Novel compact and fast magnetic bearings by saturated main coils and linear auxiliary coils for the gas turbine generator of next generation fast reactors

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Abstract

This paper presents a new design of magnetic bearing structure for application in Nuclear Power Plant (NPP). The proposed design includes so-called saturated coils which is used to generate the bias flux for bearing almost the whole mass of the rotor, and so-called linear auxiliary coil controlled to stabilize the suspension. The saturated coil is considered as an special electromagnet which is controlled to operate in the region of magnetic saturation in order to minimize the bias current as well as to enhance the magnetic flux density. This strategy will result in a very compact size of magnetic bearing as well as increasing the speed of the response of the current controller. The novel structure is expected to be applied to design very high power gas turbine generator of next generation of fast reactor in which the mass of rotor can reach 50 tons. The total power of the NPP can reach 2,000 *MW*. Moreover, the issue of arc occurrence between coils is also discussed and two solutions are proposed.

Keywords: magnetic bearing, saturation coil.

1. Introduction

Over the past 40 years, magnetic bearing has been widely researched and applied in many applications such as flywheels, turbines, or high-speed machines. In general, magnetic bearing can be classified in 3 types, namely, passive, active, and hybrid magnetic bearings (PMB, AMB, and HMB, respectively) [1]. Compared to PMB and AMB, HMB is getting more attention from researchers thanks to the fact that it combines the merits of the two former types, such as low power loss and the ability to achieve the stable suspension. However, there are two demerits that makes HMB is difficult to be applied in manufacturing magnetic bearing for very large load capacity. Firstly, in HMB, the bias flux is generated by permanent magnets which is impossible to control. Moreover, the magnetic characteristics of a permanent magnet will be degraded when the time goes by, leading to big problems of maintenance especially in very high load capacity application where the maintenance is conducted not so easily. Secondly, the structure of HMB is quite complex compared to AMB and PMB, which is not suitable for applications in industry. Hence, AMB is still likely to be used in manufacturing magnetic bearing for high power electrical generators in power plants even though its disadvantage of high power loss. There are some high load capacity applications which is operating or in progress all over the world such as: Wind turbine Harakosan Z72 with 12.5-ton rotor mass in Netherland; Gas Turbine High Temperature Reactor (GTHTR300) with 35-ton rotor in Japan (in progress), 35-ton oil-free hydraulic turbine in Japan, and 10-ton rotor mass of 9 MW synchronous turbine-generator (SKF Russia).

A project of establishing a new fast reactor of which the electrical generators and the turbines are supported by magnetic bearing, is in progress in Department of Nuclear and Quantum Engineering, KAIST. The rotor mass of the generator can reach 50 ton weight, and the total power of the NPP might get 2,000 *MW*. Therefore, a new design of magnetic bearing is necessary to extract advantages of such above kinds of magnetic bearings. Moreover, the problem of arc occurrence is also solved with potential solutions shown in Section 2.

In this paper, we presents a novel magnetic bearing design in which there is a kind of so called saturated coil which is operated in saturation region. Thanks to this coil, the bias flux will be generated with very small current leading to a compact magnetic bearing. The other kind of coil is so-called linear auxiliary one which is used to generate the control current to realize the stable suspension. It operates in linear relationship between current and magnetic flux density.

2. Technical problems and solutions

One of the most severe problem in generator operation is the arc problem. In a certain pressure and distance, the break-down voltage at which the arc occurs is expressed in Paschen's curve shown in Fig. 1. The break-down voltage can be calculated as follows.

$$V_B = \frac{a \times p \times d}{\ln(p \times d) + b} \quad (1)$$

where: V_B is the break-down voltage (*V*), p is the pressure (*atm*), d is the gap distance (*m*), and a, b, are the constants depend on the composition of gas.

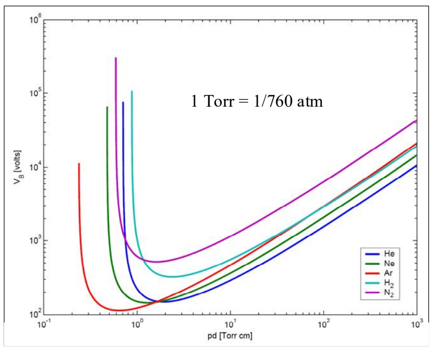

Fig. 1. Paschen's curve

As shown in Fig. 1, the break-down voltage of helium in a almost all value of pressure and distance is much smaller than that of nitrogen or air, leading to the arc occurs between coils in a generator. This fact is a serious issue because helium is used as a coolant in fast reactor. One potential solution proposed by Professor Lee Jeong Ik at Dept. Nuclear and Quantum Engineering, KAIST, to solve the problem is to increase the pressure of helium flow used to coolant in generator. The helium pressure can be increased to about 30 atm.

