Research on Monitoring and Control System Based PLC in the NF-6 Wind Tunnel

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Abstract

The monitoring and control system in the NF-6 wind tunnel is realized by PLC (programmable logic controller). In this article, we describe in detail on the monitoring and control system. At first we introduce the monitoring and control object (NF-6 wind tunnel) in brief. And then expatiate globally the monitoring and control system (topic 3). The anti-surge control system and typical parameter measurement system are analyzed. We discuss respectively the hardware structure, software and program logic structure of the monitoring and control system (topic 4), and research the experiment results. The test result indicates that the monitoring and control system which based on PLC and is composed of monitoring instrument, control valve, auxiliary subsystem, has achieved good effect in practice.

1. Introduction

The NF-6 wind tunnel which is under construction now is the continuously -running transonic airfoil wind tunnel in China. Powered by the AV90-2 Axial flow compressor which produced by Shaanxi compressor group, the air can run through the entire wind tunnel. Compared with the intermittent wind tunnel, the efficiency of transonic airfoil experiment in the NF-6 wind tunnel will be greatly improved, and NF-6 wind tunnel makes it possible to test continuously.

To the axial-flow compressor in the return-flow wind tunnel, it has characteristics of a wide scope of operation, more sensitive natural frequency of vibration and so on. Moreover, compressor driving ventilating machinery can easily cause the phenomenon of the surge, deformation by force of compressor's rotor, severe vibration caused by interstage pressure maladjustment. What's more, it may bring on collision between rotor blades and stators, and even casualty that injure people. Consequently, compressor monitoring and control is the foremost part of entire wind tunnel monitoring and control system. In order to ensure that the compressor and wind tunnel run safely, we build a high-efficiency, reliable wind tunnel monitoring and control system based on the Siemens S7-400 Programmable Logic Controller, which guarantee the compressor is running in a controllable and safety state throughout the wind tunnel experimental process, and satisfactory results were obtained in the whole wind tunnel debugging process.

2. NF-6 Wind Tunnel

NF-6 wind tunnel structure is showed in Figure 1. Its power system is composed of two 2500kw DC motor in series, which drive the axial-flow compressor rotating by speed increasing gear and long-axis, so the air can flow continuously and form a stable fluid field for the model experiment in the wind tunnel. The size of two-dimensional test section is 0.8m×0.4m×3m (high×width×length), flow mach number range from 0.2 to 1.2, the pressure within the tunnel can increase to 0.55MPa from the atmospheric pressure. In order to avoid surge and ensure the compressor running in the stability district, we added two bypass systems between the second diffuser and vent zone. Through increasing the pressure and cooling the air with nitrogen, the test Reynolds number can ascend to 23×10^6, and it makes the wind tunnel possess the capability of fixing the mach-number and changing the Reynolds number. Besides, NF-6 wind tunnel also has the advantages of dynamic test, high efficiency, and low cost, because of it's continuously running capability.

3 The NF-6 Wind Tunnel's Monitoring and Control System

The monitoring and control system of NF-6 wind tunnel mainly includes: static blade control subsystem, direct current motor control subsystem, lubrication supply subsystem, cooling water supply subsystem, gas source supply and control subsystem, axial vibration and axis temperature measurement unit, axial-flow compressor flux, pressure and temperature measurement unit etc.

When the wind tunnel is running, we need to supply the compressor and DC motor lube continuously to make sure they are running safety, and at the same time we are required to monitor some key points to ensure the safety of the wind tunnel (such as axial vibration, axletree temperature, compressor outlet and inlet pressure ratio, tunnel airflow temperature etc). When the temperature of tunnel airflow is too high, we need to open cooling water supply subsystem. If experiment is pressurized, we must open the gas source supply and control subsystem to provide anticipant high pressure air to the tunnel. The relationship of the all subsystems of the entire wind tunnel's monitoring and control is shown in Figure 2.

The most important part in the diagram is the anti-surge control system. It is based on the above measurement unit, composed of static blade control subsystem, fisher valve, DC motor control subsystem, and PLC control box. And it is also the pillar of the tunnel safe operation. Above measurement units, oil pressure and temperature of lubricating oil, angle of static blade and valve position of fisher valve make up of the entire typical parameter measurement system, and measuring the parameters of this system have become the foundation of the whole anti-surge control system. Consequently, following introduction mainly focus on the anti-surge control system and typical parameter measurement system.

