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An automatic system for pressure control and load simulation of inflatable membrane structure

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ABSTRACT

Inflatable membrane structure employs flexible membranes as main constructive materials, as well as pressurized gas in the membrane envelope aiming to provide the bearing capacity and structural integrity. Therefore, the internal pressure control and load simulation method are very significant to estimate the structural behavior of inflatable membrane structure. This paper presents an automatic system for pressure control and load simulation of inflatable membrane structure, including a pressure control subsystem and a load simulation subsystem. For pressure control, internal pressure of inflatable membrane structure is controlled by switching the high-speed on/off valves which connect air compressor to the structure. For load simulation, wind pressure and wind suck loads, acting on membrane surface in the normal direction, are simulated by controlling the solenoid valves to allow the vacuum pumps to inflate air into or pump air out from the load simulation chamber which is closely connected to inflatable membrane structure with an airtight space. More importantly, the coupling control of two subsystems can be automatically carried out to simulate the inflatable membrane structure under resisting the varied wind loads. These above actions are automatically performed based on the control logic coded in software module. In order to estimate the proposed automatic system, the internal pressure control, load simulation and coupling control tests were performed on a square double-layer ETFE (ethylene tetrafluoroethylene) cushion model. Control performance and accuracy of the proposed system are proved by analyzing the measured pressures. It is thus demonstrated that the proposed automatic system is considerably automatic, accurate, efficient and reliable for pressure control and load simulation of inflatable membrane structures.

1. Introduction

The inflatable membrane structure is any structure which obtains its bearing capacity and structural integrity from the use of pressurized air to inflate a membrane envelope, that is widely used in the fields of civil building [1,2], industrial building [3], airship [4], super-pressure balloon [5] and space antenna [6] because of its advantages of beautiful surface, large span, light weight and durability. When used as building structural system, the inflatable membrane structure is a very important intermediate element on the loading path to transfer the external loads from the building roof or building facade to the primary steel frame structure [1,7–9]. The main loads acting against the envelope are internal pressure, wind loads and snow loads [1,10]. In order to resist the external loads, internal pressure of inflatable membrane structure is accordingly adjusted [1,7,11]. Therefore, pressure control and load simulation are significant factors in investigating the structural performances of inflatable membrane structure. In this case, focusing the perspectives on the experimental methods for inflatable membrane structure, there are two main fields from the literature.

One field is pressure control, as it plays a vital role in the bearing capacity and structural integrity of inflatable membrane structure. For varied pressure control, a common practice is to measure pressure during the process of continuously inflating. For instance, the bubble tests of membrane materials were carried out under continuously inflating from the electronic pumps, meanwhile the pressure sensors were used to measure the internal pressure [12–15]. For constant pressure control, the usual practice is to close the airflow after the internal pressure reaches to expect value. For example, the inflation tests of ETFE cushions were performed by using U-shape tube to measure the internal pressure [16,17], the ETFE cushion at high temperature was

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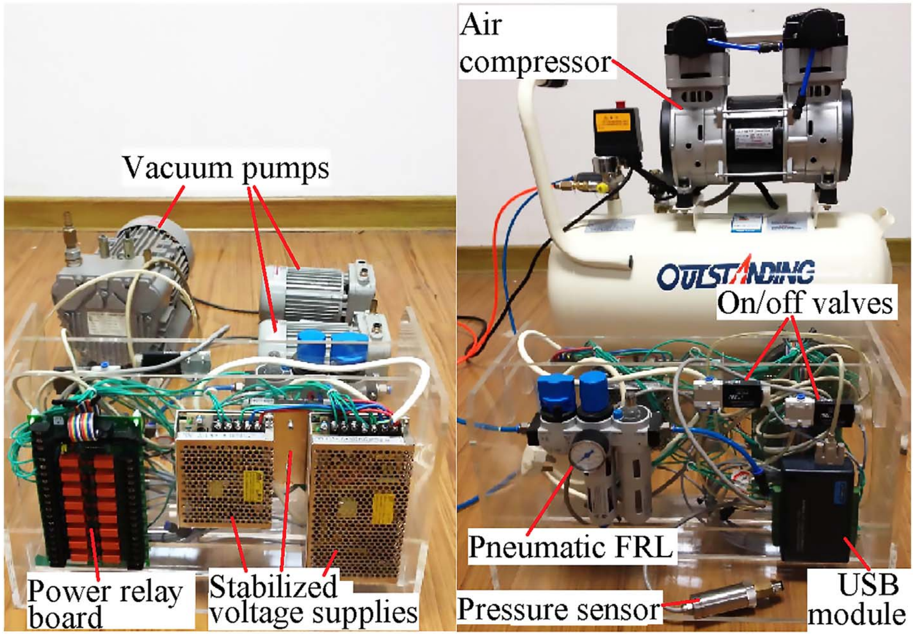

