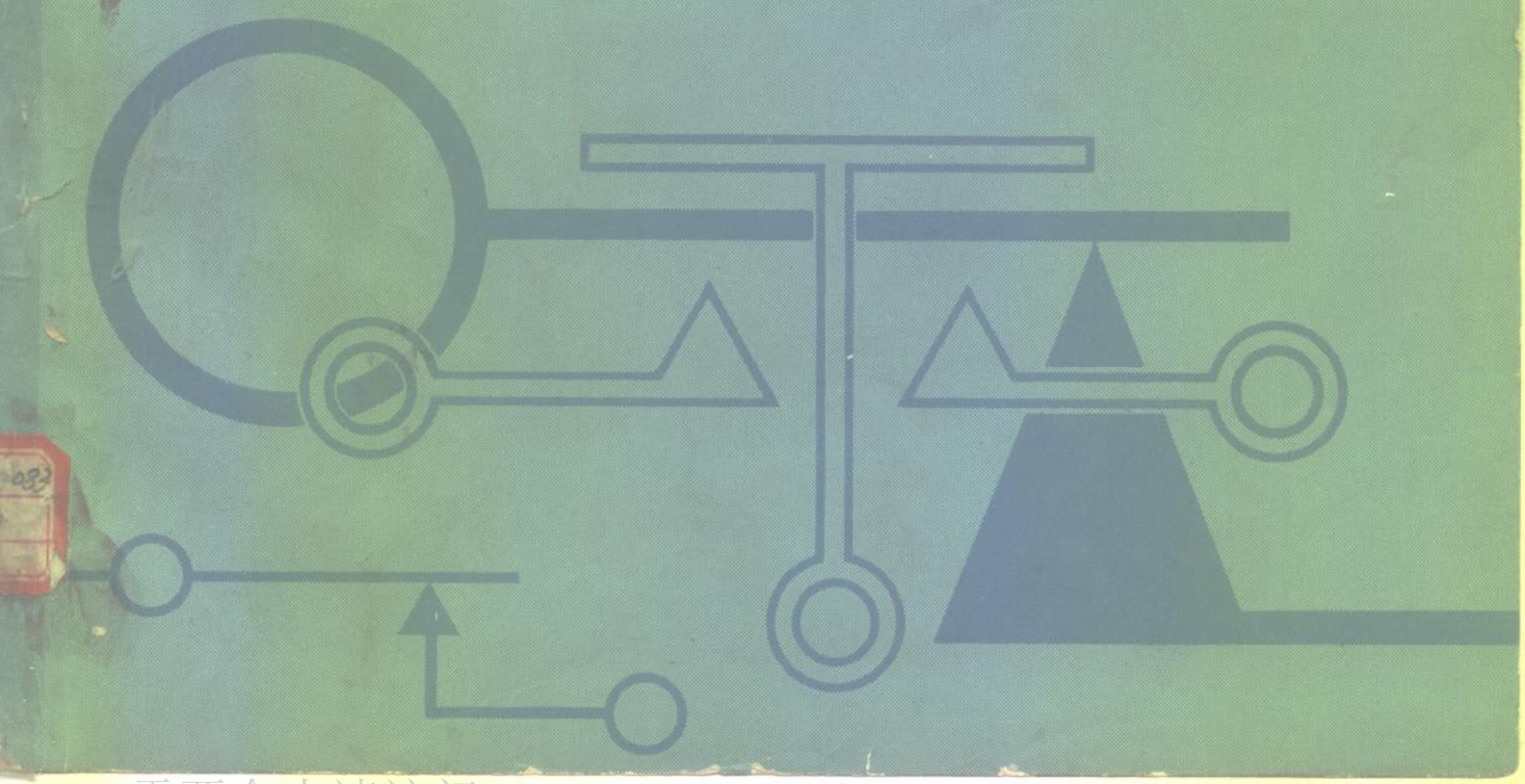
11th ANNUAL RELAY SYMPOSIUM PAPERS • 1963

NARM

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OKLAHOMA STATE UNIVERSITY, STILLWATER OKLAHOMA APRIL 23 • 24 • 25



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NARM RELAY SYMPOSIUM PAPERS

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PREFACE

This publication is a compilation of papers presented at the Eleventh Annual Relay Symposium at Stillwater, Oklahoma on April 23, 24, 25, 1963. This conference is sponsored by the National Association of Relay Manufacturers in cooperation with Oklahoma State University, and is conducted in order that various manufacturers and users of relays may exchange and discuss advances within the industry and may offer solutions to mutual problems.

We express our thanks to all those whose efforts have made this symposium successful, with particular mention to the authors without whom this publication would not be possible. We also express our appreciation to Professor Charles F. Cameron and the staff of the Engineering Department of Oklahoma State University, who have continually devoted untiring efforts toward conducting increasingly beneficial conferences each year.

The National Association of Relay Manufacturers in recognition of outstanding work in preparation and presentation of papers, awards an honorary degree of "Fellow In the College of Relay Engineers," this year presented to the following authors:

THOMAS N. LOCKYER, *Supervisor*
Components Section, Reliability Assurance Dept.
Philco Western Development Laboratory

Subject: Non-Destructive Testing for Parasitic Arc Susceptibility in Relays.

WHEELER D. MAYNARD, *Electrical Engineer*
General Railway Signal Co.

Subject: Design of a Non-Adjusted Relay

HIDEO KUBOKOYA, *Assistant Manager*
Telephone Engineering Division
Nippon Electric Co., Ltd.

Subject: Dynamic Analysis of the Relay and its Application to the Improvement of the impulse Relay

A. R. LUCAS, *Senior Engineer*
DR. WEICHIEN CHOW, *Principal Engineer*
ITT Kellogg Telecommunications

Subject: Economical Magnetic Memory Device

FRED C. EBERT, *Development Engineer*
Micro Switch Co.

Subject: Permanent Magnet Biasing and Operation of Dry Reed Switches

Additional copies of this publication may be obtained for $5.00 a copy from:

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Phoenix, Arizona 85011

INTRODUCTION

By

T. L. Sipp, President
National Association of Relay Manufacturers
Director of Sales Engineering
C. P. Clare and Company

The subject, National Association of Relay Manufacturers Today, indicates there was a yesterday. It also implies we may look forward to a tomorrow. Many say we should not look backwards but only to look ahead. I don't fully subscribe to this admonition. I think we must look back to remind ourselves of the solid foundation established on which we are building today. We must remember mistakes made yesterday so that they will not be repeated today. We must remember our successful actions yesterday so that we can expand them today, and to do so further tomorrow.

Since the inception of NARM in 1947 we have built a solid and successful base. This foundation is represented in our purposes and aims which I quote in part from our By Laws:

> "To encourage the advancement of the art and science of making and using those switching devices generally known as relays."

All of our activities have had the strong technical flavor. We are definitely a trade association wherein our 34 members are all relay manufacturers. But, as a trade association, our activities, publications, and work with this Conference would lead one to believe we are more like a professional engineering society. It is because of this unique aspect that we can attribute the success and recognition which NARM has gained.

One of our major efforts each year is this Conference. We take great pride in the privilege of working with Oklahoma State University to make this Conference possible. As you may know, back in 1953 this meeting was initiated by Professor Charles F. Cameron and the School in connection with a Navy contract held by the University at that time. Almost immediately thereafter the idea became apparent to Professor Cameron that an annual meeting of relay manufacturers and users was desirable. When contacted by Professor Cameron, the officers of the young NARM also saw the merit of a Relay Conference and joint sponsorship ensued. We certainly owe much to the foresight employed by Professor Cameron and those early officers.

Pause for a moment to look at our Conference today. An analysis of the registrants would reveal about 50% represent those interested in the design and manufacture of relays. The balance of 50% represent users of relays. Some might say that with this breakdown of attendees this can't be much of a technical conference but instead a wonderful device for the makers to compete and sell their wares to the captive group of users. Is this true? Do we have exhibits of relays as are found at certain other technical meetings? Is Stillwater noted for its gala night clubs and restaurants where customers could be entertained? Are our registrants salesmen and buyers or are they engineers?

No! By and large this meeting constitutes a medium whereby we have a free exchange of technical information relating to the design and use of relays. Papers are presented and discussed in the academic surroundings of a great university. In our meetings we have this singular advantage which we should maintain and cherish.

Where, for example, would you find the type of paper and discussion which occurred at our ninth Conference. I am referring to a relay manufacturer who discussed a series of failures that a well known user was experiencing with his relays. It so happened the application was a common one wherein the enclosure of the relay is grounded and connected to the common side of an ac contact load circuit. It further was known the relay was the popular crystal can style made by many manufacturers. The fault, as we all know now, was a damaging arc discharge internally between relay contacts and case. To many users and manufacturers this paper and explanation of the phenomenon was most enlightening. I dare say it may have saved many dollars of damage and loss that could have been experienced by others. With such examples, our Conference can only grow in size and esteem.

An idea as to other activities of NARM can be obtained by a brief review of our working committees. These are:

1. Relay Classification -- Here we are attempting to provide a useful and meaningful list of relay types. We think a common and accepted classification is desired by all who deal in one form or another with relays. R. R. Beachler of Leach Relays is Chairman of this committee.

2. Educational Committee -- The objective of this group is to stimulate and acquaint electrical and mechanical engineering students with the opportunity and challenge offered by the relay industry. A. C. Johnson of Adams & Westlake is our Educational Committee Chairman.

