

March 19, 1935.

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1,994,953

REGULATING CHOKE COIL

Filed May 28, 1932

3 Sheets-Sheet 1

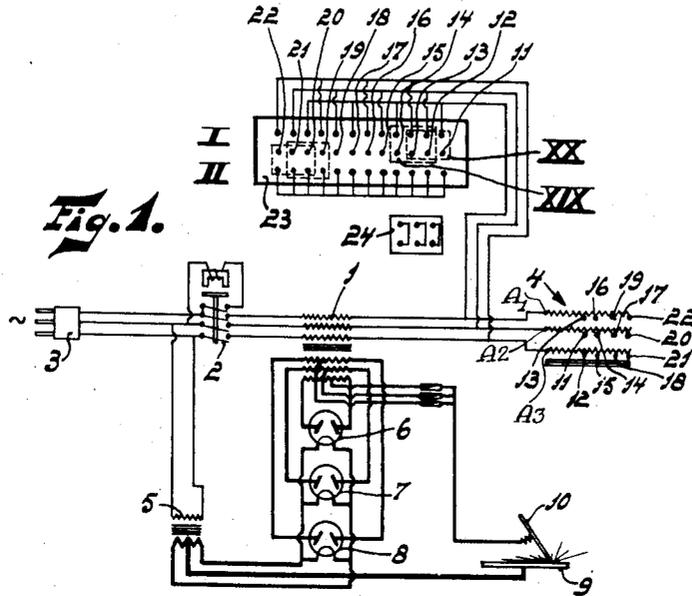


Fig. 1.

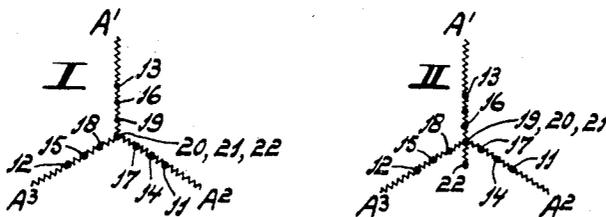
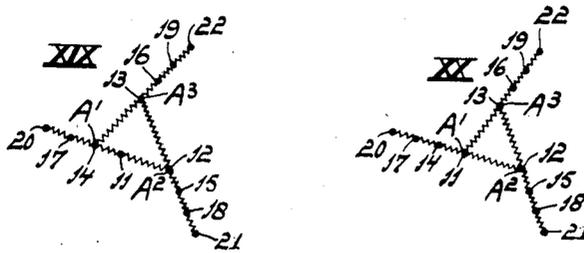


Fig. 2.



