Core Materials for Magnetic Latching Wire Spring Relays

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The magnetic characteristics of medium carbon steels were examined to determine whether these steels can be used as core materials for magnetic latching wire spring relays. The analysis of the data show that steels with a carbon content ranging from 0.35 per cent to 0.50 per cent, heat treated to a Rockwell hardness ranging from 30 to 45 points on the "C" scale, are satisfactory core materials. The analysis further shows that the relays are latched more securely if the carbon content of the steel used for the core is high, and that the hardness in the above-mentioned range has very little effect on the latching characteristics.

I. INTRODUCTION

In telephone switching circuits it is often necessary to hold a relay operated for a long period of time. An example of such a case is a relay which remains operated during a telephone conversation. In order to hold a conventional relay operated for a long period of time, it is usually locked electrically through one of its own make contacts. This method of latching requires that a continuous current be supplied to the relay coil. In the past, relays with mechanical locking features or auxiliary permanent magnets also have been used. These relays, however, frequently require two electromagnets, one to operate the relay and activate the locking mechanism and the other to deactivate the locking mechanism and allow the relay to release. A relay which requires a mechanical locking mechanism, since it needs two electromagnets, is equivalent to two relays and is therefore uneconomical.

The latching force, which holds the magnetic latching relay operated, depends upon the residual magnetic induction and coercive force of the magnetic materials used in the structure of the electromagnet. The magnetic latching relay is operated by a short current pulse. After the removal of the pulse the relay remains operated. A current pulse of opposite polarity to, and lower magnitude than, that of the operate pulse will release the relay. Once released, the relay will remain in that state until another operate pulse is supplied.

It is apparent that this type of relay is particularly useful when power is at a premium. Once the relay is operated, no more power is required to hold it in that state. Moreover, the latching relay has another useful feature: memory. It "remembers" the command "operate" or the command "release" and remains in one of these states until ordered into the other state.

Earlier studies have shown that high carbon steels can be used to obtain the magnetic characteristics needed in the magnetic structure of latching relays. An example is the hold magnet of the magnetic latching crossbar switch.[1] High carbon steels, however, are not suitable for the magnetic structures of wire spring relays because the geometry of this structure would make its manufacture very difficult and expensive. Therefore, a study was started to determine whether medium carbon steels could be used.

II. REQUIREMENTS

The magnetic latching relay has two basic requirements. (1) When the relay is in its released state it must operate upon the application of an operate current pulse and remain in the operated state after the pulse is removed and until a release pulse is applied. (2) When the relay is in its operated state it must release upon the application of a release current pulse and remain in the released state after the pulse is removed and until an operate pulse is applied.

As shown by these two requirements, the relay must have two stable states. No outside influence shall falsely operate or release the relay. In general, relays are mounted on frames on which mechanical vibrations occur. The two states, therefore, have to be such that they will not be influenced by mechanical vibrations occurring on these frames. The latching force holding the relay operated has to be large enough to hold the relay operated and to withstand the vibrations on the frame. Also, after the relay has been released, the magnetic structure must be in a magnetic state such that the mechanical back tension can securely hold the relay in its released state. Induced electrical noise in the coil must also be considered since it could change the magnetic state of the core and release the relay when it is latched.

To the basic requirements discussed, two more requirements were added: (3) The magnetic latching relay shall be of the wire spring type. (4) The magnetic latching relay shall use the same mechanical pile-up as the conventional wire spring relay and it shall be possible to manufacture the magnetic parts with the same tools that produce the magnetic parts of the conventional wire spring relay.

The third requirement was added because of the consistently good and reliable performance of wire spring relays. The fourth requirement was added to hold the cost of manufacture to a minimum. The last two requirements show that it was necessary to select a magnetic material which, when used as the magnetic structure of the wire spring relay, will satisfy the first two requirements.

In a magnetic latching relay the parameters which will determine the latching force and the security of the latched state are the residual induction and the coercive force of the materials used in the magnetic parts. Both parameters will effect the suitability of a material for this application. Fig. 1 shows typical demagnetizing hysteresis loops for two different materials. Materials (1) and (2) have residual inductions B_{r1} and B_{r2} and coercive forces H_{c1} and H_{c2}, respectively. If an air gap is introduced in the magnetic circuit, the flux density will be reduced to the points B_1 and B_2, called the remanent induction. Points B_1 and B_2 are determined by the line given by

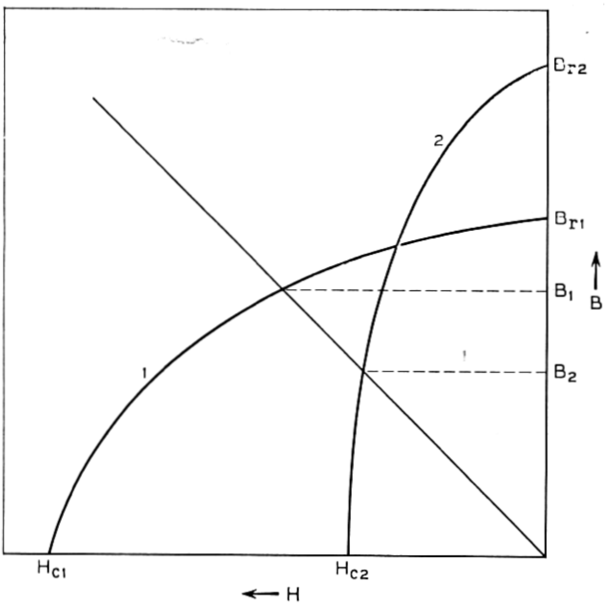

Fig. 1 — Generalized demagnetization curve.

$$B_g = H_M l_M / l_g \tag{1}$$

where: B_g = magnetic induction in the air gap
l_g = length of the air gap
H_M = field strength in the magnetic material
l_M = length of the magnet.

