The 9th International Symposium on Automation and Robotics in Construction June 3-5, 1992 Tokyo, Japan

Direction-Controlled Lifting System

Masahiro Nishimura
Construction Technology Development Department
Taisei Corporation
3-25-1 Hyakunin-cho, Shinjuku-ku, Tokyo, Japan

Shigeyuki Yamashita
Engineering Department
TOKIMEC Engineering Inc
2-16-46 Minami-Kamata, Ota-ku Tokyo Japan

Norimitsu Yoshihama
Yokohama Landmark Tower Building Project Site
Office, Yokohama Branch, Taisei Corporation
3-2-1 Minatomirai, Nishi-ku, Yokohama, Japan

ABSTRACT

In the construction of a high-rise building, structural members can be turned by the wind during lifting, making installation work more difficult and reducing productivity. This paper describes a system for the control of rotation around the vertical axis during the lifting of members. The system consists of three major units; a sensing unit, an operation unit, and an actuating unit. The operation unit incorporates a rate gyro, which keeps track of the lifted members in initial direction. It controls the actuating unit, which consists of a pair of blowers that stabilize orientation during lifting. Although this system contributes greatly to safety and work efficiency when used alone, it will also be an extremely useful sub-system in the future total automation of construction.

1. INTRODUCTION

In the construction of a super-high-rise building, it is generally the case that the more stories to be constructed, the greater the number of working days lost due to inclement weather. The major causes of this loss are rainfall and strong winds. While some days on which work must be halted occur even in the construction of lower stories regardless of the height, days lost to strong winds occur more frequently as the working height increases. Table 1 shows the rate of occurrence of days on which work could not be carried out in the past construction of super-high-rise buildings. With reference to Table 1, work was halted because of rain and wind on 14.2% of days in construction of the No. 1 Tokyo Metropolitan Government Office Building; and this breaks down to 8.8% due to strong wind as against 5.4% for rainfall. From these data, it may be said that the effects of strong winds on work efficiency are great. In particular, the installation of exterior wall precast (PC) panels, which have a large area as compared with their weight, is seriously affected.

The authors have developed a lifting system in which the lifted member is held automatically in a desired direction even in strong winds. This development proceeded on the premise that it would be used as a single unit as a lifting jig in the installation of exterior wall PC panels. The advantages that can be expected when it is used as a single unit include the following two:

- Improved safety when installing exterior wall PC panels
- Reduced construction period by reducing the number of lost days

However, it is believed that the essential effectiveness of this system will be fully displayed in a total building construction system, as expected to be realized in the future, in which it will form one of the most important sub-systems.

2. CHARACTERISTICS OF EXTERIOR PC CONCRETE PANEL INSTALLATION

(1) Development and introduction of this system was focused on construction of the Yokohama Landmark Tower, which will be the tallest building in Japan (296 m) when completed.

Looking back over the construction records of super-high-rise buildings that have already been constructed, it was anticipated that many work days would be lost due to strong winds. Table 2 summarizes the anticipated results of introducing this system, considering the days that installation work for exterior PC panels cannot be carried out due to strong winds.

As can be seen from the table, the days available for work increase and monthly operation ratio is improved. In short, it becomes possible to proceed with the work with greater efficiency, ultimately leading to a shortened construction period. In constructing the Yokohama Landmark Tower, the task of minimizing the construction period was given high priority, and as a result, introduction of this system was authorized after these advantages were elucidated.

(2) Photo-1 shows the actual installation work of exterior wall PC panels; the concrete panel suspended from the crane is pulled using a rope attached to the panel gradually nearer to its final position. After being maneuvered into position, it is secured with bolts to the designated fastener and tightened, thus completing the operation.

This operation is carried out in elevated locations, and on days when the wind is strong the panels tend to rotate around the vertical axis making the work of catching the rope and pulling the panels in very dangerous.

This system maintains the direction in the horizontal plane, so the operations of catching the rope and pulling the panel in are safer.

As already stated, even when introduced and used in construction work as a single unit, this system offers apparent improvements.