On the other hand, we also concern about an additional solution to solve the problem of arc as shown in Fig. 2.

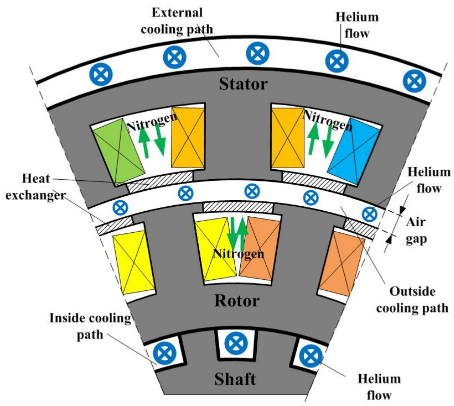

Fig. 2. Solution for arc problem.

From the figure, the nitrogen used to coolant the stator and rotor coils and the helium used to coolant stator and rotor core are separated by the so-called heating exchangers to prevent the arc problem between coils thanks to high break-down voltage of nitrogen compared to that of helium. The helium flow outside the stator, between heat exchangers and between rotor and the shaft to coolant the generator. Moreover, combined to the above solution, helium and nitrogen can be pressurized to assure that their break-down voltage are high enough.

3. The proposed saturated magnetic bearing

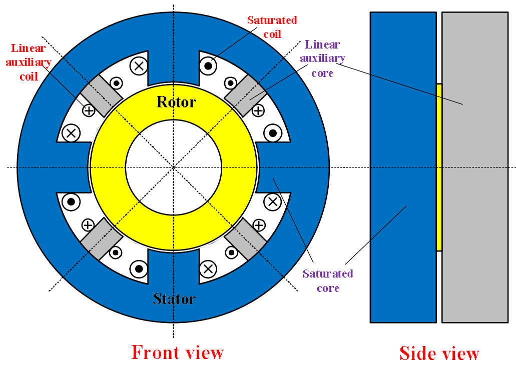

Fig. 3. Front view and side view of the proposed design.

Fig. 3 illustrates the proposed design of magnetic bearing which is called saturated magnetic bearing. As mentioned before, the saturated coil will be maintained to work in saturation region to produce the bias flux. Fig.4 shows the magnetic hysteresis loop of typical soft magnetic material. At the beginning, the current of saturated coil will be increased into saturation region (region III), and decrease so that the magnetic flux density is around the residual magnetic flux (region II). At this region which is the operation point, we will get high bias flux with very small control current. Moreover, the relationship between current and magnetic flux density is quite linear. As shown in Fig. 3, the auxiliary coil currents are considered as the control current to maintain the stable suspension. The current will work at the linear region in hysteresis loop. Since the bias current bears almost the mass of the rotor, the linear auxiliary current will small so that it can be changed quickly and have fast response, which is one of the most important advantages of the proposed design.

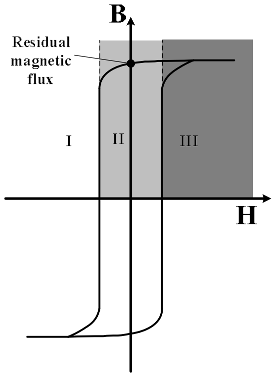

Fig. 4. Hysteresis loop.

The proposed design enables the bias flux can be fully controlled, which is very convenient in high load capacity applications. Moreover, another main advantage is to reduce significantly the size of magnetic bearing. Fig. 5 shows the comparison in size between conventional AMB design (left) and proposed design (right) with the same parameters of the rotor. Since the proposed design works at saturation region, the bias current is much smaller than that of AMB design causing the compact size of the stator of the proposed design. With generating the same 1.5 *T* magnetic flux density, the value ΔD of the stator in proposed design can just be a half of that of AMB design.

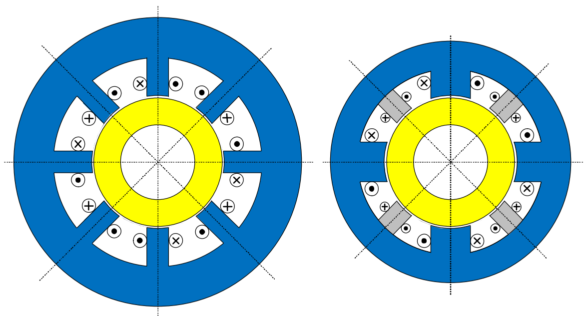

Fig. 5. Comparison of size of AMB design and the proposed design.

4. Conclusion

The paper shows some problems of generators in the next generation fast reactor and the solutions for them. It also show a promise magnetic bearing design which can be applied to the manufacturing generator for the fast reactor. The advantages of the proposed design includes the compact size and fast response.

References

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