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A Review and Prospect of Research on Centrifugal Pump Noise

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ABSTRACT

This paper presents a comprehensive review of the current state and development trends in the research on centrifugal pump noise. It first analyzes the primary sources of noise in centrifugal pumps, including mechanical noise, fluid-induced noise, and structural noise. Subsequently, it discusses in detail the main research methods employed in this field, covering experimental measurement techniques, numerical simulation approaches, and theoretical analysis methods. Finally, the paper provides a prospective outlook on future research directions, highlighting emerging trends such as interdisciplinary research, intelligent monitoring and control technologies, the application of novel materials and structural designs, as well as green design and sustainable development. This review aims to offer valuable insights and references for the continued advancement of research in centrifugal pump noise.

KEYWORDS

Centrifugal Pump; Noise; Cavitation; Review.

1. INTRODUCTION

With the rapid development of industry in China, centrifugal pumps, as a type of fluid machinery, have been widely used in various fields such as industry, agriculture, and construction as essential equipment for fluid transportation. Due to their complex structures, diverse inlet and outlet pipe configurations, and the presence of flowing working media, the operation of centrifugal pumps is often accompanied by broadband noise. In recent years, the increasing use of high-speed centrifugal pumps has made noise a particularly prominent issue, drawing growing attention. The noise generated during the operation of centrifugal pumps not only poses risks to human health but can also significantly impact the normal functioning of the pump itself. Research on centrifugal pump noise is of great significance: it enables monitoring of the pump's operational status through noise signals, mitigates the adverse effects of noise on industrial environments and daily life, reduces mechanical fatigue caused by acoustic vibrations, and contributes to the improvement of centrifugal pump design [1].

Research on centrifugal pump noise began in the mid-20th century. With advancements in acoustic theory and measurement techniques, researchers have gradually unveiled the mechanisms behind the generation and propagation of centrifugal pump noise. In recent years, the rapid development of computer technology and numerical simulation methods has provided new tools and approaches for investigating centrifugal pump noise. At the same time, the trend of interdisciplinary integration has opened up new avenues for addressing the complex issues associated with pump noise. This paper presents a systematic review of centrifugal pump noise research from three perspectives: noise sources, research methodologies, and future outlook.

2. SOURCES AND INVESTIGATION OF CENTRIFUGAL PUMP NOISE

2.1. Sources of Centrifugal Pump Noise

Centrifugal pumps have a relatively wide range of noise sources. Relative impacts and friction between components, turbulence, vortex shedding, and other factors can all induce noise generation, regardless of whether the pump is operating under normal or abnormal conditions [2]. The noise primarily originates from two aspects: mechanical structure and fluid dynamics.

Mechanical noise is mainly caused by friction, impacts, and vibrations of moving parts inside the pump, such as bearings, seals, and impellers. This type of noise typically exhibits distinct periodic characteristics, with its peak frequency often corresponding to multiples of the centrifugal pump’s rotational speed [3].

Structural noise refers to the vibration-induced radiated noise generated by structural components such as the pump casing and pipelines when subjected to mechanical and fluid excitations. The propagation path of this type of noise is complex and may extend through the pump body, pipelines, and foundation structures to the surrounding environment. The intensity and frequency characteristics of structural noise depend on various factors, including the pump's structural design, material properties, and installation conditions.

In actual operation, these three types of noise sources often couple and interact with each other, collectively forming the overall noise characteristics of the centrifugal pump.

Fluid noise, on the other hand, is generated due to instabilities and turbulence in the internal fluid flow of the pump, including noise caused by fluid impacts, cavitation, and vortex shedding. Fluid noise typically spans a wide frequency range and is closely related to the pump’s operating conditions.

2.2. Research on Centrifugal Pump Noise

(1) Research on Noise Induced by Mechanical Structures

Noise and vibration caused by rotor asymmetry and misalignment have been the subject of extensive investigation by many researchers. However, studies that directly address centrifugal pump noise from the perspective of rotor-induced excitation remain relatively limited, and relevant references are scarce. At present, comprehensive studies on the centrifugal pump as a whole are still insufficient. Existing research is mainly focused on the effects of specific components--such as the impeller, volute geometry, and shaft—on noise generation. Some studies have also explored the influence of base dimensions on pump noise.

(2) Research on Noise Induced by Fluid Dynamics

Compared to mechanically induced noise, the mechanisms of noise generation by internal fluid dynamics are more complex, cover a broader frequency range, and pose greater challenges in research. In the evaluation of centrifugal pump noise levels, fluid dynamic noise plays a crucial role in determining the quality of pump design. Key sources of fluid dynamic noise include cavitation, non-uniform velocity distribution at the impeller inlet, vortex formation, and turbulence [4]. Under the influence of cavitation, the resulting noise typically exhibits several distinct features: (1) intermittency, and (2) burst-like impacts. Furthermore, noise generated by the coupling between fluid and solid boundaries is discrete in nature and spans a wider frequency range. Due to the highly complex turbulent flow within centrifugal pumps, current research remains at a stage where empirical models are combined with theoretical analysis.