3. INFLUENCE OF WIND

3.1 Fan Operation

It was decided to examine a system in which the attitude of the lifted member is adjusted in the horizontal plane using fans, although such a technique had never been attempted before and there were many unknowns regarding effectiveness and behavior. Experiments using an actual size model were planned to obtain fundamental data prior to specific examinations of actual equipment.

The aim of the experiments was to calculate the power of the fans and to estimate the influence of wind.

3.2 In September 1991, experiments were conducted on four types of load, one empty and three PC panels hung using the jig shown in Fig. 1. The measurements included rotational angular velocity and wind velocity. A rate gyro was used to measure rotational angular velocity and an air speedometer for wind velocity, and the data were recorded every 0.5 seconds using a data recorder.

(1) Fan thrust

Since the moment of inertia of the jig and the PC panel are known, the fan thrust can be calculated from the angular acceleration obtained from measurements of angular velocity, subtracting the torque that acts on the jig and PC panels.

By obtaining data for the jig alone and for the jig in combination with three types of PC panel, the fan thrust was found to be about 214 Newtons at a motor speed of approximately 1,500 r.p.m.

An example of the experiment data is shown in Fig. 2.

(2) Rotational torque due to wind force

When wind pressure acts on the jig and PC panel, the mechanism by which the unit starts to rotate has not been fully clarified. It can be assumed, however, to be due to some structural imbalance. It was reasoned that if rotation occurs, the rotational torque due to the wind can be estimated.

Figure 3 shows the results of an experiment. The upper part of the figure shows the angular velocity in tests of the jig and a PC panel of 5.7 m, while the lower part shows the wind velocity at that time. At point A, the PC panel began right-handed rotation and accelerated up to point B. The rotation during that time was about 90°. At point B, the panel started to decelerate until about 180°, point C, where it started to accelerate once again.

Between point A and point B, the acceleration was assumed to be due to wind force, and the torque was calculated based on the moment of inertia of the jig and PC panel together. The torque due to the wind was then found to be 118Nm.

(3) Assumption of fan thrust and wind pressure torque

In the examination below, and based on experiments, the following assumptions are made:

1. The thrust of fan is proportional to the square of its rotational speed

2. The wind pressure torque is proportional to the square of the wind velocity and the exposed area of the jig and PC panel.

4. SYSTEM CONFIGURATION

4.1 Since the basic experiments indicated a good possibility of controlling the lifted member using fans, a simulation was set up of an actual system. The system consisted of three units, as shown in Fig. 4.

(1) Sensing:
Detects the angular velocity of the jig and PC panel and integrates it to obtain the orientation angle. To detect the angular velocity, use of a rate gyro with low drift was assumed.

(2) Operation:
Upon obtaining the orientation angle and angular velocity from the sensing unit, performs proportional and differential control by means of an error signal with respect to the set direction, and outputs instructions for speed and normal or reverse rotation of the fan motor.

(3) Actuating:
According to instructions from the operation unit, controls the speed of the fan motor. The torque generated by the fan is proportional to the square of the rotational speed.

4.2 Figure 5 shows a diagram of the simulation.

The orientation of the jig and PC panel is constantly compared with the set direction θ_o, and a differential voltage is supplied to the inverter, motor, and fan through the control amplifier. This controls the speed of rotation of the fan. To ensure stability of the system, signals proportional to the angular velocity are utilized.

While a torque T due to rotation of the fan is applied to the jig and PC panel, a wind torque T' also acts as a disturbing factor. The difference between the two gives an angular acceleration in inverse proportion to the moment of inertia to the jig and PC panel. The angular acceleration is integrated by the rate gyro, and the rate gyro in turn induces a voltage in proportion to the angular velocity, $\dot{\theta}$. This voltage representing angular velocity is integrated by the integrator and becomes the orientation angle θ, which is constantly compared with the set direction, θ_o.

