

May 24, 1949.

R. C. MATHES

2,470,825

ELECTRICAL CONTACT PROTECTION NETWORK

Filed April 10, 1945

4 Sheets-Sheet 1

FIG. 1

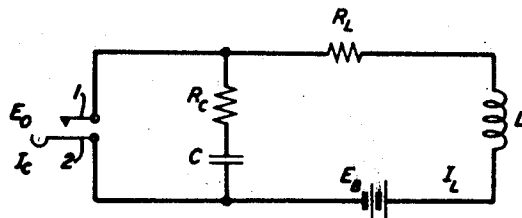


FIG. 2

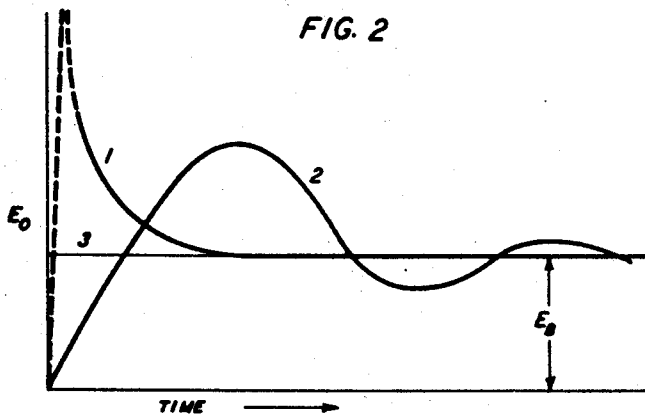
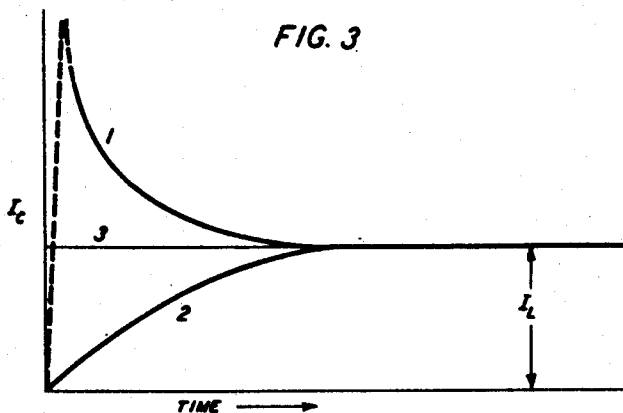


FIG. 3



INVENTOR
R. C. MATHES

BY *John H. Hall*
ATTORNEY

May 24, 1949.

R. C. MATHES

2,470,825

ELECTRICAL CONTACT PROTECTION NETWORK

Filed April 10, 1945

4 Sheets-Sheet 2

FIG. 4

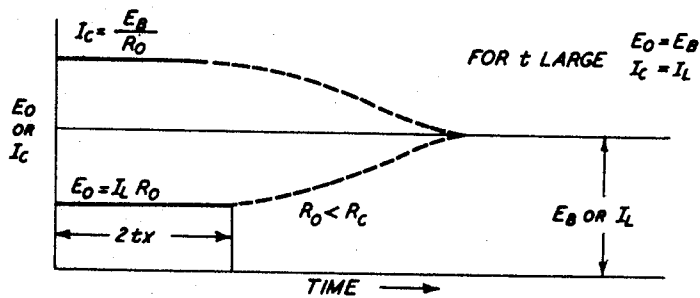


FIG. 5

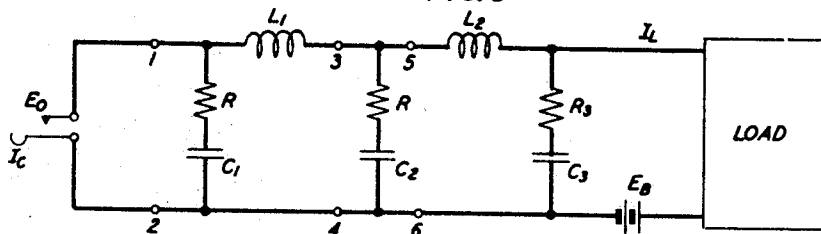
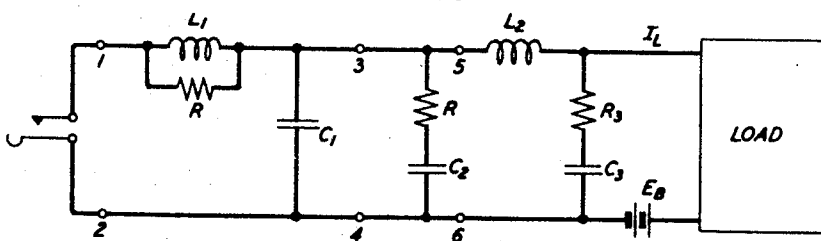


