ROLL MOTION RESTRAINT SYSTEM FOR NAL 0.6m MSBS

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SUMMARY

Suspension of a wind tunnel model and control of its motion in 5 degrees of freedom is realized in the NAL 0.6m MSBS but roll motion of the model is not controlled. Controlling the roll motion by adding additional magnets for roll control is realized in some small facilities including the NAL 0.1m MSBS, but it is not suitable for large wind tunnels. A mechanical roll motion control system for the 0.6m MSBS is described and simulation and experimental results are presented.

INTRODUCTION

Magnetic Suspension and Balance System (MSBS) for wind tunnel testing can avoid the support interference problem and has many other advantages in future wind tunnel tests. At National Aerospace Laboratory (NAL), a MSBS for the 0.1m x 0.1m test section has been developed and has succeeded in suspending and controlling the motion of a model in 6 degrees of freedom. 0.6m MSBS is designed for testing in a larger test section. Figure 1 shows the arrangement of the electromagnets of the NAL 0.6m MSBS. A model containing a cylindrical magnet is at the center of the test section and the magnetic field from the electromagnets surrounding the test section provides the lifting force that suspends the model. The position and the motion around the y-axis and z-axis of the model is controlled by modifying the current supplied to each electromagnet by digital automatic control using a personal computer. However, the magnetization of the model is equal around the x axis so the motion around x axis (roll motion) of the model causes no change of the magnetic force acting on the model. So the roll motion cannot be controlled. In wind tunnel testing, roll motion caused by some fluctuation must be considered, so some means to constrain the roll motion is necessary.

Containing another magnet besides the main magnet that obtains lifting force or using a main magnet that is not cylindrical gives the gradient of magnetization in the direction perpendicular to x-axis and enables control of the roll motion by modifying the surrounding magnetic field. Such a way to control the roll motion is realized in some facilities successfully. (Ref. 1,2) At NAL 0.1m MSBS, Sawada et.al. succeeded in controlling the motion in 6 degrees of freedom by using a model containing 4 small magnets besides the main magnet. (Ref. 3) Figure 2 shows the model used in the 0.1m MSBS and the test of the roll motion control.

In controlling the roll motion in this way, when the MSBS and the model are enlarged, a required current to the electromagnet increases proportionally to the increasing size of the test section. When the magnetic field from the main magnet becomes stronger, it deducts the effect of radial magnetization for the roll control and make the required electric supply much greater. This system has another problem that causes coupling between the roll motion and other modes. On the other hand, when the MSBS becomes larger, using large models makes it easier to contain some mechanical system in the model. So a mechanical system that controls the roll motion is designed for introduction of large scale MSBS.

DESIGN & SIMULATION

Figure 3 shows the general idea of the mechanical roll motion restraint system. In this system, the roll rate of the model is measured by the gyro and the measured roll rate is fed to the control circuit. The signal from the controller drives the DC motor with a flywheel to cancel the roll motion of the model. The controller is currently a digital controller on a personal computer and is connected by electric wire. But to keep the advantage of the MSBS, no mechanical connection is allowed, so in the future, it will be necessary to implement a controller as an analog circuit contained in the model or to communicate with the PC through a telemetry system as shown in Figure 4. In order to keep the roll-rate to zero, feedback control is necessary. Figure 5 shows the control loop for roll motion as block lines.

In order to prove the feasibility of such a system, a computer simulation was carried out. The results are shown in Figure 8 with the results of the experiment. It shows that this system has the capacity to suppress the roll motion of the model. But some results of the simulation showed that when a static moment around x axis is acting on the model, the rotation of the flywheel increases as time and reaches the maximum rotation. This will make it impossible to control the roll motion. In real cases, the distribution of the magnetization in the magnet is not equal and causes some roll moment acting on the model as a function of ϕ. It is necessary to avoid the influence of the constant moment by waiting to start controlling until the model is stable under no control or by reducing proportional control gain in exchange for tolerable degeneration of the control authority.

IMPLEMENTATION

Using the results of the simulation, a prototype of the mechanical roll motion restraint system was designed for the NAL 0.6m MSBS. To make it easy to introduce such a system, commercial products were used. In order to avoid the influence of the surrounding magnetic field, a fiber optic gyro (FOG) and coreless DC motor were used. The FOG used in this system is TA7319N1 produced by Tamagawa Seiki Co., Ltd.

Figure 6 shows the general arrangement of the system. A 55mm diameter cylindrical model is used in the NAL 0.6m MSBS and we tried to put the whole system in the 55m diameter cylinder, but we could not get the FOG that can be contained in the ϕ 55m model. So we contained the system in another 75mm diameter, 150mm long cylinder and aligned it to the model with the longitudinal axis in common. The 20mm difference in diameter is of course intolerable, but it is because of the size of FOG only so downsizing of the FOG will permit the application of such a system to the model less than 75mm in diameter. A ϕ 90mm diameter superconducting solenoid model has been introduced to 0.6m MSBS so this test also makes sense as the preparation of applying this system to the superconducting solenoid model. The cylinder is made of aluminum.

