Research on Vibration and Noise Source Identification and Optimization Practice of Hydraulic Systems in Electric Loaders

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Abstract: This paper conducts a systematic and multi-level study on vibration and noise source identification and engineering control practices for the abnormally high noise level near the operator's ear in the cab of a new electric loader developed by Liugong during mass production. First, through rigorous comparative testing, noise spectrum data of the prototype and mass-produced machines under identical operating conditions were collected. Based on detailed spectrum analysis and coherence analysis, the hydraulic system was successfully identified as the primary noise contributor. To further investigate the root cause and verify potential solutions, a comprehensive testing and analysis system was established. This method integrated high-precision acoustic measurements (near-field sound pressure method) and multi-channel vibration testing (vibration acceleration measurement), enabling synchronous monitoring and correlation analysis of noise sources, transmission paths, and response points. On this basis, a series of comparative validation tests were designed and implemented. The results indicate that the use of an internal gear pump or optimization of the connection stiffness and installation method of the confluence flange can significantly reduce the cab noise level under all operating conditions, effectively resolving the engineering problem of inconsistent noise performance between mass-produced machines and prototypes. This study establishes and validates a systematic diagnostic methodology and effective engineering solutions for NVH issues in hydraulic systems of electric construction machinery, providing a valuable practical reference and theoretical basis for low-noise hydraulic system design and noise problem mitigation in similar electric loaders and other electric construction machinery.
***Keywords*:** electric loader; hydraulic system; vibration and noise; noise source identification; noise reduction optimization; structural resonance

1. Introduction

As the core unit of an electric loader, the hydraulic system plays a critical role in its overall performance. Effective treatment of hydraulic system noise can not only improve operating performance and extend service life but also enhance the driving experience of equipment operators. Under the trend of electrification, traditional internal combustion engine noise has been substantially eliminated or shifted to a secondary position, making fluid-borne noise and structural vibration generated during hydraulic system operation increasingly prominent as key factors affecting the NVH performance of the entire machine. Such noise originates not only from periodic flow and pressure pulsations inside hydraulic pumps but also from throttling cavitation at control valve orifices, fluid turbulence within pipelines, and the broadband structural noise radiated after these fluid excitations are transmitted through structures such as pump bodies, valve blocks, pipelines, and hydraulic tanks. With the strengthening of global environmental awareness and the increasingly stringent emission regulations worldwide, electrification and low-noise development have become irreversible trends in the construction machinery industry. At the same time, end users are placing higher demands on workplace comfort, making low noise and low vibration important indicators of product premiumization and market competitiveness. Therefore, in-depth research and effective control of hydraulic system noise are no longer merely measures to improve driving comfort but have become important technical issues related to regulatory compliance, customer satisfaction, and brand value enhancement for electric construction machinery products.

Against this background, after a new electric loader developed by Liugong successfully completed prototype development and validation and entered the mass-production stage, market feedback and factory quality inspections revealed that the noise level near the operator's ear in the cab of mass-produced machines was significantly higher than that of the validated prototype. This issue was particularly pronounced under high-load and high-pressure operating conditions such as lifting and taking back bucket pressure-holding operations, seriously affecting the product's market competitiveness and customer evaluation.

To address this problem, this study aims to go beyond the traditional trial-and-error maintenance approach by introducing systematic testing, analysis, and diagnostic methods. Through the comprehensive application of spectrum analysis, near-field acoustic measurements, vibration transmission path analysis, and other techniques, the study seeks to accurately identify the root mechanisms and major transmission paths responsible for the abnormally high cab noise of the electric loader. Targeted, effective, and cost-conscious control measures are proposed to provide a scientific and reliable analytical framework and practical solution for resolving such NVH consistency issues, while also offering references for the design and quality control of similar products.

