Sept. 27, 1932. G. AUSTIN ET AL 1,879,014

CONSTANT CURRENT ELECTRIC GENERATOR

Filed Jan. 24, 1931 4 Sheets-Sheet 1

Fig. 1.

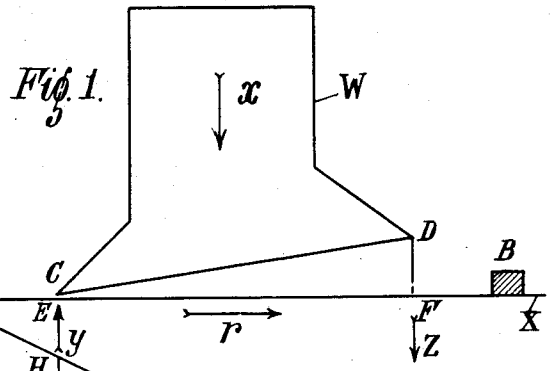


Fig. 3.

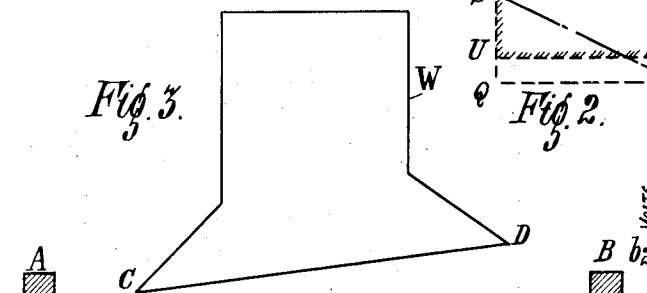


Fig. 2.

Fig. 6.

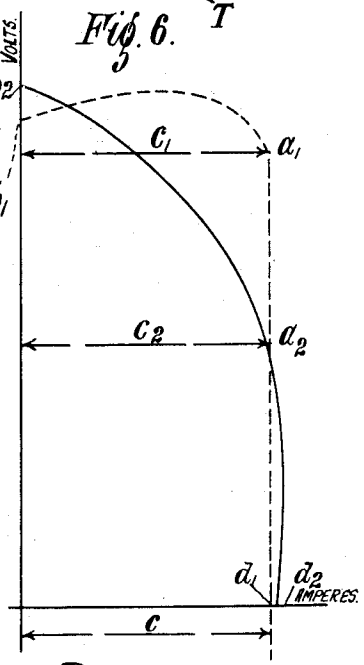
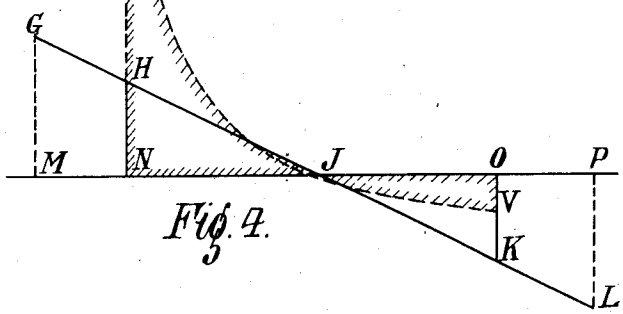


Fig. 4.



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Sept. 27, 1932. G. AUSTIN ET AL 1,879,014

CONSTANT CURRENT ELECTRIC GENERATOR

Filed Jan. 24, 1931 4 Sheets-Sheet 2

Fig. 7.

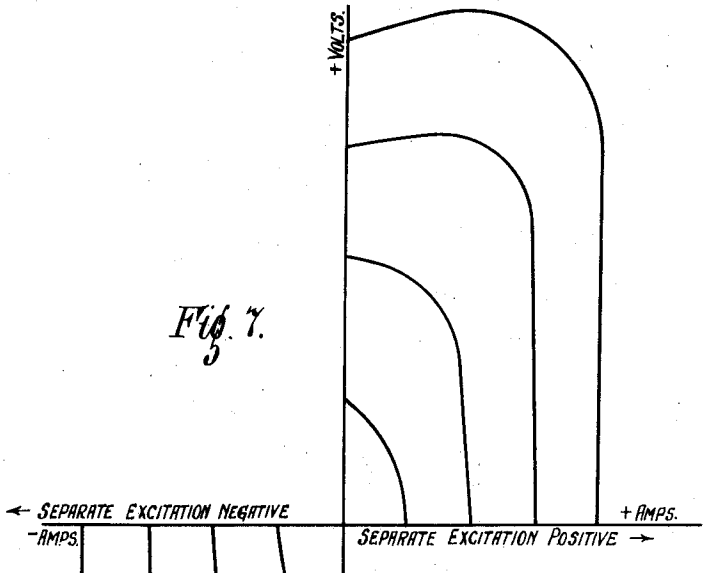
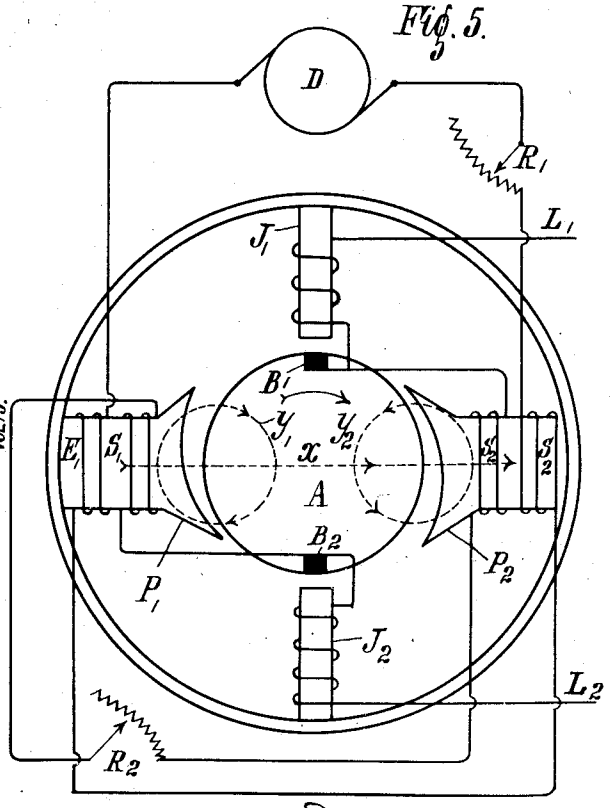


