March 18, 1941. A. W. KIMBALL 2,235,075

GENERATOR AND POWER PLANT THEREFOR

Filed April 26, 1940

Fig. 1.

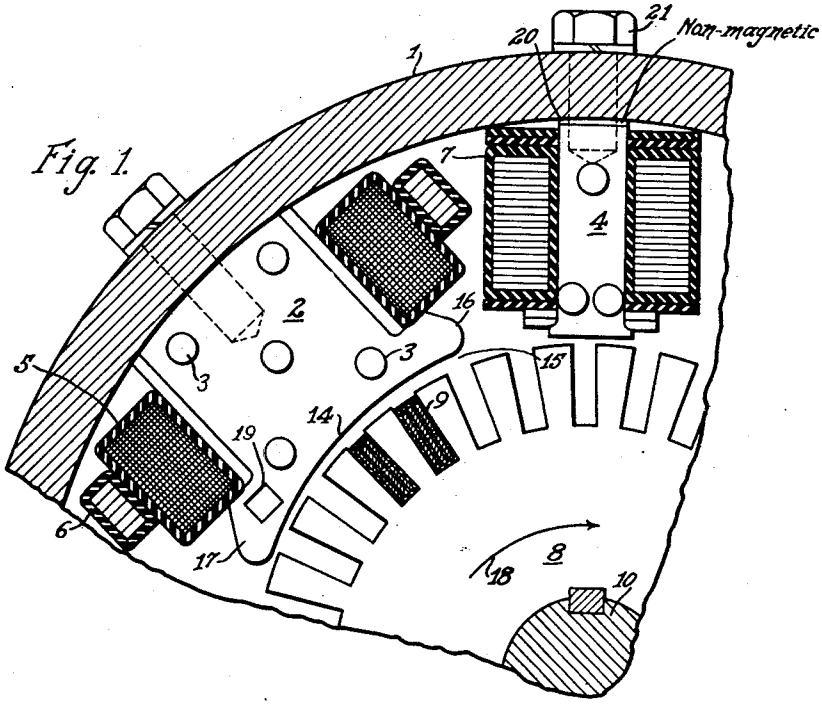


Fig. 2.

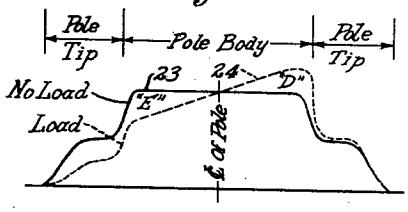


Fig. 3.

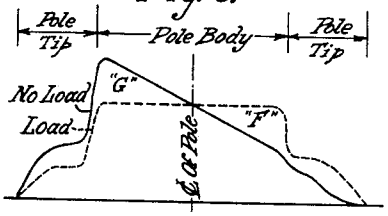


Fig. 4.

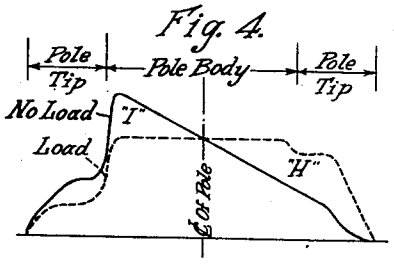


Fig. 5.

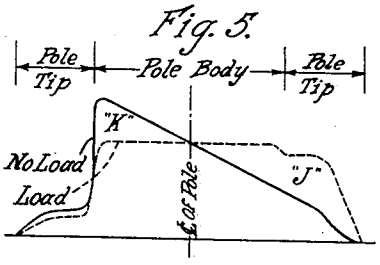
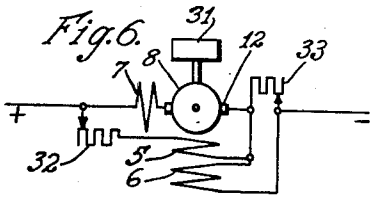


Fig. 6.



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GENERATOR AND POWER PLANT THEREFOR

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6 Claims. (Cl. 171—312)

My present invention relates to a self-regulating direct-current commutator-type generator of a special type having a relatively flat voltage-characteristic from very low loads up to somewhere in the order of 60% of the normal load which it may be called upon to carry, and a voltage-characteristic which is drooping with increased load-current thereafter, and my invention has more particular relation to a power plant including a prime mover, such as a gasoline engine, for driving such a generator. The particular application for which my invention was designed was for an anti-aircraft searchlight generator which is required to operate, most of the time, at a very low load, such as 12 amperes at 105 volts, called the "listening" load, during which time the generator-output is utilized merely to energize certain apparatus associated with the searchlight. When the presence of aircraft is detected, however, a powerful searchlight is turned on, at which time the generator or power plant is called upon to deliver a short-time peak-load of approximately 325 amperes, which reduces as the arc is drawn, and stabilizes at approximately 162 amperes, at approximately 100 volts. However, surges may occur which cause the current to vary within the range of 122 to 202 amperes. For stable operation of the searchlight, it is necessary for the voltage to decrease approximately 1¼ volts for each 10 amperes increase in load. Therefore the corresponding voltage-range must be approximately 105 to 95 volts.