3.1 Anti-surge Control System

During the running process, the compressor is always associated with compressor outlet and inlet pressure ratio, rotating speed, inlet flux. And if the compressor inlet flux is smaller than a special fixed flux in a certain rotating speed, the airflow pressure inside the compressor and the flux will oscillate fiercely, at last it result in the axial-vibration aggravation and intensive vibration of entire pipe system, namely surge generating. Severe surge may cause collision between the rotor blades and static blades, which can lead to bad accident, so we need protect compressor by special method and equipment, and the common method is emptying or making reflux [1]. Previous work [2, 3] has shown that the NF-6 wind tunnel should use making reflux to prevent surge. And just as the Figure 1 shown, we install quick exhaust valves on the two bypass systems to make reflux (fisher valve).

When the compressor's work point is approaching the surge area, it is required to open the fisher valve a certain angle to make the work point keep away the surge area. Axial-flow compressor's characteristic curves are shown in Figure 3, and the y axis is pressure ratio, the x axis is flux. In Figure 3, curve (a) is the actual surge boundary line, and curve (b) is the surge control boundary line. Between curve (a) and curve (b) the flux is different at the same pressure ratio. Once the work point approaches curve (b), we need to increase static blade angle and open fisher valve to make work point keep away the surge area.

3.2 Typical Parameter Measurement System

The basis for anti-surge is the pressure ratio between the outlet and inlet of the compressor, and its corresponding flux, so by monitoring the current flux we can judge whether the compressor's work point has entered the surge area or not. During the seeking the surge boundary line process, we should confirm the minimum flux and corresponding pressure ratio of every surge state. Accordingly, we usually combine with measuring the characteristic of the axis vibration and empirical analysis to judge whether the surge of the compressor has occurred or not in practice[4]. And in order to ensure the safety of the wind tunnel and other assisted facilities, it is very important to measure some typical parameters such as the axletree's temperature of the compressor and speed increasing gear, the oil temperature and pressure of lube in the axletree, wind tunnel's total temperature, the position of the bypass fisher valve, angle of the compressor static blades. And in practice, all temperatures are measured by platinum resistance; axial-vibration is measured by the American Bently 3300 system; we also install two piezoelectric-velocity-sensors on the axis of the compressor to monitor the vibration velocity respectively, moreover, set two non-contact electrical vortex displacement sensors vertically on the high-speed axis of the speed increasing gear to monitor the radical displacements.

4. Realization of the NF-6 Wind Tunnel Monitoring and Control System

The NF-6 wind tunnel's monitoring and control system mainly use the Siemens's SIMATIC S7 PLC as the hardware, and write the structured programming on the STEP 7 software platform. Following discussion will mainly focus on the problem how to realize the monitoring and control.

4.1 Monitoring and Control System Hardware Construction

In order to ensure the wind tunnel's running in a high safety, high reliability, and high expansibility, we use the PLC to realize the necessary functions for monitoring and control the NF-6 wind tunnel, and to make sure wind tunnel running steadily. We choose the Siemens S7 400 as the hardware platform, because the series of products have the characteristics of high reliability, powerful calculation, communication capabilities, and perfect self-diagnosis function. The structure of system is shown in the Figure 4. In the picture, AI is the analog quantity input module, RI is the thermal resistance input module, AO is the analog quantity output module, DI is the switch quantity input module, and DO is the switch quantity output module. Industrial control computer is upper computer, which takes charge of receiving the important data coming from PLC, whereas the PLC on-line computer is usually used for monitoring the real time value of the variables of the PLC control system, recompiling the PLC program and downloading program, and at the same time the information of the DC motor speed drive system must be transferred into the PLC control box through the PROFIBUS data bus.

4.2 Monitoring and Control System Software Construction

STEP 7 is a kind of standard software pack which is used for configuration and programming for the SIMATIC programmable logic controller. And it is also the S7-400 series PLC's programming software. STEP7 supports three kinds of standard programming language, which are STL, LAD, and FBD. The entire of wind tunnel control system's function is programmed by the LAD language. Monitoring and control program adopts structural programming as the main design method, and also uses a lot of FB blocks, FC blocks, DB blocks, and OB blocks to realize the control of the system.