3. Membership Committee -- Of course every organization has one of these committees and we are no exception. Philip Garnick of Sigma, and our Vice President, has this committee as his responsibility.

4. Military Specifications Coordinating Committee -- This is a most important committee whose function is to represent the collective voice of NARM relative to all Government relay specifications. Observers from major Government agencies who attend our committee meetings attest to the acceptance of this group. Chairman is Louis LaFlamme of Sigma Instruments, Inc.

5. Publicity Committee -- I believe objectives of this committee are well understood. Our chairman here is John Pfingsten of Hi-G, Inc.

6. Reliability Committee -- Without question this was our largest and most active group last year. You will hear more about the results of their efforts later in our program. Fred Blatt of Sigma, and Dr. H. G. Romig are Chairman and Co-Chairman respectively.

7. Symposium Committee -- In our role of co-sponsor for this Conference, there is much planning and preparation required which becomes the job of this committee. Noel Siegel of Electro-Tec is our able chairman here.

This very brief resume of committee activities further illustrates our technical attitudes.

Finally, we must mention our publications. The list of available items is increasing. It includes Relay Definitions, Test Procedures, Conference Papers, and now two new booklets, Recommended Specifications for High Reliability Relays and Reliability Guidelines for Relays. We hope you agree these represent a helpful service.

I have given you in a most abbreviated form a description of our National Association of Relay Manufacturers and its activities today.

In closing may I, in behalf of NARM, express our great appreciation for your attendance and participation in this Conference.

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SOME CONSIDERATIONS OF POWER SWITCHING WITH SEALED RELAYS IN SPACECRAFT SYSTEMS

by

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INTRODUCTION

This paper is based upon results obtained during evaluation of subminiature sealed relays for applications in manned spacecraft systems. In these applications, the relays will perform low power switching functions and are to be located outside of the controlled atmosphere of the spacecraft cabin.

Sealed relays in a vacuum will gradually lose their internal pressure. The internal pressure will follow the equation

$$P_t = P_i \cdot \exp\left[-\frac{Qt}{V}\right]$$

where P_t = pressure at time t

P_i = initial pressure

Q = leak rate

V = volume of gas within relay

t = time

Figure 1 shows this relationship for relay containing 1.6 cubic centimeters of fill gas at one atmosphere. An internal pressure equivalent to 53,000 feet altitude will be reached in about 42 days at a leak rate of 1×10^{-6} standard cubic centimeters per second; 13.5 months at 10^{-7} ccps; and 11.5 years at 10^{-8} ccps.

One direction of the evaluation program, therefore, was to investigate the performance of the relays at reduced barometric pressures simulating orbital altitudes. Primary consideration was given to determining the consequences of loss of hermetic seal. Accordingly, several phases of the testing were conducted in vacuum chambers with the seals of the relays deliberately broken. The tests performed under these conditions included rated load life testing and investigation of arc discharge phenomena.

We shall consider three of the significant results of these tests and their implications. There are, indeed, other areas of concern relative to application of open electromagnetic relays in space, e.g., the effect of reduced pressures on bearing friction and cold welding of contacts. However, this discussion will be confined to the topics of heat transfer, metal vaporization, and long path arc discharges.

HEAT TRANSFER

Relays switching 2 amperes resistive load at 28v dc in a vacuum failed because of overheating of the contact springs. The springs were annealed and discolored. The evidence suggested that localized temperatures in excess of 300°C were maintained even though the ambient temperature was only 25°C.

Switching in a vacuum is different than switching at one atmosphere. The duration of the arc is greater, resulting in more heat being generated at the contacts. Measurements were made of relays switching 2 ampere, 28v dc resistive loads. The arc durations at atmospheric pressure were 150 to 200 microseconds. When this same test was performed in a vacuum, the arc durations averaged 500 microseconds and at times exceeded 2 milliseconds.

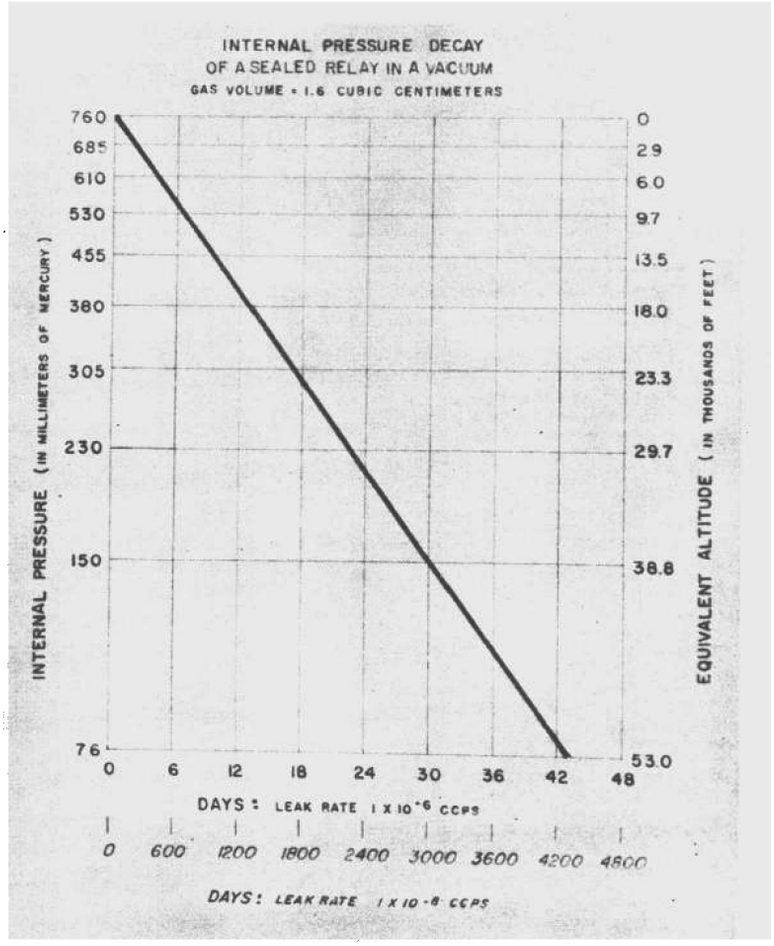


Fig. 1. Internal pressure decay of a sealed relay in a vacuum.

Convection is the major means of heat transfer from a contact spring at atmospheric pressure. Being a long, thin member, this spring is a good cooling fin -- ideal for convection. In a vacuum, convection is not possible. With this mode of heat transfer gone, the spring must lose its heat by conduction. This is its poorest characteristic. Small cross-sectional area and substantial length limit the rate at which heat can be removed from the contacts.

The temperature of a device will continue to rise until equilibrium is reached between the rate of heat production and the rate of heat removal. Empirically, we have observed that when an arcing switch is operated in a vacuum, the temperature of equilibrium can become sufficiently high so as to cause permanent damage to contact springs.

METAL VAPORIZATION

The vacuum environment also affects the performance of the contacts per se. The arc is hot enough and the ambient pressure low enough to vaporize the contact materials. In the tested relays, this vaporized metal was deposited as finely divided silver and gold of a black/purple hue throughout the vicinity of the contacts. See Figure 2, which compares a tested specimen with a new relay of the same type.

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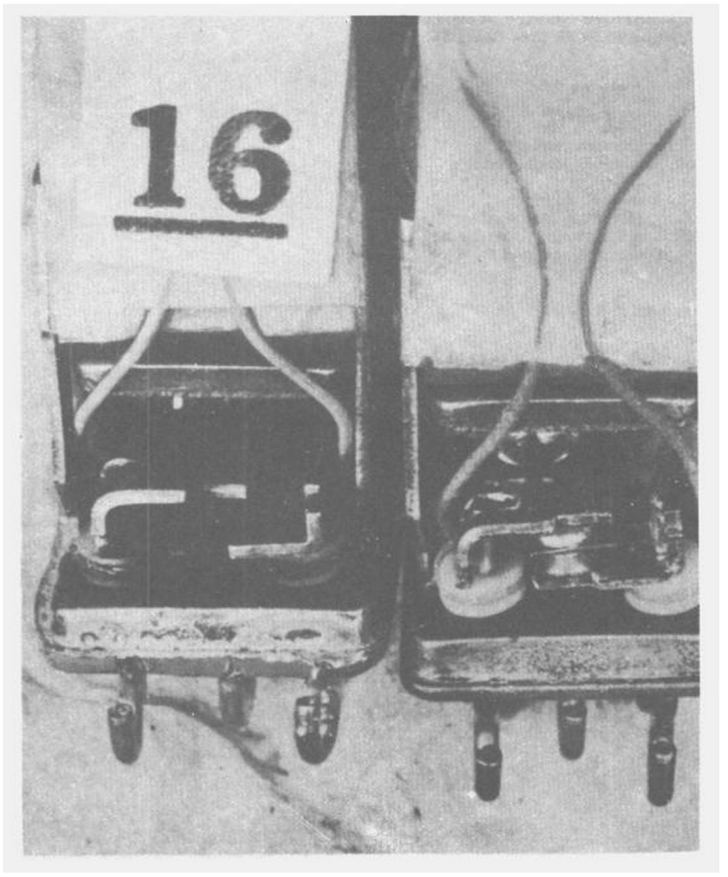


Fig. 2. Comparison of relay showing evidence of vapor deposition of contact material with original appearance.

