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Using spectrograms to identify resonance and design corrective measures for a fan assembly

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Abstract:

The operation of rotating machinery is associated with vibrations that can indicate the onset of faults. This paper deals with the vibro-diagnostic analysis of a radial belt fan, where initial measurements of the overall vibration level indicated a critical condition of the electric motor. By applying advanced analysis of spectrograms recorded during run-up and coast-down, it was found that the dominant source of vibrations is not a component fault, but resonance caused by insufficient stiffness of the fan structure. This diagnosis was further confirmed by an analysis of the fault frequencies of the bearings, which ruled out damage to the motor bearings. In the conclusion of the paper, specific structural modifications are proposed to reinforce the frame and a strategy for their verification using the Finite Element Method (FEM) is recommended. The paper demonstrates the importance of advanced diagnostic methods for the correct identification of the root cause of the problem and the effective design of corrective measures.

Keywords: fan, vibrodiagnostics, spectrogram, run-up analysis, resonance, structural stiffness

1. Introduction

Reliable and safe operation of rotating machinery such as industrial fans is crucial for the smooth running of production processes. Unplanned shutdowns caused by failures, particularly bearing damage, lead to significant economic losses [1]. For this reason, predictive maintenance strategies are gaining prominence, using technical diagnostics to monitor the actual condition of the equipment and prevent unexpected failures [2].

While conventional practices often rely on monitoring the overall vibration level (usually the RMS value of velocity in the frequency range of 10-1000 Hz) and comparing it with the limits set in standards such as ISO 20816 [3], this approach may not always reveal the true cause of the problem, especially for more complex dynamic phenomena.

Therefore, this paper focuses on an advanced vibrodiagnostic analysis of a radial fan assembly driven by an induction motor. Instead of monitoring static values, the experiments are focused on analysing the dynamic behaviour of the machine during its transient states – run-up and coast-down. For this purpose, vibration signals were recorded and processed into spectrograms that visualize changes in the frequency spectrum over time, which is a proven method for diagnosing faults in rotating machines [4].

The goal of this analysis is to accurately identify the root cause of vibrations, with an emphasis on distinguishing failures of individual components from systemic problems, such as resonance phenomena in the structure. The presented results demonstrate that transient analysis provides a significantly more detailed view of the machine's dynamics and allows maintenance interventions to be targeted with greater precision, thereby contributing to an increase in the overall operational reliability of industrial equipment.

The aim of this paper is to accurately identify the root cause of excessive vibrations in a radial belt-driven fan by analysing run-up and coast-down spectrograms and, based on the findings, to propose verifiable corrective measures to increase structural stiffness.

2. Materials and Methods

The experimental analysis focused on the vibrodiagnostics of the fan assembly, which is used to extract air and fumes in the paint shop. Specifically, it is a radial fan with a belt drive, model SRV-SP-R-530_30-4-5-50_LG270, Fig. 1.

The drive is provided by a four-pole electric motor with an output of 30 kW, operating at 1483 RPM (50 Hz). A belt drive reduces the speed of the fan shaft to 897 RPM. The rotor of the electric motor is supported by SKF 6312 2Z C3 bearings, while the fan shaft with a 530 mm diameter impeller is mounted in SKF 6311 EK C3 bearings.

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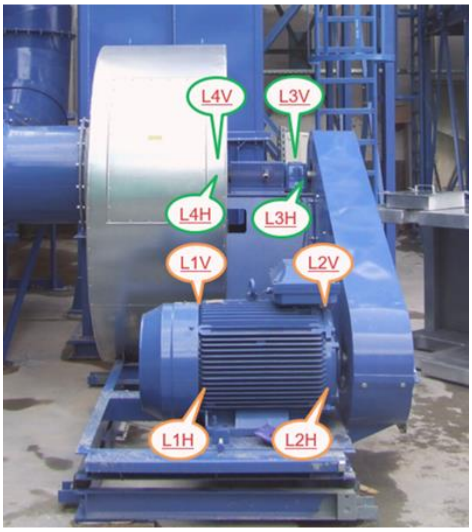