Heretofore, the equipment necessary to supply this service has included a special current-responsive solenoid, picking up at approximately 70 amperes and dropping out at approximately 35 amperes, for so changing the spring-tension on the engine-governor as to increase the speed, from an idling speed of 900 R. P. M., during listening operations, to a full speed of 1200 R. P. M. when the searchlight is energized. At the same time, in these previous installations, it was necessary to provide a voltage-regulator, or special voltage-control means in the generator, so that it would maintain acceptable voltage-conditions under the various conditions of loading.

The principal object of my present invention is to dispense with all control-means or regulators, except the engine governor and the shunt field rheostat, when a single-speed power plant is used, that is, one which does not change the governor-setting when changing from low-load to high-load conditions. Such a power plant eliminates both the speed-changing solenoid for the engine and the voltage-regulator for the generator, a thing which was heretofore believed to be impractical while still obtaining the necessary operating-characteristics from the generator. I now utilize a prime mover having an approximately constant speed, with a speed-characteristic which droops, with load, by only the amount which is necessary for stable operation. Thus, the listening-load speed can be approximately 1050 R. P. M., while the arc-load speed is approximately 1000 R. P. M. This materially simplifies the operation of the power plant, but it imposes a very special operating-condition on the generator, which has required special design, in order to cause the inherent voltage-regulation of the generator, without the assistance of any voltage-regulator, to give the required voltage-characteristic.

The principal object of my present invention is to provide a self-regulating generator having certain special design-features, in combination, as will be subsequently described and claimed, whereby these special voltage-characteristics are obtained, and to provide a power plant including such a generator, the generator being provided with a cumulative series winding for compensating for the droop in the speed-characteristic of the prime mover and for compensating for the internal voltage-drop of the generator.

With the foregoing and other objects in view, my invention consists in the apparatus, combinations, circuits, systems and methods hereinafter described and claimed, and illustrated in the accompanying drawing, wherein—

Figure 1 is a fragmentary transverse sectional view through a generator embodying my invention;

Figs. 2, 3, 4 and 5 are explanatory diagrams which will be referred to in the explanation of the special design-features relating to the main pole-pieces of the generator, and

Fig. 6 is a diagrammatic view of the power plant, and of the circuit-connections of the generator.

As shown in Fig. 1, the illustrative form of embodiment of my generator comprises a stator-member or field member, comprising an outer frame-ring or yoke-member 1 of magnetizable material such as a rolled slab of steel, four main pole-pieces 2 of magnetizable material, such as sheet-steel laminations which are held together by rivets 3, and four interpole-pieces 4 which are also of magnetizable material which may be similar to the material of which the main pole-pieces

2 are constructed. Each of the main pole-pieces 2 carries a self-excited shunt coil 5 and a cumulative series coil 6, while each of the interpole-pieces carries a series-connected commutating or interpole-coil 7.

The generator is also provided with a commutator-type rotor-member comprising a slotted magnetizable armature-core 8 carrying armature-windings 9 and mounted upon a shaft 10. In common with the other commutator-type direct-current generators, and as diagrammatically indicated in Fig. 6, the armature-windings 9 are connected to a commutator which is diagrammatically represented, in Fig. 6, as the surface of the armature 8, current being conducted to and from the commutator by means of brushes 12.

In accordance with my invention, special design-features are embodied in both the main pole-pieces 2 and the commutating or interpole-pieces 4. Each main pole-piece 2 is provided with a pole-face portion or surface 14 which is spaced, from the armature-core 8, by an air-gap which, in accordance with my present invention, is tapered, as indicated at 15. Each main pole-piece 2 is also provided with a first pole-face tip 16 in which the armature reaction produces a cumulative magnetomotive force, and a second pole-face tip 17 in which the armature reaction produces a differential magnetomotive force. This corresponds to a certain predetermined direction of rotation of the armature, as indicated by the arrow 18 in Fig. 1.

