Optimization of testing system and experiment research for pump turbine model

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Abstract. The pump turbine is key component of Pump Storage Power Plants. Moreover, the model testing proves significant guidance on design of pump turbine. Since pump turbine model testing is different from turbine model resulting from four quadrant experiment, point acquisition for transient operation conditions and special data processing, the optimization is made for these technological difficulties. In order to obtain a higher efficiency, a higher precision and a high degree of automation, the system of data acquisition is designed, in which the PXI platform was adopted, and the virtual instrument software LabVIEW was employed. And this system was successfully applied for the testing platform of Harbin Institute of Large Electric Machinery which achieves functions of transient conditions acquisition, measurement for positive and negative flow and speed, data processing, generating report, analysis for pressure fluctuation and so on. Finally four quadrant experiment was carried out in this test platform, results show that steady for the experiment operation conditions and repeatability for data which can better reflect the characteristic for “S-shaped” and reverse pump conditions. The system of pump turbine model test is significant for the research of pump turbine and has some guiding significance for the application of engineering.

1. Introduction

In face of global warming, much effort has focused on reducing greenhouse gas emissions through a variety of strategies. Much of the research and innovation has concentrated on finding less-polluting energy alternatives, especially hydraulic power. Moreover, pump storage power plants are key components for the development of renewable CO\textsubscript{2}-free primary energies \cite{1}. However, the model testing is significant on the hydraulic design of pump turbine in order to get better characteristic, and it is also vital to ensure the pump turbine safely run. Meanwhile it provides basic experimental results to validate the theoretical research. Hence, the amount of research is always undertaken at home and abroad through the model testing for the design of pump turbine model. But the traditional test rig feathers low precision, automation and complex operation.

Recently, some advanced technology is employed by researchers to improve the test precision and simply the system \cite{2-4}. An intelligent acquisition and control system is developed by Ma H J et al \cite{5}, which reduces the work load of experimental technicians, and realizes the real time, continuous, and synchronous measurement during the experimental process. In the paper which is written by Wang G M \cite{6} a comprehensive pump performance test system is established based on virtual instrument
software platform LabVIEW, which feathers high efficiency, high precision, simple operation. It represents the development trend of equipment performance testing.

In this research, virtual instrument software platform LabVIEW which is a deeply combination production of test technology and computer technology is employed based on PXI hardware platform in order to solve complex and special experiments of pump turbine. It achieves functions of transient conditions acquisition, measurement for positive and negative flow and speed, data processing, generating report, analysis for pressure fluctuation and so on. Results show that steady for the experiment operation conditions and repeatability for data which can better reflect the characteristic for “S” shaped and reverse pump conditions [7].

2. The introduction of testing rig

An experimental flow investigation in the pump turbine model operating in pump mode is performed in several sessions. The model is installed in the Harbin Institute of Large Electric Machinery testing rig IV, as illustrated in Figure 1.

![Figure 1. Turbine model testing rig](image)

The closed loop test rig design allows for both turbine and pump performance assessment within a precision of 0.2%, complying with IEC standards [8]. Its performance characteristics are summarized in Table 1. The operation of test rig is controlled with an automatic system through a LabVIEW interface that allows for real time measurement and display of flow discharge, testing head static torque and speed, and so on.

| Characteristic          | IV  |
|-------------------------|-----|
| Maximum head [mH₂O]     | 80  |
| Maximum discharge [m³/s]| 0.8 |
| Generating power [kW]   | 750 |
| Pumping power [kW]      | 750 |
| Maximum speed [rpm]     | 3000|

3. Hardware design of pump turbine model test system

The physical signal is converted into current signal by sensors. After these current signals are modulated, they are all converted digital signal which can be realized by computer through acquisition card based on PXI platform.

The hardware is composed of eight slot NI PXIe-1062Q chassis, backplane of 3GB/s total bandwidth, NI PXI-8336 system controller, NI PXI-4472B dynamic signal acquisition module, PXI-6281 data acquisition card, PXI-6602 counter and SCXI-1001 isolation amplifier combined with SCXI-1125. The composition principle is showed as Figure 2. And physical graph of hardware is showed as Figure 3.
Figure 2. Composition principle graph of hardware system  

Figure 3. Physical graph of hardware

PXI-4472B module combined with anti-aliasing filter is used for gathering pressure fluctuation dynamic signal with the maximum sampling rate of 200K/s, improving the sample precision, acquisition speed and reliability of the test. PXI-6281 and PXI-6602 card are used for gathering static signal, such as torque, and wheel speed respectively. The whole system is controlled by PXI-8336 controller and connected to PC through MIX-4 Express card that the system control and data acquisition can be achieved lightly by using LabVIEW DAQ driver.

The aforesaid configuration makes the hardware system more compact, firm, modular, reliable and handy to carry around. All these features make contributions to improving the portability of the measurement system.

4. Software design of pump turbine model test system

Data acquisition control and storage is achieved by a software developed at the Harbin Institute of Large Electric Machinery, based on virtual instrument software platform LabVIEW (NI LabVIEW 2011) running on a PC, which feathers multiple processes and multi-page display. It achieves functions of transient conditions acquisition, measurement for positive and negative flow and speed, data processing, generating report, analysis for pressure fluctuation and so on. The interface of main program is illustrated Figure 4.

For example, the interface of pump efficiency experiment are illustrated as Figure 5. The design of software includes software functions operation, experiment curve display, engineering monitoring, data parameters display, data analysis display, error analysis display and so on. All the experiments can be achieved through this software. It simplifies the operation.
The system software is designed by using queued state machine architecture. The Queued State Machine-Producer Consumer architecture [9] is essential architecture that significantly facilitates programming mid-sized to advanced LabVIEW-based projects that constitute 100 or more VIs. A common application for the QSM-PC architecture is in programming LabVIEW’s event structure to send commands for asynchronous processing in a parallel loop so that event cases can exit code execution quickly and avoid GUI lockup. Another application is in multiple parallel VI programming such as parallel data acquisition, alarm monitoring, and results analysis, where this method empowers any parallel VI to send and receive commands and data across other parallel VIs with no data loss. The use of QSM-PC makes the system have a fast response and high allowable error ability.

5. Four quadrant experiment study
This system was successfully applied for the testing platform of Harbin Institute of Large Electric Machinery. Figure 8. Presents the complete characteristic curves of a pump turbine model in n11-Q11 and n11-T11. All points of discharge and torque are obtained for at openings that are between 0.49° and 12.5°. At guide vanes opening equal or greater than 5.61°, the turbine characteristics exhibit a positive slope after runaway speed. When a pump turbine is brought in such a situation, the operation will suddenly switches to the reverse pumping mode. The discharge as well as torque are reversed, the machine operation may become strongly unstable at runaway speed and beyond, which will increase structural vibrations driven by flow instabilities. Moreover the synchronization with the electrical network in safety conditions becomes impossible. Hence, the experiment for pump turbine appear to be significant for designers.
Figure 8. Discharge and torque complete characteristics curves

This system has been successfully used to test the performance of pump turbine model. Experimental results show that steady for the experiment operation conditions and repeatability for data which can better reflect the characteristic for “S" shaped and reverse pump conditions.

6. Conclusions
Traditional testing technology of pump turbine model has more shortcomings and has been unable to meet modern testing requirements. In this research a comprehensive pump turbine performance test system is established based on virtual instrument software platform LabVIEW. And this system has been successfully used to test the performance of pump turbine model. Experimental results validate the correctness of testing data, the simple operation and high automation. Further analysis can be carried out for pump turbine based on this testing system. It can also be expanded for other related industries and has good development prospects.

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