Hindawi
Mathematical Problems in Engineering
Volume 2018, Article ID 6543109, 9 pages
https://doi.org/10.1155/2018/6543109

Research Article

Pump Selection and Performance Prediction for the Technical Innovation of an Axial-Flow Pump Station

Honggeng Zhu,[1] **Ge Bo**,[2] **Yuanbing Zhou**,[3] **Rentian Zhang**,[2] **and Jilin Cheng**[1]

[1]*School of Hydraulic, Energy and Power Engineering, Yangzhou University, Yangzhou 225127, China*
[2]*Jiangsu Surveying and Design Institution of Water Resources Co. Ltd., Yangzhou 225127, China*
[3]*Luoyun Water Conservancy Project Management Office of Jiangsu Province, Shuqian 223800, China*

Correspondence should be addressed to Honggeng Zhu; zhuhg@yzu.edu.cn

Received 11 May 2018; Revised 4 July 2018; Accepted 25 July 2018; Published 7 August 2018

Academic Editor: Jian G. Zhou

Axial-flow pumps are widely used in every sector of China. After many years of operation, the aging of mechanical and electrical facilities poses threats to their steady and safe operation. Taking the technical innovation of an axial-flow pump station as an example, the study is focused on the pump selection and performance prediction. The pump similarity law and specific speed were applied to guide the pump selection based on the designed head and discharge. The performances of pump models were compared and it is suggested for the technical innovation that when the selected model pump is adopted, the impeller diameter is kept at 3100 mm and the rotational speed is reduced from 150r/min to 136.4r/min to improve its cavitation performance. A three-dimensional pumping system model was established by using software Pro/E and CFD analyses were conducted to predict the hydraulic performance of the pumping system for the evaluation of technical innovation. It is shown through the comparison of computed results with model test results that the designed flow rate corresponding to the designed head can be fully satisfied with the selected pump and stronger pumping capacity can be prospected at the designed and mean lifting head. The pumping system model tests, in comparison between the original and the selected model pump, indicate that when the innovated pump station operates under characteristic heads, the pumping system efficiency can be raised by more than 3 percentages, and the cavitation allowance can be decreased by 0.90m; thus, better engineering and economic benefits can be prospected through the technical innovation.

1. Introduction

There are more than 500 large pump stations in China. Axial-flow pumps are widely used in every sector of the national economy, which are characteristic of large discharge, low head, and high efficiency. In the first stage Eastern Route of South-to-North Water Diversion Project in China, there are more than 40 large pumping stations in total of 13 cascades, in which about ninety percent adopt axial-flow pumps. Taking Liulaojian pump station as an example, which belongs to the fifth cascade in the Eastern Route of South-to-North Water Diversion Project, see [1]. Four sets of fully adjustment vertical axial-flow pump were installed with no stand-by. The diameter of the pump impeller is up to 3100 mm, driven by a synchronous motor of 2200 kW. Its total pumping capacity was designed to be 150 m^3/s and the net design and mean pumping head were 3.70m and 3.40m, respectively, where the dustpan-type suction box and siphon-type discharge passage were adopted.

Liulaojian pump station was put into production 1996, having done great contributions to the development and well-being of agriculture, industry, and eco-economics along banks of the water diversion route and beneficial areas in the past more than 20 years. However, the aging of electromechanical facilities and other existed problems are becoming more and more serious so that the safety and stable operation of the pump station were affected and technical innovations to the pump equipment are imperative after many years' operation, like other large pump stations in China as reported in [2]. Aiming at the existed problems and the incoming technical innovation, researches on pump selection and pump system performance prediction were conducted to provide technical support for the feasibility study and optimal engineering design of the technical innovation and summarize experiences for similar pump stations to be built or innovated.

2. Problems Existing in the Pump Station

A series of accreditation checkup were carried out on the electrical and mechanical facilities of Liulaojian pump station, and the main pump has fallen to be the fourth class, and the main motor the third class, proposing that a technical innovation on the pumping system be implemented to eliminate hidden dangers and secure operation safety, as reported in [3].

Also in the accreditation checkup it was found that the cavitation damage on pump blades was very serious, the shaft displacement and the tip clearness have exceeded the allowed values, and the wearing on the shaft neck, the pump casing, and diffuser were serious. Moreover, the vibration of the pumping sets was obviously felt and noticed by standing nearby, and the regulation device of blade setting angle was mutilated and adjusting precision affected.

The other problems found in the accreditation checkup were inclusive of the deformation and looseness of coiled silicon steel sheet, the excessive dielectric loss of stator winding and capacitance increment, and the insulation aging of the main motor. The accreditation results of the main motor and pump show that safe, stable, and economic operation of the pumping system was badly threatened and the importance and necessity of technical innovation to the pump station emphasized on the other hand.

3. Technical Approaches for Improving the Hydrodynamic Performance of the Axial-Flow Pump

Aiming at the problems revealed in the daily operation, yearly maintenance, and the special accreditation checkup, the following technical approaches will be taken to improve the hydrodynamic performance of the axial-flow pump and safety operation of the pump station. The total investment for the technical innovation of Liulaojian pump station will be up to 15 million dollars.

