AN APPLICATION OF ACTIVE MAGNETIC BEARINGS IN A MIXED GAS BLOWER

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ABSTRACT

The rotor of a blower, which was supported by rolling element bearings for transmitting some kind of mixed gas in a CO_2 laser equipment before, is required to be changed into supported by active magnetic bearings now to avoid the contamination of actuating medium by the vapor of lubrication grease. The design consideration and the results are presented in this paper.

INTRODUCTION

Many advantages of active magnetic bearings (AMB) have been reported [1-3], but only in a few cases the manufacturers would try to use AMBs in their products. Lake of experience in design in comparison with other kinds of bearings, such as rolling element bearings (REB), may be the most important reason.

In this paper the design of a set of AMBs for the rotor of a blower, which is used to transfer some kind of mixed gas under a very low pressure for a CO_2 laser equipment, is discussed and the results are presented. The rotor was supported on REBs before and it is difficult to seal up the grease vapor in casing. The vapor contaminates the actuating medium and decreases the efficiency of the equipment. Therefore, MBs re suggested to be used instead of REBs. It is clear that the design criterias for REMs can not be applied to the design of AMBs directly. The stiffness of AMBs is less than that of REMs and there exists a problem of instability in AMBs-rotor systems, which must be learnt carefully in design. Four steps have been taken in the design and they will be described in detail as follows.

STRUCTURE DESIGN

Considering the requirement of least change in casing configuration, two radial AMBs take the places of REBs and an additional double-side thrust AMB is mounted on an elongated rotor in the opposite side of the blower wheel (Fig 1). Electro-magnets with 16 poles are adopted for radial bearings and their geometric structure has been optimized under given journal diameters with a Swift Approach. The nominal diameter of inner surfaces of the electro-magnets is 60 mm while the width of the magnets (including the coils) is 60 mm as well. The results of the optimization show that when the magnet volume is selected as an objective function, 8 or 16 poles are better for the journal with a diameter equal to or less than 60 mm while 24 or 32 poles are feasible for the larger journal. Two disks of silicon steel lamination stacks with the same nominal diameter and the same width as that of the inner surfaces of the magnets are press-fitted on the journals to minimize eddy-current effect. The radial clearance is taken as 0.15 mm owing to that the original

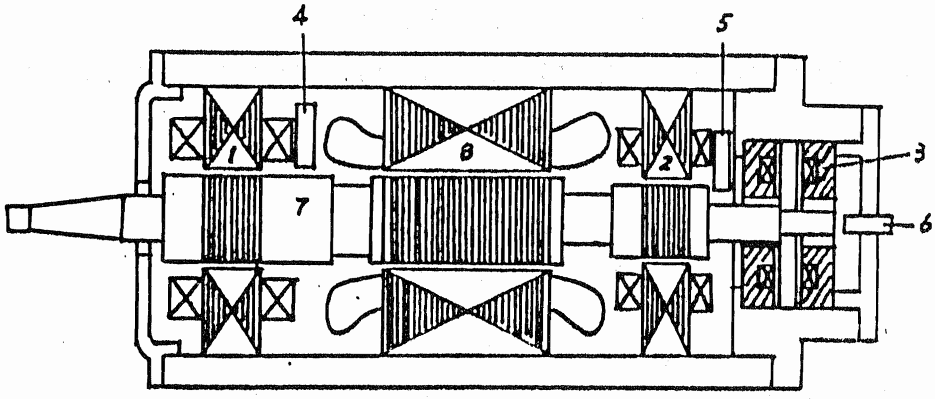

FIGURE 1: Arrangement of the Designed AMBs.
1-2, Radial Bearings; 3, Thrust Bearings; 4-6, Probes; 7, Rotor.

design was for REMs and a very high stiffness is requested by the user. Auxiliary bearings are omitted due to the limitation of space and a kind of specially designed self-lubricating polymer coating on the surfaces of magnet poles is used instead. The rotor is driven by an intermediate frequency motor with its amature in the middle of the two radial AMBs. The norminal speed of the motor is 24000 rpm (400 Hz). Five eddy-current position sensors are fixed as near as possible to the journal bearings to detect the displacement signals. The probes are designed with a screen sleeve because two probes have to be mounted very near the motor stator coil. A few tests have been carried out to check if the out-put of the sensors is affected by the magnetic field of the motor stator and the result is quite satisfactory.

