Management Systems in Production Engineering

2026, Volume 34, Issue 4, pp. 594-605

Date of submission of the article to the Editor: 05/2026
Date of acceptance of the article by the Editor: 10/2026

DOI 10.2478/mspe-2026-0050



OFF-LINE, ON-LINE AND ROUTE-BASED DIAGNOSTICS FOR MAINTENANCE SUPPORT: A CASE STUDY OF AN INDUSTRIAL ELECTRIC DRIVE

Alena Hajkova, Milos Hammer
Brno University of Technology

Abstract:
Technical diagnostics is a key tool for condition-based maintenance of industrial equipment. However, different diagnostic approaches provide different types of information, and their outputs cannot always be directly compared. This article presents a pilot case study comparing off-line, on-line, and hybrid route-based diagnostics applied to an industrial electric drive. The comparison was performed using the VA5 Pro vibration analyzer, the Siemens Simotics Connect 400 monitoring module, and the SKF QuickCollect wireless sensor. The evaluation focuses on the nature of diagnostic outputs, diagnostic depth, data continuity, the ability to track trends, and usability for maintenance support. The results show that the VA5 Pro is suitable for detailed expert analysis of the vibration signal, the Siemens Simotics Connect 400 for long-term trend monitoring, and the SKF QuickCollect for walk-by inspections and repeated condition verification at selected measurement points. The outputs of these systems must be interpreted with regard to sensor location, mounting method, operating condition, and internal signal processing. The study's contribution lies in defining the complementary roles of the three diagnostic layers within a multi-level strategy for supporting maintenance decision-making.

Key words: condition monitoring; maintenance support; on-line monitoring; route-based diagnostics; vibration diagnostics

INTRODUCTION

Technical diagnostics is an important tool for monitoring the technical condition of industrial equipment and supporting maintenance decision-making. Growing demands for the reliability, availability, and efficiency of production systems are leading to a shift away from reactive or purely periodic strategies toward condition-based maintenance [1, 2]. Diagnostic data thus becomes a key input for planning maintenance interventions, reducing unplanned downtime, and improving operational reliability.

However, the collection of diagnostic data alone does not guarantee an accurate assessment of the technical condition. In rotating machinery and electric drives, different failure mechanisms can manifest as similar changes in diagnostic parameters, such as increased vibration or a change in temperature. Interpretation based solely on a single parameter or a single type of measurement can therefore lead to ambiguous conclusions [3]. Consequently, the combination of multiple diagnostic parameters and their evaluation in mutual context becomes significant [4, 5].

Various methods of collecting diagnostic data are used in industrial practice. Off-line diagnostics allows for detailed signal analysis but is limited by the measurement frequency [6]. On-line diagnostics provides long-term monitoring of trends in selected variables [6], but its diagnostic depth may be lower than that

© 2026 Author(s). This is an open access article licensed under the Creative Commons BY 4.0 (https://creativecommons.org/licenses/by/4.0/)

of expert measurements. Between these approaches, hybrid or route-based systems are also used, which combine periodic measurements with data storage and trend analysis.
The development of on-line monitoring and cloud-based diagnostic platforms is linked to the broader trend toward cyber-physical production systems and Industry 4.0, where operational data is used to support higher-level decision-making [7]. At the same time, current literature devotes considerable attention to algorithmic methods of fault diagnosis, including machine learning applications [8]. In industrial practice, however, it remains important not only to develop new diagnostic methods but also to evaluate how various diagnostic outputs can be utilized in a specific maintenance process. The implementation of condition monitoring and predictive maintenance continues to face challenges related to data availability and quality, technological integration, organizational readiness, and the translation of diagnostic information into maintenance decisions [9, 10, 11]. Vogl et al. state that diagnostic and prognostic systems in manufacturing should provide not only data on the condition of equipment, but above all information that can be used for decision-making regarding reliability, safety, and maintenance. Therefore, the quality of the data, its interpretation, and the translation of technical indicators into maintenance decisions are key [12].
Less attention has been dedicated in the literature to a practical comparison of off-line, on-line, and route-based diagnostic approaches applied to the same industrial drive and interpreted from the perspective of maintenance decision-making. The aim of this article is therefore to compare three diagnostic approaches applied to the same industrial electric drive and to evaluate their usefulness for maintenance support. The case study is conducted on a motor driving a short-circuit generator using the VA5 Pro vibration analyzer, the Siemens Simotics Connect 400 sensor module, and the SKF QuickCollect wireless sensor. The main contribution of this article is a pilot empirical comparison of these three diagnostic layers in terms of diagnostic depth, data continuity, trend analysis capabilities, and practical applicability in maintenance decision-making.

