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USING OF VIBRATION DIAGNOSTICS TOOLS TO ASSESS THE TECHNICAL CONDITION OF COMPRESSOR UNITS

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Abstract. Compressor units are critical components of gas transportation, petrochemical, chemical, energy, and industrial production systems. Their reliable operation directly affects process continuity, energy efficiency, equipment safety, and maintenance costs. Vibration is one of the most informative parameters for assessing the technical condition of rotating machinery because mechanical defects often produce characteristic changes in vibration amplitude, frequency, and spectral composition. This article examines the application of modern vibration diagnostic tools for assessing the technical condition of compressor units. The study considers accelerometers, vibration velocity sensors, displacement sensors, portable vibration analyzers, online monitoring systems, and digital signal-processing techniques. Particular attention is given to time-domain and frequency-domain analysis, including root mean square (RMS), peak values, crest factor, Fast Fourier Transform (FFT), and vibration trend analysis. A methodological framework for identifying typical compressor faults such as rotor unbalance, shaft misalignment, mechanical looseness, bearing degradation, and abnormal aerodynamic conditions is proposed. The results demonstrate that combining several vibration indicators with continuous monitoring provides a more reliable assessment of equipment condition than relying on a single vibration parameter. The integration of vibration diagnostics with PLC, SCADA, Industrial IoT, and predictive maintenance systems can further improve the reliability and operational efficiency of compressor units.

Keywords: compressor unit, vibration diagnostics, condition monitoring, accelerometer, vibration velocity, FFT, RMS, predictive maintenance, fault diagnosis, rotating machinery, SCADA, Industrial IoT.

Introduction. Compressor units are widely used in natural gas transportation, gas processing, petrochemical production, power generation, refrigeration, and various industrial processes. Because compressor units normally operate continuously and often under high rotational speeds and significant mechanical loads, even relatively small changes in their technical condition can develop into serious failures if they are not detected at an early stage. Traditional maintenance strategies are generally based on predetermined inspection intervals or corrective maintenance after a failure has occurred. However, these approaches may result in unnecessary maintenance activities or unexpected equipment downtime. Condition-based and predictive maintenance strategies provide an alternative by using measurable physical parameters to determine the actual technical condition of machinery. Among the available diagnostic parameters, vibration is particularly important for rotating equipment. Changes in vibration characteristics can indicate rotor imbalance, shaft misalignment, bearing degradation, mechanical looseness, gear defects, structural resonance, and other abnormal operating conditions.

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The fundamental advantage of vibration diagnostics is that it can detect developing mechanical problems before they become visible through temperature, pressure, power consumption, or other conventional process parameters. Consequently, vibration monitoring can serve as an early-warning mechanism for compressor units. The objective of this study is to examine the application of modern vibration diagnostic tools for assessing the technical condition of compressor units and to develop a methodological approach for interpreting vibration measurements in order to identify potential mechanical faults.

Literature Review. Vibration-based condition monitoring has become an established approach for diagnosing rotating machinery. Randall emphasized that vibration analysis provides valuable information about the dynamic behavior of rotating equipment and can be used to identify different fault mechanisms through characteristic frequency components. Scheffer and Girdhar demonstrated the practical importance of vibration measurements in predictive maintenance, particularly for rotating machines such as motors, pumps, compressors, gearboxes, and turbines. Their approach combines vibration measurement with spectral analysis and trend monitoring. Modern measurement and instrumentation literature also emphasizes the importance of sensor selection, measurement bandwidth, signal conditioning, sampling frequency, and data-processing algorithms. Accelerometers are commonly used because they provide a broad frequency response and can capture high-frequency vibration associated with bearing and other mechanical defects.

International standards provide general frameworks for measuring and evaluating machine vibration. ISO 20816 establishes principles for measuring and evaluating machine vibration, while ISO 13373 provides guidance on vibration condition monitoring and diagnostic procedures. Recent developments in digitalization have expanded the capabilities of vibration monitoring systems. Modern systems can continuously collect vibration data, perform automatic spectral analysis, store historical trends, and transmit diagnostic information to centralized monitoring platforms.

