TYPE Editorial
PUBLISHED 03 January 2023
DOI 10.3389/fenrg.2022.1096541

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OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Process and Energy Systems Engineering, a section of the journal Frontiers in Energy Research

RECEIVED 12 November 2022
ACCEPTED 22 November 2022
PUBLISHED 03 January 2023

CITATION
Kan K, Deng ZD, Cheng Y, Guo P and Zhou D (2023), Editorial: Internal flow mechanism of modern hydraulic machinery.
Front. Energy Res. 10:1096541.
doi: 10.3389/fenrg.2022.1096541

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Editorial: Internal flow mechanism of modern hydraulic machinery

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KEYWORDS

hydraulic turbine, pump, pump-turbine, flow characteristics, transient process, cavitation, numerical method

Editorial on the Research Topic
Internal flow mechanism of modern hydraulic machinery

Hydraulic machines can be broadly defined as machines that convert the hydraulic energy of the liquid passing through them to the mechanical energy of their specific mechanical components, or *vice versa*. This definition using energy direction leads to two classes of hydraulic machinery: turbines and pumps. In these machines, the external performance characteristics are an indicator of their internal flow state. In their daily operations and in line with the system operational requirements, hydraulic machines may be forced to operate under off-design operating conditions, resulting in flow unsteadiness within the machines' fluid passage channels. Subsequently emerged secondary flow phenomena generally lead to detrimental outcomes such as flow and pressure pulsations, machine structural vibrations, noise, and machine performance degradation. Therefore, it is fundamentally important to improve the understanding of the flow dynamics of the hydraulic machines and their evolution mechanism under different operating circumstances. The improved understanding can increase the machines' operational performance, safety and associated economic benefits. Therefore, the papers included in the current Research Topic focus on the three aspects through both numerical and experimental methods: the general hydrodynamics of hydraulic machinery and its systems, fluid-solid interactions, and acoustic measurement of fluid systems.

A number of studies have been conducted on flow dynamics within pump-turbines and the parameters that influence flow unsteadiness onset and evolution process in hydraulic machinery. In a study by Zeng et al., the vortex distribution and associated energy loss characteristics within a pump-turbine in its S-shaped operating zone have been analyzed. Vortex flow structures that emerged in the S-shaped zone could be classified as leaf channel vortex and flow separation vortex for operating conditions within the runaway and turbine brake operating zones. These vortices grew larger and expanded upstream, blocking multiple channels within the guide and stay vane flow zones. Hu et al. investigated the five operating conditions in the whole four-quadrant plane of characteristics curves. They found that the flow unsteadiness increases as the machine operates at the point far away from the optimum conditions for both turbine and pump operating modes. The flow impacting on the runner blades in the pump-brake zone led to serious flow instabilities and subsequent runner force pulsations, while the rotating stall and associated pressure pulsations were obvious under hump and the S-shaped region. The highest pressure pulsations were recorded in the vaneless zone and the amplitude increased with guide vane opening. Deng et al. conducted a similar study considering the pump and turbine operating modes under four different guide vane openings (6°, 14°, 18°, and 20°). Vortices that emerged in the vaneless space under pump mode were counterclockwise-rotating flow separations. These vortices eventually blocked the flow passage, leading to massive hydraulic losses and subsequent occurrence of the hump characteristics. As for the turbine mode, most of the recorded vaneless space vortex structures showed a clockwise-rotating tendency, and the associated pressure pulsations constituted an important factor of the pump-turbine's S-shaped characteristics, as they were directly linked to the machine performance degradation, and its operational safety. In addition, Hou et al. studied the clearance flow dynamics in pump-turbines by investigating the clearance flow field between a stationary and a rotating disc using experimental measurements and numerical simulations. The distribution of the circumferential velocity showed two distinct zones in the direction of the clearance height, namely the core region and the double-boundary layer region, with the speed of the core region being 41%–42% of the rotating disc speed. They also found that the pressure and hydraulic thrust can be expressed as the functions of the inlet pressure and runner rotating speed.

