Aug. 27, 1935. J. ZETSCHE 2,012,368

DRUM WOUND ARMATURE OF DYNAMO ELECTRIC MACHINES

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Fig. 2.

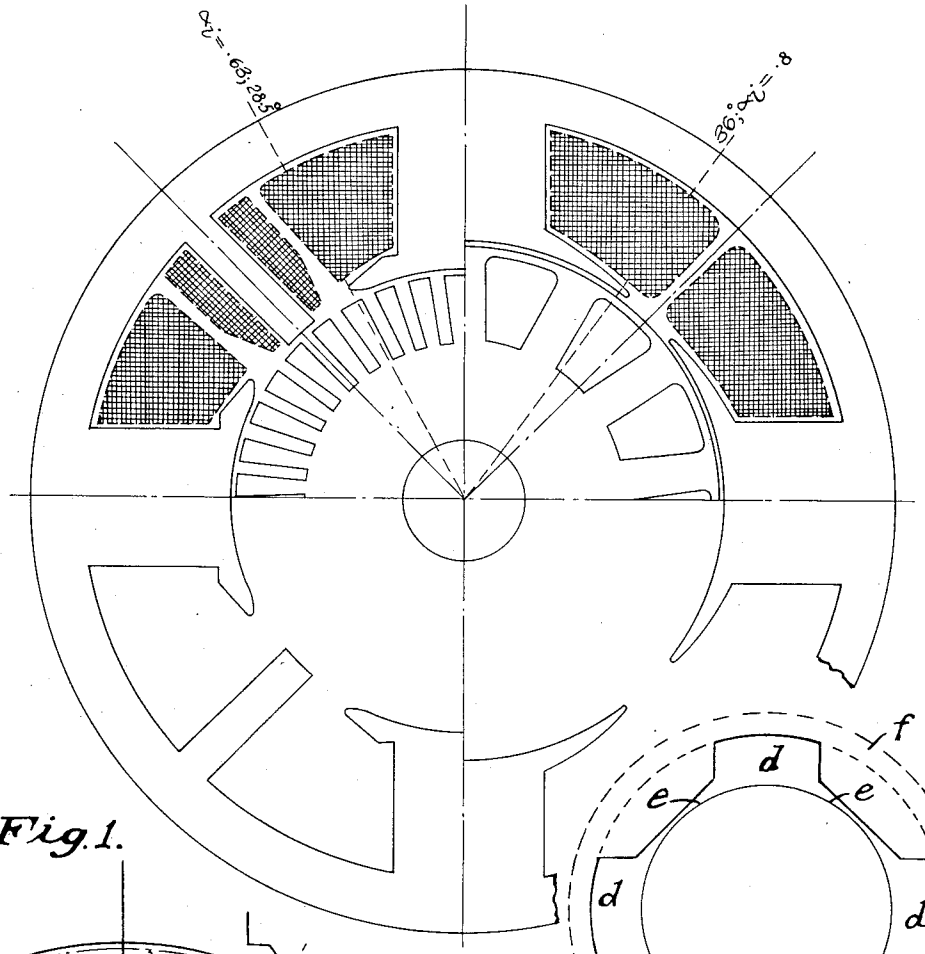



Fig. 1.

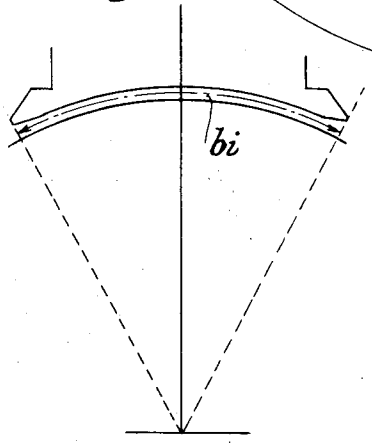






Fig. 4.

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Fig.3.

