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Air Dome Inner Pressure Control System

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Tokyo dome is Japan's first air dome. The roof of the dome is supported by air pressure. The centralized control system (YOKOGAWA's DCS : CENTUM and YEWPACK) is applied to automatically regurate the air pressure. The control system acquires signals from sensors positioned throughout the stadium and operate 36 fans to blow air into the dome. Great emphasis is placed on the reliability and safety of the system.

1.Introduction

Korakuen Stadium`s Tokyo dome so called BIG EGG is Japan`s first air domeas well as its first roofed stadium.

The centralized control system(Yokogawa`s DCS:CENTUM and YEWPACK are used) is adopted to automatically regulate the air pressure needed to support theroof. The feature of this pressure control system is described below.

The inner pressure control of air domes has already put into practice in the U.S.A. ,but the fact is that the system need to be operated by skillful operators full-time. We aimed at full automatic control of the inner pressure by DCS (Distributed Control System).

2.Outline of air dome

The roof of the air dome is consist of thick steel cables which spread lengthwise and crosswise ,and teflon-coated fiber glass cloths which are pasted among the cables. Air blown into the dome by 36 fans maintains an air pressure a little (usually 30 mmAq) higher than that of outside to support the roof. This control system mainly control these fans`on/off to regulate the inner pressure.

3.System Configuration

Fig.1 shows the system configuration.

1) Operators Console (COPSV)

Identical Operators Consoles (Main and Backup) are installed separately in the control operation room (underground 2nd floor) and in the spectator stands monitoring room (3rd floor above the ground). If any trouble should happen and automatic control could not be done, operators can operate fans manually by the backup console watching the roof from the spectator stands monitoring room.

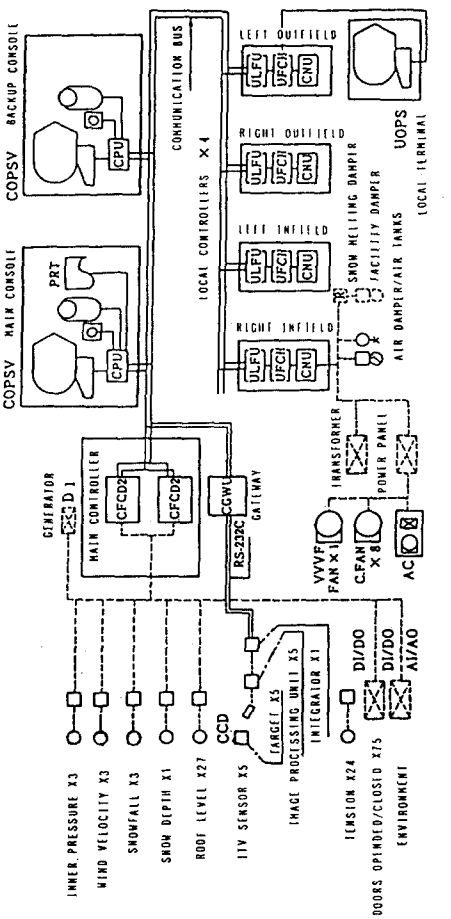

FIG. 1 SYSTEM CONFIGURATION

2) Main Controller (CFCD2)

Main controllers play an important part to integrate information corresponding to the inner air pressure support, and then give instructions to the local controllers for operating fans.

Two duplexed control stations are installed to raise up an reliability. Main controllers acquire process values from sensors such as inner pressure, wind velocity, snowfall, snow depth, roof level, opened/closed doors.

The roof vibration obtained from ITV sensors is transfered to the main controllers through the communication gateway unit(CGWU).

3) Local controller (ULFU,UFCH,CNU)

Four independent local controllers which correspond to the right infield /outfield and left infield/outfield are installed. Each local controller controls one variable frequency fan, eight constant frequency fans and some air dampers. The local terminal is prepared for maintenance of the software.

4. Sensor

1) Inner Pressure Sensor

The inner pressure sensors measure the difference between the inner air pressure and that of outside. They are very sufficient sensors to maintain the roof in this control system. To get the reliability high three pressure sensors are installed at the level of 3rd floor. One of three measured values is selected to control the inner pressure.

2) Wind Velocity Sensor

If the wind outside is strong, the roof may flutter,in such a case maintaining of the dome shape will be influenced badly. So that three wind velocity sensors are installed outside the dome. As the level of the roof and the position of the wind velocity sensors installed is different, the measured wind velocity is converted into the roof height value.

3) Snowfall and Snow Depth Sensor

If the roof is covered with snow, there's a possibility of a serious accident such as the roof crash. So that three snow sensors and one snow depth sensor are installed on the roof.