2. Problem Description and Preliminary Analysis

2.1 Problem Phenomenon

Benchmark tests were conducted on the prototype and the first batch of mass-produced machines in accordance with the loader noise testing standard. The prototype initially adopted a 9-tooth + 12-tooth gear pump configuration, in which the pump noise was slightly high at 5000 rpm. After optimization, it was modified to a 10-tooth + 12-tooth pump configuration, and the noise level was effectively controlled. However, the mass-produced machine equipped with the same 10-tooth + 12-tooth pump configuration exhibited a maximum sound pressure level of 81.9 dBA near the operator's ear under typical operating conditions. This performance not only failed to achieve the optimized noise level of the prototype with the same configuration but was even inferior to the original prototype configuration. This phenomenon indicates that the design modification of the hydraulic system introduced unforeseen adverse effects during mass-production application and that an uncontrolled noise amplification mechanism existed.

2.2 Theoretical Analysis of Common Causes of Hydraulic Noise

Hydraulic system noise mainly originates from the following aspects: periodic excitations generated by hydraulic pumps (such as gear pumps and piston pumps) due to flow pulsation, trapped oil phenomena, and mechanical friction; impact noise caused by transient pressure fluctuations in the system; fluid cavitation and turbulence noise generated during valve opening and closing; and radiated noise from structural components such as pipelines and hydraulic tanks under excitation. Among these sources, the meshing frequency of gear pumps and its harmonic components are the primary excitation sources and can readily induce resonance in downstream structures.

3. Experimental Design and Analysis Methods

To systematically identify the root cause of the noise and verify improvement measures, multiple rounds of comparative testing schemes were designed in this study:

(1) Acoustic Testing: In accordance with national standards, A-weighted sound pressure levels were measured at the operator's left and right ear positions. Meanwhile, microphones were arranged near key noise sources, including the hydraulic pump, hydraulic tank housing, and major valve blocks, for near-field sound pressure measurements to obtain the spectral characteristics of the noise.

(2) Vibration Testing: Triaxial accelerometers were installed along critical structural transmission paths, including the hydraulic pump housing, hydraulic tank wall, frame foundation, and cab floor, to measure vibration responses and analyze their correlation with the excitation frequencies of the hydraulic pump.

(3) Comparative Validation Schemes: A series of comparative experiments were designed and implemented:

① Restoring the pump configuration of the mass-produced machine to the optimized prototype configuration;

② Replacing the pump with a Casappa series low-noise gear pump;

③ Replacing the pump with an internal gear pump;

④ Removing or reconstructing the hydraulic confluence flange assembly;

⑤ Applying damping treatment and structural reinforcement to the hydraulic tank.

All experiments were conducted under identical environmental conditions and operating conditions to ensure data comparability.

4. Results and Discussion

4.1 Hydraulic Pump Configuration Optimization and Its Limitations

After restoring the hydraulic pump assembly of the mass-produced machine to the configuration identical to that of the optimized prototype, testing revealed that its noise level remained significantly higher than that of the prototype. Moreover, new noise peaks appeared within a specific hydraulic motor speed range (5000–5900 rpm). This finding indicates that simply replicating the hardware configuration is insufficient to solve the problem. It suggests that differences in tolerance accumulation, assembly stress, or system impedance characteristics during mass production altered the transmission paths, potentially triggering local structural resonance.

4.2 Analysis of the Application Effects of Low-Noise Hydraulic Pumps

To reduce excitation at the source, two low-noise hydraulic pump solutions were introduced:

(1) Low-Noise External Gear Pump (Casappa 10+10 Tooth Pump): Test results showed that, except under idle conditions where vibration was slightly higher due to the matching of the pump's inherent frequency characteristics, the cab noise level under all other operating conditions was lower than that of the original mass-produced machine and was generally close to the optimized prototype level.

(2) Internal Gear Pump: This solution achieved the most significant improvement. After replacement, the noise level near the operator's ear under all test conditions was reduced to below 70 dBA, representing a maximum reduction of 10 dBA compared with the original condition. Spectrum analysis confirmed that the internal gear pump effectively reduced the excitation amplitude at the meshing frequency, thereby suppressing noise generation at its source.