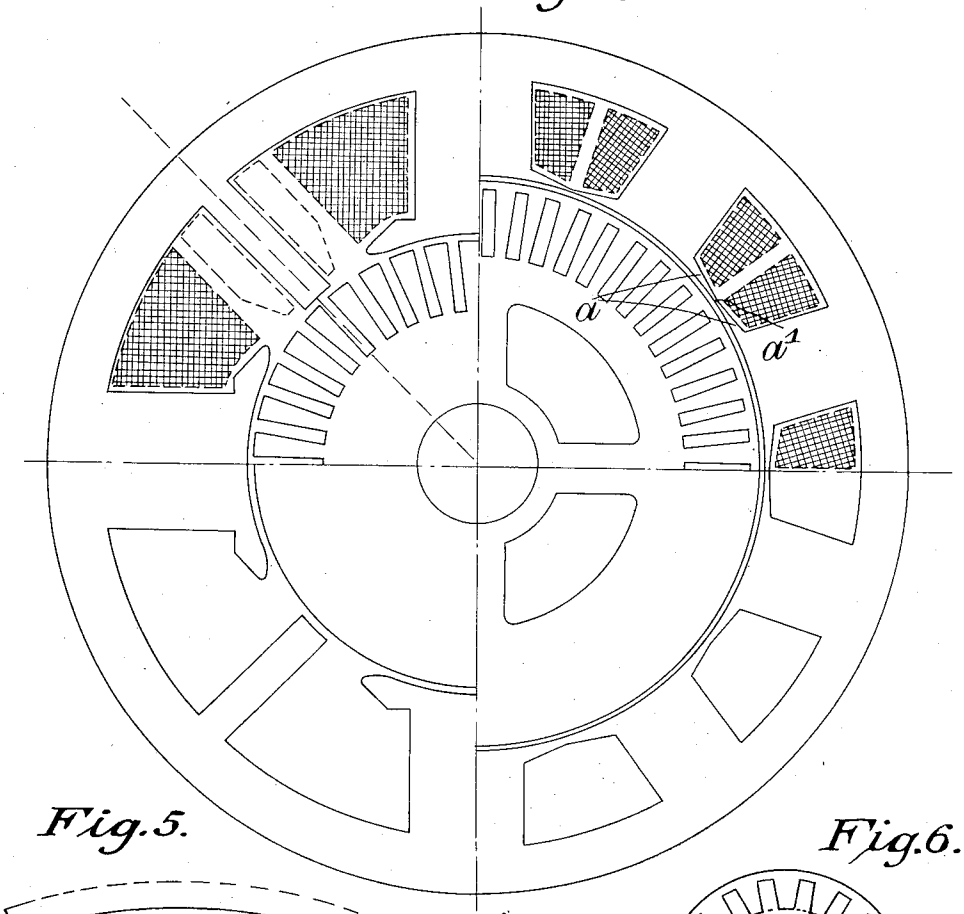



Fig.5.

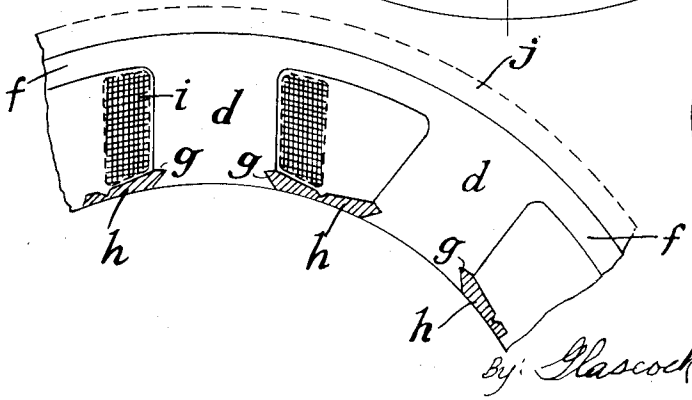
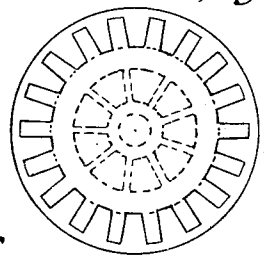



Fig.6.



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# UNITED STATES PATENT OFFICE

2,012,368

## DRUM-WOUND ARMATURE OF DYNAMO-ELECTRIC MACHINES

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Application December 14, 1934, Serial No. 757,569
In Great Britain December 22, 1933

12 Claims. (Cl. 171—206)

This invention relates to an improved construction of dynamo-electric machine.