Equation (1) provides only an approximation for the change in residual induction that occurs in a closed magnetic circuit when an air gap is introduced into the circuit. However, it does indicate these changes.

The latching force is directly proportional to the square of the remanent induction. As shown in Fig. 1, material (2) has a higher residual induction than material (1). However, when an air gap is introduced in the magnetic circuit, the remanent induction B_2 of material (2) is lower than B_1, because H_{c2} is smaller than H_{c1}. Therefore, the latching force that can be obtained from material (2) will be smaller than the one that can be obtained from material (1) for the particular air gap shown.

The third and fourth requirements dictate the geometry of the magnetic circuit. Therefore, to obtain a magnetic latching wire spring relay it is necessary to find a material which has values of residual induction and coercive force suitable for the magnetic circuit of the presently manufactured wire spring relay.

III. MAGNETIC CAPABILITY

Since the geometry of the magnetic structure is fixed by the fourth requirement of the last section, it is necessary to calculate values for the maximum latching force that can be obtained. Fig. 2 shows the individual parts of the magnetic structure of a wire spring relay.

The maximum mechanical load which must be held operated will determine the minimum latching force, which in turn determines the minimum remanent magnetic induction or remanent flux. The relation be-

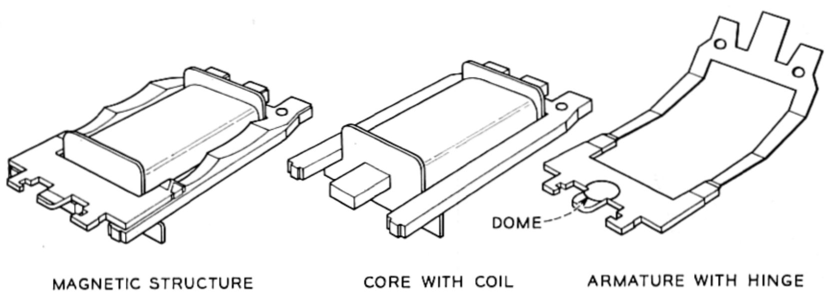

Fig. 2 — Parts of the wire spring relay magnetic structure.

tween the latching force F and the remanent flux φ_G is given by:

$$F = \frac{\varphi_G^2}{8\pi A_G}\left(\frac{1}{980}\right) k \qquad (2)$$

where:

F = latching force in grams
φ_G = remanent flux through the air gap
A_G = effective pole face area at the air gap
k = constant correcting for the nonperpendicularity of φ_G between the mating areas.

The maximum remanent flux φ_G through the air gap is determined by the flux saturation level of the armature. If the semipermanent magnet core has a remanent magnetic induction which is large enough to keep the armature saturated, the maximum φ_G and, therefore, the maximum latching force will be obtained. The attainment of this state will depend on the values of the residual induction and coercive force of the core material.

If we assume that the remanent flux of the core is large enough to keep the armature saturated, an estimate for the maximum latching force can be obtained. The armature is made of 1 per cent silicon steel and has a cross-sectional area of 0.346 cm^2. The nominal value for the operating flux density of the armature is 15,000 gauss; the calculated flux of the armature is, therefore, 5190 maxwells. As shown in Fig. 2, the armature has a dome with an area of 0.712 cm^2. When the relay is latched, the largest part of φ_G will go through the dome of the armature; therefore, A_G in equation (2) can be set equal to the dome area. The estimated value of k is about 0.8. Substituting the calculated flux of the armature, the dome area, and the constant k into equation (2), we obtain the force at the dome as 1315 grams. This force is shown in Fig. 3

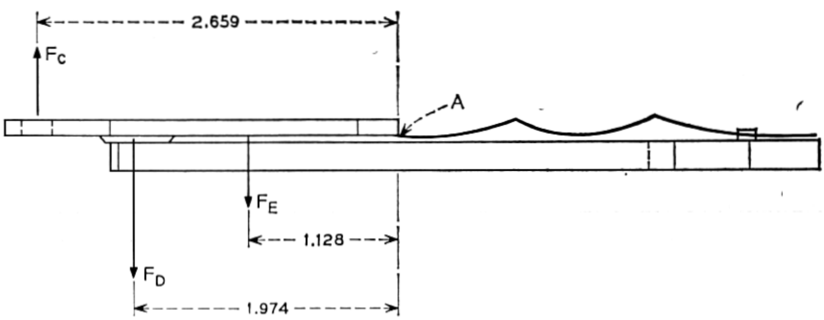

Fig. 3 — Magnetic and mechanical forces.