Fig. 5.



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Sept. 27, 1932. G. AUSTIN ET AL 1,879,014

CONSTANT CURRENT ELECTRIC GENERATOR

Filed Jan. 24, 1931 4 Sheets-Sheet 3

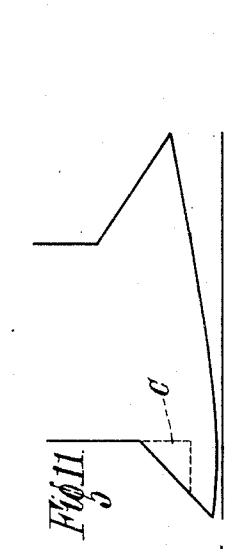


Fig. 11.

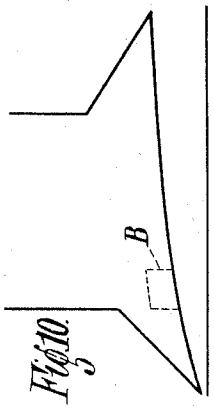


Fig. 10.

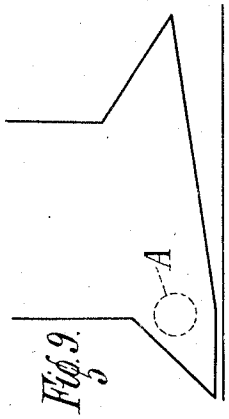


Fig. 9.

