Principle and Application in FAST of Parallel Reliability Test Bench

Jingyi Zhao*,Wei Cai*, Hao Sun* and Shaochen Wang*

Hebei Provincial Key Laboratory of Heavy Machinery Fluid Power Transmission and Control, Yanshan University, Hebei str. 438, Qinhuangdao, China*
E-Mail: chenmochiwei@163.com

The traditional hydraulic components reliability test method has a long test time, low test efficiency and high energy loss, and can not meet the requirements of the reliability test of the core hydraulic components in the hydraulic system. This paper designed a parallel energy-saving method and equipment to test the reliability indexes of key hydraulic components for the hydraulic actuator of FAST. The calculated results met the lifetime request of the gear pump and the relief valve for hydraulic actuator of FAST. The reliability model based on small sample test can be used to estimate the lifetime desperation of components accurately under the status of the limit for the number of sample.

Keywords: Reliability test, parallel energy-saving, FAST, small sample test
Target audience: Systems, Energy Management, Components

1 Introduction

Hydraulic system is at the core of control and power transmission. It is widely used in metallurgical industry, engineering machinery, aerospace, shipbuilding and other important fields. Therefore, the reliability of hydraulic components and systems has become the core factor to ensure product quality /1/. As an important part of the reliability research, the reliability test aims at discovering various defects in product design, material and workmanship, determining the failure mode and failure mechanism of the product, proposing improvement measures for the weak link and further improving the level of product reliability /2/.The 500-meter spherical radio telescope FAST (Five-hundred-meter Aperture Spherical radio Telescope) is China's major science and technology foundation project, which is the world's largest and most sensitive single-aperture radio telescope simultaneously /3/. FAST is composed of six systems, including site survey and excavation system, active reflector system, feed support system, measurement and control system, receiver and terminal system and observation base /4/.Figure 1 shows the effect of the FAST.

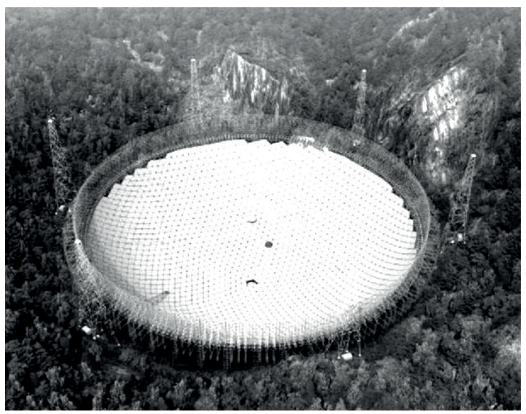

Figure 1: The effect of the FAST.

The main active reflector, as one of the three independent innovations of FAST, is implemented through the initiative configuration of the cable-net. The cable is connected to the actuator via 2225 pull-down cables. The actuator is a telescopic mechanism, one end of which is hinged to the earth anchor and the other end of which is hinged to the pull-down cable which connects the active nodes of the cable net. According to the control signal command, the actuator overcomes the internal force of the cable to generate the pull cable tension, and changes the distance between the anchor point and the end of the pull cable at the active node of the cable net by changing its own length. So as to adjust the position of the active node of the cable net and realize the shape adjustment center of the active reflecting surface of the FAST. The schematic diagram of actuator shows in Figure 2.

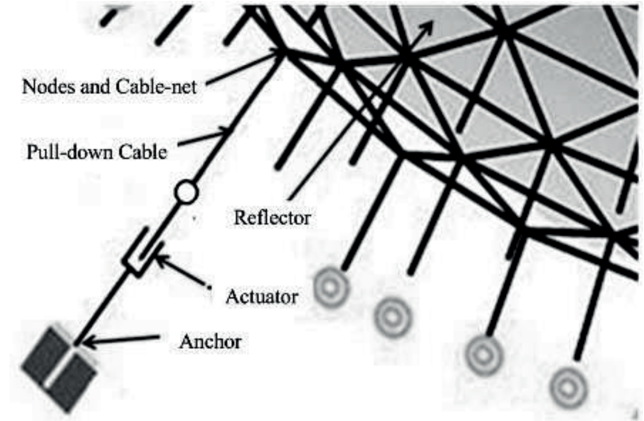

Figure 2: Schematic diagram of actuator.