It has previously been proposed in British Specifications Nos. 327,249 and 328,722 to construct both the field magnet and the armature with continuous closed iron rings, between which the air gap is formed, the armature consisting of a disc provided with single wound teeth. Such constructions have several advantages which cannot be secured with the usual constructions using open slots on the armature and open poles on the field magnet.

Experiments carried out with machines of this character when provided with drum wound armatures did not give satisfactory results, especially as regards commutation and output.

It is also known to construct either only the armature or only the field magnet with a continuous closed iron ring forming the one side of the air gap, but these constructions have certain drawbacks.

I have found that the drawbacks of the machines of the character above referred to can be avoided and still retain the advantages peculiar to them, and even enhance them, giving such machines special improved characteristics and effecting a considerable saving in weight and size per H. P. output, by using a different ratio of armature slots to number of poles than has hitherto been proposed and generally used.

In the improved-dynamo-electric machine constructed according to the present invention the magnetic and electric conditions are so balanced that all means for improving commutation can be dispensed with.

It has hitherto been considered that in order that the main poles shall not have too large an influence on the commutation, the number of the armature slots between the pole tips must not be below a certain value; the actual formula being:

$$(1-\alpha_i)\frac{Z}{2p}>3 \text{ to } 4$$

wherein

$$\alpha_i=\frac{bi}{\tau}=\frac{\text{virtual pole arc}}{\text{pole pitch}}$$

(hitherto .6 to .7 for two-pole and .65 to .75 for multi-pole machines) Z is the number of slots and $p$ the number of pairs of poles.

By "virtual pole arc" $bi$ we understand the arc lying in the middle of the narrowest part of the gap and running parallel to the armature between the radial lines from the pole tips to the centre of the armature (see Figure 1 in the accompanying drawings).

I have found that in machines in which either the armature or the armature and the field magnet is or are provided with a closed iron ring, as above referred to, perfectly sparkless commutation will be obtained if use is made of quite a different formula for the ratio of armature slots to number of poles, and the present invention mainly consists in using a ratio, which will satisfy the formula:

$$(1-\alpha_i)\frac{Z}{2p}<2.3$$

According to the invention this formula is satisfied by reducing the ratio

$$\frac{Z}{2p}$$

preferably also by increasing $\alpha_i$ as compared with the values hitherto employed.

The following constructions are mentioned by way of example:

*A. Motors with closed armature ring*

1. Starting motor for Diesel engines 4 poles, 26 slots; 1000 R. P. M. 24 volts D. C.

$\alpha_i=.7$; $Z=26$; $2_p=4$

$$(1-\alpha_i)\frac{Z}{2p}=1.95$$

2. Starting motor for Diesel engines 4 poles, 22 slots; 1000 R. P. M. 24 volts D. C.

$\alpha_i=.7$; $Z=22$; $2_p=4$

$$(1-\alpha_i)\frac{Z}{2p}=1.65$$

3. Drill motor (Universal; 4 poles; 13 slots; 220 volts; 5380 R. P. M. (with gear ratio 1:14.5 371 R. P. M.)

$\alpha_i=.8$; $Z=13$; $2_p=4$

$$(1-\alpha_i)\frac{Z}{2p}=.65$$

4. Drill motor (Universal); 2 poles; 13 slots; 5380 R. P. M. 220 volts (with gear ratio 1:13 413 R. P. M.)

$\alpha_i=.67$; $Z=13$; $2_p=2$

$$(1-\alpha_i)\frac{Z}{2p}=2.1$$

5. Drill motor (Universal); 2 poles, 11 slots;

9500 R. P. M. 220 volts; (with gear ratio 1:11.3 840 R. P. M.)

$$\alpha_i=.74;\ Z=11;\ 2_p=2$$

$$(1-\alpha_i)\frac{Z}{2p}=1.43$$

6. ¾ H. P. motor; 220 volts D. C. 500 R. P. M. 4 poles; 27 slots

$$\alpha_i=.74;\ Z=27;\ 2_p=4$$

$$(1-\alpha_i)\frac{Z}{2p}=1.75$$

*B. Motors with closed armature and field rings*

7. Motor for signalling purposes; 14 poles; 17 slots; 34 R. P. M. 10 volts D. C .

$$\alpha_i=.9;\ Z=17;\ 2_p=14$$

$$(1-\alpha_i)\frac{Z}{2p}=.12$$

8. 5 H. P. motor 1000 R. P. M. 220 volts D. C.
9. 2.5 H. P. motor 640 R. P. M. 220 volts D. C.
10. 1 H. P. motor 280 R. P. M. 220 volts D. C.
all three of same construction.
10 poles; 53 slots.