Figure 7 shows the prototype of the roll motion restraint system. In order to avoid any connection from what is not contained in the model, the power source also must be contained in the model. A commercial 9V dry cell is used and a DC-DC converter is used to produce required constant voltage. The results of the numerical simulation showed it possible to control the system by simple PI compensator. So it is not very difficult to implement the compensator circuit as an analog electric circuit. But for simplification of the system, a digital control system implemented on the personal computer is selected at first. An electric cable connection is used to monitor the roll rate and to send control signals. But it will be replaced by a telemetry system when this system is applied to wind tunnel testing.

The lifting ability of the NAL 0.6m MSBS with its ϕ 55mm diameter model is limited to 700g but the weight of the roll control system exceeded the limit. So some parts made of stainless steel were replaced by parts made of aluminum and lightening holes added. Finally the weight of the model is 650g.

EXPERIMENTS

Before suspending the model containing the roll motion restraint system in the MSBS, a test of a vertically hung model is carried out to prove the possibility to restrain the roll motion under the influence of the magnetic field caused by the main magnet of the model. Figure 8 shows the method of testing. The model with the mechanical roll motion restraint system is hung by the string and can rotate around the x-axis. The test was carried out for some control parameters of the feedback control loop.

Figure 9 shows the roll-rate ($d\phi$) in degree per second, roll (ϕ) in degree and control command in voltage. The initial value of the roll rate 20 [deg/sec] is given and the control is turned on when the amplitude of the roll rate is maximum. Because of the elasticity of the string suspending the model, the roll motion is reduced without any control. But the results of the test show that this system reduces the roll motion much faster. The magnetic field of the main magnet contained in the model did not cause any influence on the performance of this system. The strength of the magnetic field from the main magnet is superior to that from the electromagnets surrounding the test section. So the results were sufficient for constant magnetic field, but the effect of the fluctuation of magnetic field strength is not evaluated in this test.

However the results of the test showed a large difference from the results of the simulation. Especially, the required time to restrain the roll motion is longer than that in the simulation and it did not shorten as the proportional gain of the control loop increased. It is thought to be caused by the error in estimating the inductance of the DC motor, delay from the electric circuit to drive the motor, and non-linearity of the motor around the point where the rotation is equal to zero. The oscillation with small amplitude is still present even when the control is effective. It is supposed to be caused by non-uniformity of the model and the coupling between the roll motion and the pendulum motion of the model. Some results of the test show that the saturation of the rotation of the motor makes the running time of this system short especially when Kp is set at a higher number to obtain a good response. But increasing the weight of the flywheel makes it possible to obtain more torque from the same gradient of the rotation.

Figure 10 shows the results of the calibration test in the 0.1m MSBS. According to this, the roll moment acting on the model is 0.05 ~ 0.1 [mN•m/A]. The result of the experiment for the mechanical roll motion restraint system shows that the maximum torque acting on the model is about 2mN•m. When the 0.1m MSBS model is enlarged for the 0.6m MSBS, and taking the difference of the performances of the 0.1m MSBS and 0.6m MSBS into account, it corresponds to 5 ~ 20[W]. On the other hand the maximum power of the motor is 2.4 [W] and the gyro requires 2.0 [W], so the mechanical roll motion restraint system requires 4.4 [W]. When the model becomes larger, the method using a magnet for roll control needs to have the magnet similarly enlarged. But in the mechanical roll motion restraint system, only the flywheel needs to be enlarged similarly. The weight of the flywheel itself is 10% of that of the whole system, and it is easy to increase the weight of the flywheel. The mechanical roll motion restraint system is expected to cause less coupling, because it does not change the current to the electromagnets that is also used for controlling other modes of motion.

CONCLUDING REMARKS

A mechanical roll motion restraint system has been designed for use in the large scale MSBS that requires strong magnetization of the model. The results of a numerical simulation proved the possibility of such a system. A prototype of the system was made and tested under the situation that the model is hung vertically. The results showed that this system controls the roll motion in the constant magnetic field. This prototype is larger than the standard model in diameter and has some connection by electric cables. But these problems can be solved for large MSBS.

As the next step, a test with the model suspended in the MSBS is required. It may cause problems from the fluctuating magnetic field strength, coupling with other modes of motion, and electric noise from power supply. Further, this system will be applied to the superconducting solenoid model that has been introduced to the 0.6m MSBS.

REFERENCE

1) M. J. Goodyer: The Generation of Rolling Moments with the Superconducting Solenoid Model. NASA CR-172520, 1985.

2) M. J. Goodyer: Roll Control Techniques on Magnetic Suspension Systems. Aeronautical Quarterly, Vol. 18, Feb. 1967, Pt. 1, pp. 22-42.

