# United States Patent [19]

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[54] **DEVICE FOR LIMITING THE SHORT-CIRCUIT ENERGY IN ELECTROLYTIC METAL-FORMING APPARATUS**


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[51] **Int. Cl.** ..... **B01k 3/00**, B23p 1/02

[58] **Field of Search** ..... 204/224, 228, 143, 204/228 A; 321/14



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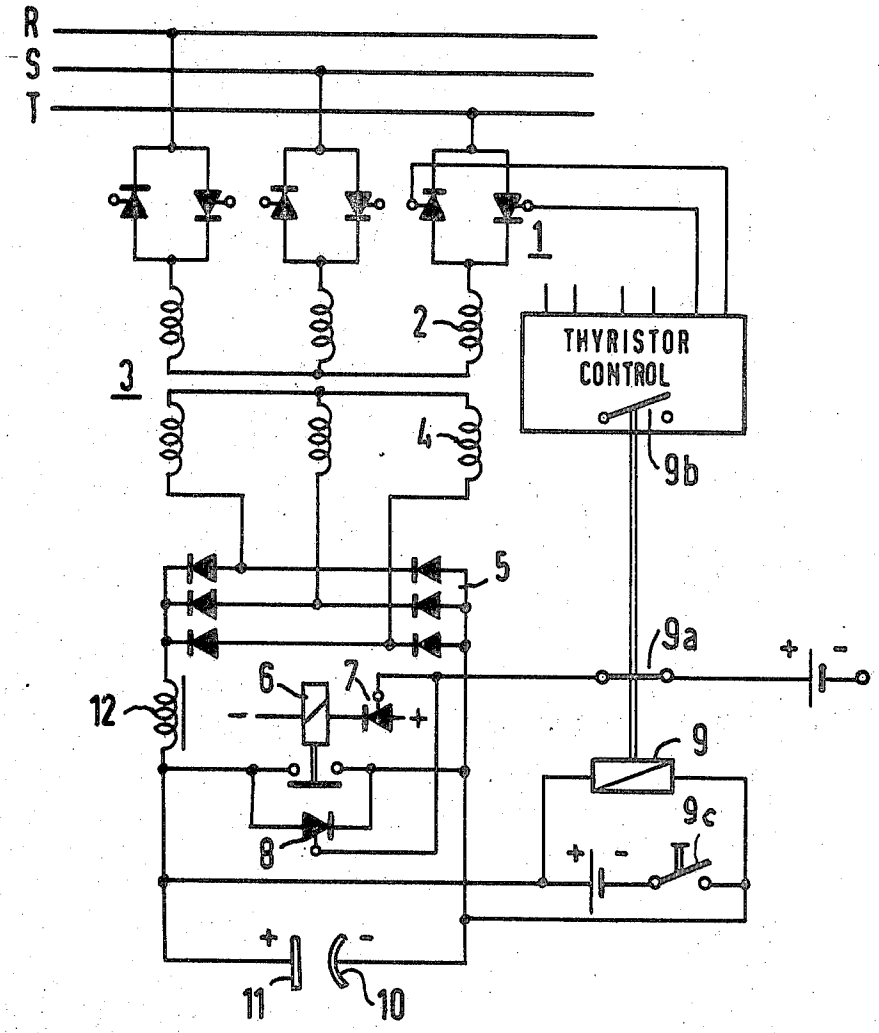
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[57] **ABSTRACT**

A device for limiting the short-circuit current between tool and workpiece of an electrolytic metal-forming machine in which an electrolyte is kept flowing through the gap between the workpiece and a shaped tool whose particular shape is to be imparted in a negative manner upon the workpiece. The tool and workpiece are connected to an alternating-current supply through an alternating-current controller and a rectifier in series with a smoothing reactor. A voltage sensing member is connected across the electrolyte gap between tool and workpiece in order to respond to a slight departure of the gap voltage from the rated operating voltage. When responding, the sensing member causes the alternating-current controller to block the further supply of alternating current and simultaneously releases a normally open power-current switch likewise connected across the electrolyte gap.