FAST used the hydraulic actuators. There are thousands of hydraulic actuators operating simultaneously in the telescope observation operation. Therefore, FAST actuator, with a large number of poor working conditions, requires long-term stability and other characteristics, it requires high reliability. The reliability of the actuator core hydraulic components is the basis of the overall hydraulic system reliability. The reliability test of the hydraulic components can be carried out in advance, and the materials and process defects of components not exposed in the design can be found in advance to verify and improve the reliability level, and increase the reliability of the weak links in the system to ensure high reliability of the system /5/. Through the analysis of the failure modes and the hazards of the FAST hydraulic actuator, it is found that the relatively fatal parts of the actuator are the gear pump, the relief valve and the non-return valve. The FAST hydraulic actuator aims at the life expectancy of key hydraulic components is 5 years, so we need to accelerate the reliability test of these three components, judging from the experimental point of view whether the components can meet the requirements. The traditional reliability test bench, each one can only test one type of hydraulic components, and each test can only test one sample component. When testing multiple types of components, it is necessary to manufacture a plurality of different test benches. Testing a number of sample elements of the same type requires multiple tests, resulting in high test costs, time-consuming energy consumption, and waste of manpower. At the same time, the hydraulic components have the advantages of large power and long life, which require a large amount of energy and time to carry out the reliability test /6/. The test cycle of traditional reliability test bench is long. The traditional reliability test bench only reuses the energy after it is used once, and does not really use the energy more than once. Energy-saving effect is not satisfactory /7/. In order to solve these problems, a parallel energy-saving accelerated life test bench for key components of FAST hydraulic actuators was designed and manufactured. The test bench is an accelerated test bench that incorporates parallel energy-saving technologies. It accelerates multiple gear pumps, relief valves and non-return valves at the same time. It enables multiple utilization of energy, shortens test time, energy-saving and efficient.

2 Principle of the Test Bench

FAST hydraulic actuator parallel energy-saving accelerated life test bed was developed to establish a harsh laboratory environment, thereby accelerating the destruction of hydraulic components tested. Test bench tests the life of the gear pump, while the non-return valve and relief valve open-close movements to achieve the effect of accelerating energy-saving. In a short time, the test bench simulate the number of pressure shocks or opening and closing times in 5 years. According to the acceleration life curve, the average lifetimes of three hydraulic components under accelerated stress level are used to extrapolate their average life under rated conditions to evaluate the performance of gear pumps, relief valves and non-return valves. The test provides a reliable guarantee of the normal operation of the FAST hydraulic actuator.

2.1 Technical requirements

Under rated conditions, gear pump and check valve working pressure is 160 bar, the impact pressure is 20 bar, the relief valve population pressure is 50 bar. According to the rated working conditions of gear pump and hydraulic valve, the impact load is determined as accelerating factor, the impact frequency is dimension. Finally, the life data is calculated in terms of time. Respectively, the gear pump, relief valve and non-return valve performance degradation data are volumetric efficiency, cracking pressure and reverse leakage. The test can be carried out in a variety of stress levels, the minimum stress level should be close to normal working stress in the selection of stress, in order to improve the accuracy of extrapolation. The maximum stress level should be selected as large as possible, but not change the failure mechanism of hydraulic components under test, with the safe use of the system as a precondition, the other test stress should be reasonable distribution.

During the test, if any of the following failure criteria appear, the gear pump, relief valve and non-return valve can be considered as failed.

1. Gear pump volumetric efficiency decreased by more than 10% or less than 80%.
2. Relief valve opening pressure lower than 10% of the set value.
3. The reverse leakage of non-return valve exceeds the specified value.
4. Hydraulic components appear noise, temperature rise, stuck, abnormal wear and other phenomena.

The performance parameters of test bench refer to the current national machinery industry standards, the oil temperature is controlled at 50℃±4℃, the oil is 46# hydraulic oil, oil cleanliness is at NAS 9.

2.2 Fundamental

The experiment proposed a multi-component reliability experiment method using parallel energy-saving principle, and designed an accelerated life test bed based on the parallel energy-saving principle. Each experiment can complete shock life test of two gear pumps, two relief valves and two non-return valves. The schematic diagram shows in Figure 3. The motors 1.1 and 1.2 respectively drive two tested gear pumps. When the left side of the electromagnetic reversing valve 4 is energized, the non-return valve sample 5.1 and the relief valve sample 6.1 are opened. The two gear pump samples complete an impact from no-load to load. When the solenoid valve 4 is in the middle, the entire system is under pressure relief to form a pressure shock waveform. When the right side of the electromagnetic reversing valve 4 is energized, the non-return valve sample 5.2 and the relief valve sample 6.2 are opened, and the two gear pump samples are subjected to a no-load-to-load impact process once again. As a result, the gear pump samples were able to complete as many as 2 times the number of check and relief valve open- close attempts.