as F_D. As shown in this figure, we also have a force on each side leg to take into account. The flux through each side leg is half of the flux φ_G through the dome, and the geometrical area of each side leg is 1.25 cm². Using these values and again a constant of 0.8 in equation (2), we obtain a force of 168 grams at each side leg. This force is shown as F_E in Fig. 3. The force F_C in this figure represents the mechanical load, which is opposite to the latching force. Taking the moments about point A with the dimensions given in Fig. 3, we find that the maximum load F_C which can be held in equilibrium by the latching forces F_D and F_E is 1120 grams. This is well above the maximum mechanical load of the relay, which is in the neighborhood of 580 grams. Therefore, based on the assumption that the remanent flux is large enough to produce a flux of 5190 maxwells, the latching force will be about twice as large as the maximum mechanical load. This means that the structure is capable of latching the maximum number of contacts, or 24.

The residual magnetic induction of the core will now be examined to see if it could be large enough to keep the armature saturated when the relay is latched. If we neglect all leakage flux, then the remanent magnetic induction of the core has to be only large enough so as to saturate the armature. Assuming no leakage flux, we have

$$\begin{aligned} \varphi_A &= \varphi_C \\ \varphi_C &= B_C A_C = \varphi_A \end{aligned} \tag{3}$$

where:

φ_A = saturation flux of the armature
φ_C = remanent flux of the core
B_C = remanent magnetic induction of the core
A_C = smallest cross-sectional area of the core.

As mentioned previously, the saturation flux φ_A of the armature is 5190 maxwells. The core cross-sectional area A_C is 0.533 cm². Using these values in equation (3), we obtain a remanent magnetic induction of 9737 gauss for B_C. This value for B_C corresponds to a value which is lower than either of the values B_{r1} or B_{r2} in Fig. 1.

Since the core has to be manufactured with tools presently used to manufacture the cores of conventional relays, only medium carbon steels can be considered. The residual induction of these steels is about 13,000 gauss. This corresponds to points such as B_{r1} or B_{r2} in Fig. 1. Since air gaps and leakage flux are present in the magnetic circuit of the relay, the operating flux level will be lower, as previously discussed and illustrated in Fig. 1. However, only 9737 gauss are required for the operating flux density of the armature. If the coercive force of the core material is large enough, it is very likely that an operating flux density of 5190 maxwells of the armature can be maintained when the relay is latched.

So far we have only looked at the maximum obtainable latching force. This was necessary in order to see if medium carbon steels should be considered. As shown, the latching force that can be obtained is about twice as large as the maximum mechanical load. However, a relay can be considered securely latched if the latching force exceeds the mechanical load by 50 per cent. Since the maximum mechanical load is 580 grams, a latching force of 770 grams minimum is needed. Using equation (2) with a latching force, F, of 770 grams, we obtain 4727 maxwells for flux φ_G. The remanent flux of the magnetic circuit has to be larger because the leakage flux was not taken into account. For the magnetic circuit under consideration, the estimated leakage flux is approximately 15 per cent of the flux through the core.

Therefore, to obtain a latching force of 770 grams minimum, the remanent flux of the core should be at least 5500 maxwells when the relay is operated.

In the above discussion, it was assumed that the coercive force of medium carbon steel is large enough so that the required remanent flux can be obtained. Since no exact relationship exists between magnetic induction and coercive force, an experimental study is necessary to see if values for these characteristics can be obtained with medium carbon steels so that these steels can be used as core materials for latching relays.

IV. STEEL STUDY

At this point in the development of the latching wire spring relay, the minimum remanent magnetic induction needed is 5500 maxwells for a full complement of contacts. The coercive force is not known, but some considerations such as the need for a securely latched relay and the need for a reasonably high dc release current with a maximum contact load seem to dictate a rather high coercive force in the magnetic structure. The only further restriction for the core material stems from an economic consideration; i.e., the steel must be commercially available and it must be soft enough to be used in present punch press tools.

A steel investigation was made to find a particular steel which should be used for the relay core and to determine how this steel should be heat treated to obtain the necessary magnetic properties. Four grades of steel containing different amounts of carbon ranging from 0.25 per cent to 0.50 per cent were obtained. The steels were commercial grades of C-1025, C-1035, C-1040 and C-1050. Results of an analysis of each type of steel are shown in Table I.

General-purpose wire spring relay cores and ring samples were made from the four lots of steel. The relay cores and ring samples in each steel group were divided into five subgroups and were heat treated to obtain different values of hardness on the Rockwell "C" scale ranging from 25 points to 45 points in 5-point steps. The C-1025 steel required a water quench to obtain the necessary hardness; this makes it unfit for a material for relay cores because it results in severe core leg twisting and misalignment. Therefore, the C-1025 steel was eliminated from the steel study.

The magnetic characteristics of the ring samples were measured with a Cioffi recording fluxmeter. The resulting measured values of coercive force and residual magnetic induction correspond to such points as H_{c1} and B_{r1} in Fig. 1 and form the raw data which was then analyzed.

