Establishment of Hydraulic Turbine Test Bench on the Tibet Plateau

H M Li¹, Q L He², Y X Xiao², H Y Luo³, H Zhang¹, X Q Xu¹ and Z W Wang²

¹ Chengdu Aerospace Beacon Precision equipment manufacturing co. LTD, Chengdu 611130, China
² State Key Laboratory of Hydrosience and Engineering & Department of Energy and Power Engineering, Tsinghua University, Beijing, 100084 China
³ Water Conservancy and Civil Engineering College, Tibet Agriculture and Animal Husbandry College, Lingzhi 860000, China

E-mail: wzw@mail.tsinghua.edu.cn

Abstract. There are abundant water resources in Tibet plateau area. With the increasing demand for electric power, it is necessary to build hydropower stations and test bench in Tibet Plateau area. The low air pressure has an influence on the flow in the hydraulic turbine. Therefore, a hydraulic turbine test bench is designed and built in the Tibet Plateau for low pressure hydraulic turbine experiment. The laboratory building is a three-storey structure with one distribution room and two control rooms. The civil structure is designed according to the layout of two test bench. The built underground storage tank has an area of 300 m², a 15-meter high water tower and a capacity of 50 m³, which can meet the requirements of simultaneous operation of the two test bench. The maximum head of the main pump is 30 meters, the rated power of the main motor is 160 kW, and the rated power of the dynamometer is 110 kW, which can be operated in both positive and negative directions. Meanwhile, a set of measurement and control system software is designed to acquire experimental data. The test bench will meet the needs of experimental teaching and scientific research of hydraulic turbines in Plateau area, and meet the performance comparison and acceptance test of medium and small hydro-machinery.

1. Introduction

The natural hydro-energy resources in Tibet are about 200 million kilowatts in reserves. The theoretical annual power generation is 1760 billion kilowatts, accounting for 29.6% of the theoretical reserves of hydro-energy resources in the whole country. Its technological development capacity is 116 million kW, accounting for 31% of the whole country. With the increasing demand for electric power and the strategy of "west-to-east power transmission", a number of large hydropower stations are being built in Tibet's high-altitude areas to alleviate the contradiction between the daily load peak and valley, improve the quality of power supply and ensure the safe and stable operation of the power grid[1,2]. Therefore, it is of great significance to establish Francis Turbine Test bench at high altitude.
This paper introduces the design, construction and overall layout of the Francis Turbine Test bench in Tibet Plateau. The measurement and control system of the test bench are introduced. The working parameters of the test bench are introduced. The requirements for the accuracy of the test bench are put forward. The matching model units are also introduced. Through the construction of the plateau experimental platform, the dual functions of teaching, scientific research and engineering research can be realized.

2. Framework
The schematic diagram of the construction scheme of the plateau hydraulic turbine test bed is shown in Figure 1 and Figure 2. The test bed is divided into two layers: ground layer (0m) and ground layer (+5.5m). The elevation of one side of the head box of the first floor above ground is +6.5m, the elevation of the model center to the main pump is 7.5m, and the elevation of the top of dynamometer is 10.8m. Set up drainage ditches and catchment wells (1*1*1 m). The high and low pressure water tank of the test bench is supported by steel structure, and the concrete foundation of the column is used in the test bench. The design of test platform layer can accommodate 50 people at the same time.

The plateau turbine test bench provides a specific head and uniform flow for the model turbine to ensure the accuracy of the measurement part and the stability of the test. Closed operation mode is adopted for the flow circulation system. The system composition and function of the test bed are briefly introduced as follows.

2.1 Steel-concrete frame structure of test bench
The test bed is divided into two layers: ground and ground. The steel-concrete frame structure of the test bed includes the layout design and manufacture of the ground, the concrete foundation of the column and the steel frame structure on the ground. Its main function is to provide foundation and support for water tank, pipeline circulation system, etc.

Figure 1. Three-Dimensional Map of Building Scheme for Plateau Hydraulic Turbine Test bench.
Figure 2. Elevation View of Construction Scheme of Plateau Hydraulic Turbine Test bench.

The layout of model turbine test section needs to be specially designed to adjust the height of the support steel frame, mainly composed of four steel pillars and steel platform, with fixed model turbine test section and dynamometer motor. Flexible height adjustment in model section can be used for model tests of mixed flow, axial flow and tubular units respectively.

2.2 Circulating Pipeline Structure

The circulating pipeline system is composed of model turbine (water pump), main pump, air tank, pressure box, tailrace tank, circulating pipeline, flange, connection, valve and electromagnetic flowmeter.

2.2.1 Research and Development of Model Turbine Unit. Tsinghua University has designed and developed a high performance model turbine unit with a head of 40-60 meters. The optimal efficiency is not less than 93%. The straight cone section of draft tube adopts transparent design to facilitate the observation of cavitation phenomenon.

The connection between model turbine and pressure box adopts eccentric structure, and the connection between draft tube and draft tank adopts movable sealing plate, so the position of inlet and outlet of model unit section can meet the connection requirements of various model units.

