ROLL MOTION RESTRAINT SYSTEM FOR NAL 0.6m MSBS
- the 2nd report -

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SUMMARY

Suspending the wind tunnel model and controlling its motion in 5 degrees of freedom are realized in the NAL 0.6m MSBS but the roll motion of the model is not controlled yet. So a mechanical roll motion control system is designed for NAL 0.6m MSBS. This system has worked well in the test with the free rotation model **hung** by the string vertically and applied to the model suspended by MSBS. A wireless communication system between the system inside the model and the observer out of the test section has also **been designed.**

INTRODUCTION

Magnetic Suspension and Balance System (MSBS) is a new technique for the wind tunnel tests that suspends the testing model by the magnetic force. It enables to avoid the support interference problem and has many other advantages in the future wind tunnel tests. At National Aerospace Laboratory (NAL), a MSBS for the 0.1m x 0.1m test section (0.1m MSBS) has been developed and succeeded in suspending the cylindrical model and controlling its motion in 6 degrees of freedom. And a MSBS for 0.6m x 0.6m test section (0.6m MSBS) has been designed to apply the techniques proved at 0.1m MSBS to the larger test section.

Figure-1 shows the arrangement of the electromagnets of 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 causes the lifting force that suspends the model. The position of the model and its attitude around y-axis and z-axis are measured by the optical position **sensor** and controlled by modifying the current supplied to each electromagnet by digital automatic control. Figure-1 also shows the outlook of the 0.6m MSBS. As shown here, it has already attached to the low speed wind tunnel and succeeded in suspending the model in the wind tunnel flow. The flow velocity is up to 28m/sec.

However, in this system, 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 by modifying the current supplied to each electromagnet. In the wind tunnel testing, some roll moment acting on the model from the wind tunnel flow must be considered, so some means to restrain the roll motion is necessary.

Containing some magnets besides the main magnet (the magnet to obtain the lifting force that suspends the model) or using the main magnet that is not cylindrical gives the gradient of magnetization in the direction perpendicular to x-axis and enables to control 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 control the motion in 6 degree of freedom by using the 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.

However, when the MSBS and the models become larger, the required current to the electromagnet increases proportionally to the increasing size of the test section in such a way to control the roll motion. And when magnetic field from the main magnet becomes stronger it deducts the effect of radius magnetization for the roll control and make the required electric supply larger. In addition, such a system has another problem that it causes the coupling between the roll motion and other mode of motions.

On the other hand, when the MSBS becomes larger, using the large models makes it easier to contain some mechanical system inside the model. So a mechanical system that is contained in the model and controls the roll motion is designed for the large scale MSBSs.

GENERAL IDEA & PROTOTYPE

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 contained in the model and the roll rate is fed to the control circuit. The control signal from the control circuit drives the DC motor with flywheel to cancel the roll motion of the model. According to an approximate numerical simulation, such a system will control the roll motion well with simple P-I compensator.

This system has two problems that are to be solved. One is that it creates counter-torque by changing the rotation of the flywheel, so when the constant moment from wind tunnel flow is acting on the model, the rotation will increase continuously to the maximum rotation of the motor. Increasing the mass of the flywheel increases the capacity of the constant moment acting on the model, but the weight of the flywheel is limited by the payload of the MSBS.

Another problem is that when the flywheel is rotating, the gyro moment changes the force required to change the attitude of the model and influences the control of the motions besides the roll motion. In the prototype designed, the mass of the part that is rotating in the model is only 1-2% of the total mass of the model, so it is expected that the gyro moment caused by the rotating flywheel has little effect on the whole control systems.

