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Editorial
Advances in Hydrodynamics of Water Pump Station System

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1. Introduction

As an indispensable part of water conservancy engineering construction, the importance of pumping stations is reflected in several aspects. First of all, pumping stations undertake the important tasks of regional flood control, flood cleanup, irrigation, water transfer, and water supply [1,2]. They can meet the needs of farmland irrigation, urban water supply, etc., and also help to preserve the ecological environment and improve the utilization rate of water resources. In particular, in modern society, the escalating demand for water resources is a consequence of the burgeoning economy and the enhancement of living standards. Consequently, pumping stations play a critical role in ensuring water resource availability, fostering agricultural progress, and sustaining the regular operations of entire cities. Secondly, the construction and management of pumping stations are also of great significance. The backwardness of pumping station technology, the decline in unit efficiency, the increase in energy consumption, and other problems not only affect the normal operation and efficiency of pumping stations but also restrict the progress of water conservation [3]. Therefore, the implementation of energy-saving measures for water conservation and the upgrading of pumping stations is an important method for improving the operational efficiency of pumping stations and reducing energy consumption. In addition, the construction and management of pumping stations also involve the maintenance and renewal of electromechanical equipment. Much of the electromechanical equipment that has run for long periods of time has already failed, but due to a shortage of funds and other reasons, this equipment is still in use, which not only affects the functioning of pumping stations but also increases the operational risks involved [4,5]. Consequently, it is critical to enhance pumping stations' construction and administration and ensure the timely replacement and maintenance of station equipment in order to guarantee secure, stable, and effective operations. Finally, from the point of view of economic and social benefits, the construction and management of pumping stations also represent an important means of achieving the efficient utilization of water resources and facilitating the sustainable growth of water conservation. By improving the quality of pumping station construction and management levels, water conservancy projects can effectively utilize their advantages and contribute to the sustainable growth of the economy and society [6].

The aim of this Special Issue is to focus on the latest advances in pumping station system research, with a particular focus on operational stability enhancement and the potential applications of energy conversion technologies. Since the December 2022 call-for-papers announcement, a total of 17 original papers have been accepted for publication following a thorough peer-review process (Manuscripts 1–17); the contents thereof cover strategies for the upgrade of pumping stations, the exploration of the water pumping station phenomenon, the fine-grained study of pumping efficacy and stability, the safe

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and stable operation of pumps as turbines, the vibration characterization of pump turbine units, and hydraulic transients in pipeline network systems. To enhance the comprehension of this particular edition, we have succinctly outlined the key points of the published articles below.

2. Overview of This Special Issue

In the field of pumping station research, scholars have endeavored to enhance system performance and efficiency through a variety of research methods and technological approaches. These studies focus not only on the optimization of individual components but also on the coordinated operation and long-term stability of the entire system.

In the study of pumping station buildings, in order to optimize the flow distribution in the pumping station forebay, Contribution 1 conducted research using numerical simulation methods to examine the impact of rectification facilities on the water flow in the pumping station forebay. Two rectification methods were suggested: one includes a solitary bottom sill and another involves a combination of a bottom sill and a diversion pier. These methods were specifically created to enhance the flow conditions in the forebay; minimize undesired flow structures, such as backflows and eddies; and ensure a more consistent flow distribution in each part. The results show that the bottom sill controls the central beam of water coming out of the water distribution pipe while the installation of the diversion pier allows for the flow to be rectified twice, thus facilitating the dispersion of the incoming water and making the flow distribution more uniform in each part.

In the study of pumping station water pipelines, Contribution 2 is the first systematic study of the water-filling process of water–gas two-phase flow in right-angle elbow pressure pipelines, especially under different water-filling velocity conditions. The integration of numerical simulations with physical model tests offers a novel approach to comprehending and forecasting water–gas two-phase flow. A staged water-filling method is proposed according to the different stages of the process to efficiently decrease the pressure peak and shorten the water-filling time. The comparative analysis of experimental and numerical simulation results provides a theoretical and practical basis for controlling the water–gas two-phase flow in actual engineering applications. Contribution 3 showed detailed numerical simulations of gas–liquid two-phase flow in a high-elevation water pipe carried out using the CLSVOF model and the RNG k-ε turbulence model, thereby providing a new perspective for understanding and predicting the flow phenomena in the water pipe system. The paper analyzes the effects of bubble size and distribution, flow velocity, and air content on the evolution of flow patterns and pressure pulsations. The analysis reveals the effects of random bubble distribution on flow patterns and pressure pulsations in high-pressure water piping systems. The results help predict the rupture risk and water hammer protection in stagnant gas pipeline systems, thereby providing theoretical support and computational parameters for engineering safety.