$$\alpha_i=.8;\ Z=53;\ 2p=10$$

$$(1-\alpha_i)\frac{Z}{2p}=1.06$$

11. 7 H. P. compressor motor; 600 volts D. C. 250 R. P. M. 8 poles; 57 slots.

$$\alpha_i=.9;\ Z=57;\ 2_p=8$$

$$(1-\alpha_i)\frac{Z}{2p}=.7$$

It will thus be seen that in the constructions according to the present invention the ratio of the slots to the number of poles is substantially below the lower limit, and the values of $\alpha_i$ higher than hitherto used especially with the motors referred to under B, in which the armatures and the field magnets have been provided with a closed iron ring. By using higher values of $\alpha_i$, the flux from the poles is caused to spread to the armature over a larger air gap area, whereby the magnetic induction is reduced throughout the machine and the number of teeth under flux, and thus the number of armature conductors creating the back E. M. F. increased.

As a result of this construction, the following advantages are attained: the field poles can be made wider, whereby the inductive relationships are improved, and the number of poles can be substantially increased as compared with previous constructions, whereby the amount of copper used on the armature and on the field magnet, and the weight of iron are reduced.

As compared with machines of usual construction and having the same outer dimensions, it is possible to shorten the poles and increase the armature diameter whereby the path for the magnetic flux is improved. Owing to the increase of the armature diameter and the decrease in the ratio of number of slots to number of poles according to the invention, the slots can be made substantially larger so that, according to requirements, the cross-section of the conductor can be made larger with a constant number of armature conductors, thereby increasing the output of the machine, or the number of conductors be increased, with a constant cross-section, thereby reducing the speed.

Figures 1–6 illustrate diagrammatically different examples of carrying the invention into effect.

Figures 2 and 3 illustrate examples of four-pole machines, the left hand side showing the conventional construction and the right hand side the construction according to the invention. The conventional construction on the left hand side of Figure 2 shows a machine provided with interpoles and with an armature having 39 open slots. The right hand side of the figure shows the same outside dimensions with no interpoles, the poles, which in this example are not connected by a closed iron ring, being shorter and wider. The armature is of larger diameter and the slots are closed, their total number being only 13, so that a largely increased winding space is available which can be used for either a higher output or a slow speed. By dispensing with the interpoles the winding space of the field coils is increased though the poles are shorter, and there is also a considerable saving in ohmic resistance.

As can be seen, the all round conditions for the flux are considerably improved by shorter iron paths, wider poles and armature teeth and by the bigger working flux angle $\alpha_i$, which amounts to .8 as compared with .63 in the left hand side. In the conventional machine (left) we have:

$$Z=39;\ 2p=4;\ \alpha_i=.63$$

$$(1-\alpha_i)\frac{Z}{2p}=3.6$$

In the machine according to invention (right) we have:

$$Z=13;\ 2p=4;\ \alpha_i=.8$$

$$(1-\alpha_i)\frac{Z}{2p}=.65$$

In the construction shown in Figure 3 a considerably greater number of poles is employed for the same outside dimension. In this case the machine, which has no interpoles, is provided with 10 poles and not only the armature, but also the field poles, are connected by a closed iron ring. It is known that the weight of the active copper and of the active iron decreases with the increase in the number of poles. As it is possible to use a large number of poles for the same outside frame I am thus enabled to secure, in addition to the advantages referred to, a saving in weight of active copper and active iron.

By dispensing with the use of interpoles the costs are reduced and the output is increased. Experiments have proved that machines with 10 poles and without interpoles constructed according to the invention give good commutation under all load conditions—from no load to 100 per cent. overload in torque.