In accordance with my invention, the large end of the tapered air-gap 15, under each of the main pole-pieces 2, is under the first-mentioned, or cumulative-flux, pole-face 16. Also, in accordance with my invention, the first-mentioned or cumulative-flux tip 16 is of an unusually large sectional area, as compared to the more common generator-designs, so as to have sufficient cross-section, in radial planes, to be substantially unsaturated for small load-currents; or for currents up to, say of the order of 60% of the normal load, by which I mean a current-range of from say 40%, to say 80% of some loading-condition which I herein designate as the normal load, or even somewhat more or less than these limits. Also, in accordance with my present invention, the second-mentioned, or differential-flux, pole-tip 17 is specially designed so that it will be substantially saturated at no-load, and at small load-currents, and even up to rather substantial load-currents of approximately 60% load, where the demagnetizing armature reaction is very considerable, in this pole-tip 17. In order to make the differential-flux pole-tip 17 saturate, its effective cross-sections must be reduced or restricted, by any suitable means, such as providing a hole 18 therein, as shown in Fig. 1, or by any equivalent means for reducing the effective cross-section of the magnetizable material which carries flux in a circumferential direction in said pole-tip 17.

In accordance with my invention, the interpole-piece 4 is specially designed so that it will include therein a section of such reduced cross-section as to saturate at very small currents, such, for example, as 30 amperes, in the illustrative embodiment of my invention. This reduced-section region of each interpole-piece 4 may be provided in any convenient manner or means, the illustrated means consisting of a special mounting, at the rear end of the interpole-piece 4, where it abuts against the frame-ring 1 of the generator. Thus, as shown in Fig. 1, the back end of the interpole-piece 4 is separated from the frame 1 by means of non-magnetic shims or spacers 20 providing, in effect, an "air-gap" between the interpole-piece 4 and the frame-yoke 1.

In accordance with my invention, however, a magnetizable flux-carrying path of reduced section is provided, between each interpole-piece 4 and the frame 1, by means of oversized attaching-bolts 21 which pass through the frame-yoke 1 and into the interpole-piece 4 for holding the interpole-piece in place. These holding-bolts 21, of which there are preferably two for each interpole-piece, are made of steel or other magnetizable material, and provide a sufficient cross-section to carry the interpole flux for small-current conditions, say, up to 30 amperes, after which the shanks of these bolts, where they pass through the non-magnetic spacer 20, become saturated, so as to begin to approach the same effect as an air-gap. To compensate for this saturation and the air gap at the back of the interpole, I provide an abnormally large number of turns on the interpole-windings 7, so as to overcompensate the machine until the bolts 21 become saturated, after which, with further increases in load, the overcompensation decreases until, at some point such as 162 amperes, the compensation is normal. The overcompensation at light loads produces a circulating current in the short-circuited armature-coils 9 which are undergoing commutation, and this circulating current has a cumulative series effect in increasing the flux through the main pole-pieces 2 under these light-load conditions.

The effect of my special design-features in connection with the main pole-piece 2 can be most readily understood by a study of the resulting field-forms. Thus, in Fig. 2, I have shown, in the solid-line curve 23, the no-load field-form of the flux under a main pole-piece of a machine having a uniform air-gap and normal pole-tips which are close to the saturation point when there is no armature reaction. When load comes on, I have assumed an armature-design and direction of rotation such as to have the armature-reaction produce a cumulative magnetomotive force on the right-hand side of the pole, and a differential magnetomotive force on the left-hand side of the pole, as indicated by the dotted-line curve indicated at 24 in Fig. 2. It will be noted that the right-hand tip saturates, so that there is very little increase in flux in it, whereas there is a considerable decrease in the magnitude of the flux carried by the left-hand pole tip, so that the over-all effect is a reduction in the flux carried by the pole-piece under load-conditions.

Fig. 3 shows similar curves for a machine having a tapered air-gap such as mine, but having normal pole-tips. Since the large air-gap under the right-hand tip reduces the flux-carried thereby, there is less saturation under no-load conditions. However, there is some saturation of the right-hand tip under load, with the result that the effect of the armature reaction is to decrease the flux carried by the main pole-piece.

In Fig. 4, I show the effect of increasing the cross section of the right-hand pole-tip, while retaining the tapered air-gap and the normal design of the left-hand pole-tip. In this case, the result of the armature reaction is to produce little, if any, change in the total flux carried by the main pole-piece, there being possibly a slight increase in the flux under load conditions.

