STUDY OF THE INDUCTION TYPE BEARINGLESS MOTOR

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ABSTRACT

A control method that achieves stabilized operation under fluctuating torque load in an induction type bearingless motor using a squirrel cage rotor, is studied. When the squirrel cage rotor is adopted in the induction type bearingless motor, fluctuations of the driving flux and control flux upon the torque loaded condition, induce the secondary current in the rotor. And this alters the magnetic flux distribution in the air gap. The fluctuation of the flux distribution interferes the generated controlled magnetic force; therefore, maintaining the rotor to stably levitate has been difficult. This problem is caused by using current feedback to control the position control flux. Then it has to be needed another control method to control the posiotion control flux distribution in the air gap for using squirrel cage rotor. In this paper, a control method for stabilization under torque load condition is proposed. Magnetic flux feedback is used to control the position control flux by detecting magnetic flux distribution. Also, results of some experiments is introduced, describing behaviors of a rotor under fluctuated load with using a bearingless motor test unit having the two ordinary squirrel cage rotors. In addition, outlines a canned motor pump, which the control method to be presented in this paper is applied to. Furthermore, experimental results are shown when this method was applied to a test unit of the 15kW power output in order to confirm the feasibility to bearingless motors with the greater output. The results of the load tests using these test units show that the proposed method is effective to stabilize the levitated rotation against fluctuating torque loads.

INTRODUCTION

The bearingless motor is a multi-functionally assembled part and has functions of an active magnetic bearing and a motor using a pair of single stator and rotor. To actualize a contact-free suspending and rotating system, majority of conventional systems have been constructed with a magnetic bearing and a motor. However, applying a bearingless motor to an ordinary contact-free suspending and rotating system allowed us to shorten the length of the rotor shaft. This advantage provides us the higher rotational speed and the smaller volume of the machine. For the bearingless motor, because the bearing force is generated by the driving flux, the unbalance force of the motor is not needed to consider when designing the bearing system. Motors for the ordinary use widely use the squirrel cage rotor because of rigidity and productivity. Therefore, developing the bearingless motor system with the squirrel cage rotor is useful for wide ranges of application. However, some problems exist when the induction type rotor is applied to the bearingless motor.

One major problem is the interference of the generated magnetic forces that are caused by the distortion of the flux distribution in the air gap due to the fluctuation of the driving and control fluxes inducing a current flow in the rotor. This makes the rotor positioning unstable.

An idea of the rotor construction and control method has been proposed in the past to solve the problem [2][5]. The idea for the rotor construction is that the windings in the rotor are constructed so that the current in the rotor is induced only by driving flux. Then, the fluctuation of the control flux does not induce any current in the rotor. This idea is quite useful to decrease induced current in the rotor if the control flux varied, and bring a simple controller, but the construction of the rotor will be complicated. And a control system to stabilize the driving flux is needed for induction type bearingless motor anyway. This idea for satblizing the driving flux in bearingless motor has also been proposed in the past [1][3][4]. But a control method to stabilize a rotor positioning using a squirrel cage rotor under torque loaded condition has not been clarified.

In this paper, a control method for stabilization using squirrel cage rotor is proposed. Also, results of some experiments are introduced with using a bearingless motor test unit having the two ordinary squirel cage rotors. In addition, outline of test results for a canned motor pump which the control method to be presented in this paper is applied to, is discussed. Furthermore, experimental results is shown when this method was applied to a test unit of the 15kW power output in order to confirm the feasibility to bearingless motors with the greater output. The results of the load tests using these test units show that the proposed method is effective to stabilize the levitated rotation against fluctuating loads.

PROBLEM OF THE SQUIRREL CAGE ROTOR

As well known, the squirrel cage rotor which is widely used for industrial purposes comprises laminated plates of silicon steel as a core, endrings of aluminum or copper, and rod members which is squirrel-cage-shaped. This structure characterizes the squirrel cage rotor as rigidity and good productivity. However, when applying the squirrel cage rotor to the bearingless motor, some problems are observed with conventional controller. The serious problem is a difficulty of stable positioning under torque loaded condition. The reason is considered as follows.

Under torque loaded condition, fluctuations of both the driving and control flux are the cause of the induced current in the squirrel cage rotor. This induced secondary current affects the flux distribution in the air gap. Distorted flux distribution disturbs the rotor positioning. To solve the problem, it is needed to consider the fluctuation of both fluxes that are brought by induced current.