(a) All four sets of old main pump and motor will be dismantled and eliminated, replaced by bland new ones to achieve technical innovation in pumping facilities.

(b) The inner surface of the new pump casing will be inlaid by stainless steel plate to improve its ability of antirust and clearance cavitation. The pump blades will be casted with stainless steel and processed by NC machine tools to achieve their precise shape and size, so that the hydrodynamic performance, water pumping capacity, and energy converting efficiency of the impeller can be brought into full play.

(c) The precision casting technique and new surface polishing technology will be adopted in the production of diffuser to realize the precise shape and size of vanes. Those new manufacturing methods will effectively decrease its water head loss.

(d) A ring-type beam, outside of the diffuser, will be added to enhance its structural support and increase its strength and stiffness, so that the vibration of pumping set will be depressed to secure the safety operation of the pumping set.

(e) The trash screen in the entrance of the suction box will be removed and a large trash-removal machine will be installed in the approach channel far away from the suction box; thus, automatic trash removal can effectively solve the problem of trash accumulation in the front of the suction box as happened often before the innovation, so that ideal internal flow patterns inside the suction box can be prospected and better flow conditions will be generated for the pump.

4. Pump Selection for the Technical Innovation

4.1. Research and Development of Pump Models in China. During the 50s of the 20th century pump models were few in China, and from 1970s to 1990 quite a few excellent pump models with independent intellectual property rights came forth, but the choices were still less. With the advancement in pump theory, design methods, and introduction of foreign technology, obvious improvements in pump performance were achieved. Due to the construction of the Eastern Route of the South-to-North Water Diversion Project, the research and development enthusiasms were vigorously promoted from research institute, universities and colleges, and pump manufacturers. A lot of funds were put into the research and many pump models were developed one after another in the past 20 years.

However, in facing so many pump models, there is a problem troubling the design engineers. That is how to compare their performance and how to evaluate their certainty factor because those models were tested on different test stands. The Tianjin pump test stand invested by the Ministry of Water Resources of China solved the problem effectively. All pump models from different researchers and institutions were asked to carry out peer contrast tests; thus, comparable test results were obtained since they all came from the same test stand. A serial of tests were done since 2004, offering a high quality database for pump development and pump selection. Such shortcomings as repeated research and development, forged test data, and waste of manpower and financial resources were effectively avoided. It is required that the preference of pump selection be given to those pump models tested at this stand for newly built and technical innovation of pump stations in Jiangsu and many other provinces in China.

4.2. The Requirement of Pump Selection. Based on the conclusion of accreditation checkup to Liulaojian pump station, the main motor and pump in use will be completely replaced in the coming technical innovation. The correct pump selection is one of the key issues assuring the safety operation and the success of pump station construction. The pump is expected to run at the high efficiency zone under the mean head of the pump station, and the designed flow rate is to be met under the design head and under the maximum head the safety and stable operation must be unconditionally satisfied. And better cavitation characteristics are also considered during the pump selection and their performance comparison, as discussed in [4–6].

4.3. Pump Selection Method for the Technical Innovation. According to the affinity theory, when a model pump and a prototype pump satisfy the requirements of geometry, kinetic, and dynamic similarity, respectively, and run under similar working conditions, the performance parameter of their flow rates, heads, and shaft powers shall obey the pump affinity law, expressed as

$$\frac{Q_P}{Q_m} = \left(\frac{D_P}{D_m}\right)^3 \left(\frac{n_P}{n_m}\right)$$
$$\frac{H_P}{H_m} = \left(\frac{D_P}{D_m}\right)^2 \left(\frac{n_P}{n_m}\right)^2 \quad (1)$$
$$\frac{N_P}{N_m} = \left(\frac{D_P}{D_m}\right)^5 \left(\frac{n_P}{n_m}\right)^3$$

where Q_m, H_m, and N_m represent the flow rate, head, and shaft power of the model pump and Q_P, H_P, and N_P represent the flow rate, head, and shaft power of the prototype pump, respectively.

The prototype pump is manufactured on the basis of similarity ratio. The model pump and its corresponding prototype pump have the same value of specific speed when they are operated under the similar working conditions. The specific speed of a prototype pump can be calculated out first by (2), depending on the designed flow rate for each pump and the designed head where the pump is served for a specific pump station, and then a few of potential model pumps can be picked out from the model pump databases discussed in Section 4.1.

$$n_s = \frac{3.65 n_P \sqrt{Q_p}}{H_P^{3/4}} = \frac{3.65 n_m \sqrt{Q_m}}{H_m^{3/4}} \quad (2)$$

In (2), n_s is the specific speed, Q_m, H_m, and n_m represent the flow rate, head, and rotational speed of the model pump, and Q_P, H_P, and n_P stand for the flow rate, head, and rotational speed of the prototype pump, respectively.

Due to the change of water regime since the construction of Liulaojian pump station, its designed head of pumping system will be adjusted from 3.50m to 3.70m in the technical innovation, and the designed flow rate of each pump holds to be 37.5m^3/s with no change.

