IECMA 2026 Conference
The 3rd International Electronic Conference on Machines and Applications
12–14 May 2026 | Online

The Influence of Operating Conditions and Measurement Duration on the Quality of Bearing Fault Information in Motor Fault Diagnostic Applications

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INTRODUCTION & AIM

Reliable rolling bearing fault diagnosis in induction motors typically requires relatively long measurement records, stable operating conditions, and high measurement accuracy to preserve fault-related information in acquired signals. However, such requirements are difficult to satisfy in practical industrial drive systems, where transient states, variable loads, and non-stationary operating conditions are common. This creates a need for diagnostic approaches capable of extracting meaningful fault information from shortened and lower-resolution measurement data.

Therefore, this study investigates how reducing measurement duration and sampling frequency influences the quality of diagnostic information associated with different types of rolling bearing faults. Particular attention is given to the degradation of feature separability under varying operating conditions, including steady-state and transient regimes, as well as different load torque levels.

METHOD

Experimental investigations were conducted on an induction motor with seeded rolling bearing faults, including inner race, outer race, and rolling element damage. Measurements were performed under different load torque levels. Vibration signals were acquired using a single-axis accelerometer mounted at the 12 o'clock position on the motor housing. The original signals were recorded with a sampling frequency of 10 kHz, and then systematically downsampled to analyze the influence of reduced temporal resolution on diagnostic performance.

Fault-related features were extracted using envelope spectrum analysis and selected statistical indicators sensitive to bearing defects, forming the feature vector {RMS, f_o, f_i, f_b}. These were then used as inputs to a Kohonen Self-Organizing Map (SOM) to assess the separability of fault-related patterns under reduced sampling frequency conditions.

RESULTS & DISCUSSION

Envelope spectrum analysis shows clear differences between healthy and faulty bearing conditions, where characteristic fault frequencies and their harmonics appear in damaged bearings and are absent or strongly attenuated in the healthy case. Figure 1 compares the envelope spectra for a healthy bearing and a bearing with an inner race defect, illustrating these spectral differences between operating states. Following the approach presented in [1], the same methodology for determining characteristic bearing fault frequencies was adopted. The corresponding expressions are as follows:

$$f_O = \frac{N_B}{2}\cdot f_r\cdot\left(1-\frac{d\cdot cos\vartheta}{D}\right),\qquad f_I = \frac{N_B}{2}\cdot f_r\cdot\left(1+\frac{d\cdot cos\vartheta}{D}\right),\qquad f_B = \frac{D}{2d}\cdot f_r\cdot\left(1-\left(\frac{d\cdot cos\vartheta}{D}\right)^2\right),$$