3) H. Sawada: Rolling Moment Control in the NAL 10cm x 10cm Magnetic Suspension and Balance System. NAL TR-1164, 1992.

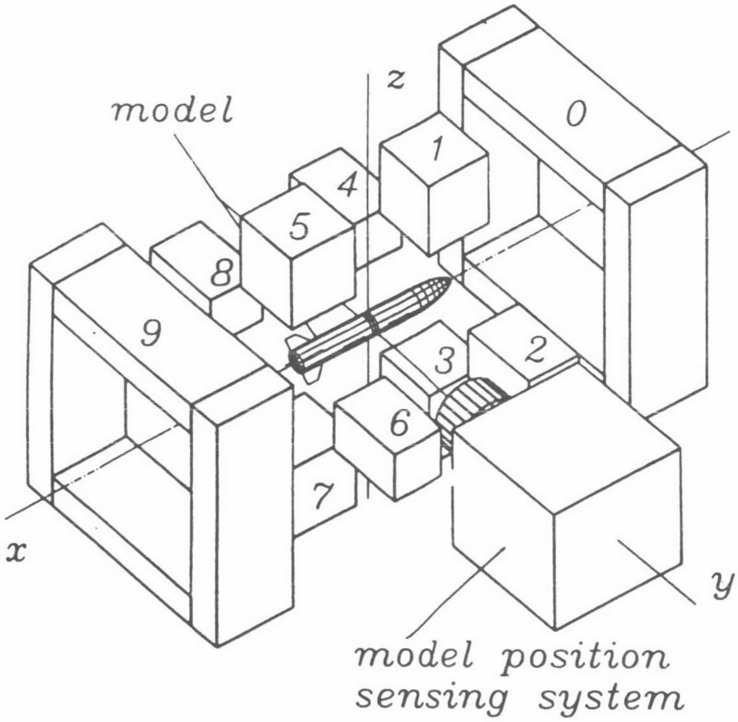


Fig.-1 Arrangement of the Electromagnets of the NAL 0.6m MSBS

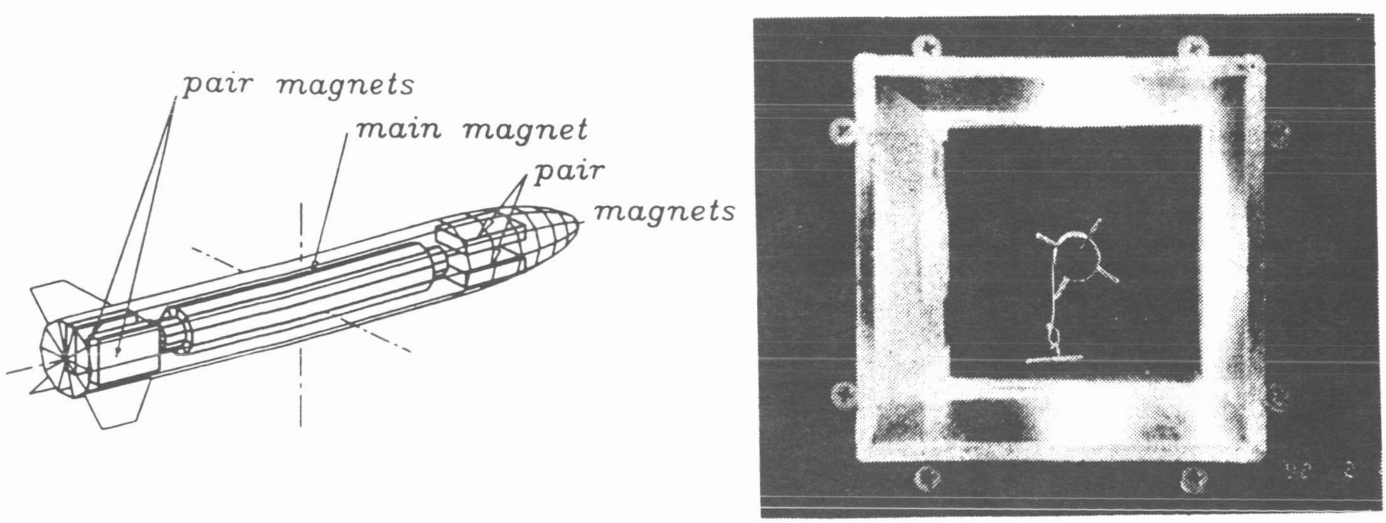


Fig.-2 Roll motion control at the NAL 0.1m MSBS (ref. 3)

