No. 644,553. Patented Feb. 27, 1900.

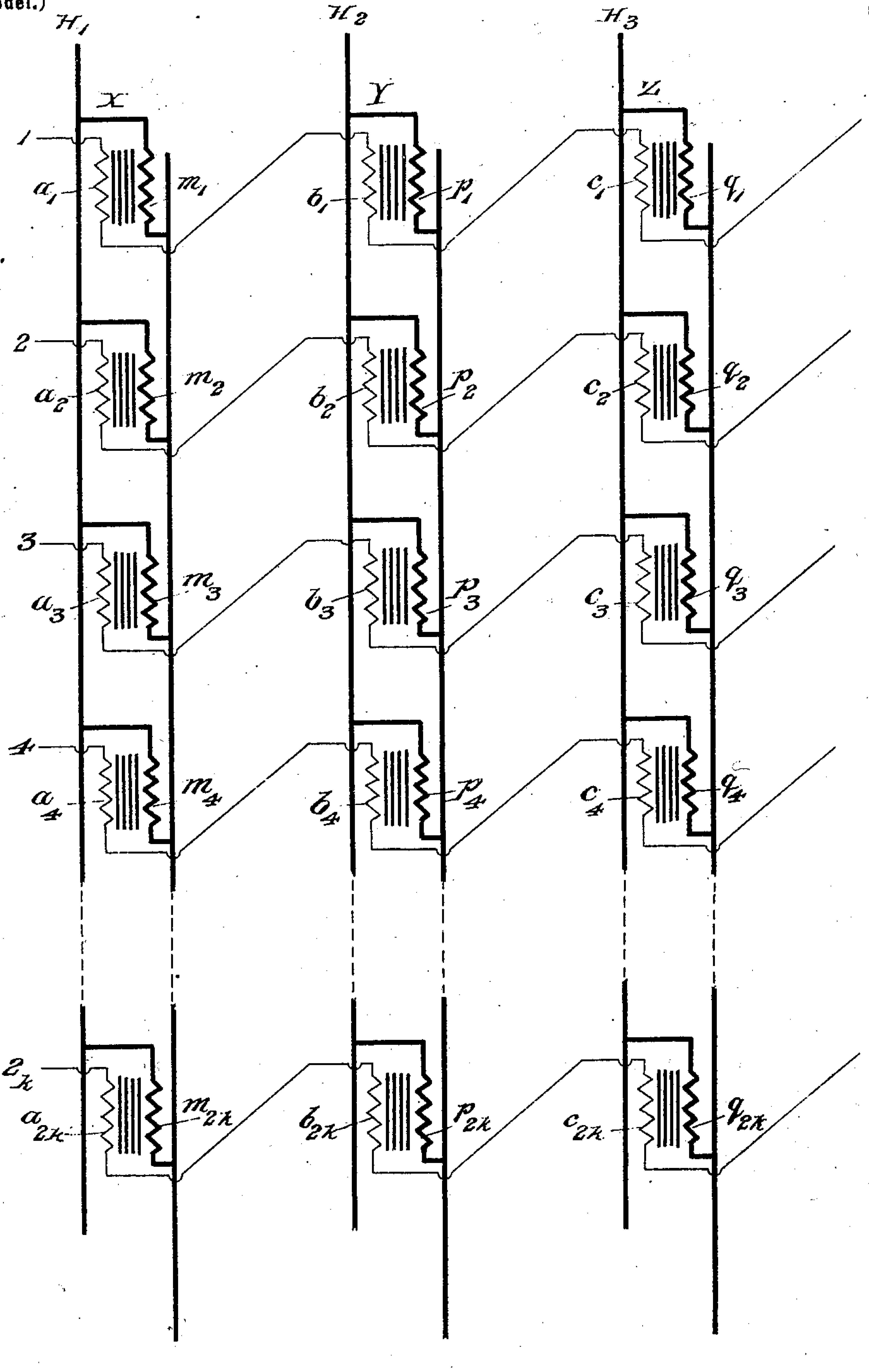
M. HUTIN & M. LEBLANC.

APPARATUS FOR CONVERTING ALTERNATING INTO CONTINUOUS CURRENTS, AND VICE VERSA.

(Application filed June 19, 1899.)

(No Model.) 6 Sheets—Sheet 1.

Fig. 1.



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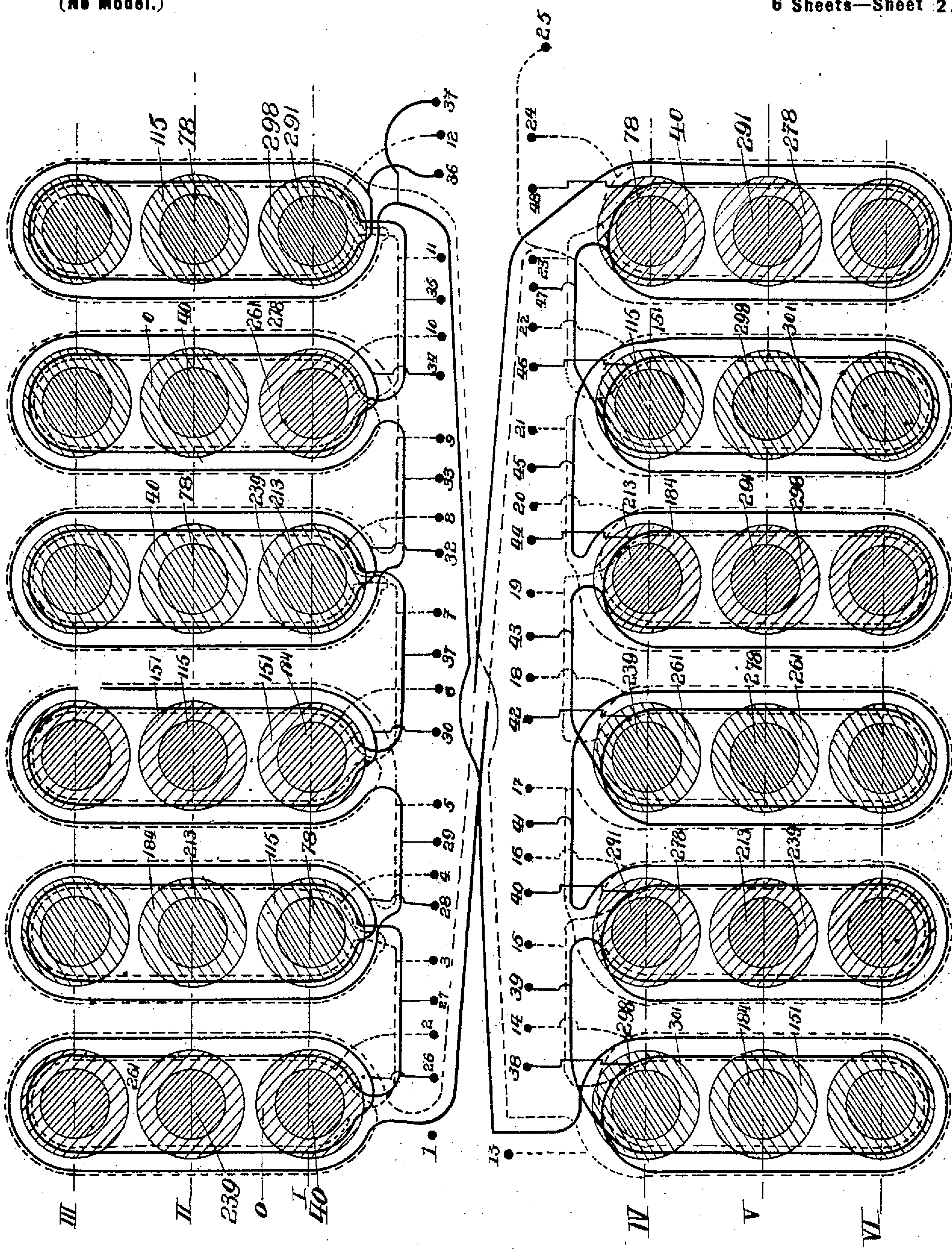