Fig. 1. Snapshot of the automatic system.

controlled by using the blower [18] and the inflation tests of a fabric spherical inflatable model were conducted by using booster pump and pressure instrument [3]. Furthermore, programmable logic controller has been applied in the pressure control of building integrated photovoltaic [19–21]. However, it is found that these methods of internal pressure control were very simple without the active and automatic controls because the air in the inflatable membrane structure would leak out under high internal pressure. Despite the pressure control methods in other fields, such as the tunnel ventilation system to provide a safe driving environment [22], the pneumatic cushions to move heavy load [23] and the pneumatic robot system [24], can be used for reference, these existing techniques are unavailable to accurately and automatically control the internal pressure of inflatable membrane structure in accordance with expected loading paths.

The other field is load simulation. The inflatable membrane structure is usually exposed to the atmosphere to face the external loads, specially the wind loads which dynamically act on the membrane surface in the normal direction [10]. For traditional rigid structures, hydraulic loading apparatuses were widely used in laboratories due to their advantages of high power density ratio and good control performance [25–28]. Moreover, an automatic three-dimensional loading apparatus was designed for static tests of truss joints used in Shanghai World Expo [29]. However, these widely used methods loading on some points are unavailable for inflatable membrane structure. To this end, some simple methods were used in the past. For example, the loading tests by paving sandbags on the upper layer were performed on the ETFE cushion structures [16,17] and an air-support membrane structure [30]. Unfortunately, it is observed that these existing methods do not conform to the characteristics of wind loads, such as uniform load, normal direction, dynamic property, etc.

More importantly, the internal pressure and external load are usually interactive under service condition. It means that the rise and internal pressure of inflatable membrane structure are varied responding to the varied external loads on the membrane surface, resulting in the adjustment of internal pressure to avoid the damage or failure of the whole structure. Therefore, it is very significant to simulate this coupling action between the internal pressure and external load based on the consideration of structural safety. However, so far there is very little literature available on this study of coupling control.

This paper presents an automatic system for pressure control and load simulation of inflatable membrane structure, consisting of a pressure control subsystem and a load simulation subsystem. For pressure control, internal pressure of inflatable membrane structure is controlled by switching the high-speed on/off valves which connect air compressor to the structure. For load simulation, wind pressure and wind suck loads are simulated in the normal direction by switching the solenoid valves to allow the vacuum pumps to inflate air into or pump air out from the load simulation chamber which is closely connected to inflatable membrane structure with an airtight space. More importantly, the coupling control of two subsystems can be carried out to simulate the inflatable membrane structure under resisting the varied wind loads. These above actions are automatically conducted based on the control logic coded in software module. In order to estimate the proposed automatic system, the internal pressure control, load simulation and coupling control tests were performed on a square double-layer ETFE cushion model.

2. Component of the automatic system

The automatic system developed in this study can be utilized to control the internal pressure of inflatable membrane structure and to perform the load simulation test on the structure. The components in the proposed system are composed of a laptop computer with control software, an air compressor machine, a multifunction USB module, a power relay board, a pneumatic FRL (Filter-Regulator-Lubricator), two high-speed pneumatic on/off valves, three one-way valves, two pressure sensors, three stabilized voltage supplies, two solenoid valves and three vacuum pumps, as illustrated in Fig. 1. According to the functions of different control objects, the automatic system can be divided into a pressure control subsystem and a load simulation subsystem, as shown in Fig. 2.

In order to control the pressure, a series of operations are performed as follows. At first, pressure signals of the controlled object are collected to the multifunction USB module from the pressure sensor and are also transmitted to the software module. Then, the software module processes the pressure signals and sends commands to the power relay board via the USB module. Finally, the proposed automatic system controls the pressure of the object by controlling the on-off switches of the performers which are used to connect the air supply to the object according to the control commands. In summary, these actions