Oct. 3, 1967 E. GRUNWALD 3,345,523

MAGNET FOR MAGNETOHYDRODYNAMIC GENERATORS

Filed April 23, 1965 2 Sheets-Sheet 1

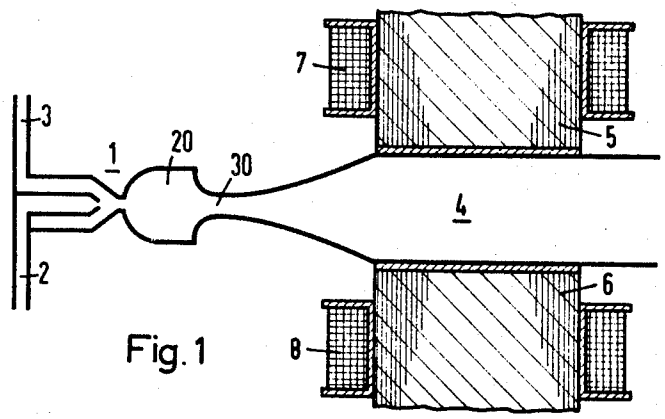


Fig. 1

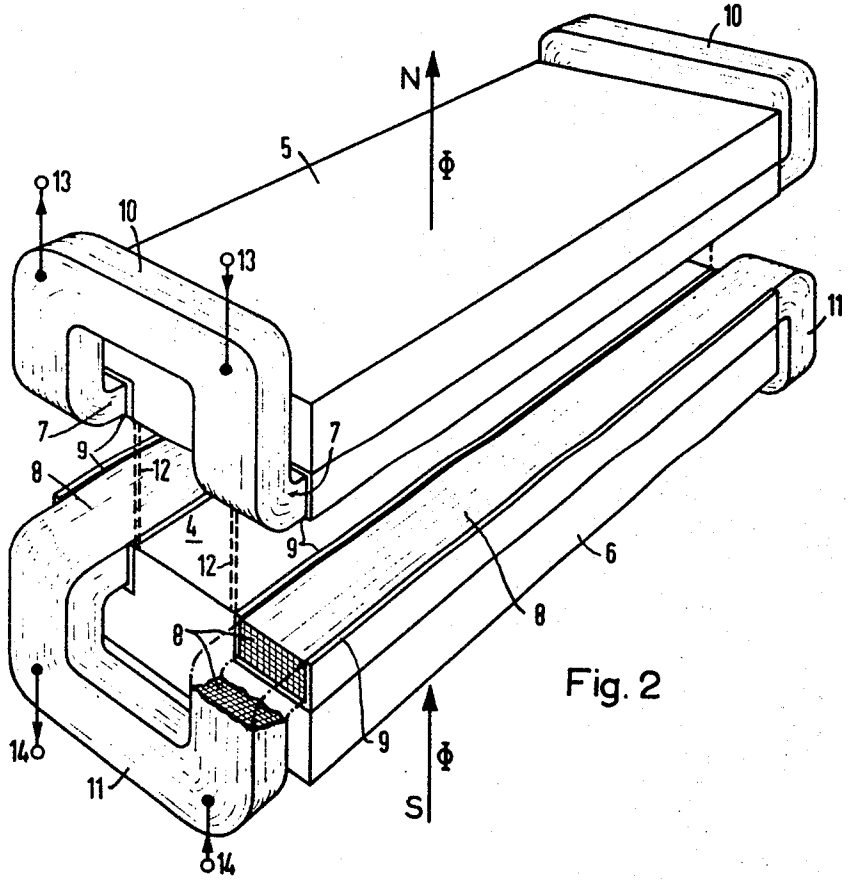


Fig. 2

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MAGNET FOR MAGNETOHYDRODYNAMIC GENERATORS

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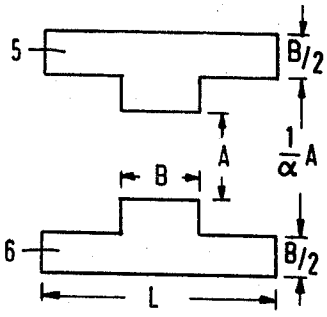


Fig. 3

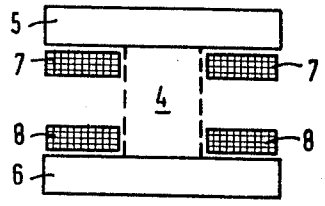


Fig. 4

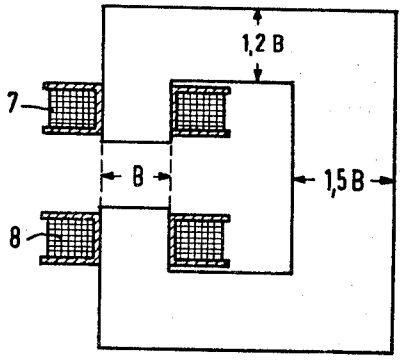


Fig. 5

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MAGNET FOR MAGNETOHYDRODYNAMIC GENERATORS

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7 Claims. (Cl. 310—11)

My invention relates to an electromagnet for magnetohydrodynamic (MHD) or magnetoplasmadynamic (MPD) generators having pole pieces arranged in the operating channel of the MHD-generator or forming the walls of the operating channel.