Fig. 2

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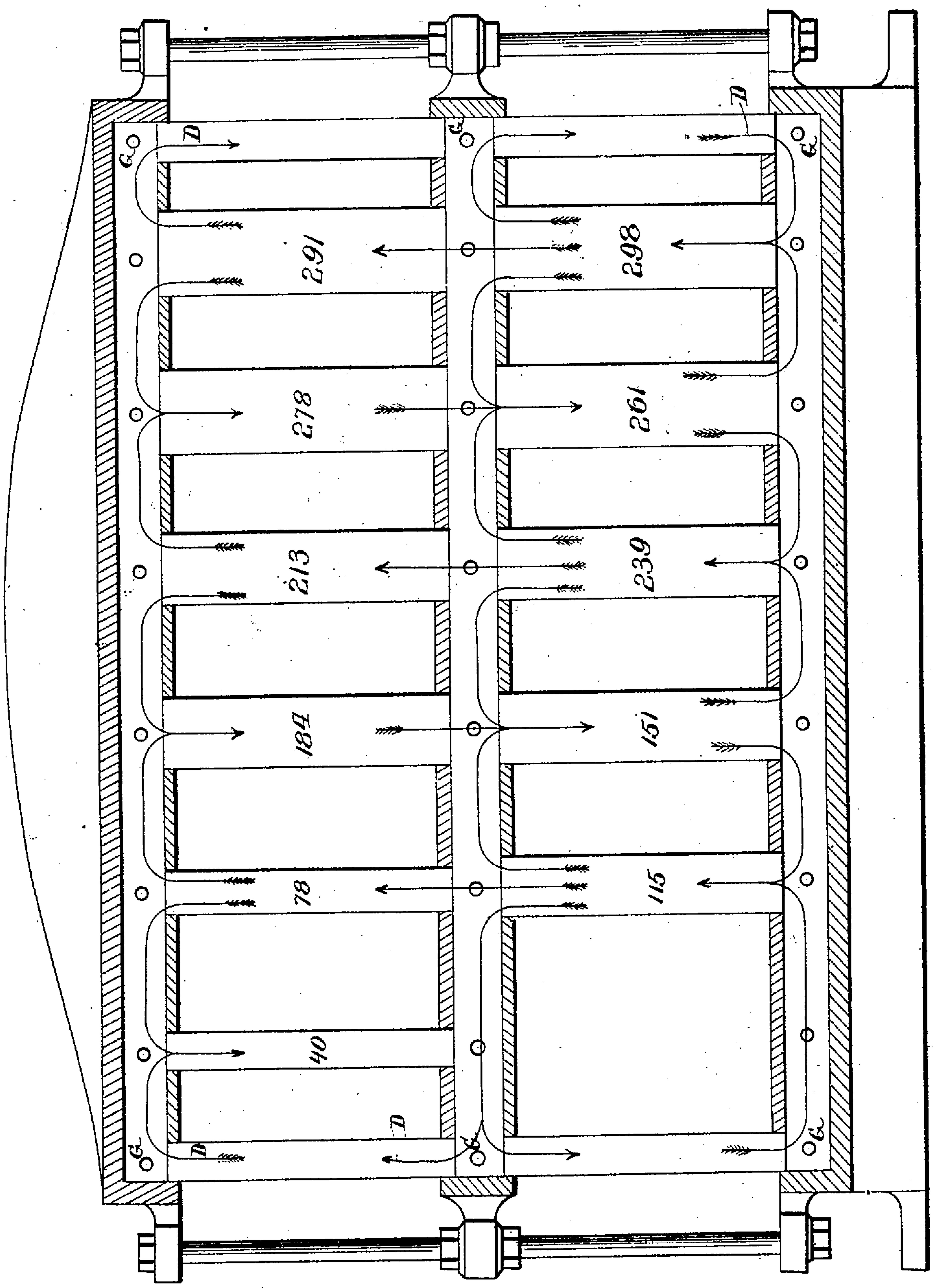
(No Model.) 6 Sheets—Sheet 3.

Fig. 3



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(No Model.) 6 Sheets—Sheet 4.

Fig. 7.

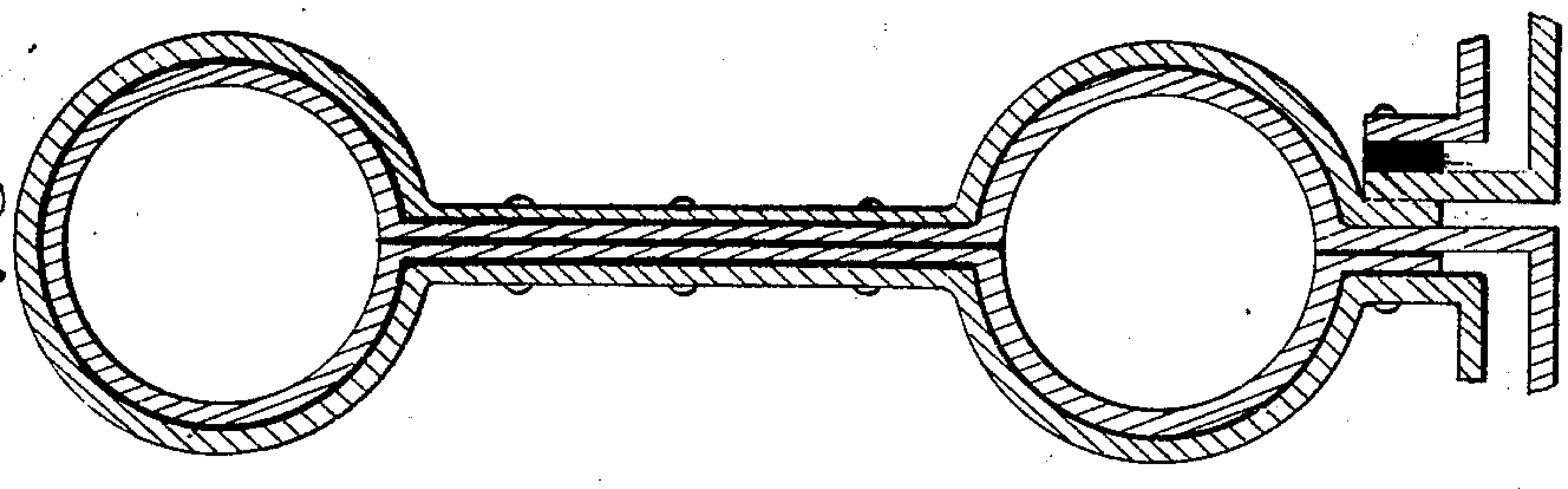


Fig. 6.