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3 Sheets-Sheet 2

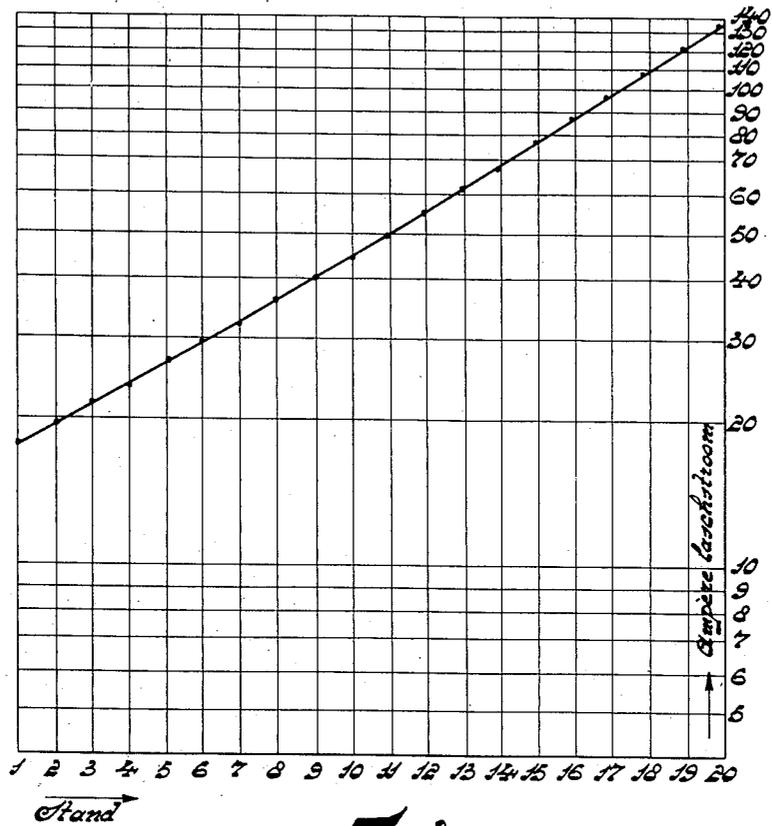


Fig. 3.

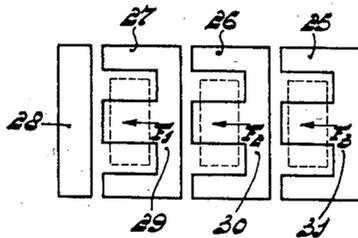


Fig. 4.

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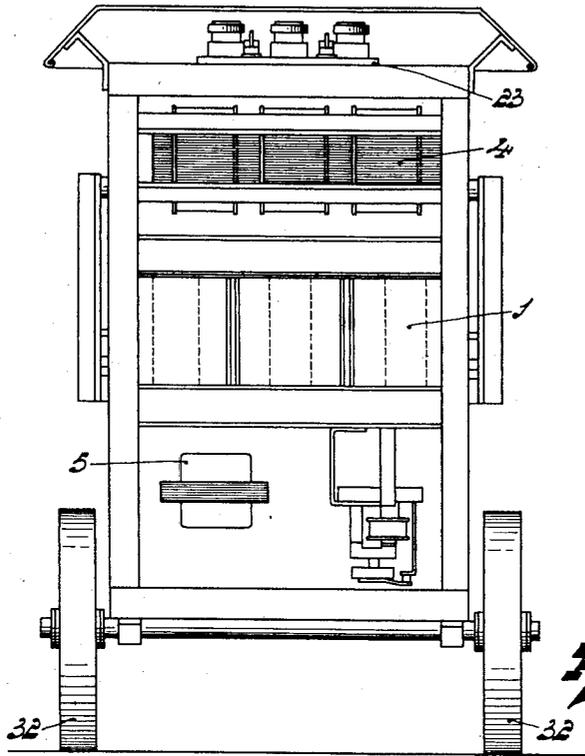
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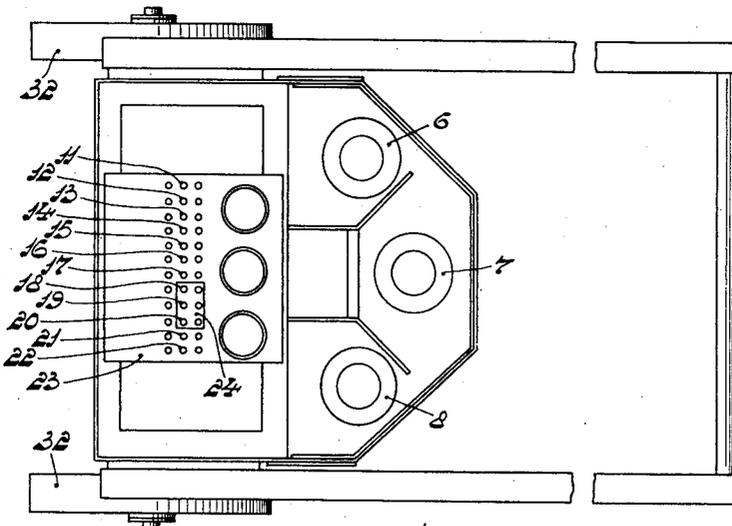
REGULATING CHOKE COIL

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3 Sheets-Sheet 3



**Fig. 6.**



**Fig. 5.**

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# UNITED STATES PATENT OFFICE

1,994,953

## REGULATING CHOKE COIL

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In Germany June 25, 1931

10 Claims. (Cl. 171-242)

This invention relates to adjustable choke coils particularly adapted for controlling the current of a non-rotary welding device fed by polyphase current. In connection with such devices it is known to control or regulate the current by modifying the reactance of a multi-phase choke coil which is inserted in the primary circuit of the welding transformer.

