EXPERIMENTS ON A NEW CONDUCTIVE STRUCTURE FOR ELECTRODYNAMIC BEARINGS

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Summary This paper presents a new conductive structure for electrodynamic bearings, replacing the coils by flexible PCB (FPCB), which largely simplifies the manufacturing and can produce much thinner windings. To verify the performance of this new concept, an axial electrodynamic bearing test rig comprising a FPCB conductive structure and a permanent magnets array is built and induced voltage measurement is performed with various axial displacements and rotating speeds.

INTRODUCTION

The principle of electrodynamic bearings relies on the relative motion of a conductor in a magnetic field, which causes a variation of the magnetic flux linked to the conductor. It generates an electromotive force that induces eddy currents, which in turn generate electromagnetic forces restoring the rotor to its nominal position. In our setup, the permanent magnets(PM) on the rotor interact with stator windings. The PM rotor rotates outside of the stator windings, when the rotor is at the axial nominal position, half of the magnetic flux issuing from the iron and interacting with the stator windings goes upwards and the other half downwards, so the net flux with the windings is zero and no current nor is force produced. Once the rotor is displaced from this nominal position, voltages and currents are induced within the windings, and an axial restoring force is created.

During the operation of electrodynamic bearings eddy currents are not always necessary, moreover, unnecessary eddy currents should be minimized to reduce power losses. Conductors in electrodynamic bearings are carriers of eddy currents, whose configurations influence eddy currents distribution and magnitude. Conductors' configurations usually can be divided into two groups: bulk disks or cylinders, and short-circuited coils. Considering eddy currents, coils have the advantage that eddy currents can be lead into desired current paths, and that stray eddy currents due to badly oriented magnets thus will have a much less negative effect on losses [1].

However, in bearings with normal discrete coils, the coils cannot occupy the whole space available, and the discrete coils lead to pulsating restoring forces. To overcome these drawbacks, a special conductive structure called "distributed coils" was presented in [2], which is composed of interconnected copper wire segments, similar to a squirrel cage induction motor. Because the available volume is optimally filled with copper, no force ripple is created. A manufacturing method comprising several steps such as winding, gluing, cutting, polishing and electroplating was also presented in [2].These steps make the manufacturing complicated and impractical, especially when the wires are demanded as thin as possible to minimize losses.

This paper presents a new conductive structure for electrodynamic bearings, replacing the coils by flexible PCB, which largely simplifies the manufacturing and can produce much thinner windings. To verify the performance of this new concept, an axial electrodynamic bearing test rig comprising a FPCB conductive structure and a permanent magnets array is built and induced voltage measurement is performed with various axial displacements and rotating speeds.

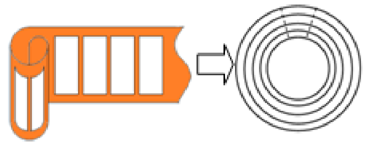
AXIAL ELECTRODYNAMIC BEARINGS TEST RIG

FPCB conductive structure

There are two specific demands for the "distributed coils" concept: each wire's thickness or diameter should be minimized, at least less than 0.3mm; spacing between each wire should be minimized, that is wires' distribution should be as dense as possible. These two demands are for reducing unnecessary eddy currents and maximally occupying the space. It's like a bulk conductor but with designed paths to guide currents.

To match the above demands, the idea of manufacturing the "distributed coils" through Flexible PCB is proposed, which is to "print copper wires" on a flexible PCB and wind it to a hollow cylinder. There are only two steps: firstly, produce the Flexible PCB pieces (Fig.1), in which the wires are parallel vertically and are only interconnected at the two ends; secondly, winding the FPCB pieces and connecting each one to form a hollow cylinder.

In this paper, 25 Flexible PCB pieces are produced. The length and width of each piece are 100mm and 18mm respectively. The thickness, length and width of each



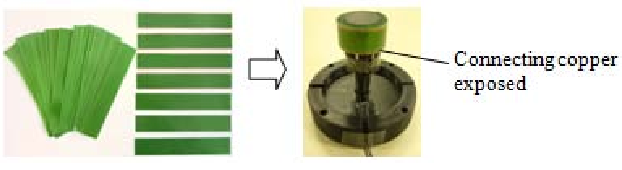


Fig.1 Sketch and pictures of Flexible PCB

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"printed wire" are 0.018mm, 14mm and 0.3mm respectively, the spacing between each wire is 0.15mm, and the width of the connecting wires at the two ends is 2mm. Copper wires are "printed" on both sides of the FPCB, and total thickness of each FPCB piece is 0.136mm. The FPCB pieces are wound and glued on a plastic mandrel of diameter 32mm (Fig.1). Note that, the connecting copper on the outermost piece are exposed without insulating material so it is convenient to connect external measurement circuits.
The main advantages of FPCB conductive structure are that the copper wires can be "printed" very narrow and thin which benefits for reducing unnecessary eddy currents, and since the wires are interconnected in each piece there is no need for electroplating an external copper plate to connect them which largely simplify the process.