A large-scale low-head pumping system consists of a suction box, pump segment, and a discharge passage, and the hydraulic losses produced by the suction box and the discharge passage will be bear by the pump. It is well known that the hydraulic loss of a suction box mainly varies with the flow rates and less affected by the flow conditions of pump except in conditions of very smaller flow rates. However, the hydraulic loss of a discharge passage is affected not only by the flow rate, but also by the rotational speed, the distribution of residual velocity circulation, and other outflow conditions of pump outlet. Hence, there exists a dilemma, to correctly select a pump, we need to know the hydraulic losses in advance, and since the pump is not determined the water losses cannot be determined in the stage of pump selection. In engineering practice, the estimation of these losses is an effective way to solve the problem. Thus, the process of pump selection is divided into two steps. Firstly, the pump is selected with estimation of the hydraulic losses. And secondly, the hydraulic losses are figured out by calculation, numerical simulation, or model tests after a specific pump is selected to verify the correctness of the estimation.

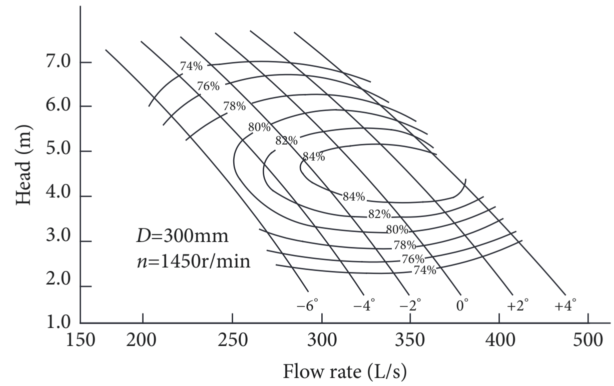

FIGURE 1: The general performance curves of original model pump used in the pump station.

According to the experience of relevant numerical simulation and model test results, the sum of hydraulic losses of a dustpan-type suction box and a siphon-type discharge passage is in the range of 0.60m to 0.70m, as illustrated in [7–12]. Therefore, the specific speed of model pump for the technical innovation of Liulaojian pump station ranges from 927 to 1122 given by (2).

4.4. Comparison of Model Pumps' Performances

4.4.1. Original Model Pump Performance before the Technical Innovation. The model pump originally used in Liulaojian pump station before the technical innovation was among the excellent ones in the 70s of the twentieth century. Its specific speed is about 1000. Its general performance curves are shown in Figure 1; when the rotational speed is 1450r/min and the setting angle of blades is at +2 degrees the highest efficiency reaches 84.5%, the pump head and flow rate corresponding to the BEP are 4.43m and 0.35m^3/s, respectively, satisfying the requirements of large pumping capacities and high efficiency of that time.

4.4.2. Model Pump Performance Selected for the Technical Innovation. The model pump selected for the technical innovation of Liulaojian pump station was chosen from the excellent ones representing the achievements and advancement in pump research and development, as introduced in [13–15]. Shown in Figure 2 is the general performance curves of the pump, the specific speed of which is around 1000 and when the rotational speed is 1450r/min and the setting angle of blades is +2 degrees, the highest efficiency reaches 86.35% and the corresponding pump head and flow rate to the BOP are 5.22m and 0.44m^3/s, respectively.

Table 1: Comparison of performances between the original and selected pumps.

Blade setting angel $\beta/^{\circ}$	Flow rate $Q/(\mathrm{L/s})$		Pump head $H/(\mathrm{m})$		Specific speed n_s		Efficiency $\eta/\%$	
	Original Pump	Selected Pump	Original Pump	Selected Pump	Original Pump	Selected Pump	Original Pump	Selected Pump
+4	375	444	4.45	5.22	1007	1022	84.2	86.4
+2	350	416	4.43	5.19	1020	993	84.5	85.8
0	330	401	4.21	4.80	1033	1034	84.0	85.7
-2	305	377	4.20	4.80	996	1002	83.7	85.5
-4	280	357	4.10	4.60	972	1007	83.1	85.3
-6	250	332	1.03	4.60	930	971	82.0	85.1

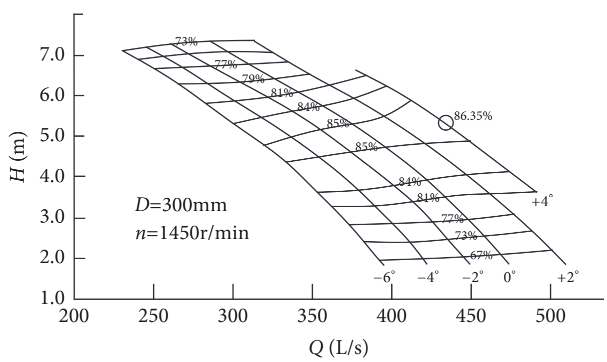

Figure 2: The general performance curves of the model pump to be used for the technical innovation.

4.4.3. Performance Comparison between the Original and the Selected Model Pumps. Table 1 gives the detailed comparison of hydraulic performances between the original model pump used in the pump station and the one selected for the technical innovation. The impeller diameter for both of the two pump models is 300 mm and the rotational speed is 1450r/min. Table 1 indicates the model pump selected for the technical innovation possesses larger pumping capacity and higher efficiency when the two model pumps run at the same setting angle and the same pumping head. Hence, if the selected pump is applied to the technical innovation and Liulaojian pump station will be run at higher efficiency and more economic, a lot of operation and management cost be saved.

