W. J. WILLIAMS.

COMPOUND TRANSFORMER.

APPLICATION FILED DEC. 21, 1909.

1,108,050. Patented Aug. 18, 1914.

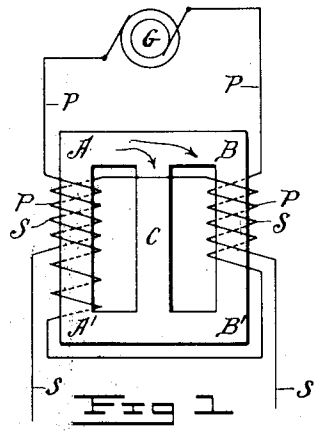


Fig 1

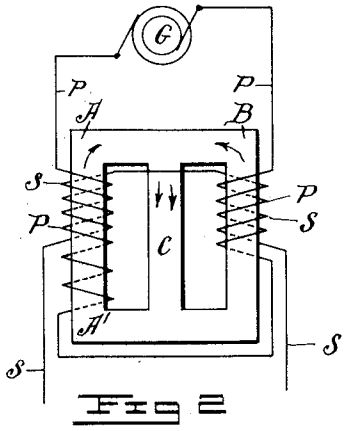


Fig 2

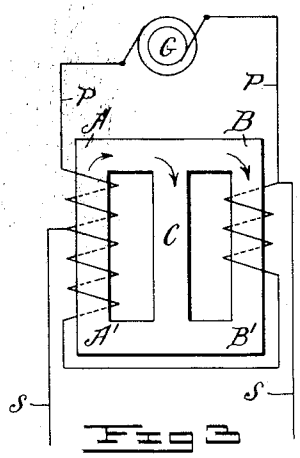


Fig 3

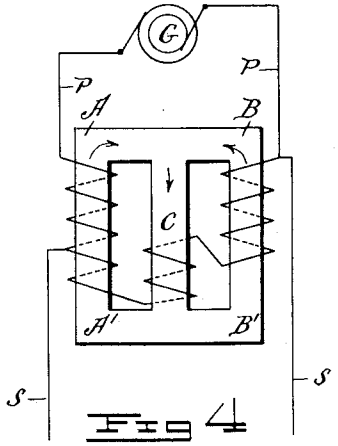


Fig 4

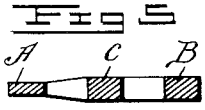


Fig 5

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COMPOUND TRANSFORMER.

1,108,050. Specification of Letters Patent. Patented Aug. 18, 1914.

Application filed December 21, 1909. Serial No. 534,377.

To all whom it may concern:

Be it known that I, WYNANT JAMES WILLIAMS, a citizen of the United States, residing at 374 Madison avenue, in the city of Albany, in the county of Albany and State of New York, have invented certain new and useful Improvements in Compound Transformers, of which the following is a specification.

My invention relates to electrical transformers, my purpose being to provide a suitable and appropriate mechanism for automatically regulating the voltage of currents generated in the secondary circuit of a transformer in such manner that said voltage will vary from a predetermined minimum to a predetermined maximum, and at any desired rate, depending upon the construction of the transformer, as the load upon the secondary circuit is increased or diminished.

More particularly stated, I produce a transformer in which a secondary circuit is caused to act upon different or variable loads in such manner that the voltage of the secondary circuit is automatically maintained at a predetermined minimum so long as there is little or no load upon the secondary circuit, but rises at the same rate that the load is increased until a predetermined maximum potential is reached, so that within limits dependent upon the construction of the particular transformer used, the secondary circuit may always produce currents the voltage of which is commensurate with the load.

My invention is based mainly upon the following principles relating to alternating currents:

1. Where lines of magnetic force flow through a paramagnetic substance, such as iron, the magnetic reluctance of the substance changes with the flux density, and as the magnetic reluctance increases the substance becomes less sensitive to the action of electric currents tending to rapidly alter its state of magnetization.

2. The magnetic flux can be rendered dense in one part of a magnetic circuit and attenuated in another part thereof, so that these different parts are affected unequally by a magnetizing current common to them both, and they also produce unequal electromotive forces of self induction in any conductor encircling each of them but common to both.

3. Where a magnetic circuit has a portion of great magnetic reluctance and a portion of less magnetic reluctance, and these portions because of their difference in magnetic reluctance are affected unequally by a magnetizing current common to them both, said current tends to distribute its energy unequally as between the said different portions of the magnetic circuit, and to concentrate all or a large proportion of its work upon the portion having less magnetic reluctance.