A prototype of the mechanical roll motion restraint system is designed for the ϕ55mm diameter cylindrical model used in NAL 0.6m MSBS. Figure-4 shows the arrangement in the system. In order to avoid the unexpected force from the surrounding magnetic field, a fiber optic gyro (FOG) and coreless DC motor are used and the frame is made of aluminum. Because we could not get the FOG that can be contained in the ϕ55mm model, the system is contained in a ϕ75mm diameter and 150mm long cylindrical frame and attached to the model with the longitudinal axes in common. The difference in diameter is off course intolerable for the wind tunnel tests. But it is only because of the size of the FOG and not an essential problem of such a system. Some smaller FOG that will be developed in future or further enlargement of the MSBS will solve the problem. A ϕ90mm diameter super-conducting solenoid model has been introduced to NAL 0.6m MSBS already so this test makes sense as the preparation for applying this system to the ϕ90mm super-conducting solenoid model. The FOG used in this system is TA7319N1 produced by Tamagawa Seiki Co., Ltd.

In order not to spoil the advantage of the MSBS that it has no support interference, no connection for the power supply between the model and the external power source is allowed. So the power source also must be contained in the model and must have the capacity to keep driving all through the wind tunnel test. A 9V dry cell on the market is used and DC-DC converter is used to produce required constant voltage. The dry cells are magnetic bodies so it's not desirable to use it actually. According to the experiments below, some effect to the MSBS control has been considered.

Figure-5 shows the outlook of the prototype of the roll motion restraint system. The lifting ability of the NAL 0.6m MSBS with its ϕ55mm diameter model is limited to 700g so the system has been made as light as possible. Finally the weight of the system is 650g with the communication system mentioned below.

COMMUNICATION SYSTEM

In the wind tunnel tests, no wire connection for data communication is allowed because it spoils the advantage of the MSBS that it has no support interference. So a wireless communication system for the MSBS is required. It must work under strong magnetic field and its interference,and strong electric noise caused by power amplifiers for MSBS and should be small and light in order to be contained in the model.

As a prototype of such a wireless communication system for the MSBS, an infrared (IR) communication system is designed for NAL 0.6m MSBS. Figure-6 shows the outlook of the IR communication system. An IR communication system has been chosen instead of conventional radio telemetry system because it is expected to have required anti-noise performance. It has one analog input and converts the data to 12 bit digital data and sends it to the PC with IR communication. It also has a 12 bit digital IR input from the PC and converts it to analog voltage output. It can keep driving for 60 minutes with conventional dry cells.

At first, a system that sends the roll rate from the FOG to the PC and receives the calculated control signal from PC was planned. But because the designed communication system does not have enough sampling rate to control the roll motion, an analog PID compensation electric circuit has been designed and implemented to control the roll motion of the model. Figure-7 shows the control circuit. So the communication system was used only to monitor the roll rate and to change the reference value of the roll rate.

Such a system can be used not only for the communication to control the motion of the model but also sending the data measured by the sensors contained in the model, such as temperature, pressure, etc. It will be a useful tool in future wind tunnel tests. However, it requires more channel numbers and further accuracy including anti-noise performance.

EXPERIMENTS

Before applying the roll motion restraint system to the model suspended in the MSBS, a test by the vertically hung model is carried out to prove the possibility of restraining the roll motion under the influence of the magnetic field caused by the main magnet of the model. The model with mechanical roll motion restraint system is hung by a string and can rotate around x-axis. First, the test was carried out without control circuit. The FOG and the motor were connected by wire to the PC and the PC calculates the control signal that drives the motor after the roll rate from the FOG. After that, the test with the analog control circuit in the model was carried out. In this system the control loop is closed in the model and the PC was used only for the monitor.

Figure-8 shows the time trajectory of the roll rate (dϕ) in degree per second and the roll (ϕ) in degree and control command in voltage. The initial value of the roll rate is given and the system works to restrain the roll rate to the zero value. Because of the elasticity of the string suspending the model, the roll motion is reduced without any control as shown in the upper chart (Fig.-8.1). But the results of the test shown in the lower chart (Fig.-8.2) shows that the roll control system reduces the roll motion much faster. The magnetic field by the main magnet contained in the model did not cause any influence on the performance of this system. The required time to restrain the roll motion is longer than expected by the numerical simulation. This is probably because of the capacity of the circuit that drives the DC motor. This circuit has been refined when it was combined to the inner control circuit, so there exists the possibility of some improvement in the response speed between the system with wire and the system with inner control circuit.

