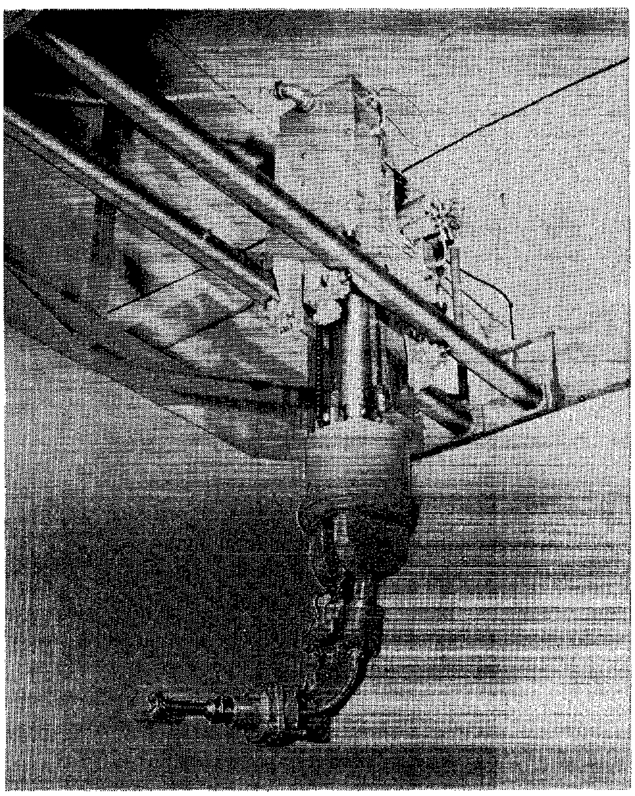
BULLETIN 102

General Mills, Inc.

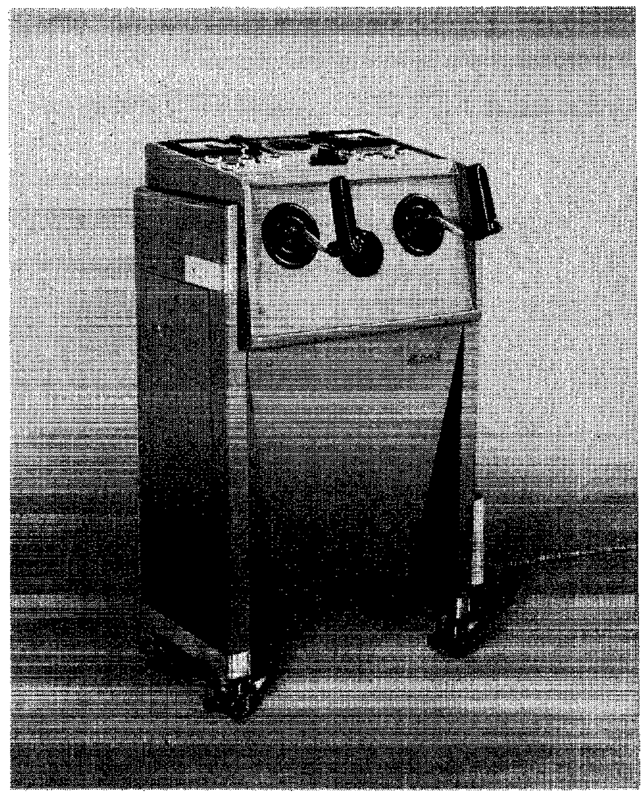
MECHANICAL DIVISION

C 28438

THE MECHANICAL ARM



The Mechanical Arm



Remote Control Unit

A remotely controlled manipulator for performing a handling job in nuclear laboratories, in powder plants, and in other activities where exposure of an operator is undesirable. This general purpose manipulator is power driven electrically. Unit provides for shoulder, elbow, wrist, and hand motions. Hand and special tools replacement remotely interchangeable. Crane bridge carriage and vertical telescoping column available for extensive space coverage if desired. Variations of unit specified obtainable for specific applications. Typical specifications, accessories, and special features indicated on reverse side of this sheet.

C 28438

TYPICAL SPECIFICATIONS*

(Specifications below based on Model C)

ARM MEMBER

SHOULDER ROTATION	2½ RPM Max. Speed, 1400° range
SHOULDER SWING	⅔ RPM Max. Speed, 180° range
ELBOW SWING	⅔ RPM Max. Speed, 110° range
WRIST ROTATION	6 RPM Max. Speed, Continuous range
HAND CLOSING	15 In. P.M. Max. Speed, 5-inch range
HAND FORCE	150 Lbs.
WRIST TORQUE	30 Ft. Lbs.
ARM SWING TORQUES	120 Ft. Lbs.
SHOULDER ROTATION TORQUE	40 Ft. Lbs.
VERTICAL LIFT (with all members of arm vertical)	750 Lbs.
CONTROL POWER SOURCE	110 Volt 60 Cycle Single Phase—1KW Normal Max.
CONTROL WEIGHT	200 Lbs.
ARM WEIGHT	135 Lbs. (without crane or column)
MATERIALS	Determined by environmental conditions
ACCESSORIES AND SPECIAL FEATURES	Telescoping columns for vertical motion, bridge carriages, under-water operation features, grip and load indicators, cable reel take-up units for crane bridge applications, use of special materials, special power source requirements, and load requirements are all items which can be supplied and/or adapted to special installations.

*Custom manipulators of all sizes and capacity can be designed and constructed to meet specific application requirements. Specifications of other models obtainable upon request.

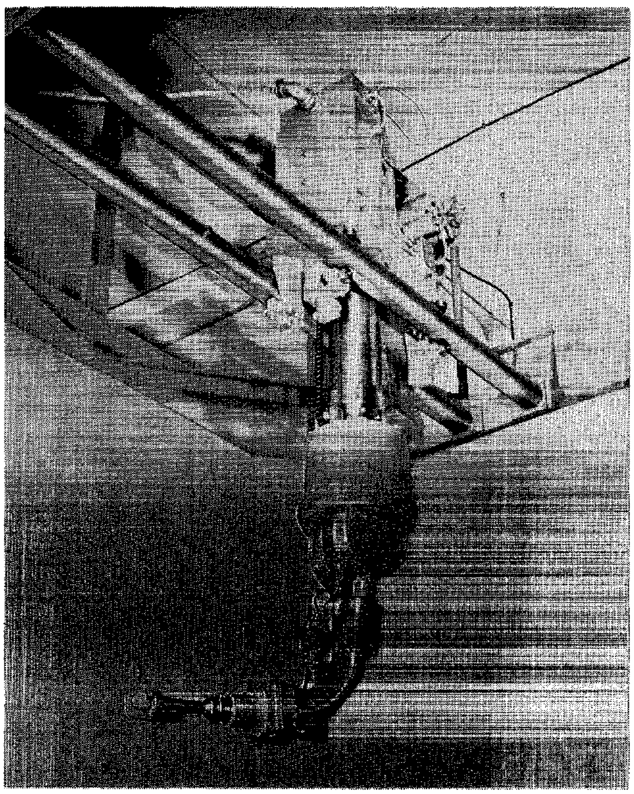
For further information
Write to . . .
EQUIPMENT SALES DEPARTMENT

Mechanical Division
General Mills, Inc.
2003 E. HENN. AVE., MINNEAPOLIS 13, MINN.
PHONE GR 8811

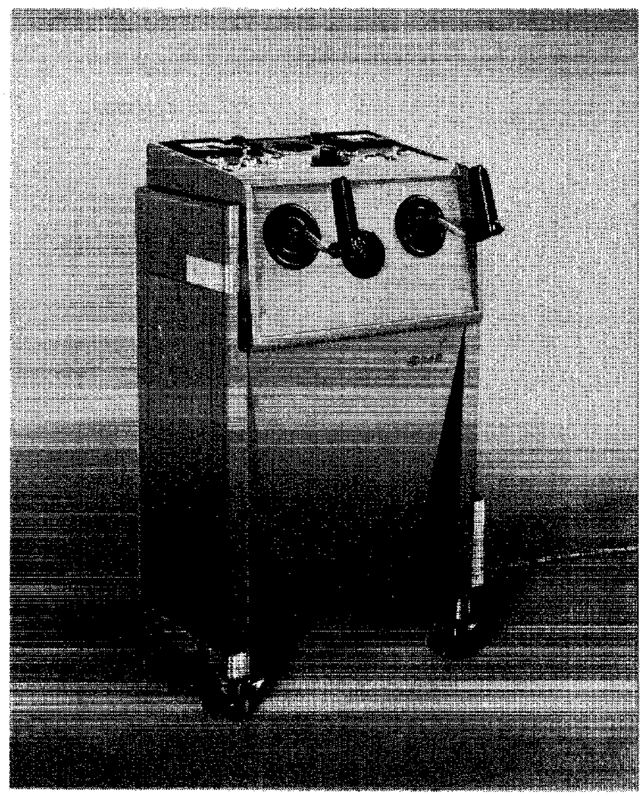
General Mills, Inc.

MECHANICAL DIVISION

THE MECHANICAL ARM



The Mechanical Arm



Remote Control Unit

A remotely controlled manipulator for performing a handling job in nuclear laboratories, in powder plants, and in other activities where exposure of an operator is undesirable. This general purpose manipulator is power driven electrically. Unit provides for shoulder, elbow, wrist, and hand motions. Hand and special tools replacement remotely interchangeable. Crane bridge carriage and vertical telescoping column available for extensive space coverage if desired. Variations of unit specified obtainable for specific applications. Typical specifications, accessories, and special features indicated on reverse side of this sheet.

TYPICAL SPECIFICATIONS*

(Specifications below based on Model C)

ARM MEMBER

SHOULDER ROTATION	2½ RPM Max. Speed, 1400° range
SHOULDER SWING	⅔ RPM Max. Speed, 180° range
ELBOW SWING	⅔ RPM Max. Speed, 110° range
WRIST ROTATION	6 RPM Max. Speed, Continuous range
HAND CLOSING	15 In. P.M. Max. Speed, 5-inch range
HAND FORCE	150 Lbs.
WRIST TORQUE	30 Ft. Lbs.
ARM SWING TORQUES	120 Ft. Lbs.
SHOULDER ROTATION TORQUE	40 Ft. Lbs.
VERTICAL LIFT (with all members of arm vertical)	750 Lbs.
CONTROL POWER SOURCE	110 Volt 60 Cycle Single Phase—1KW Normal Max.
CONTROL WEIGHT	200 Lbs.
ARM WEIGHT	135 Lbs. (without crane or column)
MATERIALS	Determined by environmental conditions
ACCESSORIES AND SPECIAL FEATURES	Telescoping columns for vertical motion, bridge carriages, under-water operation features, grip and load indicators, cable reel take-up units for crane bridge applications, use of special materials, special power source requirements, and load requirements are all items which can be supplied and/or adapted to special installations.

*Custom manipulators of all sizes and capacity can be designed and constructed to meet specific application requirements. Specifications of other models obtainable upon request.

