A Rule-Based Vibration Analysis and Diagnostic (VAD) Platform for Rotating Equipment Maintenance

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Abstract: Vibration analysis remains one of the most reliable techniques for monitoring rotating equipment health, yet in most plants it still depends on manual spectrum interpretation by a small pool of specialists, creating bottlenecks and inconsistent diagnoses. This paper presents the Vibration Analysis and Diagnostic (VAD) platform, a rule-based decision-support tool that standardizes and accelerates first-level fault diagnosis for pumps, compressors, and turbines. Built in Python with a Tkinter interface, NumPy/SciPy for frequency-domain calculation, Matplotlib for visualization, and FPDF for reporting, the platform applies diagnostic rules drawn from the Mobius Institute vibration guide. Technicians enter equipment specifications and the dominant observed frequency and receive a structured report of probable fault causes and recommended actions, while the platform simultaneously builds a verified historical database of confirmed cases. This paper describes the platform's architecture, operational workflow, and expected benefits in diagnostic speed and consistency, and outlines a roadmap toward a machine-learning-based diagnostic model.

Keywords: *Vibration Analysis, Rotating Equipment, Predictive Maintenance, Fault Diagnosis, Rule-Based Expert System, Condition Monitoring.*

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I. INTRODUCTION

Rotating equipment such as pumps, compressors, and turbines is central to oil and gas, petrochemical, and power-generation operations, and its reliability directly affects safety, uptime, and cost. Vibration analysis is a well-established predictive-maintenance technique that can detect faults such as imbalance, misalignment, bearing degradation, and looseness before they cause unplanned failures [1].

Despite its value, vibration diagnosis in most plants remains a manual, expert-dependent process. A specialist must interpret frequency spectra, cross-reference fault frequencies against equipment specifications, and apply years of pattern-recognition experience. This creates four recurring problems in organizations with large equipment fleets:

- Expert dependency, especially at remote or offshore sites with limited specialist access.
- Inconsistency, as different analysts may reach different conclusions from the same spectrum.
- Slow turnaround between an alarm and an actionable recommendation.
- Fragmented knowledge that stays with individual analysts rather than in a structured, reusable form.

These problems motivated the development of a software platform that augments — rather than replaces — technician judgment by standardizing and accelerating first-level diagnosis.

➢ *Background*

Every fault mode in rotating machinery produces a characteristic vibration signature at frequencies tied to operating speed and geometry. References such as the Mobius Institute vibration body of knowledge and ISO 20816 vibration-severity standards link frequency components — running speed (1X), harmonics, and bearing-specific frequencies (BPFO, BPFI, BSF, FTF) — to probable root causes. Commercial online condition-monitoring systems exist but are costly, hardware-dependent, and not optimized for the fast, offline diagnostic workflow used by field technicians with handheld analyzers, leaving room for a lightweight rule-based decision-support tool.

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➢ *Objectives*

The project had two complementary objectives: (1) provide immediate, rule-based diagnostic support to technicians, standardizing outputs and reducing diagnostic errors; and (2) capture a verified dataset of equipment vibration records — by prompting users to upload spectrum images and confirm root causes — as the foundation for a future machine-learning extension. The platform takes equipment configuration (driver/driven type, horsepower, operating speed, bearing type) and the dominant observed frequency as input, and returns a structured report of probable fault causes and recommended actions.

II. METHODOLOGY AND ARCHITECTURE

➢ *Software Stack*

The platform was developed in Python, with the interface and application environment built in Microsoft Visual Studio. The rule-based diagnostic engine was built on established vibration-analysis standards and the Mobius Institute vibration guide, with AI-assisted knowledge structuring during development.

Table 1 Software Stack

Function	Library	Purpose
GUI	Tkinter	Desktop interface
Processing	NumPy/SciPy	FFT & frequency calc.
Visualization	Matplotlib	Waveform/spectrum charts
Storage	JSON	Equipment/report records
Reporting	FPDF	Automated PDF reports

➢ *Functional Modules*

The architecture comprises four modules: a Data Input module (plant/equipment identification and specifications), a Data Processing module (running speed, harmonics, and bearing defect frequencies), a Reporting and Visualization module (structured report plus waveform/spectrum charts), and a Data Management module (saving and retrieving analysis records to build the historical database).

III. IMPLEMENTATION

➢ *Interface and Users*

The interface separates a data-entry form (equipment and frequency inputs) from a read-only diagnostic output panel, with actions for analyzing, charting, saving, and uploading a confirmed spectrum with technician remarks. It targets technicians with basic-to-intermediate vibration skills, letting them act proactively without always waiting on a specialist — particularly valuable at remote or offshore sites.

➢ *Operational Workflow*

The platform integrates into the existing maintenance process: a vibration alarm or survey finding triggers a technician investigation using the VAD platform; the maintenance supervisor implements the recommended action; the technician re-collects data to validate the fix; and, if the issue persists, a vibration engineer is escalated. The confirmed root cause and final spectrum are then uploaded, closing the loop and enriching the historical database. This flow is embedded in a RACI model in which the vibration technician is Responsible for day-to-day use and the reliability unit supervisor is Accountable for data quality and consistent adoption, keeping the platform aligned with existing maintenance governance.

IV. RESULTS AND DISCUSSION

The delivered platform provides rapid rule-based analysis with structured action items, automated report export (TXT/HTML/PDF), dynamic waveform and spectrum charting, and a growing, searchable database of confirmed equipment cases. Expected benefits include reduced reliance on scarce experts, faster initial troubleshooting, more consistent diagnoses across shifts and sites (since all outputs trace to the same rule base), and an implicit training effect as technicians repeatedly see the link between spectrum patterns and confirmed failure modes. Over time this is also expected to shift the technician's role toward greater diagnostic engagement and autonomy, rather than purely manual data collection.

V. CONCLUSION

This paper presented the VAD platform, a rule-based tool that standardizes and accelerates first-level vibration diagnosis for rotating equipment. By combining a lightweight Python stack with domain knowledge from established vibration standards, the platform reduces dependency on scarce expert resources and integrates cleanly into existing maintenance workflows through a defined operational process and RACI model. Its growing verified database of confirmed diagnostic cases also lays the groundwork for evolving the rule-based engine into a machine-learning-based diagnostic capability in future work, illustrating the broader potential of rule-based decision-support software in predictive maintenance.

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