Design of a comprehensive test bench for hydrostatic transmission

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ABSTRACT. *This paper aims to design a comprehensive test bench for hydrostatic transmission that satisfies the requirements in the Hydrostatic Transmission Device (JB/T 10831-2008). To adapt to the special shape of hydrostatic transmission, the modular positioning mode was adopted for the design, the virtual instrument measurement and control system software was compiled, and the data were collected, recorded, processed and analyzed automatically by computer. Then, the proposed comprehensive test bench was applied to a comprehensive test of the hydrostatic transmission system. In the test, the test bench effectively improved the test accuracy and efficiency, and the hydrostatic transmission reached the peak working efficiency under the rated pressure. The research results lay a solid basis for the test on the working conditions of hydrostatic transmission.*

RÉSUMÉ. *Ce document vise à concevoir un banc de test complet pour la transmission hydrostatique qui réponde aux exigences du Hydrostatic Transmission Device (JB/T 10831-2008). Pour s'adapter à la forme particulière de la transmission hydrostatique, le mode de positionnement modulaire a été adopté pour la conception, le logiciel du système de mesure et de contrôle des instruments virtuels a été compilé et les données ont été collectées, enregistrées, traitées et analysées automatiquement par ordinateur. Ensuite, le banc de test complet proposé a été appliqué à un test complet du système de transmission hydrostatique. Lors des tests, le banc de test a amélioré efficacement la précision et l'efficacité des tests, et la transmission hydrostatique a atteint son efficacité maximale de fonctionnement sous la pression nominale. Les résultats de la recherche apportent une base solide pour le test sur les conditions de travail de la transmission hydrostatique.*

KEYWORDS: *hydrostatic transmission, comprehensive test bench, modular positioning, virtual measurement and control, test.*

MOTS-CLÉS: *transmission hydrostatique, un banc d'essai complet, positionnement modulaire, mesure et contrôle virtuels, test.*

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1. Introduction

Hydrostatic transmission (HST) is a continuously variable transmission device formed by a closed oil circuit system composed of such power components as hydraulic pumps and such hydraulic motor and control components as hydraulic valves, with the addition of various variable control units and transmission components such as reducers or gearboxes (Dasgupta, 2000; Akkaya, 2006). It serves as a transmission machine between the prime mover and the working machine, realizing the mutual conversion between mechanical energy and hydraulic energy. With advantages of compact structure, easy operation, non-polar drive, various control modes, high transmission efficiency and long service life, HST has been widely used in modern engineering, agriculture, hoisting and transportation, and other walking mechanisms (Rabbo & Tutunji, 2008; Tatiana, 2011; Tang, 2015).

HST comprehensive test bench is a device necessary for HST performance test. When developing the new HST products, static and dynamic performance tests of the HST must be performed in order to ensure the correct design and high precision of the HST; when improving and upgrading HST, test methods are needed to analyze the impact of changes in HST parameters on their static and dynamic performance; after maintenance and repair of HST, each performance parameter of HST shall be tested using comprehensive test bench to ensure normal use of the equipments (Horst, 2014).

During the performance test of HST, on the one hand, due to the special external shape of HST, the positioning of the product during the test process is difficult, and it is difficult to complete all performance tests with a single positioning; on the other hand, the traditional test bench adopts manual data collection and recording, and the precision of the test is low as there is a large amount of data to be collected and processed. Therefore, it is necessary to design a modular comprehensive test bench with rapid positioning, and develop the software of virtual instrument measurement and control system to make use of computers for data collection and processing, which greatly improves the precision and reliability of the test results, and significantly enhances the test efficiency.

In this paper, the design requirements of the comprehensive test bench for hydrostatic transmission are discussed in the first part, and then the mechanical and hydraulic systems of the comprehensive test bench as same as the measurement and control system are designed. Finally, the comprehensive performance test was carried out. It is verified that the comprehensive performance of the test bench meets the requirements.