Vapor deposition is well-known and is used extensively in the manufacture of thin film devices. Considering the materials, low ambient pressure, and the heat produced by the arc, it is to be expected that a cloud of metal vapor would condense on cooler surfaces in the vicinity of the contacts.

Problems associated with this condition are:

1. Loss of Insulation Resistance and Dielectric Strength

   The metal is deposited on the insulating materials. This deposit is conductive and when the buildup is sufficient, it will create leakage paths.

2. Excessive Contact Erosion

   Reliable, long life performance depends upon overtravel of contacts for wipe, contact pressure, and force balance. Since the contact erosion is greater than planned, deterioration of performance will also take place at a faster rate.

LONG PATH ARC DISCHARGES

Investigation of arc discharge phenomena at reduced pressures began with exploratory tests of opened "crystal can" relays. A test circuit was arranged as shown in Figure 3. Note that one selected contact switched a 2 ampere, 115v rms, 60 cps resistive load, and that provision was made for grounding or isolation of the relay frame.

Tests were begun with the relay frames electrically isolated, in order to visually study the brilliance and coloring of the switching arc as the pressure within the chamber was reduced. However, beginning at approximately 60,000 ft. equivalent altitude, discharges occurred between the contacts and one coil termination. Figure 4 illustrates typical evidence of such discharges.

In the test circuit, the relay coil return is common with the load system return. The grounded coil termination periodically becomes some 163 volts positive with respect to the moving contact of the relay. Thus, the discharges must have occurred between the switching arc, acting as a thermionic cathode, and the grounded coil termination (anode). The rather long discharge paths may be explained by considering the fact that the mean free path of particles, e.g., electrons, within the anode-cathode field is inversely proportional to the ambient gas density.

Additional tests were performed with open, ungrounded relays, but with isolated coil supplies and with artificial anodes introduced at calibrated distances from the switching contacts. With the same voltage and current illustrated by the circuit of Figure 3, discharges were readily obtained over distances of up to 0.312 inch at pressures equivalent to altitudes as high as 400,000 ft. Testing at lower arc energy levels and lowered field strengths predictably showed reduced susceptibility to long path discharges. However, discharges were obtained over a distance of 0.150 inch while switching 2 amperes, 30v rms, at only 75,000 ft. equivalent altitude.

It is generally believed that 2 ampere, 28v dc loads, such as required by MIL-R-5757/10 for configuration NA relays, are not subject to the arc discharge failure mode. The results of the 30v rms test just cited, however, prompted investigation of the validity of this belief. Tests were conducted at reduced pressures in which opened relays were subjected to 2 ampere, 28v dc switching with the relay frame returned to the load system ground. With the positive (+) 28 volt terminal grounded, certain relay design configurations experienced arc to header discharges at equivalent altitudes of 70,000 to 90,000 ft. This finding has been verified at 150,000 ft. equivalent altitude by other investigators.[1]

From an academic standpoint, the data reported herein supports the hypothesis concerning the mechanism of arc discharge failure set forth by Nunn and Halbeck at this Conference in 1961.[2] Specifically, in the instance cited of the 0.312 inch discharge

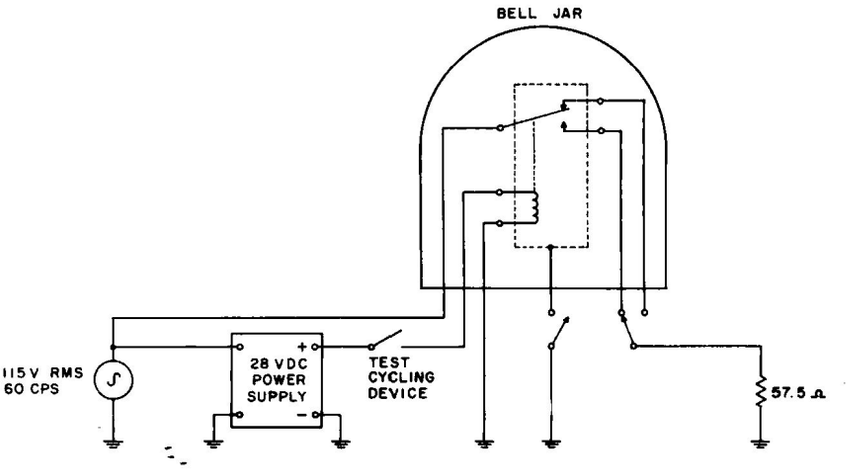


Fig. 3. Test circuit for arc discharge investigation at high altitudes.

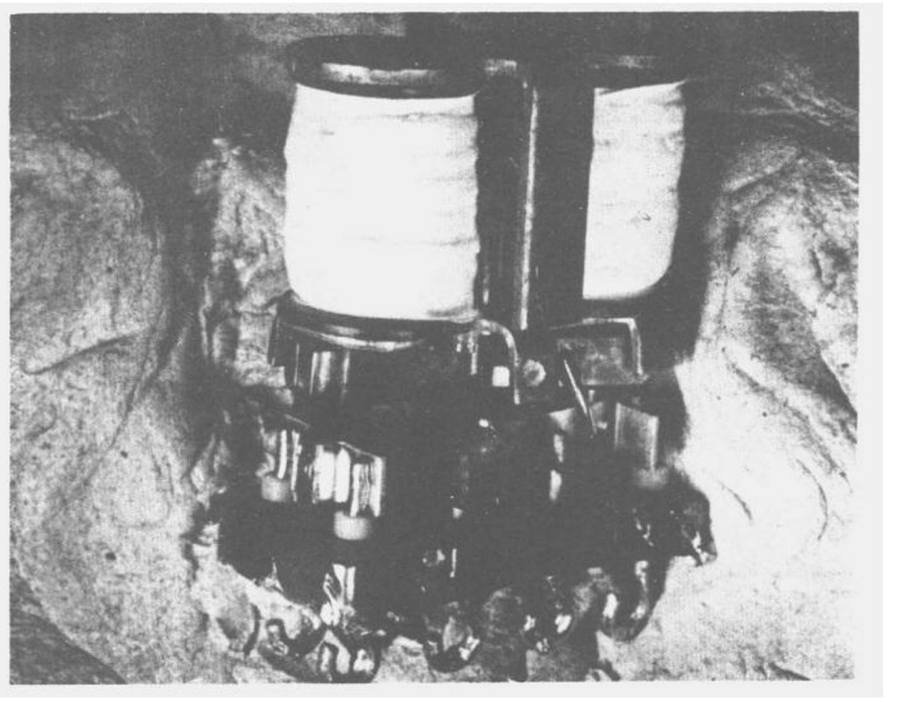


Fig. 4. Arc discharge between N/O contact and (fused) coil termination

at 400,000 ft., the field strength (approximately one-half volt per mil) and the altitude preclude field emission breakdown.

The practical implication of these findings is that imperfectly sealed relays may be susceptible to arc discharge failure in spite of precautionary mounting insulation. An airborne or space system in which both alternating and direct current power sources share the common airframe ground is an example of the type of application in which the necessary conditions could coexist.

CONCLUSION

Contact arc characteristics in a vacuum have a far more severe effect on relay performance than at one atmosphere. What can be done to assure reliable performance?

1. Never let the contacts operate in a vacuum. The requirement in MIL-R-5757D for a maximum leakage rate of 1×10^{-6} ccps is just sufficient for the present generation of manned spacecraft. As longer missions are programmed, it will be necessary to build relays which leak at a rate less than 1×10^{-7} ccps. This tenfold improvement should suffice for a while and ultimately may be supplanted by a 1×10^{-8} ccps requirement.

Remembering the relationship stated earlier and illustrated by Figure 1, the internal pressure versus time is a function of the gas volume within a given relay. The gas volume within a relay will vary according to its design. Would not a more logical specification be one which links the leak rate with a requirement for a given internal pressure after a given length of time?

2. Inhibit the arc. In the event of seal failure, proper arc suppression would eliminate a major portion of the heat in the switch, and would minimize metal vaporization and the probability of long path arc discharges. Because of the widely varying conditions of contact loading encountered in practice, effective arc suppression will require individual consideration of each application.

The use of relays in manned spacecraft applications will continue to grow as man seeks to explore further into the universe. Areas considered failure-proof may become major problems as new, strange environments are encountered.

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1. Private Communications, General Electric Co., Waynesboro, Virginia.

2. Charles P. Nunn and Reinhold Halbeck, "A Study of Discharge Transients in Relays With Grounded Cases," Ninth National Conference on Electromagnetic Relays, Oklahoma State University, Stillwater, Oklahoma, April 25, 26, 27, 1961.

ECONOMICAL MAGNETIC MEMORY DEVICE

BY

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SUMMARY

Computer and switching/control systems in use today typically require some type of memory for system operation. The memory, or data store for the system, serves to hold data in storage until it is needed by a cycle of system operation. Relays, flip-flops, punched cards, magnetic tapes, discs, and drums, ferrite cores and matrices represent some of the devices available for this purpose. This paper describes a new magnetic drum memory that has been developed as a low-cost storage device which does not require ancillary amplification for either input or output functions for switching and control systems. This memory device has some features that are characteristic of a digital computer memory, but it does not have the latter's high cost. The new memory device can be used either as a general purpose bit store, or as the main storage device in switching/control systems. The design of the memory and its typical applications are presented in this paper.