Fig. 1. Radial fan with belt drive and marked measurement points:
L1H - bearing measurement in the horizontal direction on the electric motor, L1V - bearing measurement in the vertical direction on the electric motor, L2H - bearing measurement in the horizontal direction on the electric motor, L2V - bearing measurement in the vertical direction on the electric motor, L3H - bearing measurement in the horizontal direction on the fan, L3V - bearing measurement in the vertical direction on the fan, L4H - bearing measurement in the horizontal direction on the fan, L4V - bearing measurement in the vertical direction on the fan

2.1. Instrumentation characteristics

The experimental measurements were performed using a measurement setup consisting of an Adash A4400 – VA4 Pro analyser and an A104-1A acceleration sensor (Fig. 2). To ensure high accuracy and repeatability, the sensor was attached to the machine surface using a magnetic mount that guarantees stable contact. The Adash A4400 – VA4 Pro analyser used is a versatile four-channel device for collecting, recording, and advanced analysis of vibration signals [2, 3]. In addition to standard functions, it also offers specialized modules, for example, for dynamic balancing, acoustic measurements, orbit analysis, and measurements during device run-up and coast-down [5].

Fig. 2. ADASH A4400 VA4Pro vibration diagnostic device with A104-1A vibration sensor

2.2. Characteristics of experimental vibration measurements

Data acquisition covered at least the 10–1000 Hz evaluation band used for overall velocity according to ISO 20816-3, while also preserving the lower-frequency region where structural modes were expected. Signals were recorded continuously from pre-start to complete stop to capture the full transient response. Spectral representations (spectrograms) were generated to visualise the time-varying frequency content during run-up and coast-down.

Vibration signals were analysed during unsteady operating conditions, specifically during the run-up and coast-down of the machinery. This methodological approach is essential for revealing faults such as resonances that could remain hidden at stable speeds. Data collection was initiated just before the machine was started and continued through the steady-state phase until it was completely stopped. Adash DDS 2024 software was used for subsequent evaluation and detailed analysis of the collected signals in both the time and frequency domains. This software not only enables the management of measured data within defined measurement paths and database analyses, but also provides advanced visualization tools, including the generation of spectrograms and cascade diagrams [6].

3. Results

Spectrogram analysis was key to the detailed analysis. These graphs represent a visualization of the development of the frequency spectrum of vibrations over time. A colour map is used to display the amplitude of vibrations, in which warm shades, such as red and orange, correspond to a high intensity of vibrations. Conversely, low amplitudes are represented by cool colors', such as blue and purple.

3.1. Vibrations on the electric motor

Table 1 shows the static values measured on the bearings of the electric motor at a speed of 1483 RPM. Vibration measurements were performed for channels 1 to 4 on the bearings marked L1 and L2 in the horizontal and vertical directions and evaluated according to the 20816-3 standard [3, 6].

Table 1. Vibration values measured on the electric motor bearings at a speed of 1483 RPM

Name	Vibration value [mm/s]	Device alarm
ELECTRIC MOTOR\L1RH\RMS ch:1	3.89	Warning (4.5 mm/s)
ELECTRIC MOTOR\L1RV\RMS ch:2	8.74	Danger (7.1 mm/s)
ELECTRIC MOTOR\L2RH\RMS ch:3	5.94	Warning (4.5 mm/s)
ELECTRIC MOTOR\L2RV\RMS ch:4	10.3	Danger (7.1 mm/s)

(Evaluation according to the ISO 20816-3 standard Ok - Ok, Caution, Warning, Danger)

The tabulated results clearly show that the measured vibration values, especially in the vertical direction, significantly exceed the permissible limits set by the standard. Such a condition would normally require immediate shutdown of the equipment. However, a more detailed analysis using spectrograms pointed to the real source of the problem.

Spectrogram of run-up on an electric motor

The spectrograms measured on the bearings of the electric motor, shown in Figure 3, reveal a distinct horizontal band of amplified vibrations at low frequencies (up to approximately 50 Hz).