FIG. 6



INVENTOR
R.C. MATHES

BY *[Signature]*
ATTORNEY

May 24, 1949.

R. C. MATHES

2,470,825

ELECTRICAL CONTACT PROTECTION NETWORK

Filed April 10, 1945

4 Sheets-Sheet 3

FIG. 7

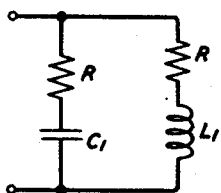


FIG. 8

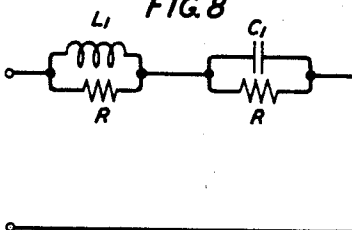


FIG. 9

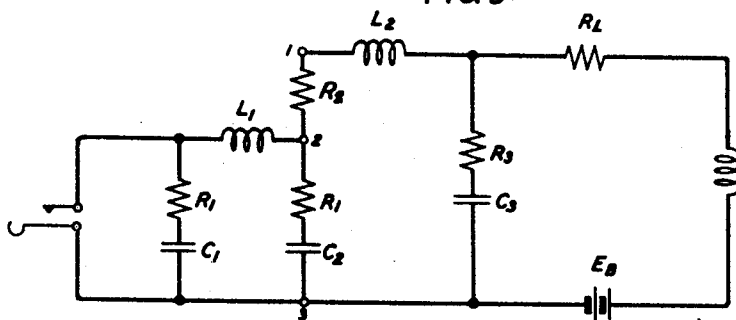
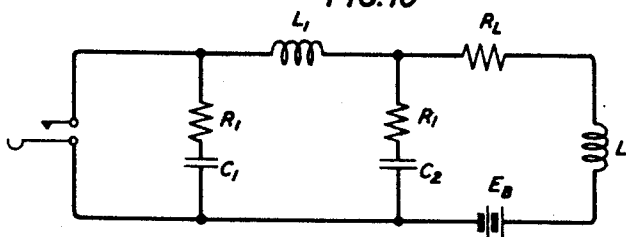


FIG. 10



INVENTOR
R.C. MATHES
BY *John A. Hall*
ATTORNEY

May 24, 1949.

