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Development of the Permissive-Make Relay

Abstract: The development of a new relay is described which meets the need for an improved general-purpose relay for use in existing and future business machines. Long life, reliability, higher speed, low power input and manufacturing economy are realized in the Permissive-Make Relay through the following factors: a new contact system; a balanced force system; optimum magnet design; limited tolerance buildup; adjustment-free assembly design.

Introduction

Relays, one of the most widely used components in business machines, are found in most small, low-cost accounting machines as well as in the largest computers. A primary requirement of today's relays is that they meet the reliability requirements of high-speed switching. In earlier machines, the speed and number of operations required of relays were much less than are usual in today's computers. A business-machine relay which formerly lasted years would now have a life expectancy measured in months. The permissive-make relay was developed to meet these increased speed and life requirements.

Relay requirements

A relay for these applications should meet the following requirements:

1. The speed and life should satisfy general-purpose application in business machines. The scope of operation should include 45-volt dc operation, operation at thyratron voltages for high speed, and low-voltage operation from transistors. A change in the coil should be the only modification of the motor unit to cover the last requirement.
2. The design should be compatible with the space, mounting requirements, and location and type of wiring terminals of present production machines.
3. The relay must be pluggable for easy service and maintenance.

Contact specifications

The relay functions required and circuit conditions encountered serve to define the problem. A synchronous system of dc pulses is generated by cam-operated circuit breakers. These are distributed to the relays as signal pulses so that the relay contacts are opened and closed before the current is applied. There are circuit applications, however, where the contacts interrupt light inductive loads of 100 ma or less; these contacts must be protected by RC networks if the points are to have life comparable with the mechanical life of the relay.

The contact system is of prime importance and should be the first consideration. Specifications for the contact system follow:

1. The contacts should be capable of carrying loads in a range up to three amperes steady-state capacity at 50 volts.
2. Contact bounce should be reduced to a minimum and should be entirely eliminated before the required operate time of the relay.
3. By substitution of the proper contact material, loads in the microampere range should be capable of being switched without excessive contact resistance.
4. A minimum of two sets of transfer contacts should be provided to insure contact reliability.

Contact system

Contact pressure and bounce are the two major problems in designing an improved contact system; past experience has shown that contact bounce could not be eliminated by external damping without critical adjustment. This served to point out that the simplest method to eliminate bounce was to make damping inherent in the contact spring without resorting to extra bounce-dissipating methods.

A mechanical analogy explaining the process of mechanical impact when contacts make at a given velocity is possibly the simplest way to analyze the bounce problem. As set forth by Brehm,[1] the elasticity of the contact is considered to be a spring of rate k and the contact masses are lumped about their center of gravity. Contact mass m_1, having an elasticity constant k_1, moves with a velocity v_1, without constraint so as to collide with contact mass m_2 which has an elasticity constant k_2 and a velocity v_2, in the manner shown in Fig. 1.

Assuming the values of elasticity k_1 and k_2 are different for the two masses, m_1 and m_2, respectively, they may be combined according to the relation:

$$k = \frac{k_1 k_2}{k_1 + k_2},$$

which represents the condition at the instant of impact.

After impact, mass m_1 moves by the displacement x_1 and mass m_2 by the distance x_2. Thus the combinational spring in existence at the time of impact is shortened by the amount

$$x = x_1 - x_2,$$

and the contact pressure is represented by

$$F = kx = (\text{mass})\ (\text{acceleration}).$$

According to the equations of motion

$$m_1 \frac{d^2x_1}{dt^2} = -(x_1 - x_2)k,$$

$$m_2 \frac{d^2x_2}{dt^2} = (x_1 - x_2)k.$$

The boundary conditions at $t = 0$, are:

$$x_1 = 0, \qquad \frac{dx_1}{dt} = v_1;$$

$$x_2 = 0, \qquad \frac{dx_2}{dt} = v_2.$$

Derivation and substitution leads to the equation

$$m_1 m_2 \frac{d^4x_2}{dt^4} + (m_1 + m_2)k \frac{d^2x_2}{dt^2} = 0.$$

Solution of this differential equation results in

$$x_1 = C_2 t + \frac{(-m_2)}{m_1} C_3 \sin\left(\sqrt{\frac{(m_1+m_2)k}{m_1 m_2}}\right) t,$$

$$x_2 = C_2 t + C_3 \sin\left(\sqrt{\frac{k(m_1+m_2)}{(m_1 m_2)}}\right) t,$$

where

$$C_2 = \frac{v_2 m_2 + v_1 m_1}{m_1 + m_2},$$

$$C_3 = \frac{(v_2 - v_1)}{\sqrt{\frac{(m_1+m_2)k}{m_1 m_2}}} \left(\frac{m_1}{m_1 + m_2}\right).$$

The period of impact, T, becomes

$$T = \frac{\pi}{\sqrt{\frac{(m_1+m_2)k}{m_1 m_2}}}.$$

According to Brehm the variable ratio of the struck or stationary contact mass m_2 to the striking or moving con-

Figure 1 **Mechanical analogy of contact impact.**

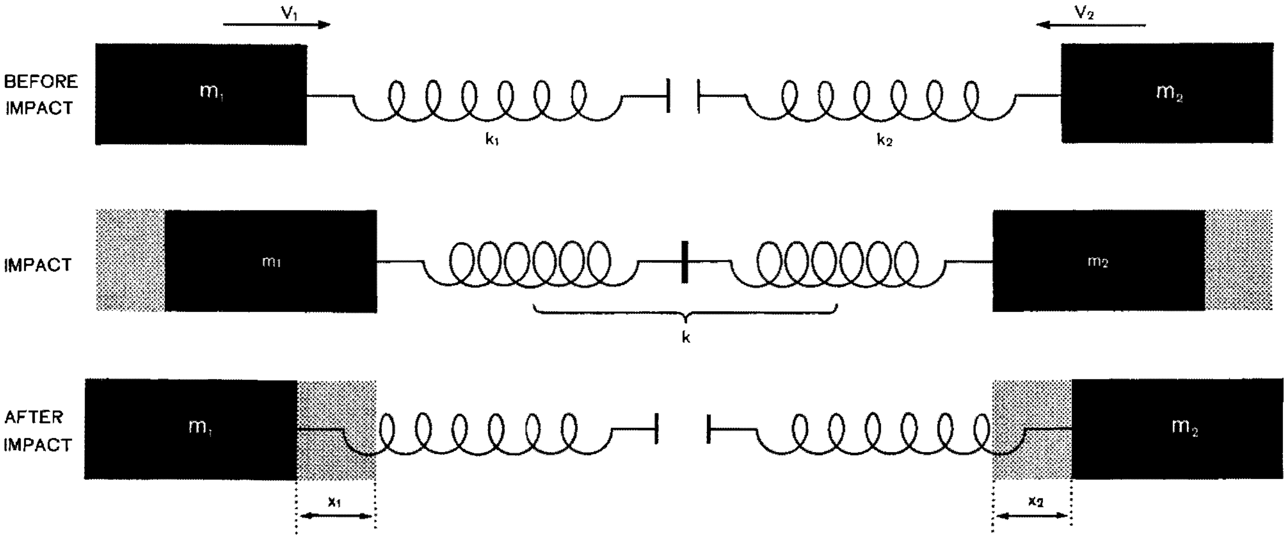
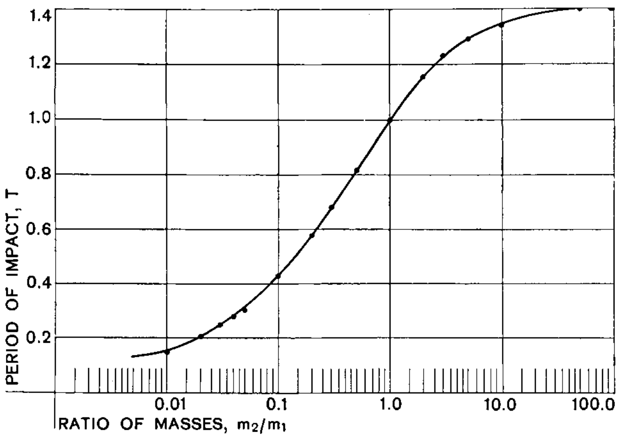


Figure 2 **Relative period of impact related to time of impact of equal masses, m₂/m₁.**



tact mass m_1 affects the relative duration of impact as related to the duration of equal masses m_1 and m_2. Mass m_2 should be greater than m_1 to achieve a longer period of impact. Mass m_2 approaching infinity allows an increased time for impact-energy dissipation. This is illustrated in Fig. 2 by a plot of period of impact *vs.* ratio of masses.[1]

With the mass parameters adjusted for a longer duration of impact, further means can be applied to overcome any contact bounce present. Since the period of impact is

$$T = \frac{\pi}{p},$$

where p = natural frequency, a reduction of the natural frequency of a system would further prolong the period of impact. This allows the inherent kinetic energy of the system to be destroyed.