Each of these magnetic characteristics was then plotted as the dependent variable against the ring sample hardness as the independent variable. The plots of the residual flux versus hardness and the coercive force versus hardness can be approximated by a straight line for a limited range of hardness. This can be done with reasonable accuracy if the "true" long-range curve has a slowly changing first derivative over the hardness range. The straight-line approximations of the data of the coercive force, as fitted by the least squares technique, are plotted in Fig. 4(a). The equations for the coercive force of the steels are shown in Table II.

The results are somewhat erratic, although they lead to the expected curve.[2] The cause of such erratic results is partly due to the impurities in the steel samples and partly due to variations in the heat treatment.

It should be pointed out that these results represent only one group of data points and that another group could lead to slightly different equations. However, these equations serve to illustrate the trends present in this range of steels.

TABLE I — PERCENTAGE OF ELEMENTS PRESENT

Type of Steel	C	S	P	Mn	Mo	Si	Cr	V	Ni
C-1025	0.24	0.028	0.024	0.39	0.02	0.002	<0.03	<0.02	<0.02
C-1035	0.38	0.024	0.024	0.83	0.04	0.258	0.07	<0.02	0.06
C-1040	0.42	0.023	0.016	0.79	0.02	0.207	0.10	<0.02	0.04
C-1050	0.49	0.019	0.018	0.79	0.02	0.172	0.08	<0.02	0.03

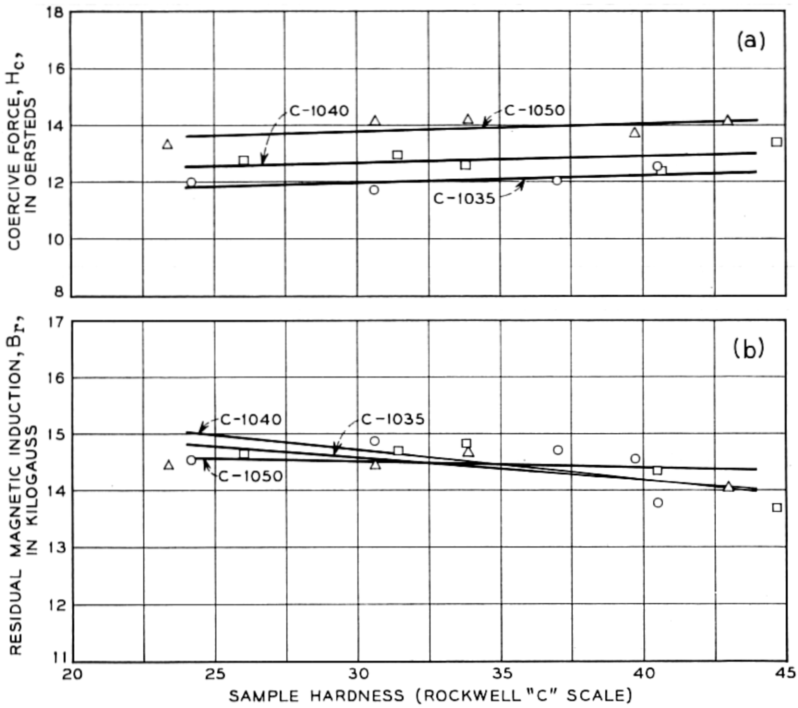

Fig. 4 — Magnetic characteristics of ring samples.

These coercive force curves show three important characteristics: (1) the coercive force increases slightly as the hardness increases, (2) the slopes of the lines are very small and are identical within experimental error, and (3) the lines are displaced from one another in such a manner that a definite trend is evident; i.e., the coercive force increases as the carbon content of the steel increases.

Straight-line approximations as obtained with the least squares tech-

TABLE II — EQUATIONS FOR COERCIVE FORCE

Steel Type	Equations
C-1035	$H_{c1} = 11.16 + (0.0268)X$
C-1040	$H_{c2} = 11.87 + (0.0266)X$
C-1050	$H_{c3} = 12.85 + (0.0305)X$

where: H_{ci} = the coercive force in oersteds, i = 1, 2, 3 depending on the type of steel, and X = the hardness in points on the Rockwell "C" scale and in the range of 24 points to 44 points.

nique were found from the data for the residual magnetic induction of the ring samples. The results of this analysis are plotted in Fig. 4(b) and the equations for these curves are given in Table III.

These three curves show that within experimental error the residual flux: (1) decreases as the hardness increases, (2) varies slowly with hardness, and (3) has about the same magnitude for the three different steel groups.

Another analysis of these data was tried. The second method was to fit a curve of the form, $H_{ci} = a_{i0} + a_{i1}X + a_{12}X^2$ to the data by solving three equations for the constants a_{i0}, a_{i1}, and a_{i2} (where $i = 1, 2, 3$ for the different steels). Results of this analysis are shown in Fig. 5(a). The same trends that were observed in Fig. 4(a) also can be seen in this figure. This analysis of the residual magnetic induction data was tried, but it produced about the same results as that of the linear analysis. The method was to fit a curve of the form $R_i = a_{i0} + a_{i1}X + a_{i2}X^2$ to the data by solving three simultaneous equations for the constants a_{i0}, a_{i1}, and a_{12} (where $i = 1, 2, 3$ for the different types of steel). The results of this analysis are plotted in Fig. 5(b).