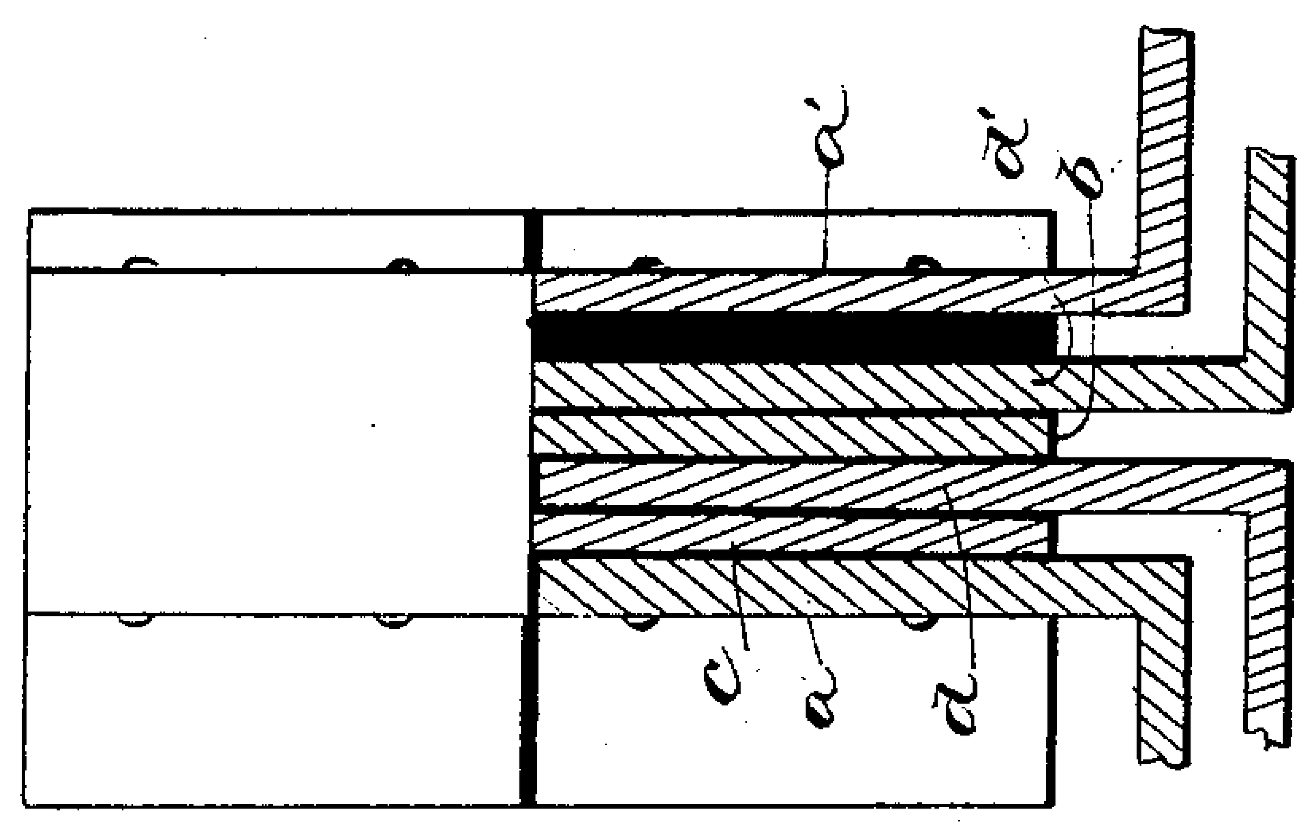


Fig. 5.

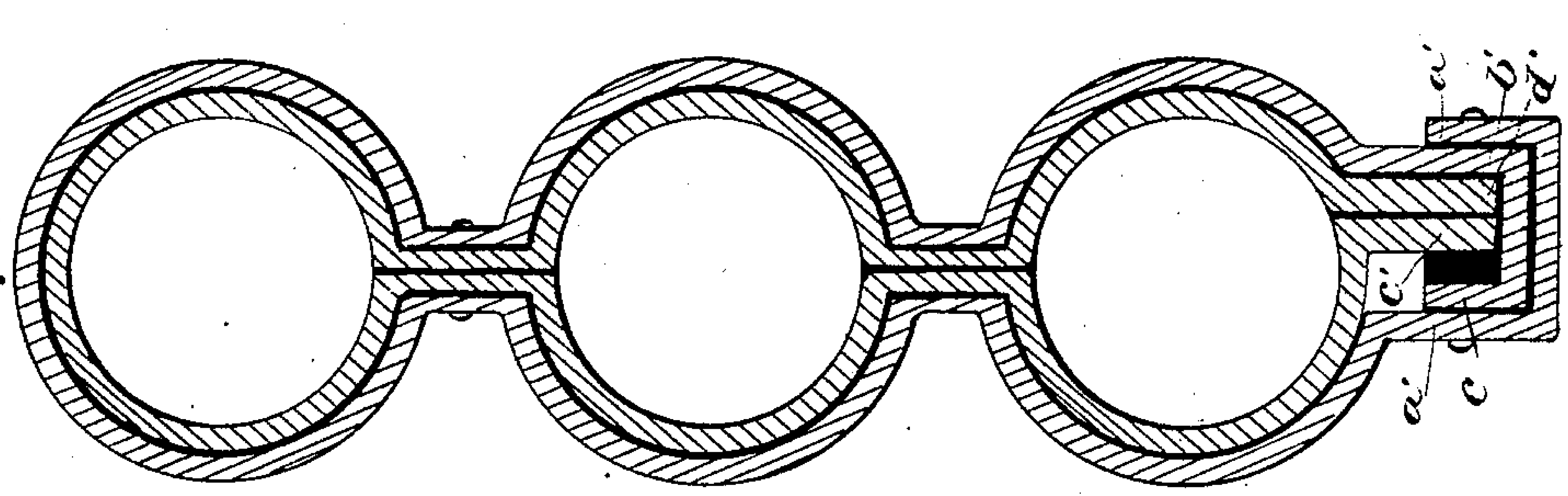
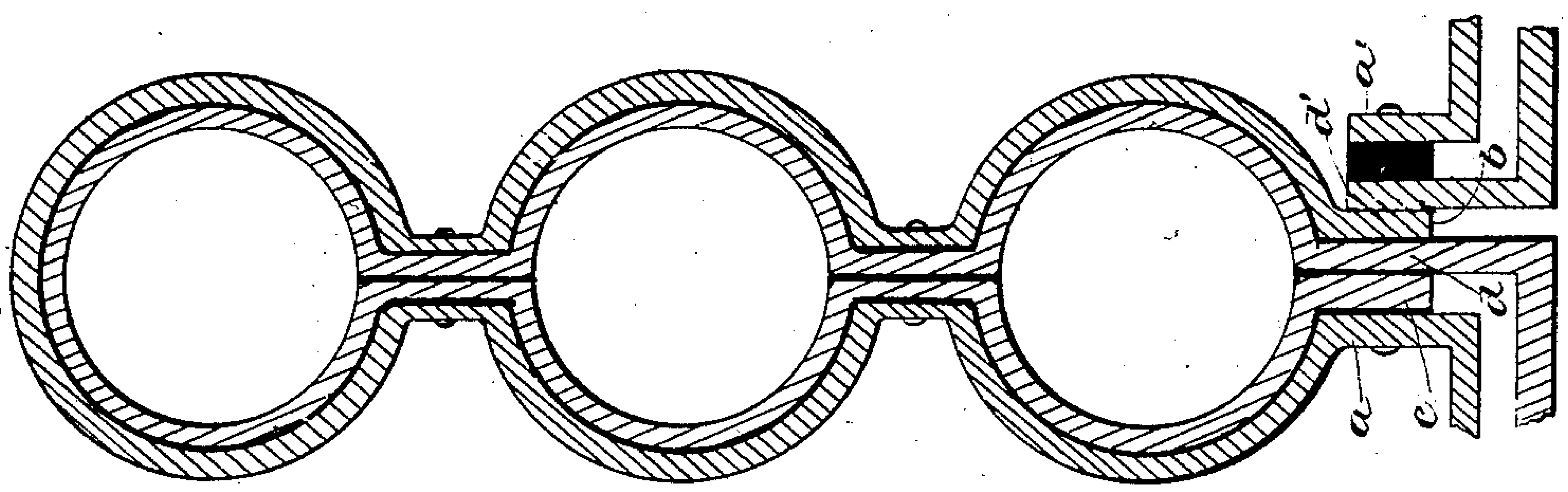


Fig. 4.