Based on the performance comparison given in Table 1, it was proposed that the rotational speed of the prototype pump be reduced from 150r/min to 136.4r/min on condition that the designed pumping capacity 37.5m^3/s under the design head shall be fully satisfied and while keeping the diameter of pump impeller at 3100 mm and the original suction box and discharge passage be remained without change. Known from pump cavitation affinity law that the net positive suction head is proportional to the square of pump's rotation speed, slowing down the rotation speed of pump is favorable for improving its cavitation performance.

4.5. Comparison of Geometric Parameters between the Original and the Selected Pump. The original pump model used in Liulaojian pump station was developed in 1970s, and the selected pump model as discussed above came out with in the early of 21st century, sponsored mainly for the Eastern Route of the South-to-North Water Diversion Project to deliver water from Yangtze river to Jiaodong Peninsula, Tianjin, and Beijing, and other northern areas of China.

Figure 3 gives a comparison of plane projections between the blades of the two model pumps. From Figure 3, it can be seen that for the original pump, about three-fourth of the inlet side of the blade near the hub protrudes forward and the remaining one-fourth inlet side close to the casing looks coincided for both blades of the two pumps. There is a noticeable difference in the outlet side of the two blades. For the original blade nearly half of the outlet side near the hub protrudes outward, while the other half retreated. In other words, the chord length of blade of the original pump is longer than that of the selected pump in the area nearing the hub, and the chord length of blade of the selected pump for the technical innovation is longer than that of the original pump in the area near the casing; see [16].

The blade angle is defined as the angle between the tangent and the circumferential velocity of the bone line along the liquid flow direction equals the sum of flow angle and attack angle. In the light of the five sections in Figure 3, Table 2 shows the difference in blade angles of the compared two pumps.

The comparison of geometric parameters between different pumps can be done from different aspects and analyzed qualitatively or qualitatively. In pump station engineering, the most important thing is the safe, steady, and economic operation of pumping system. In this article more attention is paid to the pump selection and performance prediction for the technical innovation of an axial-flow pump station. When the technical innovation of the pump station is completed the first thing for designers responsible for the innovation and the owner of the pump station is to check whether the pump station can run steadily and economically, to check whether the pumping capacity at the designed head can satisfy the flow rate requirement and operate at the high efficiency zone, since these are the top priority for them. Since the pumps are professionally designed, the pump performance and quality shall be quarantined by the manufactures, so that the difference in their geometric parameters and the inner flow of pump will not be analyzed in this article further more.

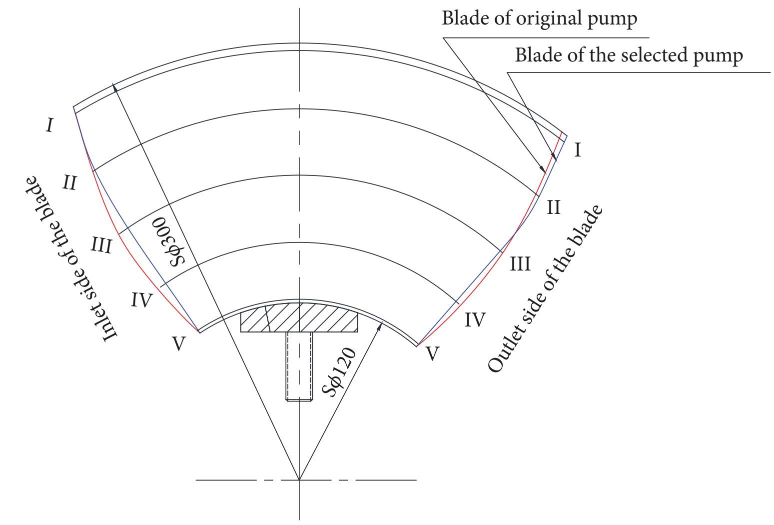

Figure 3: Comparison of blades between the original and the selected pump.

Table 2: Comparison of blade angles between the original and the selected pumps.

Section	I	II	III	IV	V
Blade angle of original pump (°)	33.53	29.34	26.12	23.71°	21.98°
Blade angle of selected pump (°)	36.25	31.61	28.34	25.55	23.47

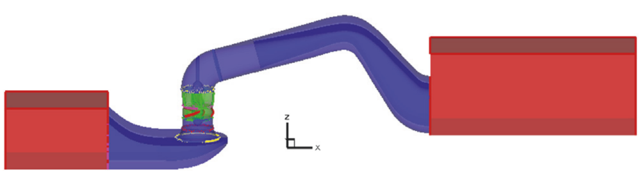

Figure 4: The 3D model for numerical simulation and performance prediction.

5. Pumping System Performance Prediction for the Technical Innovation

5.1. Three-Dimensional Modeling of the Pumping System. The completion of pump selection is the first step in the whole process of technical innovation of a pump station. It is unknown whether the pump selected satisfies the requirement of designed flow rate and run in high efficiency zone. Numerical analysis is often applied to check its feasibility and reasonableness, referring to [17–21].

A three-dimensional model of pumping system for the numerical simulation of performance prediction was established with industrial software Pro/E, as shown in Figure 4, in which the model pump was the newly selected one for the technical innovation, while the shape and size of the dustpan-type suction box and the siphon-type discharge passage were kept without change, as stated in [22–25].