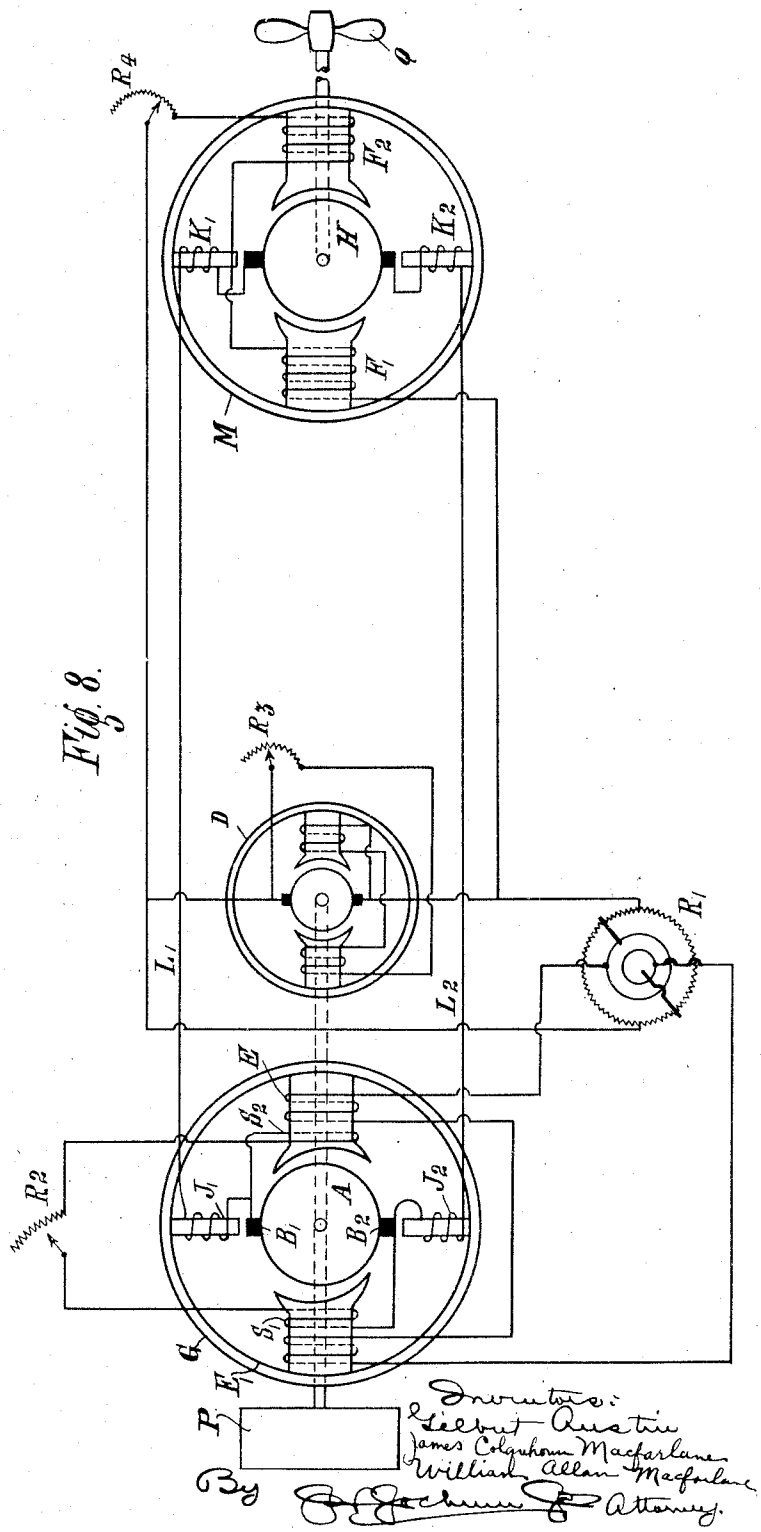


Fig. 8.

Sept. 27, 1932. G. AUSTIN ET AL 1,879,014

CONSTANT CURRENT ELECTRIC GENERATOR

Filed Jan. 24, 1931 4 Sheets-Sheet 4

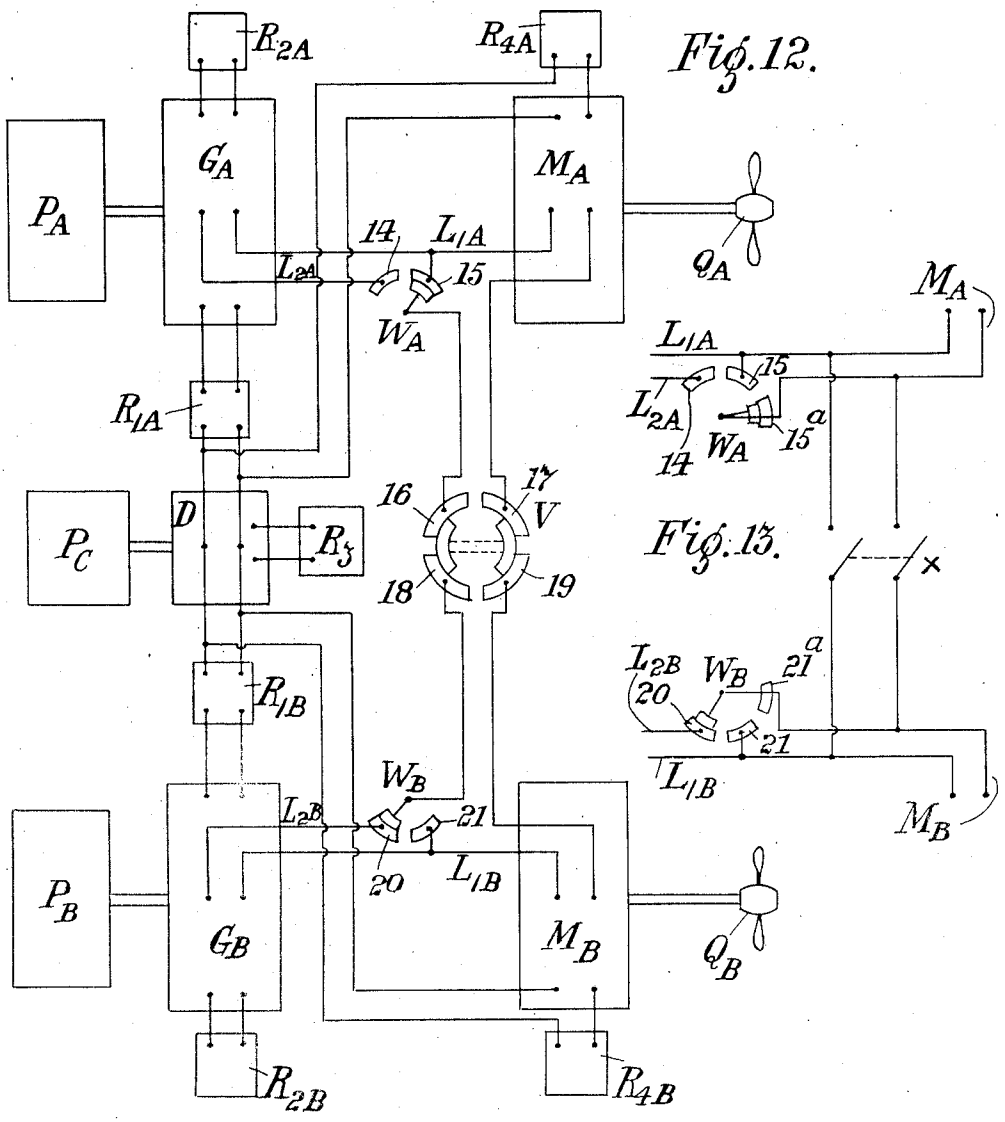


Fig. 12.

Fig. 13.

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Patented Sept. 27, 1932 1,879,014

UNITED STATES PATENT OFFICE

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CONSTANT CURRENT ELECTRIC GENERATOR

Application filed January 24, 1931, Serial No. 510,928, and in Great Britain February 18, 1930.

This invention relates to that type of constant current electric generating plant wherein the current has an approximately constant value for all values of the load, the voltage automatically varying to suit the load, but in which the value of the constant current can be adjusted to any other approximately constant value lower than its maximum value, or may be reversed, and this invention is particularly applicable to ship propulsion systems and the like where lower values of the constant current may be required for cruising at reduced speeds, or where the current may require to be reversed for manœuvering.