For further information
Write to . . .
EQUIPMENT SALES DEPARTMENT

Mechanical Division
General Mills, Inc.
2003 E. HENN. AVE., MINNEAPOLIS 13, MINN.
PHONE GR 8811

PLEASE NOTE:

Reprint of paper to be delivered at the Conference of the Instrument Society of America September 21 - 25, 1953, Morrison Hotel, Chicago, Illinois.

Price to members, 25c; to non-members, 50c.

A REMOTE CONTROLLED MECHANICAL ARM

By

E. R. VAN KREVELEN, Project Engineer
General Mills Mechanical Division
Engineering Research and Development Department
Minneapolis, Minnesota

ABSTRACT:

This paper describes an electrically powered mechanical arm and a unique remote control system. This equipment has been developed to fill a need in certain industries, such as Atomic Energy, Munitions and Chemical, for a manipulator with the versatility and flexibility of a human arm to be used in areas unsafe for personnel. The design considerations, features, and applications of the equipment are presented.

A REMOTE CONTROLLED MECHANICAL ARM

INTRODUCTION

The advent of atomic energy and increased expansion in the fields of high explosives and chemistry has brought about increased demands for the safeguarding of operating personnel. The handling of radioactive materials with their penetrating and harmful radiations requires remotely controlled manipulators. Operations in this field are many and varied, and impose difficult requirements for versatility and dependability. Such requirements preclude the design of special devices of limited use in favor of more universal units having a variety of functions.

A good compromise in remote handling equipment is the Model E Mechanical Arm described in this paper. This manipulator is a general purpose, heavy duty instrument capable of many independent and precisely controlled motions. Since the human arm is one of the most versatile handling devices known, the Model E Mechanical Arm has been designed to incorporate many of its features. Added to these features are tireless operation and the ability to assume any working position for indefinite lengths of time. A wide range of sensitivity permits the handling of fragile glassware or heavy equipment weighing up to 750 pounds. The use of electric drive motors and control circuits places no limitation on the distance between the operator and the Arm.

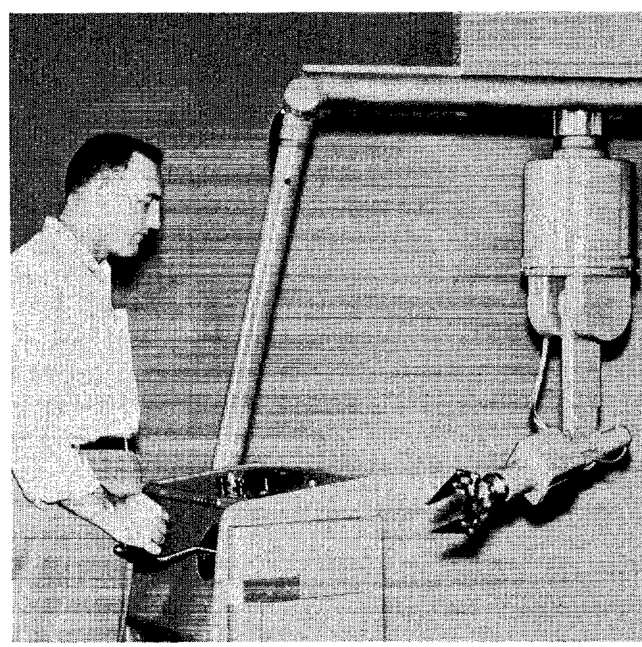


Fig. 1.—Model E Mechanical Arm and Control Console.

The Mechanical Arm with its associated crane is positioned by eight basic motions. These motions are non-interacting and are all controlled by two pistol grip type control handles on a single control console. The left hand controls the crane bridge, cross carriage and hoist while the right hand controls the shoulder rotation, shoulder joint, elbow joint, wrist rotation and grip member. Each motion has a control range of six speeds in each direction. The control handle mechanism is designed in such a way that movements of the operators arm, as he grasps each handle, corresponds to similar movements of the Mechanical Arm. The control handle motions and the resulting arm and crane motions are tabulated in Figure 2.

Arm Action	Controlling Handle	Control Handle Rotation	Control Handle	Arm Motion
Crane Bridge	Left	Left & Right Swing		
Cross Carriage	Left	In & Out Translational		
Vertical Hoist	Left	Up & Down Swing		
Grip	Right	Squeeze Handle		
Wrist Rotation	Right	Left & Right Handle Rotation		
Elbow Joint	Right	Up & Down Swing		
Shoulder Joint	Right	In & Out Translational		
Shoulder Rotation	Right	Left & Right Swing		

Fig. 2.—Table of Control Actions and Corresponding Arm Movements.

Two types of remotely interchangeable grip members or hands permit a variety of objects to be handled. One hand is a pair of spring loaded parallel jaws and is used for general purpose work. The other hand has a hook and anvil arrangement for heavy lifting and for the handling of round objects. Many special tools as well as screw drivers and socket wrenches may be grasped by these hands so that motors, gear reducers and other mechanical equipment may be assembled or repaired remotely. "Feel" has been purposely omitted from the hand in favor of visual indication of the direct measurement of gripping force and wrist torque. These meters have high and low sensitivity ranges, so that the operator can control applied forces ranging from a few ounces to several hundred pounds. An audible system for force indication has also been developed. Audio tone pulses emanate from a loud speaker in the console. As force increases the pulse rate increases proportionately making it unnecessary for the operator to take his eyes away from the work. This system is used in conjunction with the meters so that either audio or visual indication may be selected at the throw of a switch.

CRANE DESIGN

The crane mount is made in two units. One unit is a movable crane bridge which completely spans the work area. A cross carriage or trolley rides the crane bridge and provides translational freedom at right angles to the bridge travel. The Mechanical Arm proper is suspended below the carriage by a telescoping tube hoist.

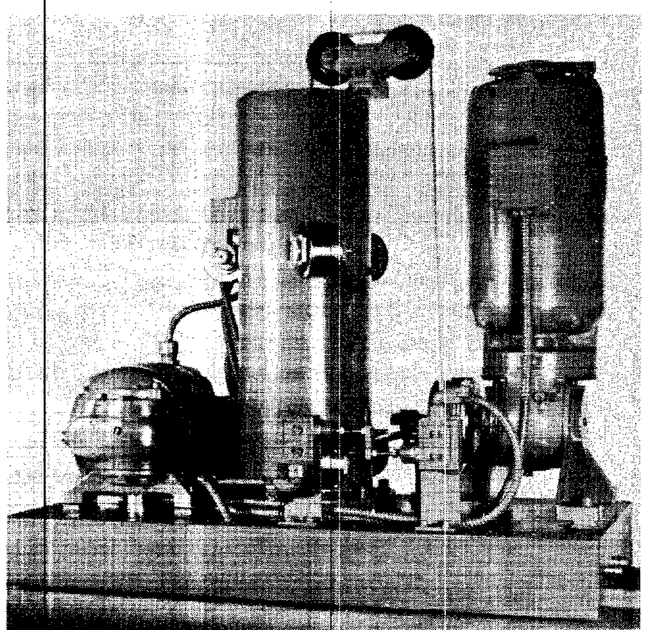


Fig. 3.—Cross Carriage Assembly showing Vertical Hoists and Transverse Drive Motors.

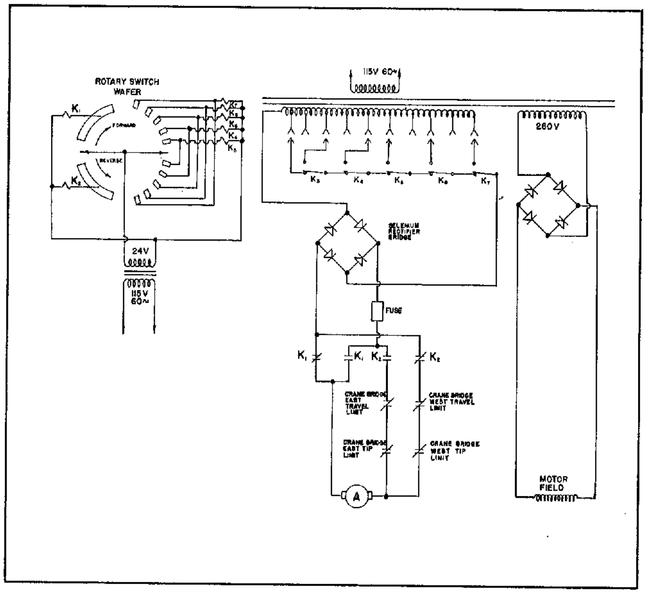


Fig. 7.—Schematic Diagram of Crane Bridge Control. This is typical of all of the Motor Control Circuits.

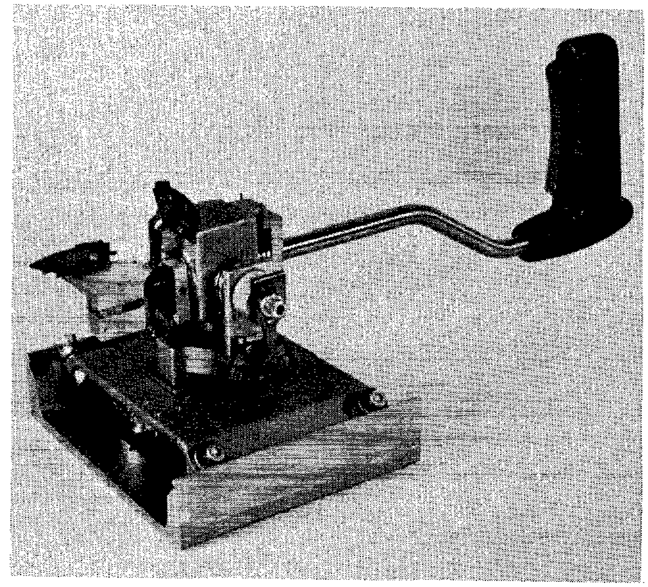


Fig. 8.—Basic Five Motion Control Mechanism showing Rotary Switch Construction.

One of the eight motor control circuits is shown schematically in Figure 7. Each motor has a bank of seven relays associated with it. The two relays K_1 and K_2 reverse the polarity of the DC voltage from the rectifier which in turn reverses motor rotation. The other five relays K_3 through K_7 are for tap switching. It can be readily seen that these relays are in a fail-safe circuit. If a relay should fail to close, only the voltage tap picked up by that relay will be lost. The rest of the circuit will remain undisturbed. If a relay should freeze in the closed position, this voltage will automatically excite the motor when the reversing relay closes. The highest speed relay closed at any time always takes precedence, so any combination of relays may be closed without danger of short circuits or other detrimental effects.

The relays are energized by rotary switches of special design. These switches are mounted on the control mechanism and are actuated by movement of the control handle. The relays operate from 24 volts AC which is supplied by a separate transformer. Each relay coil is shunted with a capacitor to reduce transients across the switch contacts when the circuit is opened on an AC peak.