R. C. MATHES

2,470,825

ELECTRICAL CONTACT PROTECTION NETWORK

Filed April 10, 1945

4 Sheets-Sheet 4

FIG. 11

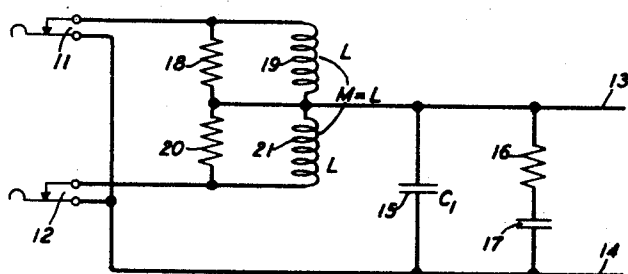


FIG. 12

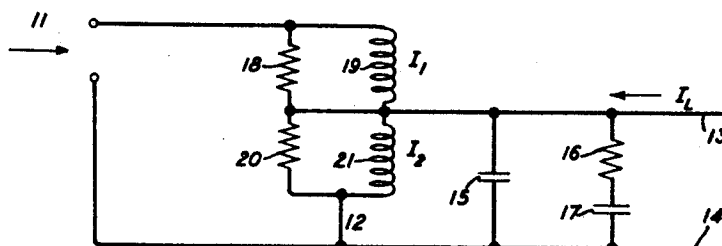
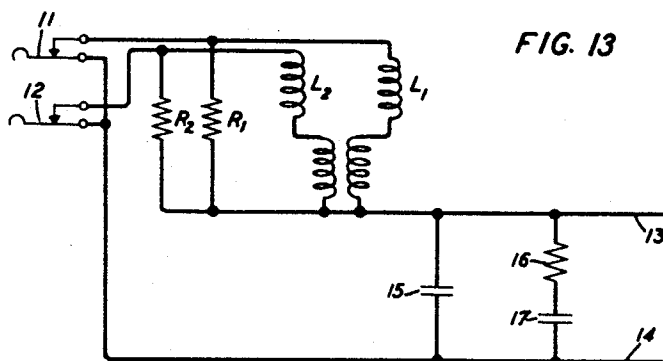


FIG. 13



INVENTOR
R. C. MATHES

BY

John A. Hall

ATTORNEY

UNITED STATES PATENT OFFICE

2,470,825

ELECTRICAL CONTACT PROTECTION
NETWORK

Robert C. Mathes, Maplewood, N. J., assignor to
Bell Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

Application April 10, 1945, Serial No. 587,462

2 Claims. (Cl. 175—294)

1

This invention relates to contact makers and breakers and particularly to the protection of contacts from the ill effects of starting and stopping the flow of comparatively heavy electrical currents.

An object of this invention is to provide an improved type of circuit presenting a constant resistance impedance to the contacts for the purpose of controlling both the breaking voltage and the closing current to the least damaging value corresponding to a given type of contact.

A further object of this invention is to provide a circuit arrangement which will particularly apply to a pair of contacts connected in parallel and intended to be operated in synchronism.

Contact protection becomes a problem where an attempt is made to provide a contact maker and breaker of a size and capacity to economically handle its ordinary duties but which must not be allowed to fail under emergency conditions which are liable to arise in service. For instance it is common knowledge that the resistance of the ordinary tungsten filament lamp rises greatly as the filament attains incandescence, whereby the current when the circuit for such apparatus is first closed is much greater than it is a short period thereafter. It will, therefore, be seen that if the circuit is closed and then almost immediately opened the contacts will be called upon to break a current many times heavier than usual. If the contacts through erosion have become other than perfect such an opening after a closing is not an uncommon occurrence and the result is further erosion and perhaps sticking contacts through welding or mechanical interlocking of the roughened surfaces.

It has been found expedient in certain circumstances in order to insure dependability in service to use a pair of contacts in parallel and while this goes a long way toward solving the problem it does not provide a complete answer.

It has been discovered that the requirements for contact protection on the opening and on the closing of a circuit are mutually conflicting. By way of example, it is common practice to connect a condenser about a pair of contacts to protect them against the ill effects of breaking a heavy current. Therefore, such a condenser becomes charged during the open periods of the contacts so that when they are closed the first rush of current therethrough is not only that due to the normal circuit functioning but also the discharge current of the condenser. The greater the capacity such a condenser has, the greater is the protection provided on the opening of the contacts, but unfortunately the greater also is the initial rush of current when the contacts are brought together.

In accordance with the present invention a type of circuit novel to the art of contact protec-

2

tion is provided for insertion between the contacts and the load circuits. This consists of a uniform line or one of that class of circuits known as constant resistance networks by means of which the breaking voltage and the closing current can be held to constant controlled values for the short times of importance in opening or closing.

In accordance with the present invention a novel means is provided to protect parallel contacts consisting essentially of contact protecting networks for each contact pair arranged to mutually effect each other whereby cancellation of heavy transients may be brought about. A feature, then, of the present invention is a circuit network applied to each of two circuit makers and breakers arranged to operate simultaneously, connected in such manner that the interlinked magnetic circuits of the two branches of such circuit network are in mutual and opposing relation to each other.