As a means of reducing the natural frequency of the contact spring, a straight wire was formed in the shape of a "U." According to S. Timoshenko,[2] only approximate solutions of the calculation of natural frequencies of vibrations for rings of the form of an incomplete circular arc are available. Professor Lamb provides a more rigorous treatment of curved-bar vibration.[3]

Consideration is given in Lamb's paper to the effect of curvature on the vibration of a curved bar where the total curvature is slight. The bar under investigation was free from external forces except at its extremities as in Fig. 3.

According to Lamb's derivation, r denotes the radius of a curved bar, having its origin at the center of the circle of which the bar is a segment. The polar coordinates of any point D are (r, θ). Assuming the bar to be free from external force, except at the extremities where forces X are active, point D assumes a new location D', the coordinates for which become $(r+a, \theta+\gamma)$, if a and γ are small.

Assuming further that

$$\gamma \propto e^{ipt},$$

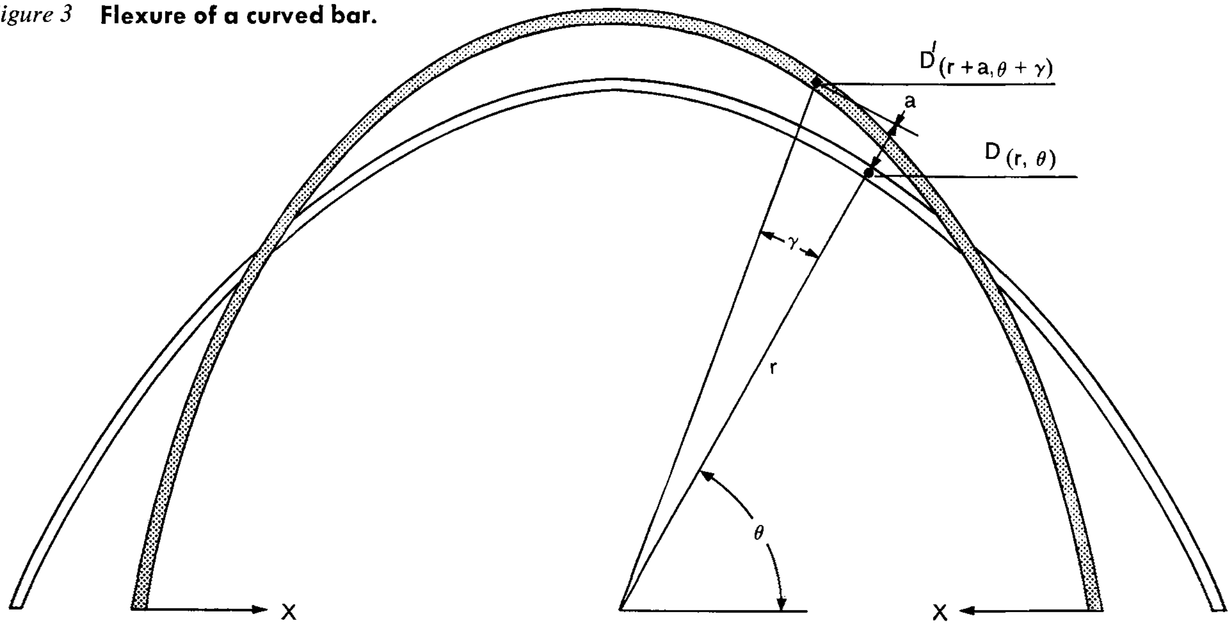
and from the differential equation

$$\gamma^{VI} + 2\gamma^{IV} + (1-k^4a^4)\gamma'' + k^4a^4\gamma = 0,$$

Lamb derived the following equations

$$\frac{\sigma p^2}{B} = k^4 \cong \frac{N^4}{l^4}$$

Figure 3 **Flexure of a curved bar.**



for a straight bar, where

$\ell = 2r$ = length of the bar,
σ = mass per unit length,
N = root of a transcendental equation, and
B = a constant that makes the potential energy of bending proportional to the square of the curvature.

To determine the change in natural frequency due to the curvature, the equation for a curved bar becomes

$$\frac{\sigma p^2}{B} = k^4 = \left(\frac{N^4}{\ell^4}\right)\left(1+\frac{2y}{N}\right)^4,$$

where

$$kr\alpha = 1/2N + y$$

and

$$N = \text{a root of } \tanh N/2 = -\tan N/2.$$

With $p_o/2\pi$ as the frequency of the corresponding mode for a straight bar,

$$\frac{p}{p_o} = \left(1+\frac{2y}{N}\right)^2 \cong 1 + \frac{4y}{N}$$

so the natural frequency of a curved bar is lower. The curvature lowers the natural frequency and makes the nodes approach the middle of the bar.

The curved wire is confined in a manner that further contributes toward overcoming bounce. The wire is preformed to a particular angle such that upon assembly, it exerts a definite pressure against the fixed contact. A minimum of three grams per wire was sufficient for bounce-free operation; however, a 10-gram contact pressure is used to reduce contact resistance. Thus the shape of the wire and the method of confinement of the wire reduce the force amplitudes of vibration

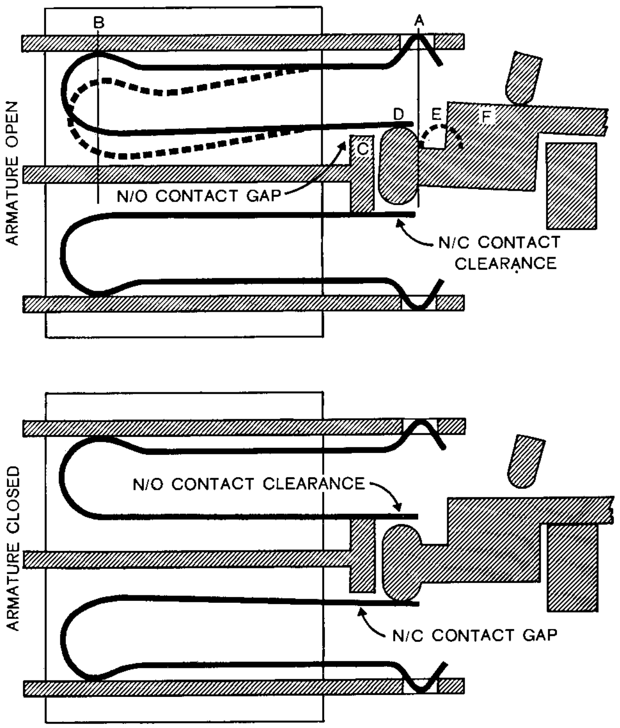
$$P_1 \sin \omega_1 t + P_2 \sin \omega_2 t + P_3 \sin \omega_3 t + \ldots$$

to a magnitude less than the contact pressure P_o.

The contact wire is permitted to make due to its own spring pressure; thus it gets its name, the permissive-make contact. The contact system is shown in Fig. 4. The fixed contact is at *C* with the upper wire shown open (normally open contact) and the lower wire shown closed (normally closed contact). Armature *F* is operated downward by an electromagnet. The wire is held by three forces either at *A*, *B* and *C* in the closed position or *A*, *B* and *D* in the open position. When the contact actuator is between *A* and *B*, the system forces the contact wire against point *B*. If the contact actuator were in the dotted position *E* and not between *A* and *B*, the force system would be reversed such that it would cause the contact wire to swing as shown in the dotted lines causing excessive contact wipe at *C*.

With the actuator at *D*, a minimum contact wipe is maintained by the geometry of the system. The mechanical wipe is sufficient to remove contact films without resulting in excessive wear of the contact and its actuator.

Figure 4 **Functional drawing of permissive-make-relay contact system.**



From displacement-time curves, armature rebound measured at the contact actuator indicate clearances of 0.0015 inch at the N/O (normally open) contact and 0.003 inch at the N/C (normally closed) contact are necessary. This controls the amount of actuator motion necessary to provide the minimum clearance between the actuator and the contact wire resting against the fixed contact after the make operation. This establishes nominal dimensions of 0.018 inch actuator motion resulting in the gaps and clearances listed in Table 1. The contact gaps are fixed to a minimum of 0.006 inch by surge-voltage limitations. Gaps and clearances are increased beyond the minimum requirements to allow for manufacturing variation and to increase the life and reliability of the contact.