In such known devices a continuous control is obtained by providing the iron core of the choke coil with a variable air gap. The great magnetic forces produced in said devices cause constructional difficulties and to obtain a satisfactory construction is comparatively expensive.

An intermittent regulation may be obtained by the simultaneous and stepwise change of the number of turns of the individual choke-coil phases, by providing these phases with a plurality of taps. However, a sufficiently fine adjustment cannot be obtained with such regulation, unless a large number of taps is provided and a correspondingly complicated switching device used.

The invention has for its purpose to provide a more simple and substantially continuous control.

In the control device according to the invention the choke coil winding comprises in each phase a plurality of taps, the taps being connected (and numbered) in a cyclical order of the phases and in the order of their distances from the starting point of the phase winding to a series of contacts of a switch device by means of which the different taps may be connected to the phase supply conductors or to a star point so as to obtain a series of control stages. In any of the stages three successively numbered taps are either connected to the preceding or succeeding phase supply conductor in order to obtain a polygon connection or are connected to the starpoint so as to obtain a star connection. In this manner, the number of stages obtained with a given number of taps is much larger than obtainable with the known adjustable choke coils, since successive stages are obtained by merely adding or omitting a portion falling between two successive taps of a single winding and furthermore by using the same taps and branches for a series of control stages obtained with star connection and a series of control stages obtained with delta connection. The adjustable choke coil above referred to may be of quite small size and of a simple and cheap construction. In one embodiment of the invention this is obtained by providing in the switch device three series or rows of contacts, each hav-

ing an equal number of contacts, the contacts of the middle row being connected to the taps of the choke coil, the contacts of one outer row being connected in a cyclical order to the phase supply conductors and the contacts of the other outer row being all electrically interconnected. The different connections are obtained by connecting each time a number of successive contacts of the middle row, which number corresponds to that of the phases, to the adjacent contacts of either one of the outside rows.

Preferably the contact points of the switch device consist of contact sleeves, while the connection between these sleeves is effected by means of a contact plug comprising two rows of three, pairwise interconnected, pins.

Circuit connections of the type above referred to, do not properly lend themselves for use with an ordinary multi-phase transformer or with a multi-phase choke coil, since in all or at least in some of the polygon switch positions the number of turns which the different phases have in the circuits is not equal, so that the sum of the magnetic fields of the individual choke coil cores, does not give zero in these cases. In order to nevertheless obtain a compact assembly and a saving in material a three-phase choke coil construction may be advantageously used, which consists of three single-phase shell type choke coils of the usual form, but in which two yokes are omitted and in which one yoke, for instance the lower, of one of the choke coils serves at the same times as the other, for instance the upper yoke of the succeeding choke coil, and in which the coil of the intermediate choke coil is connected oppositely with respect to the outer choke coils.

The invention will be more clearly understood by reference to the accompanying drawings, representing, by way of example, one embodiment thereof.

Fig. 1 is a circuit diagram of a direct current welding device in which the alternating current is rectified by means of gasfilled rectifier tubes and in which a choke coil according to the invention is used.

Fig. 2 is a diagrammatic showing of the connection of the choke-coil winding for some of the control stages.

Fig. 3 is a graphical representation of the welding current as measured in the different positions of the contact plug.

Fig. 4 is a schematic representation of the construction of the iron core of an adjustable choke coil according to the invention.

Fig. 5 is a plan view and Fig. 6 is a side view of an adjustable welding apparatus comprising a regulating choke coil according to the invention.

Referring to Fig. 1 the welding transformer 1 may be connected to the network through a switch 2 and a contact plug 3. This also connects to the network the windings of the regulating choke coil 4, hereafter more fully described. By the insertion of plug 3 a heating transformer 5 is switched on at the same time. The secondary side of the welding transformer has three windings, which by means of center taps form a 6-phase winding. These windings are connected at their ends to the anodes of three full-wave rectifier tubes 6, 7 and 8, whose cathodes are connected across the secondary winding of the heating transformer 5. The middle tap of the secondary winding of transformer 5 is connected to a work-piece 9, and the center taps of the secondary windings of the welding transformer 1 are connected to a welding electrode 10.