5.2. Parameters of the Model Pumping System. As discussed in the previous section, the impeller diameter of prototype pumping system shall be kept to be 3100 mm in the technical innovation, but its rotational speed will be reduced from 150r/min to 136.4r/min. Usually smaller pump impellers are adopted in numerical simulation in considering the storage capacity of computer and computation cost, and partly for the convenience to compare the computed results with the corresponding physical model test results. It means that the computation domain of prototype pumping system will be scaled down to a model one, the prerequisite condition of which is to keep the product of their impeller diameter and rotational speed equivalent.

The impeller diameter of a model pump usually takes the value of 300 mm in conventional physical model pump and pumping system tests in China, so that it can be computed out that the rotational speed of model pump is 1409.5r/min for the numerical simulation.

5.3. Set-Up of Mathematics Models for CFD Analysis. As shown in Figure 4, the computation domain of Liulaojian pumping system consists of a dust-pan suction box, pump segment, and a siphon-type discharge passage as well as an inlet pool and a discharge pool. Grid generation was accomplished by means of commercial code Gambit, and about 15,000,000 mixed meshes of unstructured four-face body mesh and structured six-face body mesh are generated to accommodate the complex computed models.

The commercial CFD software Fluent is adopted to simulate the internal flow. When a pumping system is steadily operating and its internal three-dimensional incompressible viscous flow can be described by the mass conservation equation and the time-averaged N-S equations; see [12, 22, 26]. The RNG $\kappa - \varepsilon$ turbulence model was adopted to close the N-S equations in the numerical analysis [18]. The discretization of governing equations was realized by finite

Table 3: List of main instruments and equipment used in the test bench.

Measurement project	Name of Instrument	Type	Scope of work	Calibration accuracy	Calibration time
Head	Differential pressure transmitter	EJA110A	0~200kPa	±0.015%	July, 2017
Flow rate	Electromagnetic flowmeter	E-mag	DN400mm	±0.18%	Oct., 2015
Torque and rotational speed	Speed torque sensor	ZJ	200N·m	±0.24%	July, 2017
Cavitation allowance	Absolute pressure transmitter	EJA310A	0~130kPa	±0.015%	July, 2017

volume method, and the multi-reference frame methodology was applied to treat the interference between the rotational impeller and the static diffuser. The algorithm SIMPLEC was adopted to couple the calculation of velocity and pressure to improve computation efficiency and accelerate convergence.

The CFD numerical simulation of Liulaojian pumping system was carried out in a Dell precision station with 48G internal storage. The checking of mesh quality and the work of independence solution of mesh size were completed before the commencement of formal numerical computations.

5.4. Performance Prediction Based on CFD Analysis. The hydraulic performance of the model pumping system of Liulaojian pump station was obtained through numerical simulation at different flow rates and setting angles of blades and the corresponding prototype pumping system performance can be predicted through conversion of the pump similarity law, as discussed in [26–29].

Figure 5 indicates that when the blade angle of the model pump is set at +2 degrees and works at 3.7m of the designed head, the flow rate of the model pumping system is $0.37m^3/s$. It would be $39.51m^3/s$ for the corresponding prototype pumping system by using the pump affinity law, which exceeds $37.5m^3/s$ of the designed flow rate for each pump set, and the pumping system efficiency would be higher than 74% when operating under the designed head.

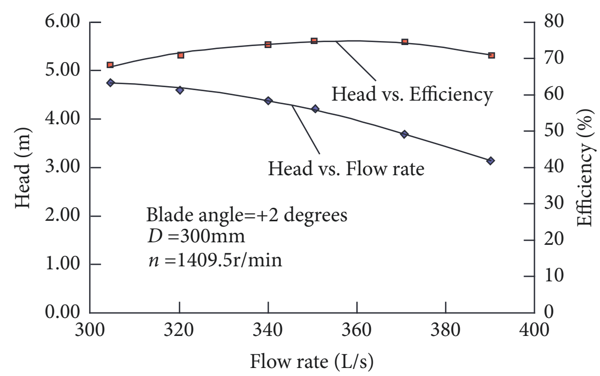

Figure 5: Performance prediction of the model pumping system based on CFD.

6. Model Test and Validity Verification of Pump Performances Prediction

6.1. Set-Up of Model Pumping System Test Bench. When Liulaojian pump station was built, a special optimal design of flow passages based on CFD analysis and a model pumping system test were carried out in 1995 (see [30]), which explains the reason why the parameters of original dustpan-type suction box and the siphon-type discharge passage remained unchanged in the technical innovation of the pump station.

To secure the success of the technical innovation of Liulaojian pump station, a new physical model test was carried out; see [31]. The comprehensive test error of the test bench for pumping system efficiency fell within ±0.39%, and its quality certification was authorized by the Ministry of Education of The People's Republic of China. The set-up of the pumping system test bench is shown in Figure 6, in which hydraulic, cavitation performance, electricity generating, and other tests of pump and pumping system as well as turbines can be conducted there. The whole test process is computerized and the collection of all measurement parameters is carried out automatically and the electromagnetic flowmeter can be calibrated on the spot.