The drawings consist of four sheets having thirteen figures, as follows:

Fig. 1 is a schematic circuit diagram showing the relations of certain theoretical circuit elements in a contact protection network;

Fig. 2 is a graphical representation of transient voltage phenomena;

Fig. 3 is a similar graphical representation of transient current phenomena;

Fig. 4 is a graphical representation of voltage and current phenomena where a theoretically perfect section of ideal line is inserted between the contacts and the remainder of the circuit;

Fig. 5 is a schematic circuit diagram showing a constant resistance network of the form of Fig. 7 inserted between a pair of contacts and the load which it is to control;

Fig. 6 is a similar schematic circuit diagram showing a constant resistance network of the form of Fig. 8 inserted between a pair of contacts and the load which it is to control;

Fig. 7 is a fundamental schematic circuit diagram of one form of constant resistance network;

Fig. 8 is a similar fundamental schematic circuit diagram of another form of constant resistance network;

Fig. 9 is a compromise contact protection network which will give practically as good results as a theoretically good circuit;

Fig. 10 is a still further simplification in a compromise circuit;

Fig. 11 is a schematic circuit diagram showing an arrangement for the protection of two simultaneously operated contact pairs;

Fig. 12 is the same circuit redrawn to explain the conditions present when one of the contacts opens before the other; and

Fig. 13 is an equivalent circuit useful in explaining the theory of operation when the coil is

so constructed that through leakage there is less than perfect mutual induction between the parts thereof.

In the study of erosion of relay contacts it has been found that phenomena at both the opening and the closing of the contacts are of great importance. Work has been done on the design of protection circuits designed in general to control the rate at which voltage across the contacts develops in the former case and the rate at which current can build up through the contacts in the other case. Usually a single invariable protection circuit is expected to take care of both cases.

In the case of opening the contacts, the ill effects result from establishing and sustaining, for periods of a few microseconds to a few milliseconds, a destructive metallic arc, a gaseous arc or both types alternating. The existence and severity of these arcs depend on the following principal factors: The contact material, the atmosphere around the contacts, the rate of contact separation, the load current, and the inductive character of the load.

In the case of closing the contacts the ill effects result from arcs just preliminary to firm metallic contact and from the rush of current on closure which may result in welding or in the transfer of material due to certain electrothermal effects. The severity of these effects depends chiefly on the contact materials, the battery voltage and the capacitative character of the load.

The palliative measures required for the two cases are to a degree mutually conflicting and the final design must in general be a compromise with the relative seriousness of the two factors often remaining to be determined by experimental means. How this comes about can be readily seen by examining in a step-by-step fashion the building up of a typical protection circuit for an inductive load.

In Fig. 1 we have an inductive load which will first be assumed to be a pure inductance L with a resistance R_L . The load current I_L will be equal to the battery voltage E_B , divided by R_L . We are interested in the voltage E_o when the contacts 1 and 2 are opened and the current I_c when the contacts are closed, for several simple protection conditions provided by the conventional shunt circuit of R_c-C . If neither is present we know from common knowledge of transient current phenomena that the voltage E_o produced at the contacts 1 and 2 on opening the circuit thereat will be in the form of curve 1 of Fig. 2 and the current produced therethrough on the closing of these contacts will be in the form of curve 2 of Fig. 3. This is a very bad condition for voltage arcing and a very favorable condition for welding current control. If now we add the capacity C but omit R_c we will get curve 2 of Fig. 2 for E_o and curve 1 of Fig. 3 for I_c . The relative severity for the two conditions is now reversed and in most cases we would be little better off.

These curves have been oversimplified in order to bring out the general nature of the circuit reactions. This is particularly true of the number 1 curves designed to illustrate the approach to infinite voltage or current if a nearly perfect opening or closure were obtainable. Actually the dotted portions of the curves are extremely irregular in practice. In the case of breaking, different types of transients such as those described by A. M. Curtis in an article entitled "Contact phenomena in telephone switching circuits" published in the Bell System Technical Journal,

January 1940, pages 40-62, may be set up, with intermittent low voltage metallic arcs or high voltage gaseous arcs. Similarly in the case of closure, the energy stored in the condenser may be dissipated in "preclosure" arcs as well as in the rush of current dissipated as simple resistance heating.