4. Where a magnetic circuit has a portion of great magnetic reluctance and a portion of less magnetic reluctance, and circumstances are such that these two portions respectively tend to set up different voltages in a secondary circuit common to them both, the current induced in the secondary circuit will have a resultant or compromise voltage so long as the secondary circuit carries little or no load, but when the load is increased so that the secondary current is allowed to flow freely, its voltage is controlled to a lesser extent by said portion of great magnetic reluctance and to a greater extent by the portion of less magnetic reluctance, and if the load be excessive the voltage of the secondary current may be controlled almost entirely by said portion of less magnetic reluctance.

In each of the various embodiments here illustrated I employ a transformer with three legs, namely, two outer legs in which the magnetic flux is generated and utilized, and a middle leg which serves altogether or for the most part as a leakage path for this magnetic flux, and in so doing controls, to some extent, the general distribution of the flux as between the outer legs. As the load increases it is apportioned more and more unequally between the two outer legs, as hereinafter described; and the middle leg, being a leakage path or common magnetic return for both of the outer legs, conveys or short circuits a quantity of magnetic flux which is varied not only by the load, but also by the unequal apportionment of

the load from time to time as between the two outer legs.

Reference is made to the accompanying drawings forming a part of this specification and in which like letters indicate like parts.

Figure 1 shows a transformer embodying my invention and having two primary windings connected in series in such manner that the magnetic flux created by each of said windings travels, in the direction indicated by the arrows, around the magnetic circuit as a whole. Fig. 2 illustrates my invention as applied to a transformer in which the two primary windings are connected in series in such manner that the magnetic flux is in the directions indicated by the arrows in different legs of the core. Fig. 3 is somewhat similar to Fig. 1, the difference being that in this instance auto-transformer connections are employed instead of separate conductors for primary and secondary circuits, the direction of the magnetic flux being indicated by the arrows. Fig. 4 illustrates my invention as applied to a transformer having auto-transformer connections, and also having windings on all the legs of the transformer core, the direction of the flux being indicated by the arrows. Fig. 5 is a substantially central horizontal section through the transformer core.

The core is made of laminated paramagnetic material, such as soft iron and is alike in all of the figures. This core is provided with three legs AA′, BB′, and C. The leg AA′ is thinner than the other two legs, but the latter have a common thickness, as indicated in Fig. 5. For the sake of clearness and simplicity, I show only one primary circuit and one secondary circuit, or equivalent autotransformer connections, on each of the transformers. An alternating generator is shown at G and its terminals are connected directly with the primary windings which are shown at P. The secondary windings appear at S and to their terminals varying loads (not shown) are applied from time to time.

In each of the transformers shown in Figs. 1 and 2, the secondary windings each have the same number of turns upon the legs AA′ and BB′, but the number of turns of the primary winding upon the leg AA′ is greater than the number of turns in the primary winding upon the leg BB′. Hence the ratio of transformation is different in the leg AA′ from that in the leg BB′. In each of the several constructions in Figs. 1 to 4, inclusive, the windings upon the leg AA′, tend to step the voltage down to a point lower than is done by the windings upon the leg BB′, though both of these legs are built for step-down action. For purposes of explanation, it is convenient to assume that the primary winding upon the leg AA′ has a number of turns rather more than sufficient to magnetize the leg in question to a point approaching saturation.

In Fig. 4 there is a winding of two turns upon the leg C of the transformer, the purpose of this winding being to control the degree of flux leakage through the leg C, which in all instances serves to facilitate closing the magnetic circuit independently of the action of any and all windings.

As the principles involved are for the most part identical in all of the transformers shown, I will use principally the device shown in Fig. 1 as a basis for further explanations. In this transformer when the primary current flows through the windings P, it induces more magnetic flux in the leg AA′ than in the leg BB′, for the reason that the leg AA′ carries more primary turns. This renders the magnetic flux very dense in the leg AA′ when the flux density is at its maximum, and the relative density per unit of area in cross-section is still further increased by the fact that the area in cross-section of the leg AA′ is reduced as compared with that of the leg BB′ or C, as will be understood from Fig. 5. Moreover, the magnetic flux passing through the leg AA′ follows a divided path, a portion extending through the leg C and another portion through the leg BB′. The result is that when the core as a whole is energized the magnetic flux in the leg BB′ is attenuated as compared with that in the leg AA′.