4) Roof Level Sensor

Sensors for measuring the roof level are installed along the roof to detect a transformation by inner pressure decrease or snowfall on the roof and so on. Tubes filled up with water are run along the roof cables. Strain gauges (27 measuring points and four basis points) are atached to the tubes. The pressure difference between measuring points and the basis points is converted to the roof level value.

5) ITV sensor

ITV sensors utilized TV cameras are installed to measure the roof vibration. Five TV cameras shoot scenes of LEDs atached the roof surface. Images of the LED targets are traced by an image processing unit and it calculates the vibration amplitude of the roof.

6) Door Open/Close Sensor

When Balanced doors (used only for exit) are opened, the air leak increase and it influences the inner pressure greatly. So that limit switches are atached to the doors.

5. Inner Pressure Control Item

Fig.2 shows the control flow of this system.

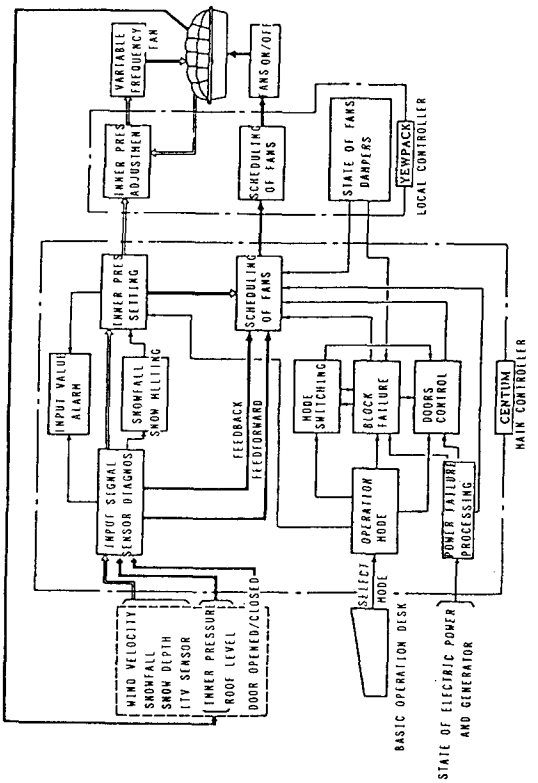

FIG. 2 CONTROL ROUTINES

1) Processing by main controllers

(a) Input signal processing

In this routine input values from sensors are averaged and the deviation among multiplexed sensors are checked.

(b) Selection of operation mode

Four operation modes ("OPEN","CLOSE", "EXIT","REFUGE") are prepared. The operators select one of them by the basic operation desk. Usually the order of the operation mode is "OPEN" -> "EXIT" -> "CLOSE". "REFUGE" mode is prepared for emergency.

(c) Snowfall / Snow Melting
By blowing hot air between the double cloth of the roof, snow on the roof is melted to protect the roof from an accident such as crash by snow weight.

(d) Setting of Inner Air Pressure
When wind is strong, the inner pressure must be high to repress fluttering of the roof. When the roof is covered with snow, the inner pressure must be high also to bear the snow weight. According to these weather condition the set value of the inner pressure is determined automatically and then transfered to the local controllers to control the variable frequency fans.

(e) Determination of the number of fans and scheduling of fans
The required number of fans is determined according to the inner pressure, the roof level and the number of opened balanced doors. Detailed items are described below.

2) Processing by local controllers
The local controllers adjust the inner air pressure by controlling the rotation of the variable frequency fans according to the set value of the inner pressure. Moreover, the local controllers gather the state of fans or air dampers, and then transfer them to the main controllers. If the main controllers should fail, they are available as backups to control the fans automatically.

6. Control of fans
36 fans are installed around the stadium. One block which is correspond to one local controller consists of one variable frequency fan and eight constant frequency fans.

1) Required number of fans
Fig.3 shows the determination flow of required number of fans. Wind velocity, snowfall and roof vibration are reflected to the set value of the inner pressure. This inner pressure set value is applied to control the rotation of the variable frequency fan. The number of fans is determined by the inner pressure, the roof level (feedback control) and the number of opened doors (feedforward control).
the difference number of fans is calcula-ted as

$$\Delta M = \Delta Me1 + \Delta Me2 + \Delta Me3 + \Delta Md$$

Because of electric power capacity, $\Delta Mmax = 3$. To protect fans from thermal trip, increasing or decreasing of fans is done at 10 seconds intervals.
It's rare case that all 36 fans are ON in condition all balanced doors closed. Only two fans can support the roof. (Usually people can use rotation doors whose air leak is little under OPEN, the balanced doors are used under EXIT.)