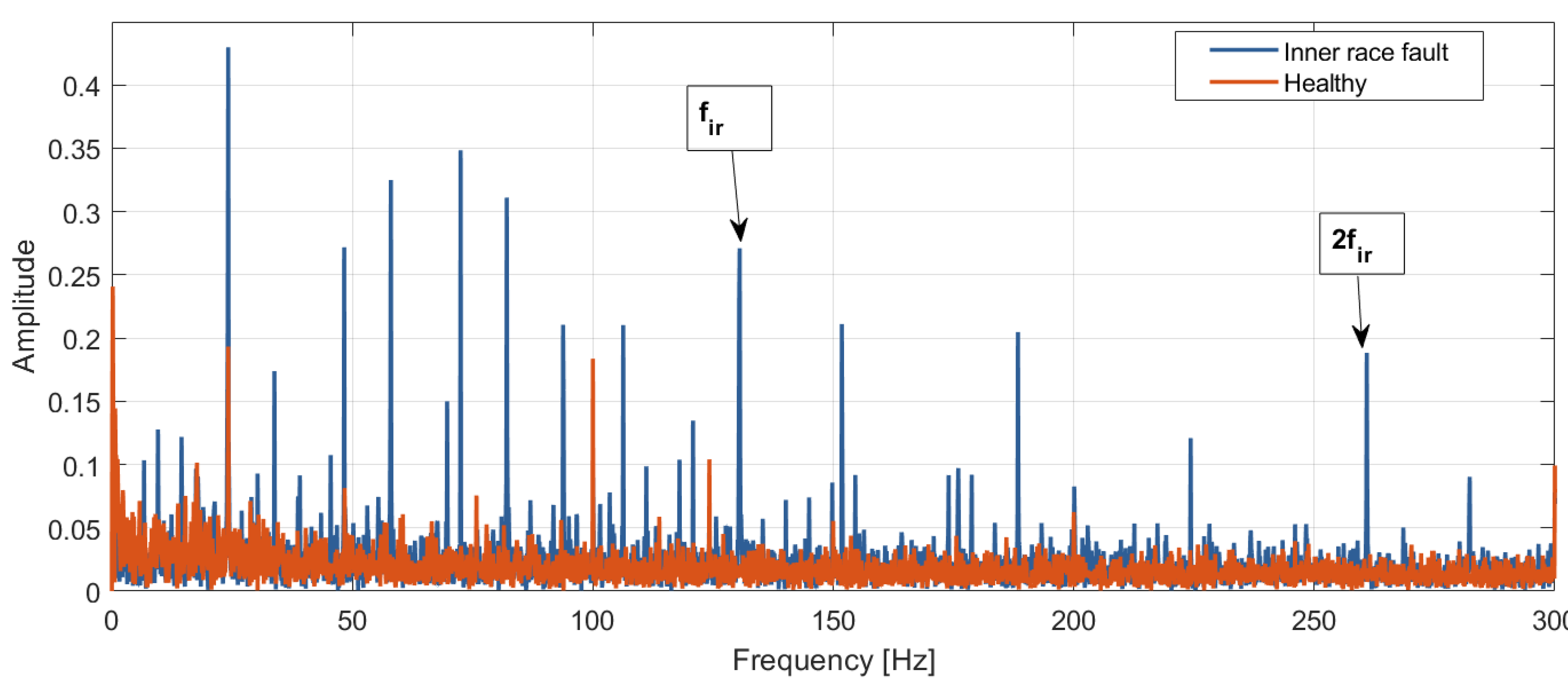

Figure 1. Envelope spectra of vibration signals measured for healthy bearing condition and inner race fault at load torque $T_L = 0.5T_{LN}$ and sampling frequency fs =50kHz.

Influence of measurement duration and sampling frequency

Having established the diagnostic relevance of envelope spectrum components, the influence of reduced measurement duration and sampling frequency was evaluated. Lower sampling frequency decreases spectral resolution and may partially mask fault-related harmonics, while shorter measurement windows reduce frequency resolution and increase estimation uncertainty. Consequently, the separability of fault-related patterns deteriorates as the available signal information is reduced.