Owing to the great flux density in the leg AA′, the magnetic permeability of this leg is correspondingly impaired, especially when the flux density is at its maximum. In other words, as the leg in question approaches magnetic saturation, it becomes less sensitive to inductive influence from any current flowing through a conductor in its vicinity. Such being the case, the leg is rendered comparatively insensitive to such inductive action as would otherwise affect it from the primary winding with which it is associated. It also becomes for the moment less capable of setting up a counter-electro motive force of self-induction in currents tending to flow through the secondary winding upon it. The leg BB′, however, being, as above explained, saturated but to a small degree with the magnetic flux traversing it, even when the flux density is greatest, is at all times comparatively sensitive to the inductive influence of any neighboring conductor. Hence when currents are induced in the secondary circuit, these currents, if allowed to flow freely as they are when a load is thrown upon the secondary circuit, have a sharply defined inductive effect tending to reduce the attenuated flux within the leg BB′, but have comparatively little effect upon, and are affected but slightly by, the dense flux traversing the leg AA′. It should be understood,

however, that no actual reduction takes place in the flux transversing the legs AA′ and BB′, particularly in the latter, for the reason that the action of the primary winding increases such flux as rapidly as it may be reduced by the action of the secondary one. In other words, increase in the secondary current ampere turns is followed by a corresponding increase in the primary current ampere turns. It is clear, therefore, that when the core is momentarily energized to its maximum capacity, the leg AA′ and the leg BB′, even if provided, as they each happen to be in this instance, with the same number of secondary turns, have very unequal effects in energizing the secondary circuit common to both of them, and are also affected unequally by the demagnetizing influence of the secondary circuit. That is to say, the current flowing through the secondary circuit easily affects the leg BB′ at all times, to an extent which may vary with the load, but has comparatively little effect upon the leg AA′, even when the load is heavy and the current in question is increased accordingly. The result is that when little or no load is thrown upon the secondary circuit, the demagnetizing influence of the secondary windings upon each leg AA′, BB′ is almost negligible, and the voltage of the secondary circuit as a whole is lower than the voltage of the primary circuit as a whole in the ratio that the total number of turns in the primary circuit bears to the total number of turns in the secondary circuit. When this occurs the voltage of the secondary circuit is at its minimum, and the action of the transformer is very much like that of any ordinary commercial transformer having a similar number and distribution of turns. When, however, the load is increased the secondary current is free to flow in greater volume and the conditions are therefore changed. As the load comes on, the leg AA′ approaches saturation primarily due to the fact that the turn ratio on leg AA′ is different from the turn on leg BB′, and because of its small area in cross-section and the larger supply of magnetic flux from the core BB′, around which the primary current is now flowing freely in consequence of the increased load. With the increase of load, and the consequent approach of the leg AA′ toward the condition of saturation, an increasing part of the load is thrown upon the leg B B.

As may readily be understood from the following description, I find it convenient to use a transformer having three legs, namely, two outer legs performing the office of transformer elements, and a middle leg serving as a leakage path for all or a part of the magnetic flux generated in the two outer legs. The legs are so proportioned and the windings so arranged that, with little or no load upon the transformer, the ebb and flow of the magnetic flux causes the two outer legs to be affected equally or almost equally, but when the load is increased the two outer legs are affected unequally, one of them approaching saturation more closely than the other whenever the general flux density rises to a maximum. The result is that as the load increases and only one of the outer legs approaches saturation, an increasing part of the load is thrown upon the other outer leg. As the two outer legs are wound for different voltages, this shifting of a part of the load from one leg of the transformer to the other must have the general effect of changing the voltage of the secondary or transformed currents as a whole.

My purpose in supplying the middle or leakage leg of the transformer is to render the two outer legs somewhat independent of each other as regards their maximum flux densities, for a given current, so that these two outer legs may act unequally, as elsewhere stated. The middle leg also serves as a compensator for preventing the magnetic flux generated by either of the outer legs from unduly affecting the other outer leg owing to the two outer legs having unequal areas in cross-section. Applying this principle to the structure shown in Fig. 1, it is easy to see how, as the load upon the secondary circuit is gradually increased, the leg AA′ gradually becomes a smaller and smaller factor in determining the voltage of the secondary circuit, and finally becomes negligible in this relation. Following this line of reasoning a step further, it will be seen that when a heavy load is on the secondary circuit, and especially during moments when a heavy load is on the secondary circuit, and especially during moments when the flux density of the leg AA′ is at maximum, this leg is unable to interfere, by inductive action, with the free flow of current through either the primary winding or the secondary winding encircling it, and hence these two windings act to some extent for the moment as if cut out or short circuited. This is because the leg AA′, being saturated, is now unable to set up inductive resistance to currents flowing in its vicinity. After the magnetic flux in the leg in question becomes too dense to be increased further, all excess of the primary current passes idly through the primarily winding upon this leg, and for purposes of such excess this winding serves merely as an ordinary conductor, free from any undue inductive resistance. Similarly if the secondary current flowing through the secondary winding upon this core is unable for the moment to diminish the flux density thereof all of the secondary current passes idly and freely through this winding. Again, to the extent that the primary current passes idly and freely through its wind-