All other voltage supplies are taken from the main power transformer. There are three secondary windings on this transformer. The first winding is rated at 260 volts and is tapped at 16, 24, 32, 48, 64, 82, 128, 156, 200, and 260 volts. These taps are wired in multiple to eight rows of 10 jacks located on the relay mounting panel. Immediately below each row of jacks is a row of 6 cords and plugs. These cords terminate at the normally open contacts of the speed relays. With this arrangement any combination of six speeds may be independently set up for each motor. The motor field rectifier is excited by the second winding which is also rated at 260 volts. The third winding supplies 18 volts to the wrist torque and grip force indicator resistance bridges. All AC voltages are about 20 per cent higher than the desired DC voltage. These higher voltages are necessary to offset the IR drop in the selenium rectifiers.

Figure 9 is a simplified diagram of one of the force measuring bridges. DC excitation is supplied to the bridge by a full wave selenium rectifier. The resistance element is in the forearm gearbox and is connected in potentiometer fashion making it possible to sense both an opening and a closing grip force. This also doubles the system sensitivity since the bridge has two active arms. The potentiometer wiper is mechanically linked to a non-linear spring which deflects with grip reaction force. The non-linear characteristic provides increased sensitivity for small gripping forces. The meter has shoulder joint and elbow joint and their respective gear trains are enclosed in the upper housing. The wrist rotation and grip motors are externally mounted on either side of the elbow. These two motors are coupled by flexible shafts to the forearm gearbox. The leads to all motors pass through a slip ring assembly inside the main housing. A multiconductor coiled cable, enclosed by the telescoping tubes, terminates in a brush assembly fixed to the wall of the main housing. A pancake slip ring is mounted above the internal gear trains allowing the whole mechanism from the shoulder down to continuously rotate within the housing. A speed range from a few degrees per minute to 8 RPM is provided for this shoulder rotation motion.

The upper arm has a vertical swing of 180 degrees about the shoulder joint at a maximum speed of ⅔ RPM and a torque of 75 foot pounds. The forearm has 200 degrees of vertical swing at approximately the same speed and torque. A pantograph chain drive between the forearm and upper arm keeps the forearm in the same angular position in space as the upper arm is swung forward and back. This feature is particularly valuable when open containers of liquid are to be handled without spilling.

The wrist may be rotated continuously in either direction at a maximum speed of 6 RPM and will exert torques up to 30 foot pounds. The hand will open or close at a maximum rate of 15 inches per minute with a maximum force of 150 pounds for the parallel jaws and 600 pounds for the hook and anvil.

CONTROL SYSTEM

All crane and arm motors, with the exception of the grip, are shunt wound and separately excited. The shunt motor was expressly selected because of its very wide speed range and constant torque characteristics. The use of shunt motors permits dynamic braking and allows changes in position of only a few thousandths of an inch at a time for all motions including the crane. A split field, series wound motor was selected for the grip because of its variable torque characteristics.

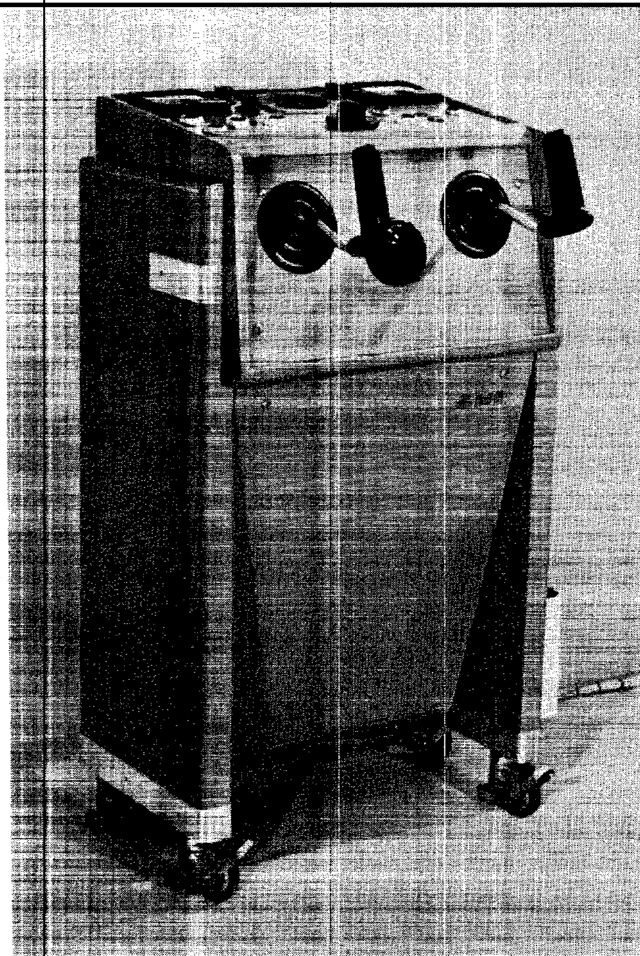


Fig. 6.—Control Console showing Tilted Control Handle Construction for Ease of Operation.

Early models of the Mechanical Arm utilized thyratrons and magnetic amplifiers for motor control. These controls provided a continuously adjustable speed range but sacrificed low cost, reliability and valuable space. Field use of these early arms showed, that at most, a six speed control was ample for even the most exacting work. With the six speed requirement definitely established, a simple Ward Leonard control system was designed.

The basic element of the present control system is a power transformer with a tapped secondary which provides a stiff source of variable voltage. Relays, actuated by the control handles, select desired voltages from the transformer and feed them to selenium rectifier bridges which in turn excite the motor armatures.

The crane bridge assembly is supported on two stainless steel tubes 3⅜ inches in diameter. This tubing size allows a maximum span of 15 feet with minimum deflection under full loading. A ¼ horsepower, 220 volt DC motor is vertically mounted at one end of the bridge. A drive shaft through one of the tubes is geared to the motor. Pinion gears on either end of the shaft engage racks on the bridge tracks. Maximum bridge speed is 15 feet per minute.

The carriage is driven by a ⅙ horsepower, 220 volt DC, gear head motor. A pinion gear on the gear head output shaft engages a single rack traveling the length of one of the bridge tubes.

The hoist is powered by a ½ horsepower, 220 volt DC motor. A drum which is geared to the motor shaft drives the hoisting cable which travels down the inside of the telescoping tubes. An electrically released brake, integral with the motor, will hold the hoist in any position. A vertical travel of 87 inches can be provided by only three telescoping tubes. Additional tubes may be added for increased vertical travel.

Over-travel in all motions of the crane is limited by cam operated micro-switches. The up and down hoist limit switches are actuated by a traveling nut riding on a threaded member directly coupled to the cable supply drum. The carriage and bridge have roller actuated switches that are tripped by stationary cams. Further protection is received from four spring loaded switches mounted below the four corners of the cross carriage. These switches are sensitive to a slight amount of carriage tilt and interrupt the appropriate motion should the arm or telescoping tube strike a fixed object.

When the Mechanical Arm is to be exposed to corrosive atmospheres, all exposed metal parts are either painted with Amercoat or are fabricated of stainless steel. By totally enclosing the electric motors and using polyethylene insulated wire, maximum protection is afforded the electrical system.

ARM DESIGN

The arm is powered by five 1/50 horsepower, 115 volt DC motors. The shoulder rotation,

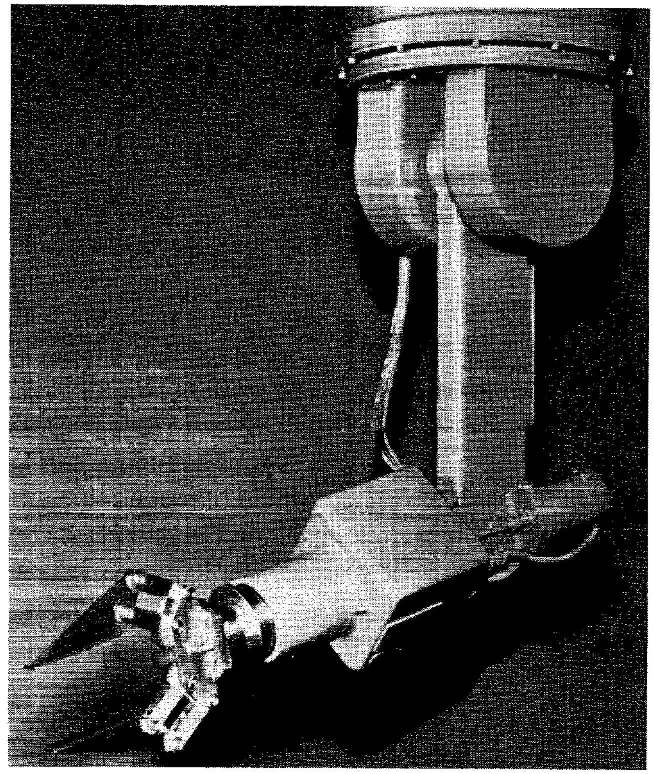


Fig. 4.—Mechanical Arm with Parallel Jaw Grip.

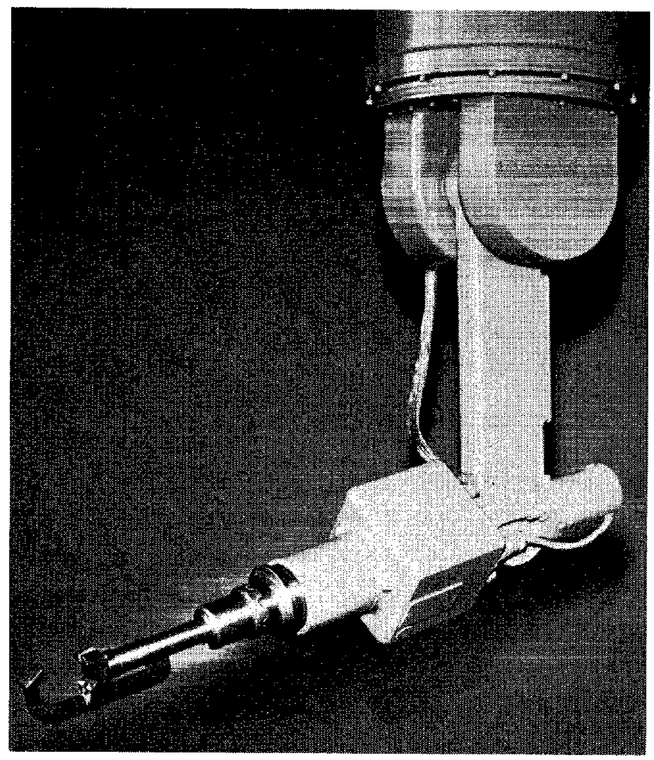


Fig. 5.—Mechanical Arm with Hook and Anvil Grip.