That is, $I\ddot{\theta}=T-T'=(\theta-\theta_o + K4\dot{\theta})\ KI * K2 - T'$

From the profile of actual wind velocity at the time of the experiment, the simulation using the jig and 9m PC panel is shown in Fig. 6. The figure shows the profile of wind velocity, the deflection from the set direction, and the output torque of the fan. The results show that the deflection angle is small up to an average wind velocity of 15 m/s (peak 23 m/s), and this is adequate for application.

5. DESIGN OF SYSTEM (Design of actual equipment)

The actual equipment was designed on the basis of the simulation results.

5.1 Design Conditions

The loads to be lifted consist of the lifting jig plus four types of PC panel (9 m maximum). After slinging and lifting the member, the position is controlled to within ±15° in the horizontal plane during the lifting operation, and when the installation location is approached the system allows the orientation to be changed to one which makes for easier alignment by remote control (radio).

Slinging:
The member is slung near to the required alignment by the operator on the ground.

Lifting:
The alignment is maintained to within about ±15° of the set direction above as long as the average wind velocity is less than 15 m/s under automatic control.

Installation:
Under the control of a worker at the installation location, the position is matched to within 5°.

5.2 Composition of the System.

The actual device is shown in Fig. 7.

o Sensor: Although a magnetic compass or gyro compass might be considered as the orientation sensor, a magnetic compass would suffer errors due to the amount of ferrous material on the site while a gyro compass is difficult to handle since it requires a warm-up time. As a consequence, a low-drift rate gyro was adopted to detect the angular velocity. By integrating the angular velocity detected by the rate gyro, the orientation angle is obtained.

o The output of the sensor is processed on the automatic control board, as described in Chapter 4.

o Inverters I and II generate a frequency (60 Hz maximum) corresponding to the error signal voltage, and this controls the rotational speed of the fan motors (7.5 kW x 2). The maximum motor speed is 1,800 r.p.m. and the diameter of the fans is 900 mm.

o As remote control is accomplished manually, a control panel, programable controller, etc., are provided.

o To inform the operator of the control mode, green, blue, and red indicator lamps and orange patrol lights are provided above and below the lifting jig.

o A diesel generator (45 kw) provides power which is supplied through an electromagnetic breaker.

o All control is accomplished by radio, both on the ground and on upper floors.

o A general view of the system is shown in Fig. 8.

6. EFFECTIVENESS OF SYSTEM

To confirm how effective the system is using actual equipment, experiments were implemented in which the main emphasis was a comparison of the non-controlled and the controlled conditions. The day of the experiments being almost calm, a rotating motion was impaired by the crane on the PC panel as a simulated disturbance.

Figure 9 shows the results of this experiment.

The figure shows that although deflection angle of about 80° occurred under the non-controlled conditions, the deflection was held to within 2.5° of the desired direction when using the system.

In addition, Fig. 10 shows the results of response in 90° increments in a case where the control parameter (damping coefficient) of the automatic control circuit was varied. Figure 10-(b) shows the behavior of the PC panel when the damping coefficient was made larger. As demonstrated by these examples, it is possible to adjust the response characteristics of the PC panel by varying the control parameter in the control circuit.

7. SUMMARY

Development of this system started in November 1990 with the initial examination, and the basic experiments were conducted in September 1991. The actual equipment was applied to the site of the Yokohama Landmark Tower Building Project in December 1991. Thereafter, comprehensive adjustments were carried out, including setting the control coefficients of control circuit and radio equipment, etc., and this took about a month and a half. The system was then in practical working order. Since the project is still in progress, we have not yet been able to measure the overall effectiveness of introducing the system. However, from experimental results taken in March 1992, it has been confirmed that the system works effectively. On the Yokohama Landmark Tower Building Project site, with the system used as a single unit, the expected effects (improved safety and operational efficiency) have been realized.

We see the future evolution of this system into one of the most useful subsystems in a total automated building construction system. Even in such a system, use of conventional cranes would mean there is no way to prevent rotation of the lifted component around the vertical axis. This new system could be an extremely important auxiliary unit in a situation where assembly robots receive the lifted components. It is possible to deliver materials in a given position that makes handling easier.