The chief object of the invention is to provide an electric generator of the aforesaid type which will have a short circuit current of reasonable size. Another object is to provide an electric generator of the aforesaid type which can be used relative to the propulsion of ships, and in which, if the load is suddenly thrown off or suddenly increased, for example, by the propeller leaving the water or becoming fouled, respectively, the current will fall very low, or the voltage will fall very low, respectively.

In our invention, we make use of a hitherto little known effect obtainable in specially designed dynamos having under each main pole an air gap which is variable in radial length along the face of the pole in a circumferential direction.

The use of such graded air gaps is already well known in connection with the improvement of the commutation and compounding properties of a constant voltage dynamo or motor.

It has already been proposed to utilize armature reaction with a graded air gap for obtaining a slight rise in voltage with increase of load by causing the polar flux on no-load to saturate the leading tip and the corresponding armature teeth, but leaving the trailing tip relatively unsaturated, and causing the armature reaction on load to increase the polar flux on the trailing tip in greater proportion that it can reduce it in the leading tip owing to the effect of this saturation.

In order that our invention may be properly understood, we show, by way of example, on the accompanying drawings, a series of explanatory figures wherein:—

Fig. 1 represents in diagrammatic form, one pole of an electric generator or dynamo according to our invention with graded air gap, but developed out flat for convenience of explanation, this pole being shown with full exciting magneto motive force (M. M. F.) thereon.

Fig. 2 represents a M. M. F. and flux distribution diagram of the fully excited pole of Fig. 1, showing the effect of armature reaction on the flux distribution.

Fig. 3 represents the same pole as in Fig. 1 but without excitation.

Fig. 4 is the M. M. F. and flux distribution diagram corresponding to Fig. 3.

Fig. 5 shows one form of the windings and connections of a dynamo according to our invention.

Fig. 6 shows a comparison between the characteristic obtainable with a dynamo in accordance with our present invention and that obtainable with a drooping characteristic dynamo of the well-known "3 coil" type.

Fig. 7 shows a group of characteristic curves obtainable with a dynamo made according to our invention with different values of the exciting current, and when the exciting current is reversed.

Fig. 8 shows our invention applied to a scheme for marine propulsion.

Figs. 9, 10 and 11 show modified forms of the graded air gap and methods of increasing the magnetic reluctance of the pole horns if desired.

Fig. 12 is a diagram illustrating the arrangement of two generators each driven from a separate prime mover and supplying a separate motor, switching means being provided for cutting out one of the generators and prime movers and connecting the two motors in series with the remaining generator.

Fig. 13 is a detail diagram illustrating how, with apparatus similar to that shown in Fig. 12, one of the generators may be cut out and the two motors may be connected in parallel with the remaining generator.

Reverting to Fig. 1, W is one pole of a machine according to our invention having a graded air gap varying from a minimum length C E at the pole tip C to maximum length D F at the pole tip D. X is the armature rotating (in a dynamo) in the direction shown by the arrow *r*. A and B are the brushes of the machine. The arrow *x* shows the direction of the main M. M. F. due to windings on the pole, and arrows *y* and *z* represent the direction of the M. M. F.'s due to the armature current at the pole tips C and D respectively.

Fig. 2 shows a diagram of the M. M. F.'s along the pole face and the flux distribution due thereto. In Fig. 2 the rectangle N Q R O shows the M. M. F. due to the pole winding having the value all over the pole face equal to the height N Q. G H J K L is the armature M. M. F. due to the constant current therein. This M. M. F. has the negative value M G at the brush A and the positive value P L at the brush B. The values of the armature M. M. F. at the pole tips C and D are respectively N H negative and O K positive. The resultant M. M. F. over the whole pole face is therefore given by the Fig. N S T O wherein N S is the resultant positive M. M. F. at the tip C, and O T is the resultant positive M. M. F. at the tip D. If the air gap is so graded that the proportion of the length C E to the length D F is the same as the proportion of N S to O T, then the flux passing across the air gap (neglecting any effect due to saturation of the iron paths) will be represented by the shaded rectangle N U V O, of constant height N U. This is the load condition wherein maximum voltage is generated, the armature current being assumed to be of the constant value.

Should the exciting M. M. F. N Q be reduced in value, the corresponding M. M. F.'s N S and O T will be correspondingly reduced and the resultant M. M. F. at the tip C will be reduced to zero and finally reversed reaching the limiting value as shown by Figs. 3 and 4 when the excitation on the main pole has been reduced to zero.

Fig. 3 is Fig. 1 repeated except that the M. M. F. shown by the arrow *x* is reduced to zero and so disappears.

In Fig. 4 as before G H J K L represents the armature M. M. F. due to the constant current, and as there is no main M. M. F. on the pole, it also represents the total M. M. F. acting on the air gap. It has the negative value N H at the pole tip C and the positive value O K at the pole tip D. Since the air gap under C is smaller than under D the resulting negative flux N U at C (neglecting iron saturation) will be much greater than the resulting positive flux O V at D. The flux will in fact (neglecting saturation) follow the curve U J V wherein it is seen that the area N U J is much greater than the area O V J. This means that under these conditions there is a resultant negative flux in the pole W (Fig. 3) which would, if this condition prevailed, generate an E. M. F. tending to oppose the constant armature current, or in other words, the machine would now be motoring instead of generating. It is obvious that any tendency for the armature current to change, with a given M. M. F. on the field, will result in a change of flux tending to prevent the change of current. Thus if the current in Fig. 2 should be reduced, the values of the M. M. F.'s N H negative and O K positive, would also be reduced with the result that the area of the flux diagram N U V O would be increased, thereby increasing the voltage of the machine.