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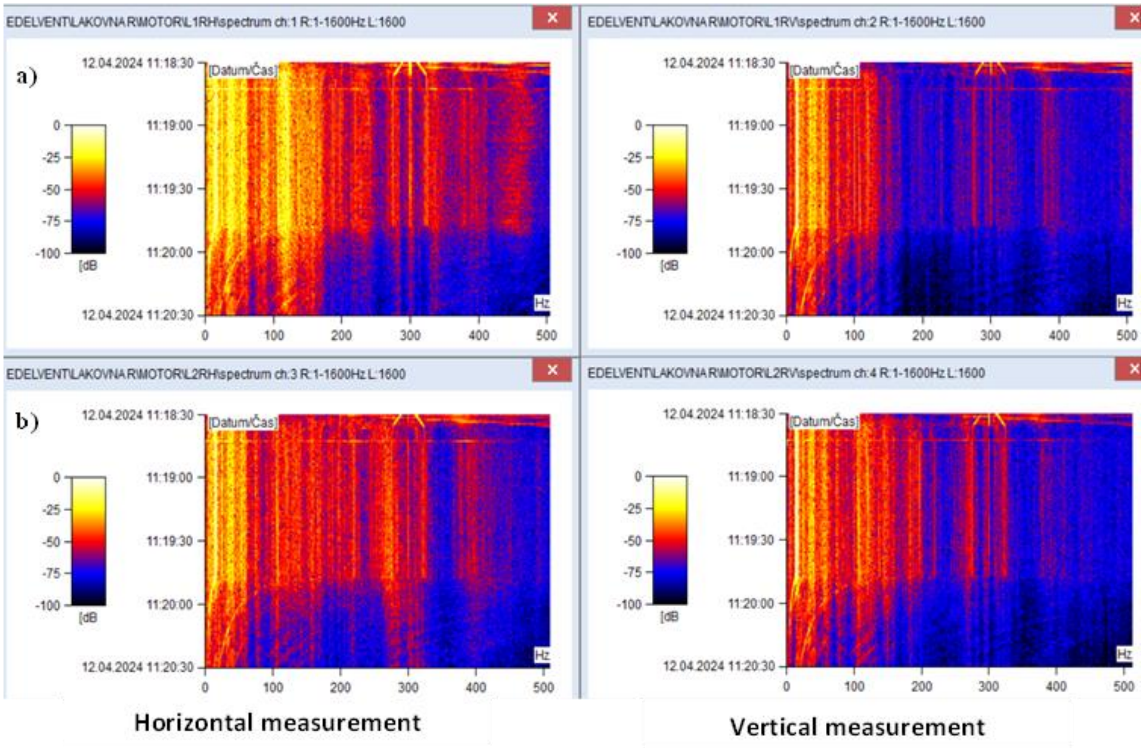

Fig. 3. Spectrogram of run-up on the motor:
a) bearing L1, b) bearing L2

This region corresponds to a structural resonance. A closer look at Figure 4 highlights the moment when the rotational frequency passes through this resonance band during run-up and coast-down.