Several additional investigations have been conducted on hydraulic pumps. Sun et al. simulated the transient characteristics of a submersible tubular pump during power-off process using a 6-degree-of-freedom model based on the fourth-order multi-point Adams-Moulton formula. They revealed that both the flow rate and impeller rotating speed decreased rapidly and changed the direction under the power failure scenario. The time interval between the zero flow and zero speed was found to be 0.6 s. Large vortices emerged within the pump's flow channels, especially at zero flow, where subsequent pressure pulsations threatened the machine operational safety. The blade passing frequency was found to be the dominant pressure pulsation frequency, the intensity of which increased with the impeller speed. Luo et al. investigated the effect of the shaft transition form on the inflow pattern and overall performance of the pre-shaft tubular pump. However, the three investigated forms of the shaft transition showed a negligible effect on the pump's energy characteristics, where the velocity contours at the outlet of the shaft were symmetrically distributed, providing favorable conditions for the impeller. In addition, recorded pressure pulsations were large at the impeller inlet and were dominated by the blade passing frequency, the amplitude of which increased in the hub-to-shroud direction. Shi et al. investigated the effect of inlet grooves on the tubular pump's flow characteristics and found that the decreasing pump flow led to saddle characteristics emergence under low flow conditions. The wall-mounted grooves at the inlet section were demonstrated to eliminate the wall-bounded vortices and backflows, thus improving the pump's head by 1. 61 m. The grooves have also considerably weakened the pump inlet pressure pulsations, which were dominated by the blade passing frequency. Another key parameter, wall roughness, has been investigated by Chen et al. using a slanted axial-flow pump operating under a wide range of flow conditions. While the wall roughness of inlet and outlet pipes did not inflict any remarkable effects on the pump's overall flow state and performance characteristics, the wall roughness within the impeller chambers considerably deteriorated the pump performance, especially under large-flow conditions. A gradual increase in wall roughness could progressively induce flow instabilities and subsequent turbulent kinetic energy in the wall vicinal zones. On the other hand, Yang et al. investigated the flow state's changing mechanism in the impeller and guide vanes of a vertical axial-flow pump under different flow conditions. They found that, as the flow increased, the flow streamline distortion zone size on the impeller blade's surface gradually decreased from $0.8Q_{BEP}$ towards $1.2Q_{BEP}$ (Q_{BEP} is the pump flow rate at its best efficiency point). Under $0.8Q_{BEP}$ condition, flow fields within both the impeller and guide vane zones experienced the highest flow unsteadiness. Under this condition, the impeller's radial force, pressure pulsation coefficient, and the energy losses within the guide vanes were the highest, while decreased with the increasing flow. Mohamed et al. (Shamsuddeen et al. studied the pump energy loss characteristics by considering a double suction multistage centrifugal pump and using baffles to counter the pre-swirl phenomenon in its second stage. They tested three baffle plate designs, the performances of which were analyzed. Compared to the vertical and four-plate baffle configurations, the horizontal baffle configuration exhibited the largest efficiency and head improvements, before it was retested for different angles to finally find its 300° clockwise inclination as the optimum configuration, with 9.08% and 3.87% improvements in terms of pump efficiency and hydraulic head, respectively. Li et al. studied the surface pressure pulsation characteristics in the centrifugal pump's shaft end-sealing membrane using the magnetic fluid as the working medium. The centrifugal pump was tested under several flow conditions, where the pressure pulsation on the surface of the magnetic fluid sealing film displayed a periodic trend. The amplitude of this pressure pulsation was found to decrease as the pump flow increased. They found that the period of its fluctuation was equivalent to the time required for the impeller blade to sweep the volute tongue. Liu et al. proposed a new expression of f_k based on rotation-corrected energy spectrum to be used with the SST k-ω PANS model for simulating rotating flows. The model was first successfully applied to the rotating flow channel case and validated through its application to centrifugal pump flow simulation. The authors showed that the model can accurately capture the time-averaged flow structure formations and associated velocity distribution within the pump flow field for both full and part-load conditions, thus demonstrating its suitability for simulating rotating flows. Han et al. investigated the vortex ring formation mechanism during nozzle injection. Among other findings, they reported that the simulated thrust considering the presence of the vortex ring was 7.0% higher than when it was ignored.