The above description, which neglects the effect of saturation in the armature teeth and pole tips is intended merely to show the manner in which with a graded air gap the armature current controls the flux passing into the armature and therefore the voltage generated.

We have found that a suitable characteristic can be obtained by supplying the field with excitation from a separate source of constant voltage and supplementing this with a shunt winding connected across the brushes of the constant current machine itself. The polar M. M. F. N Q (Fig. 2) would therefore be made up of two parts, one part due to the separate constant voltage supply and the other due to the shunt coil connected across the brushes A B (Fig. 1). That is, the shunt winding and the separately excited winding act together in the same direction to produce the M. M. F. N Q (Fig. 2). The machine, with this type of winding behaves in a somewhat similar manner to the well-known "3 coil" type of drooping characteristic dynamo wherein the poles are provided with 3 coils, one separately excited from a constant voltage source, one connected in shunt across its own brushes and assisting the separately excited coil, and one connected in series with the armature and opposing the first two coils. In one form of the machine made according to our invention we retain the separately excited coil and the shunt coil but eliminate the opposing series coil of the "3 coil" dynamo, its place being taken by the armature reaction acting across the graded air gap as described above.

This results in very important advantages being obtained in a machine made according to our invention as compared with the well-known "3 coil" dynamo or other well-known drooping characteristic machines, in respect that not only is the weight and cost of the third series winding eliminated but the space saved enables a smaller and cheaper machine to be designed for the same duty and it has the further important advantage that, as will be described later, the characteristic curve obtainable is better than that obtainable from

the "3 coil" type of machine, in that for the same working voltage it does not require such a high open circuit voltage, and the material is in consequence better utilized. Still further, the characteristic is such that in the ship propulsion scheme to be described later, there is no danger of the propeller racing if it should leave the water.

Fig. 5 shows in diagrammatic form a dynamo made according to our invention wherein A is the armature revolving in the direction of the arrow. P1, P2, are the shoes of the field poles with the graded air gaps, the smaller air gap being at the side towards which a point on the armature surface approaches, B1, B2 are the brushes, E1, E2 the separately excited coils acting in the direction of the arrow x and supplied by the constant voltage exciter D. S1, S2 are the shunt coils connected across the brushes B1, B2 and acting magnetically in the same direction x as the coils E1, E2. A regulating resistance R1 is connected in the circuit supplying E1, E2, and if desired, another regulating resistance R2 can be connected in the shunt circuit S1, S2 and used for varying the shape of the characteristic curve obtained. The direction of the armature M. M. F. is indicated by the dotted lines $y1$, $y2$ with arrow heads, being such that it assists the main M. M. F. over the larger side of the air gap and opposes the main M. M. F. over the smaller side of the air gap—L1, L2 are the constant current leads. Interpoles J1, J2 may be used not only for their normal function of assisting commutation but also for varying the characteristic of the machine by shifting the brushes within the limit of movement allowed by the width of the interpole face. Also they may be used to improve the stability of the machine by eliminating short circuit currents due to the armature cross flux acting on the short circuited coil undergoing commutation. In Fig. 6 the heavy line $b2$, $a2$, $d2$ shows the usual type of characteristic curve obtainable from a dynamo of the "3 coil" type, and the dotted line $b1$, $a1$, $d1$ shows the type of curve to be expected in a dynamo according to our invention. It will be seen that for a given initial voltage $b2$ the working voltage $a2$ of the "3 coil" dynamo is very low, and although the shape of the characteristic may be varied in various ways it always suffers from the defect of high open circuit voltage as compared with working voltage.

In a machine under our invention the working voltage $a1$ is very low below the open circuit voltage $b1$, and indeed with proper design may be made higher than $b1$, and this feature has the important advantage that if full load is represented by the current $c1$ and voltage $a1$, complete removal of the load (as in the case of a propeller leaving the water) results in the current falling to zero and the unloaded motor will continue to run at the speed represented by the voltage b. The short circuit current c (point $d1$ on Fig. 6) is determined by the value of the M. M. F. set up by the separately excited coils E1 E2 (Fig. 5), in conjunction of course with the other constants of the machine, the condition being that the separate excitation, on short circuit should overbalance the reverse M. M. F. set up by the armature (as described with reference to Fig. 4) by an amount just sufficient to generate the voltage necessary to keep the short-circuit current circulating against the resistances of the armature and external circuit.

If the separate and shunt excitations are reduced by means of the regulators R1 and R2 (Fig. 5) a series of characteristic curves can be obtained as shown on the right hand side of the diagram (Fig. 7), and further, if the separate excitation is reversed, the voltage at the brushes reverses, and consequently also the shunt excitation, and the armature current. The result is that a series of similar curves is obtained, reversed, however, as to polarity, with the same direction of rotation, by operation of the regulators R1 and R2, all as shown on the left hand side of Fig. 7.