CONTROLLER DESIGN

The controller consists of three parts: the position sensors, the regulators and the power amplifiers. Suppose the coupling action between different degrees of freedom can be neglected and then every degree of freedom or control channel can be considered independently in design. Traditionally there are two kinds of control scheme in power amplifier circuits. One is called voltage control (Fig 2) and another current control (Fig 3). Many advantages with the current control scheme have been discussed in [4] and the influence of the time constant of eletro-magnet coils on the out-put current i_c may be the most important one. Simutaneously, a collecting electrode (anode) out-put circuit (instead of the emitter out-put circuit) for the power transistors is necessary, which provides the smallest phase shift of i_c against the input voltage under high frequency on a strong inductive load. Typical PID circuits have been adopted in the regulator design. The results of different arrangements of the proportional, integral and derivative units, eg in series, in parallel or in series and parall, have been compared with each other. Suppose the transfer function of a PID regulator can be written as

$$G_r(s) = k_p + \frac{k_i}{s} + k_d \cdot s \qquad (1)$$

where k_p, k_i, k_d — the proportional, integral and derivative coefficients of the PID regulator, the relations between these coefficients and the unit parameters for different arrangement are shown in Tab 1. It is found that when a series and parallel arrangement is adopted, the independence in tuning and the scope of tuning will be larger, Fig 4.

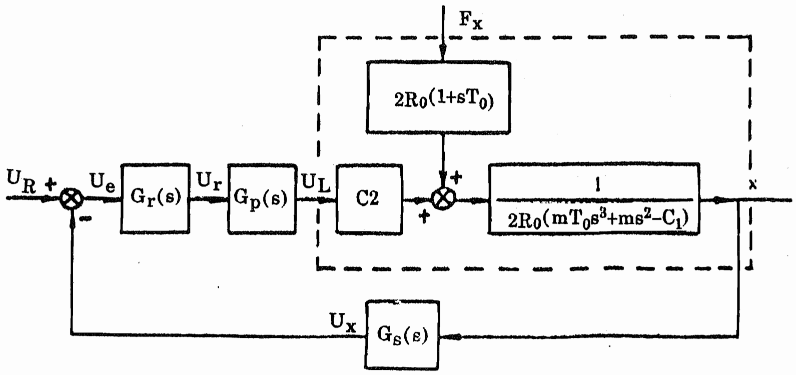

FIGURE 2: Schematic of the AMB-Rotor System of Voltage Control.

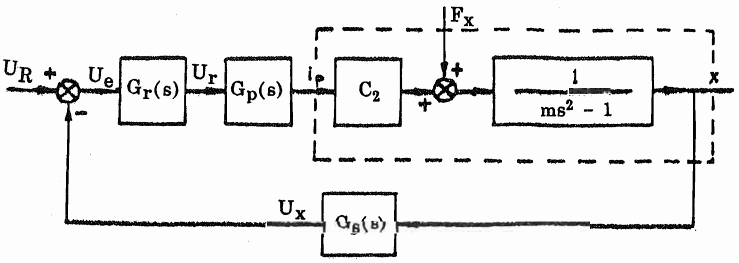

FIGURE 3: Schematic of the AMB-Rotor System of Current Control.