A 0.006-inch margin is provided between the break of the N/C contact and the make of the N/O contact. The contact actuator is moved in the N/C direction by magnetic and N/O contact forces and is returned in the N/C direction by the drop-out spring and N/C contacts. The contact-wire velocity is controlled by the actuator and the wire does not leave the actuator until it makes with the fixed contact.

Table 1 **Four-Position P-M Relay Gaps and Clearances**

	Gap (in.)	*Clearance (in.)*
N/O	0.013	0.005
N/C	0.011	0.007

For this particular application, past experience has shown that the eutectic silver-copper material used as contact wire and inserts in the IBM Wire Contact Relay has the desired tensile strength, yield strength, fatigue characteristics and elasticity modulus. The contacts are designed to carry current only. The occurrence of faulty circuit-breaker timing occasionally places the burden of breaking current on the relay contacts.

Clean contacts have yielded less than 0.006-ohm contact resistance. The contacts will carry 10 amps steady-state current without detrimental heating. Its limitation is 15 amps of long-duration current which will cause annealed and burned terminal springs.

The wire-contact spring is designed to meet space, stability, life, and manufacturing requirements. The spring rate was kept low to maintain reasonable manufacturing tolerances. The wire formed in the shape of a "U" enabled the use of twice the ordinary spring length in the space available.

A relationship between contact force and curved-wire deflection was derived to aid in the choice of preliminary dimensions for the contact system.

According to Castigliano's theorem, the deflection

$$\delta_P = \frac{\partial U}{\partial P}.$$

In the above, and in the expressions to follow:

U is the total strain energy,
V is the shearing force,
N is the normal force,
A is cross-section area,
G is modulus of rigidity,
M is bending moment,
E is modulus of elasticity.

Strain energy due to V:

$$U_V = \tfrac{1}{2}\int \frac{V^2}{GA}\,ds.$$

Strain energy due to N:

$$U_N = \tfrac{1}{2}\int \frac{N^2}{EA}\,ds.$$

Strain energy due to M:

$$U_M = \tfrac{1}{2}\int \frac{M^2}{EI}\,ds.$$

For beams where the depth of section is small compared to the radius of curvature, the energy can be taken as $U = U_N + U_V + U_M$.

Actually there is an additional term, U_{MN}, which can be neglected if

$$\frac{r}{C} \geqq 3,$$

where

C = distance from centroidal axis of wire to outer surface of wire nearest center of curvature.

Thus

$$\delta_P = \frac{\partial U}{\partial P} = \int \frac{N}{EA}\frac{\partial N}{\partial P}\,ds + \int \frac{V}{GA}\frac{\partial V}{\partial P}\,ds + \int \frac{M}{EI}\frac{\partial M}{\partial P}\,ds.$$

The effect of shear and direct stress on deflection is negligible in comparison to the influence of the bending moment. Therefore the following derived equation can be used for design purposes:

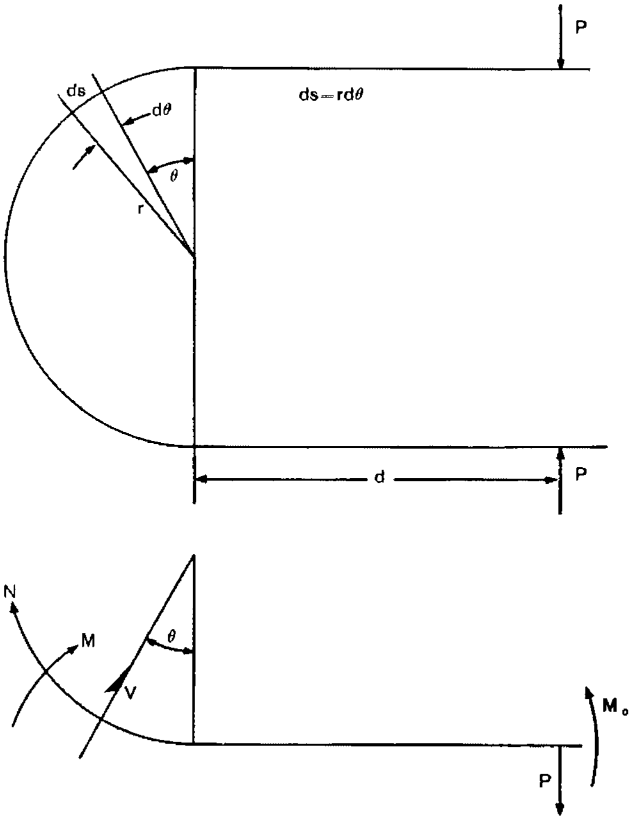
$$\delta_P = \frac{2P}{EI}\left[\frac{d^3}{3} + r\left(\frac{\pi}{2}d^2 + \frac{\pi}{4}r^2 + 2dr\right)\right],$$

where d is defined in Fig. 5.

From the above expression, contact force, P, *vs* deflection, δ_P, is plotted in Fig. 6 to ascertain the effect of tolerance variation of a $0.016^{\pm 0.00025}$ in. wire diameter on the contact pressure. The tolerance of ±1 gram on a 10-gram contact pressure was established on the basis of this analysis. A large-scale model verified the accuracy of wire calculation.

The space, mounting requirements, and type of terminals used for relays in production machines limit the physical size of the terminal block and contact molding assembly for the permissive-make relay. Underwriter's specifications further governed the terminal design. These considerations influenced the contact-molding-assembly design as shown in Fig. 7.