2. Design requirements for comprehensive test bench

2.1. Functional requirements

According to the standard of *JB/T 10831-2008 Hydrostatic Transmission Device*, the HST comprehensive test bench shall be able to complete the total efficiency test, volumetric efficiency test, overload test, commutation test, external leakage test, durability test, impact test and high temperature test (Lee *et al.*, 2015).

2.2. Performance parameters

According to the test standard and the performance index of the test piece, the main performance parameters of the comprehensive test bench are selected, as shown in Table 1.

Table 1. Main performance parameters of comprehensive test bench

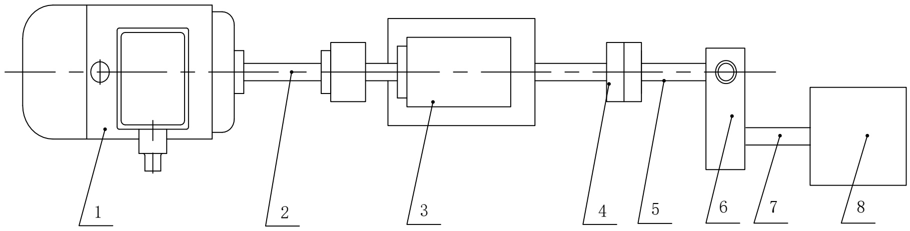
System indicators	Parameters	Remarks
Main motor power	90Kw	Variable frequency AC motor
Frequency converter power	110Kw	
Maximum speed of main motor	2975r/min	
HST rated pressure (maximum pressure)	30MPa(32MPa)	
Rated pressure of the system (maximum pressure)	35MPa(40MPa)	
System temperature range	30℃-80℃	
Temperature control precision	50℃±4℃	
Pressure (when p≤0.2MPa)	≤5%	According to C level requirements
Pressure (when p ≥ 0.2MPa)	≤2.5%	According to C level requirements
Rotating speed	≤2%	According to C level requirements
Torque	≤2%	According to C level requirements
Oil contamination degree	≤19/16	
Noise	≤100 db	Distance of 1 m

3. Design of mechanical system for HST comprehensive test bench

The HST comprehensive test bench is composed of mechanical system, hydraulic system, measurement and control system, etc., where in the mechanical system is composed of power drive system, loading system, filter temperature control system, leaked oil recovery system, etc., and the measurement and control system is composed of electric control operating system, computer data acquisition system, etc.

3.1. Mechanical system of HST comprehensive test bench

The mechanical system mechanism of HST comprehensive test bench is as shown in Figure 1.



1-power drive system 2-cardan shaft coupling 3-speed torque sensor 4-coupling 5-HST input extension shaft 6-HST 7-HST output extension shaft 8-bridge rectifier cartridge loading valve unit

Figure 1. Structure principle of mechanical system of comprehensive test bench

According to the power transmission direction, the mechanical system of the HST comprehensive test bench consists of power drive system, speed torque sensor, input shaft, HST, output shaft and bridge rectifier cartridge loading valve unit and other auxiliary systems such as filter temperature control system, oil recovery system and so on.

The power drive system includes an electric motor, a non-contact dynamic torque speed sensor, a special steering linkage for the tested device, and so on. The tested device can be quickly installed on the connecting frame through the fast-connect axle sleeve. The coupling is connected with the non-contact dynamic torque sensor and the electric motor. The electric motor provides input power for the tested device.