ing upon the leg AA′, to that extent the primary winding upon the leg BB′ is supplied with additional energy. For the moment, therefore, the leg BB′ is alone subjected to the action of practically all of the current supplied by the generator, and the voltage of the secondary circuit as a whole is determined solely by the power of the generator together with the relative number of turns in the primary and secondary windings upon the leg BB′. This leg being wound for higher voltage than the leg AA′, it follows that the voltage of the secondary circuit is higher than usual—that is, higher than when both legs are active, and therefore higher than when there is little or no load.

Considering the transformer in Fig. 1 as a concrete example, it will be noted that there are eight turns in the entire primary circuit and five turns in the entire secondary circuit. The ratio of the voltage of the secondary currents to that of the primary currents is, therefore, nominally five to eight, and this is approximately the ratio which obtains when there is little or no load, or in other words, so long as little or no current is allowed to flow through the secondary winding. Upon the leg BB′, however, there are three turns in the primary winding and two and a half turns in the secondary winding. Hence, with a considerable load upon the secondary circuit the voltage of the secondary circuit during a part of each cycle is in the ratio of two and a half to three as compared with the voltage of the primary circuit. Within limits determined by the two ratios above mentioned, therefore, the particularly transformer shown in Fig. 1 can be so proportioned that increases in the load are strictly proportionate to increases in the voltage. Moreover, if desired, the proportions may be so changed that the voltage may be stepped either up or down, and be varied disproportionately to the load.

The construction shown in Fig. 2 differs from that appearing in Fig. 1 merely in the direction of the winding upon the leg BB′ and the consequent change in the path of the magnetic flux, which is indicated by the arrows. The general result is the same in both of the constructions in question.

In the construction appearing in Fig. 3 the control of the voltage is quite similar to that of the construction shown in Fig. 1, and the direction of travel of the magnetic flux is the same as in Fig. 1. The only difference between Fig. 3 and Fig. 1 lies in the fact that in Fig. 3 the wiring is somewhat simplified by the use of auto transformer windings, rather than separate windings for the primary and secondary currents.

In Fig. 4 the general operation is much the same as in Fig. 2, the main difference being that in Fig. 4 I use auto transformer windings for the purpose of simplifying the wiring. Another difference, however, is the presence of a winding upon the middle leg C. The purpose of this winding is to affect the travel of magnetic flux through the leg C, thus qualifying slightly the character of the transformed current.

The modifications shown in Figs. 3 and 4 of the accompanying drawings disclose how my invention is applicable to the regulator or compensator set forth in Fig. 4 of my Patent No. 907,931, dated Dec. 29, 1908.

In Fig. 4 of my said patent the windings have each an independent iron core. These cores are magnetized separately by the ampere turns of their respective coils and are not individually affected by the magnetization of the other. In other words, the core of one is magnetized only by the ampere turns of the winding thereon and is not affected by the magnetization of the other core and on the other hand the other core is affected only by the ampere turns of the winding thereon and is not affected by the magnetization of the first core.

As set forth in my former Patent No. 907,931, the separate cores are magnetized differently because they are entirely separate and the ratio of the primary to the secondary ampere turns on the one core is different from the ratio on the other core. The first core is saturated easily in each cycle because the ampere turns upon it are sufficient to saturate it and the magnetic condition of this core at any time is independent of the second core since the flux of the second core does not tend to pass through the first core as these cores are entirely separate magnetically. The apparatus of my former patent therefore consists of two parts, each with a separate magnetic circuit, the two parts being connected only by the electric circuits.

In Figs. 3 and 4 of the accompanying drawings there are no separate cores, the legs A, A′, B, B′ and C, being all joined together and forming one compound core. The legs of the compound core are all magnetized not only by the ampere turns on the respective legs but also by the resultant magnetizing force produced by the ampere turns on all of the legs. For example, the leg A, A′ is magnetized not only by the ampere turns thereon, but also by the resultant magnetizing effect on that leg produced by the ampere turns on all three of the legs. In Fig. 3 of the accompanying drawing the leg A, A′ is differently magnetized as compared with the leg B, B′ not because they are separate cores with a different ratio of primary to secondary ampere turns, but because the leg A, A′ is different in construction, because it has not the same dimensions, because it may not be of the same material as the leg

B, B′ and because there is a third leg C through which can pass either the sum or difference of the magnetic flux in the legs A, A′ and B, B′. The same is true of the apparatus shown in Fig. 4 of the accompanying drawing except that in addition to the leg C to carry the sum or difference of the flux in legs A, A′ and B, B′, the leg C has a coil thereon the ampere turns of which tend to modify and control the degree of flux leakage through the core C.