**3 Claims, 3 Drawing Figures**



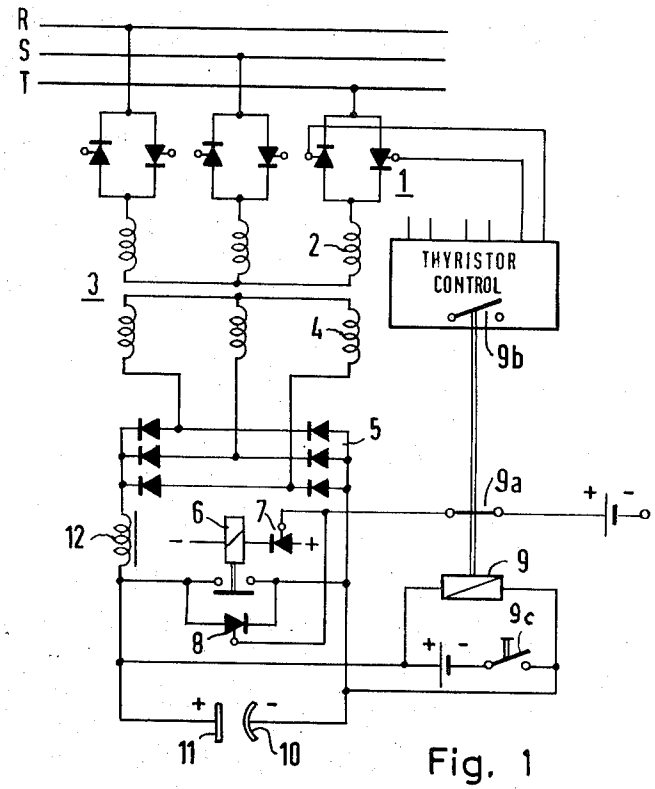



Fig. 1

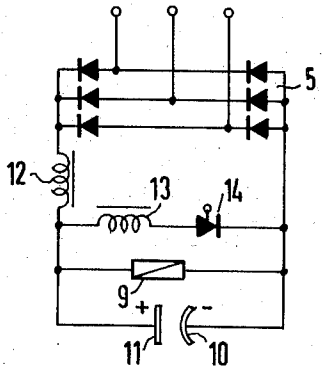



Fig. 2

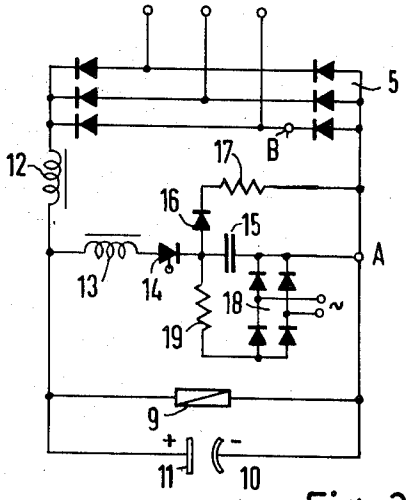



Fig. 3

# DEVICE FOR LIMITING THE SHORT-CIRCUIT ENERGY IN ELECTROLYTIC METAL-FORMING APPARATUS

Our invention relates to a device for limiting the short-circuit energy at the tool and the workpiece in electrolytical machines in which the workpiece, operating as the anode, and the tool, forming the cathode, are energized from an alternating-current line through a multi-phase current controller and through a rectifier arrangement, a smoothing reactor being serially connected in the workpiece-tool circuit.

In electrolytic metal-forming machines, the forming tool and the workpiece to be formed are subjected to a continuous flow of electrolyte liquid as long as the forming operation is being performed. The electrolyte may consist of a common salt (NaCl) solution. The tool and the workpiece are closely spaced, for example, 1/10 mm, from each other. The current flow between the two electrodes, amounting for example to $10^4$ amps at 12 volt electrode voltage, causes metal ions, for example, Fe ions, to be dissolved from the anodically connected workpiece. This effect is in accordance with the equation:

$$Fe^+ + NaCl + H_2O = FeCl + NaOH = H .$$

With a suitable dimensioning, such as the data exemplified above, the negative shape of the workpiece, for example a recess, is thus produced in the workpiece. To prevent the cathodic tool from being soiled, the electrolyte is continuously circulated by pumping and is continuously cleaned at a suitable locality of its circulatory path. The slight spacing between workpiece and tool is required because the workpiece to be formed is to correspond with best feasible accuracy to the negative of the tool configuration and because the electric power to be consumed, being substantially dependent upon the electrode spacing, is to be kept as low as feasible. The reduction in power obtained by reduced electrode spacing is due to the fact that the electrode voltage depends upon the electrode spacing.