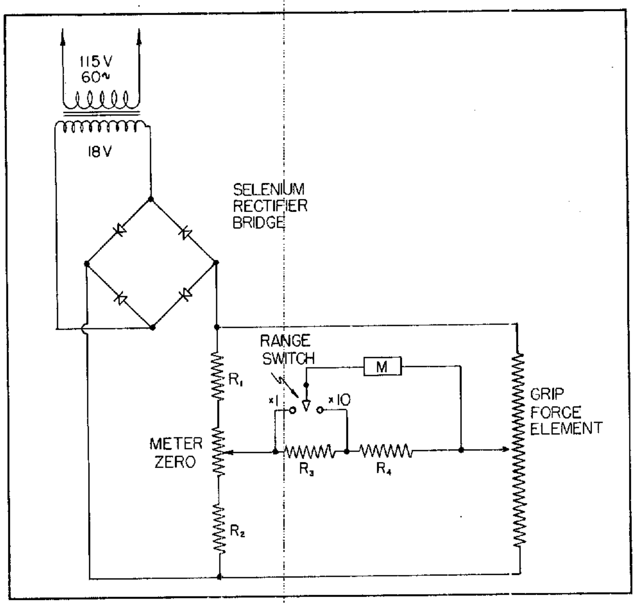


Fig. 9.—Schematic Diagram of Typical Circuit for Measurement of Grip Force.

a zero center scale, and range changing is accomplished by varying the shunt resistance across the meter terminals.

Each motor circuit is fused separately and all fuses are located in the right hand leg compartment of the control console. The output terminal strips are also located in this section. The central compartment contains the transformers, crane rectifiers and relays. The arm motor rectifiers are housed in the left leg. Front, rear, top and side panels are removable for service and maintenance.

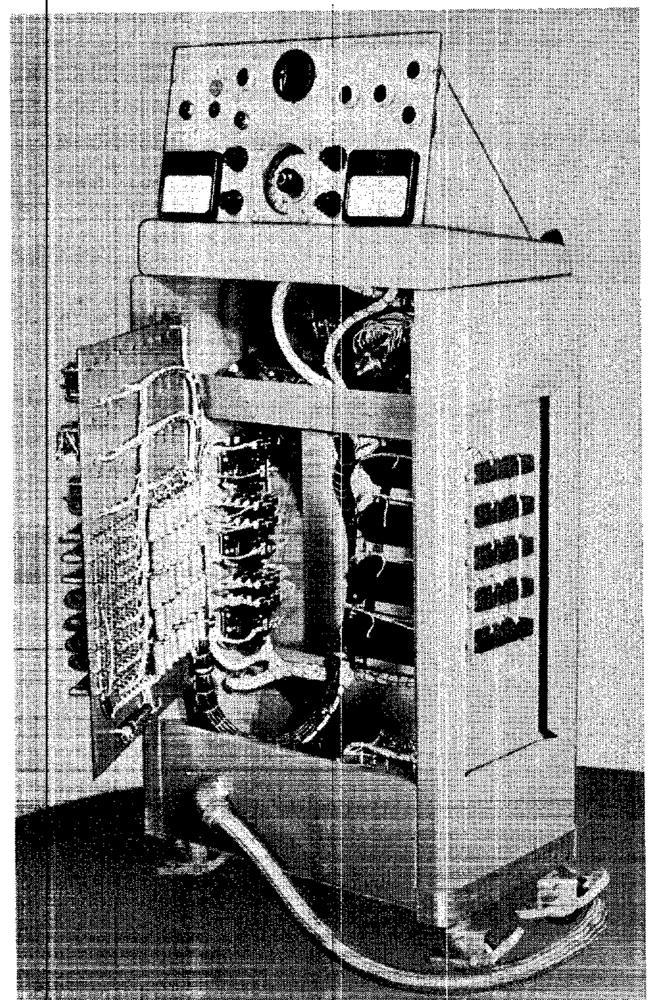


Fig. 10.—View of Control Console showing Accessibility of Components for Maintenance.

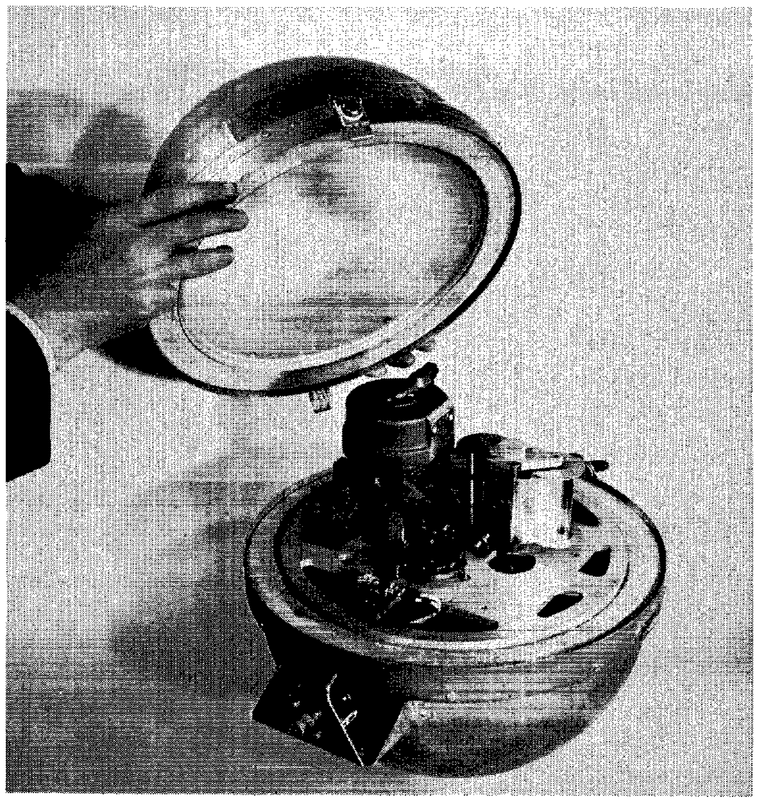
A8012

General Mills, Inc.

MECHANICAL DIVISION

THE GENERAL MILLS RYAN FLIGHT RECORDER

Model A



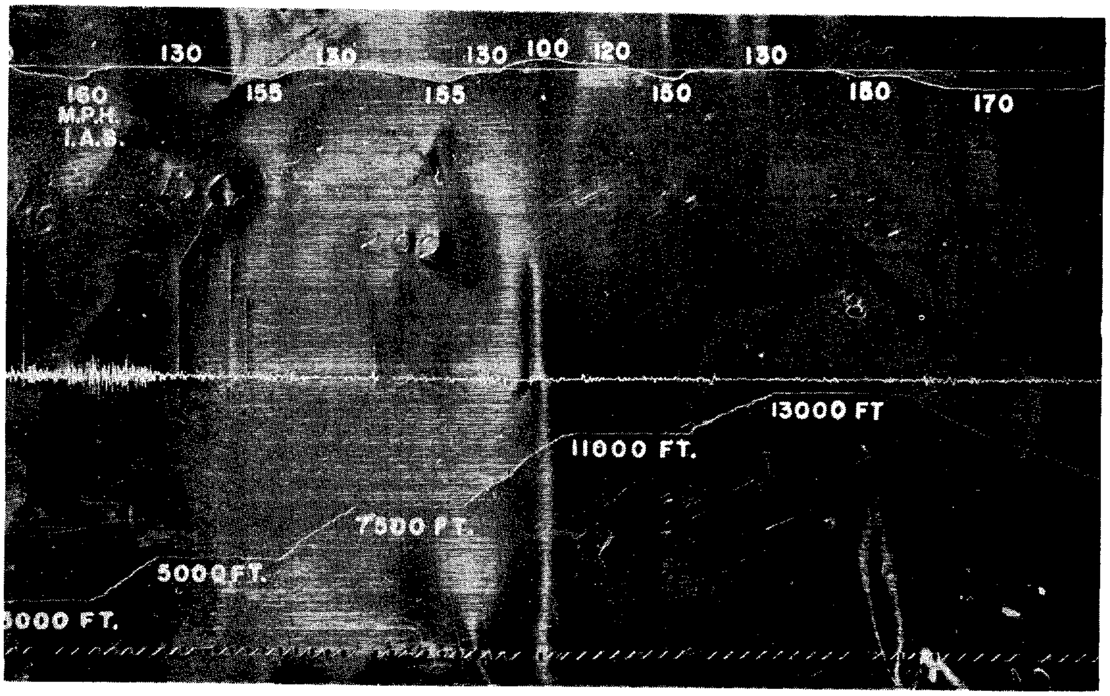
SOME IMPORTANT FEATURES AND ADVANTAGES

- **Records** air speed, altitude, vertical acceleration, time and heading (optional).
- Continuous **300-hour recording.**
- Operation for 10 minutes **following power source failure.**
- Recorded data will not be destroyed by ½ **hour exposure to 2000°F open fire.**
- **No electronic circuitry** — maximum reliability, minimum maintenance.
- Self-contained — **no remote pickups;** connections to standard equipment only.
- **Direct recording** — no magnetic playback, photographic reproduction, or other process required.
- **Weighs 16 pounds** with fireproof case; **12 pounds** with non-fireproof case.
- **Repeatability** — no sensitivity or zero shifts.