The test bench sets the flow meter 12.1 and 12.2 at the drain port and inlet port of the gear pump 1.1 to check the output flow of gear pump 1.1. The temperature sensor 13.1 is disposed in the leakage port of the gear pump 1.1 to detect the internal temperature of the gear pump 1.1. The pressure sensor 14.3 is set at the entrance of the test relief valve 6.1 to check its cracking pressure. By controlling the opening and closing of several shut-off valves, the flow meter 12.5 detects the reverse leakage of the non-return valves 5.1 and 5.2 respectively. The tested relief valves 6.1 and 6.2 and the solenoid valve 4 constitute a loading section. The peak pressure is set by the test relief valves 6.1 and 6.2, and the shock load is switched by the oil path of the solenoid valve 4. The cooler 7 and the heating meter 11 constitute the temperature control section. And the temperature of the system fuel tank is monitored by the temperature sensor 13.3 in real time.

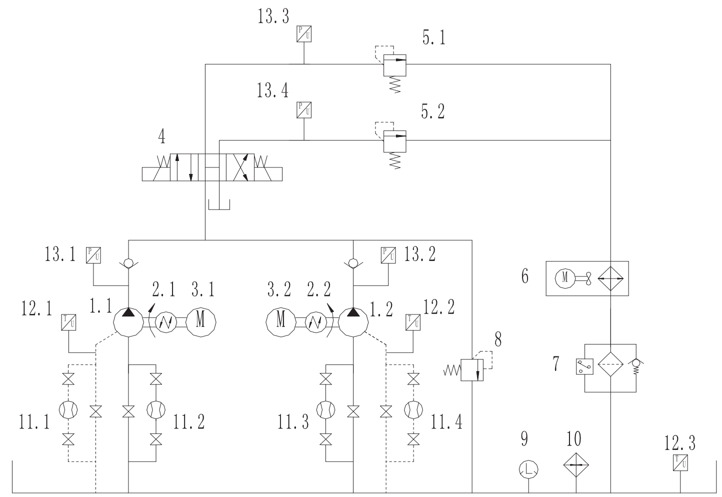

Figure 3: Principle scheme of test platform.

2.3 Experimental Features

The test bench is a typical electromechanical incorporate equipment designed for reliability weaknesses in FAST hydraulic actuators. The test bench shows in figure 4. As the test acceleration factor is a cyclic impact load, and there are three kinds of tested hydraulic components, the test bench compared with the general test stand in the mechanical and electrical design has its own characteristics, mainly in the following four aspects:

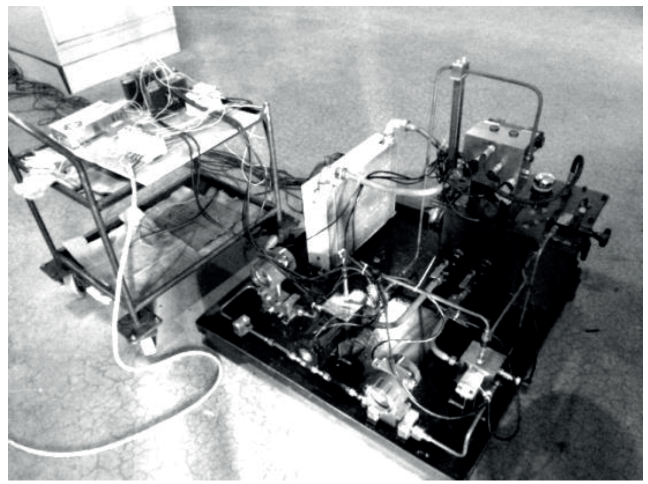

Figure 4: The test bench.

1. The test bench uses the concept of parallel energy-saving. Parallel is not only the same type of multiple components at the same time running, but also a number of different types of components at the same time running, so that energy is being used many times. The use of new components, new technologies

to achieve hydraulic system of energy saving, reduce system installed power and failure rate. In the test, adjusting the pressure relief valve under test can create different pressure levels of impact. These impacts completed the accelerated life test of the gear pump and the non-return valve, and the life test of the relief valve itself at the same time. These enable multiple efficient use of energy instead of simple power recovery. The test bench was designed with this concept. The reliability test of two gear pumps, two relief valves and two one-way valves can be carried out simultaneously in the test. The number of samples in one test is large, the number of types is various, and the time is short, with high efficiency and energy saving.

2. Test bench uses accelerated life test method. It refers to obtain failure data through the life experiment, which ensures the same failure mechanism of the sample, beyond normal stress levels. Using these data, the experimenters can infer the reliability characteristics of the samples. Gear pumps, relief valves and non-return valves are all high-reliability, long-life components. In order to shorten the test period, the test bench is designed based on the principle of accelerated life test, which can test the impact stress, temperature and motor speed as accelerated stress to ensure the smooth running of the test.
3. High degree of automation. The test bed adopts the state monitoring and control system based on PLC and MCGS. All temperature, pressure, flow and other data can be collected using the sensor and recorded in memory, enabling the visualization of the running status of the relevant test hydraulic components, automatic fault diagnosis and playback. The test bench can deal with the abnormal conditions that occur during the test, record the contents of the alarm, and manage the test process and equipment parameters.