It has been proposed to supply such electrolytic equipment with electric power by connecting the workpiece and the tool to a three-phase line through controllable rectifiers interconnected in antiparallel relation to each other in each individual phase. These controllable rectifiers are connected through a transformer and a bridge network of diodes with the electrodes (tool and workpiece) in series with a smoothing reactor to supply the electrodes with controllable direct voltage. The smoothing reactor in this arrangement is necessary because excessive waviness of the rectified current may impair the elimination of material from the workpiece, and also for reducing the current in the event of a short-circuit.

In electrolytic metal-forming machines, an electrical short-circuit occurs rather frequently due to flashover between anode and cathode. This may be caused by contamination of the electrolyte or by air bubbles resulting from local heating of the electrolyte. Even though fuses or means for immediate turn-off of the controlled rectifier units on the primary side of the circuitry may be provided, an appreciable amount of time remains involved in completely extinguishing these controlled rectifiers. For this reason, and also on account of the magnetic energy stored in the transformer and the smoothing reactor, very high short-circuit currents will continue to flow for some additional interval



of time. These high currents impose an excessive load upon the rectifier bridge network and also tend to cause other short-circuit damage, such as short-circuit or pocket marks at the workpiece as well as at the tool. This is extremely disadvantageous, especially in view of the expensive tool required for such purposes, and since a few short-circuits may result in an appreciable imprecision as to dimensions and shape.

It is an object of our invention to avoid such damage and to devise an apparatus which reliably limits the short-circuit energy that may occur at the workpiece and at the tool of electrolytic metal-forming equipment generally of the type described in the foregoing.

To this end, and in accordance with a feature of our invention, we connect parallel to the cathode-anode gap, constituted by the tool and the workpiece respectively of the electrolytic equipment, a voltage-responsive sensing member which is set to respond to a voltage change of slight magnitude relative to the normal, rated operating voltage. We connect this sensing member with a control circuit of a normally open power-current switch likewise connected parallel to the electrolyte gap between tool and workpiece, so that the power switch will close when the voltage sensing member responds to voltage departure. In this manner, the stored magnetic energy is made harmless, as well as any energy further supplied from the power supply up to complete blocking at the primary side of the energizing circuit.

Preferably, the power-current switch is constituted by a mechanical short-circuiting switch controlled by a thyristor. This results in a simple and rugged arrangement. According to another feature, one or more further thyristors are connected parallel to the mechanical power-current switch so that they will initially take care of short-circuit current until the mechanical switch has responded by closing its contact. The thyristor or thyristors may be given relatively small dimensions because they are subjected to a load only for a very short interval of time.

According to a modified way of embodying the invention, a mechanical power switch is eliminated, and the entire power is switched by means of thyristors. In order to reduce the short-circuit power to be taken up by these thyristors, it is preferable to connect them in series with a capacitor tuned to the energy of the smoothing reactor, and to place the connection between capacitor and thyristor upon a voltage potential which in the thyristor forward direction is high relative to the electrode voltage.

The foregoing and further objects, advantages and features of our invention, said features being set forth with particularity in the claims annexed hereto, will be apparent from, and will be described in, the following with reference to embodiments of apparatus according to the invention illustrated by way of example in the accompanying drawings in which:

FIG. 1 is an electric circuit diagram of an electrolytic metal-forming machine equipped with a short-circuit protective device according to the invention;

FIG. 2 is a schematic circuit diagram of a modified system portion, the system being otherwise in accordance with FIG. 1; and

FIG. 3 is a schematic circuit diagram of still another modification, also applicable in conjunction with other components shown in FIG. 1.

The same reference numerals are applied in all illustrations for similar components respectively.