If now we add the resistance R_c into the network of Fig. 1 and satisfy the condition that

$$R_c = R_L = \sqrt{\frac{L}{C}}$$

we will get curve 3 in both Figs. 2 and 3. E_o is now equal to E_B for all time after the contact opening and I_c is equal to I_L for all time after contact closing. This comes about because the impedance looking into the network from the contact terminals is a constant resistance for all frequencies and cannot, therefore, be distinguished from a single perfect resistance.

Unfortunately E_B will generally be a higher voltage than can be permitted to appear across the contacts at the moment of opening without serious arcing. As a first step in exploring a method for providing a controlled voltage, let us insert between the contacts and the rest of the circuit of Fig. 1 a section of ideal line of characteristic impedance R_o and a time of transmission t_x from one end to the other thereof. The rest of the circuit will still be assumed to meet the constant resistance relation stated above. With the contacts closed there will flow the normal closed circuit current of I_L . Upon opening the contacts the overall circuit will function as an infinite line of true resistance impedance until the first reflection arrives from the end of the line. That is, up to a time $2t_x$, there will be an open circuit voltage across the contacts.

$$E_o = I_L R_o \quad (1)$$

This is shown in Fig. 4 for $R_o < R_c$ or R_L . At longer times the voltage reaches the value E_B . Likewise when the contacts are open we have the line charged to a potential E_B and for the same interval of time after closing we will derive a current through the closed contacts of

$$I_c = E_B / R_o \quad (2)$$

Thus by making the impedance of the uniform line R_o less than R_c or R_L we have been able to control matters for a short length of time so that the open circuit voltage conditions are made more lenient at the expense of making the short circuit condition more severe. However, the latter is not as severe as curve 1 of Fig. 3. In the case of very high current loads working from low voltage battery, the reverse result could have been secured by making R_o greater than R_c . Depending on the characteristics of the load and/or other protection equipment between the load and the assumed uniform line; the dotted parts of the curves in Fig. 4 may approach the final steady value either by slow approach or by oscillating about such value.

Further information can be derived from Equations 1 and 2. If we multiply corresponding sides we get

$$E_o I_c = I_L R_o \times \frac{E_B}{R_o} = I_L E_B \quad (3)$$

The expression on the right is the steady state power required to operate the load. The expression on the left might be called a transient wattage characteristic of a given pair of contacts. E_o and I_c will need to be determined experi-

5

mentally for every physically different pair of contacts at their normal operating speeds and pressures. Once these constants have been determined we know under ideal conditions what wattage load these contacts will handle to some degree independent of whether they are operated from a high or low voltage battery. The adjustment to different battery voltages is made simply by the selection of the characteristic resistance R_0 of the uniform line.

Under practical conditions there are several factors which prevent reaching the full efficiency of use indicated by the formula (3). On the break, relay chatter or "reclosures" will require that better protection than indicated may be required. The phenomena of "reclosure" frequently occurs after the relay contacts have been somewhat roughened by the erosion process. On closure there is another phenomena which develops when the battery voltage is above 50 to 100 volts. This is known as "preclosure" and is presumed to be due to point discharges initiating an arc due to the high voltage gradients as the contacts come very close together and is discussed in the Curtis article hereinbefore noted.

For some limited fields of use small artificial lines, such as may be made by winding a solenoid to have a high capacity to ground, will be useful devices according to this invention. However such structures will in general be impractical for a great many situations, to meet which it is desired to provide other forms of constant resistance networks. Two of these are shown in Figs. 5 and 6 derived respectively from the well-known forms of constant resistance networks shown in Figs. 7 and 8. In Figs. 5 and 6 the impedance looking to the right from the contacts will be a constant resistance R if the impedance looking to the right from points 3 and 4 is also a constant resistance R and if $R^2 = L_1/C_1$. This can be made approximately true down to some frequency f_1 if C_2 and L_2 are made large enough. Then the constant resistance network proper which controls the initial voltage or current for an initial period t_1 corresponding to the uniform control time $2t_x$ of Fig. 4 is that part of the network between the contacts and the points 5 and 6.