In the future, we wish to check the function of the single unit now operating in the Yokohama Landmark Tower Project, as well as making clear positioning, role, the required functions of this system (as a subsystem) in the total automated building construction system in the future.

Lastly, we wish to express our thanks to those who have rendered us useful advice and cooperation in this development.

Table 1 The rate of occurrence of days on which construction of the super-high-rise buildings is halted.

Name of building	Ceiling height	Days of strong wind and rainfall	Holidays, etc.	Actual working days
Yasuda Fire and Marine Insurance Co., Ltd. Building	193.0 m	16.5%	17.5%	66.0%
Shinjuku Center Building	216.0 m	13.0%	24.3%	63.6%
Shinjuku NS Building	121.5 m	17.3%	20.6%	62.1%
Tokyo Metropolitan Government No. 1 Building	241.8 m	14.2%	18.1%	67.7%

Table 2 Estimated effectiveness of introducing this system

Item	Conventional operation method (system is not used)	Operational method using this system	Effectiveness
Days that the work can be carried out (Portions higher than 200 m)	15 days/month	19 days/month	. Improvement in operation ratio/ month (27%)
Number of panels installed	160 pieces/ month	200 pieces/ month	. Improvement of productivity/month (25%)
Number of days of crane operation	15 days/month	19 days/month	. Reduction of the rent of heavy equipment
Installation period of panels	257 calendar days	205 calendar days	. Shortening of construction period (52 days)

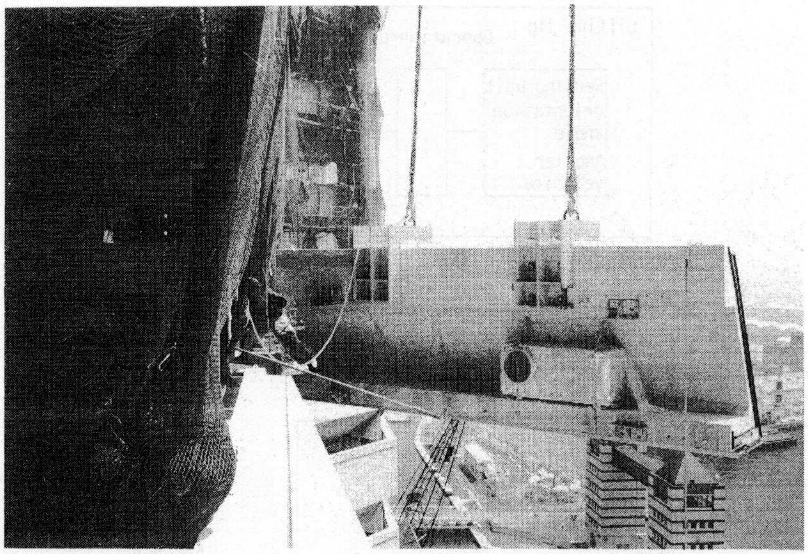
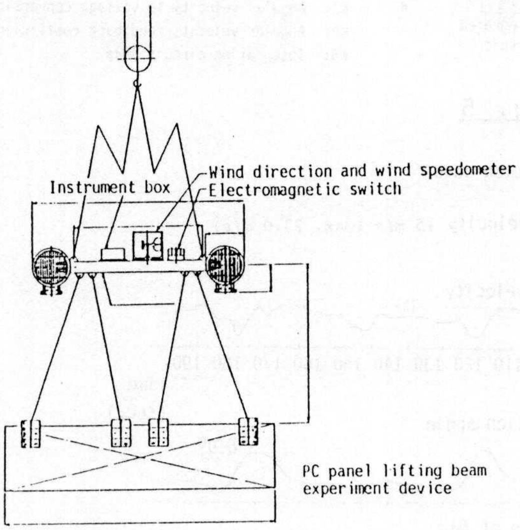


Photo 1



Main item

Rated load	20 t
Rotational torque	190 kgfm
Wind volume of fan	950 m^3/min (outlet in both directions)
Wind velocity of fan	16.7 m/min
Fan thrust	32.8 kgf (planned)
No. of fans	2 units
Fan motor	Motor bar 7.5 kW x 4 P inverter
Control	Positive and inverse operation by push button (right and left independent)
Voltage	200 V 50 Hz