In the pump unit study, Contribution 4 provides a detailed analysis of pumps' internal flow characteristics under different start-up combination scenarios, thereby uncovering the impacts of varied start-up conditions on the internal hydrodynamic behavior of the centrifugal pump. Combined with entropy generation and a vortex analysis, the paper provides a new perspective for evaluating and optimizing the internal flow and energy losses witnessed in pumping stations. The paper examines the performance of pumping stations under various start-up combinations and suggests an optimal start-up combination scheme. This scheme is crucial for enhancing the energy efficiency and stability of pumping stations. The impeller blades of water pumps can usually be simplified to be studied as hydrofoils; Contribution 5 proposes a bionic pumping device based on two oscillating hydrofoils, which aims to improve the fluidity of water bodies in the river network area. The hydraulic performance in both in-phase and out-of-phase oscillation modes was analyzed via numerical simulations and experimental validation. The finite volume method and overlapping mesh technique were employed for this purpose. The findings of this study indicate that the out-of-phase oscillation mode exhibits a superior hydraulic performance in comparison to the in-phase oscillation mode, particularly at a constant frequency. Furthermore, the pump efficiency of out-of-phase oscillation is notably higher than that of in-phase oscillation. Contribution 6 improves the hump characteristic at low flow rates through adjustments to the shapes of the impeller inlet edge and the blade. It also optimizes the matching relationship between the guide vanes and the impeller to improve pressure pulsation characteristics and optimize the width of the leafless zone. At the same time, the performance curves of the centrifugal pump at different speeds were studied, and the maximum input shaft power curves under various working conditions were determined. Based on this, an analysis was performed to identify the safe and efficient operating range of the pump. The occurrence of pump stalling is a frequent issue that arises during the real functioning of centrifugal pumps. Therefore, Contribution 7 used the scale-adaptive simulation (SAS) model and found the existence of double-hump characteristics in the head curve. Through the comparison of the flow field characteristics under various flow conditions, it was determined that the peak region near the optimal operating condition is a result of hydraulic losses, whereas the peak region further away from the optimal operating condition is caused by the combined influence of Euler head and hydraulic losses. The clock effect mechanism of the guiding vanes is examined by simplifying the model, thus revealing that the disturbance caused by the wake of the upstream vane on the downstream vane's boundary layer influences the transition; this in turn affects the friction stress of the vanes and leads to a change in the pressure amplitude. The results of this study are important for understanding and controlling the performance of centrifugal pumps under stall conditions, especially in the secure and dependable functioning of large pumping stations. In terms of vibration characteristics, Contribution 8 details a comprehensive study of the modal characteristics of the pump impeller, examining its behavior in both air and water environments. Dynamic stress simulations demonstrate that the cyclic pattern of the highest stress point is mostly influenced by the number of blades and the rotational speed of the impeller during a single rotation cycle. Using this approach, the behavior of the pump under different operating conditions can be better understood, thus improving its performance and life. Centrifugal pumps are more suited for situations that require high pressure and have low flow rates and high heads. On the other hand, axial-flow pumps are more appropriate in situations with large flow rates and low-to-medium heads. Contribution 9 evaluates the structural strength and durability of the rotor system in a large-scale vertical axial pump when operating in both pump mode and PAT (pump-as-turbine) mode, which provides strong support for the optimal design and safe operation of centrifugal pumps. An analysis was conducted to examine the deformation and distribution of equivalent stress in the blades under various flow conditions. The results revealed that the greatest deformation and concentration of stress primarily occurred near the root of the blades. The fatigue life of the blades was evaluated, and it was found that the cycle times of the blades exceeded 106 cycles under all operating conditions, which indicates that the blades have a service life and cycle times that fall within the acceptable limit for safety. Comparisons of blade safety factors in pump and PAT modes indicated that the blade root in PAT mode necessitated a careful evaluation of its material strength and safety stability. Contribution 10 proposed a method for predicting the Q–H curve of PAT at different speeds, which was validated via numerical simulations and new analytical expressions. The results show that these methods provide satisfactory results when the operating point is in proximity to the BEP (best efficiency point).