However, the practical challenge remains the reliable interpretation of vibration signals under changing operating conditions. Therefore, vibration amplitude alone should not be considered sufficient for comprehensive diagnosis. A combination of time-domain indicators, frequency-domain characteristics, operating parameters, and historical trends provides a more informative basis for technical-condition assessment.

Research Methodology. The proposed methodology consists of five principal stages: vibration signal acquisition, signal conditioning and preprocessing, time-domain analysis, frequency-domain analysis, technical-condition assessment.

Vibration Signal Acquisition. The first stage involves measuring vibration at strategically selected locations on the compressor unit.

Typical measurement locations include: compressor bearing housings, drive motor bearings, gearbox housings, compressor casing, shaft-support structures, thrust-bearing assemblies. Piezoelectric accelerometers are particularly suitable for industrial compressor units because of their wide frequency range and ability to detect both low- and high-frequency vibration components. Depending on the diagnostic objective, vibration can be measured in three directions: horizontal, vertical, axial. Multidirectional measurements are useful because certain mechanical defects produce stronger vibration in specific directions. Signal Conditioning. The raw vibration signal may contain electrical noise, structural interference, and other unwanted components. Therefore, signal conditioning is required before diagnostic analysis.

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The signal-processing sequence can be represented as:

Sensor → Signal Conditioning → Filtering → Analog-to-Digital Conversion → Digital Processing → Diagnostic Analysis

The sampled vibration signal can be expressed as:

$x[n] = x(nT_s)$

where:

- x[n] is the discrete vibration signal;
- T_s is the sampling interval.

The sampling frequency must be sufficiently high to capture the frequency components relevant to the diagnostic objective.

Time-Domain Analysis. Time-domain analysis provides information about the overall vibration behavior of the compressor.

The RMS value is one of the most commonly used indicators:

$X_{rms} = \sqrt{(1/N\ \Sigma x_i^2)}$

where:

- N is the number of samples;
- x_i is the individual vibration measurement.

The RMS value represents the overall energy level of the vibration signal and is useful for monitoring changes in machine condition.

Peak and peak-to-peak values can also be calculated:

$X_{peak} = \max|x(t)|$

$X_{p-p} = X_{max} - X_{min}$

Another useful indicator is the crest factor:

$CF = X_{peak} / X_{rms}$

An increasing crest factor may indicate the appearance of impulsive events, which can be associated with developing rolling-element bearing defects.

Modern compressor monitoring systems can be divided into portable and permanently installed systems.

Table 1. Comparison of vibration diagnostic tools

Diagnostic tool	Main parameter	Main application	Advantage
Piezoelectric accelerometer	Acceleration	High-frequency vibration	High sensitivity
Velocity sensor	Vibration velocity	Overall machine condition	Simple interpretation
Proximity sensor	Shaft displacement	Rotor dynamics	Direct shaft monitoring
Portable vibration analyzer	Multiple parameters	Periodic inspection	Flexible
Online monitoring system	Continuous vibration	Critical compressors	Real-time monitoring
FFT analyzer	Frequency spectrum	Fault identification	Spectral diagnosis
IoT vibration sensor	Digital vibration	Remote monitoring	Network connectivity

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	data		

Portable vibration analyzers are useful for periodic inspections, while permanently installed systems are more suitable for critical compressor units requiring continuous monitoring. Online monitoring systems can automatically acquire vibration signals and compare them with predefined thresholds. If abnormal behavior is detected, the system can generate an alarm and transmit information to an operator or maintenance center.

Experimental Results and Discussion. To demonstrate the application of vibration diagnostics, a hypothetical monitoring dataset was considered for a compressor unit operating under relatively stable conditions.