In the arrangement shown in Fig. 4, the transformer is provided with auto-transformer connections and the leg C is provided with a winding for modifying the magnetic flux through the core C. The coil C is in that part of the auto-transformer connection which is common to both the primary and secondary circuits and therefore carries, at any instant, a current equal to the difference between the primary and secondary current so that when no load is on the secondary, the coil C carries the no load primary current of the transformer and assists the other primary windings to magnetize the cores A, A′, and B, B′ and C, or in other words the flux passing up the legs A, A′ and B, B′, at any given instant, passes down through the leg C.

When a load is thrown on the transformer, the secondary ampere turns on legs B, B′ and C are greater than the primary ampere turns, while the secondary ampere turns on legs A, A′ are less than the primary ampere turns thereon, therefore the magnetic flux, caused by the increased current due to the load, now passing down leg B, B′ passes up legs A, A′ and C and the amount of this flux passing through leg C depends upon the number of ampere turns on the same. The greater the amount of the magnetic flux passing through leg B, B′, however, that is caused to pass through leg C rather than through leg A, A′, the shorter will be the period in each half cycle during which the leg A, A′ is saturated and therefore inactive.

As has been previously explained, the compounding action is proportional to the period of inactivity of the leg A, A′ in each half cycle and since the period is of less duration with the coil C than without the same on leg C, the compounding action will be less for any transformer load and the increase of the secondary voltage with the increase in load will be more gradual.

Considering the connections of the coil C reversed from that shown in Fig. 4, the action of the same, at no load would be to oppose the action of the coils on legs A, A′ and B, B′ and the transformer would take a larger magnetizing current.

When a load is thrown on the transformer, so connected, the ampere turns of the coils C now tend to prevent the magnetic flux, passing down leg B, B′ at any instant, from passing up leg C and thus causes leg A, A′ to carry more flux. This action keeps leg A, A′ at saturation and therefore inactive for a longer period each half cycle for a given load than would be the case without the coil on leg C. This in turn causes the compounding action to take place more rapidly than would be the case without the coil on leg C. In either case the voltage will increase with an increase in load but the rate of such increase will be less in the former than in the latter. The arrangement of the several windings, however, may be varied indefinitely as the invention is not based upon any particular distribution of the windings.

The arrangement of the windings may be varied indefinitely, in accordance with known principles of engineering, for the purpose of causing each leg AA′, BB′ to vary its transformation ratio, and with the principle of my invention properly understood it becomes an easy matter to so proportion and arrange the several windings as to set up, within reasonable limits, any desired potential in the secondary winding.

I do not limit myself to any particular construction shown, as various constructions may be had for carrying out the objects of my invention, the scope of my invention being commensurate with my claims.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent of the United States, is:—

1. In a transformer the combination of a core provided with a plurality of legs, one of said legs having a reduced area in cross-section for the purpose of increasing the density of a flux traversing it, primary and secondary windings encircling said legs, the ratio of the primary turns to the secondary turns upon one leg being different from the ratio of primary turns to the secondary turns upon another of said legs.

2. A transformer comprising a core provided with a plurality of legs, more than two in number, so proportioned and connected that a magnetic flux induced in one leg can divide and pass through other legs unequally, thus rendering dense the flux in one leg and rendering attenuated the flux in another leg, a primary winding and a secondary winding mounted upon said leg in which said flux is dense, and a primary winding and a secondary winding upon said leg in which said flux is attenuated, the ratio of the primary turns to the secondary turns upon one of said last-mentioned legs being different from the ratio of the primary turns to the secondary turns upon the other of said last-mentioned legs.

3. A transformer comprising a core having a plurality of legs, more than two in number, a primary winding and a secondary winding mounted upon one of said legs, a

primary winding and a secondary winding mounted upon another of said legs, the ratio of the primary turns to the secondary turns upon one leg being different from the ratio of the primary turns to the secondary turns upon another leg, and an additional leg so disposed that a portion of the magnetic flux induced in one of said legs may leak through said additional leg in order to render unequal the density of the magnetic flux in the two legs first mentioned.

In testimony whereof I affix my signature in presence of two witnesses.

WYNANT JAMES WILLIAMS.

Witnesses:

WALTER E. WARD,
MARGUERITE VAN DER VOLGEN.