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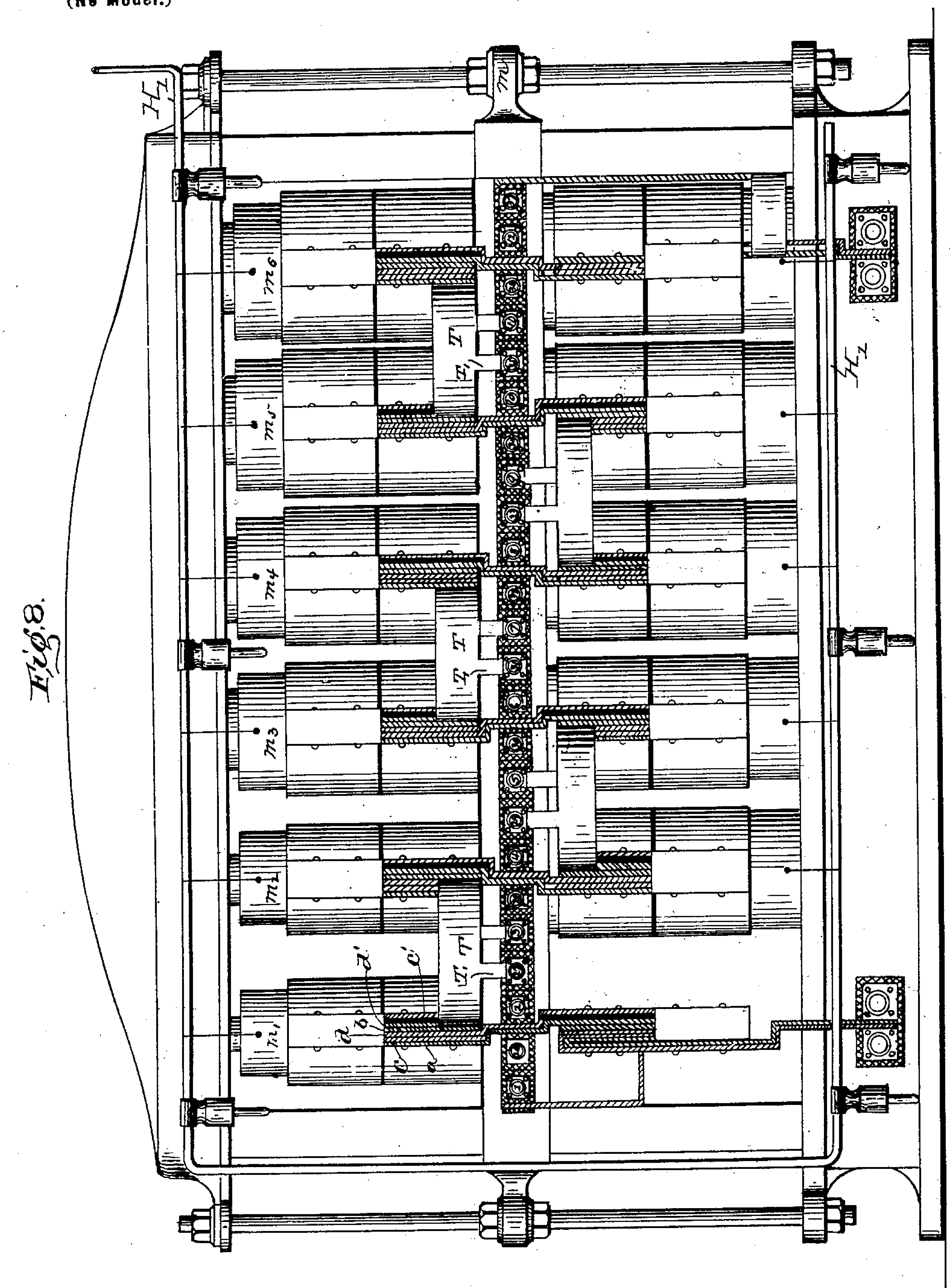
(No Model.) 6 Sheets—Sheet 5.



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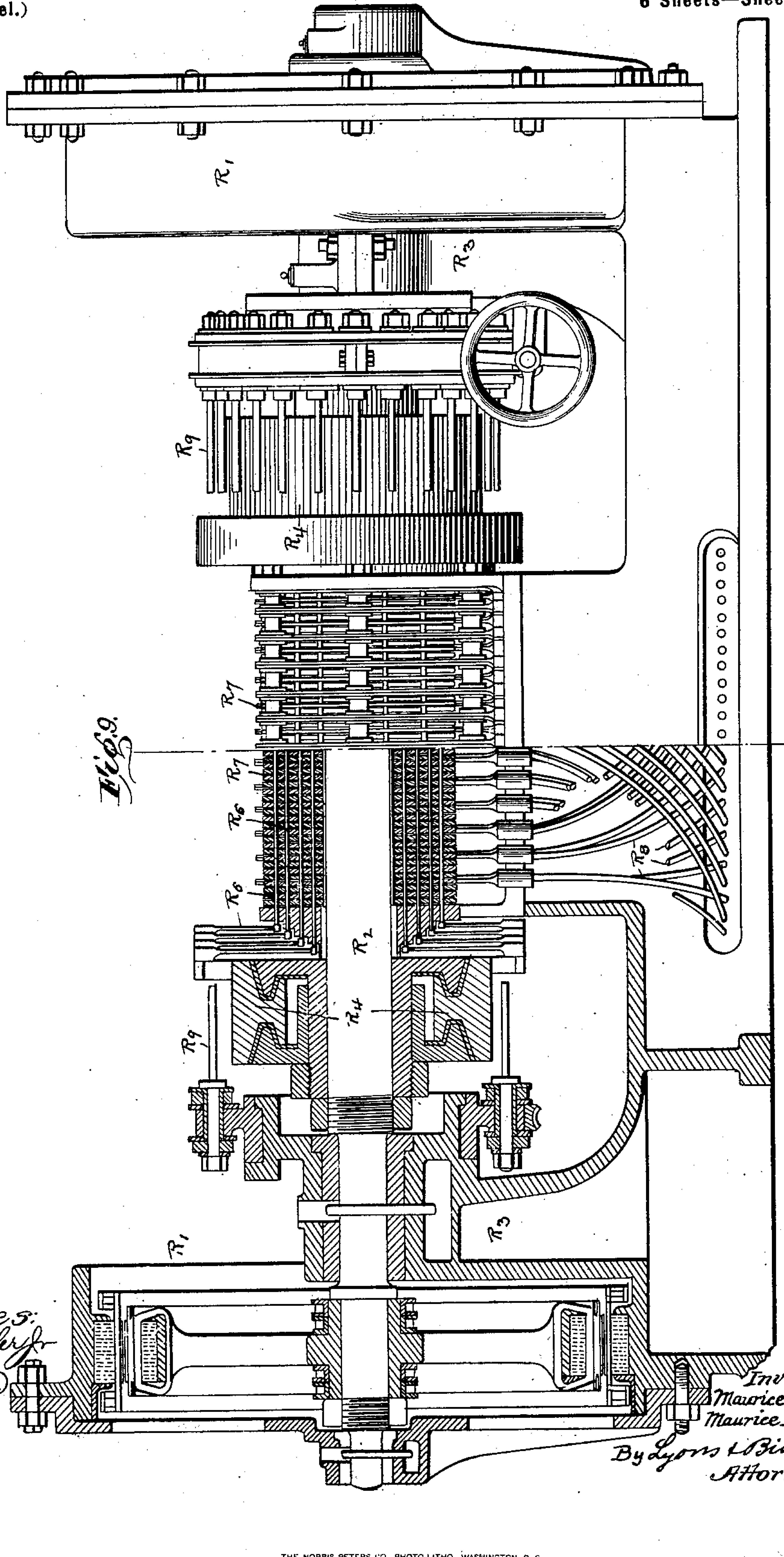

Fig. 9.

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UNITED STATES PATENT OFFICE.

MAURICE HUTIN AND MAURICE LEBLANC, OF PARIS, FRANCE.

APPARATUS FOR CONVERTING ALTERNATING INTO CONTINUOUS CURRENTS, AND VICE VERSA.

SPECIFICATION forming part of Letters Patent No. 644,553, dated February 27, 1900.

Application filed June 19, 1899. Serial No. 721,049. (No model.)

To all whom it may concern:

Be it known that we, MAURICE HUTIN and MAURICE LEBLANC, citizens of the Republic of France, and residents of Paris, France, have invented certain new and useful Improvements in Converting Alternating Currents into Continuous Currents, and vice versa, of which the following is a specification.