4.3 Logic Structure of the Monitoring and Control System's Program

The monitoring and control system's program structure is shown in the Figure 5, the key parts of the program are "data input module", "startup interlock subroutine", "interlock stop subroutine", and "automatic operation module".

After the monitoring and control system's program entering the master module, it will read the data of AI module, RI module and DI module (such as the lube pressure and temperature, angle of static blades, position of the fisher valve, lube pump's work state, cooling water state, DC motor state etc), and if the experiment has started up, the real time data (such as the values of compressor's and accelerator's axial vibration, axletree temperature, and compressor's outlet and inlet pressure, temperature etc) should be read. When lubricant pressure is normal (lubricant pumps work normally), static blades is all opened, anti surge valves is all opened, and DC motors work normally, namely startup interlock condition is satisfied, the compressor can be started up, then system enter the state of auto operation and will display the real time data of typical monitoring parameters.

Once any of the aforementioned startup condition didn't be satisfied (such as compressor's and accelerator's axial vibration is too fierce, axletree temperature is too high, or airflow in wind tunnel is overheating etc), the system enter the state of interlock stop, shut down the compressor, and display the reason at the same time. If the work point approaches the surge control boundary line, system will take measures (such as pulling the static blades, opening the fisher valve etc) to keep the compressor away from the surge area. If the machine unit has stopped, it is required to open the static blades, make the fisher valve full open, and in order to prevent the slight deformation of the axis, it is necessary to open the jigger to make the axis units stress uniformly.

4.4 Experimental Data and Analysis

A series of debugging work based on aforementioned foundation is carried out. Figure 6 shows speed increasing gear axis vibration displacement at the different compressor's rotate speed. Figure 7 shows the curve of the compressor's rear-and-forward vibration speed, and its vibration speed value isn't high, far away below the alarming and stopping value. The vibration displacements in the both x and y directions of the speed increasing gear's high speed axis are a bit larger, but they are all in the permission area for safe running. Moreover, when the system interlink stop conditions are all satisfied, it will stop the machine automatically. Through the whole monitoring and control system which is based on the PLC, we can observe the change of the values of some key parameters in real time, and can carry out experiment under control state.

5. Conclusions

Monitoring and control system based PLC in the NF-6 wind tunnel can offer the real time values of some key parameters, analyze the machine sets working state and diagnose the breakdown reason, and it also has advantages of high reliability, perfect safety, easy second developing etc. Practice indicates that the system can insure whole experiment process run under credible and safe conditions, which provided a good guarantee condition for the further improvement performance of the wind tunnel. The whole system is successful and dependable.

References

[1] Jiang W S, Yu J S. "Process control engineering". 1st edition, *Hydrocarbon Process Publishing Co*, pp. 209~212, 1988.

[2] Li Y B, Qiao Z D. "Anti-surge Control methods of continuously-running transonic wind tunnel —— research of directness expand to empty". *Experiment and Measurement of Fluid Mechanics*.Vol.15.No.3, pp. 24~29, 2001.

[3] Li Y B, Qiao Z D. "Anti-surge Control methods of continuously-running transonic wind tunnel —— research of adjust bypass". *Experiment and Measurement of Fluid Mechanics*.Vol.15.No.4, pp. 53~58, 2001

[4] Lei J Y, Liao M F. "New methods for surge board prediction". *Fan technology*.No.4, pp. 52~54, 2005.