The improved commutation in the machines according to the invention is due to the lower armature reaction of these machines.

If we follow the formula of the armature reaction given by Arnold-la-Cour, which is

$$A_r=\tfrac{1}{2}(\tau-b_i)\times AS,$$

wherein

$\tau$=pole pitch,

$b_i$=virtual pole arc,

$$AS=\frac{Ja\times N}{2\pi a.D.}\ \text{(see below)}$$

we find that the armature reaction is proportional to the values of $(\tau-b_i)$ and of AS. As the virtual pole arc $b_i$ hereinbefore described, especially with machines having both the armature and the field poles provided with closed iron rings, is larger than in machines of conventional construction, the

value $(\tau - b_i)$ will always be smaller. Further, if we consider the value

$$AS = \frac{Ja \times N}{2\pi \times a \times D}$$

wherein

$Ja$=total armature current,
$N$=number of working conductors of the armature,
$a$=half number of armature branches,
$D$=outside diameter of armature,

we find that in machines according to the invention, as described above, the diameter of the armature (for the same outside dimension) is always larger. The comparative values of $Ja$ and $a$ will be the same; the value of N, however, can be kept considerably smaller in machines according to the invention as compared with machines of usual construction.

The conventional construction is based on the fundamental principle that the pitch of the armature winding shall be equal or nearly equal to the pole pitch. Therefore, the number of the active conductors will be nearly equal to the total number of the conductors. In the machines according to the invention the armature winding pitch is not bound to this basic condition, but can be chosen much shorter. It has been proved by experiments that good commutation can be secured for all loads without the help of interpoles if the winding pitch is made approximately equal to the virtual pole arc. The winding pitch, for instance, of the ten-pole machines referred to above under B.8, B.9 and B.10 is from slot 1 to slot 4. As can be seen from Figure 3 (right hand side) this would be equivalent to about 25°, the virtual pole arc being about 28°. It can be found from the wiring diagram of the armature that the number of conductors which are in opposition plus those which are commutating amount to about 43 per cent., thus leaving only about 57 per cent. as actual working conductors.

This considerably reduced number of actual working conductors, combined with the larger armature diameter (see above), reduces the value of AS to half the value thereof, in a conventional machine, or even more. The value of the armature reaction represented by the formula:

$$A_r = \tfrac{1}{2}(\tau - b_i) \times AS$$

will therefore be less than half of the amount of a conventional construction, as both values $(\tau - b_i)$ and AS are reduced, as hereinbefore described.

If the armature winding pitch is chosen as described above so that it is $\leqq$ the virtual pole arc, the machines according to the invention can be regarded as working on the transformer principle. In machines with full pitched winding the number of conductors in opposition and commutating (inactive) is small as compared with the number of active conductors; therefore the torque is developed by the electro-dynamic force (field surrounding the conductors). In machines in which the winding pitch is equal to or less than the virtual pole arc, the number of inactive conductors or in opposition is increased and reaches the maximum when the pitch corresponds to one tooth. In such cases, the electro-dynamic force is more or less neutralized, and the torque is therefore produced by the coils, acting as ampere-turns, magnetizing the enclosed part of the armature iron, and by the lines of force produced in this part of iron being interlinked with the field flux. The back E. M. F. is not produced in the conductors by cutting sideways through the lines of force, but by the flux passing through the interior of the armature coils as in the case of a transformer.

For the design of a motor or dynamo with radially projecting poles and with normal circumferential speed, i. e. $v<30$ m/sec., the length of the armature iron is limited to certain dimensions, which are given by the formula:

$$\frac{l}{b_i} = 1.0 \text{ to } 1.3$$

wherein

$l$=length of armature iron

$b_i$=virtual pole arc

I have found that with machines constructed according to this invention, it is possible greatly to increase the armature length, without detrimentally affecting their working. According to this additional feature of the invention

$$\frac{l}{b_i} > 1.5$$

The practical examples hereinbefore given under A and B, with the exception of the motors A.6, B.8, 9 and 10, were limited by the given dimensions of the housing; they were machines of conventional construction which had to be replaced by motors according to the invention in the available housings. But, in those cases where no limitation was imposed the length of the armatures was greatly increased, giving the following results:

*Motor example A.6*

Length of armature=12 cm.
Diameter of armature=12 cm.
Virtual pole arc $b_i = \alpha_i \times \tau$

$$\alpha_i = .74$$

$$\tau = \frac{3.14 \times 12}{4} = 9.42 \text{ cm.}$$

and thus:

$$b_i = .74 \times 9.42 = 6.97 \text{ cm.}$$

$$\frac{l}{b_i} = \frac{12}{6.97} = 1.72$$

*Motor examples B.8, 9, 10*

Length of armature=15 cm.
Diameter of armature=19.6 cm.

$$\alpha_i = .8$$

Virtual pole arc

$$b_i = \alpha_i \times \tau = .8 \times \frac{3.14 \times 19.6}{10} = 4.92 \text{ cm.}$$

$$\frac{l}{b_i} = \frac{15}{4.92} = 3.06$$

This increased ratio of

$$\frac{\text{armature length}}{\text{virtual pole arc}}$$

allows the length of the iron parts of the armature and field to be greatly increased, with the result that the flux is increased with the same outside dimensions and the output is still further increased as compared with the conventional construction. It is also known that the weight of the active copper decreases with the increasing value of the above ratio.

$$\frac{l}{b_i}.$$

By using the values above given for the relations

$$(1-\alpha_i)\frac{Z}{2p} \text{ and of } \frac{l}{b_i}$$

in the construction of the machines, it has been

found that, as compared with the conventional constructions, the same output can be obtained with much smaller dimensions. From a series of machines built according to the invention it has been ascertained that the cubic contents of the machines was reduced to about one third of the usual cubic contents of machines of conventional constructions.

Another feature of the machines according to the invention is their flat speed and efficiency characteristics, which is additional to the feature common to all machines built on the principle of the closed iron rings, viz., that their no-load speed is low.

In order to obtain the best flux distribution for these purposes, use is made for the interconnection of the poles of the field magnet, of an annular ring which is not of uniform cross-section but tapers from the poles, as will be seen at *a* in Figure 3. If the iron parts of the ring between the poles were of uniform cross-section, there would be a great flux leakage; the tapering, however, causes a high saturation to be produced quickly with increasing load. In this way the leaking away of the pole flux is prevented and good commutation in ensured. At the same time, the increase in the cross-section towards the poles causes the pole flux to be spread out as much as possible for crossing over the air gap to the armature, and the desired flux distribution is effected automatically as required for the various loads.

In machines running as both motor and dynamo the thinnest parts *a'* of the said iron ring lie in the middle between the poles. In machines running only as motors or only as dynamos the thinnest parts preferably lie nearer to one or the other of the adjacent poles, owing to the different reaction of the armature.

It has also been found that the starting current of the machines constructed according to the invention, when suddenly connected to the mains without a starting resistance, is substantially smaller than in machines as hitherto constructed. Further, the machines, when switched on against full load, obtain their normal speed in a very short time. It is, therefore, possible to start these machines against full load, or 100 per cent. overload, without a separate starting device, as the commutation is always good with these different load conditions.

The invention is applicable to both D. C. and A. C. machines, the same advantages being obtained in both cases.

Various methods have hitherto been proposed for providing the armature and the field magnet with a closed iron ring.

Figure 4 shows a construction in which the field poles and the closed iron ring are made from stampings *c*, each comprising, in this example, four pole parts *d* and four interconnecting paths *e*. The stampings are riveted together and former wound field coils (not shown) are pushed over the poles in the usual way. The yoke *f*, shown in the dotted lines, is then forced over the field magnets and connected thereto in a known manner.

Figure 5 shows part of another construction, for instance, of a ten-pole machine, which likewise permits of former wound field coils being used. *d*, *d* are two of the field poles forming with the other poles and with the yoke part *f* one piece of stamping. The lower parts of the poles *d* facing the air gap are cut in, on both sides of each pole, as shown at *g*, to take up the interconnecting bridge parts *h* and hold them in position. These bridge parts may, according to design and dimensions of the machine, consist of stampings or be made of one solid piece. After the pole stampings have been riveted together, the field coils *i* are placed over the pole parts *d*, and thereupon the bridge parts *h* are inserted in between the pole ends, thus forming with the latter the closed iron field ring. *j* is a steel tube of the housing.