2.2.2 Main Pump Unit. A double suction centrifugal pump with a maximum lift of 30m is developed and installed in the main circulation pipeline system, which is connected with 160kW DC motor. By opening and closing different valves, the main pump can realize two functions of water supply and drainage, and meet the requirements of two kinds of tests of turbine and pump.

2.2.3 Head tank and tailrace tank. The function of the head box is to eliminate the disturbance of water flow into the unit, make the flow velocity distribution uniform before entering the unit, and ensure the steady flow before entering the model unit. The water tank is made of stainless steel with a diameter of 2.2m, a length of 3m, a maximum pressure of 50m head and a volume of 11.4m3. By calculating the structural strength, the wall thickness of the pressure box is 8 mm. An exhaust solenoid valve is arranged on the top of the head box. According to the calculation and analysis, the inlet height and size of vertical and horizontal units are different, and the position and size of the openings of pump units in the head box are different from that of turbine units. Therefore, a number of inlet
(outlet) holes are opened on one side of the head box, and their positions and sizes are determined by the size of model units.

In order to adapt to the special plateau environment, the size and size of tailrace tank and head tank are exactly the same, which can provide conditions for the functional expansion of the follow-up test bed.

2.2.4 Air Tank Compressor and Air Compressor. The air tank is installed on the tailrace tank to regulate the tailrace pressure. The diameter of air irrigation is 0.6m and the length is 1m. It can bear the maximum negative pressure of -10m. The top of the tank is equipped with an exhaust solenoid valve. The compressor is connected with the air compressor and the air tank. The compressor can be pressurized and vacuum pumped separately to meet different water level differences and cavitation test requirements. As the main equipment of circulating pipeline system of model test bench, its design directly affects the function of model test bench.

2.2.5 Air Tank Compressor and Air Compressor. Pipeline adopts stainless steel pipe with diameter of 400 mm and wall thickness of 8 mm. Pipeline length is about 50 m. Flange connection is used between pipes. Expansion joint is designed. In order to reduce hydraulic loss, the corresponding guide grate can be designed and manufactured in 90 elbows.

2.2.6 Bypass, branch and connecting section. Closed circulation pipeline system connects various systems, and its pipeline connection design has many bypass and branch pipes. Through the switch of different valves, the water filling, drainage and water circulation in different directions of the main pipeline are realized.

2.2.7 Valves. In order to control the circulation of water in pipeline, it is necessary to install several valves, including solenoid valves for flow control, butterfly valves and gate valves for pipeline and bypass control, etc.

2.2.8 Drainage System and Small Pump Unit. When filling water in the main pipeline system, water outside the test bed should be introduced. When the test bed empties water, water should be discharged. Drainage and drainage system should be designed in the main circulation system, and small pumps should be installed. It is connected to the existing 300 m³ reservoir of the school.

![Figure 3. Local Layout of Hydraulic Cycle System of Plateau Hydraulic Turbine Test Bed.](image)

2.3 Electric machinery
2.3.1 Main pump motor. Main motor: rated power 160kW, maximum speed 1500rpm; DC motor, pump speed can be adjusted.

2.3.2 Dynamometer. Dynamometer is a specially designed DC motor, which is supported on a single fixed platform with sufficient rigidity. When the speed of the dynamometer in the model unit is equal to 1500rpm, the maximum power of the dynamometer is 110 kW. It can rotate bidirectionally to meet the requirements of different test conditions of hydraulic turbines and pump turbines.

The dynamometer is connected with the power system through the frequency conversion system to form a reversible frequency conversion system. The frequency conversion system consists of two sets of synchronous-DC and DC-synchronous motor units. The power system supplies power to dynamometer or dynamometer feeds to power system.

2.3.3 Frequency Converter Control Cabinet. The frequency conversion control cabinet has the functions of power switching and protection, frequency conversion speed regulation and visual control. The display device and operation panel are designed on the cabinet body. It is connected with the electrical components inside the frequency conversion control cabinet. It can visually display the operation status of the frequency conversion control cabinet. At the same time, it is convenient for the operator to control the operation of the frequency conversion device and to operate the controlled equipment such as the motor on the spot. The operation and operation status of the frequency converter control cabinet can be directly reflected on various instruments and indicators to realize time-to-time monitoring of the working status of the frequency converter. It is necessary to consider the influence of altitude of 3000m on the plateau.

2.4 Experimental Instruments and Measurement and Control

2.4.1 Torque meter. A torque and speed sensor, one for measuring speed and shaft power; parameters: Hunan Instrument 500N.m, etc.

2.4.2 Flowmeter. Electromagnetic flowmeter, range Q = 0.1-1.0 m³/s, accuracy is 0.2%.

2.4.3 Pressure gauge. Water pressure and pressure fluctuation were recorded and measured with an accuracy of 0.15%. For the vacuum pressure measurement of tailrace tank of the test bench, the model produced by Yokogawa Motor Co. Ltd. of Japan can be selected as EJA430A-DAS4A-92DA sensor, etc. The range of measurement is 0-9.5 m water column, and the accuracy is 0.075%.