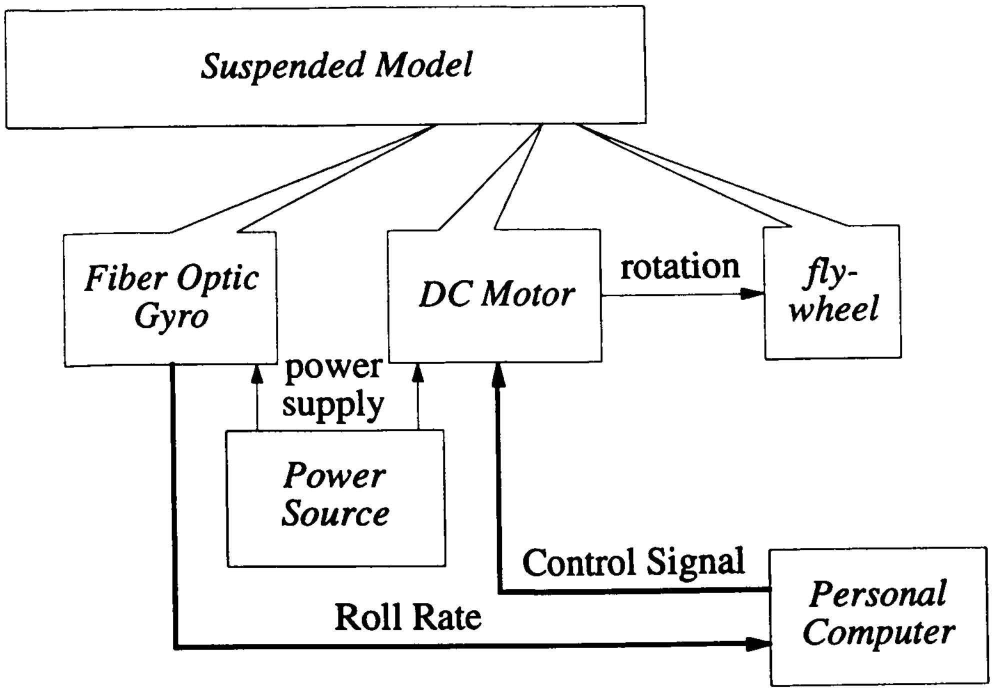


Fig.-3 General idea of the mechanical roll motion restraint system

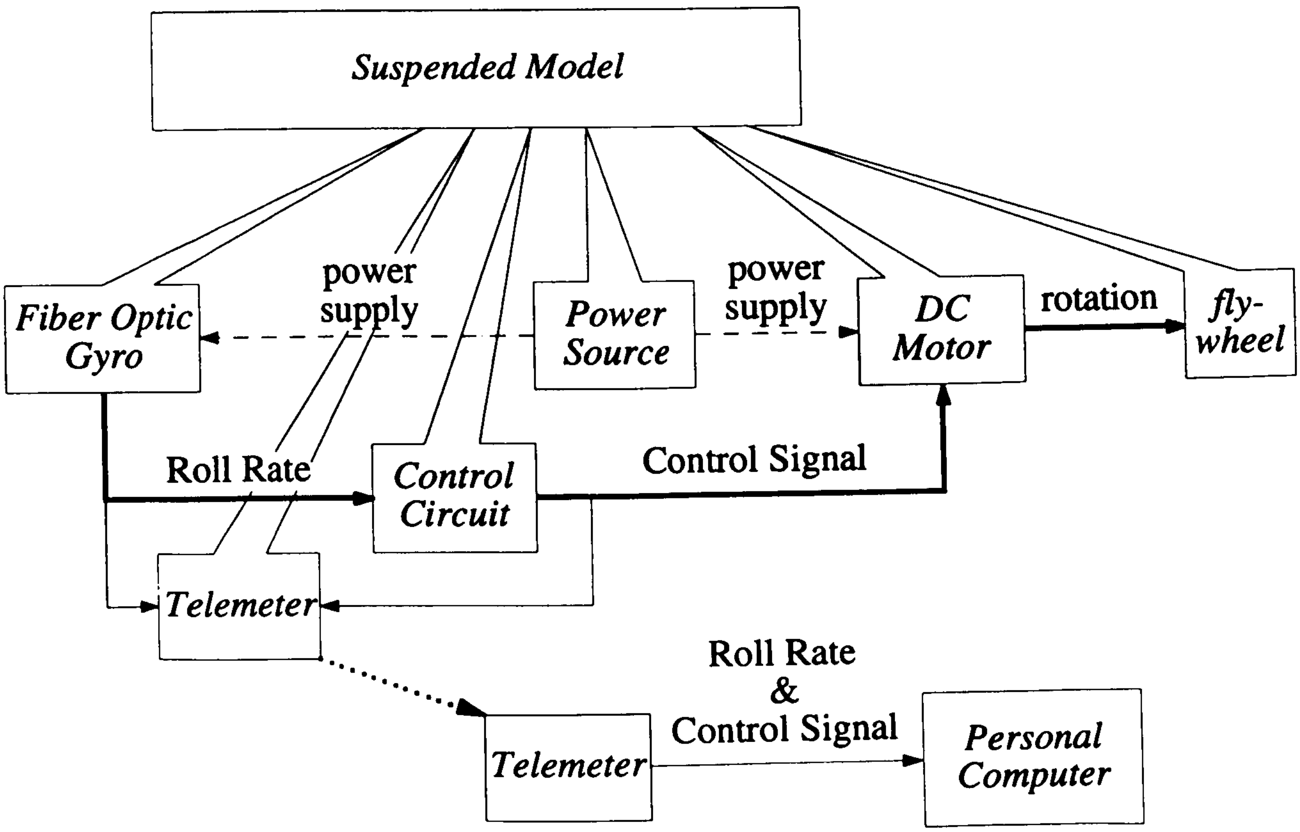
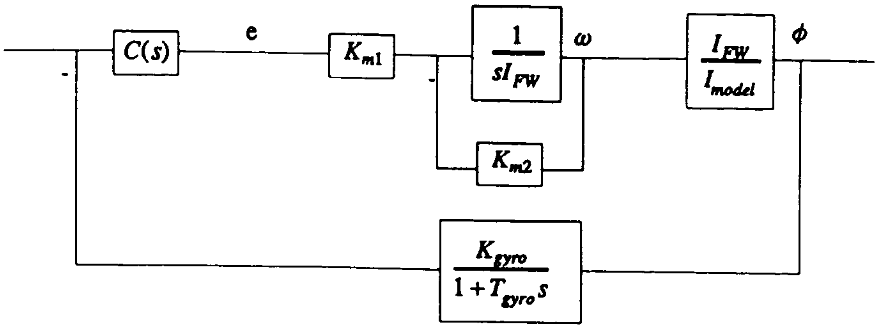


