RELAY VALVES AS TIMING DEVICES IN SEAM-WELDING PRACTICE

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Summary. The usual method of bonding two pieces of metal by spot-welding is to pass a very high-ampere alternating current through them. Practical experience in recent years has shown that to obtain a reliable bond it is essential to limit the time the current is passing to a few hundredths of a second, i.e. to a small number of periods at a 50-cycle frequency. In welding long seams the parts to be bonded are passed between roller-type electrodes at a constant speed, a series of welding-spots being produced by passing a current impulse of the above mentioned duration through the electrodes at uniform intervals.

A timing device designed for this purpose must therefore allow the current to pass for a certain number of cycles \( x \), then arrest the current for a further number of cycles \( y \) and repeat this sequence \((x-1-y)\) continually. Mechanical timing devices are not suitable for this purpose owing to the extremely short period of time involved (of the order of 0.02 second) and the powerful current used (usually several 100 amps). The employment of a relay valve controlled by a relaxation oscillation offers considerable advantages as it operates with perfect synchronism and can be readily and instantaneously regulated within wide limits. The design and operation of a timing device of this type are described below.

In addition to arc welding, two pieces of metal can also be bonded electrically by resistance welding in which a powerful current is passed through the metal. In this process the greatest resistance to the flow of current is encountered at the gap between the two surfaces, the heat generated at this point causing the metals to fuse together to give the desired bond. Usually the current is supplied to the two pieces of metal by means of more or less tapered electrodes, the weld covering an area with a diameter of only a few millimetres. Hence the term “spot-welding”. To produce long seams, a series of welding-spots are required, to obtain which the electrodes are made in the form of rollers that are brought in contact with the metal surfaces to be bonded. The metal is then passed between the rollers at a speed determined by the distance required between the welding-spots, which in turn depends on the required mechanical strength and impermeability to liquids of gases. The present paper deals essentially with this method of seam-welding.

The heat generated at a welding-spot is determined by the strength of the current passed and its duration of flow. Investigations during recent years have shown that it is important for the current to be sufficiently powerful to allow it to pass through the metal for only an extremely short period of time, in order that the heat generated is restricted to the spot where it is required. The heating of the surrounding material, which is avoided by this means, is not only of no practical value but may also have a most deleterious effect on the quality of the weld, since it may cause oxidation and other undesirable chemical and physical changes.

The method of interrupting the flow of the welding current periodically signifies an important advance in this method of welding, as compared with a non-periodic interruption. In the first place it has led to a marked speeding up of welding, and secondly it has enabled such metals as stainless steels and aluminium alloys to be welded satisfactorily.

In some cases it may be necessary to restrict the passage of the current to a few hundredths of a second, in other words to a few cycles of the alternating current, and it is evident that to give a satisfactory uniform weld a circuit breaker capable of performing this duty must operate in perfect synchronism with the mains supply and permit of such accurate adjustment that the intervals between the opening and closing of the associated circuit can be maintained absolutely constant. With the short times of current flow involved here, a difference of half a period (0.01 second) either way is already sufficient to produce a marked alteration in the amount of heat produced. Furthermore, as the primary current of the transformer is several 100 amps (the secondary current being 1000 to 10000 amps at 3 to 10 volts), it is apparent that a mechanical device is quite impracticable, especially as it would be exposed to the most severe wear.

A more satisfactory and more efficient method for the synchronous opening and closing of the circuit is obtained by means of relay valves. These are gas-filled hot-cathode rectifiers with control grid; the ignition voltage of such valves can be adjusted by means of the grid voltage, as shown by fig. 1, the characteristic for Philips relay valve DCG 5/30. It will be noticed that at positive grid voltages exceeding 12 volts the
ignition voltage is low (<100 volts), whereas in the case for instance of −2 volts grid voltage the valve ignites only at 11000 volts anode voltage. These relay valves render it possible, by means of certain circuits (see below) to close the current for any desirable number of cycles (x = 1, 2, 3, ...) and to open it for any other number of cycles (y = 1, 2, 3, ...), and this sequence x + y to be repeated periodically. The values of x and y can be varied independently of each other within wide limits. The principal advantages of a timing device of this type are:

1. Absence of all moving and revolving parts, no wear or noise;
2. Perfect synchronism with the mains supply;
3. Ready and instantaneous regulation of time intervals x and y;
4. The value of x can be reduced to a single cycle (0.02 second);
5. Uniformity in operation in any setting when once made.

Fig. 2 shows the various circuits making up the timing device, and which consist essentially of the three following:

A. The oscillating circuit;
B. The time-delay circuit;
C. The interrupter circuit;

these circuits are also shown separately and slightly simplified in figs. 3, 7 and 5.