In the system according to FIG. **1**, the primary winding **2** of a transformer **3** is energized from a **50** Hz three-phase line RST through an alternating-current controller constituted by a pair of antiparallel thyristors **1** in each of the three phases. Connected to the secondary windings **4** of the transformer **3** is a bridge network **5** of rectifier diodes whose direct-voltage output terminals are connected through a smoothing reactor **12** to the positive bus attached to the workpiece **11** and to the negative bus leading to the tool **10.** Thus the workpiece constitutes the anode and the tool **10** the cathode of an electrolyte gap which is submerged in a suitable vessel and is constantly traversed by a flow of circulating electrolyte, such as an aqueous solution of NaCl.

A voltage-responsive sensing member **9,** here constituted by a voltage relay **9,** is connected parallel to the electrode gap, that is, between the workpiece **11** or the positive bus and the tool **10** or the negative bus. The relay **9** responds when the electrode voltage drops to a given slight value below the normal operating electrode voltage. A mechanical rapid-action switch **6** rated for power current as may occur under short-circuit conditions, is also connected between the positive and negative buses and consequently parallel to the electrolyte gap between the two electrodes. The contact of switch **6** is normally open and is released to close under control by a thyristor **7** which is normally turned off. One or more thyristors **8** are preferably connected in parallel relation to the contact of the power switch **6.**

The voltage relay **9** is essentially a sensitive measuring relay which is energized and attracts its armature at the normal operating voltage of 12 volts. The relay contact **9***a* is normally open, the relay contact **9***b* normally closed. When the operating voltage drops on account of a short-circuit, the relay **9** will drop off, for example at 11.5 volts (or if desired at **11** volts, for example). This closes the relay contact **9***a* which connects the gate circuits of thyristors **7** and **8** to a positive firing voltage. The thyristors **7** and **8,** therefore, are turned on. Simultaneously, the contact **9***b* opens and interrupts the firing circuit of the thyristors **1** in the alternating-current controller. Details of the thyristor control circuit thus actuated by the contact **9***b* are not illustrated because they are well known in a variety of configurations (for example, SCR-Manual of General Electric Co., Second Edition, 1961, FIG. 8.2). It will be understood that while only one contact **9***b* is illustrated, corresponding contacts may be provided for the gate circuits of the other thyristors. It should further be understood that while the mechanical control of the thyristors by relay contacts is shown for simplicity, the thyristor switching operation may be controlled by means of circuits composed entirely of electronic or solid-state components, this being likewise well known and not essential to the present invention proper.

To permit the system to be set into operation, a manually operable key **9***c* permits applying voltage to the relay **9** during the start-up stage in which the normal operating voltage between the electrodes is not yet established.

In the event of short-circuit conditions, the sensitive relay **9** operates to have the short-circuit current first pass through the thyristor **8** and upon response of the power switch **6,** namely after about 1 msec, through the closed contact of the switch **6.** This consumes the considerable amount of magnetic energy stored in the smoothing reactor **12,** as well as the residual amount of energy still furnished from the power line RST up to the complete extinction of the thyristors **1.** As a result, workpiece and tool are protected from damage.

In the modified embodiment according to FIG. **2,** the entire short-circuit current is taken up by a group of parallel thyristors, of which only one is shown at **14.** A reactor **13** is connected in series with the thyristor group **14** in order to limit the current increase. The relay **9** also controls the blocking of the thyristors **1** on the primary side of the system in the manner illustrated in FIG. **1** and explained above.

In the embodiment according to FIG. **3,** a capacitor **15** is connected in series with a thyristor **14** (or group of thyristors) according to FIG. **2.** The capacitor **15** is dimensioned in accordance with the energy of the smoothing reactor **12** for a given power rating of the system. A relatively high negative auxiliary direct voltage, for example, 200 V, relative to the electrode voltage for example of 20 V, is applied at a circuit point between thyristor **14** and capacitor **15.** This high negative voltage is furnished from the output of a separate rectifier network **18** through a charging resistor **19.** By virtue of the negative counter voltage, the energy stored in the smoothing reactor **12** will more rapidly decay when the thyristor **14** is fired. A diode **16** and a discharge resistor **17** serve to eliminate the voltage of the opposed polarity occurring at the junction point due to oscillations. In the embodiment of FIG. **3,** the high auxiliary voltage is also impressed upon the cathodic tool **10.** If this is to be prevented, the connection of the high auxiliary voltage is to be made not at point A but instead at the locality B in the rectifier network **5.**