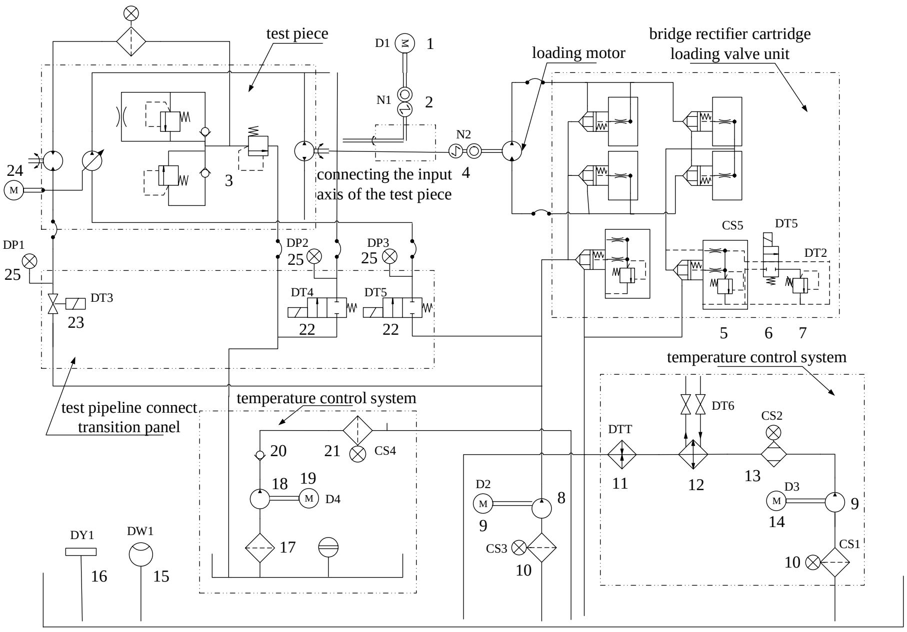
Bridge rectifier cartridge loading valve unit is the loading system of the comprehensive test bench, which consists of loading motor, loading control valve and loading oil supply auxiliary pump. The motor suction and discharge ports are connected to the bridge rectifier cartridge valve group. The loading control valve unit mainly realizes the function of switching between the oil supply circuit and the high-pressure overflow damping loading when the loading motor rotates in forward and backward directions. By adjusting the loading pressure of the electric proportional overflow valve, the valve set can realize the output loading of the tested device.

Filter temperature control system consists of main tank, gear pump electric motor unit, two-stage filter, radiator plate and other components. Temperature measuring points are provided on the hydraulic pipeline and the oil tank, and the oil temperature of the test system is controlled through the automatic control of the heater and the electromagnetic water valve action, so as to keep the main oil temperature of oil tank constant. Meanwhile, the filter temperature control system can effectively guarantee the oil cleanliness requirement of the test system.

The leaked oil recovery system sets up a collection tank to collect the leaked hydraulic oil during exhaust discharge and disassembling in the device test, and the liquid level control relay in the oil collection tank automatically controls the start and stop of the pump electric motor unit. Then the filtered oil in the oil collection tank is input into the main tank, so that the hydraulic oil can be recycled.

3.2. Hydraulic system of HST comprehensive test bench

According to the specific test requirements of HST, the hydraulic system of the HST comprehensive test bench is designed, and its principle is as shown in Figure 2.



1- converter motor; 2-torquel speed sensor; 3- test piece; 4- constant rate pump / motor; 5- pressure line filter; 6 and 22-electromagnetic ball valve; 7- electric proportional overflow valve; 8 and 18-internal gear pump; 9,14 and19- electric motor; 10,13,17and 21-filters; 11- heater; 12- plate heat exchanger; 15- temperature sensor; 16- level indicator controller; 20- check valve; 23- solenoid valve; 24- electric actuator; 25- pressure sensor

Figure 2. Schematic diagram of hydraulic system of comprehensive test bench

The comprehensive test bench drives the rotation of the two-way variable displacement pump and slippage pump in the tested device by controlling the driving torque and speed sensor of the converter motor, thus to complete the oil suction and discharge operation of the output motor in one direction of the tested device. In the test process, the manual handle can be adjusted to realize the oil suction and discharge in the other direction of the output motor of the tested device.

High-pressure ball valve is installed at two oil ports of the tested device, one oil outlet of the ball valve is connected with the leaked oil recovery tank of the test bench through a hose, and another oil outlet is connected to the auxiliary oil supply branch circuit. If the motor of the device starts to rotate for the first time, the device is filled with oil by loading the auxiliary oil supply branch circuit, and the high-pressure ball valve is opened at the same time to vent the test device. The motor output shaft of the device under test drives the loading motor through an externally connected rotational speed torque meter, and the bridge rectifier cartridge loading unit and a pressure sensor are set at the oil inlet and outlet of the loading motor. The pressure of the loading valve unit is adjusted by the proportional relief valve, and the loading motor is loaded by adjusting the loading pressure. Finally, the loading of the tested device and the detection of torque, rotational speed and pressure are completed, so that the detection performance can be achieved.