Fig. 1

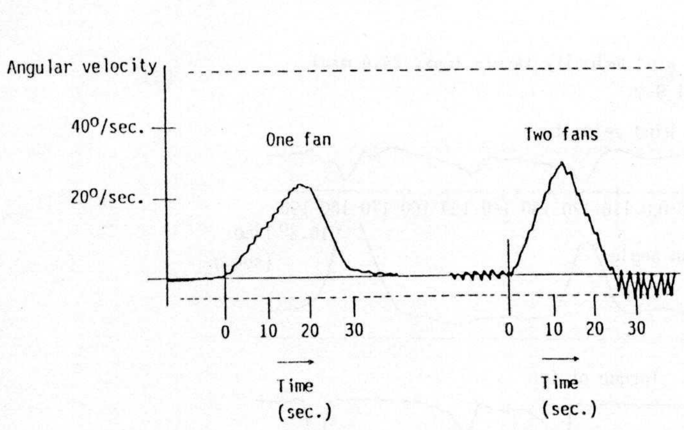


Fig. 2

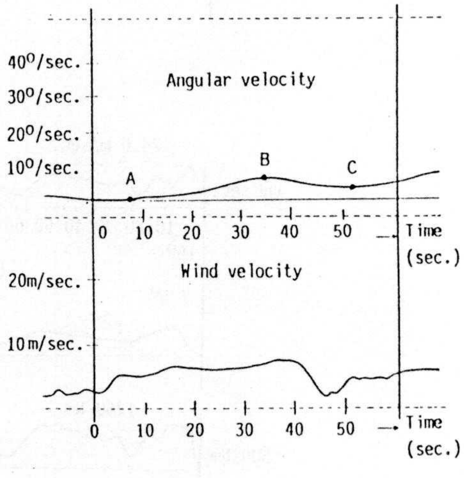


Fig. 3

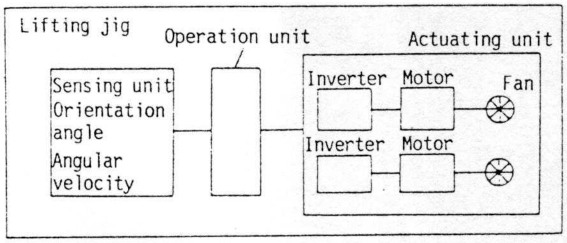
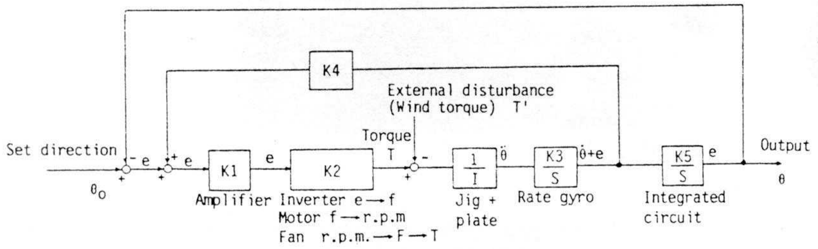


Fig. 4

Direction controlled lifting system
Block diagram

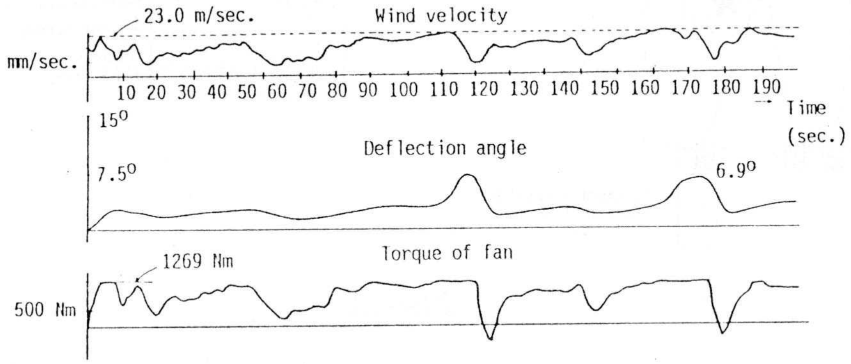


e: Voltage
θ: Direction
θ_0: Set direction
$\dot{\theta}$: Angular velocity
$\ddot{\theta}$: Angular acceleration
T: Torque
T': Wind torque
K1: Gain
K2: Voltage to torque conversion coefficient
K3: Angular velocity to voltage conversion coefficient
K4: Angular velocity feed back coefficient
K5: Integrating circuit gain