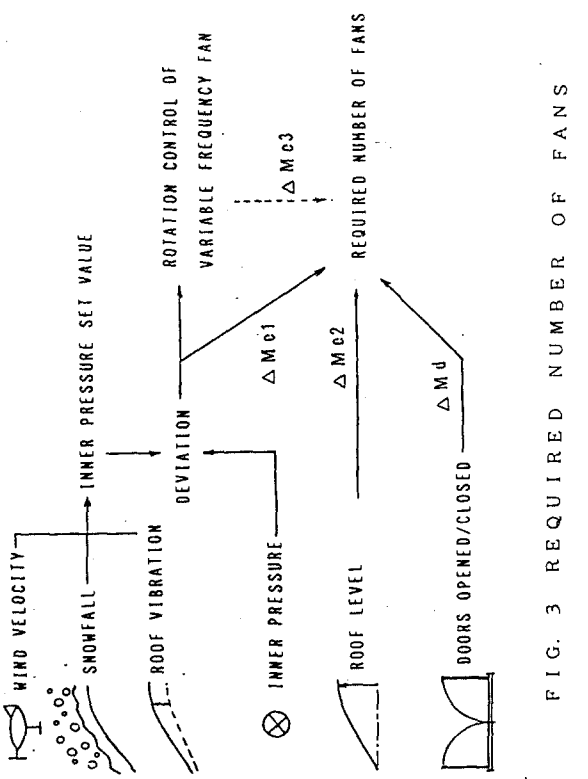

FIG. 3 REQUIRED NUMBER OF FANS

2) Scheduling of fans
The fans are on or off in scheduled order, which is determined by the main controllers. When the stadium is OPEN, mainly the infield side fans are used. When it is CLOSE, mainly the outfield fans are used. The fans used under CLOSE are ON in long hour, so that their scheduled order is rotated. Fig.4 shows an example of scheduled order which is applied under OPEN. The variable frequency fan is ON first, then the constant velocity fans are ON in succession.

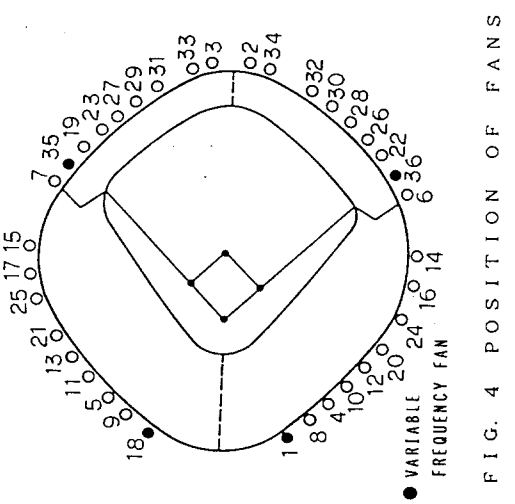

FIG. 4 POSITION OF FANS

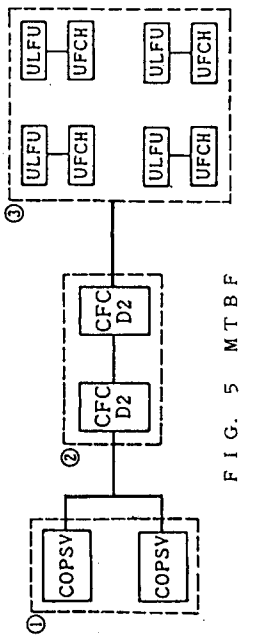

FIG. 5 MTBF

8. Reliability of this system

THe reliability of this system is a very important feature to support the roof in safety. (see Fig.5)

assuming that

availability of operators console

$A_{ops} = 0.9984495$

availability of main controller

$A_{fcs} = 0.999988$

availability of duplexed communication bus

$A_{hf} = 0.999999999$

availability of local controller

$A_{yp} = 0.99964$

Two operators consoles are identical, so that

$A_{①} = 1 - (1 - A_{ops})^2 = 0.9999976$

Two main controllers take pertial charge of the function,so that

$A_{②} = A_{fcd}^2 = 0.999976$

Four local controllers are independent, but according to the operation rule 3 out of 4 controllers must be in order, so that

$A_{③} = A_{yp}^4 + 4 \cdot A_{yp}^3 \cdot (1-A_{yp}) = 0.9999992$

Then totally

$A = A_{①} \cdot A_{②} \cdot A_{③} \cdot A_{hf} = 0.999973$

assuming that MTTR = 8 [hours]

MTBF = 296,000 [hours] = 34 [years]

9. Conclusion

After start-up at the end of June in 1987, this system was tested practically until March in 1988. From then on this full automatic inner pressure control system has been operated satisfactorily.