DESIGN PARAMETERS FOR A MEMORY DEVICE (LOW-SPEED ACCESS)

Memory device design should incorporate both the general and specific objectives that are essential in a system memory. In general, the memory should receive, record and deliver information, as required, within the framework of the using system. Specifically, a memory device for switching and control applications should handle data as follows:

1. Store data without deterioration.
2. Access data selectively and/or sequentially, in minimum time. (Time is equated here in terms of electro mechanical systems as opposed to electronic systems.)
3. Erase data when new data storage is to be made.
4. Have a large data-bit capacity.
5. Cost a minimum per data bit stored.
6. Have a reasonable total cost.

MEMORY DEVICE MEDIA

Of the memory techniques available for achieving the above design objectives, the magnetic media are most suitable for switching and control applications. These media allow easy change in recorded data, with new data being recorded over old, either directly or by erasure. Also, the magnetic media have inherent convenience; any error in the memory being automatically corrected when new data is recorded. In addition, salient operational features, such as fast bit-access time or fixed sequencing of data bits, can be supplied as necessary; the ferrite cores and magnetic tape being appropriate for these applications respectively. Magnetic drums and discs meet most of the above design parameters and have had successful system application. While their bit-access time exceeds that of ferrite cores, they are nevertheless commonly used as the main storage mechanism for computing systems with high-reliability memories, such as the general-purpose digital computers. Similarly, fast bit access is not generally a critical requirement for switching/control system memories. The favorable design parameters of magnetic drum storage may be extended to switching/control system memories, their less stringent requirements affording a lower cost device. A comparison of the design requirements for digital computer and switching/control magnetic drum memories shows the areas of relaxable features and the basis of the final, low-cost design.

DATA STORAGE PRINCIPLE

The magnetic drum memory operates on the principle of switching the polarity of bit magnets. The bit magnets are miniature, U-shaped magnets mounted on a drum with write and read heads being mounted about the drum periphery. For bit storage, the polarity of a bit magnet is switched or reversed by means of a DC potential applied to a write coil head. When a stored data bit is to be read, the bit magnet is then rotated to a read head, which consists of a permanent magnet of the appropriate polarity. Magnetic attraction of the read head to the memory bit magnet on the drum operates read head contacts, giving bit readout. Further, memory of the bit on the drum is retained until the bit is intentionally erased, through second use of the write head. A bit on the drum is erased by rotating the bit magnet to the write head and then applying the DC write-in potential in reverse polarity. The reversed field of the write electromagnet serves to restore the bit magnet to its original polarity, and erase the bit from the memory.

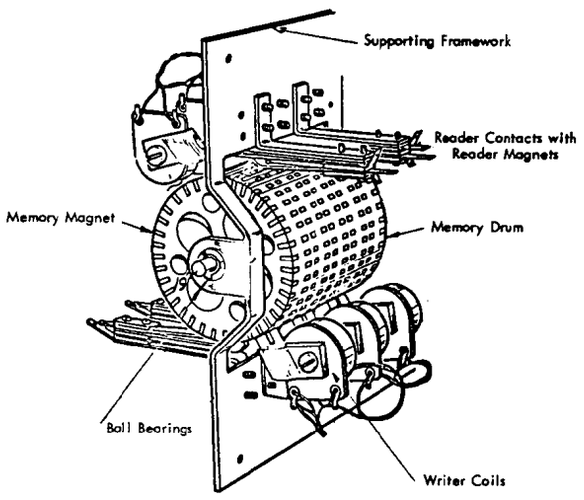


Fig. 1. Low Cost Memory Device Prototype Model

PHYSICAL ARRANGEMENT OF FUNCTIONAL ELEMENTS

The memory consists of a 3-inch diameter non-ferrous drum having bit magnets and associated read and write head. (Fig. 1). Memory bit magnets are mounted as a layer on the drum periphery, the magnets being arranged circumferentially in five parallel rows of fifty magnets each. For bit storage or access, the drum must be rotated to the read or write head respectively, an external driving source (stepping switch, motor, etc.,) being required. With this type of construction, the dynamic balance of the drum is not critical. Dynamic balance is neither used nor required for the usable record-access speeds of up to twenty-five bits per second.

Write and read heads are provided for each ring of fifty magnets, a total of five heads for each function being provided. Hence, five bits can be recorded, or read out, at a time. The write head for each ring of fifty-bit magnets is essentially an electromagnet whose polarity is maintained in one direction or the other for write and erase functions. The read head for each ring is a permanent magnet which is polarized opposite to that of a bit magnet's "storage" polarity. The read head can be equipped with make or break contacts for readout.
Fig. 2 shows the basic wiring of the writer coils and reader contacts, including the write-in and erase features. Fig. 3 shows the finished product photograph.

MAGNETIC DESIGN CONSIDERATION

In any magnetic storage system, the speed of operation and over-all size are largely determined by the physical and magnetic properties of the magnetic medium and the head structures. The magnetic requirements of the low-cost memory drum device is such that the magnetic field must be large enough to perform the actual physical function of moving a contact which in turn applies the actual power output.

The principal properties of the permanent magnets desirable in a low-cost magnetic drum are best described as follows:

In the magnetic material, the atoms which possess the magnetic characteristics are grouped into regions called domains. In unmagnetized ferromagnetic materials, the domains are randomly oriented and neutralize one another. Magnetic forces in the form of positive and negative poles are present. Application of an external magnetic field causes the magnetic poles in all the domains to become aligned, so that their combined magnetic moments are additive under the influence of the applied field.

In the case of soft magnetic materials such as soft iron, small external fields will cause a great degree of alignment; but, because of the small restraining force, very little of the magnetism will be retained when the external field is removed.

Permanent magnet materials are characterized by a severely-strained lattice, fine-grain material, high hardness and high alloy content. For optimum retentive properties, the hysteresis loop must be large and the material must possess a high value of residual induction and coercive force. The latter fact is better appreciated when it is remembered that residual induction (B_r) gives an indication of "how magnetic" a substance is after it has been magnetized, and coercive force (H_c) gives an indication of "how difficult" it is to demagnetize the magnet.

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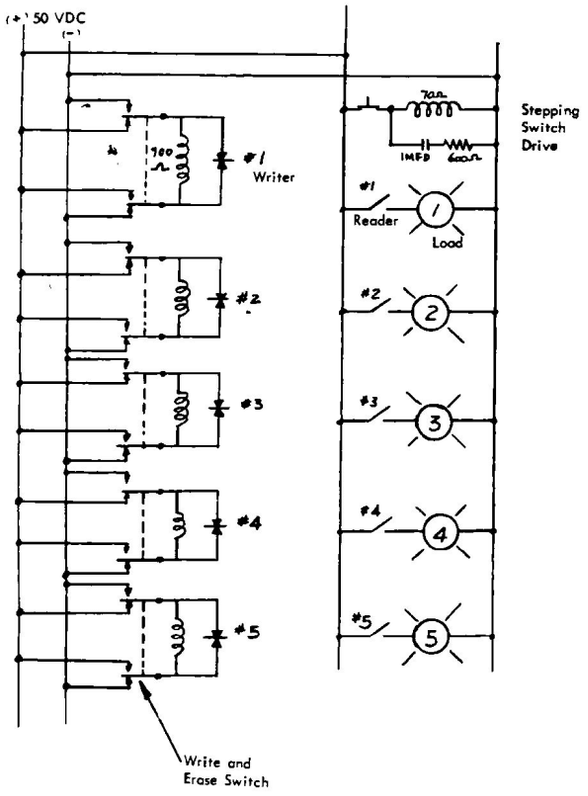


Fig. 2. Circuit With Stepping Switch as Driver

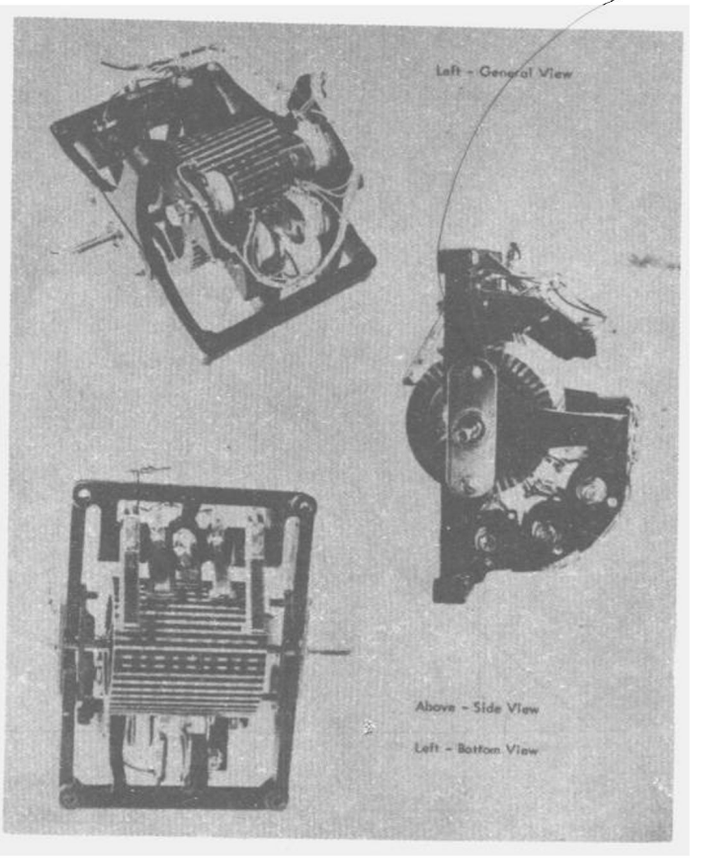


Fig. 3. ITTK Magnetic Memory Device

DESIRABLE HYSTERESIS LOOP

The memory permanent magnet must have different properties from either the reader permanent magnet or the electromagnet. High permeability is still required, but moderate coercive force (H_c) and high residual induction (B_r) are preferred. The memory magnet must not be influenced by stray magnetic fields; however, the polarity of the field must be reversible by a relatively small power source. The memory magnet must retain a large field because the purpose of this magnet is to generate an attraction or a repulsion force with the reader magnet, and the larger the field, the stronger will be the reader magnet responses.