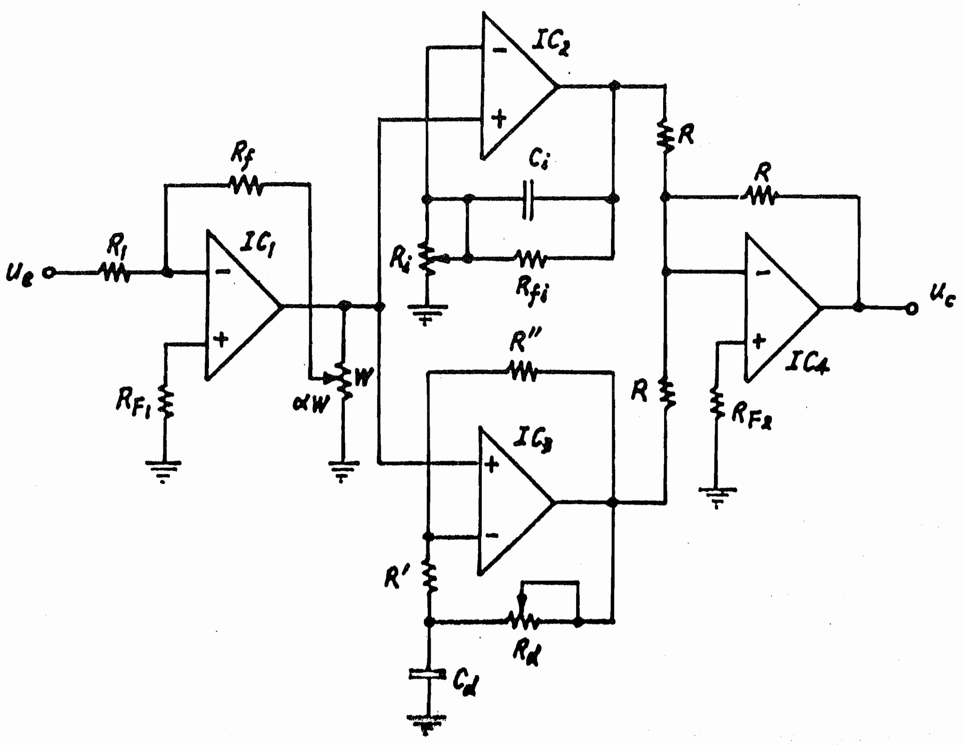

FIGURE 4: Schematic of the PID Regulator.

TABLE 1: Proportional, IntegralandDerivative Cofficients of theRegulatorswithDifferent Arrangement.

	k_p	k_i	k_d
S PID	$A_s[1 + (1 - \varepsilon)\frac{T_d}{T_i}]$	$\frac{A_s}{T_i}$	$A_s[1 - \varepsilon + (1 - \varepsilon)\frac{\varepsilon T_d}{T_i}]T_d$
P PID	$2 + A_s$	$\frac{1}{T_i}$	$(1 - \varepsilon)T_d$
SP PID	$2A_s$	$\frac{A_s}{T_i}$	$A_s(1 - \varepsilon)T_d$

S - Series; P - Parallel; SP -Series and Parallel.

ANALYSIS AND TEST

With a PID regulator as shown in Fig 4, the total transfer function of the controller is

$$G(s) = G_S(s)G_r(s)G_p(s) \qquad (2)$$

where

$$G_s(s) = \frac{A_S}{1 + s\,T_s} \qquad (3)$$

and

$$G_P(s) = \frac{(1 + s\,T_l)}{P_2 s^2 + P_1 s + P_O} \qquad (4)$$

are transfer function of position sensor and that of power amplifier respectively, and

$$P_2 = T_p T_l,$$

$$P_1 = T_l + R_L T_d,$$

$$P_0 = 1,$$

and A_S, , T_S, T_p, T_l, T_d, R_L are the gain of position sensor, the gain of power amplifier, the time constants of position sensor, power amplifier, lead network and delay network, and the resistant load respectively for this situation.

The stability margins for voltage control and for current control have been analysed and compared. The results are given in Fig 5 and Fig 6. In these figures it is defined

$$K_p = A_S k_p, \; K_i = A_S k_i, \; K_d = A_S k_d.$$

A frequency response analysis and an unit-step response analysis have been carried out, the results are described with Bode-Plots (Fig 7) and response curves in time domain (Fig 8)