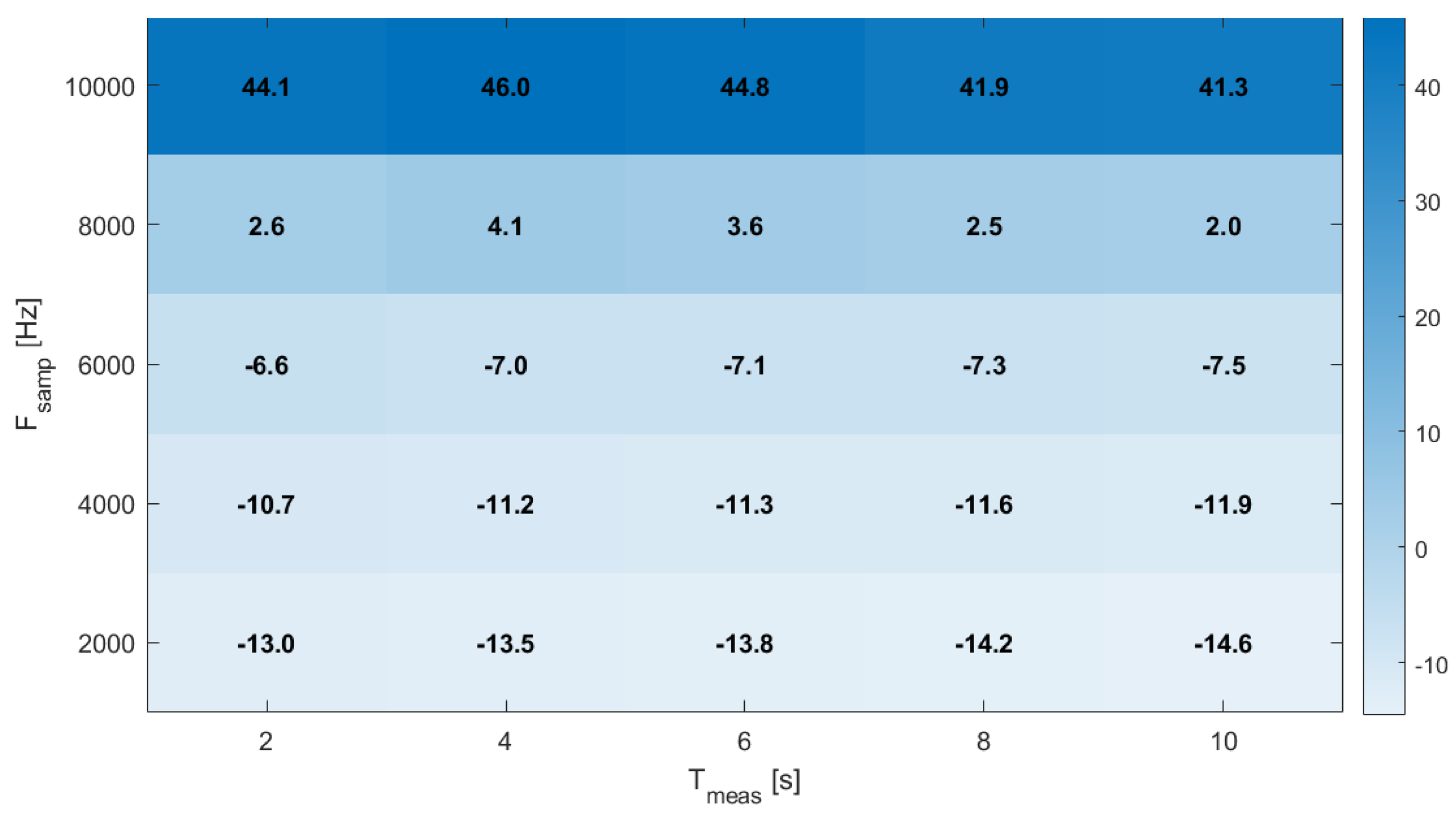

Figure 2. Relative RMS change for rolling element fault under varying measurement durations and sampling frequencies ($T_L = 0.5T_{LN}$, fs =50kHz).

To quantify the effect of signal reduction on time-domain features, the RMS value was analyzed for different measurement durations and sampling frequencies. As shown in Figure 2, shortening the observation window has only a minor effect on RMS variation, indicating good stability. In contrast, reducing the sampling frequency significantly increases sensitivity degradation relative to the healthy condition.
As shown in Figure 3, the first harmonic of the outer race fault frequency remains consistently higher than in the healthy case across all analyzed conditions, indicating that its detectability is largely preserved even for reduced data records.