4. Design of measurement and control system of HST comprehensive test bench

The measurement and control system of HST performance test bench is constructed by using virtual instrument technology. The virtual instrument is used to replace the dispersive instrument and torque meter, and the flexible software function is used to replace the solidified hardware to improve the automation and measurement precision of the original testing system.

4.1. Design principle of measurement and control system

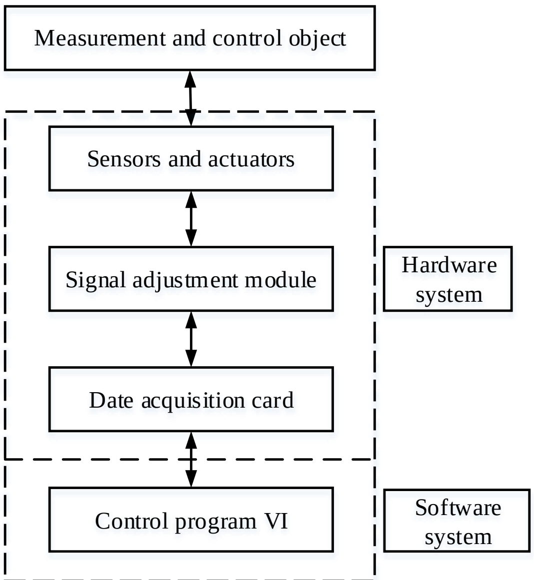


Figure 3. Schematic diagram of virtual measurement and control system

The measurement and control system is mainly composed of hardware system and software system. The hardware system mainly includes various sensors, signal conditioners and circuits, data acquisition cards and PCs. In the software system, the signals collected by the data acquisition card are sent to the computer, where they are programmed and analyzed.

According to the actual requirements of the console, the hardware core of the control system is a data acquisition card, and its composition is as shown in Figure 3.

Before designing the measurement and control system, it is necessary to specify the specific objects for measurement and control, that is, the test parameters that need to be measured. The main parameters of this test bench to be measured include: motor output speed, input speed and torque; HST output speed and torque; loading valve group oil temperature, and pressure. After the object of measurement and control is defined, the overall hardware structure of the test bench measurement and control system is designed, and its principle is as shown in Figure 4.

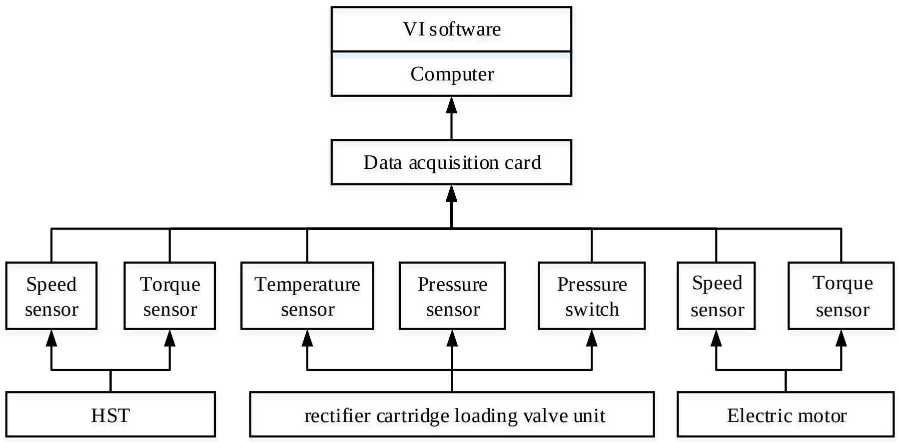


Figure 4. Overall structure of hardware of measurement and control system

4.2. Software system of HST comprehensive test bench

When developing the software for the measurement and control system of the HST comprehensive test bench, the respective advantages of LabVIEW and Matlab are fully exploited. LabVIEW realizes the functions of data acquisition, instrument control, data storage and graphic display, and Matlab implements the functions of digital-analog modeling and algorithm simulation (Kim *et al.*, 2015; Mashed *et al.*, 2015).