In United States Letters Patent granted to us on December 1, 1896, No. 572,510, we have described a method of and an apparatus for transmitting electrical energy, the principal feature of which is the conversion of alternating currents into currents of one direction, generally spoken of as "straight" currents, and the conversion of straight currents into alternating currents. In either case the alternating currents may be monophase or polyphase and of any tension, and the straight currents may also be of any tension. An apparatus for carrying out the process above indicated may in its entirety be designated as a "rectifying-transformer." A study of Patent No. 572,510 shows that such a rectifying-transformer consists of two principal parts—namely, a transformer for transforming a monophase or a polyphase current of any desired number of phases into polyphase electromotive forces of a greater number of phases and a collector or commutator for transforming these polyphase electromotive forces into continuous or straight currents, and conversely. The transformer carries n primary circuits subject to the action of n alternating electromotive forces of the same effective strength, but successively dephased by $\frac{1}{n}$ of a period. In other words, the number of primary circuits is equal to the number of phases of the alternating or polyphase current to be transformed. The transformer furthermore carries $2k$ secondary circuits, which are the seat of $2k$ electromotive forces of the same effective strength, but successively dephased by $\frac{1}{2k}$ of a period. These $2k$ secondary circuits are connected between themselves like the consecutive sections of the armature of a continuous-current machine divided into $2k$ section. This means that there are as many secondary currents on the transformer as there are phases of the secondary polyphase electromotive forces to be generated. In other words, if we assume that the primary circuit to be transformed is polyphase of order n and that the secondary electromotive forces into which the primary circuit is to be transformed are polyphase of order $2k$, a study of the patent shows that the number of primary circuits in the transformer is n and the number of secondary circuits of the transformer is $2k$. The collector of such a rectifying-transformer has $2k$ contacts. The different contacts are connected either directly or through the intervention of rings and brushes to the junction-wires of the $2k$ secondary circuits, just as the contacts of the commutator of a continuous-current machine are connected to the junction-wires of the consecutive sections of its armature. We repeat that all this appears from even a casual study of our Patent No. 572,510. Under these conditions it is apparent that the $2k$ secondary electromotive forces may be utilized for the production of a polyphase current of the order $2k$ by merely suppressing the commutator or collector. If, on the other hand, the frequency of the alternating current which one wishes to transform is equal to a and if a synchronous motor impresses upon the commutator a velocity of a turns per second, one may by utilizing the commutator take a continuous current from any exterior circuit branched upon its brushes. If there is no magnetic leakage in the transformation, the phenomena of commutation will be the same as those which would be produced, under equal conditions of electrical output, in transforming into a continuous-current dynamo the polyphase-current alternator which feeds the rectifying-transformer and in dividing for this purpose its armature into $2k$ identical sections. In reality, however, the coefficient or self-induction of each of the sections of the machine thus obtained should be augmented by a supplementary coefficient representing the magnetic leakage of each secondary circuit of the transformer at the same time that the resistance of each of these sections is augmented by that of a secondary circuit. This shows at once that it is necessary to devise transformers having the smallest amount of magnetic leakage. In the apparatus of this type which is described in our patent above referred to the number of magnetic cores and of primary circuits of the transformer is equal to the order of the primary polyphase currents which one wishes to transform, and is thus necessarily reduced. Thus there are three cores and three primary circuits in case a triphase current is to be transformed and four in case a quadruphase current is to be transformed. One is thus led to construct an apparatus of great power with a small number of large elements, in which case the magnetic leakage is considerable.

It is therefore the object of the present invention to devise a new arrangement in which the transformer has a large number of elements of small dimensions in which the sum total of magnetic leakage will be small and commutation correspondingly easy. For the sake of convenience we shall divide this specification into a number of parts, each dealing with a separate portion of the description, which will make ready reference to a desired portion of the description more ready.

In the drawings, Figure 1 shows a network of a triphase primary circuit and $2k$ secondary circuits into which it is to be transformed. Fig. 2 shows a diagram of the magnetic cores of the transformer and of the secondary circuits which surround them, the primary circuits being suppressed. Fig. 3 shows the magnetic frame of the transformer. Figs. 4, 5, 6, and 7 show the secondary circuits thereon. Fig. 8 shows a side elevation of the transformer, some of the secondary circuits being shown in section; and Fig. 9 shows, partly in section and partly in side elevation, a collector adapted to transform the $2k$ secondary currents obtained from the transformer into continuous or straight currents.

Let us suppose that we have at our disposal three electromotive forces H_1 H_2 H_3 of the same effective strength, but of which the variations present phase differences equal to a third of the period. We may then put—

(1)
$$H_1 = H \sin. 2\pi \alpha t,$$
$$H_2 = H \sin. 2\pi (\alpha t + \tfrac{1}{3}),$$
$$H_3 = H \sin. 2\pi (\alpha t + \tfrac{2}{3}).$$

We have now to arrange the parts in such a manner as to produce in the $2k$ secondary circuits $2k$ electromotive forces of the same effective strength, but successively dephased by $\frac{1}{2k}$ of a period, such that we may put—

(2)
$$h = h \sin. 2\pi \alpha t,$$
$$h_2 = h \sin. 2\pi \left(\alpha t + \frac{1}{2k}\right),$$
to
$$h_{2k} = h \sin. 2\pi \left(\alpha t + \frac{2k-1}{2k}\right).$$

As is plain from Fig. 1, each secondary circuit is composed of three distinct bobbins a b c, mounted in series, each bobbin having a constant number of coils v. They surround, one each, the magnetic cores X Y Z. These cores are also covered by primary circuits m p q in the three sources of electromotive force H_1 H_2 H_3. We fix the number of coils of these primary circuits in such a manner that if we designate by e_1 e_2 e_3, the electromotive forces developed in each turn surrounding the core X, the core Y, and the core Z, one may put

(3)
$$e_1 = \Sigma \sin. 2\pi \beta . \sin. 2\pi \alpha t,$$
$$e_2 = \Sigma \sin. 2\pi (\beta + \tfrac{1}{3}). \sin. 2\pi (\alpha t + \tfrac{1}{3}),$$
$$e_3 = \Sigma \sin. 2\pi (\beta + \tfrac{2}{3}). \sin. 2\pi (\alpha t + \tfrac{2}{3}),$$

where Σ and β designate two constants. Under these conditions the electromotive force e, which is developed in the secondary current under consideration, will be expressed by

(4)
$$e = v(e_1 + e_2 + e_3) = v \Sigma \left\{ \begin{array}{l} \sin. 2\pi \alpha t . \sin. 2\pi \beta \\ + \sin. 2\pi (\alpha t + \tfrac{1}{3}). \sin. 2\pi (\beta + \tfrac{1}{3}) \\ + \sin. 2\pi (\alpha t + \tfrac{2}{3}). \sin. 2\pi (\beta + \tfrac{2}{3}). \end{array} \right.$$

Now a simple trigonometric transformation gives us

(5)
$$\text{Sin. } 2\pi \alpha t . \sin. 2\pi \beta = \tfrac{1}{2} [\cos. 2\pi (\alpha t - \beta) - \cos. 2\pi (\alpha t + \beta)].$$
$$\text{Sin. } 2\pi (\alpha t + \tfrac{1}{3}). \sin. 2\pi (\beta + \tfrac{1}{3}) = \tfrac{1}{2} [\cos. 2\pi (\alpha t - \beta) - \cos. 2\pi (\alpha t + \beta + \tfrac{2}{3})].$$
$$\text{Sin. } 2\pi (\alpha t + \tfrac{2}{3}). \sin. 2\pi (\beta + \tfrac{2}{3}) = \tfrac{1}{2} [\cos. 2\pi (\alpha t - \beta) - \cos. 2\pi (\alpha t + \beta + \tfrac{4}{3})].$$
$$\text{Cos. } 2\pi (\alpha t + \beta) + \cos. 2\pi (\alpha t + \beta + \tfrac{2}{3}) + \cos. 2\pi (\alpha t + \beta + \tfrac{4}{3}) = 0,$$

from which we deduce

(6)
$$e = \tfrac{3}{2} v \Sigma \cos. 2\pi (\alpha t - \beta)$$

as the expression for the electromotive force in the secondary circuits. If in passing from one secondary circuit to the next we vary β successively by quantities equal to $\frac{1}{2k}$, these $2k$ circuits will be the seat of electromotive forces of the same effective strength, but successively dephased by $\frac{1}{2k}$ of a period. We now determine the number of turns N_1 N_2 N_3 to be given to the different primary circuits which act upon the bobbins of the secondary circuits.