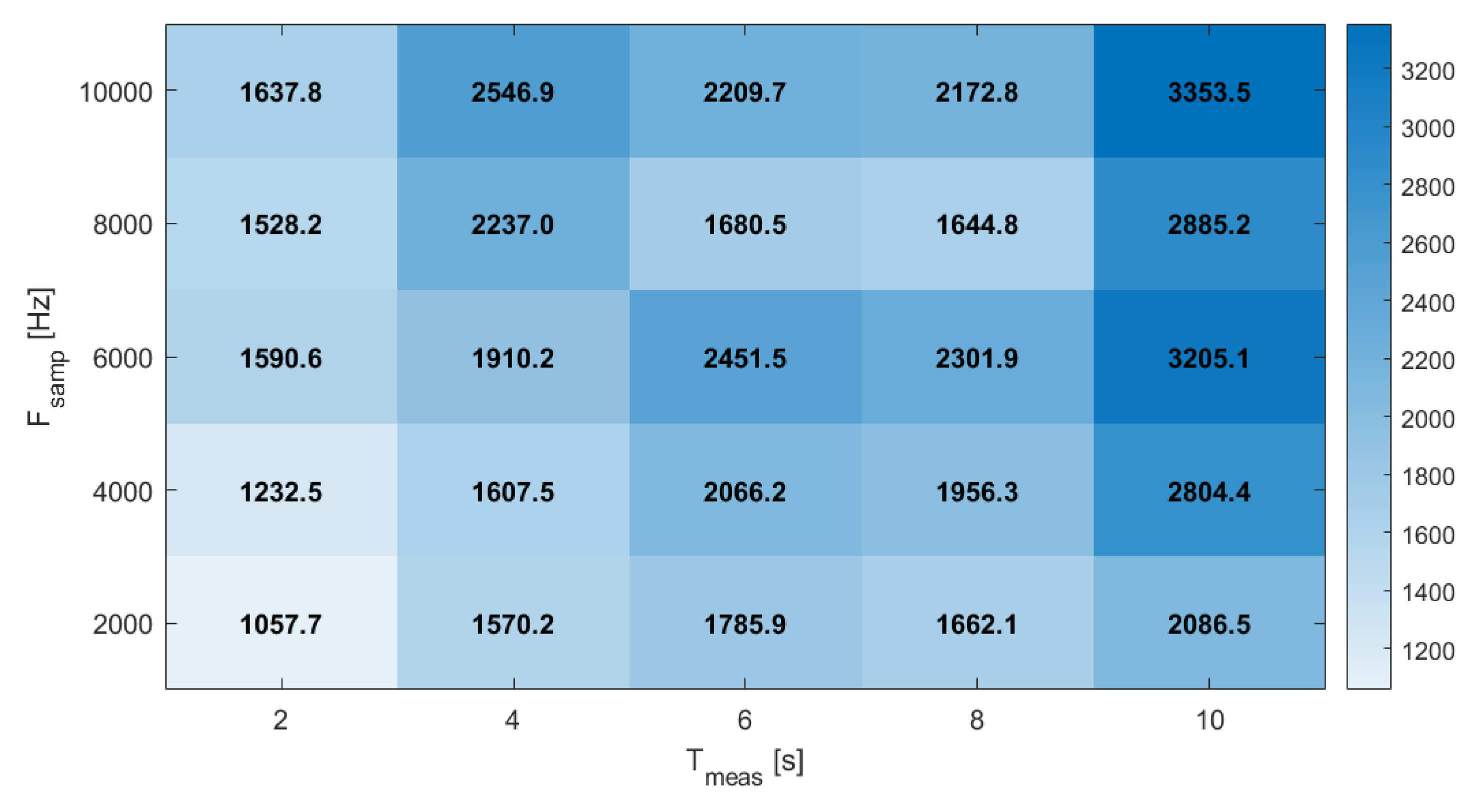

Figure 3. Relative amplitude change of the first harmonic of the outer race fault frequency under varying measurement durations and sampling frequencies ($T_L = 0.5T_{LN}$, fs =50kHz).

Influence of operating conditions: speed and load torque

Analysis of the experimental results shows that operating conditions have a significant impact on the visibility of fault-related features in vibration signals. At low rotational speeds, the changes induced by bearing faults are relatively small, which reduces the separability of diagnostic features and makes fault detection more challenging using the applied methods. In terms of load torque, the most problematic cases are no-load and nominal-load conditions. Variations in load level strongly influence the overall vibration amplitude, which can mask or distort fault-related components and affect the reliability of diagnostic indicators.

SOM clustering of bearing fault features

A Kohonen Self-Organizing Map (SOM) was trained using vibration feature vectors obtained for a 200 ms measurement duration and 1 kHz sampling frequency. The network consisted of a 10×10 neuron grid and was trained for 2000 epochs with an initial learning rate of 0.8 and neighborhood size of 10. The dataset was split into training and test sets with equal class representation. Figure 4 presents the SOM projections of test data (a) and class centroids (b), showing clear separation between Class 1, Class 2, and the healthy condition. In contrast, Class 3 partially overlaps with other states, indicating reduced separability under these conditions.