Table 3 gives a list of main instruments and equipment used in the test bench for measurement of experimental data in the model pumping system test; all instruments were calibrated and work in the effective use period.

Figure 7 shows that the model pumping system was installed in the test bench, with the same suction box and discharge passage and the selected model pump as shown in Figure 3. The only difference from what was done in 1995 is the adoption of different model pumps. Hence, it is a kind of comparative model tests, and the test results can be directly compared and used to verify the correctness in pump selection and performance prediction for the technical innovation of Liulaojian pump station.

6.2. Comparison of Model Pumping System Performance before and after the Technical Innovation. Since the impeller of the prototype pump was equal to 3100 mm unchanged, and the rotational speed was proposed to reduce from 150 r/min to 136.4 r/min in the technical innovation, the corresponding rotational speed of the model pumping system was reduced from 1550 r/min to 1409.5 r/min based on the rule of keeping the product of diameter of impeller and its rotational speed in the model test, which means that the pump head in the model and prototype pump system is equal.

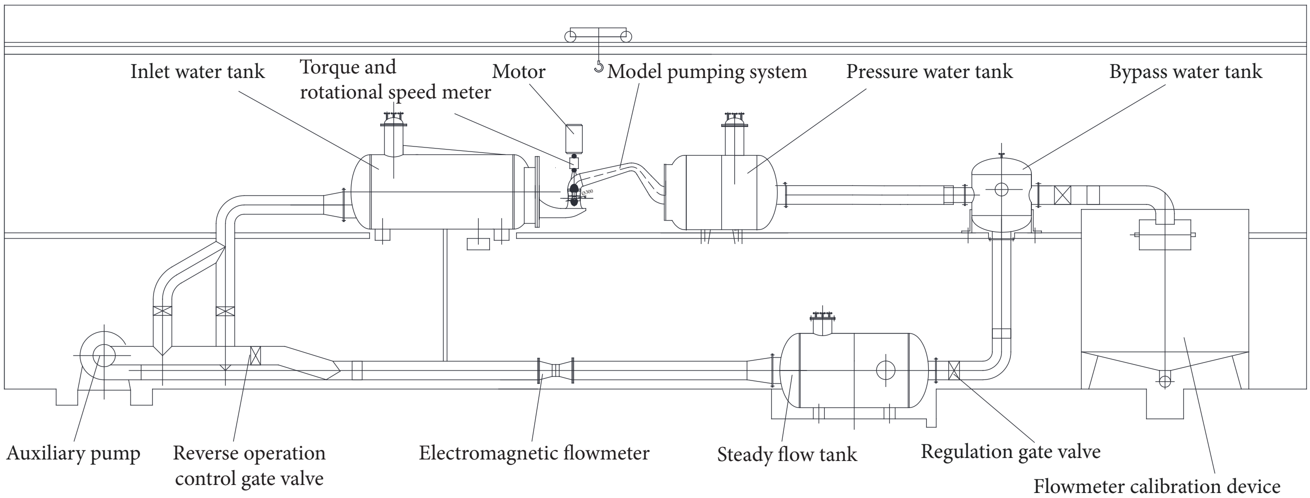

Figure 6: Set-up of the pumping system test bench.

Figure 7: Model pumping system installed in the test bench.

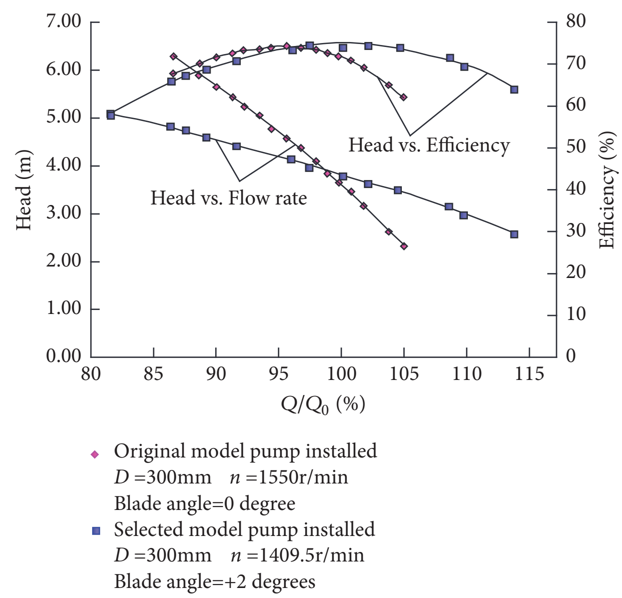

Figure 8: Comparison of pumping system performances obtained in the model tests.

Figure 8 shows the comparison of pumping system performances obtained through model tests, in which the unit of abscissa is the percentage of relative flow rate in considering of the different rotational speed and blade setting angle in different model pumping system tests.

From Figure 8 it can be seen that when the newly selected axial-flow pump model was applied, the pumping system shall possess greater pumping capacity under the same head, while the pump runs at slower rotational speed and larger blade setting angle. Compared with the numerical simulation, the predicted head versus flow rate curve complies approximately with the model test result sharing the similar changing trend, and for the pumping efficiency curve the best efficiency point a little bit biased to small flow rates; thus, the validity of CFD analysis was verified. Through the comparison it was found that after the technical innovation by replacing with the newly selected model pump the pumping efficiency shall be raised by 3.20 percentages when it runs under the design head of 3.70m. The pumping efficiency shall be improved by 3.40 percentages when running under the mean head of 3.40m.