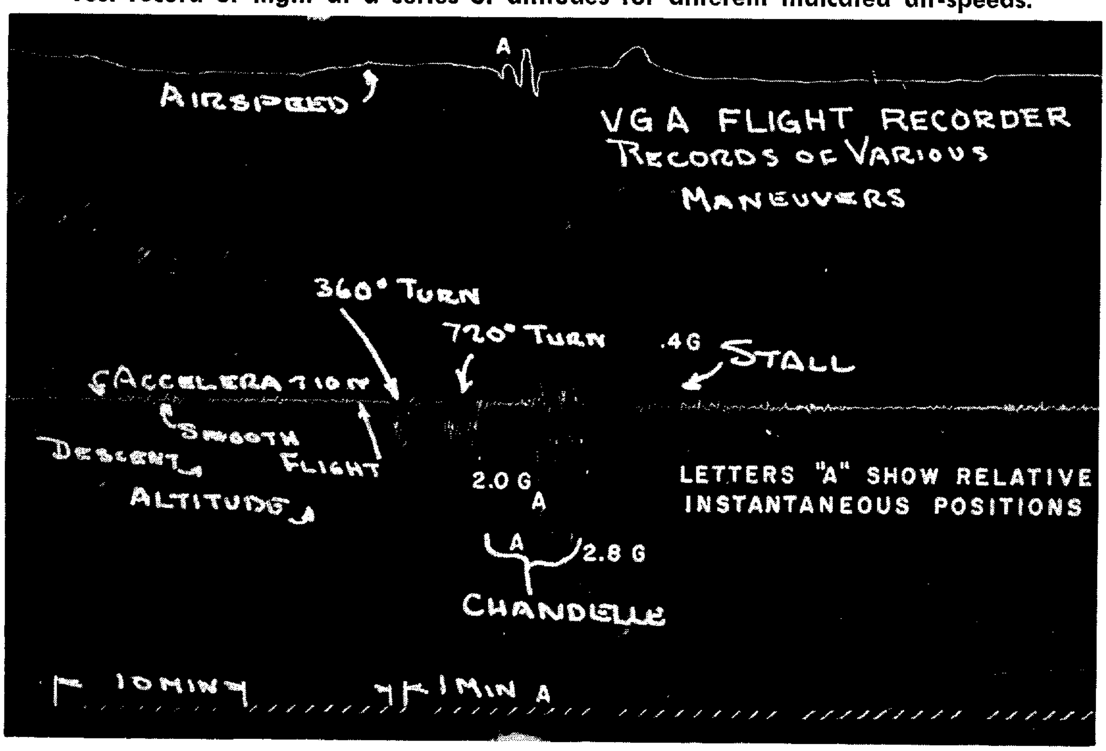
SPECIFICATIONS FOR THE GENERAL MILLS RYAN FLIGHT RECORDER

RANGE OF FUNCTIONS MEASURED* - - - -	Indicated air-speed: 0 to 500 miles per hr. Altitude (standard pressure conditions): −1000 feet to +40,000 feet. Vertical acceleration: −3G to +12G's. Time: 1 minute, 15 minute, 30 minute and 60 minute marks. Heading (optional): 0-360°.
ACCURACY OF RECORDING - - - - - - -	±2% of full scale altitude pressure and indicated air speed, ±0.2G on vertical acceleration, and ±3° on heading. Vertical accelerometer flat to two cycles per second for optimum measurement of gust and shock characteristics. Calibration charts provided with recorder.
OPERATING AMBIENT TEMPERATURES - - -	−30°C to +50°C.
METHOD OF RECORDING - - - - - - -	Styli embossing on aluminum foil 2¼ inches wide and 1 mil thick.
SPEED OF RECORDING CHART - - - - - -	3½ to 5½ inches per hour (constant rotational speed on take-up spool). Time marks coordinate trace events.
LENGTH OF RECORDING - - - - - - -	Continuous, 300 hours maximum.
METHOD OF DRIVE - - - - - - - - -	28-volt motor with power spring to escapement mechanism which controls speed of chart take-up drive.
PRESSURE SOURCE - - - - - - - - - -	Operates from standard pitot-static tube installed on aircraft. ¼ inch flared tubing connection for pitot tube, ⅜ inch flared tubing connection for static pressure.
POWER SOURCE - - - - - - - - - -	22 to 32 volts D.C. No change in chart speed results from voltage variation.

TYPICAL RECORDS FROM
THE GENERAL MILLS RYAN FLIGHT RECORDER



Test record of flight at a series of altitudes for different indicated air-speeds.



A record of a flight with various maneuvers.

For further information
Write to . . .
MECHANICAL DIVISION

PHONE GR 8811

TIME OF OPERATION WITHOUT POWER - - -	Approximately 10 min. (except heading).
WEIGHT - - - - - - - - - - - - -	16.5 lbs. total with fireproof case; 12 lbs. with non-fireproof case.
EXTERNAL DIMENSIONS - - - - - - - -	With fireproof case including supports, approximately 13½ inches x 16 inches x 15 inches high. With non-fireproof case, approximately 11½ inches x 14 inches x 13 inches.
INSTRUMENT MATERIALS - - - - - - - -	Frame, aluminum; spherical fireproofing case is double walled; outside wall zinc plated mild steel; inside wall aluminum; insulation between walls Perlite.
RESISTANCE TO FIRE** - - - - - - - -	Record is preserved under 2000°F temperature for one-half hour resulting from open fire when fireproof case is used.
RESISTANCE TO SHOCK - - - - - - - -	Designed such that record will not be damaged under 100G acceleration or shock.
RESISTANCE TO SEA WATER AND HUMIDITY -	Record will withstand 36 hours immersion in sea water. Instrument designed to withstand salt spray and normal humidity tests.
METHOD OF ANALYSIS OF RECORD - - - -	Use of transparent overlay for rapid scanning: For precision analysis, tool maker's microscope or photographic enlargement.
INSTALLATION*** - - - - - - - - - -	Recommended for installation in tail of aircraft to further increase resistance to fire.
MOUNTING - - - - - - - - - - - - -	Mounting lugs at essentially C.G. of instrument provided.

* Heading function optional; availability subject to type of compass instruments installed on aircraft.

** Fireproof case optional.

*** All functions self-contained. No remote pickups required (except for connection to existing pitot-static and compass instruments already installed in the aircraft). It is believed sufficient evidence exists to conclude that acceleration response of commercial aircraft to gusts and landing shock is essentially the same in any part of the aircraft as it is at the C.G.

Preprint of paper to be delivered at the Eighth National Conference of the Instrument Society of America, September 21-25, 1953, Hotel Morrison, Chicago, Ill.
Discussion sent to the ISA will be considered if received by October 1, 1953.
This paper or any part thereof must not be reproduced in any form without the written permission of the Instrument Society of America, 1319 Allegheny Avenue, Pittsburgh 33, Pa.
Price to members 25 cents, to non-members 50 cents.
Please Note: Statements and opinions advanced in this paper are to be understood as individual expressions of the author(s) and not those of the Society.

Paper No. 53-9-1

The V.G.A. Flight Recorder

By GERHARD O. HAGLUND*[1] AND JAMES J. RYAN*[2]

Abstract. The V.G.A. Flight Recorder is a permanently installed instrument for continuously recording, on aluminum foil, the indicated air speed, static pressure-altitude, compass heading, and vertical acceleration of aircraft for long operating periods. The instrument records information sufficient for determining the three dimensional flight path of the aircraft. Abnormal atmospheric disturbances, aircraft operational variations, and other flight conditions are recorded.
The instrument, mounted in the tail of the aircraft, is light in weight, small in size, predominantly mechanical, extremely rugged, fire resistant, designed for minimum maintenance, and will operate for a period of time without electrical power.

In 1948, the Civil Aeronautics Administration outlined suggested specifications for a flight recorder which was proposed for installation in all commercial aircraft. The purpose of the recorder at that time was to aid the government in accumulating data which could be employed in arriving at recommended operating procedures designed to reduce air mishaps.

A survey revealed that there was a need for development of a recorder which would require a minimum of attention with maximum reliability, provide for long recording, and offer resistance to destruction by fire, water and shock. Since that time, a number of recorders have been developed. One or more of the following disadvantages has been found to prevail: weight was too great; occupied considerable space; recording time was low; no resistance to water, fire and shock was nil; electronic circuitry generally increased maintenance, made reliability uncertain, and offered questionable repeatability characteristics. Initial, operating, and maintenance costs were high.

Recognizing the limitations of electronic type recorders, Professor James J. Ryan of the University of Minnesota, developed a recorder which would preclude these difficulties and disadvantages. The principles developed by him have since been embodied in the General Mills Ryan Flight Recorder.

This recorder is unique in that it is small; light in weight; preserves the record under conditions of high temperature, shock, and exposure to water; is self-contained; and provides for long recording. Elimination of electronics on all functions, with the possible exception of one, provides a high degree of reliability, low maintenance, and repeatability. Operation for a short time following a power failure is another advantageous feature.

Fig. 1. Upper Half of Housing Being Removed

DESCRIPTION

The Flight Recorder shown in Fig. 1 measures vertical acceleration, indicated air speed, standard pressure-altitude, and time. Direction recording, with the requirement of remote sensing, is available as an optional feature. These functions, and the direction element, are mounted in a spherical case, 11½-in. x 14-in. x 13-in. high, including the external instrument supports. An insulated fireproof case, also available, slightly increased the external dimensions to 13½-in. x 16-in. x 15-in. high.

Fireproof Case

The fireproof case, made in two hemispheres as illustrated in Fig. 1, consists of an outer stainless steel shell and an inner aluminum shell. Between these shells is a one-inch layer of granulated Perlite, an excellent temperature insulator. At the separation diameter of each half of the case, a solid retainer is made from Marinite, also a high temperature fire resistant material. The fireproof case prevented destruction of the record when the instrument was exposed to a 2,000 F. flame for a period of 30 minutes.

General Assembly of Recording Mechanisms

Fig. 2 illustrates an exploded view of the recorder elements.

Fig. 3 shows the recorder with the upper and lower housings removed. A portion of the instrument is mounted on the upper side of a support plate and the remainder on the lower side. The upper assembly contains the recording mechanism and the air speed sensing component; the lower assembly contains the altimeter sensing unit, the electric chart drive motor, and the accelerometer element. Pipelines leading to the pressure sensing components are connected at the side of the case. An electrical receptacle for connection to the 28-volt motor on the chart drive mechanism and the conductors for the direction function are at the same location.

The total weight of the instrument is 16.5 lbs in the fireproof housing and 12 lbs. with a non-fireproof case. The instrument assembly without a case weighs 8 lbs.

Air Speed and Altimeter Elements

The air speed element is a pressure diaphragm having static and dynamic chambers. The air speed unit provides a total displacement at the chart of about ¾-in. for an indicated speed of 500 miles per hour at sea level. The altimeter unit is an aneroid bellows and provides, at the chart, approximately two inches of displacement for altitude indications up to 40,000 feet. In each of these elements, the diaphragms act upon simple lever mechanisms providing a magnification of approximately five at the recording styli.

Vertical Accelerometer

The accelerometer element consists of a block of metal supported by cantilever springs. It is so designed that the movement of the weight and, therefore the stylus, is in a straight line. The accelerometer measures between the limits of minus 3G and plus 12G for a total displacement of about two inches on the recording chart. The natural frequency of the accelerometer is approximately

*[1] Manager of Market Development, Mechanical Division, General Mills, Inc., Minneapolis 13, Minn.
*[2] Technical Specialist, Engineering Research and Development Department, University of Minnesota.

430 cycles per minute. It is, by design, damped for flat response up to approximately two cycles per second. This value was selected after careful consideration of the nature of aircraft movement due to air disturbances and landing shocks. Therefore, in order to maintain this natural frequency in the most active range, a secondary spring is introduced in the assembly which increases the over-all spring rate when shock loads are between 4.5 and 12G.

Recording Styli

The styli of all the elements are slightly displaced in the direction of chart movement to prevent interference. An additional stylus provides a base line for all the primary functions. The styli emboss impressions to a line width of approximately 0.001 inches, as the chart passes over a backing plate.