Figure-9 shows the picture of the roll motion restraint system attached to the cylindrical model actually suspended in the MSBS, but with no wind tunnel flow. The IR communication system was attached to the model but could not perform as expected probably because of the heavy electric noise from the power amplifiers of the MSBS. So in the experiments below, it is replaced by a wire connection temporarily. But the P-I control loop itself was implemented as the analog control circuit contained in the model and closed in the model.

At first, the roll motion restraint system also could not perform as expected because of the heavy electric noise from the power amplifiers of the MSBS. So the test was carried out again by the system whose anti-noise performance is enhanced by strictly shielding the electric circuits. Figure-10 shows the time trajectory after some initial roll rate. The initial rate is not accurately the same but it is clear that the roll motion restraint system works to reduce the roll rate much faster. The position of the model and its attitude around y-axis and z-axis changed little while the roll motion restraint system was reducing the initial roll rate. This means that there exists little coupling with the roll motion control.

As mentioned before, this system works to restrain the roll rate to the reference value, so was not designed to control the roll value itself. The easiest way to know the roll angle is to integrate the roll rate but it did not work well when the roll rate value is affected by the electric noise. So the position sensor of 0.6m MSBS was refined to be able to measure the roll angle and modify the reference value of the roll rate to control the roll angle. The reference value of the roll rate is fed to the control system once a second from the external PC by the IR communication system. Figure-10 also shows that the roll angle is kept the same as that before the impulse has been given in spite of the outer moment given as the initial roll rate.

CONCLUDING REMARKS

A mechanical roll motion restraint system is designed for use in the large scale MSBS that requires strong magnetization of the model. A prototype of the roll motion restraint system and the IR communication system has been designed. This prototype is temporarily larger than the model in diameter but this problem can be solved for larger MSBS.

Some tests by the model hung vertically was carried out. The results showed that this system control led the roll motion in the constant magnetic field. Further tests have been carried out with the model actually suspended in the MSBS. The system restrained the roll motion from outer force in the strong magnetic field and its fluctuation by the MSBS. But the IR communication system could not perform as expected probably because of the heavy electric noise from the power amplifiers of the MSBS. It should be refined in the near future because this system is very important not only for control but also for data acquisition such as pressure and temperature.

As mentioned before the tests were carried out under the no flow condition. The next step is to increase the performance enough to control the roll motion of a cylindrical model in the wind tunnel flow with this roll motion restraint system. It requires that the cylindrical model completely contain the mechanical roll motion restraint system in it and further improvement in accuracy and reliability of this sytem.

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.

4) T. Kohno; H. Sawada; T. Kunimasu : "Roll Motion Restraint System for NAL 0.6m MSBS", Proc. 4th International Symposium on Magnetic Suspension Technology, pp.141~150, NASA/CP-1998-207654, May, 1998