The product L_1C_1 will be larger the longer the time over which it is desired to hold the initial control without serious reaction from the next mesh. The time constant C_1R should be approximately equal to this time t_1 . Then

$$L_1C_1 = t_1^2$$

The resonant frequency of this mesh would appear to be a reasonable one to which to maintain the constant R characteristic, so

$$f_1 = \frac{1}{2\pi\sqrt{L_1C_1}}$$

and

$$f_1 = \frac{1}{2\pi t_1}$$

At this frequency, f_1 , the reactance of the condenser C_2 should be small compared with that of the inductance L_1 . The resonant frequency f_2 of L_2-C_2 will thus be considerably lower than f_1 and the time constants of that mesh much longer. If it is desired to lengthen the time of flat voltage or current control without going to larger values of L_1 and C_1 (and hence also of L_2 and C_2) this can be done by adding additional sections identical with those included between the contacts and the points 3 and 4. Each of these if properly

6

terminated to the right then automatically provides the constant R terminating impedance required by the section to the left. Other more complicated types of constant resistance circuits may be employed, especially if it is desired to compensate for parasitic capacitance or inductance.

The next section of the figures may be looked upon as a low-pass filter or might be designed as another constant resistance section designed to put another step in the curve of transition to the final current or voltage values. This would have an impedance between that of the first section and the final section. It will thus not be possible to match these sections and also have both of them constant resistance. An approximation as shown in Fig. 9, however, may give very satisfactory results. Here R_1 plus R_2 would be made equal to R_3 and

$$R_1^2$$

would be equal to L_2C_2 . C_3 would have its reactance small compared with that of L_2 at the frequency f_2 .

In many cases encountered in telephone practice the simpler form of circuit shown in Fig. 10 may suffice. In the case of a heavy telephone relay load the values for Fig. 10 would be about as follows:

$$\begin{aligned} I_L &= .4 \text{ ampere} \\ E_B &= 50 \text{ volts} \\ E_0 &= \text{initially } -8 \text{ volts} \end{aligned}$$

whereupon

$$R_1 = \frac{8}{.4} = 20 \text{ ohms}$$

and for $t_1 = .0001$ second.

$$C_1 = \frac{.0001}{100} = 5 \text{ microfarads}$$

$$L_1 = .002 \text{ henry}$$

C_2 should be about ten times C_1 . If t_1 must be held for one millisecond, the above figures for C_1 and L_1 must be multiplied by ten or if it must be held to only 10 microseconds they may be divided by ten. This shows the value of a high initial acceleration of opening if simple contact protection circuits are to be attained. Actually the lower figure would probably meet most telephone cases.

For heavy loads such as small motors with 5 to 10 amperes current the characteristic impedance becomes very low and R or R_1 will be about 1 ohm. For these heavy currents it becomes especially important to hold the free wiring between the contacts and the protection network to a minimum. Such wiring is a short piece of uniform line of about 500 ohms characteristic resistance. Hence, at 5 amperes we would get an initial voltage of 2,500 volts lasting .002 microsecond per foot of wiring. Condensers should also be free of parasitic inductance.

In cases where the load conditions do not impose too stringent requirements, the circuit of Fig. 6 reduces to a form of protection which has often been used, simply the first series element and the first shunt condenser. In this situation the series element has been made by winding the inductance coil upon a conductive permeable core. This provides the approximate equivalent of a coil shunted by a resistance and provides a small unit which can readily be mounted very close to the contacts to be protected, the importance of which has already been indicated.

The design of contact protection circuits is thus seen to be one of many compromises which should always be thoroughly investigated experimentally. The importance of what happens in a few microseconds depending on the very high frequency properties of connected circuit elements cannot be overemphasized. A feature of the constant resistance method of design is that the open circuit voltage can be held uniform after the initial jump for a selected short interval of time (corresponding to these critical first few microseconds) instead of starting to rise immediately as is the case with the more conventional type of protection circuit.

The principles of this invention may be further applied to the operation of two contacts in parallel. The use of double contacts is becoming increasingly more common so the use of this arrangement does not become unduly expensive in practical use.