Figure 5 **Wire parameters for curved-wire deflection.**



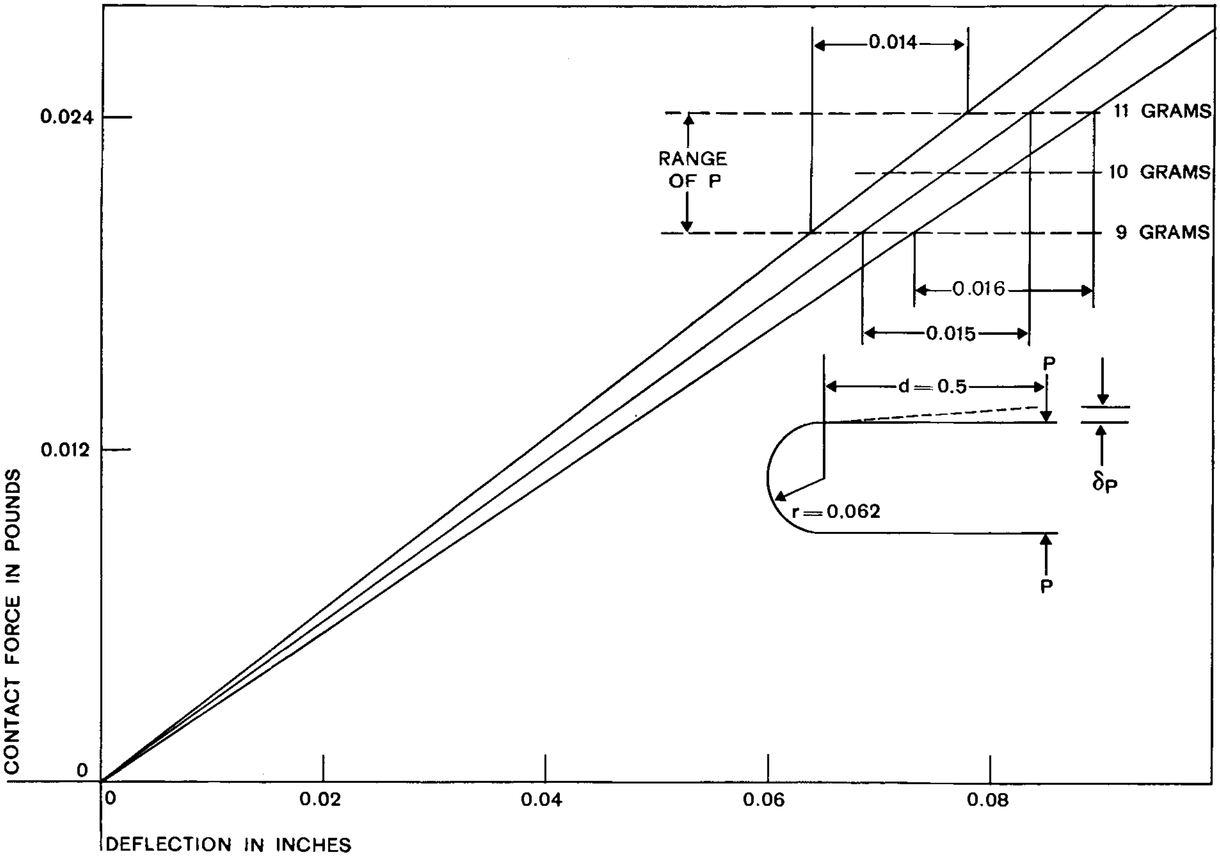


Figure 6 **Contact force as a function of wire-contact deflection.**

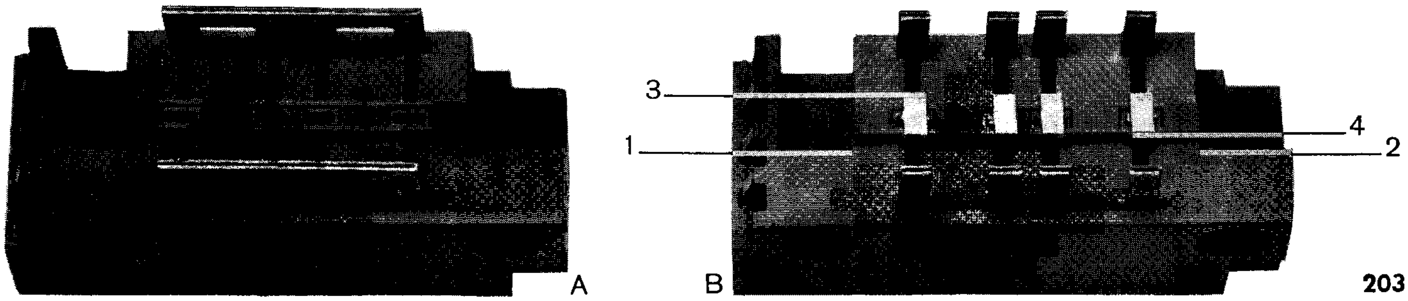
The plastic material is Glaskyd which gives exceptional dimensional stability, mechanical strength and a fast molding cycle time. View *A* of Fig. 7 shows the contact molding assembly as it is removed from the mold; the outer inserts are brass clad with eutectic silver. View *B* of Fig. 7 is the completed contact molding; the center contacts (also eutectic silver) are pressed into the molded part immediately after its removal from the mold. The center-contact surfaces 3 and 4 are machined with reference to the flat molded surfaces 1 and 2 and the design allows one-pass machining after molding.

(Details on assembly of the permissive-make relay are shown in Fig. 15 and described in the accompanying text.)

As shown in Fig. 8, two wires are used per N/O position and two per N/C position. This provides a greater contact reliability. The contact wires and contact molding assembly are designed for ease of wire replacement in the field. Occasion for replacement arises when faulty circuit-breaker timing causes contact burning.

The contact inserts are adaptable to changes in material. By cladding the inserts with Western Electric No. 1

Figure 7 **Contact molding assembly showing relation of dimensioning surfaces.**



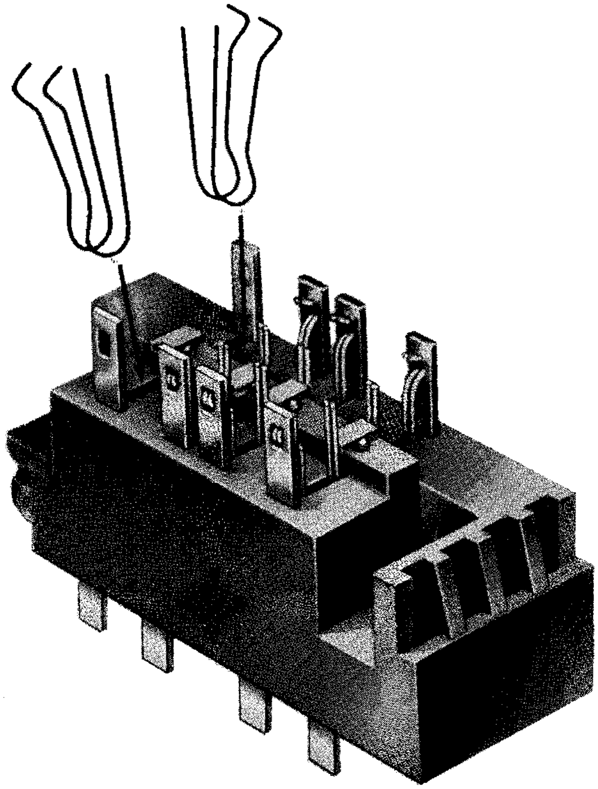


Figure 8 **Positioning of contact wires in the assembly.**

contact material (gold-silver-platinum) and using the same material in the wires, the system becomes capable of switching loads in the microampere range without excessive contact resistance.

Magnet design

The three types of magnet structures most commonly used are two-leg, three-leg and E-core. Of these, the E-shape core is used in the permissive-make relay because of space limitation, low reluctance and its adaptability to the permissive-make contact.

● *a) Optimization*

Mathematical calculation of the operating characteristics of relays has previously been considered extremely difficult, if not impossible, because of the implicit and nonlinear relationship of the variables. However, by use of a digital computer, such as the IBM 650 Magnetic-Drum Calculator, an analytical solution has been evolved whereby the flux, current, displacement, etc. are computed as a function of time. This method requires that each variable be expressed mathematically as accurately as possible. The expression is solved, individually, by difference calculus and the result applied to the solution of the next expression. A complete solution is obtained by a reiterative procedure. The magnet parameters are varied and a new solution is obtained for each variation. The results are analyzed to determine the most efficient design. In this manner the four-point permissive-make relay shown in Fig. 9 was optimized. The same procedure was used to design six- and twelve-point permissive-make relays.

The initial conditions must be evaluated to arrive at a solution for the operate characteristics; the procedure is as follows:

1.

The total inertia of the moving system is evaluated and converted to the equivalent mass at the center of the pole face:

$$m' = \frac{I'}{r^2}.$$

2.

The initial spring forces are translated to act at the center of the pole face by taking moments. This force is designated F_0.

3.

Since the magnetic force developed in the permissive-make relay is generated in the outer legs as well as the main working gap, the effective pole face area A' will be used in calculations of force and reluctance. (See Figs. 10 and 11.)

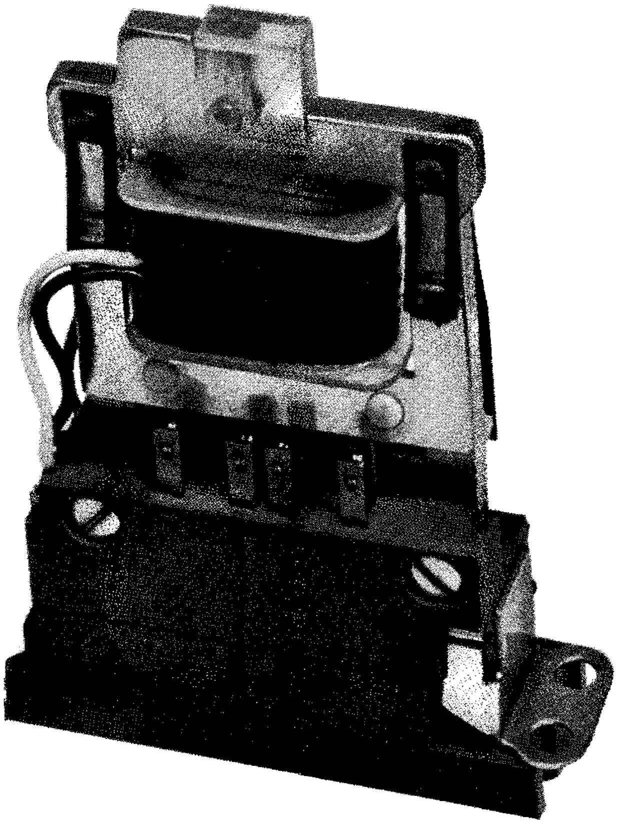
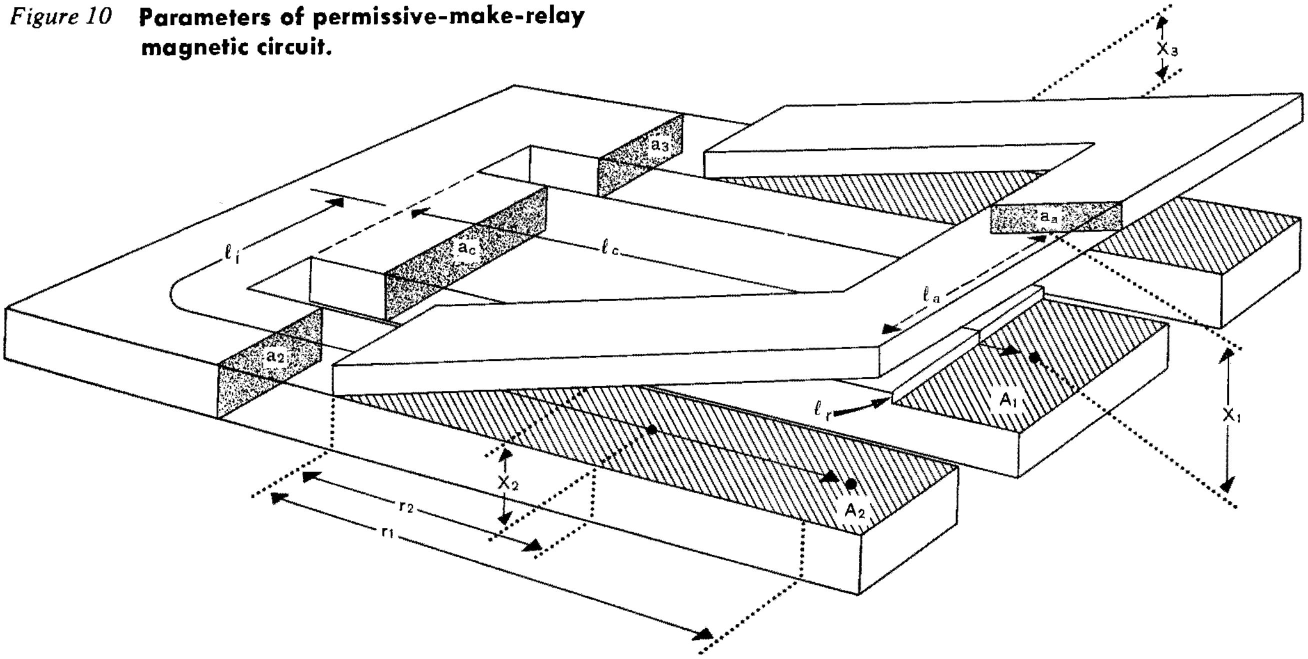