The regulating choke coil 4 comprises three phase windings, the starting points or terminals A<sub>1</sub>, A<sub>2</sub> and A<sub>3</sub> of which may be connected to the network through the welding current transformer. Each phase winding of the regulating choke coil is provided with four taps, including the free ends of the windings. These taps are marked by the reference numerals 11—22 in the order of their distance from the starting points or terminals A<sub>1</sub>, A<sub>2</sub>, and A<sub>3</sub> of the respective windings. When going round the three phases always in the same sense the twelve taps are traversed in the order of the numbering. Consequently of the optional three successive taps there is each time one on each phase.

A series of ten star-connected control stages is obtained by interconnecting each time three successively numbered taps so as to form a star point.

A series of ten delta-connected control stages is obtained by connecting each of three successively numbered taps to the beginning of the preceding (or succeeding) phase winding.

The position of the taps may be such that the ten star connected control stages join the ten delta-connected control stages.

The upper portion of Fig. 1 shows how the connections are established in the switch arrangement.

The taps 11—22 are connected to a series of contact sleeves which are shown at the top of the drawings. These sleeves are disposed in an insulating plate 23 and are marked with the reference numerals of the taps to which they are connected.

These contact sleeves just referred to constitute the middle series or row of three series of contact sleeves. For the sake of clarity, the connections between the contact sleeves and the taps are omitted from the drawings.

The twelve contact sleeves of the upper row are connected in groups of three in a cyclical order to the starting points A<sub>1</sub>, A<sub>2</sub> and A<sub>3</sub> of the three phase windings and in such a manner that opposing contact sleeves of the two rows are always connected to different phases.

All of the contact sleeves of the lower row are inter-connected and form the star-point for star-connection.

These contact sleeves cooperate with a contact plug provided with six pairwise inter-connected pins. This plug is separately shown in Fig. 1 and denoted by 24.

This arrangement of the contact sleeves per-

mits the above-referred to connections to be established in a very simple manner. In order to obtain a star-connection each of three succeeding contact sleeves of the intermediate row is connected by means of the plug to the corresponding contact sleeve of the lower row and for obtaining a delta-connection each of them is connected to the corresponding contact sleeve of the upper row.

In the drawings four positions of the plug are indicated in dotted lines by way of example. These four positions correspond to the four connection diagrams marked I, II, XIX, XX of Fig. 2 and give corresponding adjustments of the welding current.

In the position I, the windings of the regulating choke coil are connected in the manner indicated in Fig. 2, on the upper left. In this case the full phase windings A<sub>1</sub>—22, A<sub>2</sub>—20, A<sub>3</sub>—21 are star-connected. The current fed from the welding transformer 1, viz. the welding current, has its minimum value.

When the plug is moved to the right in the position marked "II" so as to engage the succeeding contact sleeve, the full phase-winding A<sub>2</sub>—20 and A<sub>3</sub>—21 remain in the circuit, but from the phase-winding A<sub>1</sub>—22 the portion 22—19 is cut out and only the portion A<sub>1</sub>—19 remains in the circuit; at the top and on the right of Fig. 2 are shown the circuit connections thus obtained. In this position of the switch apparatus, the current is increased compared with position I.

When through successive displacement of the plug to the right so as to engage successive sleeves all of the star-connected stages have been traversed, the plug is returned to the left, but now in the position to interconnect the sleeves of the upper and middle rows for delta-connection. After a number of these stages have been traversed the plug occupies for instance the position XIX, to provide for the delta-connection shown in Fig. 2 at the bottom on the left. If it is desired to still further increase the current, the plug is moved further to the right so as to occupy the position XX thus cutting out the portion 11—14 in the corresponding winding of the regulating choke coil. The connection thus obtained is shown in Fig. 2 at the bottom on the right. This position corresponds to the last stage and gives the maximum current strength obtainable. Fig. 3 shows a curve corresponding to the actually measured welding currents for the successive control stages, the numbers of amperes of the welding current obtained at the secondary side of the welding transformer being plotted in a logarithmic scale. The fact that the curve is substantially a straight line, shows that the percentage of current increase with the transition from any stage to the succeeding stage is the same throughout.