Although in Fig. 7 we have shown a series of curves of a shape usually desirable in a machine of this type, we may for any special purpose modify the shape of the curves greatly by altering the amount and relative proportions of the shunt and separately excited winding, by altering the shape of the pole face and/or the amount of grading of the airgap, by increasing the saturation of either or both pole tips as indicated by Figs. 9, 10, 11, by shifting the brushes, particularly where interpoles are used, by the use of the additional regulator R2 (Fig. 5) in the shunt circuit beyond, or below, the value necessary to give the curves shown on Fig. 7, by adding series excitation coils, carrying the whole or a portion of the constant current, in combination with both shunt, and separately excited coils and acting in the same direction, or by combining any or all of the above methods in order to get the exact shape of characteristic desired.

If the regulator R2 is used beyond the value necessary to get the curve $b1$ $a1$ $d1$ (Fig. 6), that is, with a higher resistance, the result will be that the straight part of the curve $a1$ $d1$ will tend to slope inwards in some degree, so that the load current C1 will become less than the short circuit current C, and conversely, if R2 has a lower resistance than is necessary to obtain the straight part of the curve $a1$ $d1$ it will tend to slope outwards, that is the load current C1 will be greater than the short circuit current C, and these effects will be more pronounced as the separate excitation is reduced in order to reduce the short circuit current C.

Where series windings are used in conjunction with the other windings as specified above for the purpose of varying the characteristic curve, it will generally be desirable to add a certain amount of saturation at the pole tips in order to stabilize the machine and thus saturation may, as explained above, be added at either or both pole tips.

Fig. 8 shows our invention applied to a system of ship propulsion wherein G is the drooping characteristic dynamo already described. The dynamo G is driven by the main prime mover P which may be a steam or Diesel engine or of any other known type. D is the constant voltage exciter which can be driven directly by the main engine or by an auxiliary engine or in any other suitable manner. M is the main propulsion motor, the armature H of which is connected to the propeller I. The field of the motor M is excited by the constant voltage exciter D. The armature H is connected across the constant current circuit L1, L2. A regulator R4 may be connected in the field of M if desired. Regulators R2 and R3 can be used in the shunt field of the generator and exciter if desired. The separately excited coils E1, E2 of the main generator G are excited by the constant voltage dynamo D and include in their circuit the potentiometer type regulator R1 by means of which the excitation of the coils E1, E2 can be reduced and if necessary reversed. The regulator R1 can be located on the bridge of the vessel thereby putting the whole control of the manœuvring of the ship directly in the hands of the officer in charge and avoiding all the delays and risks of a signalling system. The motor M would normally be operated on full load at or about the point $a1$ on the characteristic curve, Fig. 6, and as already explained if the propeller should leave the water, the current will fall to zero with voltage $b1$ and with full field on the motor the speed would be that corresponding to the voltage $b1$. Further, should the propeller become fouled by any obstruction or by picking up a rope or cable, thereby bringing the armature H of motor M to stand still, the voltage will fall to zero (point $d1$ on Fig. 6) with current C, but will not deliver more than its full torque as determined by the current C and the field F1, F2 of the motor. No damage will result to either the generator or the motor as a result of such stoppage of the propeller, and further, in the event of its being necessary to unwind the fouling rope or cable, the motor can be run very slowly in the reverse direction under control of the bridge potentiometer R1.

Under the construction provided by the present invention, the flux from each pole neglecting saturation altogether, is given by the formula:—

$$\phi = \frac{WLM}{.8(G-g)}\left[2-\frac{G+g}{G-g}\log_e\frac{G}{g}\right]+\frac{WLX_0}{.8(G-g)}\log_e\frac{G}{g}+\frac{WLX_1}{.8(G-g)}\log_e\frac{G}{g}$$

Where W = axial width of the pole.

L is the length measured circumferentially.

G is the radial length of the airgap at the large end.

g is the radial length of the airgap at the small end.

M is the armature reaction at the tip of the pole.

X_0 and X_1 are positive M. M. F.'s due to pole windings.

The first term of the formula is due to armature reaction, the second term to separate excitation and the third term to the shunt excitation.

The part (1) of the above formula which is due to M only, is always negative, the parts (2) and (3) are always positive—if X_0 and X_1 do not exist then a negative flux passes through the pole due to the action of the armature M. M. F. on the taper airgap. If $G=g$ that is, a parallel airgap, no reverse flux can pass because (1) = zero.

The system is also applicable to twin screw vessels in which two engines drive two generators G with either two exciters or one common exciter D and two motors M. In the event of a breakdown of one generator or its corresponding engine the motors M can be run at reduced speed off one generator, either in series sharing the voltage between them or in parallel sharing the constant current between them as may be most convenient.

In Fig. 12 are shown twin propellers Q_A and Q_B driven respectively by motors M_A and M_B supplied with current from separate generators G_A and G_B driven respectively by prime movers P_A and P_B. D is a common exciter for the machines G_A, M_A, G_B, M_B, and is driven by prime mover P_C. Regulators R_{1A} and R_{1B}, R_{2A} and R_{2B}, R_3, R_{4A} and R_{4B} have the same significance as the similar regulators shown in Fig. 8. Should either of the generators G_A and G_B or prime movers P_A, P_B go out of order, or for any other reason, the motors M_A and M_B may both be switched into series with the remaining generator, for example, G_B, by means of the series connecting switch V and selector switches W_A, W_B, this state being indicated on Fig. 12. Switch W_A first bridges contacts 14, 15 and short circuits generator G_A and then, after the field of G_A is reduced to zero by the potentiometer regulator R_{1A}, the switch W_A is moved from contact 14 to contact 15 thereby open, circuiting G_A and connecting M_A in series with M_B. Should it be desired to cut out generator G_B, then switch W_A is retained on contact 14, while switch W_B is moved from contact 20 to contact 21. When both gen-

erators are to be used and the two motors are operated separately, switch V is moved to a position at 90° to that shown, thereby joining contacts 16—17 and 18—19. L_{1A} L_{2A} and L_{1B}, L_{2B} are the main conductors leading from generators G_A and G_B to the respective motors.