LITERATURE REVIEW: DIAGNOSTIC APPROACHES IN MAINTENANCE

In the context of condition monitoring for maintenance purposes, diagnostic approaches can be distinguished not only by the measured variable, but also by the method of data collection, the timeliness of information, the depth of diagnosis, and the complexity of operational implementation. Off-line, on-line, and hybrid route-based diagnostics therefore represent not only different technical measurement approaches but also distinct sources of information for maintenance decision-making. The following section briefly outlines their basic characteristics, advantages, and limitations, which form the basis for a subsequent comparison in the case study.

Off-line diagnostics

Off-line diagnostics is a traditional approach to monitoring the technical condition of machinery and equipment. According to ČSN ISO 13372, this is a non-connected method of data collection, performed either once or periodically, in which sensors are not permanently attached to the diagnostic object [6]. In practice, this approach is usually implemented using portable measurement systems, temporarily installed sensors, and subsequent expert analysis of the measured data.
For rotating machinery and electric drives, off-line diagnostics is often associated primarily with vibration diagnostics, but also with electrical diagnostics or thermal diagnostics. Vibration diagnostic measurements allow for the evaluation of time histories, broadband vibration values, frequency spectra, or envelope spectra, which are significant, for example, in the diagnosis of rolling bearings [13, 14, 15]. The root mean square (RMS) vibration velocity is a commonly used indicator for assessing the technical condition of machines and is also utilized in normative frameworks for measuring and evaluating machine vibrations [16]. Thanks to the ability to configure measurements in detail and perform subsequent signal analysis, off-line diagnostics provides a high level of diagnostic depth. The main limitation of off-line diagnostics is the discontinuous nature of the measurements and the dependence of the results on the

selection of measurement points, sensor mounting, measurement mode settings, and the diagnostician's experience.

On-line diagnostics

On-line diagnostics is an approach in which sensors are permanently connected to the diagnostic object, and data is collected continuously or at regular intervals. According to ČSN ISO 13372, this is a coupled measurement method in which sensors are permanently connected to the monitored equipment, even though the actual sensing may not take place continuously [6]. This approach is used primarily for equipment whose failure can cause significant economic losses, unplanned downtime, or safety risks. Wireless sensor systems are used in condition monitoring primarily where it is desirable to reduce cabling costs and expand the availability of trend data for predictive maintenance of rotating equipment [17].

The main advantage of on-line diagnostics is the long-term monitoring of diagnostic indicators, such as vibration, temperature, rotational speed, or other operational parameters. Continuous monitoring of selected variables makes it possible to detect deviations from normal operating conditions and provides a basis for condition-based maintenance and predictive maintenance [1, 18]. A limitation of on-line diagnostics may be lower diagnostic depth compared to expert off-line measurement, as many industrial systems primarily work with aggregated indicators, trend values, or limit states. For compact microelectromechanical systems (MEMS) sensors, it is also necessary to consider the mounting method, frequency range, and internal signal processing [19].

Hybrid route-based diagnostics

Hybrid route-based diagnostics combines selected features of off-line diagnostics and on-line monitoring. It is based on periodic measurements without permanent sensor installation, but is often supported by mobile applications, wireless data transfer, cloud storage, route management, and trend analysis. It is suitable where full on-line monitoring is not economically or technically justified, but repeated and systematic condition checks are required. Its advantages include flexibility, easy deployment, and standardized repeated measurements, while its limitations include lower diagnostic depth than expert off-line analyzers and the absence of continuous data collection. When using MEMS sensors, it is particularly important to consider the mounting method, frequency range, measurement orientation, and internal signal processing, as these factors influence the interpretation of diagnostic indicators [19].

MATERIALS AND METHODS

This section describes the diagnostic object, measurement equipment, and comparison methodology. The case study was designed to compare off-line, on-line, and hybrid diagnostics applied to the same industrial electric drive, with emphasis on data type, measurement configuration, and usability for comparative evaluation.