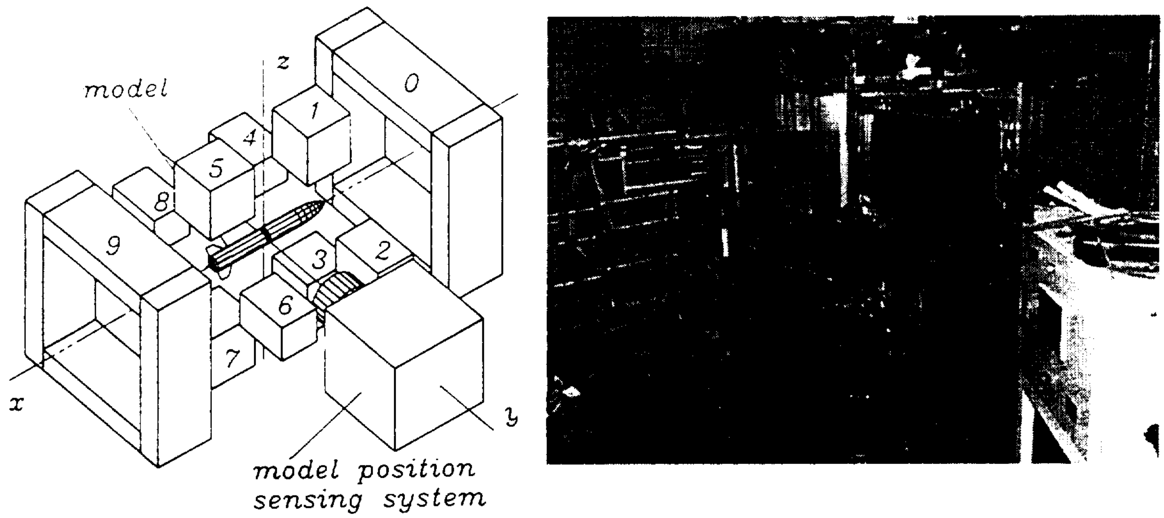

Fig.-1 : arrangement & outlook of the NAL 0.6m MSBS

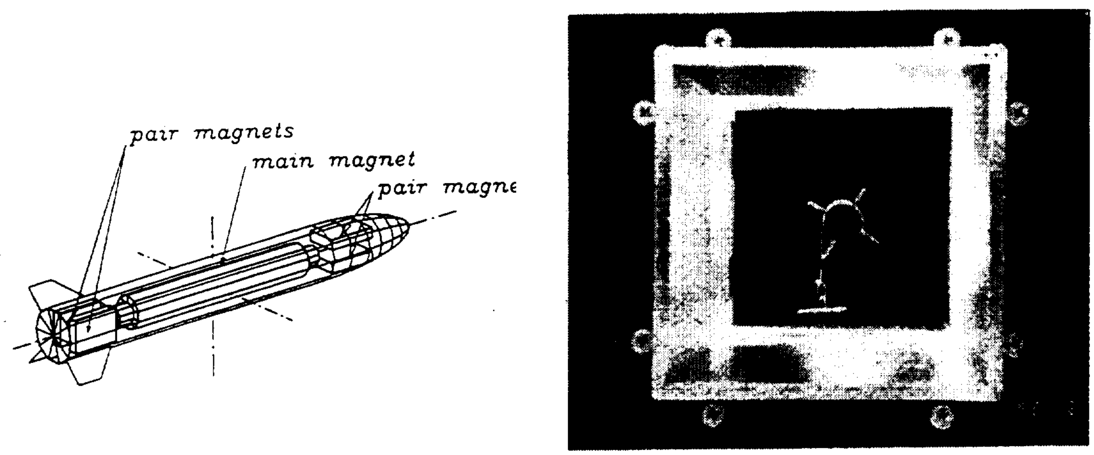

Fig.-2 : roll motion control in NAL 0.1m MSBS

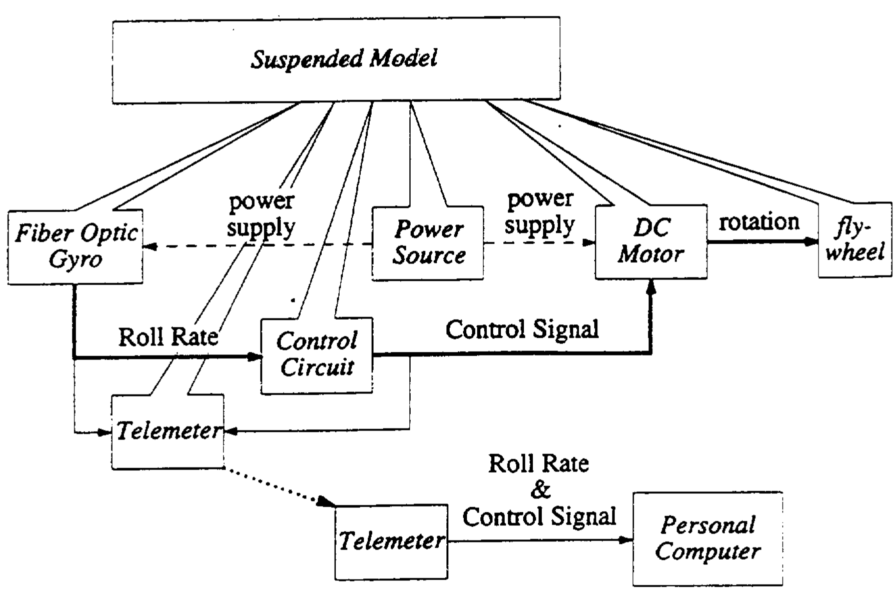

Fig.-3 : general idea of the mechanical roll motion restraint system