Fig. 5

Simulation data

Average wind velocity 15 m/s (max. 23.0 m/s)
PC panel 9 m



Average wind velocity 16 m/s (max. 24.6 m/s)
PC panel 9 m

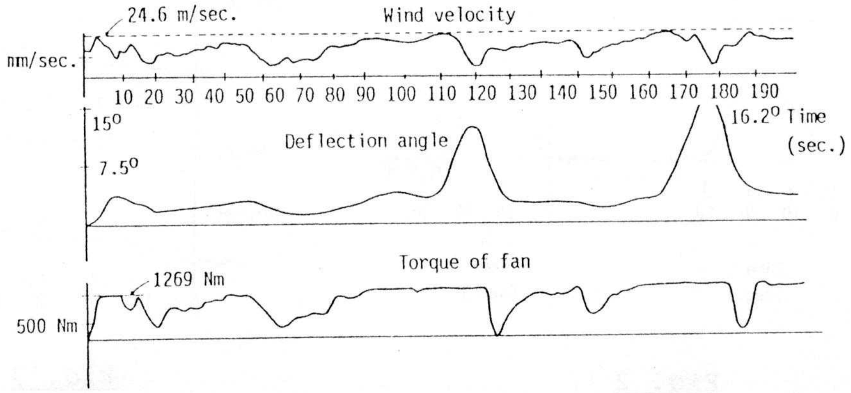


Fig. 6

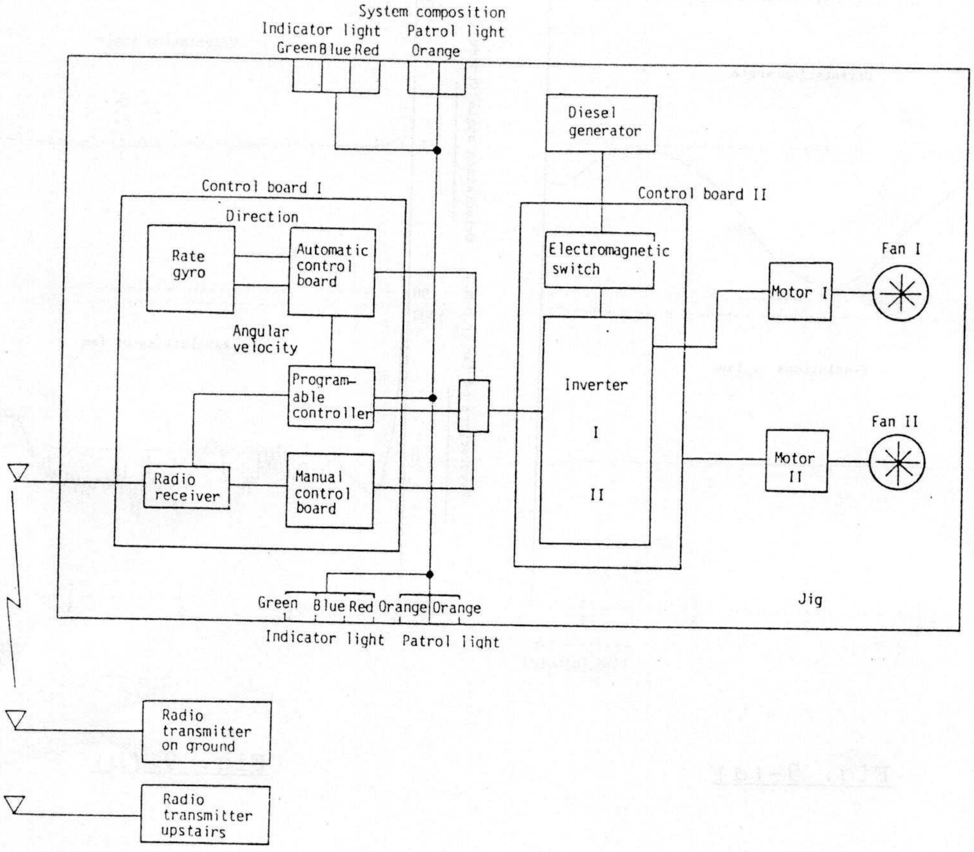
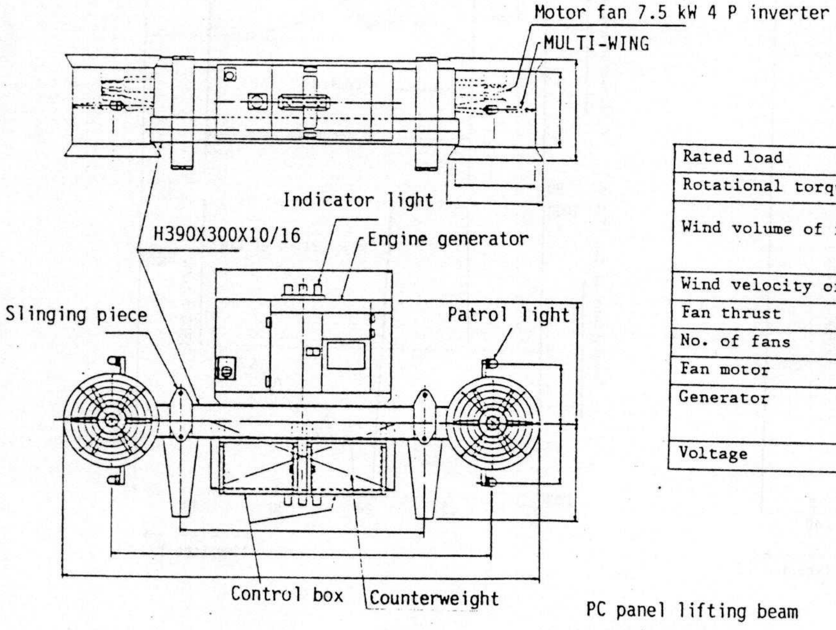


Fig. 7



PC panel lifting beam experiment device

Main item

Rated load	14 t