3 Result Analysis

Built FAST hydraulic actuator gear pump, relief valve and non-return valve parallel energy-saving accelerated life test bench, in accordance with the above design. The test bench completed 500000 impacts on the gear pump, relief valve and non-return valve in the impact test. Measured pressure shock waveform shown in Figure 5. In the process of debugging, the test rig is also used to deal with the reliability assessment of other components besides the tested components, such as:

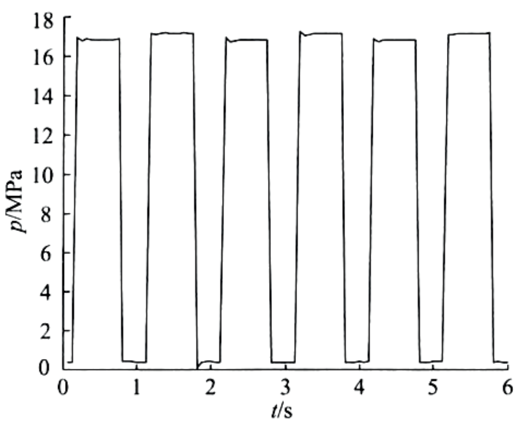

Figure 5: The shock waveform of gear pump pressure.

1. At the beginning of the experiment, both servo motors showed irregular vibration. After demolition, the reason is that the output speed and torque less than the rated speed requirements. It is because the motor drive and the selection of PLC models do not match. The servo motor works back to normal by replacing PLC.
2. After the operation of the test bench, one of the gear pumps abnormal noise, flow meter shows instability, the more obvious when the pressure is loaded. The reason for this phenomenon is the different between gear pump installation screws preload force, resulting in gear pump and installation of valve block joints lax, air inhalation. After adjusting the gear pump mounting screws, the fault is eliminated.

The above problems did not reappear in the test of the following 4 weeks, and the whole test bench operated smoothly and steadily. According to FAST hydraulic actuator test requirements, the test bench stands to complete the gear pump impact life test and relief valve, non-return valve opening and closing accelerated test. The test bench is used to test the reliability indexes of many kinds of hydraulic components at the same time. The test results show that this parallel mode has a short test period and obvious energy-saving effect, which greatly reduces the total power of the test bench and worth popularizing.

4 Conclusion

In view of the weak points in the reliability of FAST actuator hydraulic system, a parallel energy-saving accelerated life test bed is developed from the viewpoint of shortening the test period and reducing the waste of resources. It is capable of performing reliability tests on two gear pumps, two relief valves and two non-return valves simultaneously. The test bench is used to simulate the operating environment of the three hydraulic components under test in the laboratory to accelerate the test process and evaluate the performance indexes of gear pumps, relief valves and check valves. The design method of this test bench is of guiding significance to the development of an accelerated life energy saving test stand for hydraulic core components.

5 Acknowledgements

The authors are sincerely grateful to the supports of National Natural Science Foundation of China (Grant No.51405424, 51675461, 11673040).

References

/1/ Zhao Jingyi, Yao Chengyu, *Progress of reliability research on hydraulic system*, Hydraulics Pneumatics & Seals, Vol. 3, pp. 50-52, 2006.

/2/ Zhao Jingyi, Yao Chengyu, *Overview of China's Hydraulic Reliability Technology*, Vol. 10, pp. 1-7, 2013.

/3/ Nan Rendong, Ren Gexue, Zhu Wenbai, et a1． *Adaptivecable Mesh Reflector for the FAST．ActastronomieaSinica*, Vol. 44, pp. 13-18, 2003.

/4/ ZHU M., WANG Q.M., LEI Z., WU M.C., *Research for reliability of the actuator of FAST reflector based on FMECA*,10.1109/ICRMS.2014.7107271.2014,Guangzhou,1-6.．

/5/ YAO C.Y., ZHAO J.Y., *Research on Fuzzy Fault Tree Analysis Method for Hydraulic System Based on T-S Model*. China Mechanical Engineering, vol.20, no.16, pp.1913-1917,2009.

/6/ ZHANG X.P., CHEN X., ZHANG C.H., *Lifetime assessment method for products with dependent competing failures based on copula theory*. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, vol.228, no.9, pp.1-7, 2016.

/7/ Angadia S.V., Jacksona R.L., et al., *Reliability and life study of hydraulic solenoid valve*. Part 1: A multi-physics finite element model. Engineering Failure Analysis. Vol.16, no. 3, pp.874–887, 2009.