Figure 9 **Four-point permissive-make relay.**

Figure 10 **Parameters of permissive-make-relay magnetic circuit.**



4.

The force F_o is the mechanical force that must be overcome for motion to start (drop-out spring minus N/O contact force). Therefore, at the time motion is incipient the magnetic force f_o is equal to the mechanical force F_o.

$$f_o = \frac{0.0139\,\phi_{go}^2}{A'};$$

$$\text{then } \phi_{go} = \left(\frac{F_o A'}{0.0139}\right)^{\frac{1}{2}}.$$

This gives the value of ϕ_{go} required to begin motion.

5.

The reluctances of the magnetic circuit are now calculated.

a) Reluctance of hinge:

$$\mathcal{R}_H = \frac{0.313\ell_H}{2a_H} \qquad \ell_H \cong 0.002.$$

b) Reluctance of residual:

$$\mathcal{R}_r = \frac{0.313\ell_r}{a_r}.$$

c) Reluctance of working gap:

$$\mathcal{R}_{\text{gap}} = \frac{0.313X}{A'}.$$

As the reluctance of the iron is a function of ϕ, the reluctance is expressed in terms of the Froelich constants C_1, C_2, C_3 and C_4. For the yoke and core the reluctance is assumed constant at the value of ϕ_{go} previously determined. (Care must be taken to be sure that the yoke and core operate below the knee of the magnetization curve at maximum value of flux.)

d) Reluctance of core:

$$\mathcal{R}_c = \frac{C_4\ell_c}{a_c C_3 - \phi_{go}} \times 10^{-3}.$$

e) Reluctance of yoke:

$$\mathcal{R}_i = \frac{C_4\ell_i}{2a_i C_3 - \phi_{go}} \times 10^{-3}.$$

f) Reluctance of armature:

$$\mathcal{R}_a = \frac{C_2\ell_a}{2a_a C_1 - \phi_{go}} \times 10^{-3}.$$

g) The leakage reluctance $\mathcal{R}_L$ is solved.[4]

h) The approximate equivalent circuit for the reluctance of the permissive-make relay is shown in Fig. 11,

where

$$\mathcal{R}_o = \mathcal{R}_c + \mathcal{R}_i + \mathcal{R}_H + \mathcal{R}_r \qquad \text{(assumed constant)}$$

and

$$\mathcal{R}_t = \frac{\mathcal{R}_\ell\left[\mathcal{R}_a + \mathcal{R}_o + (0.313X/A')\right]}{\mathcal{R}_\ell + \mathcal{R}_a + \mathcal{R}_o + (0.313X/A')}.$$

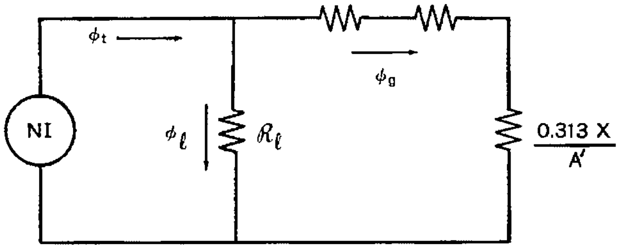


Figure 11 **Equivalent circuit of permissive-make relay.**

6.

The initial inductance of the magnet is now calculated. It will be seen from the foregoing calculations that the greater percentage of the total reluctance resides in the working and residual gaps. For this reason, the inductance of the magnet is considered constant until the armature starts to move and the air gap diminishes.

$$L_o = \frac{N^2 \times 10^{-8}}{\mathcal{R}_t}.$$

7.

The value of current which is required to produce ϕ_{go} is:

$$i_o = \frac{\mathcal{R}_{go}\phi_{go}}{N} \times 10^3.$$

8.

The time at which motion is incipient is:

$$t_o = \frac{L_o}{R} \ln \left(\frac{E}{E - Ri_o} \right).$$

This ends the calculation for the first stage of the relay-operate cycle. From these results we are able to provide the constants necessary for the dynamic solution.

9.

The second stage of the operate cycle is the dynamic solution. For this we must define the mechanical force as a function of displacement, $P = f(S)$. The relation $f(S)$ is a force function which is approximated by a series of spring constants multiplied by the displacement. The force P is translated by moments to the center of the main working gap. (See Fig. 12.) Relation $P = f(S)$ is defined as:

$P = K_1 S$ when $O < S < S_1$,

$P = K_2 S$ when $S_1 < S < S_2$,

$P = K_3 S$ when $S_2 < S < S_3$.

10.

The solution of the permissive-make relay is completed by the reiterative calculation of the following equations in the sequence shown. The derivations of the expressions are given in a previous paper by M. J. Kelly and J. E. Wallace.[5]

$$i_n = \left\{ \frac{L_{n-2}}{L_{n-1}} i^2_{n-1} + \frac{L_o E^2}{L_{n-1} R^2} \left[(1 - \varepsilon^{-(Rt_n/L_o)})^2 - (1 - \varepsilon^{-(Rt_{n-1}/L_o)})^2 \right] - 0.113 \left[\frac{M'(V^2_{n-1} - V^2_{n-2}) + K(S^2_{n-1} - S^2_{n-2}) + (2F_o + P_{n-1})(S_{n-1} - S_{n-2})}{L_{n-1}} \right] \right\}^{\frac{1}{2}} \quad (1)$$

$$\phi_{gn} = \frac{Ni_n(10^{-3})}{\mathcal{R}_{gn-1}}. \quad (2)$$

$$f_n = \frac{0.0139\phi^2_{gn}}{A'}. \quad (3)$$

$$F_{an} = f_n(F_o + P_{n-1} + KS_{n-1}). \quad (4)$$

$$V_n = \frac{\Delta t}{M'} - \left(F_{A1} + F_{A2} + F_{A3} \cdots + \frac{F_{an}}{2} \right). \quad (5)$$

$$S_n = \Delta t \left(V_1 + V_2 + V_3 \cdots + \frac{V_n}{2} \right). \quad (6)$$

$$P_n = f(S). \quad (7)$$

$$X_n = X_o - S_n. \quad (8)$$

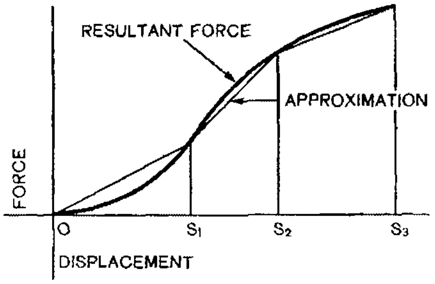


Figure 12 **Static-force-displacement diagram.**

$$\mathcal{R}_{an} = \frac{C_2 \ell_a}{2a_a C_1 - \phi_{gn}} \times 10^{-3}. \quad (9)$$

$$\mathcal{R}_{gn} = \mathcal{R}_{an} + \mathcal{R}_o + \frac{0.313X_{n-1}}{A'}. \quad (10)$$

$$\mathcal{R}_{tn} = \frac{\mathcal{R}_\ell \mathcal{R}_{gn}}{\mathcal{R}_\ell + \mathcal{R}_{gn}}. \quad (11)$$

$$L_n = \frac{N^2(10^{-8})}{\mathcal{R}_{tn}}. \quad (12)$$

The problem is terminated when $X = 0$.