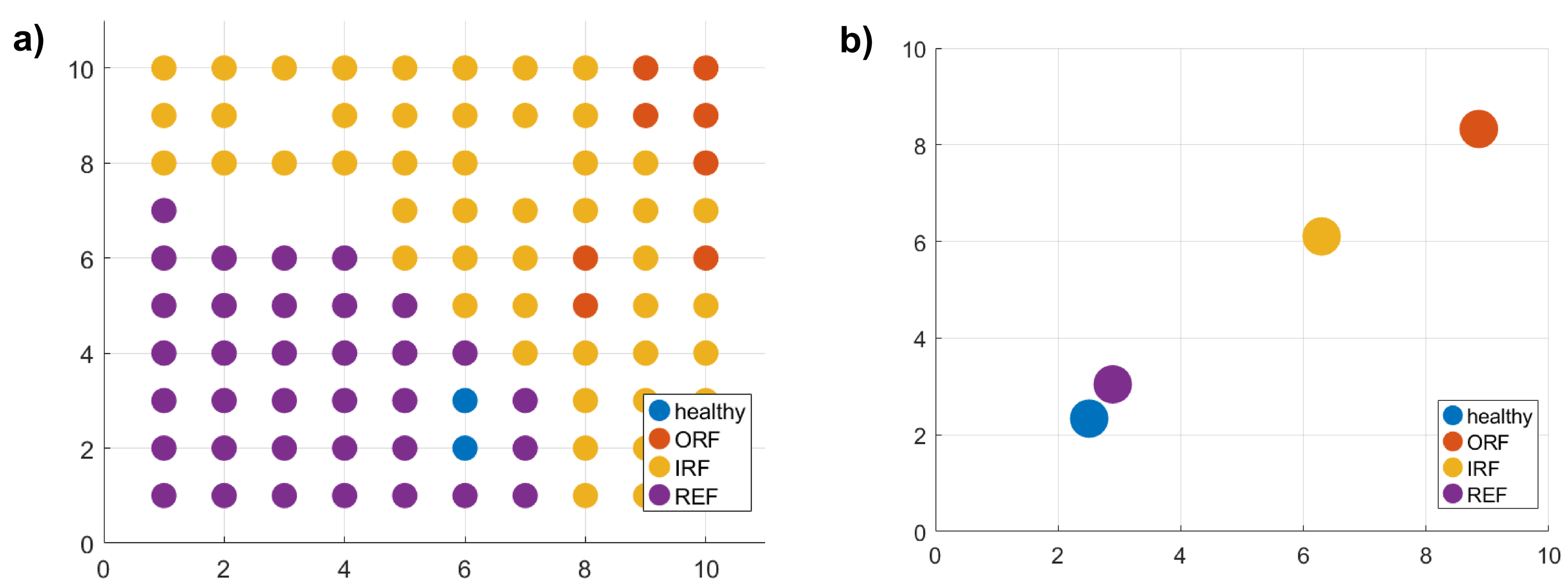

Figure 4. Kohonen SOM map showing clustering of test data for different bearing fault classes under 200ms measurement duration and 1 kHz sampling frequency.

CONCLUSIONS

The study shows that reducing measurement duration and sampling resolution has a strong impact on the quality of fault-related information in induction motor bearing diagnostics. While characteristic frequency-domain features remain highly informative for some fault types, others exhibit reduced separability when the available data window is shortened. The results indicate that even very short measurement windows (e.g. 200 ms) can still provide sufficient information for distinguishing selected fault classes from the healthy condition, particularly under quasi-steady operating states. However, the effectiveness of diagnosis becomes limited for more complex or overlapping fault patterns. Although dynamic operating conditions were not fully investigated in this study, the obtained results suggest that the proposed approach could be extended to slowly varying transient states. This will be addressed in future research, together with a more detailed analysis of the minimum data requirements under non-stationary conditions.

ACKNOWLEDGMENT
The work was supported by the project Minigrants for doctoral students of the Wrocław University of Science and Technology.

REFERENCES
[1] Skowron, M., Frankiewicz, O., Jarosz, J.J., Wolkiewicz, M., Dybkowski, M., Weisse, S., Valire, J., Wyłomańska, A., Zimroz, R. and Szabat, K., 2024. Detection and classification of rolling bearing defects using direct signal processing with deep convolutional neural network. Electronics, 13(9), p.1722.