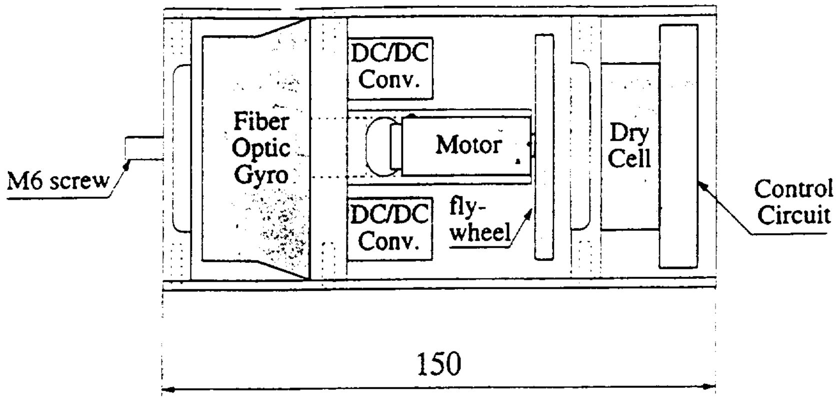

Fig.-4 arrangement of the mechanical roll motion restraint system

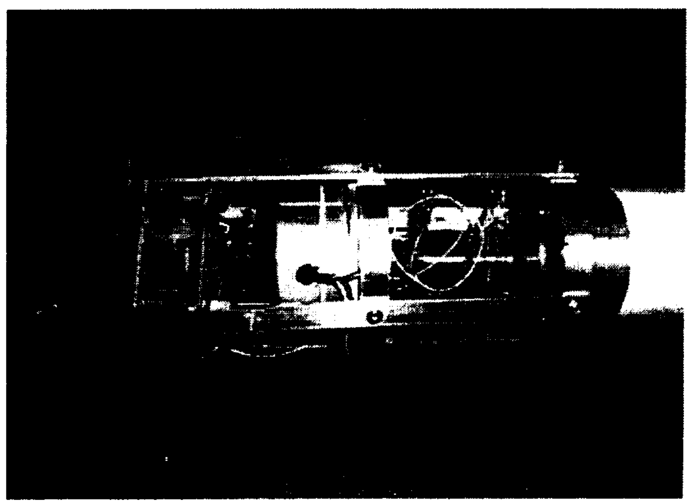

Fig.-5 : outlook of the mechanical roll motion restraint system

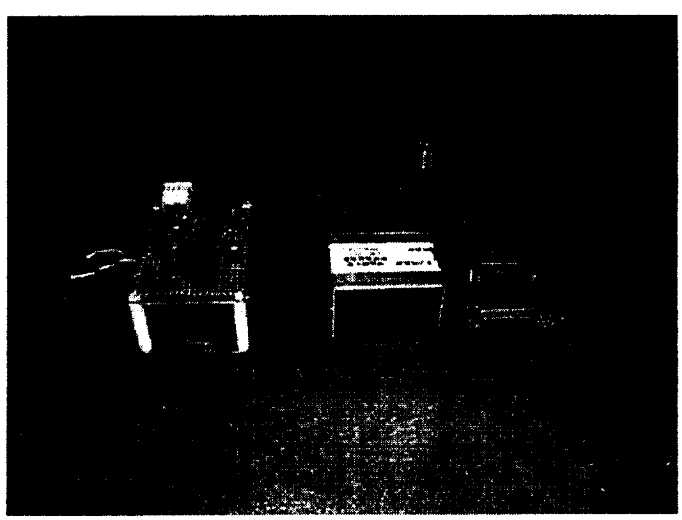

Fig.-6 : outlook of the IR communication system