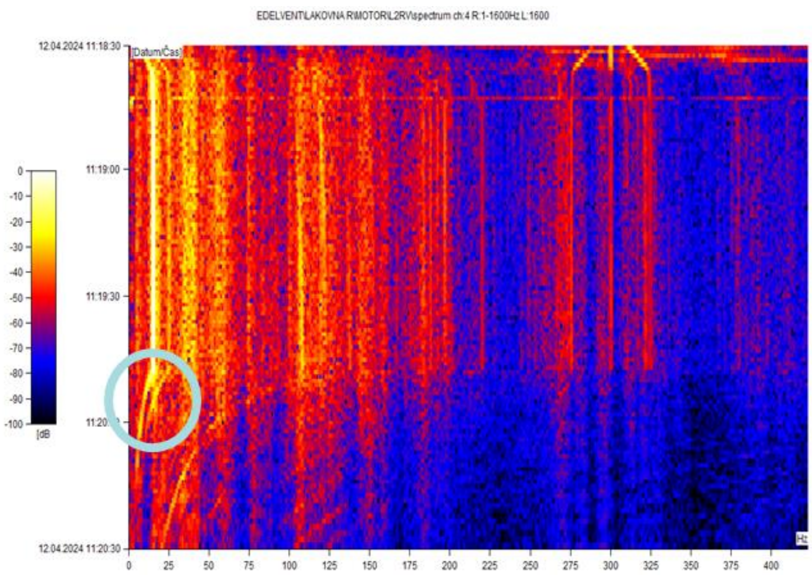

Fig. 4. Run-up spectrogram for bearing L2 in the vertical direction

This phenomenon is illustrated in detail in the cascade diagram in Figure 5, which shows how the intersection of the rotational frequency line with the resonance region causes a temporary but significant amplification of the vibrations.

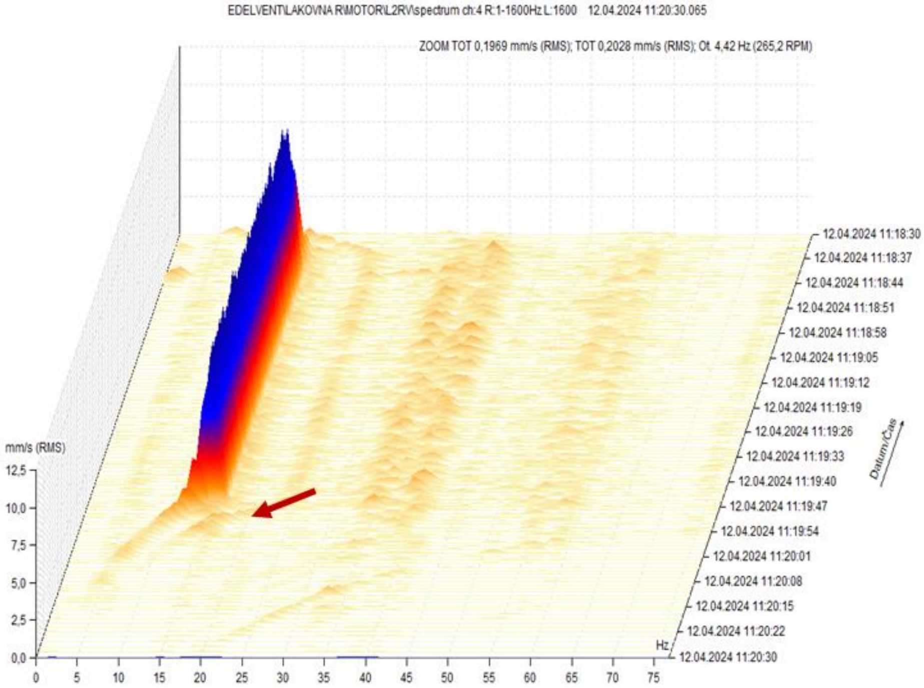

Fig. 5. Run-up spectrogram – cascade plot

3.2. Vibrations measured on the fan

Table 2 shows the static values measured on the fan bearings at 897 rpm, evaluated according to the ISO 20816-3 standard. These results indicate that the values exceed the permitted limits for continuous operation. Spectrograms from the measurement points on the fan reveal a wide and pronounced resonance band at low frequencies, which indicates insufficient structural stiffness.

Table 2. Vibration values measured on the fan bearings at a speed of 897 rpm

Name	Vibration value [mm/s]	Device alarm
FAN\L3H\RMS ch:1	4.13	Warning (2.3 mm/s)
FAN \L3V\RMS ch:2	5.73	Warning (4.5 mm/s)
FAN \L4H\RMS ch:3	3.17	Warning (2.3 mm/s)
FAN \L4V\RMS ch:4	4.42	Warning (4.5 mm/s)

Fan run-up spectrogram

Spectrograms measured on the fan (Fig. 6, bearings L3 and L4) confirm that the design of the device and its mounting have insufficient rigidity (high compliance).