In Fig. 5, I show the effect of reducing the section of the left-hand pole-tip so as to cause it to be saturated, even under load-conditions, while

retaining the previously described unsaturated design of the right-hand pole-tip and the tapered air-gap. In this figure, it will be easy to see that the saturated condition of the left-hand pole-tip prevents the armature reaction from reducing the flux as much as was previously the case, at the left-hand end of the pole-piece, while the unsaturated condition of the right-hand pole-tip permits a considerable increase in the flux passing through the right-hand half of the pole-piece, with the result that there is a definite increase in the useful exciting-flux of the machine, as a result of armature-reaction, with increasing loads.

The effect of an overcompensated interpole-design at light loads produces a cumulative compounding effect, as previously described, as the result of the magnetizing armature-reaction of the circulating currents which flow in the short-circuited coils during commutation. In this manner, I am enabled to secure an additional increase in the main-pole flux as the result of the armature-reaction, particularly at the light loads under the 30-ampere value at which the interpole-bolts 21 begin to saturate. In this manner, I am enabled to better maintain the required generator-voltage during the "listening" load-conditions when the generator is delivering its lightest load, of the order of 12 amperes.

Fig. 6 shows the general combinations and connections of a power-plant including a generator, as above described, and a prime-mover 31, which will preferably have an approximately flat, or slightly drooping, speed-characteristic with increased loads. The positive and negative generator-terminal-leads are indicated at (+) and (−). The main circuit may be traced from the negative lead (−), through the series field-coil 6, the armature 8 and the commutating coil 7, to the positive lead (+). The shunt coil 5 is illustrated as being shunted around the armature 8 and the commutating or interpole-coil 7, although other excitation-means are known for the shunt coil. The shunt-coil exciting-current is regulatable by means of a field-rheostat 32. The series exciting coil 6 is connected so as to produce cumulative compounding in an amount which is approximately correct to compensate for the IR drop due to the resistance of the main circuit of the generator, and also to compensate for the slight droop in the speed-characteristic of the prime mover 31. The compounding-effect of the series winding 6 may be adjusted by means of an adjustable shunting-resistance 33 which is connected therearound.

While I have illustrated my invention in a preferred form of embodiment, I wish it to be understood that various changes of omission, substitution or addition may be made by the skilled workers of the art without departing from some of the essential broader features of my invention. I desire, therefore, that the appended claims shall be accorded the broadest construction consistent with their language and the prior art.

I claim as my invention:

1. A self-regulating direct-current commutator-type generator of a special type having a relatively flat voltage-characteristic from very low loads up to somewhere in the order of 60% of the normal load which it may be called upon to carry, and a voltage-characteristic which is drooping with increased load-current thereafter, said generator comprising a field member comprising a yoke member, a plurality of main pole-pieces and a plurality of interpole-pieces, a rotor member comprising an armature core separated from the main pole-pieces and interpole-pieces by air-gaps, a self-excited shunt coil on each main pole-piece, and a series-connected interpole-coil on each interpole-piece, each main pole-piece having a pole-face with a tapered air-gap, and each main pole-piece having a first pole-face tip in which the armature reaction produces a cumulative magnetomotive force and a second pole-face tip in which the armature reaction produces a differential magnetomotive force, the large end of the tapered air-gap being at the first tip, the first tip being of sufficient cross-section to be substantially unsaturated for small load-currents, and the second tip being of such restricted cross-sections as to be substantially saturated at no-load and at small load-currents.

2. A self-regulating direct-current commutator-type generator of a special type having a relatively flat voltage-characteristic from very low loads up to somewhere in the order of 60% of the normal load which it may be called upon to carry, and a voltage-characteristic which is drooping with increased load-current thereafter, said generator comprising a field member comprising a yoke member, a plurality of main pole-pieces and a plurality of interpole-pieces, a rotor member comprising an armature core separated from the main pole-pieces and interpole-pieces by air-gaps, a self-excited shunt coil on each main pole-piece, and a series-connected interpole-coil on each interpole-piece, each main pole-piece having a pole-face with a tapered air-gap, and each main pole-piece having a first pole-face tip in which the armature reaction produces a cumulative magnetomotive force and a second pole-face tip in which the armature reaction produces a differential magnetomotive force, the large end of the tapered air-gap being at the first tip, the first tip being of sufficient cross-section to be substantially unsaturated for small load-currents, the second tip being of such restricted cross-sections as to be substantially saturated at no-load and at small load-currents, each interpole-piece including therein a section of such reduced cross-section as to saturate at certain small currents, and the interpole-coils being of such number of turns as to produce overcompensation at all loads up to a certain predetermined large load-current.