The software system can implement two functions: simulation test mode and physical test mode. In the simulation test mode, the simulation results of the control algorithm are displayed, through the operation of the various system components on the interface and the data interaction with the internal mathematical model of Matlab. In the experimental mode, the actual PLC, instrument, and acquisition card and other hardware devices are driven through the measurement and control commands to achieve signal acquisition and control functions, and to implement the test process of HST.

The software system is installed on the test console, which consists of a digital pressure gauge, a digital thermometer and a digital speed torque meter. The test parameters can be displayed by instruments, and can be collected manually or automatically. The computer data acquisition and processing software adopts Windows platform and visualized menu, with data acquisition and processing, printout, drawing and other functions.

The electrical control operating system consists of electrical control of power distribution, frequency converter cabinets and console. The electrical control of power distribution and frequency converter cabinets realize the control over speed adjustment, start-stop, and load pressure of converter motor. The console is provided with a motor rotation control knob, a pressure control knob, and an alarm indicator. In order to avoid signal interference, the line adopts strong and weak isolation routing.

In summary, the designed measurement and control console of the HST comprehensive test bench is as shown in Figure 6.

Figure 6. Measurement and control console of the HST comprehensive test bench

5. Performance test of HST comprehensive test bench

5.1. Test principle and method

The test bench may conduct performance test and reliability test for hydrostatic transmission, wherein the performance test includes total efficiency test, volumetric efficiency test, overload test and commutation test, and the reliability test includes durability test and impact test.

When the total efficiency test and the volumetric efficiency test are performed, the electric motor 9 (D2) is started first to energize the solenoid directional valves DT4 and DT5, and the test piece is filled with oil and its exhaust is discharged. Then the drive motor 1 (D1) is started to drive the speed to the rated speed, then the solenoid directional valves DT4 and DT5 are powered off, and the solenoid valve DT1 is energized. The proportional solenoid valve DT2 is adjusted so that the system starts to be gradually loaded until the number of the DP2 or DP3 reaches 30MPa. During the loading process, the input and output torques and speed values corresponding to the five pressure values are collected.

During the overload test, based on the overall efficiency test flow, the proportional solenoid valve DT2 is continued to be adjusted to raise the system pressure to the maximum. Under the conditions of rated speed and maximum pressure, the test pieces are operated for 15 minutes under the conditions of maximum forward and reverse displacement, and there is no abnormal phenomenon.

During the commutation test, the electric motor 9 (D2) is started first to energize the solenoid directional valves DT4 and DT5, and the test piece is filled with oil and its exhaust is discharged. Then the drive motor 1 (D1) is started to the rated speed, and shift actuator 24 acts. Then the solenoid directional valves DT4 and DT5 are powered off, and the solenoid valve DT1 is energized. The proportional solenoid valve DT2 is adjusted and the system starts to be gradually loaded until the number of the DP2 or DP3 reaches 30MPa. Under rated conditions, that shift actuator 24 is controlled to switch forward and backward 10 times to observe whether the commutation is normal. The time at the middle position after each commutation shall not be less than 5S, and it is necessary to observe whether there is output.

Table 2. Test action sequence

	D2	DT4	DT5	D1	Shift actuator	DT1	DT2
Preparation stage	+	+	+	+			
Total efficiency test	+	-	-	+		+	+
Volumetric efficiency test	+	-	-	+		+	+
Overload test	+	-	-	+		+	+
Commutation test	+	-	-	+	Forward/backward switch	+	+
Durability test	+	-	-	+	Forward/backward switch	+	+
Impact test	+	-	-	+		+ -	+

During the durability test, the shift actuator is operated to switch forward and backward at a rate of 5 times per minute at a rated speed and pressure for 500 hours. The reduction value of volumetric efficiency shall not exceed 3%, and the parts shall not be abnormal or damaged in other forms.