Multiphase flows in hydraulic machinery were also studied. Both Wang et al. and Cheng et al. investigated the dynamics of the solid-liquid two-phase flows in hydraulic pumps and turbines, respectively. Wang et al. focused on the wear characteristics of the pump blade as a function of solid particle's diameter, solid particle's concentration, and the pump blade material. They reported that, while the common zones of wear concentration were the blade middle zone and trailing zone, the gradual increase in the particle mass concentration led to the correspondingly increasing material loss due to blade wear, while the gray cast iron material (HT200) exhibited the best wear-resistive performance. Cheng et al. studied the effects of the same particle parameters (particle size and concentration), on the tubular turbine's cavitation performance. While the cavitation development areas were commonly located at the blade leading edge's hub-vicinal zone, both particle parameters exhibited an inhibitive effect to the local cavitation development, with the particle concentration increase having the biggest impact. Xin et al. studied the pump turbine under transient conditions by exploring the emergence of flow vortices and associated pressure pulsations in the runner inter-blade channels and the vaneless space, especially under high-speed/low-flow conditions. Using the two-way fluid-solid coupling analysis, they found that structural stresses were built at the runner blade inlet zone, precisely at the connection zones between the blade, the upper crown and lower ring. Maximum deformation was predicted to take place in the middle area of the blade due to the occurred fatigue damages. Chen et al. noted that water hammer-induced vibrations within hydropower plants' long diversion pipelines mostly lead to fluid-structure interaction (FSI) occurrence and studied the same phenomenon in the pipeline embedded in concrete. They used a six-equation model to investigate the interaction between the fluid, the pipe, and the concrete. They reported that, some of the concrete properties, such as the Poisson's ratio and density, negligibly contributed to the FSI response; whereas others, such as the elastic modulus and thickness-to-radius ratio, played important roles.

Finally, (Xu et al.; Xu et al.) studied the modal coherence characteristics for broad band noise determination in flow ducts, as well as the mode identification error characteristics of fan noise. In the first study (Xu et al.), three types of ducted sound source distribution modes were investigated. Study results have shown that the coherence of some modes has little impact on the measurement of incident acoustic waves in the flow duct, while it leads to about 3 dB deviation in the prediction of the reflected modal sound power and has little influence on the spectral shape of reflected acoustic waves. The second study (Xu et al.) investigated the mode identification error characteristics of a fan noise and compared two measuring techniques, the radial rake and axial microphone array. They found that the radial rake method can measure the radial distribution of the modal amplitude, but has large errors in mode identification of low frequencies. Compared to the radial rake method, the axial array method exhibited a better accuracy in mode recognition thus making it fit for real life applications.

In conclusion, the papers in this Research Topic have touched several important aspects of flow structure formation mechanisms and associated phenomena within different hydraulic machinery and systems, where different research methods have been presented and various techniques for system performance improvement have been suggested. In addition, the presented contents stimulate new ideas that can be investigated in future studies. Both the authors and editors hope that this Research Topic sheds light on the current state of knowledge in this field, thus opening the horizon for further research, which would contribute to the improved performance and operational safety of hydraulic machinery and associated economic benefits.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Funding

Kan Kan was supported by the National Natural Science Foundation of China (52009033), the Natural Science Foundation of Jiangsu Province (BK20200509), the Postdoctoral Research Foundation of China (2022T150185; 2022M711021). Daqing Zhou was supported by the National Natural Science Foundation of China (51979086).

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