4.3 Optimization of Structural Transmission Paths and Key Findings

To further investigate the noise transmission paths, structural decoupling tests were conducted:

(1) Contribution Analysis of the Hydraulic Tank and Side Enclosure: Tests performed after removing the hydraulic tank and side enclosure indicated that, within the 5000–5900 rpm range, structural noise radiation from the hydraulic tank wall was the dominant noise source. Applying constrained-layer damping treatment to the hydraulic tank effectively suppressed noise within this frequency range.

(2) Structural Resonance Problem of the Confluence Flange: On another mass-produced machine, tests were conducted after removing the hydraulic confluence flange. The results were remarkable: noise levels under idle conditions decreased by 6.4–8.8 dBA, while noise reductions under lifting conditions reached 11–17.4 dBA. Vibration data analysis showed that, after removal, pump-frequency vibration on the hydraulic tank was significantly reduced.

This low-cost solution confirmed that unfavorable structural coupling existed between the original confluence flange assembly and the vehicle frame. At specific frequencies, this coupling created an "amplifier" effect, significantly enhancing the transmission of pump-induced vibration into the vehicle structure.

4.4 Comprehensive Analysis

Based on all experimental data, the root causes of the hydraulic system noise problem in this new electric loader can be summarized as follows:

(1) Primary Noise Source: The meshing force of the external gear pump is the primary source of structural vibration excitation.

(2) Amplification and Transmission Path: Under mass-production conditions, the hydraulic piping system—particularly the confluence flange assembly—exhibits unfavorable dynamic coupling with vehicle structures such as the hydraulic tank. This coupling forms structural resonance at specific frequencies, greatly amplifying pump-induced excitation and efficiently transmitting it to the cab through structure-borne noise paths.

(3) Hierarchy of Solutions:

① Excitation Source Control (Fundamental Measure): Adopt low-pulsation pump types, such as internal gear pumps, to fundamentally reduce the input excitation force.

② Transmission Path Control (Efficient and Economical Measure): Optimize or remove pipeline connection components prone to resonance (such as the confluence flange), and enhance the stiffness or apply damping treatment to thin-walled radiating structures (such as hydraulic tanks) to interrupt or attenuate vibration transmission.

③ System Consistency Control (Key Quality Management Measure): Ensure that component quality, assembly processes, and commissioning conditions in mass production remain strictly consistent with the validated prototype baseline.

5. Conclusions and Applications

Through the systematic engineering approach of "test diagnosis–mechanism analysis–measure verification," this study successfully identified and resolved the hydraulic noise problem encountered during the mass production of a Liugong electric loader. The main conclusions are as follows:

(1) NVH variations during the mass-production stage of construction machinery often originate from local structural resonance caused by interactions between the design state and manufacturing and assembly conditions. Systematic transmis-

sion path analysis is the key to effective diagnosis.

(2) The adoption of internal gear pumps is the most effective measure for reducing hydraulic noise at the source and can achieve significant noise reduction under all operating conditions.

(3) Optimizing key connection structures in the hydraulic pipeline system (such as the installation method or structural design of the confluence flange) can effectively avoid unfavorable structural dynamic coupling, providing direct noise reduction benefits with excellent engineering cost-effectiveness.

(4) The problem-analysis framework and solution developed in this study have been successfully applied to quality improvement of this product model. The methodology has significant reference value for addressing hydraulic system NVH issues in similar electric construction machinery.

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References

[1] Liu Hongguang, Lu Senlin. Noise Analysis of Wheel Loader Cab Interior[J]. Transactions of the Chinese Society for Agricultural Machinery, 2005, 36(2): 103–106.

[2] Bi Huangtao. Analysis of Sound Quality Characteristics and Improvement Strategies for Loader Cabs[D]. Shanxi: Taiyuan University of Science and Technology, 2025.

[3] Zhang Qiang, Wei Hai, Luo Qingyu, et al. Analysis and Optimization of Motor Noise in a Pure Electric Loader[J]. Construction Machinery, 2021, 52(1): 30–34.

[4] Zhang Nan, Duan Chuandong, Yang Xiaoxiao, et al. Analysis and Mitigation of Abnormal Noise in the Hydraulic Power Steering System of a Loader[J]. Construction Machinery, 2022, 53(1): 41–47.

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