Thus the device makes it possible to obtain twenty different stages or adjustments in the welding current strength and requires only four taps per phase, including the free end terminals of the phases. At the same time the maximum current carried by the conductors connecting the choke coil to the switch apparatus and by the pins and sleeves of the switching apparatus amounts only to

$$\frac{1}{\sqrt{3}}$$

times the maximum network current, so that the switch device may have a small size.

The transition from one connection to another

may be readily effected under tension, provided the welding operation be interrupted at this moment, in which case the current to be interrupted by the switching apparatus amounts only to

$$\frac{1}{\sqrt{3}}$$

times the no-load current of the transformer.

The regulating apparatus is small, simple and cheap and the control in twenty stages allows a practically continuous control. Of course, the number of stages may be increased in a simple manner.

In case the taps of the different phase windings are provided at equal distances from the starting point, in certain stages the different phases will be symmetrically loaded, while in other stages will be asymmetrically loaded, as appears from Fig. 2. However, the last stage will be a symmetrical one so that the maximum power of the welding apparatus is not decreased by the control device.

In one embodiment of the invention the distance between the starting points of the windings and the successive taps increase toward the free end terminals of the phase windings. Such a division has the advantage that the maximum load difference between the individual phases is materially smaller than in the case of an equal spacing of the taps.

As has already been stated it is not advisable to use the regulating arrangement referred to with a normal three-phase transformer or a three-phase choke coil. In fact, since these have only three cores which are magnetically interconnected at the upper and at the lower end by means of yokes, the sum of the fields is zero. Consequently the sum of the electro-motive forces induced by the fields in the three windings is not zero for those connections in which the number of turns are unequal. Due to this, unduly large compensating currents would occur in the asymmetrical delta-connections. This also holds good for the multi-phase constructions having a phase number other than three.

The arrangement according to the invention may be also used if instead of a combined  $m$ -phase core,  $m$  separate single phase cores are provided. However, the combined core has the advantage of a saving in materials and of greater compactness. This advantage is also partially lost when the multi-phase construction is provided with an additional unwound core by which the yokes are magnetically interconnected. However, the construction in which the compensating current is suppressed has other drawbacks.

The same important saving in material obtained with the standard three-leg construction can, however, also be obtained by means of a construction of the multi-phase core as shown in Fig. 4, which construction has several further practical advantages.

The device illustrated may be regarded as consisting of an assembly of three single-phase shell type cores 25, 26 and 27 in which two yokes are omitted. When denoting the magnetic fields of the three cores by  $F_1$ ,  $F_2$ , and  $F_3$ , the yokes 28, 29, 30 and 31 carry the following fields:

$$\frac{1}{2}F_1, \frac{1}{2}(F_2 - F_1), \frac{1}{2}(F_3 - F_2), -\frac{1}{2}F_3$$

The fields  $F_1$ ,  $F_2$ , and  $F_3$  are assumed to be positive in the directions indicated by arrows in the drawings. Should the three coils be wound and connected in the same sense, each of the two middle yokes would in accordance with the above

terms, carry a field having a value which is approximately

$$\sqrt{3}$$

times that of the field of the end yokes. However, when the coil of the middle winding of the three single-phase windings is oppositely connected, instead of the usual relation existing between the core fields namely:

$$F_1 + F_2 + F_3 = 0$$

the relation will be

$$F_1 - F_2 + F_3 = 0 \text{ or } F_2 = F_1 + F_3$$

When inserting the so found value of  $F_2$  in the above terms for the yoke fields, the latter become

$$\frac{1}{2}F_1; \frac{1}{2}F_3; -\frac{1}{2}F_1; -\frac{1}{2}F_3$$

From this it appears that in this case the four yoke fields are equal. Consequently the two middle yokes need not be thicker than the terminal yokes. Thus with this construction the amount of material required is practically the same as that required for the normal combined three-phase construction. Furthermore the above arrangement has the following advantages:

1. The mutual inductance due to the leakage fields are practically zero. Consequently, the troublesome effect due to unequal mutual inductances is absent, whereas this is quite pronounced in the case of a standard three-legged choke coil and results in unequal loading of the rectifying valves, which drawback also manifests itself even when the number of turns on each of the three cores is the same.