We designate by φ_1 φ_2 φ_3 the maximum values of the fluxes developed in the cores X Y Z. We then have

(7)
$$e_1 = 2\pi \alpha \varphi_1 \sin. 2\pi \alpha t,$$
$$e_2 = 2\pi \alpha \varphi_2 \sin. 2\pi (\alpha t + \tfrac{1}{3}),$$
$$e_3 = 2\pi \alpha \varphi_3 \sin. 2\pi (\alpha t + \tfrac{2}{3}).$$

We also make

(8)
$$2\pi \alpha \varphi_1 N_1 = H,$$
$$2\pi \alpha \varphi_2 N_2 = H,$$
$$2\pi \alpha \varphi_3 N_3 = H.$$

We obtain from the preceding equations 3, 7, and 8, after having eliminated the quantities $e_1\ e_2\ e_3$ and $\varphi_1\ \varphi_2\ \varphi_3$,

$$(9)\qquad N_1=\frac{H}{\Sigma \sin. 2\pi\beta},$$

$$N_2=\frac{H}{\Sigma \sin. 2\pi(\beta+\frac{1}{3})},$$

$$N_3=\frac{H}{\Sigma \sin. 2\pi(\beta+\frac{2}{3})}.$$

If now

$$(10)\qquad \text{Sin. } 2\pi\beta=0,$$

or

$$\text{Sin. } 2\pi(\beta+\tfrac{1}{3})=0,$$

or

$$\text{Sin. } 2\pi(\beta+\tfrac{2}{3})=0,$$

one would have to give to the corresponding bobbin an infinite number of turns; but since the secondary bobbin which accompanies it is the seat of a zero electromotive force, as appears, for instance, from equation 3, we simply suppress this bobbin, its magnetic core, and the primary bobbin which excites it. From this we see that each secondary circuit surrounds three distinct magnetic cores X Y Z, each supplied with an especial primary circuit. The maximum intensity of the fluxes developed in these three cores as we pass from the core X to the core Y and then to the core Z will vary according to a sinusoidal law. This appears, for instance, from the set of equations 7.

If one consider all the cores the primary circuits of which are supplied from the same source of electromotive force, the intensities of the fluxes which are there developed will also vary according to a sinusoidal law, as appears, for instance, from equations 8 and 9 by varying β. It will therefore be necessary to vary the sections of these cores in proportion to the intensities of the fluxes of which they are the seat. We may remark, besides, that the secondary circuit of order n will always be the seat of an electromotive force equal to but of opposite sign with that of the circuit of order $n+k$. This appears from equation 6, since in passing from one secondary circuit to another secondary circuit the quantity β varies by $\frac{1}{2k}$—that is to say, in order to get the electromotive forces for all of the $2k$ secondary circuits there will be $2k$ equations like the equation (6), but with the quantity β replaced by $\frac{1}{2k}, \frac{2}{2k}, \frac{3}{2k}$, &c. In the secondary circuit of order n the quantity β will be represented by $\frac{n}{2k}$. In the secondary circuit of order $n+k$ the quantity β will be represented by $\frac{n+k}{2k}$. We note further that there is a constant multiplier 2π. The difference between the two quantities just noted when multiplied by 2π will therefore be π, which means that the cosines are equal in amount but opposite in sign. It will therefore be possible to make the same magnetic core react upon two secondary circuits by merely winding one in one direction and the other in the other direction. In this manner it will merely be necessary to have $3k$ distinct magnetic cores instead of $6k$ magnetic cores for exciting the $2k$ secondary circuits with a triphase system of primary circuits.

In that which precedes we have assumed a triphase primary current which was to be transformed into a secondary current having $2k$ phases. The same method, however, may readily be extended to a polyphase current of order p. One would then make p distinct magnetic cores react upon each secondary circuit-developing in each coil surrounding a magnetic core the following electromotive forces:

$$(11)\qquad e_1=\Sigma \sin. 2\pi\beta . \sin. 2\pi\alpha t,$$

$$e_2=\Sigma \sin. 2\pi\left(\beta+\frac{1}{p}\right). \sin. 2\pi\left(\alpha t+\frac{1}{p}\right),$$

to

$$e_p=\Sigma \sin. 2\pi\left(\beta+\frac{p-1}{p}\right). \sin. 2\pi\left(\alpha t+\frac{p-1}{p}\right).$$

The quantity β would be varied by $\frac{1}{2k}$ each time that one passed from one secondary circuit to the next.

Practical application of the invention.—It is obvious that the different magnetic cores which enter into the construction of a transformer such as we have above described in the general case may be grouped among themselves in an almost infinite variety of ways; but to fix ideas it will be necessary to describe some one arrangement, and this we proceed to do, although it is to be understood that it is done solely by way of example. We consider an apparatus in which triphase primary currents are to be transformed into forty-eight-phase secondary currents—that is to say, in which the quantity $2k$ is equal to forty-eight. We shall assume that the tension of the primary current is six thousand volts and that the frequency of this current is fifty, and we further assume that the apparatus, through the intervention of a commutator, is to deliver a continuous current of sixteen hundred amperes under a tension of two hundred and fifty volts. We proceed first to describe the section of the magnetic cores; second, the mode of grouping the cores; third, the character of the primary circuits; and, fourth, the character of the secondary circuits. We shall conclude by briefly describing the commutator or rectifier.

The magnetic cores.—As there are forty-eight secondary circuits and the primary currents are triphase, we should have three times forty-eight, or one hundred and forty-four, magnetic cores; but by winding two secondary circuits in opposite directions on a single core one core may take the place of two, and the total number of cores may thus be reduced to seventy-two. There will be twenty-four of these cores in one primary circuit of the triphase system, twenty-four cores in the second primary circuit of this system, and twenty-four cores in the third circuit of this triphase system. It will, manifestly, only be necessary to consider any one set of twenty-four of these cores. If we designate by S_1 S_2 to S_{24} the section of these cores in square centimeters the above equations will show us that it will be proper to give them the following values:

$S_1 = 0$	$S_7 = 213$	$S_{13} = 301$	$S_{19} = 213$
$S_2 = 40$	$S_8 = 239$	$S_{14} = 298$	$S_{20} = 184$
$S_3 = 78$	$S_9 = 261$	$S_{15} = 291$	$S_{21} = 151$
$S_4 = 115$	$S_{10} = 278$	$S_{16} = 278$	$S_{22} = 115$
$S_5 = 151$	$S_{11} = 291$	$S_{17} = 261$	$S_{23} = 78$
$S_6 = 184$	$S_{12} = 298$	$S_{18} = 239$	$S_{24} = 40$

A calculation not necessary here to recite shows that the maximum value of the electromotive force developed in each secondary circuit will be equal to 17.65 volts. The maximum specific inductions in each of the magnetic cores will be made equal to six thousand.