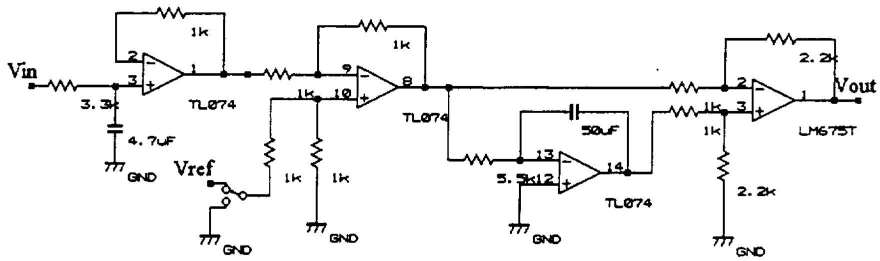

Fig.-7 : analog control circuit of the roll motion restraint system

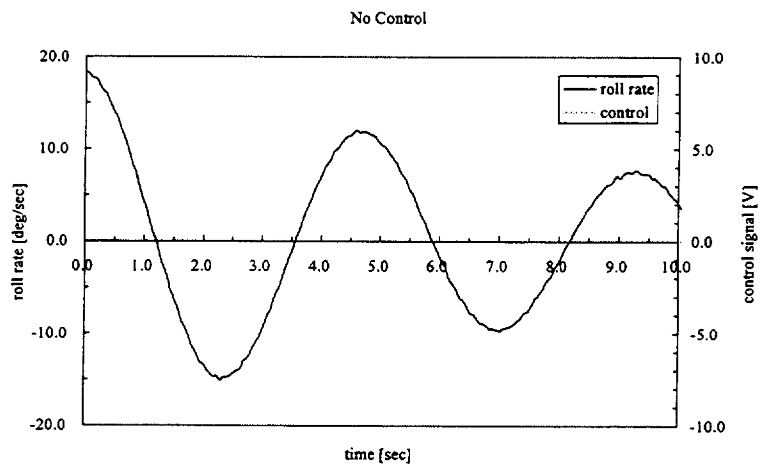

Fig.-8.1 : Trajectory of the roll rate (with no control)

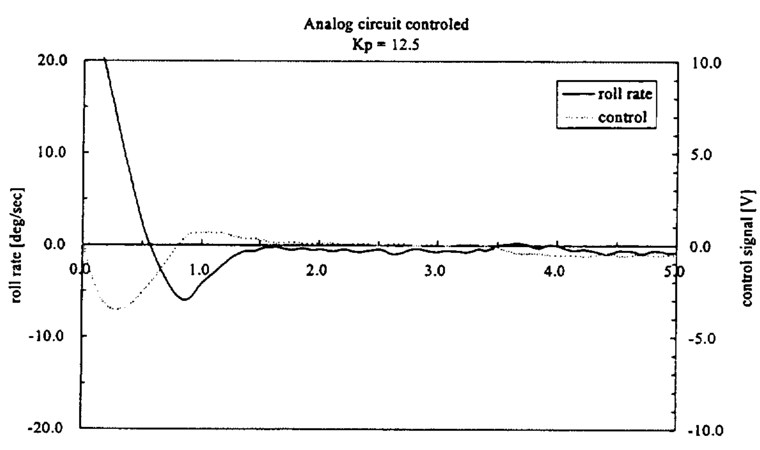

Fig.-8.2 : Trajectory of the roll rate (controlled)