6. Copyright Issues

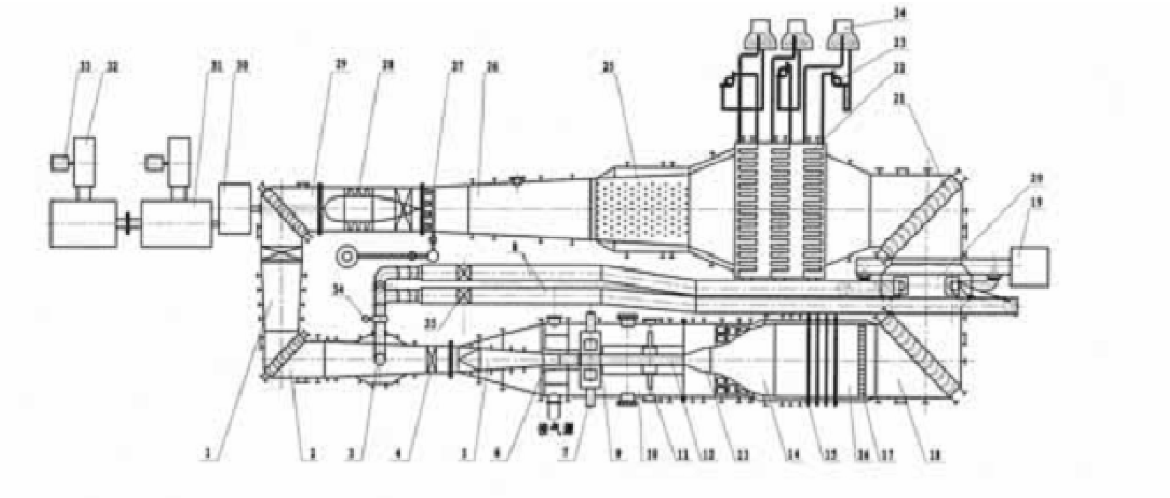

Fig.1 the sketch of NF-6 wind tunnel

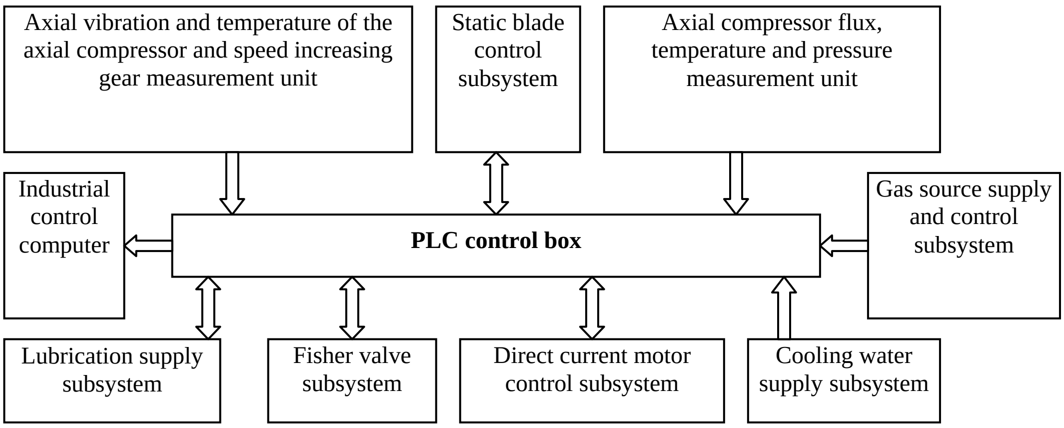

Fig. 2 the block diagram of monitoring and control system in the NF-6 wind tunnel