From these results the operation of a given design can be predicted. The procedure is now to vary the parameters of the magnet, individually, and perform a new solution for each variation. The effect of the variation of the parameters is then apparent in the new solution. In this manner the permissive-make relay was optimized with a minimum of effort. (See Fig. 13.)

● *b) Design*

The yoke is punched from 1% silicon iron. Silicon is beneficial since it increases the resistivity and retards aging. The silicon content is presently limited to 1% since higher percentages make the material hard and more difficult to machine. To increase the sensitivity and reduce the residual force of the relay, the yoke is annealed in hydrogen. Further reduction of the residual force is achieved by undercutting the center leg 0.002 in. for an area equal to A_1 (Fig. 10). The yoke is chromium-plated so as to reduce the effects of corrosion.

The armature is punched from SAE 1010 steel. Type 1010 steel was chosen for this application because of its high value of flux density, machineability, permeability, mechanical properties and low cost. It is not annealed because at the designed thickness it would become dimensionally unstable.

The use of molded coils is being investigated as a possible means of improving the relay's duty cycle for high-voltage operation.

Assembly

In-line dimensioning eliminates critical adjustment by reducing tolerance buildup. As shown in Fig. 14, all dimensions originate from the yoke with the armature in the sealed position *X-X* and the N/O contact surface (point 1) is assembled in line with the *X-X* surface. Preformed stainless-steel dropout springs are used to establish definite forces upon assembly. The result is an adjustment-free relay.

The magnet and contact units are permanently assembled to prevent adjustment in the field; if necessary, contact wires can be replaced. The use of solderless coil-lead inserts reduces the cost and hazard of coil assembly. Figure 15 gives a graphic exploded view of the parts and their assembly. The parts were designed for automatic assembly.

To show that the coil has been energized, an indicator is mounted on the end of the magnet unit (Fig. 15). The indicator is a colored metal flag confined in a clear plastic case. Leakage flux from the magnet causes the shim-steel flag to be repelled when the coil is energized. It is capable of static and dynamic indication; its value as a field-maintenance aid is apparent.

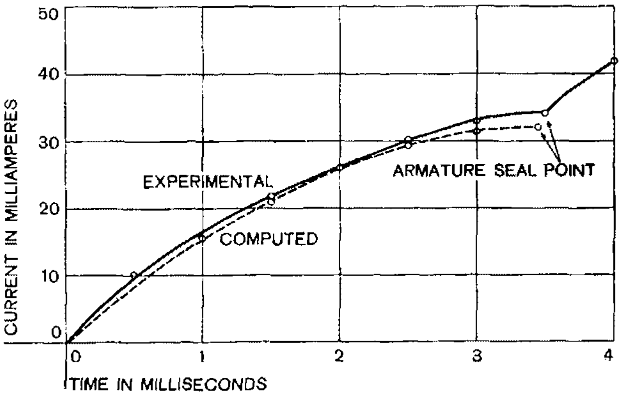


Figure 13 **Current vs. time curve, dynamic condition, four-point standard relay.**

The application of human engineering to the design of the permissive-make relay greatly facilitates its installation and maintenance. Color-coding the terminal molding, contact molding and coil assembly of the four- six- and twelve-point relays red, green and blue, respectively, enables installation and maintenance personnel to identify or locate the type of relay in question in a minimum of time. Identifying each contact by number and

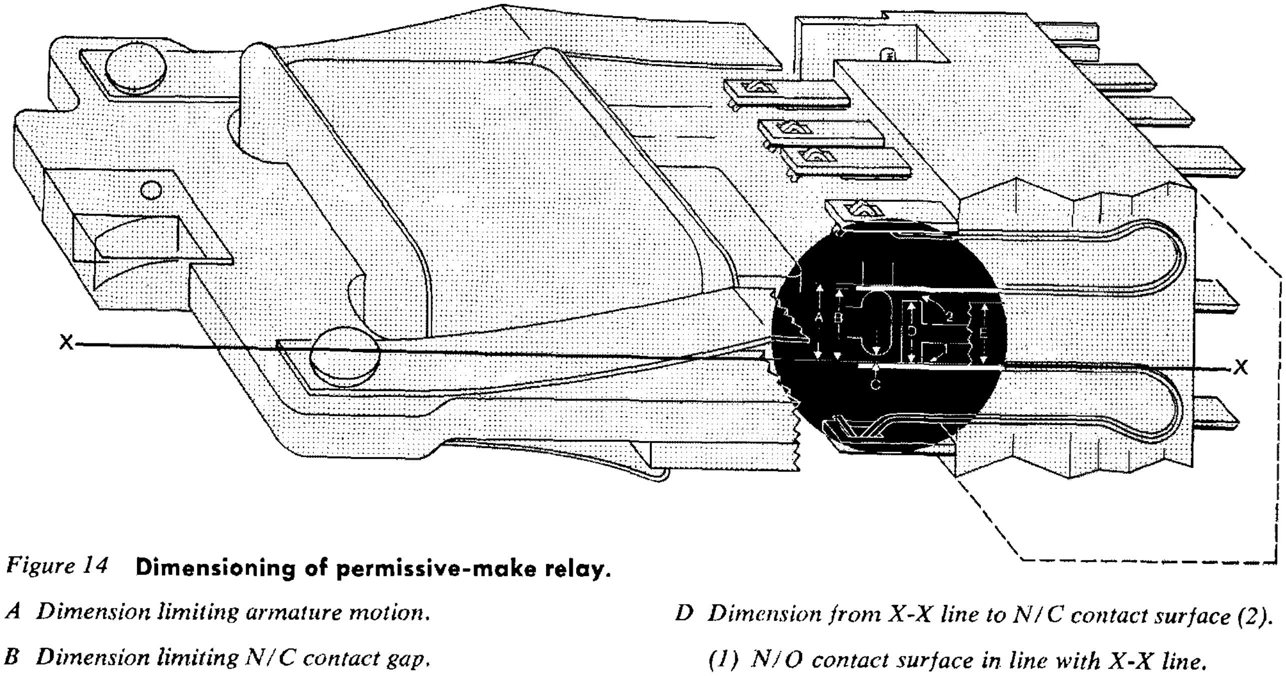


Figure 14 **Dimensioning of permissive-make relay.**

A Dimension limiting armature motion.

B Dimension limiting N/C contact gap.

C Dimension limiting N/O contact gap and clearance.

D Dimension from X-X line to N/C contact surface (2).

(1) N/O contact surface in line with X-X line.

E Yoke thickness.