The test results of the coercive force and residual induction for the ring samples show that in the hardness range between 24 and 44 points on the Rockwell "C" scale, variations in the coercive force between steels seem to be larger than variations in the residual induction. Also since all of the values for the residual flux fall in a relatively narrow band (between 13.98 K gauss and 15.0 K gauss), all of the three steels considered here should provide latching forces with very similar magnitudes. Therefore, latching relays should have cores manufactured from materials which provide the largest possible coercive force.

With these preliminary results, relay cores were manufactured from the three grades of medium carbon steel: C-1035, C-1040 and C-1050. Relays were assembled from these cores and the magnetic characteristics of the relays were then measured. Again, a straight-line approximation of the data for the coercive force and the remanent magnetic

Table III — Equations for Residual Magnetic Induction

Steel Type	Equations
C-1035	$R_1 = 15.74 - (0.039)X$
C-1040	$R_2 = 16.30 - (0.053)X$
C-1050	$R_3 = 14.76 - (0.0079)X$

where: R_i = the residual flux in gauss, $i = 1, 2, 3$ depending on the type of steel, and X = the hardness in points on the Rockwell "C" scale in the range of 24 points to 44 points.

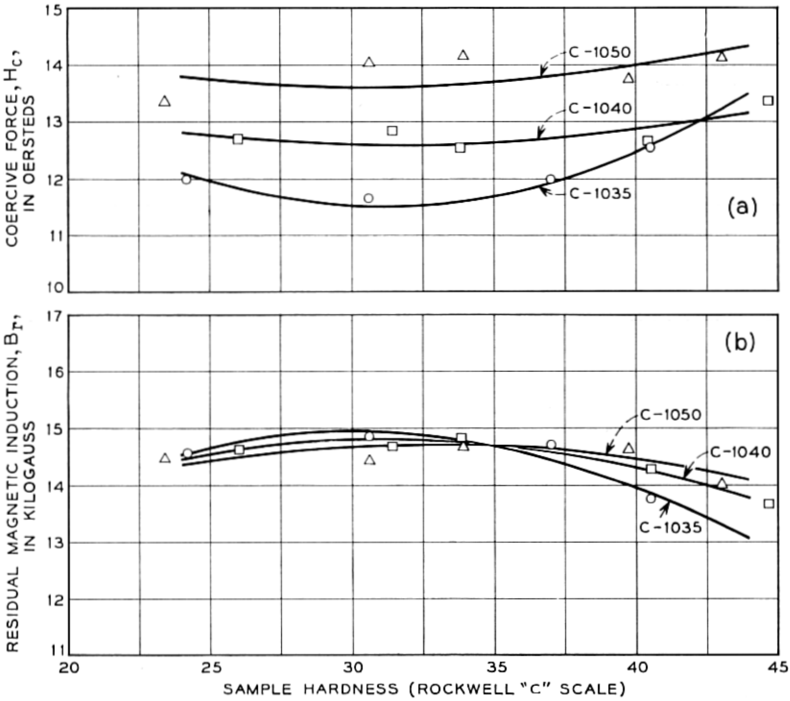

Fig. 5 — Magnetic characteristics of ring samples (cont.).

flux was used. The results for the coercive force are plotted in Fig. 6(a) and the results for the remanent magnetic flux are plotted in Fig. 6(b). Table IV gives the equations of the curves for these two figures.

Examination of coercive force and remanent flux versus hardness shows that for any small range of hardness, say five points on the Rockwell "C" scale, the remanent flux varies less than 8 per cent between the different samples. That is, the value of remanent flux, while it is a function of the carbon content of the steel, is insensitive to large variations of the carbon content. Since the value of the ultimate latching force depends on the amount of remanent flux which can be established in the magnetic circuit of the relay, this result means that the latching force will be insensitive to minor carbon variations in a particular steel. This is an important result for the economical mass production of a latching relay.

Variations in coercive force which are larger than variations of the remanent flux within the same hardness range are observed between