Figure 9 gives the performance curves of the prototype pumping system converted from model test by means of the similarity law. The pumping capacity will reach 38.54m3/s, and the corresponding pumping efficiency is as high as 74.6%. Through the model test for Liulaojian pumping system it proves that the selected pump is suitable for the characteristic parameters of the axial-flow pump station, not only will more water be delivered after the technical innovation, but also a lot of electrical energy be saved due to the improvement of pumping efficiency, especially for such a large pump station that operates more than 5000 h per year.

According to the cavitation affinity law, when the diameter of an impeller keeps unchanged, the cavitation allowance of a pump is directly proportional to the square of its rotational speed. The model test result indicates that the slowing down of the rotational speed of prototype pump from 150r/min to 136.4r/min in the technical innovation

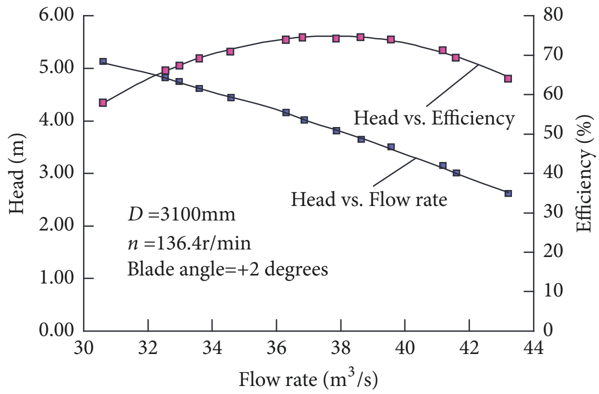

Figure 9: Performance prediction of prototype pumping system based on model test.

of Liulaojian pump station, the cavitation allowance shall be reduced by 0.90m when it runs under the designed conditions. The decrease extent of cavitation allowance is not as much as what computed by the theoretical equations; the explanation is that when the rotational speed of the pump is slowed down, the pumping systems are still required to satisfy the flow rate.

7. Conclusions

(1) Axial-flow pumps are widely used in China, and many pump stations like Liulaojian pump station have run more than 20 years. Serious aging of mechanical and electrical equipment, vibration of pump set, low operation efficiency, and other hydrodynamic problems pose threats to their safety and economic operation, and technical innovations have become a necessity.

(2) The pump similarity law and specific speed were applied to the process of pump selection for the technical innovation of the pump station. The model pump selected possesses excellent performance and higher efficiency, reflecting China's advancements in the research and development area of pump models.

(3) Through the performance prediction based on numerical simulation and comparison of model test results, the validity of CFD analysis was verified, confirming that the selected pump for the technical innovation is reasonable. When the selected model pump is applied to the technical innovation of Liulaojian pump station, the designed flow rate can be satisfied and the pumping system efficiency be raised by more than 3 percentages under the designed and mean head, and better engineering and economic benefits can be prospected.

(4) The reducing of prototype pump rotational speed while keeping at the same impeller diameter in the technical innovation is favorable to improve its cavitation performance. The use of new pump model, together with the automatic trash removing device, ring-type support beam, stainless steel blades, and other measures will greatly improve the hydrodynamic performance of the pumping system to achieve economic, stable, and safe operation of the pump station.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This paper is financially supported by China National Science and Technology Supporting Program (no. 2015BAB07B01) and funds for the feasibility study of technical innovation of Liulaojian pump station.

References

[1] W. Ding and J. Wen, "Pump Renovation of Jinagsu Liulaojian Pump station," *Drainage and irrigation Machinery*, vol. 1, pp. 35-36, 1997.

[2] M. Q. Chen, Q. Y. Gu, Y. B. Wang, and Q. Qing, "The mesoscal convective cloud cluster features of a severe torrential rain caused by southwest vortex," *Plateau and Mountain Meteorology Research*, vol. 28, no. 4, pp. 66–71, 2008 (Chinese).

[3] Report of the accreditation checkup for Liulaojian pump station. The quality Inspection Station of Jiangsu Water, 2015.

[4] C. Liu, *Pump and pump Station*, China Water & Power Press, 2009.

[5] H. Liu, J. Ding, H. Dai et al., "Numerical Research on Hydraulically Generated Vibration and Noise of a Centrifugal Pump Volute with Impeller Outlet Width Variation," *Mathematical Problems in Engineering*, vol. 2014, Article ID 620389, 13 pages, 2014.

[6] W.-L. Chuang, S.-C. Hsiao, and K.-S. Hwang, "Numerical and Experimental Study of Pump Sump Flows," *Mathematical Problems in Engineering*, vol. 2014, Article ID 735416, 20 pages, 2014.

[7] L. Lu and R. Zhang, *Optiamal hydraulic calculation of suction boxes in pump station*, China Water & Power Press, Beijing, China, 18-25, 1997.