Rotational torque	133 kgfm
Wind volume of fan	750 m^3/min (outlet in both directions)
Wind velocity of fan	19.7 m/min
Fan thrust	30.3 kgf (planned)
No. of fans	2 units
Fan motor	Motor bar 7.5 kW x 4 P inverter
Generator	Soundproof engine generator 57 PS 45 KVA
Voltage	220 V 60 Hz

Fig. 8

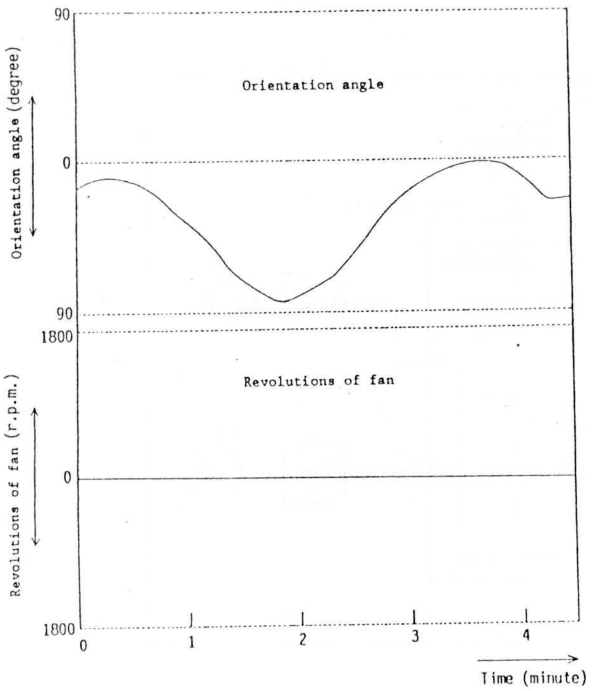


Fig. 9-(a)