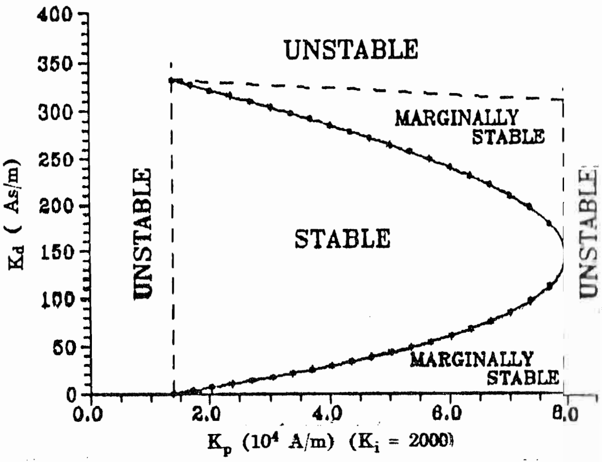

FIGURE 5: Stability Margins of Kp &Kd of the Regulator with Voltage Contorl.

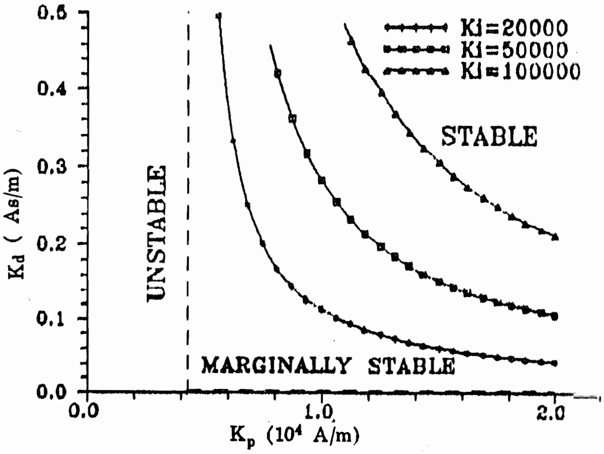

FIGURE 6: Stability Margins of Kp & Kd of the Regulator with Current Control.

respectively.

Comparing Fig 5 with Fig 6, it is clear that the performance of the current control is better than that of the voltage control. Another conclusion that a collecting electrode out-put for the power transistors is necessary can be obtained from the curves in Fig 7.

The complex stiffnesses of AMB relative to the frequency of harmonic input calculated with different sets of parameters are shown in Fig 9.

A test has been brought about for the same purpose. The rotor was excited by a B & K 4809 exciter and the response was measured by a B & K 2626 and 2636 combination. One of the results is shown in Fig 10, which shows a fair agreement with the theoretic analysis.

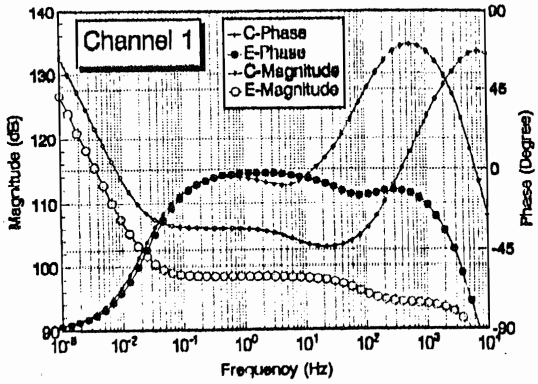

FIGURE7: Comparison between Collecting ElectrodeOutput (C) andEmissiveElectrode Output (E) on Bode-Plots.