Permanent magnets array
The FPCB conductive structure works as the stator in the electrodynamic bearing test rig, and the main rotating part is a permanent magnets array. As shown in Fig.2, the PM array is made of three layers and each layer consists of 24 pieces of cylinder magnets of diameter 12mm and length 6mm. The magnets are assembled to produce alternative magnetic field, and the soft iron plates between the magnets are for guiding the magnetic circuits.

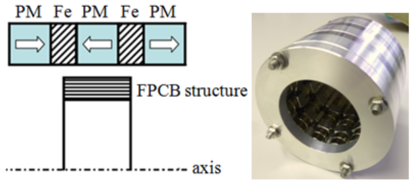
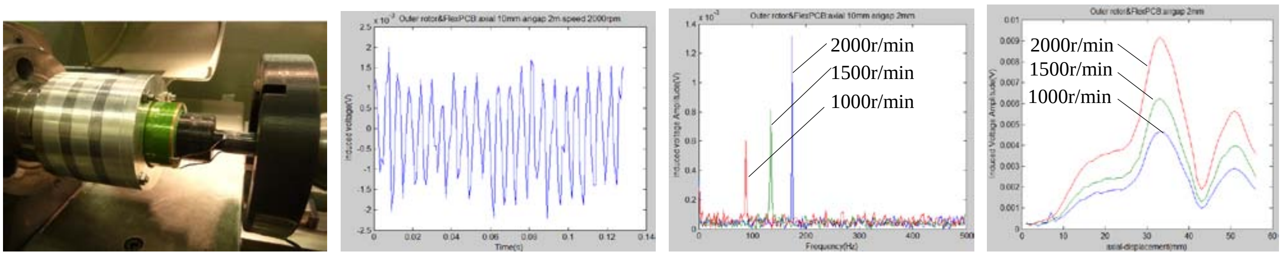


Fig.2 Sketch and pictures of PM array

INDUCED VOLTAGE MEASUREMENT WITH THE FPCB CONDUCTIVE STUCTURE

To verify the performance of the FPCB conductive structure, induced voltages are measured with various axial displacements and rotating speeds. The PM rotor is mounted on a lathe's spindle and the FPCB structure with its base is clamped by the chuck of the tailstock (Fig.3). The air gap between the PM array and the FPCB structure is 2mm. An external circuit is connected with the outermost FPCB piece to measure the induced voltage on it. During the measurement, firstly align the ends of the PM array and the FPCB structure and then move the tailstock to insert the FPCB structure into the PM array, the axial increment of each movement is 1mm, the total axial movement is 58mm, and record the induced voltages at each rotating speed. There are 3 rotating speeds in the measurement: 1000r/min, 1500r/min and 2000r/min.



(a) Induced voltage measurement (b) Induced voltage with time, 2000 r/min, 10mm axial displacement (c) Induced voltage FFT analysis 10mm axial displacement (d) Induced voltage amplitude along axial displacement

Fig.3 Induced voltage measurement and results

Fig.3 shows the induced voltage measurement and results. In Fig.3(b) it is the induced voltage with time with 2000 r/min rotating speed and 10mm axial displacement, Fig.3(c) shows the FFT analysis of the induced voltages with 3 rotating speeds and 10mm axial displacement, and Fig.3(d) shows the induced voltages amplitude along total axial displacement with 3 rotating speeds. It can be concluded that the dominant frequency of the induced voltage varies with the rotating speed, and with same axial displacement the induced voltage amplitude increases with the rotating speed, and the induced voltage amplitude varies with axial displacement which not only determines the net flux but also the flux density distribution.

CONCLUSIONS

The concept of FPCB conductive structure for electrodynamic bearings is proposed to simplify the "distributed coils" manufacturing processes and with the advantages of thinner windings and less losses. The induced voltage measurement verifies the new conductive structure's feasibility and performance, and the result is consistent with the theoretical analysis. The FPCB structure's parameters such as each piece's length, each wire's width, spacing, connecting part's width, etc., can be optimized for different bearing's characteristics. Besides the "distributed coils" structure, other coils configuration with similar demands can also be realized through FPCB.

Acknowledgment
Doctoral assistant Laura Santos Carreras in LSRO, EPFL has been of great help in proposing the original idea of FPCB conductive structure and manufacturing the test rig.

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