The desirable hysteresis loops of the memory magnet, reader magnet and the write electromagnet are shown in Figure 4.

SELECTION OF THE PERMANENT MAGNET MATERIALS

The magnetic circuit, including the magnet, contains an air gap; consequently, the magnet always operates under the influence of a demagnetizing medium (the air gap) and not at residual induction (B_r) but at some lower value of "B." Thus, the important curve for a permanent magnet material is that portion of the hysteresis loop that lies in the second quadrant between residual induction and coercive force; this is called the demagnetization curve. For a magnetic circuit with an air gap of specified area, length and flux, the volume of magnetic material is least when the energy-product is a maximum.

Figure 5 shows the demagnetization curves and the energy-product curves of 36% cobalt steel; 17% cobalt steel; group of 3% cobalt steel, 6% chromium steel and 6% tungsten steel; Alnico II, Alnico V, and Alnico XII. From the standpoint of high energy product $(BH)_{max}$ it is natural that Alnico V is considered as the best choice for the reader permanent magnet material. Alnico XII has a higher coercive force of 950 oersteds, but the maximum

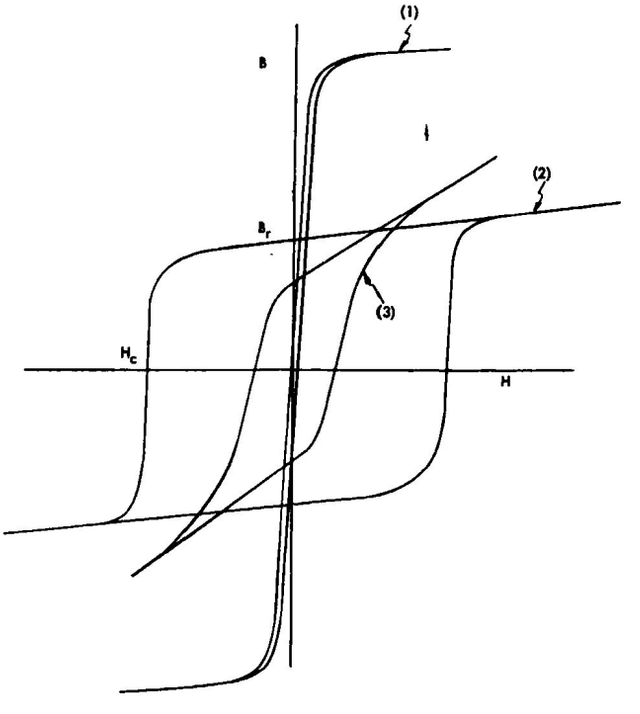


Fig. 4. Desirable Hystersis Loops Of: (1) Electromagnet (Writer); (2) Reader Magnet; and (3) Memory Magnet

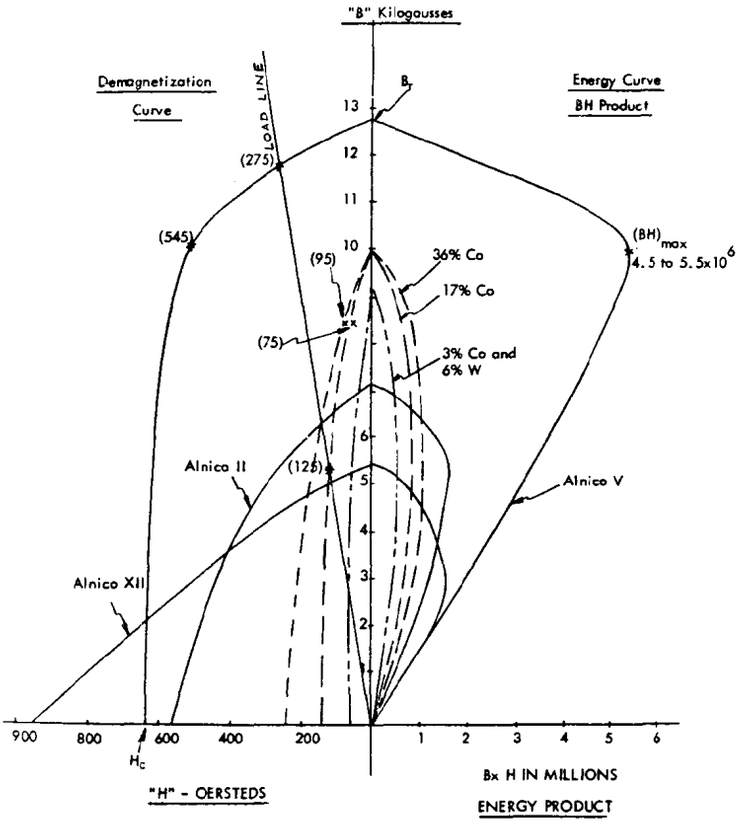


Fig. 5. Demagnetization and Energy-Product Curve for Magnet Steels and Alnicos

energy product $(BH)_{max}$ (1.5×10^6) is lower than that of the Alnico V (4.5×10^6).

The heat treatment of Alnico V consists in heating the alloy to 2,400°F and cooling to room temperature in the presence of a magnetic field of 1000-3000 oersteds and then aging for several hours at about 1,150°F. The coercive force (H_o) at the maximum energy-product point of the Alnico V is equal to 545 oersteds and its corresponding induction (B_o) is equal to 10,000 gauss. The maximum energy product $(BH)_{max}$ may vary from 4.5×10^6 to 5.5×10^6. Alnico V with field treatment has a residual induction (B_r) of 12,500 gauss and a coercive force (H_c) of 575 oersteds. However, without treatment, the residual induction is only 8,300 gauss. Maximum energy-product of untreated Alnico V is 1.7×10^6 and the coercive force is 535 oersteds.

The lower grades of material such as 6% tungsten or 6% chromium or 3% cobalt steel are not adequate for the memory magnet selection because of their relatively low energy-product and low coercive force (H_c). The iron-cobalt alloys are usually used when high inductions are advantageous. Cobalt 36% has a coercive force of 220 to 260 oersteds. However, cobalt 17% is less expensive. Its coercive force (H_c) is 150 oersteds and is about four times less than that of the Alnico V. This steel can be cold stamped and is suitable for mass production techniques, since the hardness of the steel in the annealed state is only Rockwell 27-30°C scale. Because of the relatively lower magnetomotive force needed to charge or reverse the polarity of the memory magnet and the relative high residual induction property, the cobalt magnet steels were favored as a choice for the low-cost memory magnet.

The saturation induction (B_s) of the 17% cobalt steel is 23,000 gauss; the residual induction (B_r) is 9,500 gauss, and the coercive force (H_c) is 150 oersteds. The maximum energy product $(BH)_{max}$ is 0.65×10^6; the induction (B_o), and the coercive force (H_o) corresponding to this maximum energy-product are 5,200 gauss and 125 oersteds, respectively.

The composition and hardness of the 17% cobalt steel used as the low-cost memory magnet are as follows:

Composition:	Cobalt	16 - 20%
	Chromium	2 - 4%
	Tungsten	6.5 - 8.25%
	Carbon	0.6 - 1.0%
	Silicon	0.15 - 4%
	Manganese	0.2 - 0.6%
Hardness:	Anneal State	27 to 30 Rockwell C State
	Harden State	62 to 68 Rockwell C

CHARGING, AGING AND STABILIZATION

The retentive magnetic properties of the permanent magnet depend on may other factors in addition to the physical configuration, composition, hardness state and field treatment. The permanent magnet must be fully magnetized to saturation in order to obtain the maximum residual induction. Recommended values of magnetomotive force vary from about 600 ampere turns per inch for cobalt steel to 5,500 ampere turns per inch for Alnico V. The direction of the magnetizing field should be essentially the same as that desired in final assembly, so that no energy will be required to orient the field when the magnet is placed in service.

If a magnet is charged immediately after hardening, it gradually loses some of its strength but can be remagnetized to recover strength equal to or in some cases greater than its initial value. Aging is due to metallurgical changes within the steel. In general, it is best to allow a period of time to elapse between hardening and use of the magnet. However, none of the grades of Alnico age to any appreciable extent.

Three important factors which tend to demagnetize permanent magnets are the effects of stray fields, heat and vibration. Loss of magnet flux at high temperatures is appreciable; however, upon return to room temperature, approximately half the loss is recovered, provided the Curie Point was not reached. The Alnico magnets are suitable for temperatures approaching 750°F, but the cobalt steels are unsatisfactory at temperatures much over 400°F. Stabilization against vibration and shock can be achieved by subjecting the magnet to repeated impacts until the value of flux change has leveled off. The Alnicos are almost unaffected by limited vibration and shock. In the case of cobalt steel, the percent magnetization retained levels off after approximately 500 impacts. Severe impacts that produce a 15% loss in tungsten and cobalt steel will cause only a fraction of a percent loss in Alnico II and a negligible loss in Alnico V.