The stampings of the iron parts of the armature with closed iron ring may be designed in different ways, according to the size of the machine and the kinds of armature windings which it is desired to use. It has been found that tunnel winding can be used without increasing the manufacturing costs. This method is preferred, especially in the case of large machines wherein a small number of conductors of strip copper is used. In such a case the armature stamping is designed as illustrated on the right hand side of Figure 3.

It is, however, possible so to form the stampings that former wound coils can be used therewith and Figure 6 illustrates such an example. In this construction the armature stamping comprises a closed iron ring *k* and slots *l* which are open towards the inner side. This method is especially useful with a single tooth winding, it being possible to slip over the former wound coils from inside. When the winding is completed, the whole is forced over a centre iron part *m* (shown in dotted lines) which, as illustrated, may be constructed in the form of a wheel to save weight.

The use of the closed iron ring on the armature has the further advantage that it is not necessary to secure the winding in a radial direction by separate mechanical means, as is necessary with machines of usual construction, thus increasing the space available for the winding.

Having now described my invention, what I claim as new and desire to secure by Letters Patent is:—

1. A dynamo-electric machine comprising a field magnet having a number of poles and a slotted drum-wound armature having a continuous closed iron ring facing the air gap between field magnet and armature, and in which the ratio of the number of armature slots (Z) to number of pole pairs ($p$) and the ratio ($\alpha_i$) of the virtual pole arc ($b_i$) to the pole pitch ($\tau$) satisfies the formula:

$$(1-\alpha_i)\frac{Z}{2p}<2.3.$$

2. A dynamo-electric machine comprising a field magnet having a number of poles and a slotted drum-wound armature, both field magnet and armature having a continuous closed iron ring facing the air gap between field magnet and armature, and in which the ratio of the number of armature slots (Z) to number of pole pairs ($p$) and the ratio ($\alpha_i$) of the virtual pole arc ($b_i$) to the pole pitch ($\tau$) satisfies the formula:

$$(1-\alpha_i)\frac{Z}{2p}<2.3.$$

3. A dynamo-electric machine as claimed in claim 1, in which the ratio of armature length ($l$) to virtual pole arc ($b_i$) satisfies the formula:

$$\frac{l}{b_i}>1.5.$$

4. A dynamo-electric machine as claimed in

claim 2, in which the ratio of armature length ($l$) to virtual pole arc ($b_i$) satisfies the formula:

$$\frac{l}{b_i} > 1.5.$$

5. A dynamo-electric machine as claimed in claim 1 in which the ratio of armature length to virtual pole arc is about 3.

6. A dynamo-electric machine as claimed in claim 2 in which the ratio of armature length to virtual pole arc is about 3.

7. A dynamo-electric machine as claimed in claim 2 and in which the part of the continuous closed iron ring of the field magnet which lies between the poles has a cross-section which tapers from the poles.

8. A dynamo-electric machine as claimed in claim 2 and in which the field magnet is composed of stampings made integral with its closed annular ring part facing the air gap.

9. A dynamo-electric machine as claimed in claim 2 in which the part of the continuous closed iron ring of the field magnet which lies between the poles has a cross-section which tapers from the poles and in which the field magnet is composed of stampings made integral with its closed annular ring part facing the air gap.

10. A dynamo-electric machine as claimed in claim 2 and in which the continuous closed iron ring of the field magnet comprises bridge members inserted between the poles.

11. A dynamo-electric machine as claimed in claim 2 and in which the continuous closed iron ring of the field magnet comprises bridge members inserted between the poles, which bridge members have a cross-section tapering from the poles.

12. A dynamo-electric machine as claimed in claim 1 in which the armature body consists of stampings having a closed iron ring at its outer periphery and slots open towards the inner side, and of a centre iron part, as and for the purpose set forth.

JONNI ZETSCHE.