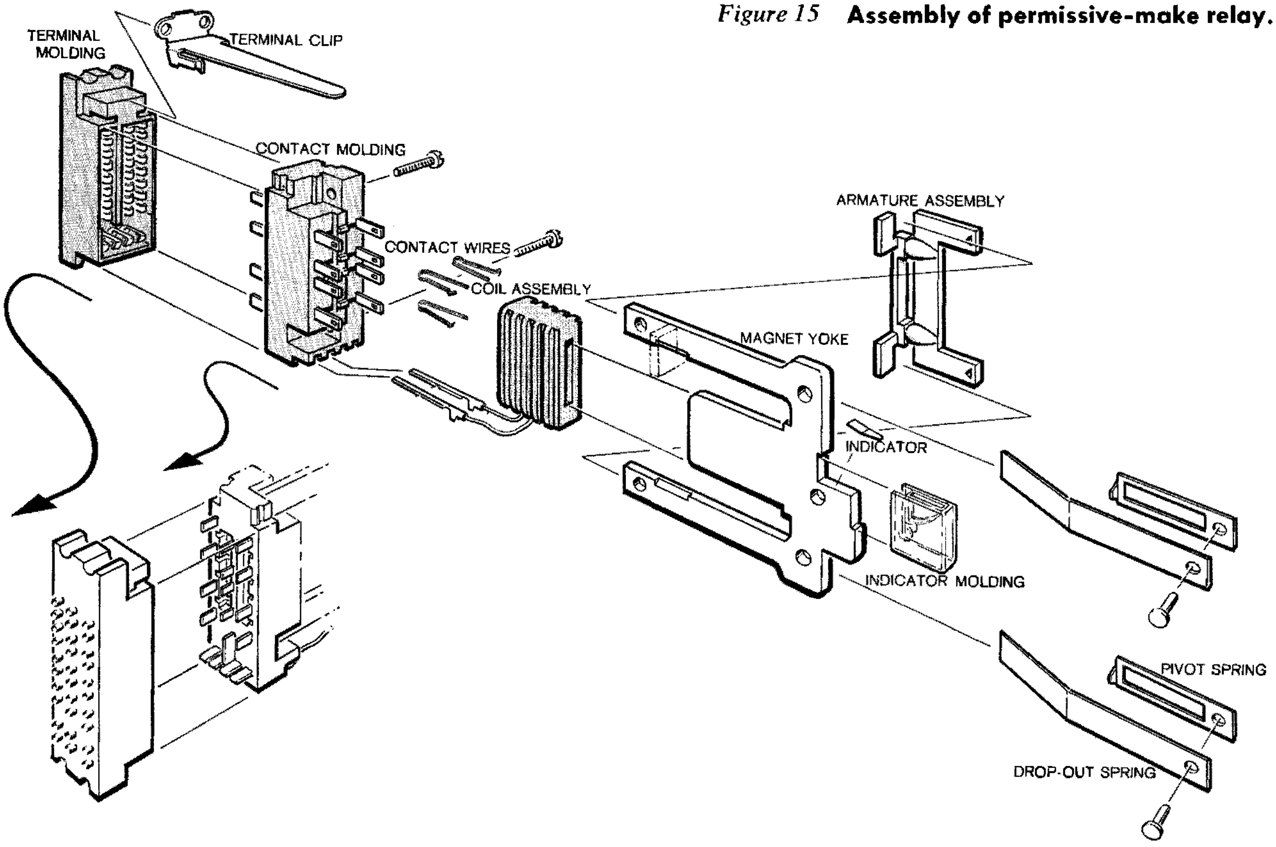


Figure 15 **Assembly of permissive-make relay.**

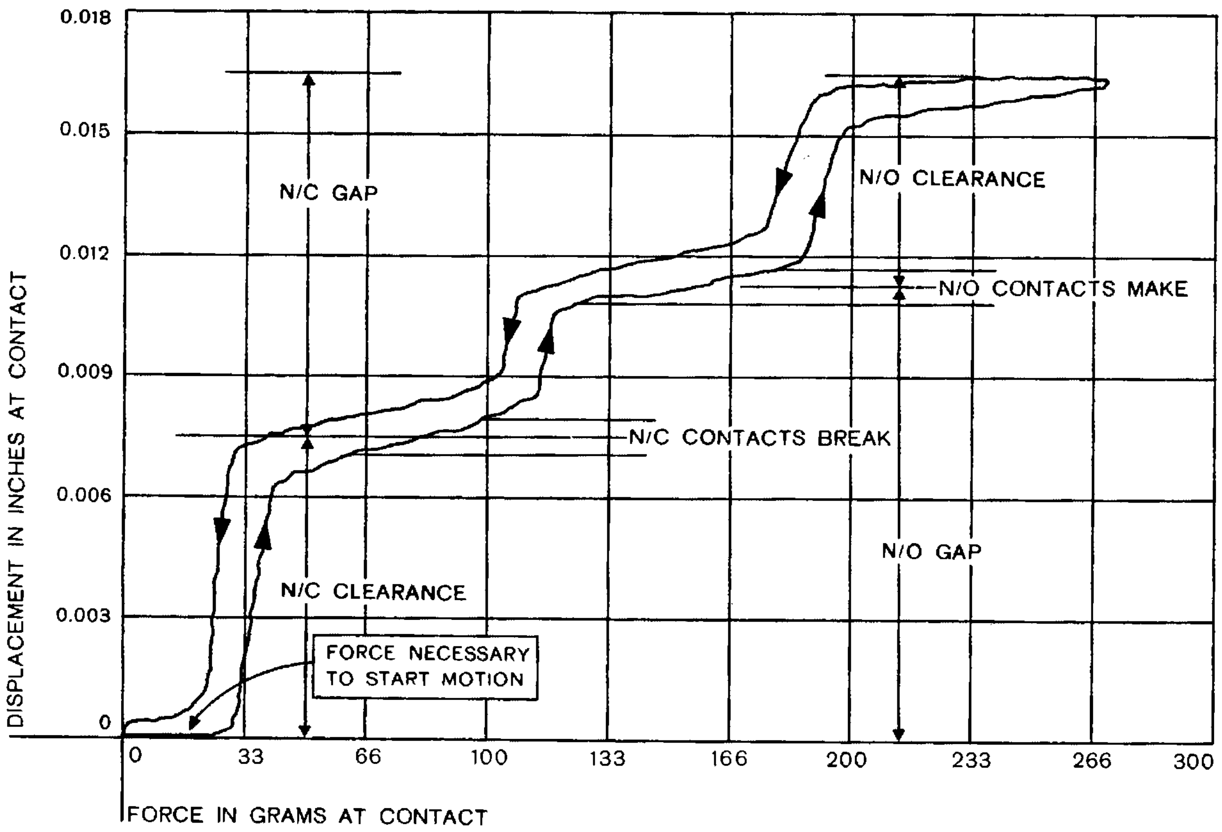


Figure 16 **Displacement vs. force, showing static condition of permissive-make relay.**

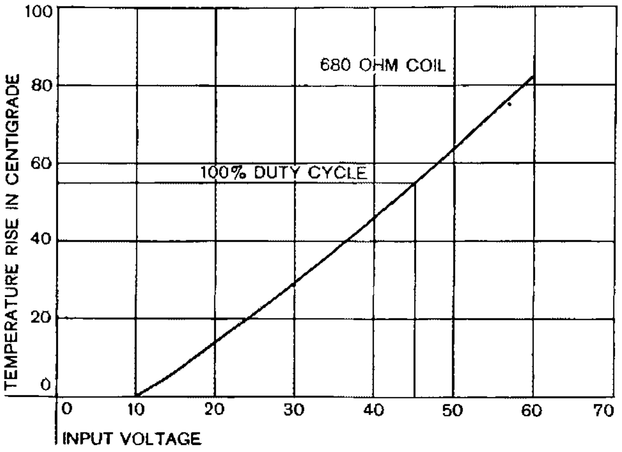


Figure 17 **Temperature rise as a function of voltage input for the four-point permissive-make relay.**

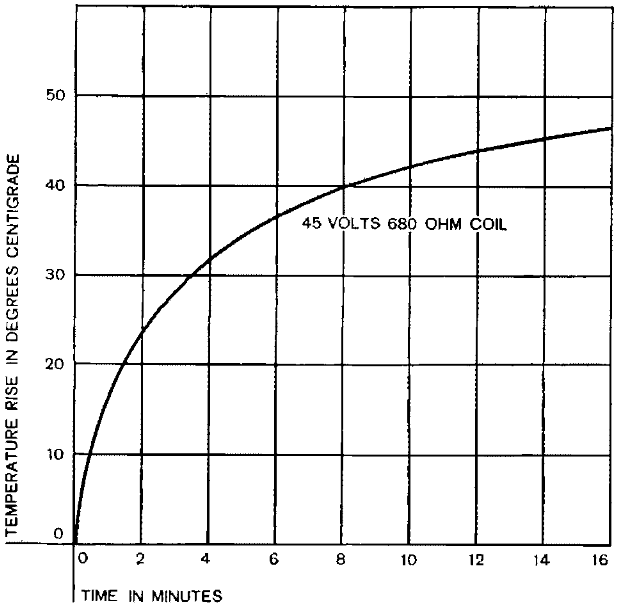


Figure 18 **Temperature rise as a function of time for the four-point permissive-make relay.**

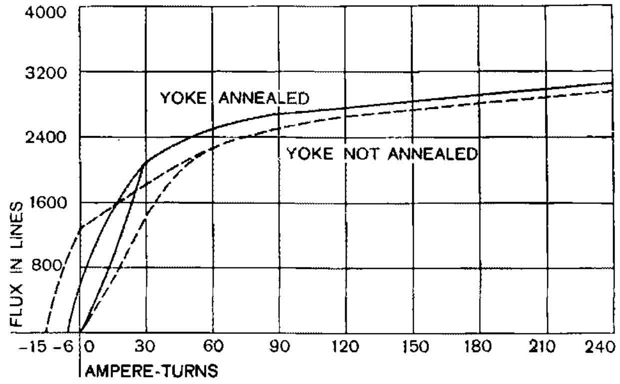


Figure 19 **Flux as a function of ampere-turns for the four-point permissive-make relay.**

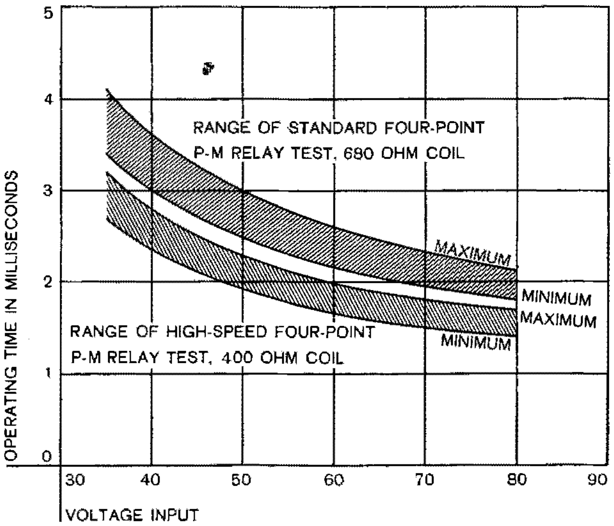


Figure 20 **Operating time as a function of voltage input.**

type (normally open, normally closed or common) on the contact molding assembly further expedites equipment installation and maintenance.