Fig.-4 Future plan of the mechanical roll motion restraint system



K_{m1} : torque-roll rate coefficient
K_{m2} : voltage-torque coefficient
I_{FW} : Inertia Momemt of the Flywheel
I_{model} : Inertia Momemt of the Model
K_{gyro} : Gain of the Gyro
T_{gyro} : Time Constant of Gyro

Fig.-5 Block lines of the roll control loop

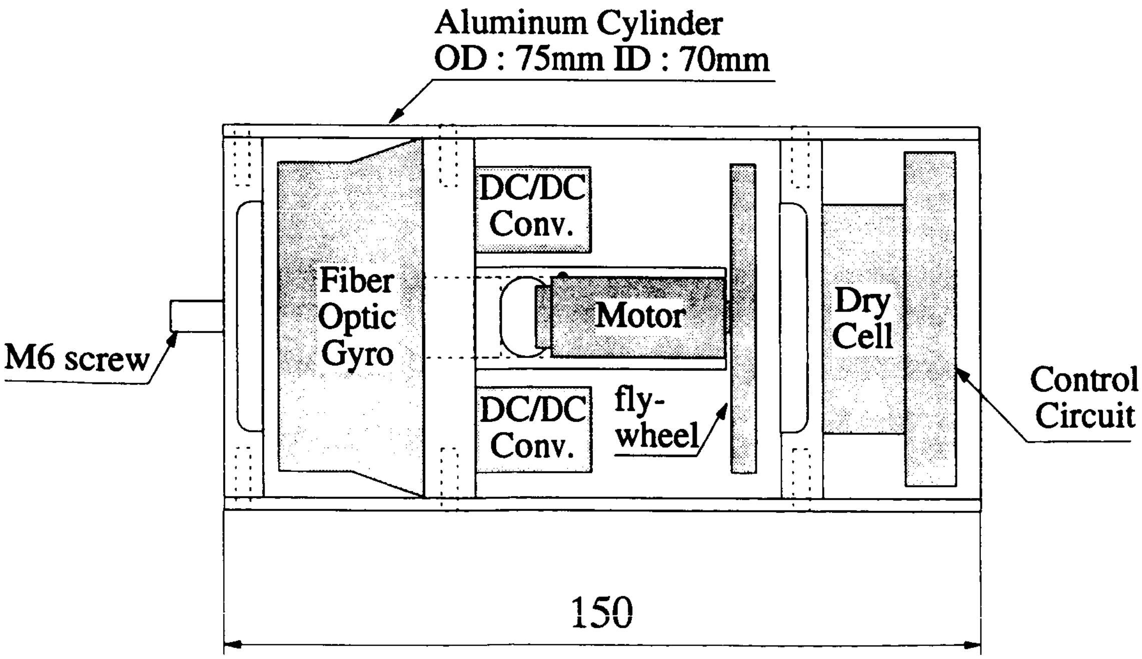


Fig.-6 General arrangement of the mechanical roll motion restraint system