The driving flux is controllable to maintain constant with the field orientation control method even during the transition of torque load as well as its direction is predictable. If before-mentioned unique rotor, to which no induced current is generated due to the fluctuation of the control flux, was used with the technique mentioned above, stable positioning can be achieved when the torque load is varied.

On the contrary, if the squirrel cage rotor was used, there still exists the problem of a treatment of the control flux is. The control flux is commanded by the error of the rotor position. Therefore, the control flux vector fluctuate against loads to the rotor. Furthermore, in order to generate bearing forces as expected in control directions, the distribution of the control flux is bounded by the driving flux vector.

As a conclusion, in the case of the squirrel cage rotor adoption to the bearingless motor, it is needed new control method to control a position control flux with consideration of the induced current by the variation of the control flux under torque loaded condition.

CONTROL METHOD

As described in the problems mentioned in the previous section, it is considered to be difficult that controlling the control flux of the bearingless motor with the squirrel cage rotor only by detecting the current values. Therefore, a control method is studied, which detects the flux of the air gap and perform computation of its distribution. Mounting a detector makes the control unit size larger; however, detecting the flux provides an advantage that it is not necessary to take care of changes of the motor characteristic. If reliability of the system for detection and computation is assured, reliability of the whole system will be improved because no presumed value is used.

Figure 1 shows the conventional control system for controlling the control flux. This system has already introduced in some literatures[3][4]. The driving and position control currents are detected by the current detector (CT). The control current command value $i_4{}^*$ is obtained by calculating with them and position compensator output, and amplify the currents. The local feedback of the detected position control current brings an agreement with the control current command and its current. Hence, this block diagram can control the position control flux when the control current is equivalent to the position control flux. However, if a rotor which the induced current is generated by the fluctuation of the position control flux is adopted, the flux distribution in the air gap is not equivalent to the current command value. Because the induced current causes to fluctuate the flux distribution in the air gap. As a result, interfered position control magnetic force is generated and makes it hard to achieve the stable levitated-rotation of the rotor in the loaded state.

Figure 2 shows a block diagram of the induction-type rotor proposed in this paper. In this diagram, the magnetic flux distribution of the driving ψ_2 and position control ψ_4 in the air gap, are detected. From the detected results and the position compensator outputs, performs computation of the flux distribution command $\psi_4{}^*$, and the voltage to be applied to the position control windings are calculated in actual time. As a result, this block diagram controls so that the actual flux distribution correspond to the command value.

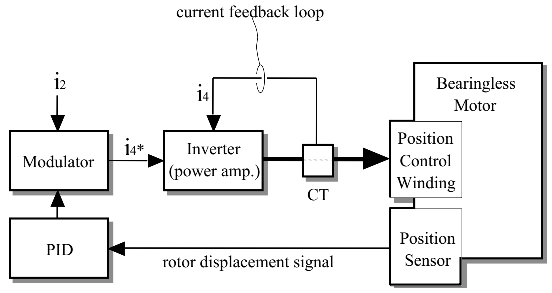

FIGURE 1: Conventional Configration for Position Control (Current Feedback)

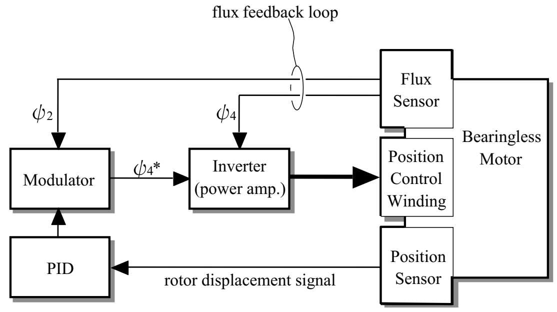

FIGURE 2: Proposed Configuration for Position Control (Flux Feedback)

EXPERIMENT ON THE PROTOTYPE MOTOR

In order to verify the control method of the described, a prototype was manufactured. Figure 3 is the prototype used in this experiment. The rotor, which diameter was 68mm, weighted 12kg. Two bearingless motors with a squirrel cage rotor respectively, were mounted on the prototype. They have 2-pole windings for drive and 4-pole windings for position control. A generator/motor and torque detector were connected to the shaft with flexible coupling to generate and measure the torque load. Magnetic fluxes were detected by the 12 search coils embedded. Figure 4 is the results obtained when the control system with the current feedback shown in Figure 1. The figure indicates a time history of displacements of the rotor when the torque load was varied from 0.4 to 1.0 Nm at approximately 6000rpm by stepping up a voltage to the field winding of the generator. As the torque load was changed, the rotor displacement was seriously varied. In particular, it indicated the contact with the auxiliary bearing in the vertical direction. Figure 5 shows the case shown in Figure 2 with the flux feedback control. The experiment was done with previous condition in same way. Compared with the previous figure, the rotating rotor was kept suspended steadily even when its torque load was increasing.