The arrangement shown in Fig. 11 is one in which two contact pairs 11 and 12 are intended to simultaneously open the circuits therethrough and to thus control a secondary circuit. When the device is normal a conducting path is closed between the conductors 13 and 14 and when the device is operated this path is opened.

Between the conductors 13 and 14 there is one path containing a condenser 15 and another path containing in series a resistance 16 and a condenser 17. Between the conductor 13 and the contact 11 the two circuit elements, resistance 18 and inductance 19, are connected in parallel and likewise between the conductor 13 and the contact 12 the two circuit elements, resistance 20 and inductance 21, are connected in parallel. The two inductances 19 and 21 are parts of one coil and hence there is a mutual inductance factor L , equal to the inductance of each coil.

If, for purposes of examining the characteristics of this circuit, we measure the high frequency impedance looking into the circuit from the contact 11 (opened as indicated in Fig. 12) while the contact 12 is still closed, we will get essentially a short circuit with high mutual inductance between the two halves of the coil 19 and 21. Hence at the moment the circuit is opened at contact 11, if the other is still closed, we would expect a voltage build-up starting from zero similar to curve 2 of Fig. 2.

If we measure the impedance at the contacts 11 with contacts 12 open we will get a resistance at high frequencies. Hence, if the two contacts open together (or at the instant the contacts 12 open after the contacts 11 have opened) we would get a controlled voltage jump corresponding to the differential division of the two currents in the upper and lower halves of the coil. If the currents divided equally as they normally would and the two contacts opened at the same instant there would be no voltage jump and we would get the full benefit of the contact protection of C_1 , the condenser 15. This is because in this circuit there is under these conditions no energy stored in the magnetic field of the coil as there is in Fig. 6.

If, however, contact 11 opens first and contact 12 opens a little later, in this time I_1 in coil 19 will have decayed by discharge through the parallel resistance 18, and I_2 will have increased

with the condition maintained that $I_2 = I_1 + I_2$. Then the energy stored in the coil field which must be dissipated in the resistances is proportional to $I_2 - I_1$ approaching I_1 as a maximum if the differential time of opening is long.

Hence, at the worst, contact 12 if it opens at a considerable time after contact 11 (considerable in relation to the time constant of this circuit) will have to bear the full brunt of the opening to the same degree that the single contact in Fig. 6 does. The more nearly the two contacts operate at the same time, the more benefit will be derived from the circuit.

However, if we look at the situation on closing, with perfect mutual, we note that the coil circuit cancels out as soon as both contacts are closed and no protection is provided against current rush, although good protection is provided for the contact which closes first.

Hence, an arrangement equivalent to that shown in Fig. 13 is provided, in which the coil is made with considerable leakage between the two halves. In this circuit $L_1 - R_1$ and $L_2 - R_2$ would give the individual protection equivalent to $L_1 - R$ of Fig. 6, while the mutual M would protect either contact during the interval due to non-synchronous operation.

The situation here seems to be in a general way similar to that in the case of a single contact; the circuit requirements for opening and closing are mutually conflicting and final design will be a matter of compromise. It is of interest in this connection that in certain cases the difference in time between the opening of two contacts may be systematically different from that corresponding to closing. For example, it has been observed that the difference in time of closing of two glass sealed contacts units whose magnetic circuits are operated in parallel may be as high as one millisecond. The difference in the time of opening, however, will not be more than 50 or 60 microseconds. This systematic difference may be used to advantage in the design of the coil as it will dictate the amount of mutual impedance in the coil.

What is claimed is:

1. The combination of a pair of circuit makers and breakers connected in parallel and arranged to operate simultaneously, of a constant resistance protecting network in series with each consisting of an inductance shunted by a resistance, said inductances being mutually coupled.

2. The combination of a pair of circuit makers and breakers connected in parallel and arranged to operate simultaneously, of a constant resistance protecting network in series with each consisting of an inductance shunted by a resistance, said inductances being mutually coupled and a condenser bridged about said combination.

ROBERT C. MATHES.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,929,057	Dellenbaugh	Oct. 3, 1933
2,285,691	Wegener	June 9, 1942
2,394,389	Lord	Feb. 5, 1946