In Fig. 13, in order to switch the motors M_A and M_B into parallel and to cut out generator P_A, paralleling switch X is closed, and switch W_A is moved from contact 14, over contact 15 and finally to dead contact 15^a thereby open-circuiting generator G_A. If generator G_B is to be cut out, then switch W_A is left on contact 14 and switch W_B is moved gradually to dead contact 21^a.

The choice of series or parallel working will depend on the results desired and on the torque—slip characteristics of the propellers Q_A and Q_B. More than two generators and motors may of course be used, and the connections for these will be obvious to one skilled in the art.

Although exciter D is shown as driven by a separate prime mover P_C in Fig. 12, it may be driven by either of the prime movers P_A or P_B, or, alternatively, two sets identical with that shown in Fig. 8 may be employed, each exciter being made large enough to supply two motors, in which case the motor fields are connected in parallel across the armature of the exciter actually in use.

Although we have described the generator particularly in connection with marine propulsion systems, we do not limit the application of our invention to this, as it is obvious that it can be applied to other uses such, for instance, as the propulsion of railway trains.

It is also obvious that modifications will occur to the practical engineer, for instance the exciter D shown in Fig. 8 may be compound wound and may be made large enough to supply the ship's lighting system, fan and auxiliary motors, etc. in addition to acting as an exciter for the main generator and motor. Further, if a separate source of constant voltage is available, such as a public supply, the exciter D may be eliminated and the coils E1, E2 can be excited from such a separate source.

With regard to the grading of the air gap, we do not limit ourselves to the uniformly graded air gap shown in Fig. 1 but may for special reasons alter the grading in any suitable way, for instance, as indicated in Figs. 9, 10 and 11, which for convenience of comparison with Fig. 1 are developed out flat.

Further, although the description given with reference to Figs. 1, 2, 3 and 4 assumed that magnetic saturation was absent, in practice it plays an important part in settling the shape of the characteristic particularly with regard to the maximum voltages obtainable, and we may make use of this fact to modify the shape of the characteristic by increasing the magnetic reluctance of the pole horns by drilling holes as at A, Fig. 9, or nicking the horn as at B, Fig. 10 or by reducing its section as at C, Fig. 11, or in any other suitable manner, and this may be applied to either or both pole horns as may be found preferable for the purpose desired. The generator in accordance with the invention is operated so that none of the iron parts of the magnetic circuit are saturated above the knee of the saturation curve between the voltage limits at short circuit and full load. Above full load, it is saturation which makes the top of the curve $d1$, $a1$, $b1$ (Fig. 6) bend over as shown from $a1$ to $b1$. The term "saturation" employed in the above statement is intended to mean the general saturation of the magnetic circuit such as will ultimately occur if magnetization is raised to a high enough value in the pole body, yoke, teeth, armature core etc. and does refer to purely local saturation of the pole tips or teeth under them. "General" saturation as distinct from "local" saturation is the cause of bending over of the curve above $a1$ (Fig. 6), but with "general" saturation alone the point $b1$ would usually be decidedly higher than the working point $a1$. Saturation of the pole tip C (Fig. 1) has the effect of causing the curve to drop again after bending over so that by the introduction of an appropriate amount of saturation at the pole-tip C the point $b1$ can be kept at a height not greater than that of $a1$ or even below $a1$. A motor therefore working on load at the voltage represented by $a1$ would not increase in speed when the load is entirely removed.

For the purpose of definition it is to be understood that by the term "leading pole tip" is meant the pole tip which a point on the periphery of the armature first passes during rotation, and by the term "trailing pole tip" is meant the tip which a point on the armature periphery last passes during rotation. Also by the use of the term "iron parts" of the machine, in the claims, is meant the iron parts of the generator included in the complete magnetic path through the same, that is, the yoke, the pole (including the shoe), the armature core and the armature teeth.

We claim:

1. A constant current variable voltage electric generator of the aforesaid type, comprising an armature and a polar field system having graded polar air gaps, the air gaps increasing in radial length from the leading tips of the poles to the trailing tips of the poles, the saturation of the iron parts of the machine being maintained below the knee of the saturation curve therefor for working conditions between the voltage limits at short circuit and full load, whereby a drooping characteristic for the generator is obtained by the action of the armature cross ampere

turns acting across the graded air gap of each pole to vary the value of the resultant polar flux.

2. A constant current variable voltage electric generator of the aforesaid type, comprising in combination, an armature, a polar field system with air gaps which taper, increasing in radial length from the leading to the trailing pole tips, a separately excited constant voltage magnetizing winding adapted to just overbalance the reverse armature magneto-motive-force on short circuit and a shunt magnetizing winding in shunt with said armature and acting in the same magnetic sense as said separately excited winding.