The following example illustrates the energy conditions obtaining in the arrangement last mentioned:

Assume that the operating voltage between the electrodes **10** and **11** is 20 V, the operating current $I =$ 3,000 A. and that the reactor **12,** to provide for sufficient smoothing, has an inductivity of $L = 250 \cdot 10^{-6}$ *H.* The magnetic energy stored in the reactor **12** can thus be computed as:

$$1/2\ LI^2 = 1/2 \cdot 250 \cdot 10^{-6} \cdot 9 \cdot 10^6 = 1{,}125\ \text{Wsec},$$

and the electrical energy of the capacitor **15** as:

$$1/2\ CU^2 = 1{,}125\ \text{Wsec}.$$

It follows that the capacitor **15** must be given a capacitance *C* of:

$$C = (1{,}125 \cdot 2)/(200+20)^2 \approx 50 \cdot 10^{-3}\ F.$$

Consequently, if only the short-circuit energy of the smoothing reactor **12** were to be absorbed, a capacitor **15** of $50 \cdot 10^{-3}$ F would be sufficient. The short-circuit energy still passing from the power line through the then conducting thyristor **1** till the end of the voltage halfwave, referring to a maximal current-flow duration of 6 ⅔ msec, is approximately:

$$6.7 \cdot 20 \cdot 3{,}000 = 360\ \text{Wsec}.$$

In order to also absorb this energy, the capacitor **15** must be increased by about 30 percent and hence should be about $65 \cdot 10^{-3}$ F.

The above-described system according to the invention affords a full-automatic operation of electrolytic metal-forming machinery. The rectifier or thyristor

units turned off upon occurrence of each short-circuit can be turned on after a lapse of a given interval of time. If then the short-circuit conditions have vanished, be it due to cooling or because the circulating electrolyte has become sufficiently cleaned, the voltage sensing member will no longer respond and the system will remain switched on. In the event of a persistent short-circuit, indicated by a repeated response of the voltage sensing member, the system is switched off continuously by hand upon observation of instrumentalities or automatically by integrating or counting equipment as known for such purposes.

To those skilled in the art it will be obvious upon a study of this disclosure that our invention permits of various modifications and may be given embodiments other than particularly illustrated and described herein, without departing from the essential features of our invention and within the scope of the claims annexed hereto.

We claim:

1. Device for limiting the short-circuit energy in electrolytic metal-forming apparatus having means for anodically connecting a workpiece, a cathode-forming tool for acting through a flowing electrolyte upon the workpiece, alternating-current supply means, a rectifier, alternating-current control means connecting the input of said rectifier to said supply means, and a smoothing reactor serially connected with said tool and said workpiece anodic connecting means to the output of said rectifier, said device comprising a voltage sensing member connected across the electrolyte gap between said tool and said workpiece connecting means and responsive to a given voltage change which is slight relative to the electrode operating voltage, circuit means connecting said sensing member with said alternating-current control means for blocking said control means to discontinue the supply of alternating current upon response of said sensing member, and normally open power-current switching means connected across said gap between said tool and said workpiece anodic connecting means and having a control circuit connected to said sensing member for causing said switching means to close upon response of said sensing member, said power-current switching means comprising a normally open switch contact and said control circuit being connected in parallel to said switch contact in a manner whereby said control circuit is turned on to conduct short-circuit current while said switch changes from open to closed state of said contact.

2. In a device according to claim 1, said power-current switching means consisting substantially of thyristor means.

3. A device according to claim 2, comprising a capacitor connected in series with said thyristor means and having substantially the same power rating as said reactor, and directvoltage means connected to a circuit point between said capacitor and said thyristor means and having at said point a voltage poled in the forward direction of said thyristor means and highly negative with respect to said electrode operating voltage.

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