The disturbing effects of temperature on the magnetic material are complicated. If a bar is magnetized at room temperature and then heated with no applied field present, the induction will usually decrease as the temperature rises and increases again as it falls, but generally not all of the induction will return. The extent of recovery depends primarily on the metallurgical stability of the alloy and this varies considerably from one material to another. The cheaper magnet materials, such as 3.5 chrome steel, suffer a loss in remanent induction of over 10% when heated to 400°F for a half-hour and cooled in air. However, both Alnico V and cobalt steel could stand indefinitely at 300°F to 400°F without suffering heavy loss of induction.

PROBLEMS INVOLVING PRACTICAL DESIGN

An important problem in efficient design is to select the appropriate material. The next step is to use a minimum of magnet material consistent with the strength of the field desired in a given volume of space. The following shows some of the factors involved in such a practical design:

INFLUENCE OF CONCENTRICITY OF THE DRUM

The magnetic circuti is analogous to the electric circuit in that the flux (ϕ) is proportional to the magnetomotive force (F) and inversely proportional to the reluctance (R). In the magnetic circuit, consisting of the writer coil and the memory magnet, the magnetic path of the flux (ϕ) has to go through the iron core of the coil, two pole pieces, two air gaps and the memory magnet. If the ampere turns of the coil is 300, the total line of flux (ϕ) would be calculated to be 850 maxwells. Since the cross section of the air gap is known, the flux density (B) will be calculated to be 13,300 gauss for .001" air gap.

It is noted that the reluctance of the cobalt path in hardened state is quite high as compared with the air gap (.001"). However, when the air gap increased from .001" to .003" the flux density would be reduced to 78% of the flux generated by the coil. The flux density available to the memory magnet is further reduced to 7,000 gauss if the air gap is .006". Since the air gap depends on the concentricity of the drum, it is imperative that the concentricity of the drum be kept within .003" T.I.R. or ± .0015" when a flexible bracket is used, but when a rigid bracket is used the tolerance is more critical and should not exceed .0015" T.I.R. concentricity, in order to allow the memory magnet to receive sufficient charge to insure high residual induction. This tolerance is within the limit of today's manufacturing technique.

STRAY FIELD

Theoretically, the saturation flux density of the cobalt steel is 23,000 gauss. If the ampere turns are increased, the flux density available to the memory magnet would increase. The stray field, in this case, is the coercive force generated by the writer coil tending to influence the neighboring memory magnet. Because of the limitation in the size of the drum, the air gap between the pole tips of the writer coil and the next neighboring memory magnet is around .080", by using the same formula of the flux (ϕ) being equal to magnetomotive force divided by reluctance.

The maximum stray field with which the writer coil could influence the neighboring cobalt magnet is calculated to be 25 oersteds. Since it will take a coercive force of 150 oersteds to reverse the polarity of the memory magnet, a 25-oersteds maximum stray field is considered safe for the design.

EFFECT OF VOLTAGE VARIATION ON CHARGING THE MEMORY MAGNET

The voltage of 50 ± 10 volts variation is desirable in a practical design because of the coil resistance and the supply voltage source. If a coil is designed for 300 ampere turns at 50 volts, it would give only 240 ampere turns when the supply voltage is reduced to 40 volts. From the fact that the desirable residual induction (B_r) of cobalt steel is 9500 gauss, the available flux density from the writer coil should be at least 10,000 gauss in order to reverse the polarity of the field. Thus, a coil design to give 300 ampere turns at 40 volts in ambient temperature of 135°F is therefore required.

DUTY CYCLE OF THE WRITER COIL

The calculation of the winding size involves many factors such as: ambient temperature, duty cycle, wire resistance, winding tolerance, supply voltage variation, ampere turns required (hot), space factor and power dissipation.

In order to design a coil that will give 300 ampere turns at the final coil temperature, a coil of outside diameter of 0.96 inches and inside diameter of 0.44 inches and coil length of 0.63 inches is required. This coil will be suitable for a duty cycle of 64% when the ambient temperature is 70°F. If the ambient temperature is raised to 135°F, the recommended duty cycle of the coil is 30%. In the application of the memory device, most of the time is spent in searching the location; therefore, a 30% duty cycle of the write-in coil is considered adequate.

MEMORY MAGNET STRIP

The physical dimensions of the memory magnet are shown in Fig. 6. It is noted that all of the five horseshoe magnets are integrally connected together in the form of a strip. This arrangement is desirable from an economical production assembly point of view. Because of the high reluctance of the cobalt steel, the flux leakage to the integrally connected adjacent magnet of the strip is small enough so that the proper operation of the system will not be affected.

The cobalt steel will be received in the annealed state, having a hardness of 25 to 30 Rockwell C Scale. If not, the process of annealing at 1300°F for two to three hours in a controlled neutral atmosphere furnace must be made. The steel can be sheared and stamped. There will be no grinding operation before assembly to the drum. The strips are then hardened to within a range of 62 to 68 Rockwell C. Slight camber from end to end of the strip is not to be considered as cause for rejects. After hardening, the strips can be inserted in the slotted drum. Adhesives will be applied on the periphery of the drum after the strip insertion. The drum is ground to a very close concentricity with respect to the shaft.

The hardness of the memory strip does not tell the full story of the magnetic property of the cobalt magnet. To verify this phenomenon, a number of magnet strips were hardened and quenched at 1700°F. The hardness of the strips was measured. The average hardness of the strips of 67 Rockwell C Scale was obtained. The specimens were then heated one hour at different tempering points of 100°F intervals. It was found that the hardness scale remained on 67 Rockwell C when the tempering point was raised up to 700°F. The hardness dropped very little from 700°F to 1000°F, but from 1000°F up, the hardness dropped rapidly. Figure 7 shows the effect of probe of the Radio Frequency Gaussmeter. It is noted that the residual inductance decreases more than one-third of its possible full value while the hardness remains constant at 67 Rockwell C scale.

CHOICE OF MATERIALS FOR THE DRUM

There are many plastic materials in the market which can be used for the drum. Of these,

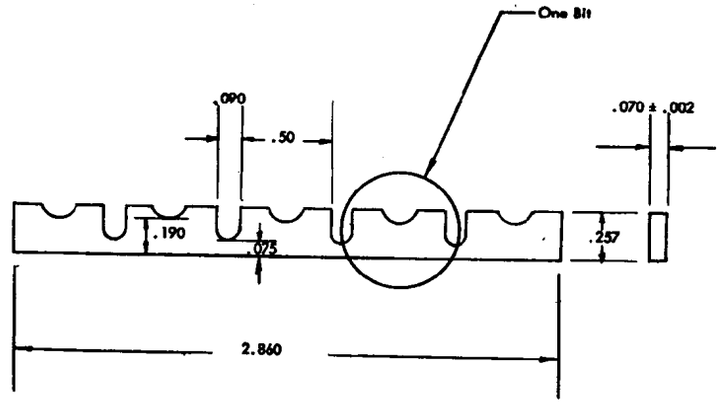
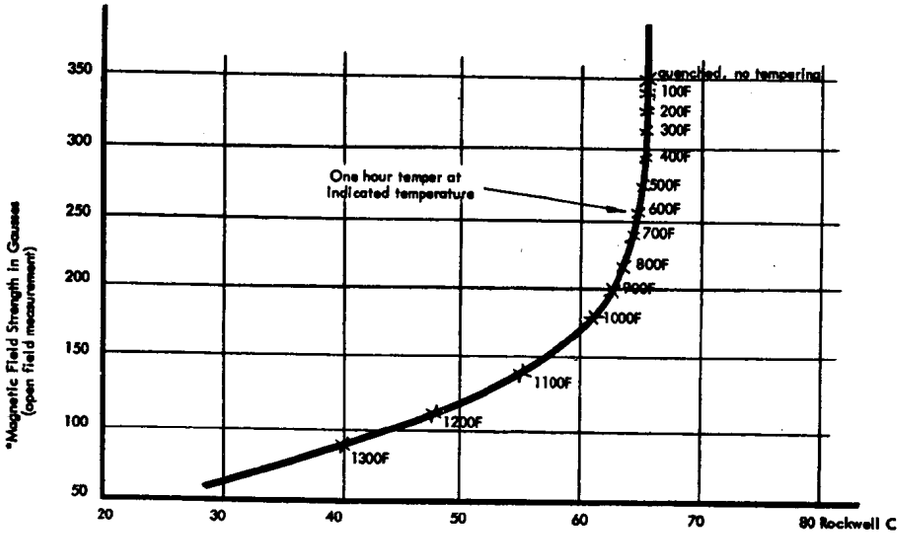


Fig. 6. Memory Magnet Strip



HARDNESS OF COBALT STRIP

*Use of Radio Frequency Model 1890, Gaussmeter, Flat Probe

Fig. 7. Effect of Hardness on Magnetic Field

the epoxy cast, Acetal Resin (Delrin) and Polycarbonate (Lexan) are all acceptable. For pilot production run, the epoxy cast material is selected. It is found that 25% Calcium Carbonate filled epoxy would give excellent machinability with 1.36 specific gravity and fair water absorption properties. Since the weight of the drum is concentrated at the circumference, the moment of inertia of the drum is largely dependent on the weight of the memory magnets, and is calculated to be .00356 lb.-inch-seconds^2. The over-all size of the drum is 2-3/4" in diameter x 3" wide, and the weight of the drum, with 50 memory magnet strips, is approximately one pound.