2. The air gap of each choke coil core may be adjusted separately, in contradistinction to the three-leg construction, thus making it possible to compensate for differences which may exist for some reasons between the three phases.

3. The same type of stamps and punches may be used as for single-phase choke coils.

4. Instead of clamping the yokes between angle bars the side cores are clamped between brass strips. For this purpose the bolt apertures already normally provided in the core sheets may be used. When using common strips for the three choke coils they are assembled so as to form a unit. The strips must be provided with oblong apertures so that the air gaps may be adjusted. There is no danger of the brass strips being heated by Foucault currents as may be the case with angle bars.

5. The core sheets need not be wound into the coils but the coils may be slipped over previously formed cores.

Figs. 5 and 6 show the arrangement of the regulating choke coil 4 in a welding apparatus comprising wheels.

In Fig. 5 the rectifier tubes 6, 7 and 8 are shown as disposed in a separate space. Furthermore this figure shows the plate 23 together with the contact sleeves and the plug 24 in plan view.

Fig. 6 shows the switch device arranged centrally above the choke coil 4 so that the twelve connecting wires are as short as possible while the assembly remains clear.

The regulating device is mounted on the top of the casing, thus at a readily accessible and properly illuminated place. A hinged cover may be provided above this regulating device.

A ventilator (not shown) may serve for cooling the rectifying valves, and may be placed at the bottom of the case, whereby it also cools the choke coil and other parts of the apparatus.

Of course, the invention is not limited to the forms of construction described and illustrated; for instance it is possible to replace the lower row of contact sleeves, shown in Fig. 1, by a tripolar 5 plug whose pins are electrically interconnected, and which plug may be inserted in the contact sleeves of the middle row for those regulating stages which require star-connection.

It will be appreciated that the regulating device 10 may also be equipped with single-phase choke coils. In this case, however, the advantages resulting from the combined construction are not obtained.

What I claim is:—

15 1. A control device for the control of a poly-phase current comprising an adjustable choke-coil to regulate said current, said choke-coil having a plurality of phase windings, and each winding having a plurality of taps, a conductor 20 for each phase and connected to one end of its respective phase winding, a switching device having a series of contacts, the taps of said windings being connected to said contacts in a cyclical order of the phases and in the order of their distance 25 from the starting point of their respective phase, said switching device comprising means to connect successive taps, one of each phase, to the preceding or succeeding phase conductor to obtain a polygon connection of said phases.

30 2. A control device for the control of a three-phase current comprising an adjustable choke coil to regulate said current, said choke coil having three phase windings each having a plurality of taps, a conductor for each phase and connected 35 to one end of its respective phase winding, a switching device having a series of contacts, the taps of said windings being connected to said contacts in a cyclical order of the phases and in the order of their distance from the starting point 40 of their respective phase winding, said switching device comprising means to connect three successive taps to the preceding or succeeding phase conductor to obtain a polygon connection of said phase windings.

45 3. A control device for the control of three-phase current comprising an adjustable choke coil to regulate said current, said choke coil having three phase windings, each phase winding having a plurality of taps, a switching device having a series of contacts, the taps of said windings being 50 connected to said contacts in a cyclical order of the phases and in the order of their distances from the starting point of their respective phase, said switching device comprising means to connect three successive taps to a common point, to 55 obtain a star connection of said phase windings.

4. A control device for controlling three-phase current comprising an adjustable choke coil to regulate said current, said choke coil having three 60 phase windings, each phase winding having a plurality of taps, a supply conductor for each phase and connected to one end of its respective phase winding, a switching apparatus comprising a series of contacts, the taps of said windings being 65 connected to said contacts in a cyclical order of the phases and in the order of their distance from the starting point of their respective phase winding, said switching device comprising means to alternatively connect three successive taps to the 70 preceding or succeeding phase supply conductor to obtain a polygon connection of said phase windings and to connect three successive taps to a common point to obtain a star connection of said windings.