Mode of grouping the cores.—If we bear in mind that a commutator of the kind shown in Fig. 9 is necessary when the secondary currents are to be commuted into a straight current it will be natural to arrange our cores on opposite sides of this commutator. We shall thus, in order to diminish the length of the connecting-wires, dispose half of the cores on one side of the commutator or rectifier and the other half of the magnetic cores on the other side. We shall also, in order to avoid mutual induction between the primary circuits branched upon different sources of electromotive force, connect magnetically those cores between themselves which are the seat of variations of flux of the same phase—that is to say, we shall only connect those cores among themselves the primary circuits of which are all in the same lead or branch of the triphase primary current. Finally, in order to reduce the length of the system of cores with reference to their height, we shall mount the cores in two stories, one above the other. This means that of the seventy-two cores thirty-six will be on one side of the rectifier or commutator and thirty-six will be on the other side thereof. Of the thirty-six cores on a given side of the commutator eighteen will be in the upper story and eighteen will be in the lower story. Twelve of these thirty-six cores will be acted on by the branch H_1 of the primary circuit, twelve will be acted on by the branch H_2 of the primary circuit, and twelve will be acted on by the primary branch H_3 of the primary circuit. The thirty-six cores on the opposite side of the commutator will also be arranged in three groups of twelve each acted on respectively by the three leads H_1 H_2 H_3 of the primary circuit. All this will become more clear by examining, for instance, Figs. 2 and 8 of the drawings. In Fig. 2 the cores of the upper story are represented by the smaller circles and the cores of the lower story are represented by the larger circles concentric with the smaller circles. In reality the rows I and IV are to be considered as part and parcel of the same row, since both the cores of the upper and lower stories in rows I and IV are acted upon by the same branch—say the branch H_1 of the triphase primary circuit. So the rows II and V may be considered as part of one and the same row acted upon by the primary circuit H_2, and the same remark applies to the rows III and VI, which are acted upon by the primary circuit H_3. On the other hand, the sets of three cores each perpendicular to the rows just referred to are surrounded by one and the same secondary circuits. Take, for instance, the three cores of the upper story in the upper left-hand corner of Fig. 2 running parallel with the signature-line of the sheet. These three cores are surrounded by two secondary circuits, one wound in one direction (indicated in full lines) and the other wound in the other direction, (indicated in dotted lines.) Such three cores would correspond to the three cores X Y Z of Fig. 1, since each of the cores is acted upon by the same secondary circuit. It will be remembered from what has been said in the preceding portion of the specification that the cores of order n may exercise the functions of cores of order $n + k$ by merely winding the secondaries thereon in opposite directions. So, too, the three cores in the upper left-hand corner of Fig. 2 below those just mentioned, which are represented by larger circles and are in the lower story, are each surrounded by two secondary circuits, one wound in one direction, being shown in full lines, and the other wound in the other direction, being shown by dotted lines.

If we turn now to Fig. 8, which is a side elevation, we find six cores in the upper story and six cores in the lower story. The magnetic framework corresponding to Fig. 8 is shown in Fig. 3. The structure of Fig. 8 or Fig. 3 represents the line of twelve cores. (Shown along the line 1 in Fig. 2.) There are then six in all of the magnetic structures similar to that shown in Fig. 3, three on one side and three on the other side of the rectifier.

From what has just been said a clear idea should be obtained of the construction of the transformer, which is indicated diagrammatically in Fig. 2 and one-sixth of which is shown in Fig. 8. Coming more into detail we note that there are numbers affixed to the cores in Fig. 3

and also to the circles representing the cores in Fig. 2, which numbers show the sections of these cores in square centimeters and which numbers agree with those given in the system of equations 12. We further call attention to the fact that some of the circles in Fig. 2 have hachures in one direction, and other sets of circles have hachures in the other direction. This means that the primary circuits which are to be wound on the cores represented by the circles, which primary circuits are not indicated in Fig. 2, are to be wound in one direction or the other according to the direction of the hachures. In concluding this portion of our description we note that the cores in Fig. 3 are shown as connected by yokes and by exterior cores D D, through which the fluxes developed in the cores are closed.

Instead of reducing to a minimum the sections of the yokes and of the exterior cores D D we have supposed that the fluxes develop in the cores of each column go in one direction in the columns of even order and in the other direction in the columns of odd order. The direction of the fluxes is represented by arrows in Fig. 3. In this manner we have to pass through the yokes and exterior cores only the difference and not the sum of fluxes, by means of which we are permitted to much reduce their section and the losses due to hysteresis, of which they are the seat.

Primary circuits.—One of the primary circuits H_1 is shown in Fig. 8 conveying current to the primary bobbins m_1 m_2 m_3, &c., and current being taken therefrom at the point m. As will be readily understood, these parts will be properly insulated, as is indicated in the drawings. In order to avoid confusion, the primary circuits have not been indicated in Fig. 2. As appears from the equation 8 above, the number of turns in a primary circuit vary inversely with the sections of the cores which they surround. As the different cores have twelve different sections, we should have primary circuits having twelve different numbers of turns. Again in our construction the number of ampere turns developed by each secondary circuit is made the same, and each primary coil develops a number of ampere turns very nearly equal to and of a sign opposite to that developed by the secondary coil which surrounds it. The intensity of the current of each primary circuit will therefore be inversely proportional to its number of turns. It will therefore be necessary to have the section of the conductor vary as we pass from one circuit to the next.

The following table gives the number of turns of a primary circuit surrounding the core of a given section, the diameter of the wire that it is necessary to employ, and the number of such circuits that the apparatus contains:

Sections of the core.	Number of turns of primary circuit.	Diameter of the wire.	Number of like circuits in the apparatus.
*Centimeters.*²		*Millimeters.*	
40	11,352	0.7	6
78	5,736	0.9	6
115	3,900	1.1	6
151	2,976	1.2	6
184	2,436	1.4	6
213	2,100	1.5	6
239	1,872	1.6	6
261	1,716	1.6	6
278	1,614	1.7	6
291	1,536	1.7	6
298	1,500	1.7	6
301	1,488	1.7	3

Secondary circuits.—Referring again to Fig. 2, we find that the secondary circuits surround the cores in groups of three, perpendicular to the lines I and IV, respectively. As has before been noted, there are two secondary circuits upon the cores of the upper story and two secondary circuits upon the cores of the lower story. Considering the two secondary circuits upon the cores of the upper story we find that one circuit (represented in full lines) is wound in one direction and the other circuit (represented by dotted lines) is wound in the other direction. Similarly the two circuits upon the cores of the lower story are wound, the one in one direction and the other in the other direction. These secondary circuits are connected among themselves in a manner which is fully and clearly shown in Fig. 2, and the extremities of the secondary circuits around each group of three cores each are connected with binding posts or terminals 1 2 3 4, &c., as shown. It will be unnecessary to go into any detailed description of these connections of the secondary circuits among themselves, as this will fully appear from an inspection of the diagram.

Each secondary circuit consists of one turn of a heavy band of copper. This is fully indicated in Figs. 4, 5, 6, and 7. Fig. 4, for instance, shows two secondary circuits, one within the other, and each insulated from the other. The terminals of these strips of copper have been lettered *a b c d a′ b′ c′ d′*. The type of terminal shown in Fig. 4 or Fig. 5 is to be used in accordance with the requirements.

Wherever there is a gap in the series of cores—that is, wherever the cross-section of a core is zero—the strips of copper are bent, as shown, in the central portion of Fig. 7, so as to lie against each other and to inclose no magnetic flux.

By referring to Fig. 8 it will be seen that the secondary currents in the upper story are connected among themselves by copper strips T, each having a tag or terminal T_1, running to the central row of terminals 27 3 29 8, &c., in the figure. It will also be seen that the upper secondary circuits are connected with the lower secondary circuits by copper strips connected in turn to other of the terminals

2 26 4 28, &c. It will be merely necessary to call attention to the fact that the connections which are effected by the lateral and vertical copper strips between the adjacent secondaries in the same story or between superimposed secondaries in different stories are effected in accordance with the scheme of the diagram of Fig. 2.

The apparatus thus far described is, in effect, the transformer for transforming a triphase current into a current of forty-eight phases. In order to transform such a current of forty-eight phases into a continuous or straight current, we make use of the rectifier or commutator shown in Fig. 9, which is similar to that shown in our prior patent. There is a synchronous motor R′ at each end of the rectifier which serves to rotate a shaft R^2, mounted in stationary bearings R^3. Upon this shaft is mounted commutators R^4, having forty-eight sections connected by means of the wires R^6 to the rings R^7. Upon these rings R^7 slide stationary contacts leading to the wires R^8. As there are forty-eight rings R^7, there are forty-eight wires R^8, twenty-four of which are mounted on one side of the rectifier and are connected with the terminals of the secondary circuits 1 26 2 27, &c., in Fig. 2, the other twenty-four wires being connected to the contacts 13 38 14 39 of Fig. 2. The stationary brushes are not shown, but are mounted on insulated supports R^9 and serve to take off continuous or straight currents. Any two opposite brushes will serve this purpose.