Recording Medium and Drive

The recording medium is full-hard aluminum foil, 2¼-in. wide and 0.001-in. thick. The recorder will accommodate a chart strip up to 100 feet in length. This length of record provides recording for approximately 300 hours flight time. The recording strip is rolled on a spool which is driven at the rate of one turn

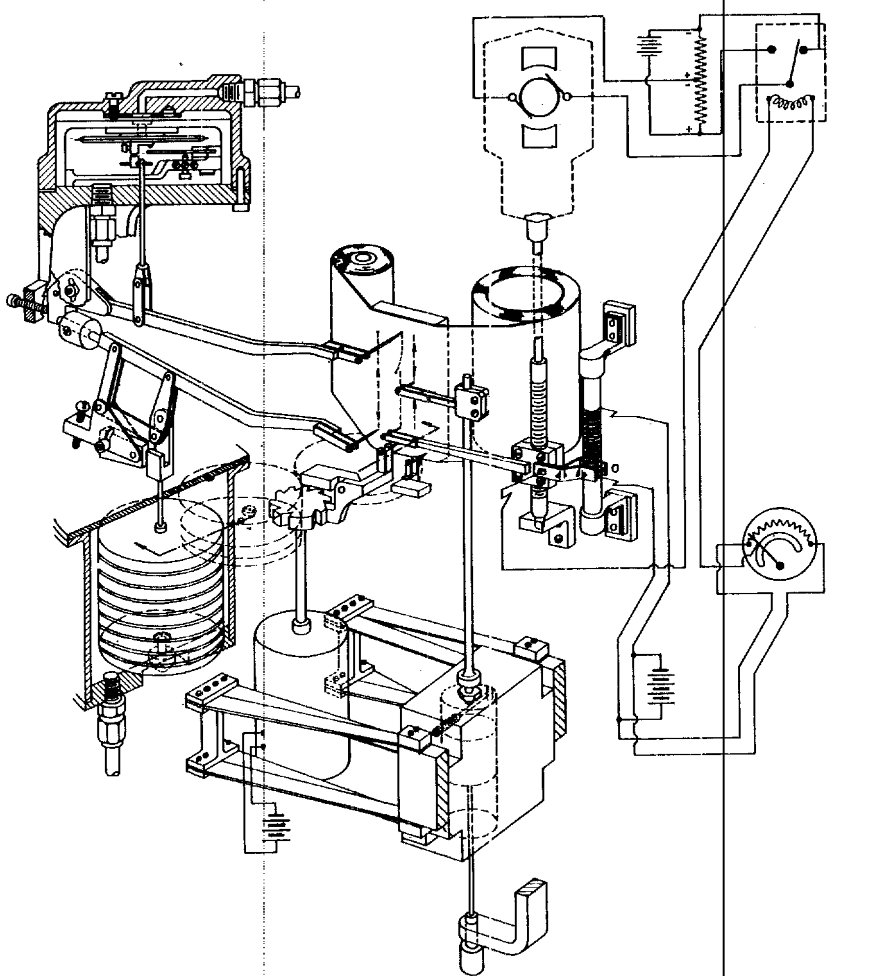


Fig. 2. Exploded View of Recording Mechanism

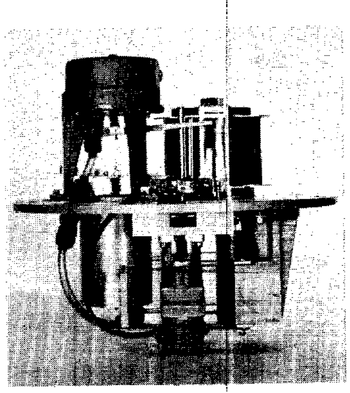


Fig. 3. Recorder Without Housing

per hour by means of a small 28-volt d-c motor operating at 6 revolutions per hour. At this drive speed, the chart movement varies from 3.5 to 5.5-in. per hour, depending upon the diameter of the roll, or an average of 4½-in. per hour. The speed of the chart drive motor is governed by a clockwork mechanism. A spring drive between the motor and the escapement mechanism permits the chart drive to run approximately 10 minutes after the power to the chart drive motor is turned off, or if the power in the aircraft fails.

Time-Marker

A cam-operated stylus, activated by a gear, indicates 1-minute time intervals with successively larger indications each fifteen minutes, 30 minutes and 60 minutes of time. These markings correlate all recorded events with time.

Record Analysis

For a quick analysis of the record to provide a general indication of the magnitude of recorded data, a transparent template, which shows the calibration

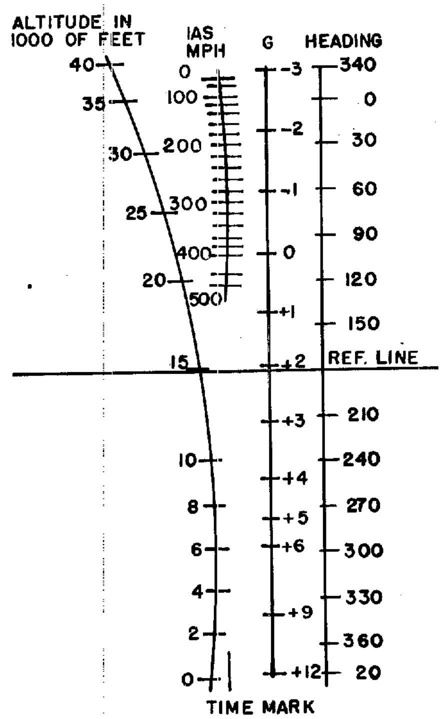


Fig. 4. Transparent Template Markings

of each function, is placed over the record for reading at any instant of time. The template, illustrated in Fig. 4, is marked in miles per hour, the altitude in feet, the acceleration in G's, and the direction in degrees. The template and foil may be magnified by means of a film reader for continuous scanning. For a more accurate analysis, the record may be analyzed under a toolmaker's microscope or other magnifying device; or it may be photographed with edge lighting and enlarged to any size desired.

Operating Conditions

The instrument is highly resistant to extreme humidity effects, and will withstand the vibration and impact conditions experienced by normal aircraft operation. The recorder is so designed that the record will not be damaged under a 100G acceleration.

The record will not be destroyed when exposed to a 2,000 F temperature, resulting from an open fire, for a period of up to 30 minutes and will be preserved for over 36 hours when immersed in sea water.

Operating ambient temperatures are in the range between minus 30 C and plus 50 C.

The drive motor input voltage may vary from 22 to 32 volts d-c without affecting the operation of the chart drive.

Accuracy

The accuracy of recording is commensurate with the pilot's instrument indications, since standard aircraft sensing elements are employed. Simplicity of design, ruggedness, reliability and repeatability of results led to an instrument with the following performance tolerances:

1. *Pressure-altitude at standard conditions*: Plus or minus 2 per cent of full scale and plus or minus 200 feet at low altitudes.
2. *Vertical acceleration*: Plus or minus 0.2G over the full range.
3. *Air speed*: Plus or minus 3 per cent of full scale and plus or minus 6 miles per hour at low speeds.
4. *Direction*: Plus or minus 3°.

Figs. 5, 6 and 7 illustrate typical calibration curves for acceleration, air speed, and altitude, respectively. Fig. 8 is an altitude correction chart taking into consideration the existing barometric pressure at the time of recording. As an instrument to provide data for analyzing air mishaps, it is desirable to have a repeatable record based on standard atmospheric conditions which may be later corrected to the existing barometric pressure for the area at the time corresponding to the recorded event. Such information is available from meteorological records throughout the country.

Fig. 9 is a chart converting pressure in millibars to altitude in feet.

Figs. 10 and 11 are typical flight records illustrating recorded impressions for various aircraft maneuvers.

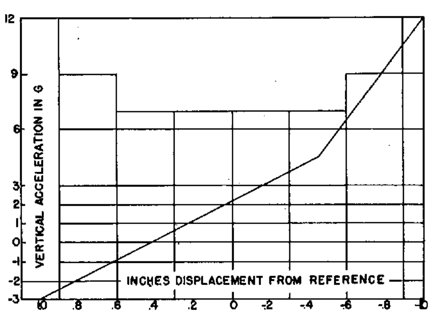


Fig. 5. Typical Calibration Curve for Vertical Accelerometer

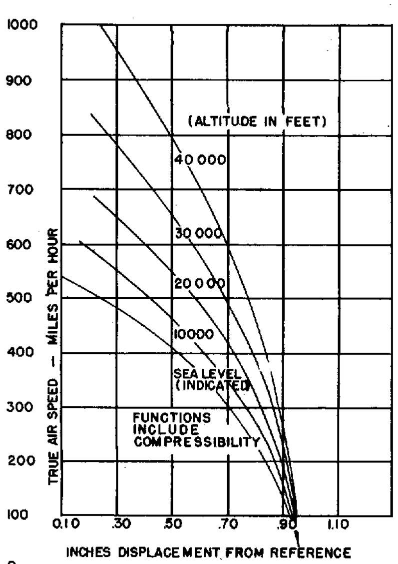


Fig. 6. Typical Calibration Curve for Air Speed Element

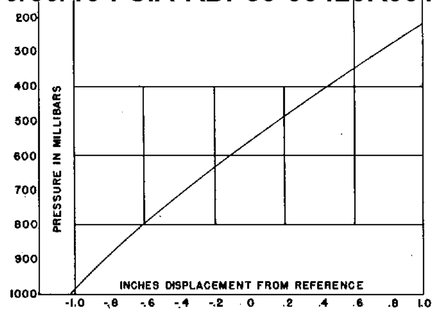


Fig. 7. Typical Calibration Curve for Pressure-Altitude (Standard Atmosphere)

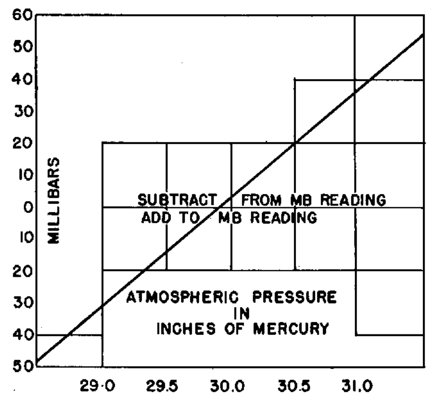


Fig. 8. Altitude Correction Curve

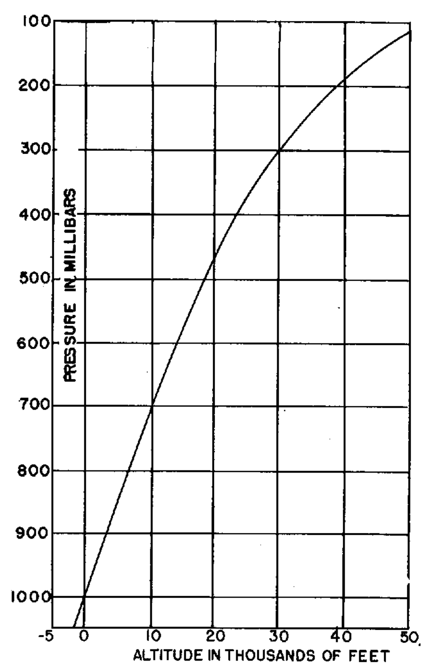


Fig. 9. Conversion Curve, Pressure in Millibars to Altitude in Feet

INSTALLATION

For most applications, recommendation is made that the recorder be installed in the tail of the aircraft to aid in its recovery in the event of an accident. There is sufficient evidence to indicate that the movement of most aircraft responding to gusts or landing shock is essentially the same in the nose and the tail as it is at the center of gravity. Installation in the tail, therefore is quite feasible and desirable. there are no special remote pickups required; all connections being made directly to existing aircraft signals in parallel with instrumentation in the cockpit of the aircraft.