- *Relay Operation*

The detailed characteristics of the four-point permissive-make relay are reviewed in this section. A displacement-force curve (Fig. 16) is used to investigate the static condition of a typical relay. Information such as force to start motion, armature motion, contact gaps and clearances, and friction is obtained.

To ascertain the safe power input into coils, it is necessary to study the temperature rise *vs* voltage input and time in Figs. 17 and 18. A maximum allowable temperature of 95°C is the criterion used to established maximum power input and duty cycle.

In Figure 19, flux is shown as a function of ampere turns for a typical relay with the armature in the sealed position. From this curve, it is evident that the sensitivity and residual force of the relay are improved by hydrogen-annealing the yoke.

Operating characteristics of the standard and high-speed versions of the permissive-make relay are shown in Fig. 20. Operate time as function of voltage input indicates the span of typical voltages and its effect on the speed of the relay. For transistor application, the coil has been designed to operate the relay at lower voltages than shown in Fig. 20.

Table 2 **Relay operation**

Relay		Current* (ma)	Maximum Operate Time*(ms)	Maximum Release Time* (ms)	Duty Cycle* (%)
4-Position					
	Standard	65	3.2	2.5	100
	High Speed	115	2.5	2.5	70
6-Position					
	Standard	75	3.2	2.5	100
	High Speed	125	2.5	2.5	60
12-Position		130	3.2	2.5	60

*At 45 volts

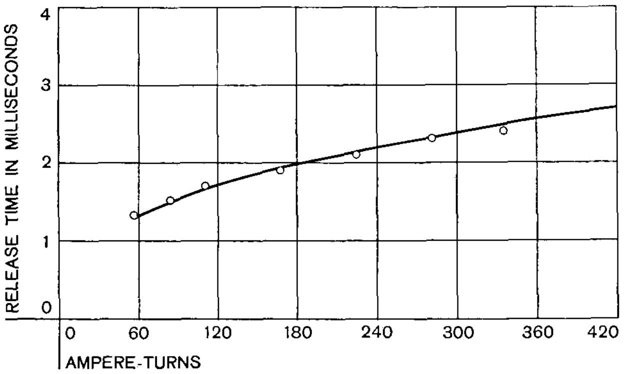


Figure 21 **Relay release time as a function of applied ampere-turns for the four-point permissive-make relay.**

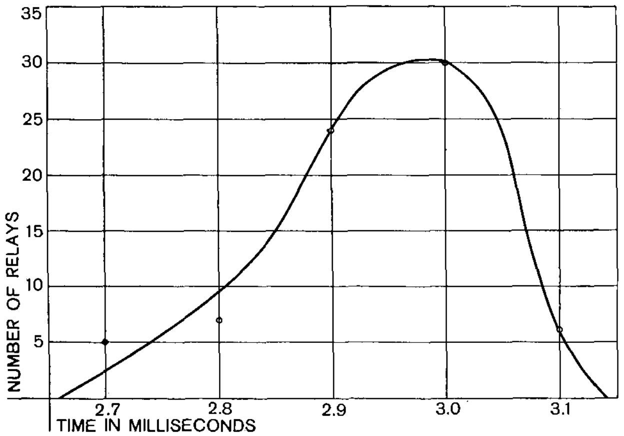


Figure 22 **Frequency distribution of number of relays vs. operate time.**

Relay release time as a function of applied ampreturns for a four-position relay is shown in Figure 21.

In Fig. 22 the frequency distribution of 72 relays versus the operate time constitutes a normal curve. Such a curve can be expected from production relays since the assembly of parts selected at random from independent normal distributions result in a normal distribution of the assembly dimensions and relay performance.

Figure 23 shows the operate time as a function of the number of operations of relays presently on test. It is of interest to note that the operate time gets slightly faster as relay life increases. Previous laboratory tests indicate that the life of the permissive-make relay will be in the order of 400–500 million operations.

Figure 24 shows typical contact operation. Minimization of contact bounce allows more effective use of the contact time and reduces wear.

From the results of analytical design and laboratory experiments the 4-, 6-, and 12-point production permissive-make relays should operate as shown in Table 2.

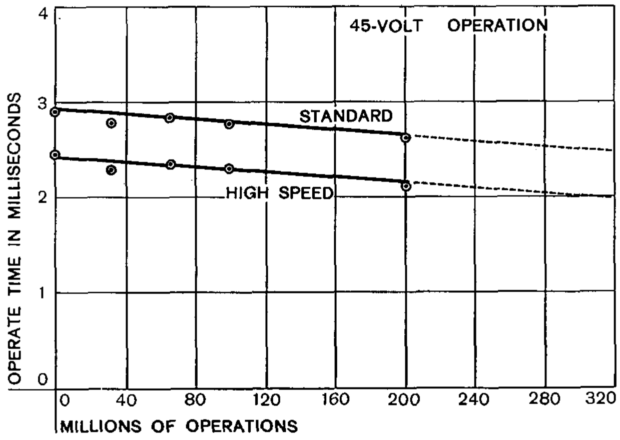


Figure 23 **Average operate time as a function of number of operation.**

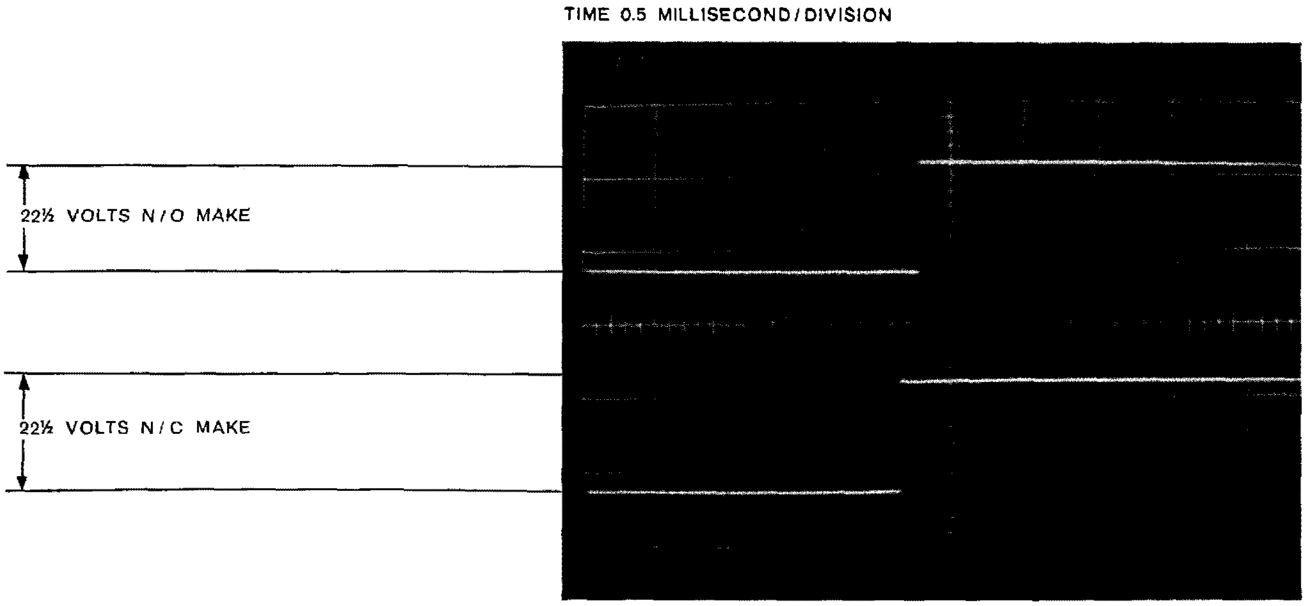


Figure 24 **Oscillographic representation of typical contact operation for the permissive-make relay.**

Conclusion

The permissive-make relay, a general-purpose relay designed specifically to meet the demands of business machines, gives life, reliability, low cost, speed and low power input. The design provides adjustment-free assembly, control of contact wipe and elimination of bounce.

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