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Multi-parameter decoupling and slope tracking control strategy of a large-scale high altitude environment simulation test cabin

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Abstract A large-scale high altitude environment simulation test cabin was developed to accurately control temperatures and pressures encountered at high altitudes. The system was developed to provide slope-tracking dynamic control of the temperature–pressure two-parameter and overcome the control difficulties inherent to a large inertia lag link with a complex control system which is composed of turbine refrigeration device, vacuum device and liquid nitrogen cooling device. The system includes multi-parameter decoupling of the cabin itself to avoid equipment damage of air refrigeration turbine caused by improper operation. Based on analysis of the dynamic characteristics and modeling for variations in temperature, pressure and rotation speed, an intelligent controller was implemented that includes decoupling and fuzzy arithmetic combined with an expert PID controller to control test parameters by decoupling and slope tracking control strategy. The control system employed centralized management in an open industrial ethernet architecture with an industrial computer at the core. The simulation and field debugging and running results show that this method can solve the problems of a poor anti-interference performance typical for a conventional PID and overshooting that can readily damage equipment. The steady-state characteristics meet the system requirements.

1. Introduction

A multi-parameter large-scale high altitude environment simulation test cabin can simulate multiple parameters of aircraft flying at high altitudes. It has important significance to develop the linear passenger aircraft and large military transport aircraft.[1–3] With the improvement of the aircraft environmental control system test requirements, aimed at saving effective cost, environmental cabin is designed to achieve low temperature, low pressure and temperature shock test in the same

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chamber. A multi-parameter large-scale high altitude environment simulation test cabin is shown in Fig. 1. The system consists of a refrigeration system, a vacuum system, an environmental cabin and an observation and control system. The cabin can be used for ground simulation tests of equipment that subject to temperatures and pressures of high altitude. Fig. 2 shows a flowchart describing test procedures with the cabin. The system is operated as described below. When there is no requirement for a given cooling rate, the air refrigeration turbine can be used as a cooling device, based on the cabin temperature control requirements, by opening the control turbine inlet with pneumatic valve QF1. Opening QF1 could not only change the cooled turbine inlet pressure and the corresponding cooling turbine expansion ratio and adjust the temperature drop passing the turbine, but also change the flow in the cooling turbine. Therefore opening QF1 could effectively adjust the amount of the refrigerant in the refrigeration turbine and control the cabin temperature. By adjusting the cold air inlet tube pneumatic valve QF2, the flow of cold air going to the turbine outlet and the back of the environmental cabin is controlled, which means the cabin temperature may be controlled. When there is a requirement for rapid cooling and depressurization, liquid nitrogen should be primarily used for refrigeration. Adjust the inlet tube pneumatic valve QF6, which connects liquid nitrogen tank and environment cabin. This will control the cabin cooling rate. At the same time, the cooling air made by turbine is accessed directly into an orifice plate and there is radiation cooling under a low pressure environment. It is needed to ensure the turbine speed via controls QF2 and QF3. Therefore the temperature control of the environmental cabin is actually a control of the pneumatic control valve. The simulation of the environmental cabin's low pressure is achieved by a vacuum pump working continuously while controlling the exhaust valve QF4 and the fill valve QF5, as shown in Fig. 2. The advantage of this method is that tests could quickly realize a variety of pressures as may be required to mimic various altitudes. However, there is a multi-parameter control coupling in the large-scale multi-parameter high altitude environment simulation and a large inertial lag link, especially when it is simulating high-altitude environment. The system thus needs slope tracking control to overcome the control difficulties of meeting control precision requirements, when it is cooling and depressurizing.

Fig. 1 Large multi-parameter environmental simulation test cabin.

In the system control aspect of environment simulation equipment, Dong et al. proposed use of a double PID controller to control the environmental chamber temperature,[4] while Yuan and Li proposed to use a PI controller to control the pressure.[5] Pang et al. proposed the use of a fuzzy PID controller to control the electric heater in the central air-conditioning system.[6,7] Zhao and Song designed a fuzzy PID controller to control the temperature and the pressure of the cabin separately,[8,9] however they did not give the way to control them at the same time. To solve the difficulty in tracking and controlling the slope of the curve in a multi-parameter large-scale high altitude simulation chamber test equipment, the refrigeration equipment needs to be safe in service.[2] This paper proposes a decoupling and slope tracking control strategy, and a fuzzy control strategy combined with an expert PID judge is used to slope track and automatically control the temperature and pressure parameters. Fuzzy algorithms have the advantages of being simple, flexible, easy adjustment with a small amount of calculation, practical, rapidity, strong stability, high robustness, and the ability to achieve high control accuracy.[10–12] The introduction of expert judgment can reduce the problems associated with the turbine rate, bring the refrigeration system to a stable state as soon as possible and improve the efficiency of the experiment. Using this method will solve the multi-parameter slope curve control problem of cooling while depressurizing and have better control accuracy, thereby ensuring the normal operation of large-scale multi-parameter environmental simulation tests.

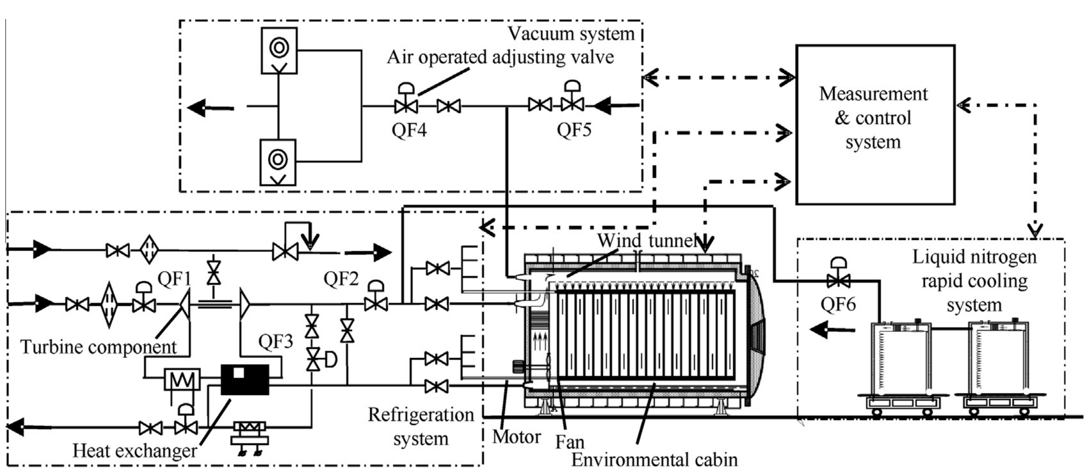

Fig. 2 Flowchart of large multi-parameter environmental simulation test cabin.