vapors of the laser cloud with the electrical discharge.

In the use of lasers without electrical discharges the reproducibility of the intensity of spectral lines is characterized by a standard deviation of 0.20 to 0.30 [76,94,110]. The relative standard deviation of the relative intensity is

approximately a factor of two lower. In the majority of work in which lasers are used in combination with spark discharges values are also cited within the limits 0.10-0.30. In [202] it is shown that in the best case the relative standard deviation is 0.10, and is normally 0.15-0.40. On the other hand, in [206] in determining the composition of manganese and chrome in steels the value of the relative standard deviation is 0.06-0.08, and in [197] a value of 0.039 is cited for recording the signal from the magnesium line. The authors of [88,196], who used a laser in the free generation mode with an energy of 20 J, concluded that the reproducibility of analysis was greater when using the laser without a spark discharge than it was in combined use. In [96] the statistical significance is shown for divergences in values of the relative standard deviation for free (0.17-0.28) and single-pulse (0.07-0.16) generation with combined use of a laser and a spark discharge.

According to evaluations performed in [20], analytic error in the use of lasers in combination with electrical discharges is composed of the error in generation of the laser energy (relative standard deviation 0.05-0.10), the ejection of laser erosion products ($\sim$0.50), the deposition of erosion products on the electrodes ($\sim$0.10), and the error of the electrical light source ($\sim$0.05).

In the use of lasers there is a reduction in systematic analytic error resulting from differences in composition and structure of the analyzed samples and standards. A considerable decrease was observed in the effect of composition in the analysis of complex nickel alloys [112], the effect of silicon on results of the determination of zinc content in the analysis of brasses both in the use of a laser in the free generation mode in combination with electrical discharges [48] and in the use of a laser without electrical discharges [48,59,94,208]. In the case of the use of lasers there is essential identity of calibrated plots for the determination of manganese and nickel content made of two types of cast iron [22]. Buravlev et al. have found that the use of lasers in combination with electrical discharges leads to a considerable decrease in the effect of the composition of steels on the determination of the content of a number of elements, with the exception of aluminum and titanium in heat-resistant steels [42,67,206,209,210]. In the analysis of aluminum alloys using a ruby laser in the single-pulse mode it was discovered that the presence in the alloy of zinc in a concentration of 5.7% increases the ratio of the intensity of the copper line (324.7 nm) to that of the aluminum line (396.1 nm) by 15% (in analysis using a spark -- by 17%) [205]. The effect of the chemical composition of powder samples on the results of spectral analysis in the case of the use of lasers also is evident, but to a lesser degree than for a dc arc [71,119].

It should be noted that the effect of the composition of the sample on the results of spectral analysis when lasers and electrical pulses are used in combination may appear at the stage of vaporization of the laser erosion products. With incomplete vaporization of ejection products there may occur systematic changes in the relative intensity of lines.

A number of articles [210-213] indicate the effect of alloy structure on analytic results when a laser is used, leading to errors which do not exceed 15-20% [210].

In laser effects on materials the intensity of spectral lines may vary depending on the chemical composition of the sample [95,214] and the chemical compound in which the element to be determined is found [119]. It was proposed that these variations in intensity when performing rough quantitative analysis with lasers be corrected by taking into account variations in the volume of depressions [214,215]. (The correctness of quantitative atomic emission spectral analysis depends primarily on the preservation of the relative intensity of lines when their relative concentration is constant. In this sense there is no doubt of the superiority of spectral analysis using lasers over traditional analysis using electrical discharges.)

In the combined action of laser pulses and electrical discharges on hard materials the parameters of the discharge may have an effect on the intensity of the spectrum and the dimensions of the depressions. The intensity of spectra increases with an increase in voltage on the capacitor in the spark discharge circuit and with a decrease in circuit resistance and inductance [202]. With high inductance in the discharge circuit (the LMA-1) the plasma cloud of the spark is small in size and has no effect on the breakdown of the sample. In the case of low inductance the size of the plasma cloud increases and the spark plasma heats the surface of the sample, increasing the dimensions of the affected portion. In these cases the spectral analysis of glasses is possible using the laser of the LMA-1 in the free generation mode [216].

Standardization. Successful application of the methods of quantitative spectral analysis is possible with the appropriate standards. At the same time it must be taken into account that spectral analysis using lasers is a local method. On one hand, standard samples should be uniform in chemical composition within the boundary of the zone of laser breakdown of the sample. On the other hand, the local nature of laser effects makes it possible to reduce considerably the influence of chemical composition on analytic results. This makes it

possible to decrease the quantity of standards necessary for the analysis of various materials. Naturally, in laser spectral analysis the same methods of standardization are used as in other methods of local analysis, described in [5,7,8,217].

In the analysis of metals and alloys, as a rule, the same standard samples are used as in the case of spectral analysis with electrical light sources. These same standards are used successfully for the analysis of small parts made from the corresponding alloys [152,153].

In the case of mineral analysis, in [163] standard rock samples were also used. For quantitative determination of the content of mineral inclusions, minerals with a known content of the basic components and admixtures are used as standards [7,8]. In the absence of sufficiently uniform natural minerals previously analyzed for content of the elements to be determined, synthetic standards may be used. The mixtures obtained may be pressed [8,21,126,175] or glued with an organic glue [20,22, 116,218]. In some cases powder samples of known composition have been fused in advance in the craters of carbon electrodes using electric discharges [151,176]. The fusing of samples was used also in [170].

Standards for the analysis of biological tissues were prepared by the authors of [189] by adding the appropriate salts to the tissues, incinerating them, and subsequently pressing them into tablets. In [219] the standards used were gels saturated with a solution.

For the determination of silicon content in gallium arsenide [177] standard samples were prepared by thermally depositing on a polished surface of gallium arsenide an even layer of silicon dioxide of known thickness. In the action of laser radiation on such a sample the quantity of vaporized silicon is proportional to the thickness of the layer and to the diameter of the affected zone.

This brief review of basic published work makes it possible to conclude that scientific and applied research in atomic emission spectral analysis using lasers has become widespread. This is a result of the fact that laser spectral analysis has a number of unquestionable advantages over spectral analysis using electrical light sources. It makes it possible to expand considerably the range of materials which can be analyzed directly, to obtain a high degree of locality, to suppress the effect of "third" elements and other causes of systematic errors, to perform "sterile" analysis, etc.

The indicated advantages are far from being realized in their entirety. In this direction there are still a number of scientific and applied problems to be solved. The widespread introduction of laser spectral analysis into the procedure of analytical laboratories depends primarily on the creation of sufficiently reliable laser instruments with various generating modes.

A majority of the industrial instruments produced is intended for local laser spectral analysis using single laser pulses. At the same time it is unquestionably attractive to use lasers also for determining the average content of samples, particularly of electrically non-conducting substances. For this it is necessary to create repetitively pulsed lasers which enable one to obtain spectra over short exposure periods. This will make it possible to apply photoelectric methods of recording laser spectra using modern means of automation based on computers.

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