75 5. A control device for the control of a poly-

phase current comprising, a choke coil to regulate said current, said choke coil having a plurality of phase windings and each phase winding having a plurality of taps, a supply conductor for each phase and connected to one end of its respective phase winding, a switching apparatus 5 having a series of contacts connected to the taps of said windings in a cyclical order of the phases and in the order of the distance of the taps from the starting point of their respective phase wind- 10 ings, said switching device having a second series of contacts connected in a cyclical order to the phase supply conductors, the numbers of the contacts of each series being equal to the total number of taps, and means to interconnect the 15 contacts of the two series to connect three successive taps of the phase windings to the phase supply conductors to obtain a polygon connection of said phases.

6. A control device for the control of three- 20 phase current comprising, an adjustable choke coil to regulate said current, a supply conductor for each phase and connected to one end of its respective phase winding, said choke coil having three phase windings, the starting point of each 25 phase winding being connected to one of said phase supply conductors, each phase winding having a plurality of taps, a switching device having a series of contacts, the taps of said windings being connected to said contacts in a cycli- 30 cal order of the phases and in the order of their distance from the starting point of their respective phase winding, and a second series of contacts on said switching device connected in cycli- 35 cal order to said phase supply conductors, and means to connect three successive taps to the phase supply conductor so that the taps are connected to different supply conductors as are the starting point of their respective phase-winding.

7. A control device for the control of three- 40 phase current comprising an adjustable choke coil to regulate said current, said choke coil having three phase windings and each having a plurality of taps, a supply conductor for each phase and connected to one end of its respective 45 phase winding, a switching device having a series of contacts the number of which equals the total number of taps, said taps being connected to said contacts in a cyclical order of the phases and the order of the distance of the taps from 50 the starting point of their respective windings, a second series of contacts connected in a cyclical order to the phase supply conductors, a third series of electrically interconnected contacts, and means to alternatively connect three successive 55 contacts of the intermediate series with the three phase supply conductors to obtain a polygon connection of said phase-windings and to connect them with said third series of contacts to obtain a star connection of said phase-windings. 60

8. A control device for the control of polyphase current comprising an adjustable choke coil to regulate said current, said choke-coil having a plurality of phase windings and each phase winding having a plurality of taps, a switching device having three series of contacts, each series 65 having a number of contacts equal to the total number of taps, one series of contacts being fixedly connected to the taps, and a switching member to alternatively connect one tap contact of each 70 phase with the corresponding contact of the second series to obtain a polygon connection and with the corresponding contact of the third series to obtain a star connection.

9. A control device for the control of polyphase 75

current comprising an adjustable choke coil to regulate said current and having a plurality of phase windings, a supply conductor for each phase and connected to one end of its respective phase winding, said phase windings being connected with their starting point to one of said phase supply conductors, each phase winding having a plurality of taps, a switching device having three rows of contact sleeves, the contact sleeves of the intermediate row being fixedly connected with the taps of said windings in a cyclical order of the phases and in order of the distance of the taps from the starting point of their respective phase, one outer row of contact sleeves being connected in a cyclical order to the phase supply conductors and the other outer row of contact sleeves being electrically interconnected, and a movable contact plug having pairs of contact pins the number of which equals the number of phases and so disposed as to be adapted to engage opposing contact sleeves of the middle row and either one of the outer rows to alternatively es-

tablish a polygon connection and a star connection of the choke-coil windings.

10. A control device for the control of three-phase current comprising a choke-coil having three-phase windings, and a conductor for each phase and connected to one end of its respective phase winding, each phase winding having a plurality of taps and being connected with its starting point to one of said conductors, and a switching device adapted to provide a plurality of polygon connections of said phases, the number of which is equal to the number of phases multiplied by the number of taps less two, and to provide a plurality of star connections of said phases, the number of which is equal to the number of phases multiplied by the number of taps, minus two, the transition from successive connections causing a substantially uniform increase of the current, so that the change of the current through the whole range of control is substantially linear.

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