The operating principle of MHD-generators is as follows: By applying a magnetic field perpendicularly to the flow direction of a partly ionized, seeded gas having the property of a plasma, electrical energy can be taken from electrodes located perpendicularly to the magnetic field and the flow direction of the plasma. As a rule the electrodes are arranged in an operating channel traversed by the plasma. In order to achieve a high power yield per unit volume of the channel, very powerful magnetic fields are required.

To produce the required large inductance in the generator channel, it is customary to interconnect the pole shoes or pieces by yokes which serve as magnetic return paths therefor. Such yokes are expensive and moreover, they hamper access to the electrodes. Consequently, magnets of the most varied construction have heretofore been suggested. Nevertheless, accessibility to the electrodes continues to remain a technological operating prerequisite until success is achieved in developing electrodes that are reliably protected against being burned off and that require no maintenance.

It is accordingly an object of my invention to provide an MHD generator with magnetic circuit means that avoid the disadvantages of the known MHD generators.

It is a further object of my invention therefore to eliminate the yoke heretofore employed to conduct the magnetic flux between the pole shoes and thereby permit access to the electrodes through the space heretofore occupied by the yoke.

It is also an object of my invention to reduce the cost of making an MHD generator by eliminating the yoke and increasing the number of magnetic coil windings thereof since it has been found that the cost of the increased number of windings for producing the same magnetic induction through an air gap as for a yoke with conventional number of windings is less than the cost of the iron yoke, a fact which is particularly true of large channel cross sections of one meter or more.

With these and other objects in view, I provide in accordance with my invention an MHD generator in which the magnetic circuit does not pass through iron except for the pole pieces.

In accordance with a further aspect of my invention in addition to eliminating the yoke of the magnetic circuit, I increase the number of the magnetic coil windings so as to produce the same magnetic induction in the air space left by removing the yoke as would normally have passed through the yoke of a generator having a conventional number of magnetic coil windings.

Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as embodied in a magnet for magnetohydrodynamic generators, it is nevertheless not intended to be limited to the details shown since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

The construction and method of operation of the invention, however, together with additional objects and advantages thereof, will be best understood from the following description with specific embodiments when read in connection with the accompanying drawings, in which:

FIG. 1 is a diagrammatic view of a basic MHD generator with a conventional magnet shown in section;

FIG. 2 is a perspective and partly diagrammatic view of an embodiment of a magnet according to my invention which is adapted to be substituted for the magnet shown in FIG. 1;

FIG. 3 is an end view of FIG. 2 with the excitation windings omitted and including dimensional symbols;

FIG. 4 is an end view, partly in section, of another embodiment of FIG. 2; and

FIG. 5 is an end view, partly in section, of a conventional magnet including dimensional symbols related to those of FIG. 3.

Referring now to the drawings and first particularly to FIG. 1, there is shown diagrammatically a basic arrangement of an MHD generator. Fuel oil is supplied to a burner nozzle **1** through a pipe line **2** and combustion air provided with readily ionizable additive (seed material such as cessium or potassium) through a pipe line **3**. Upon ignition the flame burns in a combustion chamber **20** and the flame exhaust gases are brought to a high flow velocity through an acceleration nozzle **30**. A magnetic field is supplied to the generator channel **4** through the pole pieces **5** and **6** by means of the excitation windings **7** and **8** of magnetic field coils. Electrodes (not shown) are arranged above and below, i.e., on both sides of, the plane of the drawing in the generator channel. In addition, the generator channel and electrodes are enclosed by magnetically nonconducting walls (not shown) also located above and below the drawing plane.

An embodiment of a magnet constructed according to the invention is shown diagrammatically and in perspective in FIG. 2. The pole shoes **5** and **6** have a T-shaped cross section and are arranged in such a way that the base legs of the two T's are located spaced apart and opposed to each other. In the rectangular spaces **9** of the T-shaped pole shoes **5**, **6**, there are arranged bundles of electrically conductive wires of induction coils which form the excitation windings **7** and **8**. The end windings **10** and **11** are bent outwardly in order to clear a flange-like connection (not shown) for the pole shoes. The generator channel is laterally enclosed by magnetically nonconductive walls **12** indicated by the dotted lines. The magnet as shown in FIG. 2, thus has no yokes and affords free access to the electrodes which are also located laterally of the generator channel adjacent the walls **12**. (The excitation windings **7**, **8** may also be arranged laterally of the channel, between the pole shoes, if the electrode maintenance problem is secondary to a requirement for very powerful magnetic fields.) The electrical connections to the excitation windings **7** and **8** are indicated by **13** and **14**. With direct current supplied in the direction of the arrow **13**, **14** of the embodiment shown in FIG. 2, a north pole is formed above and a south pole below, so that a magnetic flux traverses the generator channel in the direction of arrows N, S.