The air speed and altimeter elements are connected to the aircraft pitot-static lines. Similarly, appropriate signals from the fluxgate/gyrosyn instruments in the cockpit are received by the recorder for use in the servo unit of the direction element. In the event such navigation instruments are not available or do not lend themselves to connection in this way, a separate signal-producing compass may be employed.

APPLICATION CONSIDERATIONS

It is believed that a recorder of the design described should have wide application by commercial airlines, executive aircraft operators, the transport service of the military, fighter and bomber wings, and aeronautical research and development activities.

The Airlines and Executive Aircraft Use

Some uses, mentioned below, have been suggested as a means of increasing efficiency and reducing operating and maintenance costs. There are very likely many more uses of benefit to the airlines not mentioned here.

1. Minimize inspection time required through a knowledge of gust, landing shock, and other overstressing loads. An inspection procedure could be established such that the degree of inspection is a function of the degree of acceleration measurement which the aircraft has experienced. For instance, a small recorded shock may suggest limited inspection, a larger record of acceleration would mean slightly more inspection; and a large record of shock may mean complete inspection. The problem of how much inspection need no longer be left to guesswork.
2. Minimize consumption of fuel by statistical determination of optimum altitude, air speed, and take-off conditions, for specific aircraft and various payloads.
3. Comparison of performance of like and different aircraft to aid in evaluating future fleet purchases.

4. Statistical determination of elapsed time of flight between established points; assisting in the preparation of time tables and providing statistical information for establishing engine checkup and overhaul periods.

5. Statistical determination of the practicability of following flight plans in altitude and direction for given forecasted weather and traffic conditions.

6. Based on the statistical determinations of best flight conditions for maximum efficiency, pilots can be advised as to how best to fly the aircraft to obtain flight efficiency and to reduce wear and tear on equipment.

7. Determination of the degree of flight roughness experienced for reported atmospheric conditions; providing data for determining the limiting passenger comfort conditions and the limiting conditions for precluding overstressing the aircraft.

8. Determination of fatigue conditions through a knowledge of frequency and intensity of stress conditions, permitting studies on the life expectancy of aircraft.

The executive aircraft owner gains the same kind of benefit from the use of such a recorder.

Development and Design Use

The use of a recorder which will reproduce true acceleration phenomena is vital in aircraft structural design. The concept of a true recording at low frequency conditions is very important, since the majority of overstressing conditions resulting from air disturbances and landing shocks are believed to occur at frequencies below two cycles per second.

The V.G.A. Flight Recorder, of course, is not a laboratory instrument; but it is a simple and rugged instrument for field use and will yield results, the validity of which, within the error tolerances specified, is certain because of the direct linkage recording mechanism.

Its direct recording feature is desirable in flight test work where immediate analysis is necessary to permit continuation of the next phase of the test program.

The Military Use

The Armed Services can rightfully claim to be the largest operating airline in the world. While the military can gain through reduction of operating and maintenance costs of this vast fleet, the matter of safety in this particular operation is an aspect where an immediate gain can be realized. Analysis of air accidents is extremely vital not only to the saving of lives, but also in minimizing the number of aircraft losses.

To emphasize the unusual need for reducing air accidents in the military, one has only to review statistics presented recently by the past president of the Aero Medical Association, Major General Harry G. Armstrong, in a talk expressing the need for "An Aero Medical Center for the United States Air Force."[1] He said:

> "During the first two years and eight months of World War II, the United States Air Force lost approximately 7,700 aircraft in combat overseas. Meanwhile, it lost approximately 11,000 through flying accidents in the United States. Altogether, during that war the Air Force, within the continental limits of this country, suffered 55,821 major aircraft accidents resulting in the death of 15,613 crew members; major injury to approximately 15,500 others; the total loss of 14,604 airplanes; and major damage to 41,217 more. This loss of life, the billion or more dollars lost in totally destroyed aircraft, and the other billions spent on repair of the damaged airplanes represents only part of the cost for the effort and time consumed in the training of the crews, and the fabrication of the airplanes was also lost and the whole war effort accordingly delayed and weakened."

These figures are phenomenal and indicate that there is much to be gained in studying flight records as an aid in promotion of safety; that is, in reduction of aircraft losses, in training of pilots, etc.

There is another area of benefit to be derived by the military service from the use of recorders. Installation of flight records aboard combat aircraft may provide statistical data relating to the maner in which pilots fly aircraft under combat conditions. This data would seem important to operational research units of the military to aid in determining statistically, if possible, how the *Ace* pilot differs from other pilots in terms of methods of handling combat aircraft.

In summary, instrumentation, as in the V.G.A. Recorder, has application in the promotion of safety, in research and development, and in reducing aircraft operating and maintenance costs. It is hoped that the acceptance of recorders will be as wide as possible so that every aircraft will carry a permanent record of the unusual conditions which it has encountered.

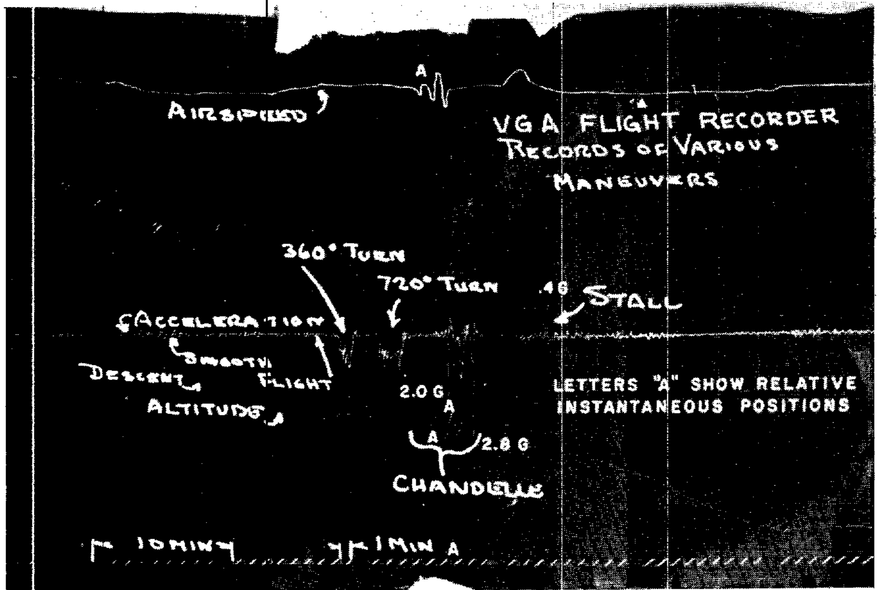


Fig. 10. Typical Flight Record of Hard Turns, Drives, Pull-outs, and a Stall, Showing the Variation in Normal Acceleration, Altitude Air Speed, and Time During Maneuvers for a DC-3 Airplane.

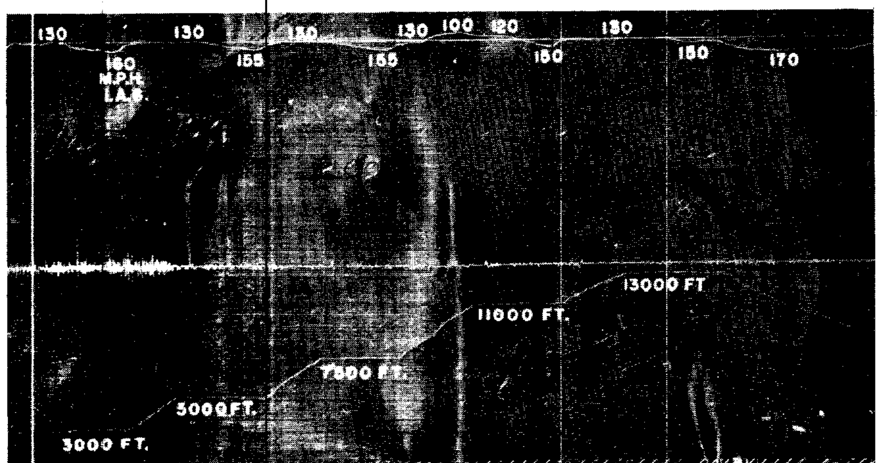


Fig. 11. Test Record of Flight at a Series of Altitudes for Different Indicated Air Speeds of a DC-3 Airplane.

[1] "Crash-Worthiness of Aircraft and Crash Injury Prevention", by E. J. Baldes and J. J. Ryan, The Journal of Aviation Medicine, Volume 23, October 1952, p. 443.

PLEASE NOTE

Reprint of paper to be delivered at the National Instrument Conference and Exhibit of The Instrument Society of America, September 8 - 12, 1952, Public Auditorium, Cleveland, Ohio.

Price to members, 25c; to non-members, 50c.

A NEW TYPE OF PACKAGE HYGROMETER

By

KENNETH C. COON*

INTRODUCTION

The predominant factors affecting the preservation state of materials in storage are the existing temperature and moisture conditions. In determining the pertinent moisture condition for non-hygroscopic materials, it is obvious that a relative humidity measurement is sufficient. For moisture determination of hygroscopic materials in equilibrium with the surrounding atmosphere either absolute moisture content or relative humidity may be measured. A number of instrument types, such as the sling psychromater, hair hygrometer, dew point indicator, and electric hygrometer are and have been available for determining relative humidity in physically large enclosures. The Package Hygrometer was primarily developed as an instrument to be used in determining moisture conditions existing within small low-cost packages or enclosures where conventional instrumentation techniques are impractical. Two types of Package Hygrometer, differing primarily in the type of sensing system, have been developed and tested. A description of each type and its relative merits will be presented and discussed.

GENERAL DESCRIPTION

Though not limited to use in small spaces, the Package Hygrometer's greatest usefulness is expected to be in the field of packaged perishables. A small, dual passage probe is used to pierce the container or package and project into the enclosed air space. A continuously flowing air sample is withdrawn from the package by a small centrifugal blower. The air sample passes from the probe passage into the measuring chamber, through the blower housing and is returned to the package through a second probe passage. The sensing elements are mounted in the measuring chamber.

The determination of relative humidity involves the measurement of two variables: temperature, and quantity of water vapor present per unit volume. The package hygrometer utilizes a thermistor for obtaining the temperature measurement, while commercially available Dunmore type humidity sensing elements are used for obtaining the humidity measurement. Each Dunmore type element consists of a bifilar coil wound on a polystyrene form. The form provides a base for a lithium chloride coating, which serves as a variable resistance conductor between the two halves of the bifilar winding. The resistance of the conductive lithium chloride coating is a function of the quantity of water vapor present in the surrounding air, and decreases as the quantity of water vapor per unit volume increases. The sensing elements are mounted in the probe unit as shown in Figure 1.