The primary circuit of the welding transformer (T₁, fig. 3) includes the primary winding of a transformer (T₂), whose secondary winding is connected to the cathode and anode of a relay valve (M₁). Transformer T₂ serves for heating the cathode of valve M₁. When the potential difference between the grid and the cathode of M₁ reaches such a value that the valve passes current, transformer T₂ is shorted 1), practically the whole of the mains voltage is applied across the terminals of T₁ and welding takes place. The grid of M₁ is now given a negative potential sufficiently large to prevent ignition of the valve: the secondary circuit of T₂ remains open, and only the weak magnetising current flows through the primary circuit; the welding current is then practically zero. A grid potential of −Vₖ volts (e.g. derived from a battery) is sufficient to prevent ignition of the valve. What potential difference must be applied to the grid between the points 1 and 2 (fig. 3) so that the primary current can flow for a single cycle (x = 1) and be cut off for y cycles (y being integral)? It follows from the above that this is obtained by imparting to the grid a positive potential impulse every (1 + y) cycles, at the instant the anode becomes positive with respect to the cathode. We therefore require a potential of the

1) This applies only for one direction of the secondary current, but for the primary current this has practically the same effect as a complete short-circuit (cf. e.g. P. Lenz, Archiv für Elektrotechnik 27, 497, 1933).
form shown in fig. 4, i.e. an alternating voltage with a fundamental frequency \(1/(1+y)\) times the mains frequency. Such demultiplication of the frequency may be conveniently obtained by means of relaxation oscillations 3), which brings us to the oscillating circuit shown in fig. 5.

A small relay valve (\(M_2\)) of low output is connected in parallel with the condenser \(C_1\), which is slowly charged from a source of direct current through a high resistance \(R_1\) after the circuit is closed by the switch; the anode current of the valve is blocked and only no-load current flows through the primary circuit of \(T_2\). Grid (1) is given a potential causing ignition of the valve; transformer \(T_2\) is shorted and practically the whole of the mains voltage is applied across the welding transformer \(T_1\). This cycle then starts all over again. A free relaxation oscillation of this type has a frequency proportional to \(1/R_1C_1\), although it can be very readily synchronised with a higher or lower harmonic of any other frequency introduced into the system. This is illustrated in fig. 6: anode and condenser voltage with respect to the cathode \(K\) show an exponential trend \((A, C)\). The trend of the critical grid voltage (dotted line \(g\)) has been deduced from this by means of the characteristic, i.e. the grid voltage required for ignition at the anode voltage in question. Actually the grid voltage \(G\) consists of the voltage-drop across \(R_1\) \((V_{R_1})\) with the superimposed A.C. voltage \(V_s\). Ignition takes place the moment the actual grid voltage exceeds the critical one, i.e. at the point of intersection of the curves \(G\) and \(g\). As this point of intersection will always be situated near the peak of \(V_s\), only such conditions will occur at which an integral number \((1, 2, 3 \ldots)\) of cycles of the frequency of the synchronising voltage elapses between two successive ignitions. The frequency of the free relaxation oscillation will therefore adapt itself to that of the adjacent lower harmonic \((1/1, 1/2, 1/3 \ldots)\) of the imposed mains-frequency. It is, for instance, sufficient to apply to the grid circuit a low-voltage 50-cycle alternating current (fig. 5) in order to

\[Fig. 4. \text{Required voltage waveform between terminals 1 and 2 (fig. 3) in order to obtain welding-spots during a single cycle at intervals of } y \text{ cycles.}\]

\[Fig. 5. \text{Oscillating circuit (simplified) (Cf. "A" in fig. 2).}\]

\[\begin{align*}
T_1 &= \text{Welding transformer.} \\
T_2 &= \text{Series-transformer.} \\
T_a &= \text{Filament heating transformer.} \\
M_1 &= \text{Main relay valve.}
\end{align*}\]