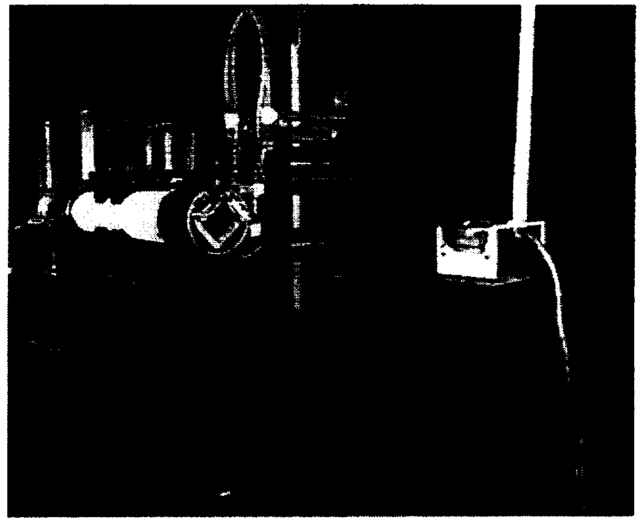

Fig.-9 : roll motion restraint system in the MSBS

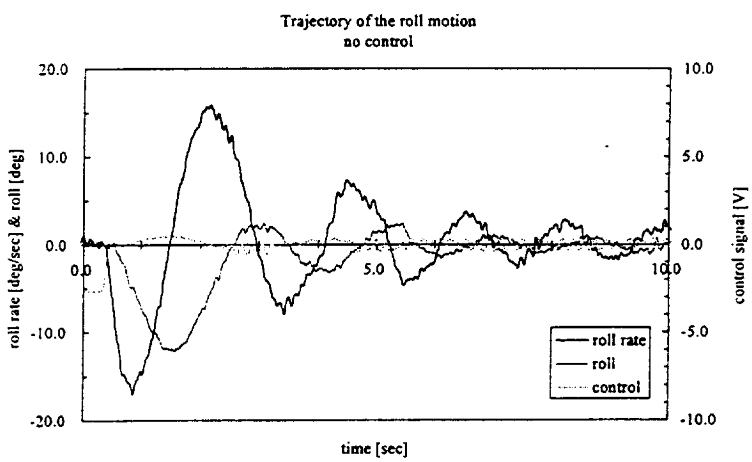

Fig.-10.1 : Trajectory of the roll rate (with no control)

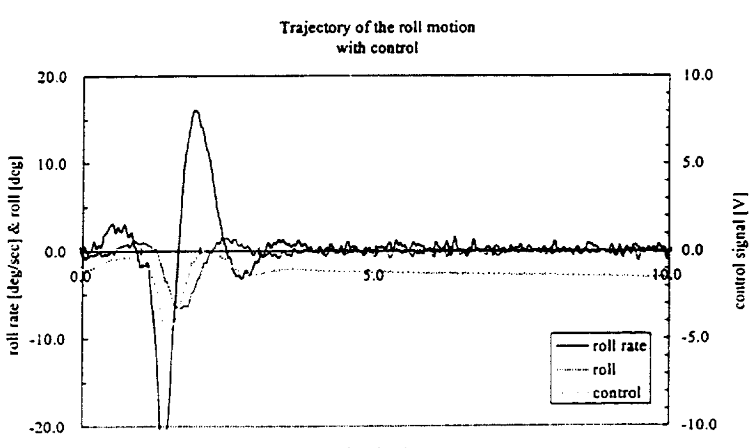

Fig.-10.2 : Trajectory of the roll rate (controlled)