3. A constant current variable voltage electric generator of the aforesaid type, comprising in combination, an armature, a polar field system with air gaps which taper variably, increasing in length from the leading to the trailing pole tips, a separately excited constant but adjustable voltage magnetizing winding, and a shunt magnetizing winding in shunt with said armature and acting in the same magnetic sense as said separately excited winding.

4. A constant current variable voltage electric generator of the aforesaid type, comprising in combination, an armature, a polar field system with graded polar air gaps which increase in length from the leading to the trailing tips of the poles, at least one of the horns of each pole being of greater magnetic reluctance than the normal for the purpose of modifying the voltage-current characteristic, a separately excited constant voltage magnetizing winding, and a shunt magnetizing winding in shunt with said armature and acting in the same magnetic sense as said separately excited winding.

5. A constant current variable voltage electric generator of the aforesaid type, comprising in combination, an armature, a polar field system with air gaps which taper, increasing in length from the leading to the trailing pole tips, a separately excited constant voltage magnetizing winding, a shunt magnetizing winding in shunt with said armature so that the voltage across the shunt coils varies with the load, and a series magnetizing winding connected in series with said armature, all three windings acting in the same magnetic sense.

6. A constant current variable voltage electric generator of the aforesaid type, comprising in combination, an armature, a polar field system with air gaps which taper, increasing in length from the leading to the trailing pole tips, a separately excited constant voltage magnetizing winding, a regulator in the circuit of said separately excited winding whereby the value of the constant current supplied from the armature may be reduced or reversed when desired, and a shunt magnetizing winding in shunt with said armature and acting in the same magnetic sense as said separately excited winding.

7. A constant current variable voltage electric generator of the aforesaid type, comprising in combination an armature, a polar field system with air gaps which taper, increasing in length from the leading to the trailing pole tips, a separately excited constant voltage magnetizing winding, a regulator in the circuit of said separately excited winding whereby the value of the constant current supplied from the armature may be reduced or reversed when desired, a shunt magnetizing winding in shunt with said armature and acting in the same magnetic sense as said separately excited winding, and a regulator in the circuit of said shunt winding for the purpose of varying the shape of the characteristic of the generator.

8. A constant current variable voltage electric generator of the aforesaid type, comprising in combination, an armature, a polar field system with air gaps which taper, increasing in length from the leading to the trailing pole tips, a separately excited constant voltage magnetizing winding, a shunt magnetizing winding in shunt with said armature and acting in the same magnetic sense as said separately excited winding, interpoles over the brushes of the generator thereby enabling the characteristic of the generator to be varied by shifting the brushes within the limit of movement allowed by the interpole face.

9. The combination with a constant current variable voltage electric generator of the aforesaid type comprising an armature and a polar field system having graded polar air gaps, the air gaps increasing in length from the leading tips of the poles to the trailing tips of the poles, a drooping characteristic for the generator being obtained by the action of the armature cross ampere turns acting across the graded air gap of each pole to vary the value of the resultant polar flux, of a main prime mover driving said generator, constant voltage exciting means for said generator, an electric motor excited by said constant voltage exciting means, and having its armature connected across the constant current mains from said generator, and a regulator connected in the constant voltage supply to the separately excited coils of the constant current generator.

10. In combination with a plurality of electric motors, a plurality of prime movers, one for each motor, and a constant current variable voltage electric generator of the aforesaid type for each motor, adapted to supply current thereto and comprising an armature and a polar field system having graded polar air gaps, the air gaps increasing in length from the leading tips of the poles to the trailing tips of the poles, a

drooping characteristic for the generator being obtained by the action of the armature cross ampere turns acting across the graded air gap of each pole to vary the value of the resultant polar flux, of constant voltage exciting means and means for connecting the motors in series or in parallel across at least one of the constant current generator output circuits for the purpose of reducing the number of prime movers required when the load on the motor is low or if one prime mover or generator should break down.

11. A constant current variable voltage electric generator of the aforesaid type, comprising in combination, an armature, a polar field system with air gaps which taper, increasing in length from the leading to the trailing pole tips, a part of increased magnetic reluctance in at least one of the horns of each pole, a separately excited constant voltage magnetizing winding, a shunt magnetizing winding in shunt with said armature so that the voltage across the shunt coils varies with the load, and a series magnetizing winding connected in series with said armature, all three windings acting in the same magnetic sense.

12. A constant current variable voltage electric generator of the aforesaid type, comprising an armature and a polar field system having graded polar air gaps, the air gaps increasing in radial length from the leading tips of the poles to the trailing tips of the poles, the poles being constructed and the excitation being arranged, so that the saturation of the poles will be maintained below the knee of the saturation curve therefor throughout the working range of the machine from short circuit to full load.

13. A constant current variable voltage electric generator of the aforesaid type comprising in combination an armature, a polar field system with air gaps which taper, increasing in radial length from the leading to the trailing tips, a separately excited constant voltage magnetizing winding, and a shunt magnetizing winding in shunt with said armature and acting in the same magnetic sense as said separately excited winding, the parts being so proportioned that the open circuit voltage of the generator will be substantially the same as the full load voltage thereof, and the short circuit current will be substantially the same as the full load current, while the output current will remain substantially constant with variation of voltage from the short circuit value (zero) up to the full load value.

In testimony whereof we affix our signatures.

GILBERT AUSTIN.
JAMES COLQUHOUN MACFARLANE.
WILLIAM ALLEN MACFARLANE.