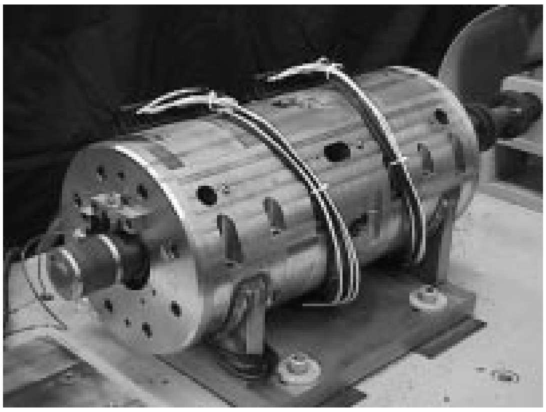

FIGURE 3: Test Machine

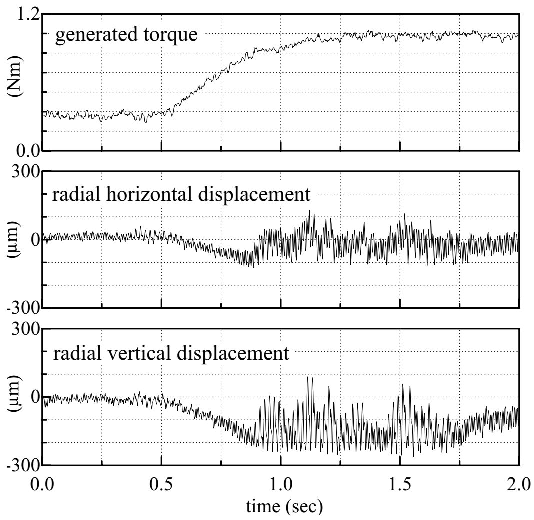

FIGURE 4: Torque-up Response (Current Feedback)

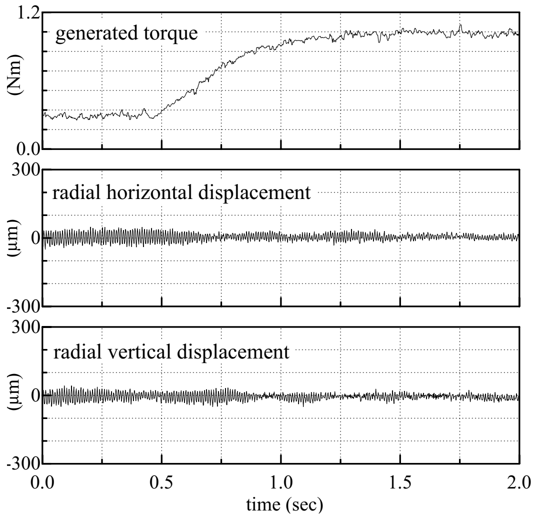

FIGURE 5: Torque-up Response (Flux Feedback)

APPLICATION TO A CANNED MOTOR PUMP

From the results above, we have verified that the tested flux-feedback control method was effective to stabilize loads to the bearingless motor with the squirrel cage rotor[6]. With the results, we have applied the control method to a canned motor pump that carries the actual fluid load. Figure 6 shows the appearance of the pump. Two bearingless motors were used. As in the prototype presented above, the squirrel case rotor in the bearingless motor was magnetically suspended and supported in the radial direction. Support in the axial direction was given by the conventional magnetic bearing. The rotation detecter was situated in the center of the prototype. The impeller and casing were utilized from a volute pump of EBARA product for 1.5kW motor. A metal can was situated to suit whole inside of the stator.

Table 1 lists the specifications.