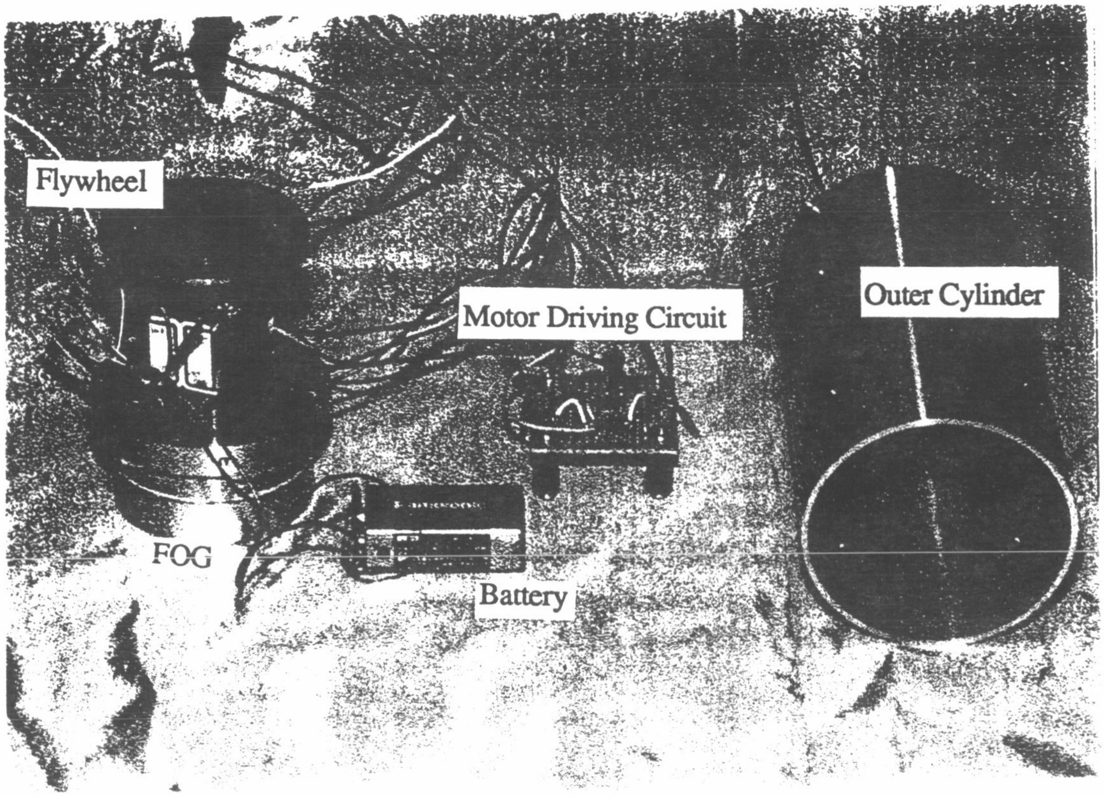


Fig.-7 Picture of the prototype

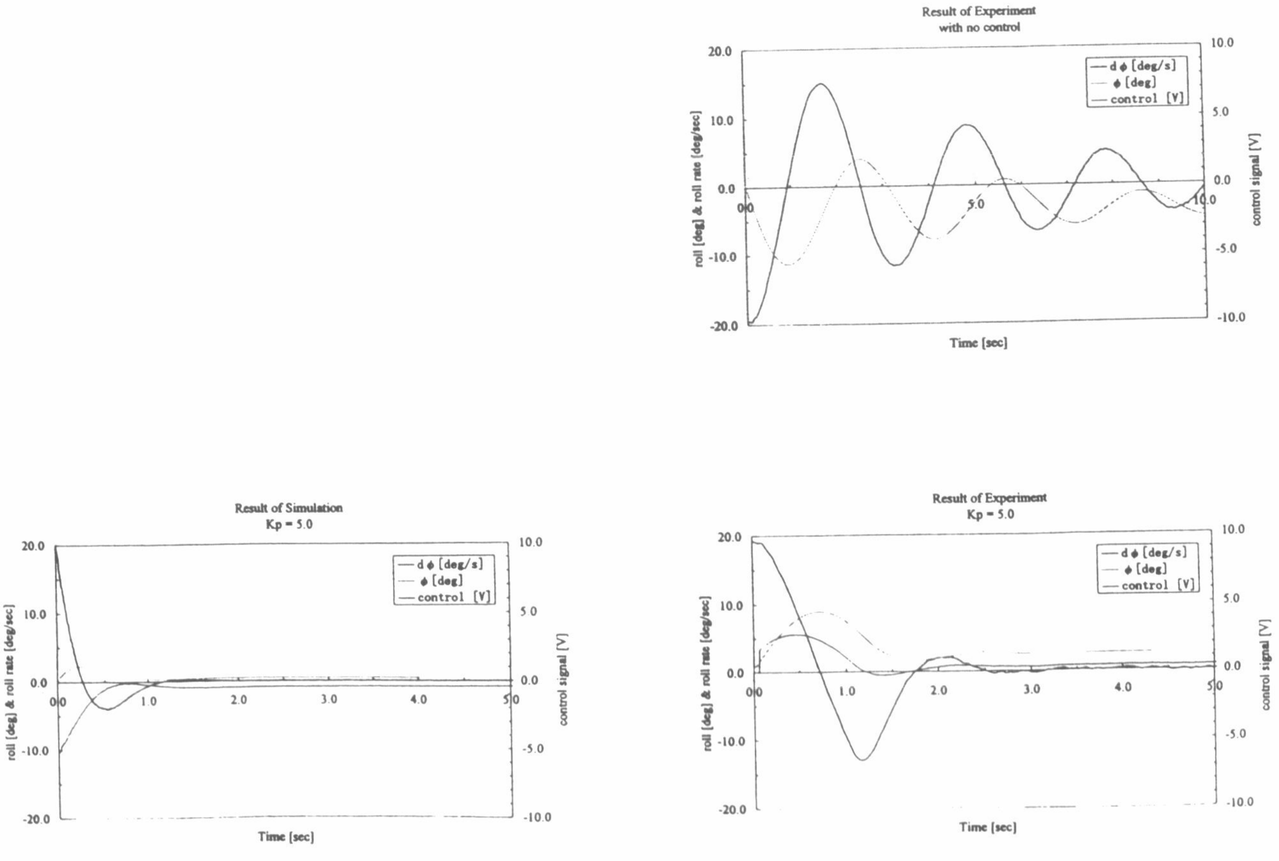


Fig.-8 Results of the simulation and experiment

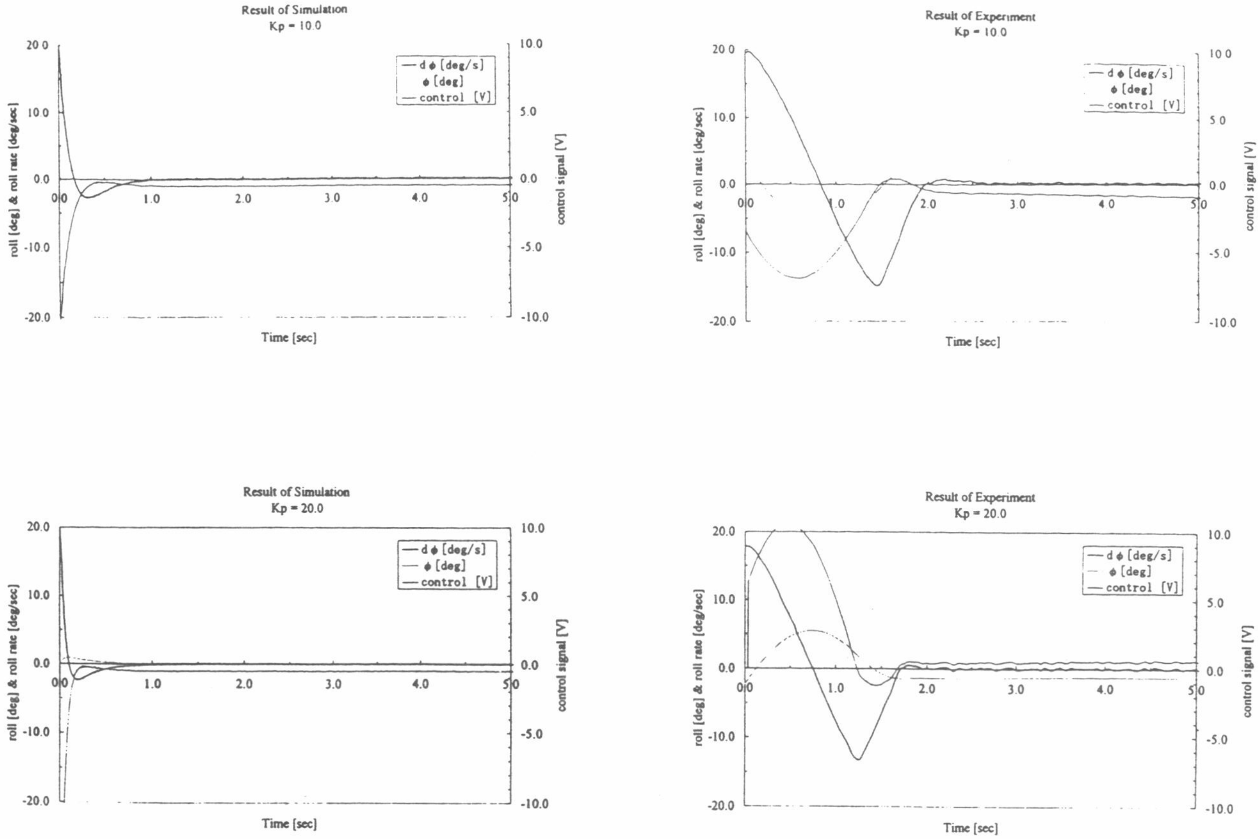