[8] H. Zhu and S. Yuan, "Optimal design of inlet conduit for technical innovation of large pumping stations," *Shuili Fadian Xuebao/Journal of Hydroelectric Engineering*, vol. 25, no. 2, pp. 51–55, 2006.

[9] H. Zhu, "Analysis on the hydraulic characteristics of siphon discharge passage of large pumping station," *China Water & Wastewater*, vol. 22, no. 6, pp. 54–57, 2006.

[10] Y. Li, W. Shi, D. Yan et al., "Experimental study and effect prediction of large axial- flow pumping station rehabilitation," *China Rural Water and Hydropower*, vol. 8, pp. 119–122, 2007.

[11] C. Stephen, S. Yuan, J. Pei, and G. Xing Cheng, "Numerical Flow Prediction in Inlet Pipe of Vertical Inline Pump," *Journal of Fluids Engineering*, vol. 140, p. 051201, 2018.

[12] H. Bing, L. Tan, S. Cao, and L. Lu, "Prediction method of impeller performance and analysis of loss mechanism for mixed-flow pump," *Science China Technological Sciences*, vol. 55, no. 7, pp. 1988–1998, 2012.

[13] L. Nin, W. Yisen, and Z. Gang, *Test of pump models in the same test stand for South-to-North Water diversion Project*, China Water Power Press, Beijing, China, 2006.

[14] X. Guan, "Test reports of a new series of axial-flow pumps," *Drainage and irrigation Machinery*, vol. 23, no. 4, pp. 1–5, 1994.

[15] R. Zhang, "Key issues in the selection of pumps and their systems for the project of water transferring from south to north in China," *Journal of Hydroelectric Engineering*, vol. 22, no. 4, pp. 119–127, 2003.

[16] Y. Lu, X. Wang, and R. Xie, "Derivation of the Mathematical Approach to the Radial Pump's Meridional Channel Design Based on the Controlment of the Medial Axis," *Mathematical Problems in Engineering*, vol. 2017, Article ID 7027016, 15 pages, 2017.

[17] H. Bing, S. L. Cao, C. L. He, and L. Lu, "Experimental study of the effect of blade tip clearance and blade angle error on the performance of mixed-flow pump," *Science China Technological Sciences*, vol. 56, no. 2, pp. 293–298, 2013.

[18] S. Kim, K.-Y. Lee, J.-H. Kim, and Y.-S. Choi, "A Numerical Study on the Improvement of Suction Performance and Hydraulic Efficiency for a Mixed-Flow Pump Impeller," *Mathematical Problems in Engineering*, vol. 2014, Article ID 269483, 17 pages, 2014.

[19] J. Sun and H. Tsukamoto, "Off-design performance prediction for diffuser pumps," *Proceedings of the Institution of Mechanical Engineers*, vol. 215, no. 2, pp. 191–202, 2001.

[20] C. Yan, J. Yu, J. Xu et al., "On the achievements and prospects for the methods of computational fluid dynamics," *Advances in Mechanics*, vol. 41, no. 5, pp. 562–589, 2011.

[21] F. Wang, "Application of CFD to turbulent flow analysis and performance prediction in hydraulic machinery," *Journal of China Agricultural University*, vol. 10, no. 4, pp. 75–80, 2005.

[22] H. Zhu and R. Zhang, "Numerical simulation of internal flow and performance prediction of tubular pump with adjustable guide vanes," *Advances in Mechanical Engineering*, vol. 2014, Article ID 171504, 2014.

[23] Report on numerical simulation of performance prediction and optimal design of Liulaojian pumping system. Yangzhou University, 2016.

[24] S. Derakhshan and N. Kasaeian, "Optimization, numerical, and experimental study of a propeller pump as turbine," *Journal of Energy Resources Technology-Transactions of the ASME*, vol. 136, no. 1, 2014.

[25] W. Li, X. Zhao, W. Li et al., "Numerical Prediction and Performance Experiment in an Engine Cooling Water Pump with Different Blade Outlet Widths," *Mathematical Problems in Engineering*, vol. 2017, Article ID 8945712, 11 pages, 2017.

[26] V. Yakhot and S. A. Orszag, "Renormalization group analysis of turbulence. I. Basic theory," *Journal of Scientific Computing*, vol. 1, no. 1, pp. 3–20, 1986.

[27] H. Zhu, S. Yuan, H. Liu, and W. Shi, "Research on conversion methods of hydraulic characteristics between prototype and model pumps and pumping stations," *Transactions of the Chinese Society of Agricultural Machinery*, vol. 37, no. 12, pp. 91–95, 2006.

[28] M. Golcu and M. F. Koseoglu, "Energy saving by using an axial flow deep well pump: an application in the net frames in lake karacaoren-2," *Journal of Thermal Science and Technology*, vol. 32, pp. 33–40, 2012.

[29] Z. Wang, G. Peng, L. Zhou, and D. Hu, "Hydraulic performance of a large slanted axial-flow pump," *Engineering Computations*, vol. 27, no. 2, pp. 243–256, 2010.

[30] Research report on the model pumping system test of Jiangsu province Liulaojian pump station. Jiangsu University of Science and Technology, 1995.

[31] Research report on the model pumping system test for the technical innovation of Jiangsu province Liulaojian pump station. Yangzhou University, 2018.