TABLE 1: Specifications of the canned motor pump

Rotor diameter	68mm
Widths of the rotor and stator	50mm
Shaft length	600mm
Shaft weight	14kg
Magnetic clearance	0.6mm
Can thickness	0.2mm
Impeller diameter	137mm
Pump fluid	Water
Motor winding	2-pole
Position control winding	4-pole

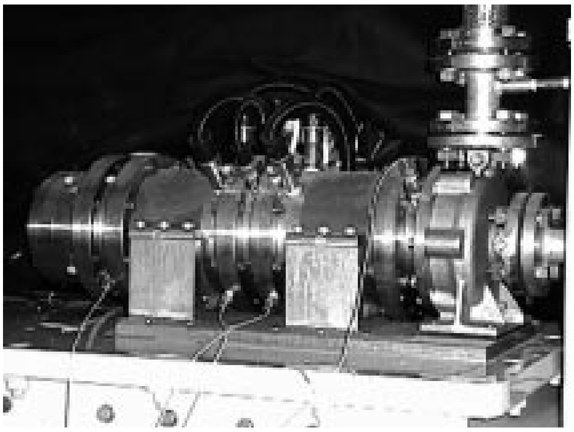

FIGURE 6: Canned Motor Pump Prototype

Figure 7 presents the rotor displacements upon start-up of the test pump. The rotation of the rotor was increased from 100 to 3300rpm approximately for one second. Due to the fluid dynamics, the position of the rotor was fluctuated after the rotation speed was increased. However, considering that the rotor vibration amplitude in the normal operation is approximately 20μm, the rotor positioning is considered stable. To note, the measured flow rate, due to the time constant employed by the flowmeter, it has a delay from the actual time.

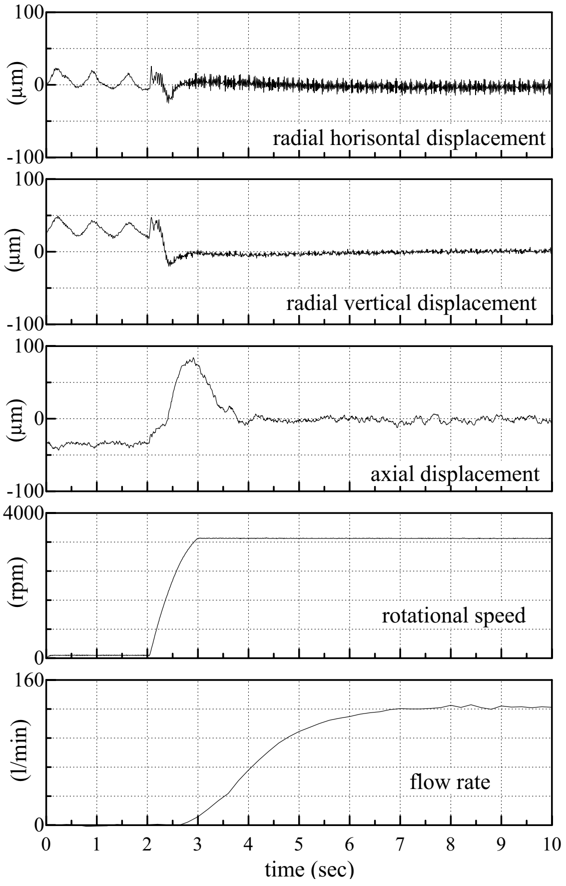

FIGURE 7: Start Up Response of Canned Motor Pump

APPLICATION TO A 15KW PROTOTYPE

Powers of the prototypes described above were both approximately 2.2kW. To verify this control's applicability to higher power devices, we have tested the control method on a prototype of 15kW. Figure 8 is a photograph of the 15kW prototype appearance. The structure is the same as those in the previous experiments, except a thrust magnetic bearing in the center of the prototype. With a flexible coupling, one end of the motor shaft is coupled, via a transmission, to the DC genarator/motor, which is the source of the torque load. Major specifications of the prototype are listed in Table 2.