On some occasions, turbines serve as the power source of pumping stations, using the kinetic energy of the water to drive the pumps to operate in service of water extraction and transfer [7]. Contribution 11 details a systematic analysis of the flow-induced noise of the Francis turbine under different operating conditions. The analysis was carried out through the application of a combination of CFD simulations and sound power-level assessment methods. Through a comparison of experimental and simulated values, three distinct loading circumstances situated in the permissible, limited, and forbidden zones were chosen for the investigation. This selection facilitated a more comprehensive understanding of the creation and distribution of flow-induced noise. The relationship between the flow-induced noise and the internal flow characteristics of the turbine (e.g., vortex, guide vane opening, etc.) is revealed, which provides a scientific basis for the low-noise design of the turbine and the diagnosis of noise problems. By analyzing the flow characteristics under different operating conditions, a design method to reduce the flow-induced noise is proposed, which is of great significance for the design and optimization of hydraulic turbines. In addition, Contribution 12 compares the pressure pulsation characteristics of Francis turbines with varying draft tube arrangement directions. The VMD approach is used here for the first time to analyze pressure pulsations in the Francis turbines, which helps clearly extract the signal characteristics and obtain more explicit results. Based on a real engineering case, the findings offer a hydrodynamic benchmark for the design of the deflector casing of a Francis turbine. Meanwhile, in order to have a more comprehensive understanding of the performance characteristics of the turbine, Contribution 13 conducted a cavitation characterization study of the axial-flow paddle turbine for both the prototype and the model in the surrounded vortex rope. It is suggested that the critical cavitation coefficients between the prototype and the model remain similar under varied cavitation coefficients. This similarity serves as a significant reference for the design and operation of the prototype. The article also examines the alterations in the cavitation properties of the runner chamber of both the model and the prototype when the model critical cavitation coefficient is reduced below the prototype critical cavitation coefficient, which is of practical significance for the understanding and prevention of cavitation damages in the operation of hydraulic turbines.

With renewable energy receiving global emphasis and investment, the current base of intermittent renewable energy sources like wind and solar will continue to increase. The power generation of these energy sources is unstable and requires energy storage technology to balance power supply and demand. Pumped storage power plants, as one of the key technologies and economically feasible energy storage methods, have a significant impact on the transition of energy structure [8,9]. In an in-depth study of pumped storage unit performance optimization, Contribution 14 proposes the use of fractional-order PID (FOPID) controllers to improve the control performance of pumped storage units. The FOPID controller differs from standard PID controllers in its incorporation of two additional adjustable parameters, namely differential order and integral order, thus providing higher control freedom and better robustness; this provides a new solution to the control problem of pumped storage units and helps improve the stability and regulation performance of the system. In order to have a more comprehensive understanding of the pumped storage unit's performance in actual operation, Contribution 15 details a field study of the pressure fluctuation and vibration stability characteristics of the prototype pump turbine under multiple operating conditions. In turbine mode, the pressure variations exhibit distinct characteristics; in pump mode, the pressure fluctuations at different measurement locations exhibit changes in the low-frequency region. The vibration acceleration characteristics are affected by the interaction between the rotor and stator and the frequencies of the structural modes. These findings are crucial for guaranteeing the stability and dependability of the unit. Contribution 16 describes an analysis of the energy loss mechanism in a pump turbine equipped with diverter vanes at various characteristic heads. The study employed the entropy generation theory in conjunction with the flow field distribution to quantitatively evaluate the energy loss and internal flow state changes of the pump turbine at various characteristic heads. The investigation aimed to uncover the underlying causes and distinctive features of energy loss. Through the application of the entropy generation theory, a new approach is provided to analyze and optimize the hydraulic design of pump turbines, which helps improve their efficiency and operational performance. Contribution 17, in order to explore in depth the internal flow characteristics of a single-pier, front-loaded pump turbine in a draft tube at partial load, investigates the interactions between vortex ropes and return zones and their effects on the pressure fluctuation characteristics within the tailrace. A preliminary explanation of the phenomenon of fluid kinematic progression based on vortex theory is presented, and a theoretical analysis of the distortion of vortex tubes under the influence of geometric potential is presented. This study not only helps us understand the operating characteristics of the pump turbine under partial load but also provides an important reference for optimizing the design of the unit and improving the operating stability.

3. Conclusions

This Special Issue not only presents the latest research results in the field of pumping stations but also provides a wealth of practical experience and insights. The guest editors believe that the following concerns in the field of pumping stations need continued attention:

(1) For the lack of applicable hydraulic pump models for water conservancy pumping stations, continued research and the development of high-performance hydraulic models with excellent cavitation performance and little pressure pulsation are necessary in order to effectively support the efficient operation of pumping stations.
(2) In light of the numerous space vortices and insufficient submergence depth of the pump suction flapper in the front and intake pools of water conservancy pumping stations, a flow control system must be implemented in order to enhance the pumping stations' intake conditions.
(3) Improving the control performance of water conservancy pumping stations by enhancing the performance of gate valves should receive additional prioritization.

We believe that through future research, pumping station technology will continue to make new breakthroughs, thereby providing a strong guarantee for urban and rural water supply security and sustainable development.

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