3. RESEARCH METHODS FOR CENTRIFUGAL PUMP NOISE

Research methods for centrifugal pump noise primarily include experimental studies, numerical simulation approaches, and theoretical analysis methods.

Experimental studies form the fundamental basis for investigating centrifugal pump noise. Common techniques include sound pressure measurement, sound intensity measurement, and vibration analysis. Sound pressure measurement involves arranging microphone arrays around the pump to capture the spatial distribution of the acoustic field. Sound intensity measurement allows for more accurate localization of noise sources, while vibration measurement is used to analyze the structural vibration characteristics of the pump body, providing essential data for studying structural noise. In recent years, advanced measurement technologies based on devices such as acoustic cameras and laser vibrometers have also been widely adopted.

Numerical simulation methods offer powerful tools for centrifugal pump noise research. Computational Fluid Dynamics (CFD) methods can simulate complex three-dimensional internal flows, enabling the prediction of the location and intensity of fluid noise sources. Acoustic Boundary Element Method (BEM) and Finite Element Method (FEM) are commonly employed to model the propagation and radiation of acoustic waves. Typical CFD approaches include finite difference, finite volume, finite element, and boundary methods. In recent years, the development of fluid-structure interaction (FSI) simulation techniques has made it possible to predict noise while simultaneously accounting for the coupling between fluid flow and structural dynamics.

Theoretical analysis methods are primarily based on acoustic theory and the operational principles of pumps, aiming to develop mathematical models that describe the generation and propagation mechanisms of noise. Theoretical frameworks commonly include Lighthill's acoustic analogy, vortex sound theory, and dimensional analysis. Although these methods may offer lower precision compared to experimental and numerical approaches, they provide valuable insights into noise mechanisms and serve as a theoretical foundation for guiding both experimental measurements and numerical simulations.

4. PROSPECTS FOR RESEARCH ON CENTRIFUGAL PUMP NOISE

Future research on centrifugal pump noise is expected to follow a trend of increasing interdisciplinary integration. The deep convergence of disciplines such as acoustics, fluid dynamics, solid mechanics, and materials science will provide new ideas and methods for addressing the complex challenges associated with centrifugal pump noise. For instance, combining fluid dynamics with acoustic theory can lead to more accurate predictions of fluid-generated noise and its propagation; meanwhile, advances in materials science may enable the development of novel materials with superior damping properties, thereby effectively reducing structural noise.

The development of intelligent monitoring and control technologies will offer new tools for real-time noise monitoring and active noise control in centrifugal pumps. Intelligent monitoring systems based on Internet of Things (IoT) technologies can facilitate real-time tracking of pump operating conditions and noise levels. Coupled with machine learning algorithms, predictive models for noise can be established, enabling early warning and fault detection. On the control side, active noise control (ANC) technologies and adaptive control strategies hold promise for achieving real-time and precise control of centrifugal pump noise.

The adoption of novel materials and innovative structural designs will also provide new solutions for noise control. The application of nanomaterials, composite materials, and smart materials can significantly enhance the damping characteristics of pump components, thereby reducing vibration and noise. In terms of structural design, the application of biomimetic principles could lead to breakthrough innovations, such as low-noise impeller designs inspired by biological structures. In addition, the utilization of 3D printing technologies opens up possibilities for manufacturing complex geometries, promoting the development of more optimized, low-noise pump designs.

The concepts of green design and sustainable development will profoundly shape the future direction of centrifugal pump noise research. Increasing emphasis will be placed on noise control at the source, with noise reduction considerations integrated early in the design phase to achieve a balance between low noise and high efficiency. Furthermore, the application of life cycle assessment (LCA) methods will facilitate a comprehensive evaluation of the environmental impact of pump noise, promoting the development of more environmentally friendly and sustainable centrifugal pump technologies. Emerging pump technologies based on renewable energy may also become a key research focus, offering not only reductions in energy consumption but also new opportunities for noise control.

5. CONCLUSION

Research on centrifugal pump noise is a complex field involving multiple disciplines and diverse technologies. This paper has reviewed the sources of centrifugal pump noise, the research methodologies employed, and the future development trends. Studies have shown that centrifugal pump noise primarily originates from two aspects: mechanical structures and fluid dynamics. Addressing these noise sources requires an integrated approach that combines experimental investigation, numerical simulation, and theoretical analysis.

Looking ahead, key directions in centrifugal pump noise research will include interdisciplinary integration, intelligent monitoring and control technologies, novel materials and structural design, as well as green design and sustainability concepts. With continuous advancements in related technologies, it is reasonable to expect that more efficient and low-noise centrifugal pumps will play an increasingly important role in industrial applications and daily life, contributing to the creation of quieter and more comfortable environments.

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