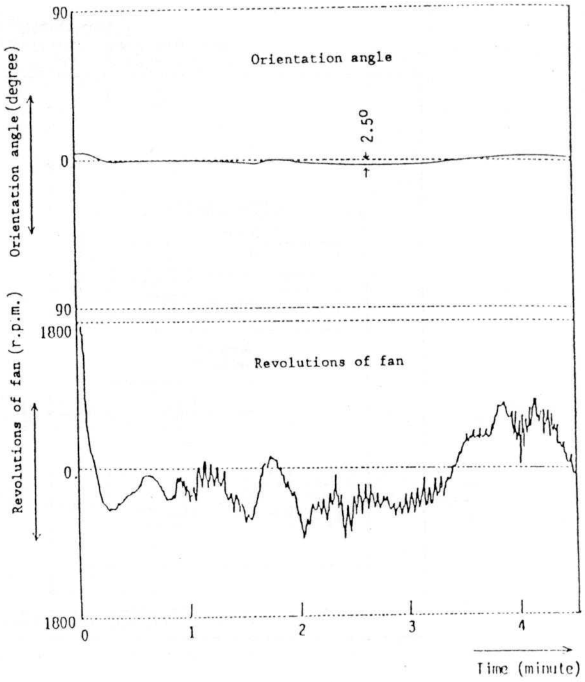


Fig. 9-(b)

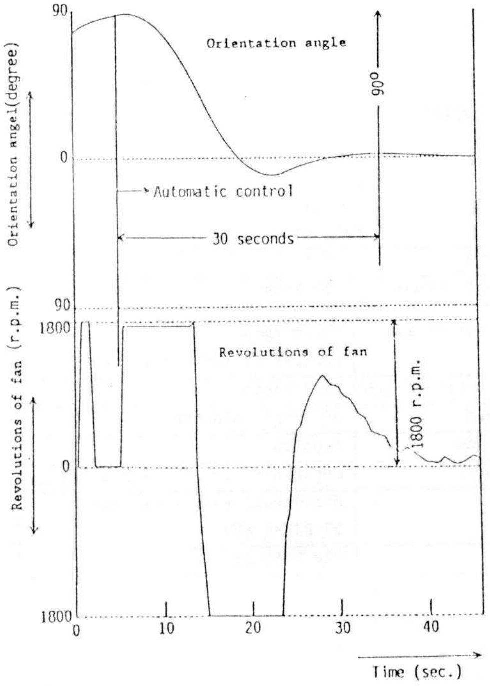


Fig. 10-(a)

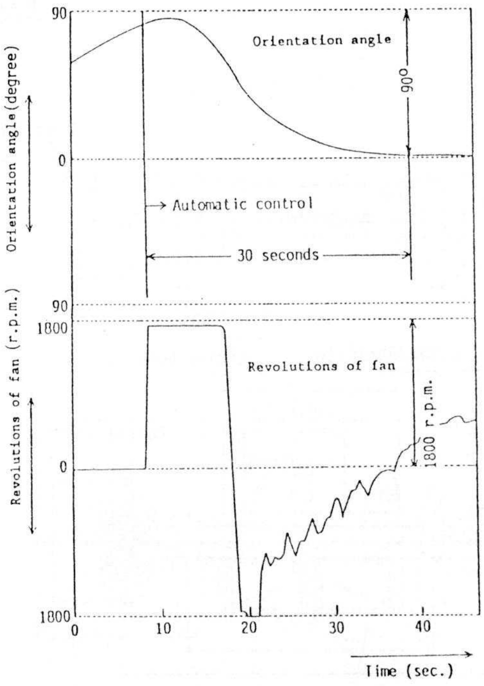


Fig. 10-(b)