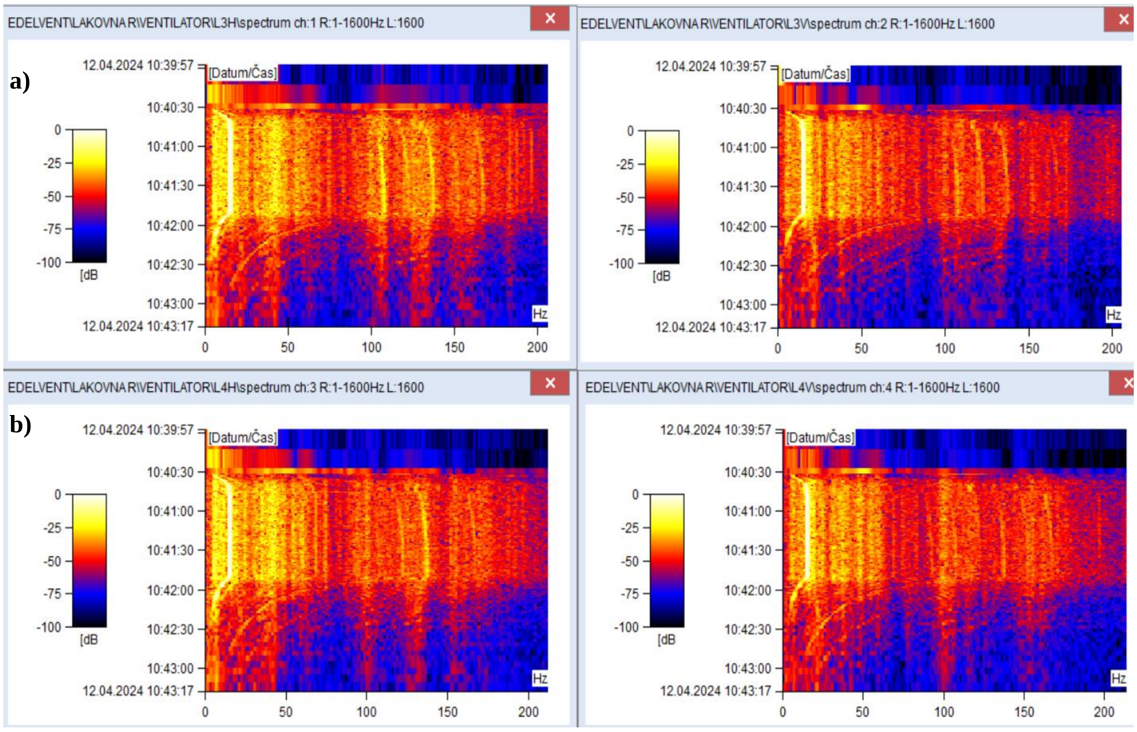

Fig. 6. Spectrogram of fan run-up:
a) bearing L3, b) bearing L4

This deficiency is manifested as a wide and pronounced resonance band in the low frequency range. It is this “soft” design that is the reason why the machine is prone to resonances that cause vibrations even at low excitation levels. Ultimately, this negatively affects its dynamic state, reliability and overall performance.

3.3. Analysis of fault frequencies of electric motor bearings

In order to definitively confirm or refute the suspicion that the source of high vibrations is the rolling bearings of the electric motor (type SKF 6312 2Z C3), their characteristic fault frequencies were calculated [4, 6]. These frequencies indicate damage to specific parts of the bearing (outer race, inner race, rolling elements or cage) [7, 8, 9].