Fig.-8 Results of the simulation and experiment

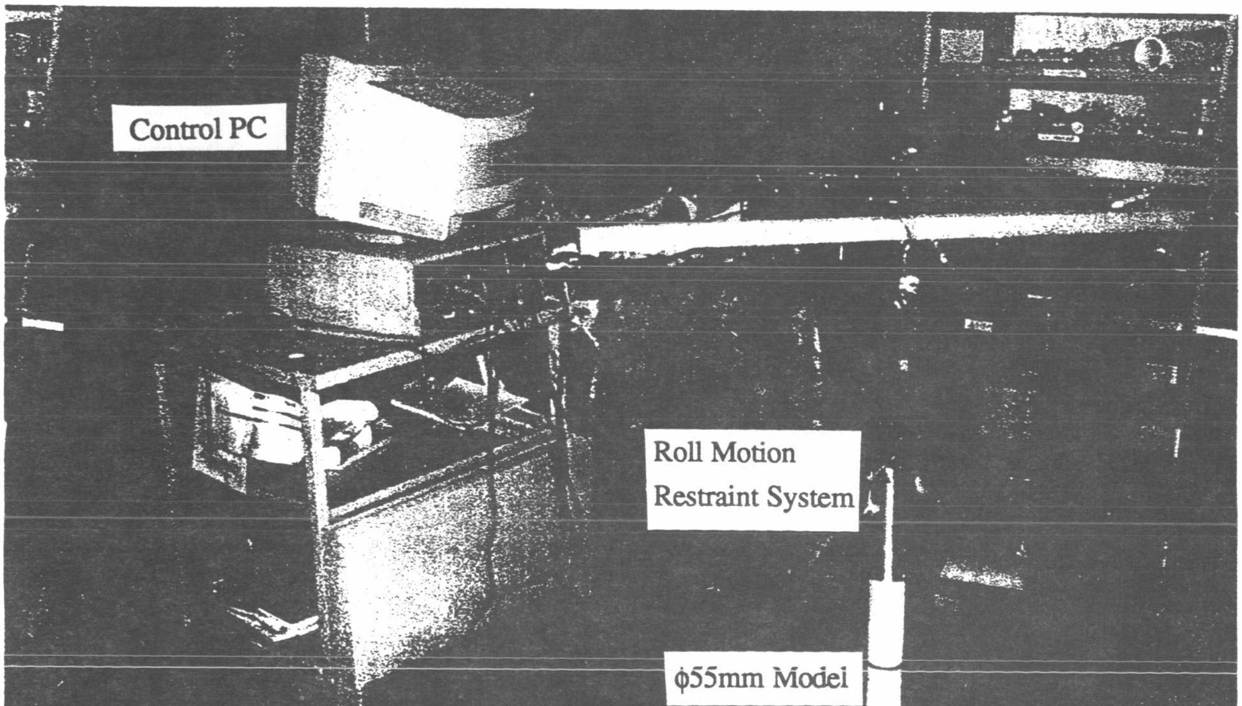


Fig.-9 Testing by hung model

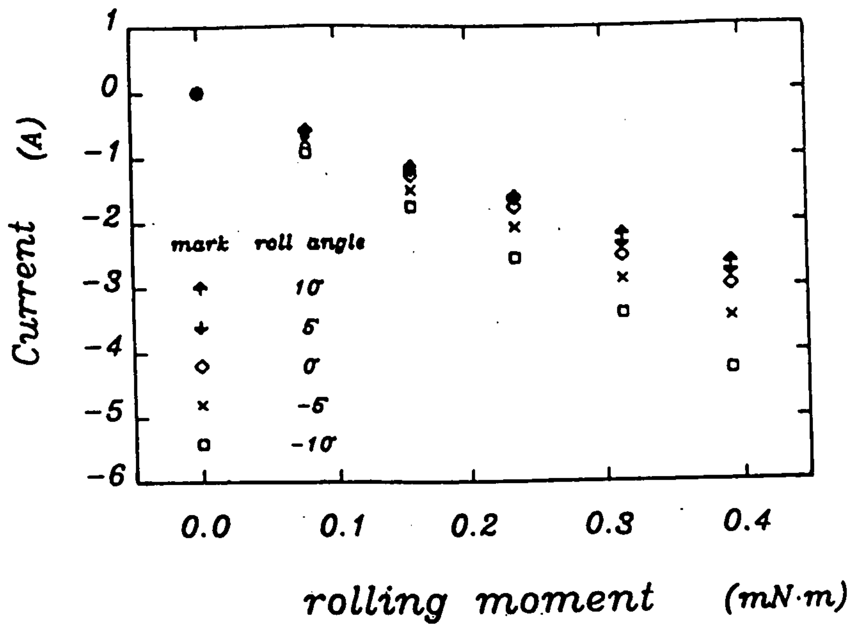


Fig.-10 Calibration test of roll moment in the 0.1m MSBS (ref. 3)