\[\begin{align*}
\text{Grid (1) is negative with respect to cathode (2): the anode current of the valve is blocked and only no-load current flows through the primary circuit of } T_2. \text{ Grid (1) is given a potential causing ignition of the valve: transformer } T_2 \text{ is shorted and practically the whole of the mains voltage is applied across the welding transformer } T_1. \text{ This cycle then starts all over again. A free relaxation oscillation of this type has a frequency proportional to } 1/R_1C_1, \text{ although it can be very readily synchronised with a higher or lower harmonic of any other frequency introduced into the system. This is illustrated in fig. 6: anode and condenser voltage with respect to the cathode } K \text{ show an exponential trend } (A, C). \text{ The trend of the critical grid voltage (dotted line } g) \text{ has been deduced from this by means of the characteristic, i.e. the grid voltage required for ignition at the anode voltage in question. Actually the grid voltage } G \text{ consists of the voltage-drop across } R_1 \text{ (} V_{R_1} \text{) with the superimposed A.C. voltage } V_s. \text{ Ignition takes place the moment the actual grid voltage exceeds the critical one, i.e. at the point of intersection of the curves } G \text{ and } g. \text{ As this point of intersection will always be situated near the peak of } V_s, \text{ only such conditions will occur at which an integral number (} 1, 2, 3 \ldots) \text{ of cycles of the frequency of the synchronising voltage elapses between two successive ignitions. The frequency of the free relaxation oscillation will therefore adapt itself to that of the adjacent lower harmonic (} 1/1, 1/2, 1/3 \ldots) \text{ of the imposed mains-frequency. It is, for instance, sufficient to apply to the grid circuit a low-voltage 50-cycle alternating current (fig. 5) in order to}
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\text{limit the possible frequencies of the relaxation oscillations to 50, 25, } 16^{2}/3, 12^{1}/2 \text{ and } 10 \text{ cycles, etc. If to the capacity of } C_1 \text{ values are given at which}
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the free relaxation frequency would be in the neighbourhood of these fractions of the mains frequency, a current impulse will flow through the resistance $r$ (fig. 5) every 2, 3, 4 or more periods of the mains supply. The potential at $r$, combined with the battery voltage $-V_g$, then fluctuates as shown in fig. 4. The condenser $C_3$ and resistance $R_3$ (fig. 5) permit the phase displacement between the mains voltage and the grid potential of $M_2$ to be adjusted in such a way that $M_2$ is ignited exactly at the instant the anode of $M_1$ becomes positive. The phase displacement requires adjustment only once and remains constant.

By connecting terminals 1 and 2 in fig. 5 with terminals 1 and 2 in fig. 3, an arrangement is obtained which allows current to be passed through the associated circuit for one single cycle at intervals of 2, 3, 4 or more cycles. For some purposes this duration of current flow may be too short, and one would like to be able to prolong it as required to 2, 3, 4 or more periods, retaining at the same time a suitable interval with no current-flowing. This can be readily achieved by inserting a time-delay circuit between the circuits $C$ and $A$ in figs. 3 and 5, which will prolong as required the time the positive impulse is applied to the grid of $M_1$. A circuit of this type is shown in fig. 7; it has a condenser $C_2$ in parallel with the resistance $r$ (fig. 5) which is charged the instant the valve $M_2$ becomes ignited and is discharged slowly through the high resistance $R_2$ (a rapid discharge of $C_2$ through $r$ is prevented by the valve $V_2$). By increasing the capacity of $C_2$ (or the resistance $R_2$) the interval during which the grid of $M_1$ remains positive with respect to the cathode can be increased as required, this interval corres-
ponding to the number of cycles \( x \) the welding-current flows. The apparatus thus has two control knobs by means of which the capacities of \( C_1 \) and \( C_2 \) can be varied: With \( C_2 \) \( x \) is adjusted and with \( C_1 \) the whole sequence \( x+y \).

Returning to the complete diagram (fig. 2), which incorporates the individual circuits shown in figs. 3, 5 and 7, it is seen that the batteries in the latter have been replaced by rectifiers (valves \( V_1 \) and \( V_3 \)) which are provided with condensers for smoothing the rectified voltage. The apparatus is protected against the high tension of the transformer \( T_2 \) on the one hand by earthing the cathode of \( M_1 \), and on the other hand by the fuse \( F \) and the rare gas cartridge \( G \) (fig. 2). In the event of a short-circuit between the grid and anode of valve \( M_1 \), the cartridge \( G \) ignites and blows out the fuse \( F \), thus disconnecting the valve from the rest of the circuit.

An apparatus of the type described here is shown in figs. 8 and 9. The controls referred to above are mounted on the front panel. Transformer \( T_2 \) is accommodated in the lower part of the housing, and the relay valves \( M_1 \) and the auxiliary circuits in the top part. A number of oscillograms of the primary current obtained with this apparatus are reproduced in fig. 10; it is seen that there is perfect periodicity in the opening and closing of the circuit in synchronism with the mains supply. These curves also show that a wide variety of settings can be obtained with this apparatus.

The above description brings out the many practical advantages of a relay-valve timing circuit as compared with mechanical devices.

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**Fig. 10. Oscillograms of the primary current: Circuit closed for \( x \) cycles, and opened for \( y \) cycles.**