FIG. 3 is a simplified end view of FIG. 2 with the excitation windings omitted and including dimensional symbols having a relationship in accordance with the following equation:

$$\frac{L}{A}=k\cdot\frac{\pi}{4}\cdot\frac{1}{\alpha}\left[\frac{B}{\alpha_A}\cdot\tan\frac{\frac{\pi}{2}}{1+\alpha\xi}\right]^2-\frac{\pi}{4}\cdot\frac{1}{\alpha}-\frac{1}{2}\frac{B}{A}$$

Following is an explanation of the symbols in the foregoing equation and in FIG. 3:

α=a coefficient ($\alpha \leqslant 1$) as defined by the data shown in FIG. 3

ξ=resistance ratio or the ratio of

$$\frac{\text{Magnetic resistance of the yoke path}}{\text{Magnetic resistance of the useful air gap of the width A}}$$

k=an empirical factor for ambient conditions or external influences and may be set equal to 1.

With the foregoing equation, the profile dimensions of the pole shoe or the "resistance ratio" may be approximately determined.

For example, if

$$\frac{B}{A}=1 \text{ and } \alpha=\frac{1}{2}$$

and if L/A is to be determined, then for a given resistance ratio of $\xi=0.5$

$$\frac{L}{A}=1.6$$

In FIG. 4, plate-shaped pieces **5** and **6** of another embodiment of a magnet according to the invention, are represented in end view. The profile of the pole shoes **5**, **6** in FIG. 4 is obtained for $\alpha=1$. The excitation windings are also indicated by **7** and **8** in FIG. 4. By the arrangement of the excitation windings **7** and **8** between the pole shoes **5** and **6**, almost the entire magnetic flux is passed through the generator channel **4** and through the useful air gap.

With a conventional magnet for MHD generators as shown diagrammatically and in side view in FIG. 5, there will now be compared a magnet constructed in accordance with my invention in which $A=B=L$, $k=1$ and $\alpha=0.464$. With an assumed ratio of

$$\frac{\text{Iron required for a magnet according to FIG. 5}}{\text{Iron required for pole shoes in a magnet according to the invention}}=5$$

and a resistance ratio of $\xi=0.56$, the ratio of ampere turns for equal magnetic induction is:

$$\frac{\text{Ampere turns in pole shoes of a magnet according to invention}}{\text{Ampere turns in a magnet according to FIG. 5}}=1.56$$

The ratio of excitation outputs is then:

$$\frac{\text{Excitation output for a magnet according to FIG. 5}}{\text{Excitation output for a magnet of this invention}}=2.44$$

The amounts of copper required for the excitation windings, then are in the following ratio:

$$\frac{\text{Copper quantity for a construction according to the invention}}{\text{Copper quantity for a construction according to FIG. 5}}=2.44$$

If it is assumed generally that iron makes up 80% of the total cost of a magnet and copper about 20%, then the following price comparison is obtained.

For the embodiments of the magnet constructed according to my invention, the iron requirement drops to 16% while the copper requirement increases to 49%.

The cost thereof is consequently only 65% of the cost for a magnet constructed according to FIG. 5.

In the magnet of the invention the air gap provides the return path for the magnetic flux. It is therefore advantageous to widely "scatter" the magnetic flux by shaping the pole shoes so that they are for example, of wider dimension than the generator channel and consequently afford a large cross section for the return path of the magnetic flux.

I claim:

1. In an MHD generator having a plasma flow channel, an electromagnet comprising a pair of pole shoes located respectively at opposite sides of the plasma flow channel, and electrically energizable coil means for producing a magnetic field in a circuit passing through said pole shoes and said channel, said pole shoes being the only components of said circuit made of iron.

2. In an MHD generator having a plasma flow channel, an electromagnet comprising a pair of pole shoes located respectively at opposite sides of the plasma flow channel, said pole shoes having a width greater than the width of said channel, and electrically energizable coil means for producing a magnetic field in a circuit passing through said pole shoes and said channel, said pole shoes being the only components of said circuit made of iron.

3. In an MHD generator having a plasma flow channel, an electromagnet comprising a pair of pole shoes located respectively at opposite sides of the plasma flow channel, said pole shoes having a T-shaped cross section with the base legs of the T's located directly opposite one another, and electrically energizable coil means for producing a magnetic field in a circuit passing through said pole shoes and said channel, said coil means being located in the rectangular spaces of the T-shaped pole shoes, and said pole shoes being the only components of said circuit made of iron.

4. In an MHD generator having a plasma flow channel, an electromagnet comprising a pair of pole shoes located respectively at opposite sides of the plasma flow channel, said pole shoes being in the form of substantially flat plates, and electrically energizable coil means for producing a magnetic field in a circuit passing through said pole shoes and said channel, said coil means being located between said plates and externally of the channel, and said pole shoes being the only components of said circuit made of iron.

5. MHD generator according to claim **1** wherein said pole shoes form walls of the plasma flow channel.

6. MHD generator according to claim **1**, wherein said magnetic field circuit passes through an air gap between said pole shoes externally of the plasma flow channel.

7. MHD generator according to claim **6**, wherein said coil means has a number of coil windings for producing a given magnetic flux through said air gap for a given energizing current, said number of coil windings being greater than a given number of coil windings which, for the same given energizing current, produces the same magnetic flux through an iron yoke located between said pole shoes.

No references cited.

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