The following parameters were used for the calculation:

- **Motor operating speed *(fr)*:** 1483 ot/min ≈ 24.72 Hz
- **Geometry of the SKF 6312 bearing:**
  - Number of rolling elements *(Z)*: 8;
  - Rolling element diameter (B_d): 22.225 mm;
  - Pitch diameter (d_p): 92.5 mm;
  - Contact angle (α): 0° (for a radial ball bearing)

Based on these parameters, the following theoretical fault frequencies were calculated:

- **Outer race damage (BPFO):** f_{BPFO} = 100.5 Hz
- **Inner race damage (BPFI):** f_{BPFI} = 155.7 Hz
- **Rolling element damage (BSF):** f_{BSF} = 69.1 Hz
- **Cage damage (FTF):** f_{FTF} = 9.4 Hz

A detailed visual inspection of the spectrograms measured on the motor bearings did not identify any persistent and significant frequency components at steady speed that would correspond to the calculated fault frequencies. This result provides relevant evidence supporting the conclusion that the technical condition of the motor bearings is not the primary cause of the measured vibrations and confirms that the primary problem is structural resonance.

3.4. Corrective action proposal and verification strategy

As was proven, the primary cause of high vibrations is the resonance of the system caused by insufficient structural rigidity. The basic principle of the solution is to increase the rigidity of the structure, thereby shifting its natural frequency beyond the excitation frequencies arising during operation [10, 11, 12]. Based on common engineering practice, the following measures are recommended:

1. **Reinforcement of the support frame:** The support frame should be additionally reinforced by welding diagonal or cross braces, which significantly increases its resistance to bending and torsional vibrations.
2. **Reinforcement of the fan attachment:** It is necessary to check and, if necessary, strengthen the connection between the fan housing and the support frame by adding corner stiffeners (sheet metal gussets).
3. **Check and strengthen the anchorage:** It is necessary to carefully check the tightness of the bolted joints anchoring the frame to the foundation.

To verify the effectiveness of the proposed measures, we would recommend using Finite Element Method (FEM) analysis. The verification procedure should include creating a 3D model of the structure, performing a modal analysis to calculate the existing natural frequencies, virtually adding the proposed reinforcements, and re-running the analysis to verify that the new natural frequencies are shifted into a safe range [13, 14].

4. Discussion

These observations are consistent with published findings that transient analysis improves separation of structural resonances from component-related fault signatures in rotating machinery [4, 7, 15].

Although high vibration values were measured on the electric motor, their primary cause is not its technical condition. The real source of the problem is the fan, from which vibrations are transmitted and amplified through the common structure. Analysis of the spectrograms clearly confirmed that the main cause is the passage of the rotational frequency of the machine through the resonance region. This resonance, identified at low frequencies, is a direct consequence of the insufficient stiffness of the fan structure and its frame [6, 15]. Correct identification of this phenomenon is crucial, as it prevents maintenance from being incorrectly focused on repairing the electric motor, which would not address the root of the problem [6].

5. Conclusions

In conclusion, this vibro-diagnostic study has provided a comprehensive insight into the dynamic behaviour of the analysed fan assembly. The key contribution was the application of an advanced method of spectrogram analysis during run-up and coast-down, which allowed for the correct interpretation and identification of the root cause of the critical vibrations.

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The experiments have demonstrated the following findings:

- The main source of the excessive vibrations is not a fault in any of the electric motor's components, but rather a resonance of the fan's support structure, which is caused by its insufficient stiffness.
- An additional analysis of the characteristic fault frequencies of the electric motor bearings (type SKF 6312) confirmed their fault-free condition, whereby the motor was definitively ruled out as the source of the problem.
- It was shown that standard diagnostics based solely on the comparison of overall values with the ISO 20816 standard would have led to incorrect conclusions and subsequent uneconomical attempts to repair the electric motor.

Based on these findings, specific measures to increase the stiffness of the structure were proposed. For their optimal design and verification, it is recommended to use simulation analysis using the Finite Element Method (FEM). Future research should focus on performing an FEM modal analysis, implementing the proposed measures, and conducting subsequent verification vibro-diagnostic measurements that would quantify the effectiveness of the adopted solutions.

Practically, the workflow can be adopted in maintenance programmes to avoid misdirected repairs and to prioritise structural stiffening where resonance governs the vibration response.

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