PULL FORCE BETWEEN THE READER MAGNET AND MEMORY MAGNET

In order to calculate the pull force between two permanent magnets, the demagnetizing curves, as shown in Figure 5, are used. Load line is drawn from origin and intercepts the cobalt 17% curve at its $(BH)_{max}$ point which is 125 oersteds. The corresponding point at the Alnico V curve is taken as 275 oersteds. With these two data, and since there is no field due to external electric circuit which means the sum of total lines of flux $HdL=0$, the flux density (B) at the air gap can be derived. This flux density (B) is calculated to be 2040 gauss with a .050" air gap. Using the force formula of $B^2A/8$, the pulling force between the two permanent magnets at .50" air gap is 10.8 gram. In practice, because of the flux leakage and the preloading force of the contact spring, the net pulling force between the memory magnet and the reader magnet is somewhat less than the theoretical maximum. The gram force, as measured, varies with different air gaps. It is registered at 50 gm at .010" air gap, down to 20 gm at .030" and 5 gm at .060" air gap.

PRELOADING OF THE READER SPRING

Because the initial force between the reader magnet and the memory magnet is less than 10 gm, the gravity force, created by the weight of the Alnico reader magnet (± 2 gm, depending on the mounting location), would affect the contact adjustment to a certain extent. Also, the residual induction (B_r) of the memory magnet will be knocked down after several passes by the Alnico reader magnet, especially when the air gap is comparatively small. The knockdown value could be as much as 70% of the original retentivity. In order to compensate for the gravity and the knockdown problem, preloading of the reader magnet supporting spring is considered important.

Let F_N equal the attraction force between the reader magnet and the memory magnet when the memory magnet is in the neutral state; i.e., when

the memory magnet has become so weak that it behaves like soft iron rather than a magnet. Let F_A equal the initial attraction force between the two magnets when the memory magnet is at its full remanence value and is in magnetic phase with the reader magnet. Let F_R equal the repulsion force between the two magnets at the maximum air gap, and when these two magnets oppose each other in their respective magnetized state, then preloading force (F_X) is now adjusted so that: the preloading force (F_X) is equal to the sum or difference of F_N and F_g where F_g is the gravity force due to the weight of the moving magnet; i.e., the preloading force of the reader supporting spring will be adjusted to overcome the gravity mass and the attraction force of the neutral state of the memory magnet. In other words, the air gap between the reader magnet and the surface of the drum will be maintained at its maximum setting by the preloading force of the reader supporting spring, even when the memory magnet loses all its magnetic properties necessary to keep them in the repulsion state.

CASE I. FORCE OF ATTRACTION

When the memory magnet poles operate magnetically in phase with the reader magnet by coming directly opposite to each other, a force of attraction (F_A) occurs. Since the preloading force (F_X) is acting against F_A, the net resultant force will be $F_A - F_X - F_N$ (neglecting the gravitational force for which compensation has been made by the adjustment process of F_X). Since, by definition, the force of attraction F_A is greater than F_N, the reader magnet will attract to the drum surface because of the power of the Alnico magnet, if the air gap is not over the allowable limits. In this process, sufficient pull force is generated when the air gap decreases to give a contact pressure of at least 25 gm. The memory magnet is now under the influence of the Alnico magnet at close air gap. This is favorable because of the polarity of the two magnets involved. The memory magnet will gain some of the magnetic flux from the stronger Alnico field. However, if the adjustment of F_X is in excess of the sum of F_N and F_g to an amount exceeding the allowable tolerance, then operation by attraction will not take place.

CASE II. FORCE OF REPULSION

When the memory magnet poles, which were out of phase with the reader magnet poles, comes directly opposite to each other, a force of repulsion (F_R) occurs. Since the preloading force (F_X) is in the same direction as the force of repulsion (F_R), the resultant force will be $F_R + F_X + F_N$ (neglecting gravity). Because of the preloading force adjustment, these two magnets are always in a state of repulsion, no matter how small the value of F_R becomes. This adjustment is necessary to prevent oscillation of the contact spring due to limited vibration. Because of the air gap involved (which is about .050"), the magnetic polarity of the cobalt magnet will not be endangered by the strong Alnico field. The force of repulsion (F_R), therefore, will never reach zero, due to the knockdown by the Alnico reader magnet. It therefore follows that the information stored in the memory drum is non-destructive by repeated operation. Also, F_N is not a constant value but is dependent on the initial air gap setting. In other words, F_X has to be increased for a smaller air gap or mounting upside down. This means that there must be a final adjustment of the reader supporting springs after the assembly of the complete device has been properly mounted.

READER CONTACT ASSEMBLY

There are many possible methods to translate the attraction and the repulsion of the reader magnet into the closing and opening of a contact.

Method I. Open Type Relay Contacts

The contact assembly is similar to a standard relay contact stack with only one set of normally open contact. The reader magnet is cemented at the end of the moving contact spring. This design provides lowest material cost with highest current rating. The contact pressure available will be up to 25 gm. Various contact materials could be used to meet individual customer requirements. The mounting bracket can be integrated in the frame casting.

Method II. Snap Action Microswitch

A sub-miniature snap switch such as CEMCO mac-100 low force switch could be used and is actuated mechanically by means of a flat spring which carries the reader magnet. The over-all size of the switch is .156 x .542 x .52. The differential movement is 0.022" with operating force of 1 oz. maximum or as low as 22 grams. Mechanical life of this switch will be 1,000,000 with S.P.D.T. and 5 amperes 250 VAC.

Method III. Dry Reed Switch

The use of dry reed switch is being explored but is not practical for the time being due to the non-linearity of the reed switch properties. An external relay would be required for higher current switching.

REPEATED POUNDING LOSS

An experiment was run by pre-programming the information to the drum. The drum was then driven by a continuous motor at 36 PPS. After 8,000,000 poundings between the reader magnet and the memory magnet, the information was checked. No change of information was found. This evidence indicates that the Alnico can stand impacts without serious loss of magnetic properties and the possible design step of adding a stop in order to avoid reader magnet oscillation which might cause it to touch the memory magnet is not considered necessary.

OPERATING SPEED

The maximum operating speed of the drum depends on the weight of the Alnico magnet, the natural frequency of the reader magnet supporting spring and the inductance time constant of the writer coil. The weight of the drum and its moment of inertia will control the time required to start and stop the drum.

For all practical purposes, the write-in and read-out speed should be under 25 pulses per second. In some experiments, these speeds could go as high as 40 pulses per second (25 milliseconds) with faithful reproduction.

To prove reproduction and write-in speed, two drums were used. The first drum was pre-programmed. The information of the first drum was then transferred to the second drum at different speeds.

LARGE CAPACITY DRUMS

A large capacity, 6000 bit drum, using the same principle, was made for experimental test. This was driven at a constant speed and appears to be practical. Further tests are being performed in this field for information to establish the operational parameters as well as the economic boundaries.

TYPICAL APPLICATIONS AS A SYSTEM COMPONENT

The "Magnetic Memory" will have principal application as a low-cost storage device in the industrial system market to O.E.M. (original equipment manufacturer) where data storage requirements can be satisfied at operating speeds typical of electro-mechanical equipment. This type of storage device will be capable of providing data storage for production lines, machinery, processes, and also a wide variety of systems application such as programming, scheduling, paging, display and advertising, timing, security, etc., in such locations as stores, industries, hotels, motels and libraries.

MARKETING SPECIFICATION

1. Cost Factors

The market segment in which the low-cost storage device will compete is presently being served by relays, diodes, magnetic tapes, neon tubes and similar devices which are relatively expensive as storage devices for bit quantities in excess of fifty. Electronic storage devices which are normally applied to larger and equally rapid access systems are usually not competitive in this market.

2. Configuration

The basic module contains five tracks per row and 50 rows per drum. This provides a storage capacity for 250 bits. The five writing heads and five reading contact stacks, plus mounting frame, complete the basic standard module. Two or more drums can be connected in series, thus potentially increasing the capacity proportionately.

3. Data Input

The input level requires approximately 3.5 watts per coil at 50 volts DC. The frequency or speed is up to 25 PPS writing input. The same coil is used for both the write and erase function by reversing the polarity.

4. Data Output

Selective, automatic, sequential or repetitive reading may be made. Read-out contact rating is recommended to be 3 ampere or 150 watts AC non-inductive.

5. Reliability, Size and Weight

Life expectancy: 100 million pulse cycles. The entire drum assembly, when equipped with drive and index unit, is less than 6-1/2" x 8" x 11". The weight of the memory drum, less drive and index unit, is normally less than 3-1/2 pounds.

6. Environmental Requirements

The drum shall perform satisfactorily from -20°C to 55°C. Humidity, 0 - 95% with no condensation. The memory unit is designed for use in a fume-free, non-corrosive atmosphere.