Table 2. Example of vibration trend monitoring

Operating time, min	RMS vibration, mm/s	Diagnostic condition
0	2.1	Normal
10	2.2	Normal
20	2.4	Normal
30	2.6	Normal
40	2.9	Observation
50	3.3	Warning
60	3.8	Diagnostic inspection required

The data demonstrate a gradual increase in vibration amplitude. The increase from 2.1 to 3.8 mm/s represents a significant change in the vibration trend. The important point is that the final vibration value should not be considered independently from the historical trend. A gradual increase may indicate developing deterioration even when the instantaneous value has not yet reached a critical threshold.

A more comprehensive diagnostic procedure should therefore combine:

RMS trend + peak value + frequency spectrum + operating parameters + historical data.

For example, if the RMS value increases simultaneously with the growth of the 1× rotational-frequency component, rotor unbalance may be considered as one possible diagnostic hypothesis. If high-frequency vibration and impulsive components increase, bearing degradation may require investigation. These interpretations should always be confirmed using additional measurements and knowledge of the particular compressor design and operating conditions.

Based on the analyzed diagnostic parameters, a conceptual condition assessment model can be represented as:

Vibration Sensors → Data Acquisition → Signal Processing → Feature Extraction → Fault Indicators → Condition Assessment → Alarm/Prediction

The feature-extraction stage may include: RMS, peak amplitude, peak-to-peak value, crest factor, dominant frequency, harmonic amplitudes, spectral energy, envelope-spectrum indicators, vibration trend. A condition-monitoring system can then classify the equipment condition into several operational categories:

Condition	Main characteristics	Recommended action
Normal	Stable vibration trend	Continue monitoring
Developing abnormality	Gradual increase	Increase monitoring frequency
Warning	Significant spectral or amplitude change	Schedule inspection

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Critical	High vibration or rapid deterioration	Immediate technical assessment

The exact alarm and shutdown limits should be established according to the compressor design, operating conditions, applicable standards, and manufacturer recommendations rather than using universal values.

Integration with SCADA, IoT and Predictive Maintenance. Modern vibration monitoring systems can be integrated into industrial automation architectures.

A typical architecture can be expressed as:

Vibration Sensors → Edge Device → PLC/Industrial Controller → SCADA → Database → Diagnostic Platform

Such integration enables: real-time visualization, automatic alarm generation, historical data storage, vibration trend analysis, remote technical assessment, maintenance planning, predictive maintenance. Industrial IoT technologies further enable vibration data to be transmitted to centralized or cloud-based analytical systems. Machine-learning algorithms can also be applied to historical vibration datasets. A trained classification model may distinguish between normal operation and different fault categories.

A predictive maintenance framework can therefore be organized as:

Data acquisition → Feature extraction → Machine-learning model → Fault classification → Remaining-condition assessment → Maintenance recommendation.

The use of artificial intelligence does not eliminate the need for engineering analysis. Instead, it can complement conventional vibration diagnostics by identifying complex patterns in large datasets.

Conclusion. Vibration diagnostics is an effective method for assessing the technical condition of compressor units because many mechanical and operational abnormalities produce measurable changes in vibration behavior. Accelerometers, vibration velocity sensors, proximity sensors, portable analyzers, and permanently installed monitoring systems can provide valuable information about the dynamic condition of compressor equipment. The analysis demonstrates that a single vibration parameter is generally insufficient for comprehensive diagnosis. A combined approach involving RMS values, peak indicators, crest factor, frequency spectra, vibration trends, and process parameters provides a more informative basis for condition assessment. FFT-based spectral analysis can assist in identifying characteristic frequency components associated with rotor unbalance, shaft misalignment, mechanical looseness, and other faults. High-frequency analysis and envelope techniques can provide additional information about bearing degradation. The integration of vibration diagnostic tools with PLC, SCADA, Industrial IoT, and predictive maintenance technologies can transform periodic vibration measurements into a continuous condition-monitoring system. Such an approach supports earlier detection of developing faults, more informed maintenance planning, and improved operational reliability. Future research should focus on developing hybrid diagnostic models that combine vibration signals with pressure, temperature, rotational speed, power consumption, and other compressor operating parameters. The application of machine-learning and artificial-intelligence algorithms to these multimodal datasets may further improve automated fault detection and predictive maintenance capabilities.

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