Experimental generation and analysis of pump fault data using a pump test bed for development of pump monitoring system

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1. Introduction

Pumps are among the most critical rotating machinery in operating nuclear power plants, playing a vital role in maintaining reactor power output and cooling performance. Since pump failures can significantly affect plant safety and reliability, the development of highly reliable monitoring and diagnostic technologies is essential to ensure pump integrity and support the safe and stable operation of nuclear power plants.

In domestic nuclear power plants, pump monitoring systems are currently in operation; however, they are dependent on overseas technologies and system and are generally limited to simple alarm notifications and data acquisition functions. As a result, identifying the root causes of pump failures often requires additional expert intervention and extensive data analysis.

To address these limitations, artificial intelligence (AI) techniques have emerged as a promising approach for early fault detection and root-cause diagnosis of pump anomalies. While various studies have investigated the application of AI to condition monitoring in rotating machinery, the lack of high-quality fault data remains a major challenge. Since both the quantity and quality of data are critical for developing high-performance AI models.

To address the data shortage issue, various methods, such as finite element analysis and digital twins, are being proposed. However, these data production methods also require validation based on actual data. Furthermore, because model-based data are typically idealized, diagnostic models trained using this data can suffer from performance degradation due to discrepancies between the trained data and actual field data. Therefore, Our research group designed and built a dedicated testbed system to generate a representative pump failure data set. The testbed reflects the characteristics of field-collected data and takes into account various factors that affect data quality, such as experimental conditions and experimental repeatability. Using this testbed, we have been collecting diverse fault scenarios to acquire abnormal pump vibration and operational data under controlled conditions.

This study introduces the types and characteristics of fault data obtained using a pump testbed. Data were generated not only for single faults but also for cases where two faults occurred simultaneously. The characteristics of the generated data were analyzed, and characteristic parameters were compared to verify their validity.

2. Data acquisition

The pump testbed was designed and built to simulate bearing defects, misalignment, and impeller imbalance. Each defect was quantitatively simulated, and equipment was designed and installed to minimize human influence during repeated experiments.

The misalignment simulation system is designed and manufactured to quantitatively simulate angular misalignment and equilibrium misalignment, and can also be implemented when both misalignments occur simultaneously. For misalignment defects data, six severity levels were defined for both parallel misalignment and angular misalignment, with the thresholds determined based on the alignment tolerances specified in the pump operation manuals.

For impeller unbalance defects, the pump was modified to allow for adjustment of the impeller unbalance amount without disassembly and assembly. The system was also designed to allow the experimenter to adjust the weight as desired Data was collected by simulating six levels of impeller unbalance defects.

The bearing defect simulation system was designed and manufactured to enable bearing replacement without disassembly or assembly of the pump shaft and impeller. The defect bearings were manufactured by artificially creating wear defects on the inner and outer rings of the bearings. Six wear levels were established to create the defective bearings.

First, data was secured when each defect occurred singly, and the characteristic parameters of the secured data were extracted to confirm the appropriateness of the defect stage and the reproducibility of repeated experiments. By analyzing the data characteristics for single defect occurrences, we identified data features that could be utilized for anomaly diagnosis.

We also acquired data for both single defect occurrences and simultaneous occurrences. As with the data analysis for single defects, we performed preprocessing techniques and feature parameter analysis to identify data characteristics and utilize them for fault diagnosis.

In order to diagnose the pump, it is also possible to check the correlation with the pump's operating conditions, data acquisition for each pump fault simulation environment involved varying pump operating conditions to ensure a diverse range of data.

3. Conclusions

Experimental data were acquired by simulating four types of pump defects: parallel misalignment, angular misalignment, impeller unbalance, and bearing faults. The dataset includes not only single-fault scenarios but also combined fault conditions, and the quality of the collected data was evaluated through comprehensive characteristic parameter analysis. Using this dataset, ongoing research focuses on developing data preprocessing techniques to establish an AI-based pump monitoring and diagnostic system. Additional experiments are currently being conducted to obtain data on various levels of fault severity and complex fault combinations. Ultimately, the objective is to construct a comprehensive pump fault diagnosis database suitable for AI model training and to develop an accurate and robust fault diagnosis framework based on this dataset.

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