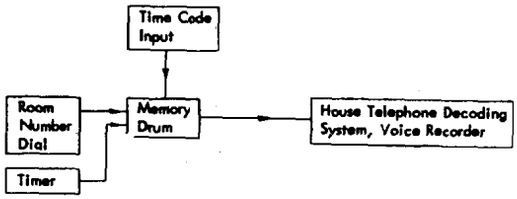
The following list shows some other possible system applications of the low-cost storage device:

1. Automatic Toll Ticketing and Intercom Systems.
2. Programming for Hospitals, Libraries, Paging, Hotels, Motels, etc.
3. Repetitive and/or Selective Operations in Processing.
4. Types of Automatic Machine Controls.
5. Juke Box Vending and Automat Equipment and Machines, and Super Markets.
6. Display and Advertisement Control Systems.
7. Switching System Controls, Signal Systems.
8. Stock, Reference, and File Rapid Access Systems; Automatic Warehousing.
9. Automatic Alarm Records, Lumber Mill Automation, Mining.
10. Parking Lot Facilities and Location Records.
11. Unattended Substation, Power Plant Automation, Relay Stations.
12. Utilities, Sanitation Plants, Water Works, Pumping, Filtration Plants.
13. Fire Alarm Systems, Burglar Alarm Systems, Unattended Forestry Protection.
14. Automatic Weather Stations, Satellite Observation Station.
15. Automated Farm and Plantation Record and Order Stations.
16. Stadiums, Theaters, Tote Boards, Curb Service.
17. Stock Exchanges, Banks, Railroad, Stock Yards.

ILLUSTRATIVE BLOCK DIAGRAMS FOR SOME SPECIFIC APPLICATIONS

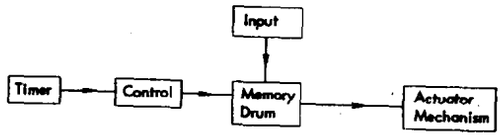
A. Motel Wake-Up System

Up to 50 rooms; wake-up time between 4:00 a.m. to 12 noon at 15-minute intervals requires a total of 32 codes: i.e., 2^5 or a 5-bits code per room.



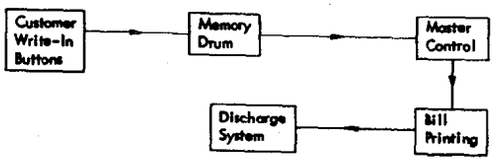
B. Conveyor Belt Discharge System

Up to 5 discharge stations per drum. The conveyor may be moving continuously or indexing 50 locations per cycle. When the parcel enters the conveyor, the writer coil is energized. When the destination station is reached, the reader contact actuates the mechanism which discharges the parcel. Up to 50 parcels can be resting on the conveyor at any one time.



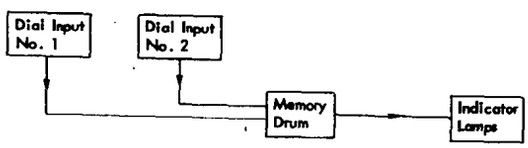
C. Supermarket System

Up to 50 items per dual drum; 2^{10} or 1024 varieties to choose from. After the customers satisfy their selection, a master control, actuated by the cashier, discharges all the items while check is being printed.



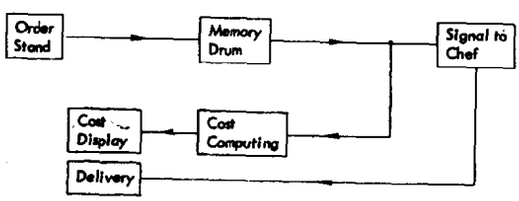
D. Doctors' Message and Absence Indicator System

Up to 125 doctors in a hospital. Each doctor will have two bits; one for absence and presence, and one for with and without message. When he leaves the hospital, he dials out; when he comes back, he dials to check message. Two or more registering stations can be incorporated for one drum.



E. Curb and Short Order System

Up to 50 items (quantity up to 10 each) that can be ordered by the stand attendant, then processed via the system and delivery.



HAZARDS IN THE USE OF DOUBLE-THROW CONTACTS

BY

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A possible source of trouble in application of relay contacts apparently has not been universally recognized. If one of the fixed contacts of a double-throw set is connected to a source of power and the other fixed contact of the set is connected to ground, another power source, or to some other point in the electrical system, there is a possibility of short-circuiting the power source through an arc across the contact gap. The result is likely to be destruction of the contacts, a blown fuse, damage to equipment, interruption of the service that the equipment was intended to provide, and a report that the relay has "failed" in service. In such a situation the load is usually connected to the moving contact. The following are some examples of the use of this type of connection:

1. Transfer of a load from one power source to another, or to another phase of a 3-phase system. The contact involved might be on a power-off or undervoltage relay, for example, to transfer to a standby source.

Another common situation is during preflight check of an aircraft or missile involving separate power sources on the ground and the aircraft. These would commonly be 28 VDC or 3-phase, 4-wire, a-c, and the neutrals of the two systems would be tied together through the test cable connections for safety reasons. Certain relays on the aircraft may be called on to switch from ground power to aircraft power during such checking.

Figs. 1 and 2 show typical circuits.

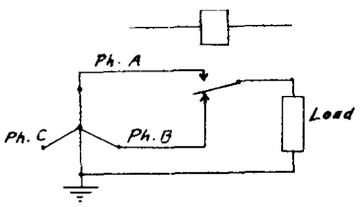


Fig. 1. Transfer of Load From One Phase to Another.

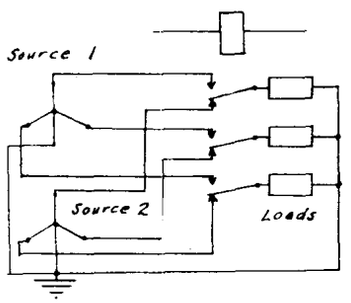


Fig. 2. Transfer Between 3-Phase Sources.

2. For connecting the load circuit to ground when it is disconnected from the power source. (Fig. 3)

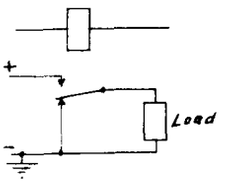


Fig. 3. Grounding Circuit.

Changing the connections for a 3-phase load from delta to wye, as shown in Figure 4. This is sometimes done to adjust the power, for example, in heater loads; 3-phase motor windings are sometimes wye connected for reduced voltage starting to keep down the inrush current and are transferred to delta connection for running. If the common connection of the loads is connected to the neutral of a 4-wire, 3-phase system, the situation becomes similar to Figure 3 in that a phase-to-neutral short-circuit could be produced through an arc across the contacts. Even if the common load connection is left isolated, there is a possibility of a phase-to-phase short during contact transfer through arcs at two contacts in series. Other schemes for using double-throw contacts to change phase connections may provide similar possibilities of a short-circuit through an arc at the contact.

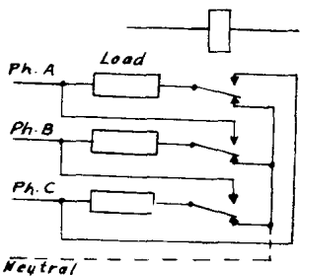


Fig. 4. Transfer of 3-Phase Load From Wye to Delta Connection.

4. For reversing a motor. For example, the armature may be connected to one polarity or phase through the normally open contact and to reverse polarity or another phase through the normally closed contact. (Figs. 5 & 6 show typical circuits)

5. In some schemes for dynamic braking of a motor. The simple reversing control shown in Fig. 5, suitable for a small motor, also provides dynamic braking by shorting the armature when both relays are released. Similarly, Fig. 3 might be used for a non-reversing control, the load in this case becoming the armature. A braking resistor could be added in series with the fixed N.C. contact.

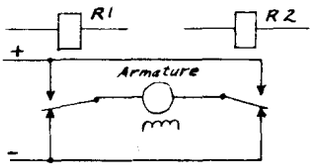


Fig. 5. Reversing Motor Control With Dynamic Braking. Relay R1 Controls Normal Rotation; R2 Reverse. Field is permanent magnet or separately controlled.

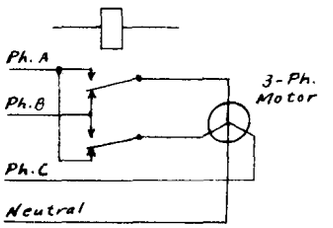


Fig. 6. Reversing Control for 3-Phase Motor.

6. The use of two double-throw contacts in a pole-changing arrangement as shown in Figures 6 and 7. Note that if the power source is connected to the fixed contacts of the pole-changer, a condition of shorting the power supply through an arc may occur at either contact. If the connections are interchanged so that the power source is connected to the two moving contacts and the load to the fixed contacts, the power source could be shorted through an arc at one contact during interruption if the arc does not extinguish before the other moving contact closes in the new position. In this second arrangement it should be noted also that there is a hazard in using double-throw contacts that are not synchronized in their operation. If the moving contacts connect to the power source in Figure 7 and on release, for example, one moving contact makes against its N.C. contact before the other moving contact opens on the N.O. side, the power source will be short-circuited. Such a situation could occur as a result of poor adjustment of a multi-contact relay and is very likely to occur if the two contact sets are on separate relays. Contacts on separate relays, regardless of whether the relay coils are connected in series or in parallel, should not be used in this way; nor should contacts on separate armatures of the same relay assembly unless the armatures are positively linked so that they cannot move independently of each other.

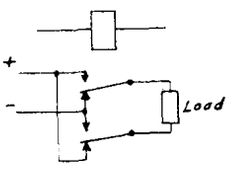


Fig. 7. Pole-changing Contacts.

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