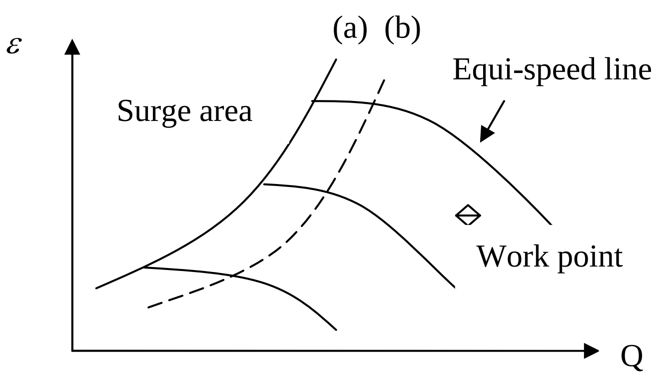

Fig.3 axial-flow compressor’s performance cure

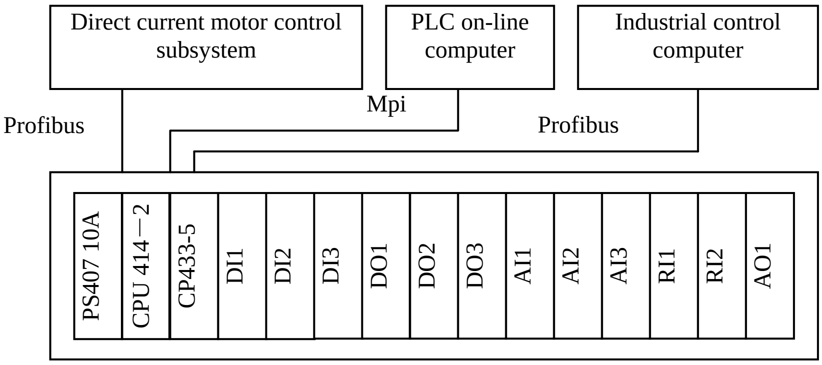

Fig.4 the hardware structure of plc monitoring and control system

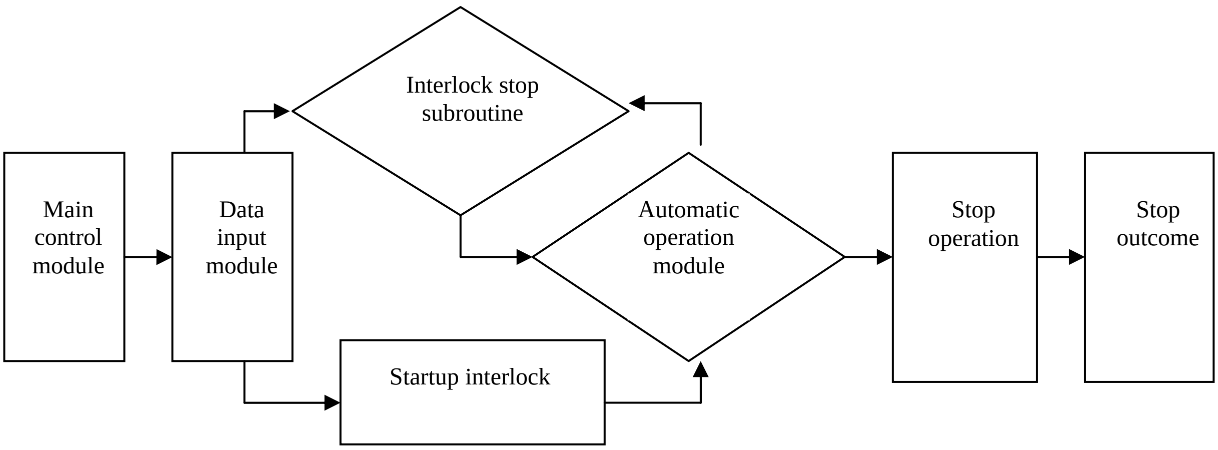

Fig.5 the monitor and control program logic block diagram

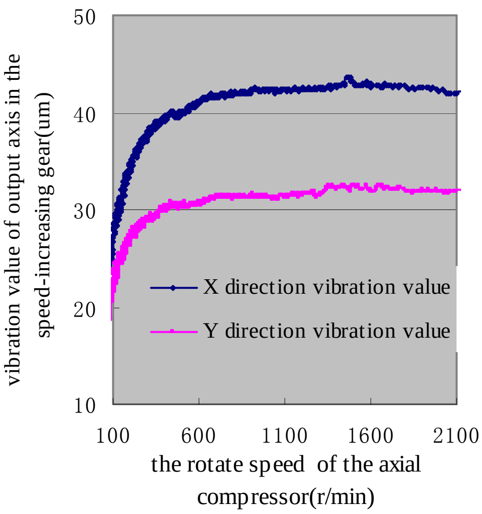

Fig.6 the vibration curve of output axis in the speed-increasing gear

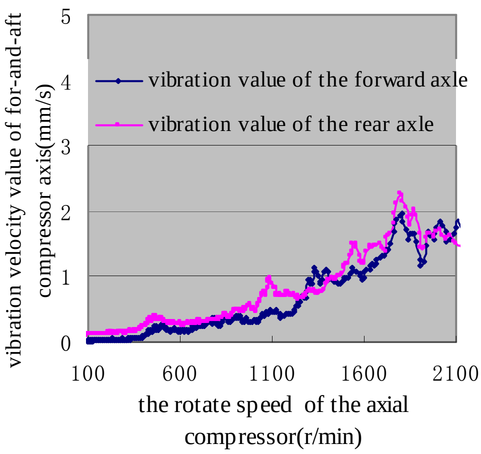

Fig.7 the axis vibration curve of the compressor