During the impact test, under the maximum displacement and rated speed, the solenoid valve DT1 is energized and de-energized, and the motor is subjected to a pressure impact test without operating the proportional solenoid valve DT2. Test frequency can be adjusted according to actual needs.

The action sequence of each motion control component under different tests is shown in Table 2.

5.2. Test

Figure 7. Test of HST comprehensive test bench on site

In order to verify the design performance of the test bench, it is necessary to verify the test bench according to the test standard. The impact performance test and efficiency test of the hydrostatic transmission device are simultaneously performed on the assembled test bench, as shown in Figure 7. The number of impacts is set before the test piece is subjected to the impact test. After the impact test is completed for the set number of times, the computer control program ends the impact test and the efficiency test is simultaneously completed

5.3. Test results and analysis

The impact test and efficiency test results are shown in Figure 8.

Five impact tests are performed on the comprehensive test bench, which show a rapid and accurate response throughout the test process, achieving the design requirements and effectively improving the test efficiency.

At the same time, the analysis of the efficiency test results shows that, the higher the test pressure, the higher the transmission efficiency of HST, and the higher the transmission efficiency of HST under the laid load condition will be, which provides a basis for the working conditions of HST.

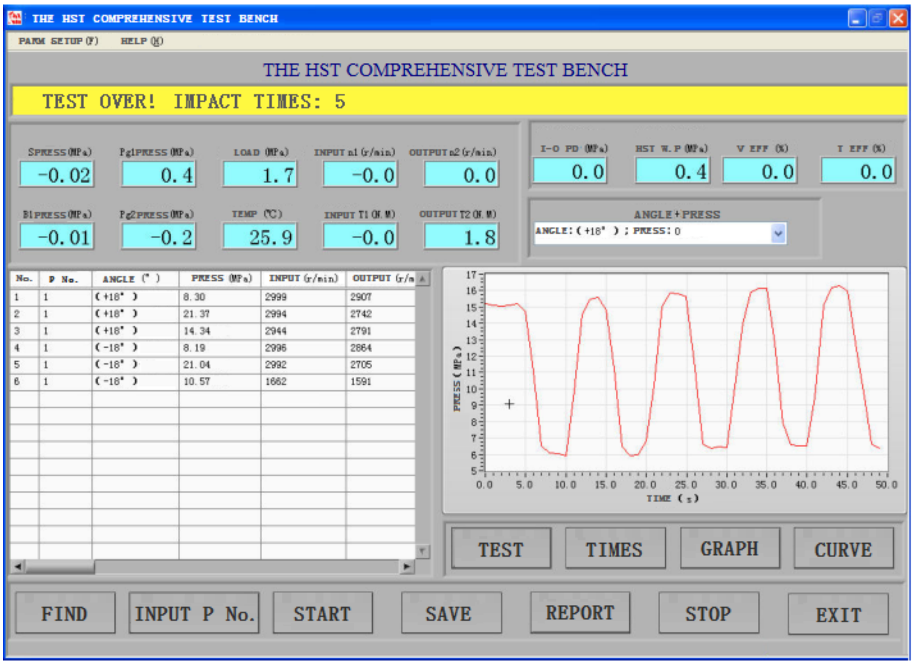


Figure 8. Results of impact test and efficiency test

6. Conclusions

Based on the performance requirements specified in the standard *JB / T 10831-2008 Hydrostatic Transmission Device*, this study designs a HST comprehensive test bench and carries out the corresponding performance tests. The main conclusions are drawn as follows:

(1) The mechanical mechanism and control system of the test bench are designed. The test results show that the test bench can meet the requirements of design and test.

(2) The precision and test efficiency of the HST comprehensive test bench are significantly improved.

(3) HST has a low efficiency under low load conditions, and the transmission efficiency is the highest under the rated load, providing the basis for the working conditions of HST.

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