Torque and speed measurements can be made by using the torque and speed sensor produced by Changsha Xiangyi Power Testing Instrument Co., Ltd., model JCZ-1000N.m, accuracy of 0.1%.

2.5 Measurement and Control Software.

The test bench is equipped with two industrial control computers, one for control (dynamometer, water pump, electric valve, etc.) and one for test, test and analysis. And control software and performance testing software are set up.

The main contents of the measurement and control system are as follows: the overall design of the control system and the test system; the programming of the system core control PLC; the establishment of the upper computer SCADA system and the test database; the scheme and application of DC digital dragging; the programming of the application software for the test; the design of field instruments and sensors; and the design of electrical equipment.

Functions of the system: Man-machine interaction to set various parameters of the test system; efficient completion of various hydraulic turbine test tasks; automatic detection of the system and the detection information of system status; automatic or man-machine interaction control of the test process; automatic treatment of abnormal system (such as equipment overheating, overcurrent, overpressure, overspeed); normal maintenance, detection and diagnosis of the system (Execution equipment, valves,
motors, data acquisition equipment, sensors, etc.); data and graphics analysis; database management; data and graphics printing.

Test process and requirements: The test bench is based on the model test of hydraulic turbine. Its control system and test system are designed around the test requirements. The following tests are completed: turbine, pump and pump/turbine test, energy test, cavitation test, flight test and pressure fluctuation test.

3. Functional parameters

3.1 Main parameters of the test bench

(1) Main motor: rated power 160kW; DC frequency conversion speed regulation, can be adjusted pump speed.
(2) Main pump: maximum lift 30m; flow range 0-0.3m³/s, supporting the main motor.
(3) Dynamometer motor: rated power 110kW, rated speed 1500rpm, vertical and horizontal dual-purpose, can be positive and reverse operation, can carry out electric and power generation operation mode, respectively, to achieve the function test of turbine and pump.

Table 1. Test parameters of plateau hydraulic turbine test bench.

| parameters                             | value   |
|----------------------------------------|---------|
| Maximum test head                      | 30 m    |
| Model Runner Diameter                  | 300 mm  |
| Maximum Speed of Dynamometer Motor     | 1500 rpm|
| Dynamometer power                      | 110 kW  |
| Main motor                             | 160 kW  |
| Maximum test flow                      | 1.0 m³/s|
| Minimum Cavitation Coefficient         | 0.01    |

(4) Pipeline: Circulating stainless steel pipe diameter 400 mm, set up electric butterfly valve.
(5) Water tank: stainless steel pressure water tank diameter 2.2m, length 3m, maximum pressure 50m; tailrace tank and pressure water tank size consistent.
(6) Control system: There are two industrial control computers in the laboratory, one for control (dynamometer, pump, valve) and one for test, test and analysis. Using Labview development platform, control and test analysis software is developed.

3.2 Main parameters of the test bench

The test accuracy of the plateau hydraulic turbine test bench takes all factors into consideration. The comprehensive error of efficiency test is less than (+0.35). The stability and repeatability of the test bench meet the test requirements. In order to ensure the high precision test requirements of the test bench, a batch of high-performance and high-quality test instruments and instruments should be equipped on the test bench, and the measurement errors of the main instruments and instruments should be strictly limited. The design is carried out in accordance with the relevant test specifications of hydraulic turbines. After considering the random measurement error of the test bed, the single measurement error of each main instrument should not exceed the following provisions:

- Flow measurement Error <0.2%
- Head (Head) Measurement Error <0.2%
- Torque (Axis Power) Measurement Error <0.2%
- Speed measurement error <0.1%

The hydraulic circulation system design of the test bed is novel. The multi-functional test requirements can be met by switching the control valves. The auxiliary pump is controlled by AC speed regulating motor, and the head can be adjusted smoothly within 30 meters in the pump test. The test bed
adopts centralized control, and the measurement data can be collected and processed automatically by computer. The accuracy of the test bench meets the requirements of the Specification for Acceptance and Acceptance of Pump Model Test (SL140-97), and exceeds the standard accuracy of ISO/DIS5198 (A), reaching the advanced level in China. The plateau turbine test bench can be used for the experimental research of Tibet hydropower station and pumping station engineering and the development of hydraulic unit models for medium and small hydropower stations.

4. Summary
The plateau turbine test bench will meet the needs of teaching and scientific research, and has multi-functional characteristics. It can meet the performance comparison and acceptance test of small and medium-sized fluid machinery, including model turbine, pump energy, cavitation, flight, pressure fluctuation and other tests. Model turbines can carry out model efficiency test, cavitation test and observation test of cavitation phenomena for vertical, horizontal, inclined and tubular turbines. The experimental platform can meet the normal needs of scientific research and teaching.

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