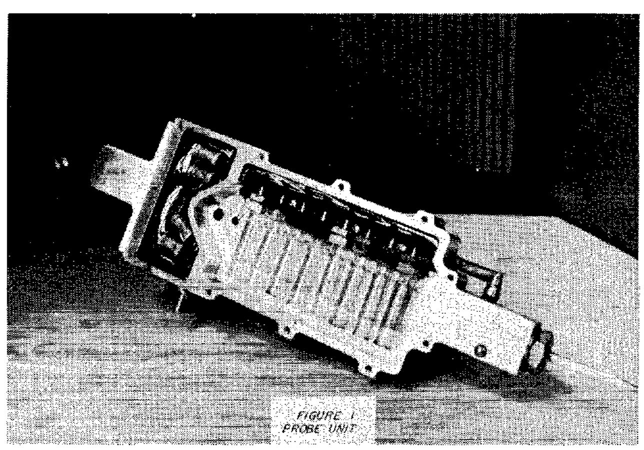


FIGURE 1
PROBE UNIT

The power supply and indicating equipment are included in a separate, portable case. The indicating equipment is used to measure the

*—*Associate Engineer, General Mills, Inc., Engineering Research and Development Department.*

conductance of the humidity sensing elements, and, by proper switch positioning, of the thermistor. A current magnitude in microamperes, when referred to the proper calibration curve, is a measure of the humidity or temperature.

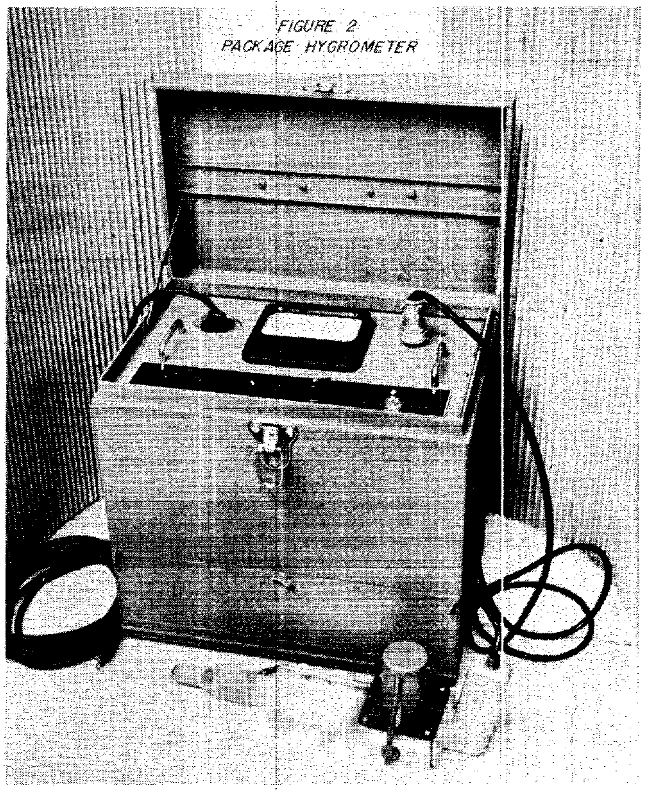


FIGURE 2
PACKAGE HYGROMETER

The indicating equipment may be operated from the AC line, or from self-contained storage batteries. For battery operation a 24-volt vibrator supply is incorporated. The meter, sockets, and all controls are mounted on the instrument panel. The indicating equipment and probe unit are illustrated in Figure 2.

MULTIPLE HUMIDITY ELEMENT SENSING SYSTEM

Since each humidity sensing element is sensitive over only a narrow range of relative humidities, a total of eight elements are necessary to cover the entire humidity range. The eight elements are paralleled through a suitable resistance network, so that only a single conductance measurement is necessary.

Operating procedure for the instrument is straightforward. The cables are connected to their respective sockets and the instrument warmed up and standardized. The package whose humidity is to be measured is pierced with the probe. The blower motor is then energized and allowed to run until the humidity meter indication stabilizes. If the measured relative humidity is only moderately different (20% - 30%) from the relative humidity of the air trapped within the enclosed probe passages from previous measurements, stabilization will have occurred within two and one-half minutes. The temperature is obtained by switching the indicating circuit to temperature and referring the microammeter scale reading to the thermistor calibration curve. After the measurements have been completed and the probe withdrawn from the package, the small hole must be carefully sealed to maintain the package integrity. The stabilized humidity reading is referred to the humidity calibration curve for the particular temperature. Interpolation between humidity element temperature curves may be necessary. The relative humidity in percent is obtained directly from the humidity

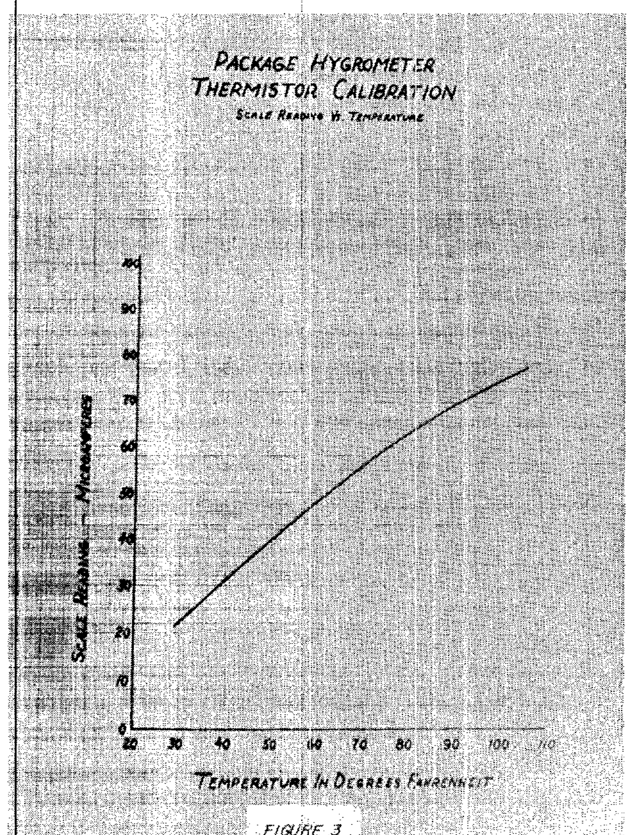


FIGURE 3

element calibration curves. The thermistor and humidity calibration curves are illustrated in Figures 3 and 4.

With careful operation, the accuracy of the instrument is plus or minus 3% relative humidity. It has been calibrated for use over the temperature range of 40 - 100 degrees F. However, increased error will be introduced if the package free air space is less than 500 cc.

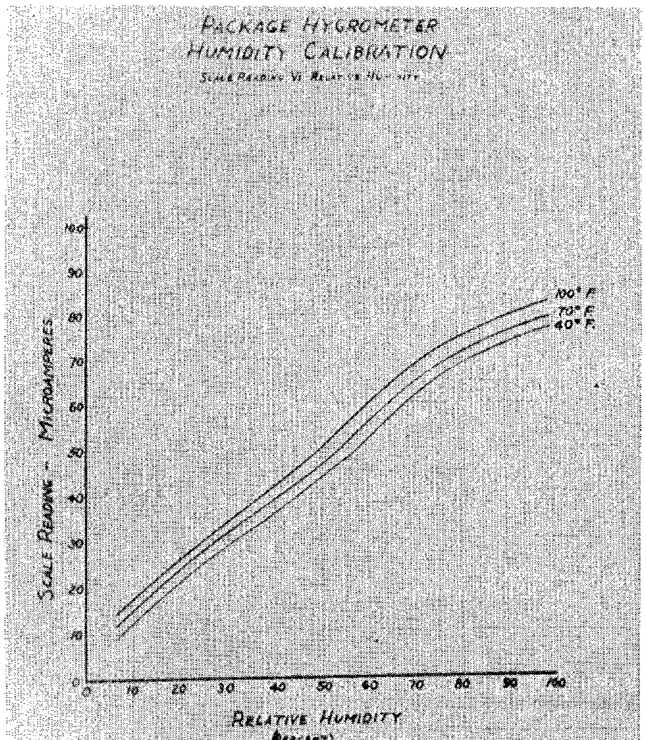


FIGURE 4

SINGLE HUMIDITY ELEMENT SENSING SYSTEM

A probe unit using a single Dunmore type element was designed and tested. The humidity element which was selected is sensitive to low relative humidities only. An electric heater was introduced in the air inlet passage to the measuring chamber. When relative humidities above the normal range of the single humidity element are encountered, the heater is energized, which raises the air stream temperature. Since the absolute quantity of water vapor contained in the air stream is constant, raising the temperature effectively decreases the relative humidity. The air stream temperature is gradually increased until the relative humidity lies within the sensitivity range of the single humidity element.

This type of construction reduced the volume of air passages enclosed within the probe unit, enabling accurate measurements to be made in enclosures as small as 250 cc. However, the humidity elements are temperature sensitive as well as humidity sensitive; and the humidity elements introduced excessive thermal lag into the system. Also, a high humidity measurement could not be immediately followed by a low humidity measurement, since sufficient heat remained in the probe unit to reduce the relative humidity below the sensitivity range of the single humidity element. The unit was satisfactory as a laboratory instrument, but was limited to semi-continuous use.

CALIBRATION

To calibrate both instruments it was necessary to provide a wide range of constant relative humidities. The relative humidities above enclosed saturated salt solutions were accepted as standard. Published data is available *, ** on the equilibrium relative humidities over various salt solutions. The use of supersaturated solutions must be avoided, and extreme care exercised to maintain constant temperature. The Package Hygrometer was calibrated directly using the salt solutions as absolute standard.

MAINTENANCE

Routine maintenance should include no more than storage battery servicing. The sensing elements should maintain their calibration for at least one year. However, excessive dust has a detrimental effect on the elements; generally slowing the response time and/or shifting the calibration slightly. To maintain extreme accuracy, the unit should be re-calibrated periodically.

SUMMARY

The Package Hygrometer is a portable instrument, primarily useful in determining moisture conditions existing within low cost cartons or packages. The multiple sensing element type is recommended for ease of operation and maximum reliability. The accuracy of 3% relative humidity is maintained without difficulty. The instrument is calibrated for a wide range of temperature and relative humidity, covering most commonly encountered storage conditions. The instrument is a useful aid in packaging development and research.

*—*American Paper and Pulp Assoc., Report No.* 40 (1945).

**—*International Critical Tables, Vol.* 1, *pp.* 67, *McGraw-Hill*, (1926).

Acknowledgement: The support of Wright Air Development Center, United States Air Force, in sponsoring this project is gratefully acknowledged.

A

25X1A2g

ATTACHMENT TO [redacted]

Inquiries for Info. on Flight
Recorders, Mechanical Arms,
Package Hygrometer and Plastic
Balloons.