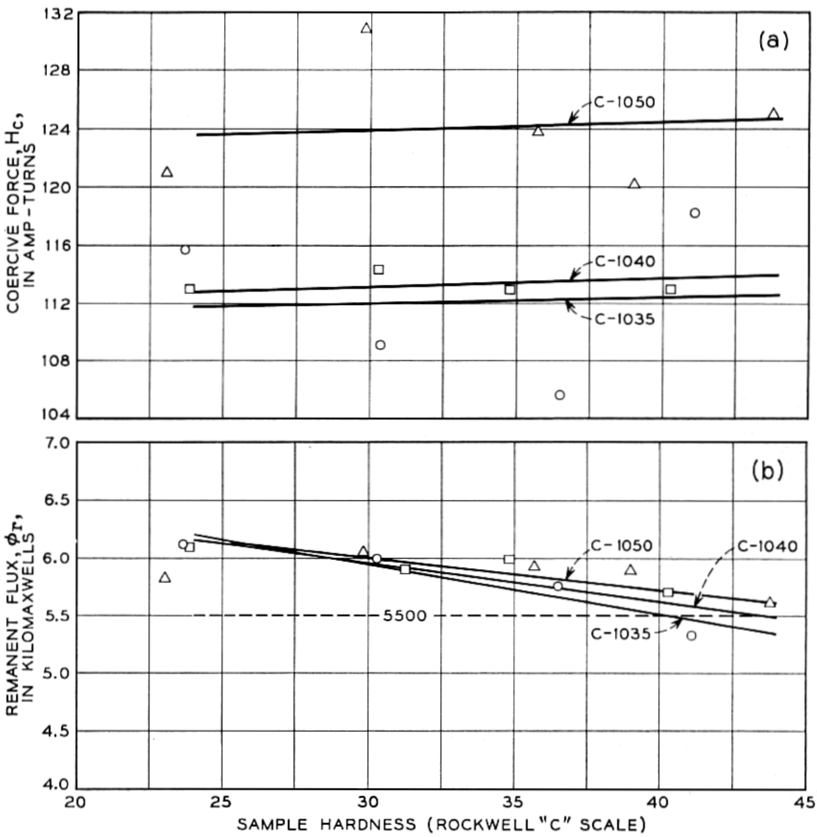

Fig. 6 — Magnetic characteristics of relay samples.

the different steel groups. However, the ability to maintain the level of the latching force once it has been established, and not the magnitude of the force itself, is affected by changes in coercive force. Therefore, large variations of this parameter can be tolerated in manufacturing situations provided that enough margin of force has been designed into

TABLE IV — EQUATIONS FOR COERCIVE FORCE AND REMANENT FLUX

Steel Type	Equations for Coercive Force	Equations for Remanent Flux
C-1035	$H_1 = 110.9 + (0.040)X$	$\varphi_1 = 7.23 - (0.043)X$
C-1040	$H_2 = 111.4 + (0.060)X$	$\varphi_2 = 6.99 - (0.034)X$
C-1050	$H_3 = 122.5 + (0.050)X$	$\varphi_3 = 6.48 - (0.028)X$

where: H_i = coercive force in ampere-turns, X = the hardness in points on the Rockwell "C" scale in the range of 24 points to 44 points, φ_i = remanent flux in kilo-maxwells, and i = 1, 2, 3 depending on type of steel.

the latched relay. Since the stability of the latching force is principally a function of the coercive force and varies directly as the coercive force, it is reasonable to attempt to heat treat the core to produce a high coercive force. Furthermore, any increase in coercive force which can be obtained by increasing the carbon content of the core material should be pursued.

From theoretical calculations a minimum value of remanent flux was found to be 5500 maxwells. Since this value is below all predicted values of remanent flux for the three group of relays, plotted in Fig. 6(b), more emphasis should be placed on choosing a steel to give the maximum security of the latching force and obtaining the best core hardness. Since steels which have carbon percentages above 0.50 per cent are difficult to machine on a mass production basis, this percentage of carbon represents a maximum allowable value. Therefore, Fig. 6(a) shows that the best steel for magnetic latching wire spring relays based on the magnetic characteristics is the C-1050 steel. The carbon content of this steel is 0.5 per cent, +0.05 per cent, −0.02 per cent.

Until now, the remanent flux and the coercive force have been treated as separate and distinct quantities which vary with the carbon content and with the hardness of the steel. In the magnetic circuit of the relay, these parameters each influence the dynamic characteristics in such a manner that measurements of the latching force can show the validity of the choice of the core material. Results of a straight-line approximation of the data for the latching force versus hardness are shown in Fig. 7, and the associated equations are given in Table V.

Several conclusions can be drawn from Fig. 7: (1) Within the group of steels that were tested, the best core material is the C-1050 steel as indicated previously. (2) Since theoretical calculations, based on the

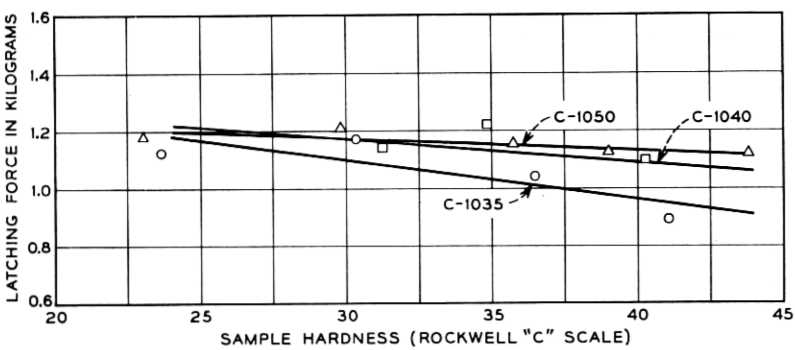

Fig. 7 — Total latching force of relay samples.

TABLE V — EQUATIONS FOR LATCHING FORCE

Steel Type	Equations
C-1035	$F_1 = 1499 - (13.46)X$
C-1040	$F_2 = 1407 - (7.95)X$
C-1050	$F_3 = 1297 - (3.96)X$

where: F_i = the total latching force in grams, X = the sample hardness in points on the Rockwell "C" scale in the range of 24 points to 44 points, and i = 1, 2, 3 depending on type of steel.

assumption that the armature would be saturated, produced a force of 1120 grams, it appears that the C-1050 and the C-1040 groups are producing saturation in the armature. (3) Since it appears that there is armature saturation in the two groups, the latching force to latch the full complement of 24 contacts has been obtained.