It will be seen from what has been said above that our apparatus consists, primarily, of a transformer for transforming alternating currents of any number of phases, which means an alternating current of any order into alternating currents of any other number of phases. The primary coils of the transformers are connected in what may be called "dephased groups"—that is to say, all the primary coils which are fed by the line H_1 in Fig. 1 belong to one group, and the phase of the current of all the coils in this group is substantially the same. Again, all of the primary coils fed by the line H_2 in Fig. 1 belong to another group, of which all the coils are supplied by current in the same phase; but the coils in group H_2 are dephased from the coils in group H_1, which means that the phase of the current in the primary coils belonging to the group H_2 is different from the phase of the primary currents in the primary coils belonging to the group H_1. A similar remark applies to the electromotive forces in the groups of the secondary coils. Thus if our primary alternating current is of order p and our secondary current is of order k it will be seen, in a general case, that there are p groups of primary coils and k groups of secondary coils. As one passes from one primary group to the next, the phase of the current varies by $\frac{1}{p}$. As one passes from one secondary group to the next, the phase varies by $\frac{1}{k}$. It will also be plain in case we use two secondary circuits wound in opposite directions on one and the same cores the total number of coils will be reduced by one-half, as has been fully explained above.

Should we desire to transform an alternating current of any number of phases into a continuous current, we do it by transforming the alternating current of a given number of phases with which we start into an alternating current of a greater number of phases. We then connect the terminals carrying the secondary currents of the larger number of phases to a commutator or rectifier, such as shown, for instance, in Fig. 9, in the manner described above, whence we are enabled to take off straight currents from the brushes of the rectifier. Without the use of the rectifier our apparatus transforms alternating currents into alternating currents. By the use of the rectifier our apparatus transforms alternating currents into direct currents. It is also manifest from what has been said that this apparatus is entirely reversible and that the transformer may operate either to transform an alternating current of a given number of phases into an alternating current of a greater number of phases, or that it may act to transform an alternating current of a large number of phases into an alternating current of a small number of phases. Similarly the rectifier may act in connection with the transformer to transform alternating currents into continuous or direct currents or to transform direct currents into alternating currents.

What we claim is—

1. An apparatus for transforming alternating currents of any order into alternating currents of any other order comprising a number of separate magnetic cores wound with primary and secondary coils, the primary coils being connected in dephased groups so that each member of the same group is affected by the same phase of the primary current and the secondary coils being connected in dephased groups so that each member in the same group is the seat of an electromotive force of the same phase, substantially as described.

2. An apparatus for transforming alternating currents of order p into alternating currents of order $2k$ comprising pk separate magnetic cores, each wound with one primary circuit and two secondary circuits, the secondary circuits being wound in opposite directions, the primary circuits and secondary circuits being each respectively connected in dephased groups, so that any secondary coil of a group is the seat of an electromotive force of substantially the same phase as any other coil of the same group, substantially as described.

3. An apparatus for transforming alternat-

ing currents of order p into alternateing currents of order k comprising a number of separate magnetic cores wound with primary and secondary coils, the primary coils being so grouped among themselves that as one passes from one group to the next the phase of the current varies by $\frac{1}{p}$ and the secondary circuits being grouped among themselves so that members of the same group are in the same phase but as one passes from one group to the next the phase varies by $\frac{1}{k}$ of a period, substantially as described.

4. An apparatus for transforming alternating currents of any order into alternating currents of any other order comprising a number of separate magnetic cores wound with primary and secondary coils, the primary coils and secondary coils being each respectively connected in dephased groups, and the number of turns of a primary coil on a core as one passes from core to core acting on the same secondary circuit, varying according to a sine law, substantially as described.

5. An apparatus for transforming alternating currents of any order into alternating currents of any other order comprising a number of separate magnetic cores, each wound with primary and secondary coils respectively grouped among themselves, the number of turns of a primary coil on a core, as one passes from core to core acting on the same secondary circuit, varying according to a sine law, and the number of turns to a primary coil on a core, as one passes from core to core acted on by the same primary circuit, varying according to a sine law, substantially as described.

6. An apparatus for transforming alternating currents of order p into alternating currents of order k, comprising a number of separate magnetic cores, wound with primary and secondary coils respectively connected in dephased groups, members of the same group being in the same phase and the windings being such that the intensities of the fluxes developed in the cores acting on the same secondary circuit are represented by a series of sines whose arcs vary by $\frac{2\pi}{p}$, and the intensities of the fluxes developed in the coils by the same primary circuit are represented by a series of sines whose arcs differ by $\frac{2\pi}{k}$, substantially as described.

7. An apparatus for transforming alternating currents of any order into alternating currents of any other order comprising a number of separate magnetic cores whose sections vary according to a sine law, as one passes from core to core, substantially as described.

8. An apparatus for transforming alternating currents of any order into alternating currents of any other order comprising a number of separate magnetic cores whose sections vary according to a sine law connected by yokes, the winding being such as to produce fluxes having one direction in the core of odd order and fluxes having an opposite direction in the cores of even order, whereby the cross-section of the yokes or connecting-pieces is reduced, substantially as described.

9. An apparatus for transforming alternating currents of any order into alternating currents of any other order comprising a number of separate magnetic cores mounted in two stories, each core above another, and yokes or connecting-pieces therefor, the winding being such as to produce fluxes having one direction in any superposed pair of cores and having opposite directions in laterally-adjacent cores, whereby the cross-section of the yokes or connecting-pieces is reduced, substantially as described.

10. An apparatus for transforming alternating currents of any order into alternating currents of any other order comprising a number of separate magnetic cores, each supplied with two secondary circuits formed of low-resistance bands, insulated from each other and bent about the cores and each further supplied with a primary coil, the number of turns of which, on successive cores, varies according to a sine law, substantially as described.

11. An apparatus for transforming alternating currents of any order into alternating currents of any other order, comprising a number of separate magnetic cores whose cross-sections vary according to a sine law, each core supplied with two secondary circuits formed of low-resistance bands insulated from each other, bent about the cores, and each core further supplied with a primary coil, the number of turns of which, on successive cores, varies according to a sine law, substantially as described.

12. An apparatus for transforming alternating currents of any order into alternating currents of any other order comprising a series of separate magnetic cores with cross-sections varying according to a law, with a gap or gaps in the series where the cross-section is zero, and primary and secondary circuits wound thereon, the secondary circuits being formed of low-resistance bands and shaped to lie against each other and to inclose no magnetic flux at the points corresponding to the gaps, substantially as described.

13. An apparatus for transforming alternating currents of any order into continuous currents, or reciprocally, comprising a transformer having a number of separate magnetic cores wound with primary and secondary coils, the primary coils and secondary coils being each connected in dephased groups, the number of secondary phases being greater than the number of primary phases, and the secondary coils being connected to a rectifier comprising commutator segments and brushes

moving with relation to each other, substantially as described.

14. An apparatus for transforming alternating currents of any order into continuous currents, or reciprocally, comprising a transformer having a number of separate magnetic cores, wound with primary and secondary coils, the primary coils and secondary coils being each connected in dephased groups such that the number of secondary phases is greater than the number of primary phases, a commutator comprising stationary brushes connected with the secondary coils, rotating rings in contact with the brushes, commutator-sections electrically connected and mounted to rotate with the rings and stationary brushes contacting with the commutator-sections for taking off straight currents, substantially as described.

15. An apparatus for transforming alternating currents of any order into alternating currents of any other order comprising a number of separate magnetic cores wound with primary and secondary coils, the primary coils and secondary coils being each respectively connected in dephased groups, and having the number of turns of the primary coils on a core, as one passes from core to core in the same group, varying according to a sine law and having the section of the wire of the primary coil varying inversely with the number of turns in the primary coil, substantially as described.

In testimony whereof we have signed our names to this specification in the presence of two subscribing witnesses.

MAURICE HUTIN.
MAURICE LEBLANC.

Witnesses:
EDWARD P. MACLEAN,
PAUL BOUR.