TABLE 2: Specifications of the 15kW Prototype

Rotor diameter	95mm
Shaft length	1000mm
Shaft weight	42kg
Magnetic clearance	0.8mm
Stator width	85mm
Motor winding	2-pole
Position control winding	4-pole
Output	7.5kW × 2

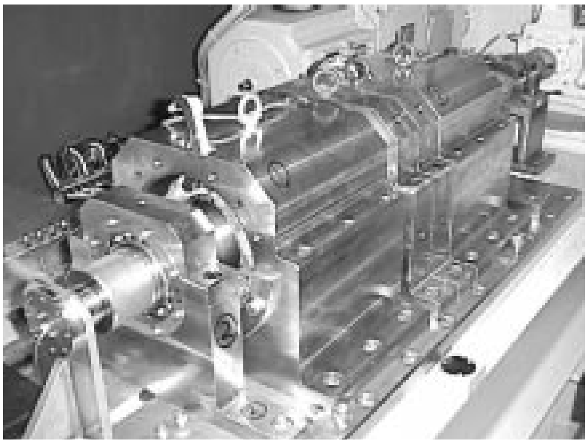

FIGURE 8: 15kW Prototype Appearance

Figure 9 and 10 present the results of the torque load test.

Figure 9 is the time history of the rotor displacements, measured during the acceleration from 0 to 6000rpm, taken in 2 seconds, without applying the torque load. Upon the initial acceleration of the rotation, the rotor displacement was increased. However, its levitated condition was kept steadily and its vibration amplitude at 6000rpm was approximately 50μm.

Figure 10 is the case when the torque load 2.4Nm was increased to 19.3Nm when the rotation speed was approximately at 7000rpm. However, no large fluctuation in the vibration amplitude of the rotor was observed. This change was translated to the power change of the prototype motor from 1.9kW to 14.3kW.

In addition, it is not shown in the figure, a fluctuation of the displacement of the rotor in axial direction was not observed.

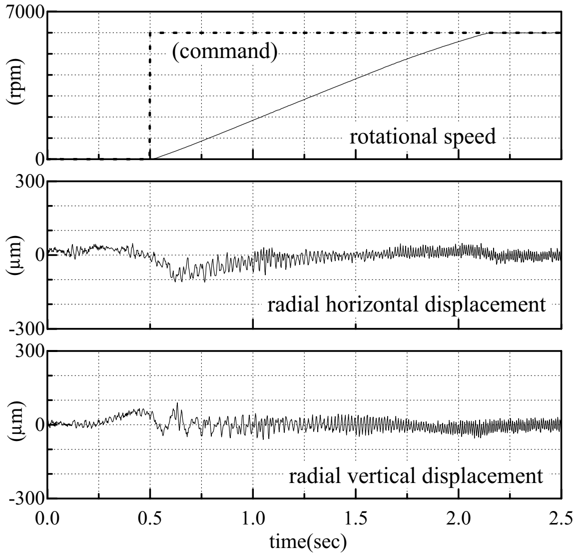

FIGURE 9: Speed UP Response of 15kW Prototype

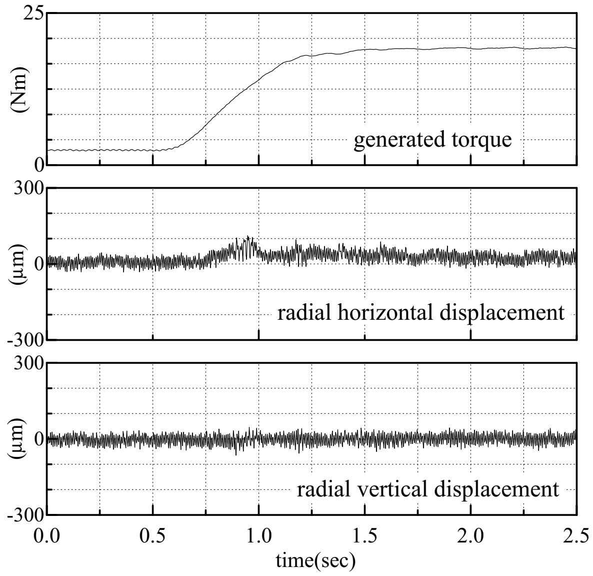

FIGURE 10: Torque Up Response of 15kW Prototype

CONCLUSIONS

The control method by magnetic flux detecting for the inductive bearingless motor with a squirrel cage rotor was proposed. The control method was applied to a prototype motor for its validity, and it has been confirmed.

A prototype of a canned pump was designed and applied this control method on the prototype. The result of the test was favorable and confirmed stableness of the control method even to the fluid load.

Further, proposed control method was applied to a 15kW test machine as a higher power prototype. The stability on the varied torque load condition was confirmed in

same way.
These test results show that this control method was effective even to the transitional load fluctuation and was applicable to a higher power bearingless motor, of which class is 15kW with squirrel cage rotor.

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