The optimum hardness is determined from curves showing the magnetic characteristics of the sample relays — i.e., Figs. 6(a) and (b). It was calculated that a remanent flux of 5500 maxwells should be a minimum value (this allows a 50 per cent operated load margin). Using 5500 maxwells as a lower bound in Fig. 6(b) and considering an experimental error of ± 2 per cent, the highest value of hardness would be 40 points on the Rockwell "C" scale. Allowing a manufacturing variation of ± 2.5 points, the hardness to be specified in manufacture is Rockwell "C" 37.5 ± 2.5. With this hardness, the relays should have a total latching force greater than 770 grams and they should have good margin with this force.

V. RELAY STUDY

Latching relays, after being operated and latched, can be falsely released by extraneous effects such as random electrical noise induced in coil leads and mounting plate vibrations, if these effects are severe enough. To obtain release parameters in the form of load versus release ampere-turns for different steels, relays having known loads were operated, latched magnetically and released by applying a reverse current to the coil. Fig. 8 shows the results of this test. Two important conclusions can be drawn: (1) The C-1050 steel again is the best steel for the magnetic latching application, and (2) The slope at any point along the curve is very steep. A steep slope indicates that the relay should be capable of accepting various values of loads and still release correctly.

Referring to Fig. 8, a third conclusion can be drawn: the release ampere-turns for the C-1050 steel is larger than 70 NI with a 600-gram

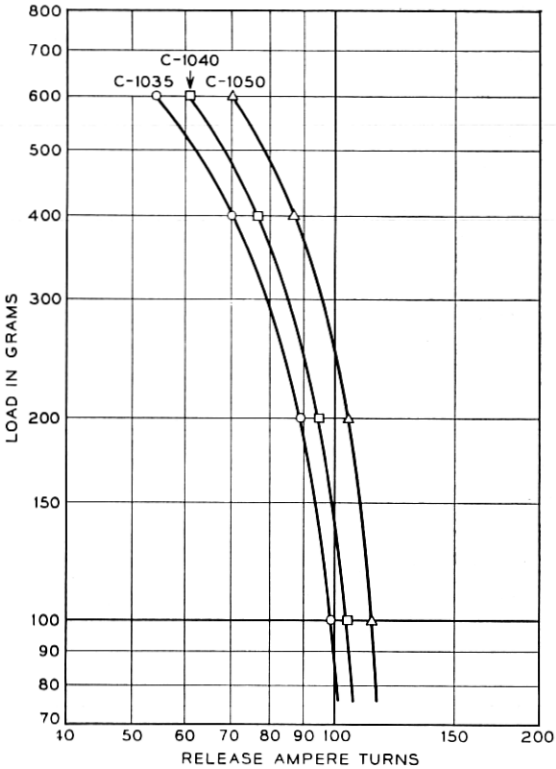

Fig. 8 — Release with a known load for relay samples.

load. The significance of the load value of 600 grams is that this represents a higher value of operated contact load than the maximum operated load (580 grams). A release ampere-turn value of 70 NI represents a large amount of power in a relay coil; i.e., this amount of power is much larger than the expected power which a random electrical pulse could provide by stray coupling to the relay coil. (The coil represents a high impedance for this type of energy transfer.) Therefore, there is adequate latching force so that induced random noise pulses should not release the relay from its latched state.

The test relays were studied to determine dc operate parameters. The resulting curves, pull versus ampere-turns at constant gaps, are shown in Fig. 9 for the C-1050 steel. Similar curves for conventional relays usually display a linear region which has a slope of 2. This region corresponds to a fairly linear section of the magnetization curve below

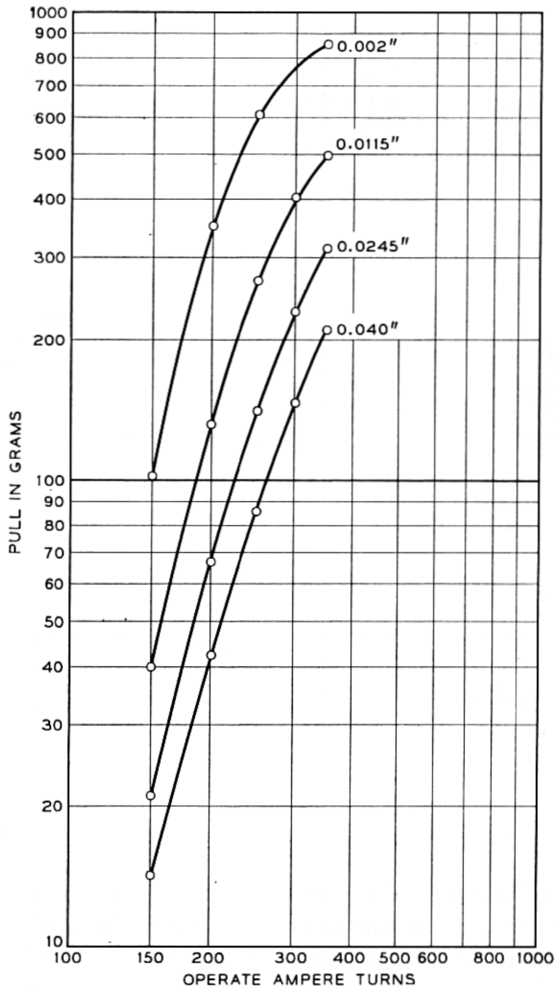

Fig. 9 — Constant-gap pull curves for relay samples made from C-1050 steel.

the knee and above the region of easy magnetization (toe to instep). It is this linear portion of the magnetization curve that produces the linear section of the pull versus ampere-turns on a log-log plot. In higher carbon steels that have been magnetically hardened, the magnetization curve is characterized by the absence of a linear section. For this reason and due to armature saturation, Fig. 9 has no linear section.