3. A self-regulating direct-current commutator-type generator of a special type having a relatively flat voltage-characteristic from very low loads up to somewhere in the order of 60% of the normal load which it may be called upon to carry, and a voltage-characteristic which is drooping with increased load-current thereafter, said generator comprising a field member comprising a yoke member, a plurality of main pole-pieces and a plurality of interpole-pieces, a rotor member comprising an armature core separated from the main pole-pieces and interpole-pieces by air-gaps, a self-excited shunt coil and a cumulative series coil on each main pole-piece, and a series-connected interpole-coil on each interpole-piece, each main pole-piece having a pole-face with a tapered air-gap, and each main pole-piece having a first pole-face tip in which the armature reaction produces a cumulative magnetomotive force and a second pole-face tip in which the armature reaction produces a differential magnetomotive force, the large end of the tapered air-gap being at the first tip, the first tip being of sufficient cross-section to be substantially unsaturated for small load-currents, and the second

tip being of such restricted cross-sections as to be substantially saturated at no-load and at small load-currents.

4. A self-regulating direct-current commutator-type generator of a special type having a relatively flat voltage-characteristic from very low loads up to somewhere in the order of 60% of the normal load which it may be called upon to carry, and a voltage-characteristic which is drooping with increased load-current thereafter, said generator comprising a field member comprising a yoke member, a plurality of main pole-pieces and a plurality of interpole-pieces, a rotor member comprising an armature core separated from the main pole-pieces and interpole-pieces by air-gaps, a self-excited shunt coil and a cumulative series coil on each main pole-piece, and a series-connected interpole-coil on each interpole-piece, each main pole-piece having a pole-face with a tapered air-gap, and each main pole-piece having a first pole-face tip in which the armature reaction produces a cumulative magnetomotive force and a second pole-face tip in which the armature reaction produces a differential magnetomotive force, the large end of the tapered air-gap being at the first tip, the first tip being of sufficient cross-section to be substantially unsaturated for small load-currents, the second tip being of such restricted cross-sections as to be substantially saturated at no-load and at small load-currents, each interpole-piece including therein a section of such reduced cross-section as to saturate at certain very small currents, and the interpole-coils being of such number of turns as to produce overcompensation at all loads up to a large load-current.

5. A power-plant comprising a prime-mover having a slightly drooping speed-characteristic with increasing loads, and a self-regulating direct-current commutator-type generator, said generator comprising a field member comprising a yoke member, a plurality of main pole-pieces and a plurality of interpole-pieces, a rotor member comprising an armature core separated from the main pole-pieces and interpole-pieces by air-gaps, a shunt coil and a cumulative series coil on each main pole-piece, and a series-connected interpole-coil on each interpole-piece, each main pole-piece having a pole-face with a tapered air-gap, and each main pole-piece having a first pole-face tip in which the armature reaction produces a cumulative magnetomotive force and a second pole-face tip in which the armature reaction produces a differential magnetomotive force, the large end of the tapered air-gap being at the first tip, the first tip being of sufficient cross-section to be substantially unsaturated for small load-currents, the second tip being of such restricted cross-sections as to be substantially saturated at no-load and at small load-currents, and the cumulative series coils having approximately the correct number of turns to compensate for the armature resistance drop and the droop in the speed-characteristics.

6. A power-plant comprising a prime-mover having a slightly drooping speed-characteristic with increasing loads, and a self-regulating direct-current commutator-type generator, said generator comprising a field member comprising a yoke member, a plurality of main pole-pieces and a plurality of interpole-pieces, a rotor member comprising an armature core separated from the main pole-pieces and interpole-pieces by air-gaps, a self-excited shunt coil and a cumulative series coil on each main pole-piece, and a series-connected interpole-coil on each interpole-piece, each main pole-piece having a pole-face with a tapered air-gap, and each main pole-piece having a first pole-face tip in which the armature reaction produces a cumulative magnetomotive force and a second pole-face tip in which the armature reaction produces a differential magnetomotive force, the large end of the tapered air-gap being at the first tip, the first tip being of sufficient cross-section to be substantially unsaturated for small load-currents, the second tip being of such restricted cross-sections as to be substantially saturated at no-load and at small load-currents, each interpole-piece including therein a section of such reduced cross-section as to saturate at certain very small currents, the interpole-coils being of such number of turns as to produce overcompensation at all loads up to a large load-current, and the cumulative series coils having approximately the correct number of turns to compensate for the armature-resistance drop and the droop in the speed-characteristic.

ALBERT W. KIMBALL.