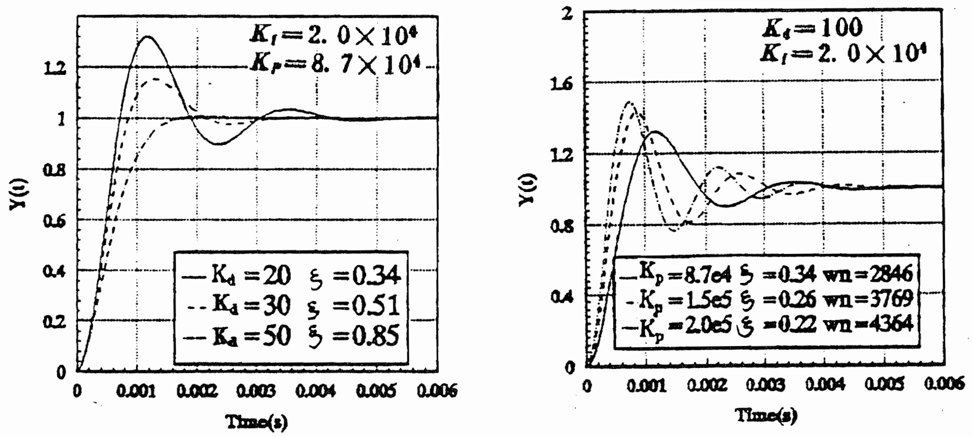

FIGURE 8: Unit-Step Responses of the Controller. [6]

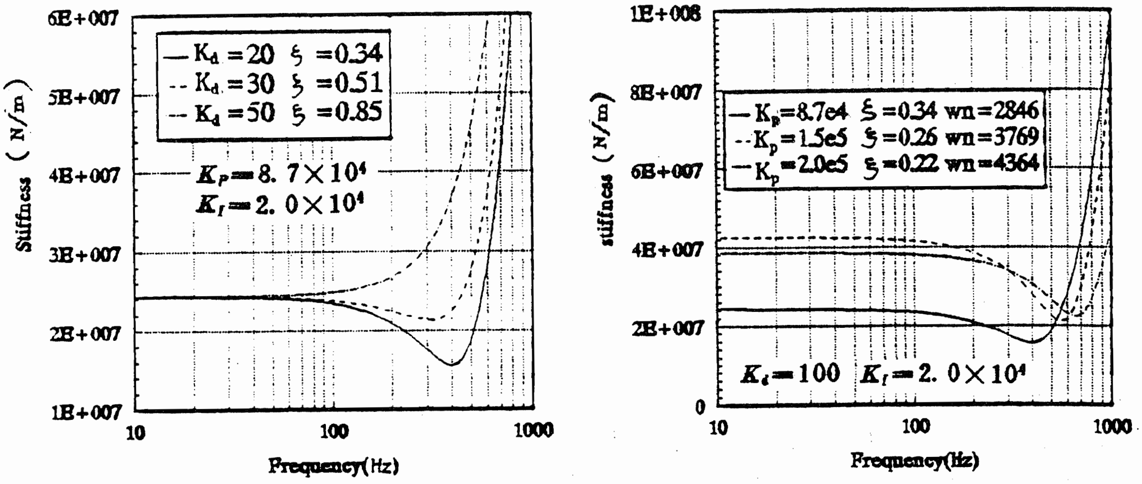

FIGURE 9: Calculated Stiffness of the AMB vs Frequency. [6]

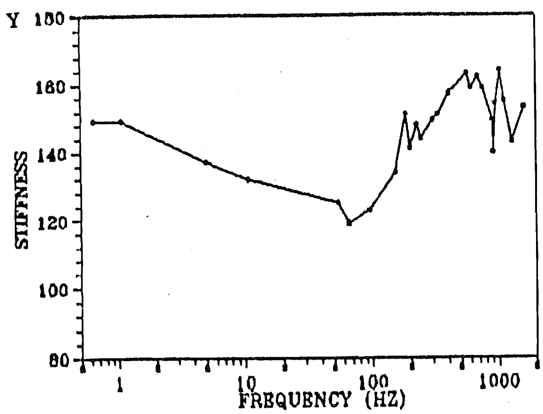

FIGURE 10: Measured Stiffness of the AMB vs Frequency. (Stiffness = $10^{Y/20}$ N/m)

CONCLUSIONS

The process of design of a set of AMBs and the results are presented. The configuration of AMBs has been optimized and the auxiliary REBs in traditional design are changed into by a layer of polymer coating to economize the space. A series and parallel arrangement in the PID regulator and a current control scheme with collecting electrode out–put circuit are adopted in the design after careful comparison. The performance has been checked from several aspects by analysis and tests. The prototype of the AMBs runs well on nominal speed and on speed varied from 20,000 rpm to 30,000 rpm. It proves that with correct design AMBs can operate as well as any other kinds of bearings.

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