The dc operate current for a magnetic latching relay must be found from the constant gap curves, shown in Fig. 9. The use of these curves assumes: (1) The relay has received enough power from the last release pulse so that the core can be considered in the demagnetized state. (2) The critical load point is found from values of load for the conventional wire spring relay. (3) The minimum operate saturation current will be exceeded.

At this point it is helpful to define the operate flux direction as the positive flux direction and the release flux direction as the negative flux direction.

It is not absolutely necessary for the release pulse to return the core to its zero flux state; however, the pulse must return the core close to that state and must not allow the core to return to a negative flux state. If the core is left in such a state, the operate current will be higher than the current which is found from the pull curves. The operate current which is found from the pull curves represents a current value which is useful only as a readjust current for the relay. However, correct dynamic operation of the relay requires that the operate current supply: (1) sufficient magneto motive force to saturate the magnetic structure, and (2) the saturation flux for a minimum pulse time of at least 15 per cent longer than the operate time of the relay.

Therefore, the minimum dynamic operate current is a current capable of saturating the structure, and higher operate currents can be used to obtain faster operate times. A further requirement for operating the relay is that the current shall not reverse when the current to the coil is turned off.

A contact protection network used across the coil forms an L-R-C circuit. If the protection network is not chosen correctly, oscillations will result (the under-damped case). Then, if the amplitude and period are large enough, the relay will unlatch because of the current reversal.

The dc release current is obtained from a load versus release ampere-turns curve. Again, this current is useful only as a relay readjust current because there is no assurance that the core will return to its zero flux state after the release pulse is turned off.

A N.F. current, meaning "No Flux" current, is specified for magnetic latching relays. This value of current, when used to release the relay from its latched state, returns the core very close to its neutral magnetic state.

VI. CONCLUSION

The data presented show that C-1050 steel, heat treated to a hardness of 37.5 ± 2.5 points on the Rockwell "C" scale is a satisfactory material for the core of a magnetic latching wire spring relay. It was the best choice of the medium carbon steels investigated. Satisfactory latching forces can be obtained with medium carbon steels ranging from C-1035 to C-1050; however, as the carbon content increases, more secure latching is obtained.

Magnetic latching wire spring relays presently manufactured are shown in Fig. 10. The cores of these relays are made with C-1050 steel, heat treated to a Rockwell "C" 37.5 ± 2.5 hardness. These latching relays are used in the No. 1 ESS system. Because of the characteristics of magnetic latching relays, it is anticipated that the demand for them will increase in the future.

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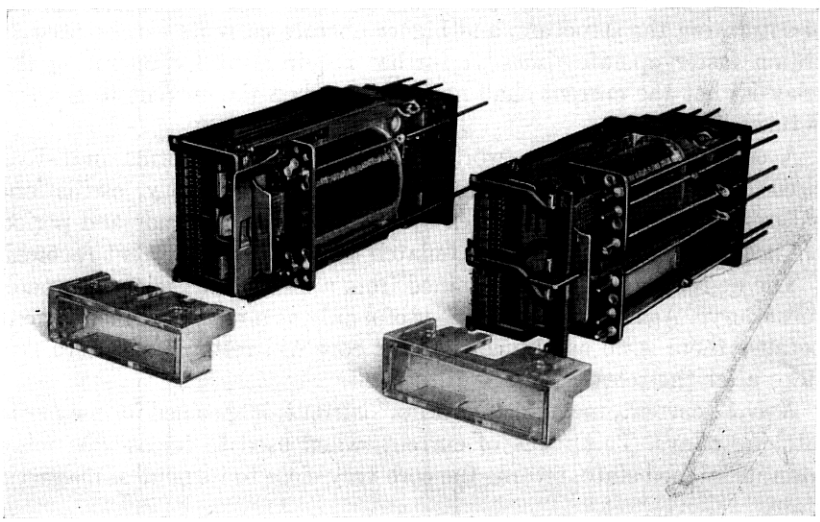

Fig. 10 — Magnetic latching wire spring relays: AL type on left and AM type on right.

REFERENCES

1. Zupa, F. A., Magnetic Latching Crossbar Switches, B.S.T.J., *39*, September, 1960, p. 1351.
2. Bozorth, R. M., *Ferromagnetism*, D. Van Nostrand Co., New York, 1956, Fig. 9–22, p. 370.
3. Peek, Jr., R. L., and Wagar, H. N., *Switching Relay Design*, D. Van Nostrand Co., New York, 1955.
4. Parker, R. J., and Studders, R. J., *Permanent Magnets and Their Application*, John Wiley and Sons, Inc., New York, 1962.