The case study was conducted on a three-phase Siemens squirrel-cage induction motor that drives a short-circuit generator. According to the nameplate data, the motor has a rated power of 545 kW, a supply frequency of 50 Hz, a rated speed of 993 min^{-1}, a voltage of 690/400 V, and a weight of approximately 3.3 t. The equipment was selected due to the possibility of applying permanent on-line monitoring, route-based measurements, and expert off-line vibrodiagnostics to the same drive. The objective of the measurements was not to validate a specific failure model, but to conduct a pilot assessment of the differences between the individual approaches in terms of the type of data provided, diagnostic depth, measurement continuity, and the possibility of trend analysis.

Off-line measurement using VA5 Pro

Off-line diagnostics were performed using the VA5 Pro portable vibration analyzer from Adash. The DDS software was used for subsequent processing of the measured data, enabling the evaluation of broadband vibration values, time histories, and frequency spectra. The measurement was performed in a four-

channel configuration. Four accelerometers were mounted on the motor, and the measurement setup also included a tachometer sensor for measuring rotational speed. The rotational speed data was used to correctly interpret the frequency components of the vibration signal. The sensor placement was chosen to obtain information about the motor's vibration behavior at relevant measurement points. One of the channels, designated as Ch4, was placed near the SKF QuickCollect sensor, allowing for a subsequent comparison of the off-line and route-based measurement approaches.

On-line monitoring using Siemens Simotics Connect 400

On-line monitoring was implemented using a Siemens Simotics Connect 400 wireless sensor module. The system was used to perform long-term monitoring of selected operational and diagnostic parameters of an electric motor. For example, the module monitors vibrations, temperature, and the frequency of the stator's electric field. The measured data is transmitted to the SIDRIVE IQ Fleet cloud environment, where the development of selected parameters over time can be monitored and trend information analyzed. The sensor module was installed directly onto the motor housing using a two-component epoxy adhesive, and data transmission was facilitated via a Wi-Fi router located near the sensor.
Although the system provided long-term on-line trend data, only time windows in which data was simultaneously available from both the VA5 Pro and SKF QuickCollect were used for comparative evaluation. As part of the study, the Siemens Simotics Connect 400 was therefore primarily used as a source of on-line trend context for comparison with periodic measurement approaches.

Route-based measurement using SKF QuickCollect

The route-based measurement approach was represented by the SKF QuickCollect wireless sensor. This is a battery-powered sensor designed for mobile diagnostics of rotating machinery. The system enables vibration and temperature measurements and transmits data via a mobile app to the SKF Enlight or SKF DataCollect cloud environment. The sensor can be used for direct measurements as well as for walk-around measurements along predefined routes. The configuration of the device, measurement points, and routes takes place in the Enlight Centre web environment, where data can subsequently be stored, analyzed, and evaluated for trends.
In the case study, measurements using SKF QuickCollect were performed on the same motor as other diagnostic approaches. One of the measurement points was selected near channel Ch4 used in measurements with the VA5 Pro, allowing for a comparison of the outputs of both periodic measurement systems. The sensor locations are shown in Fig. 1.

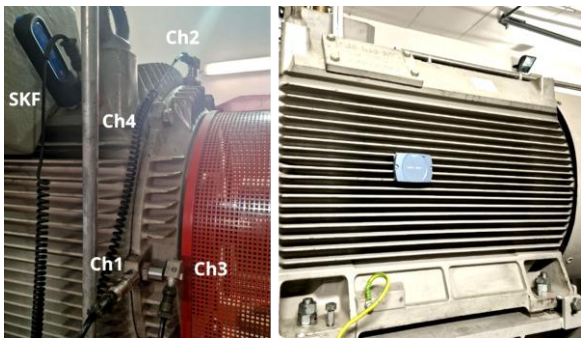


Fig. 1 Sensor placement for VA5 Pro, Siemens Simotics Connect 400 and SKF QuickCollect measurements on the monitored electric motor

Alt-text: *Monitored electric motor with labelled sensor locations for temporary measurements and permanent on-line monitoring.*

To enhance the reproducibility of the case study, the basic measurement parameters are summarized in Table 1, which lists the measured variables, frequency ranges, processing methods, and outputs used to compare the diagnostic approaches. The measurements were evaluated at 1000 revolutions per minute (RPM).

Table 1

Basic measurement parameters and outputs of the diagnostic systems used in the case study

System	Measured variable and configuration	Frequency settings and processing	Output used
VA5 Pro	RMS vibration velocity; 4-channel measurement; magnetic mounting; Ch4 near SKF point; tachometer reference	2-1000 Hz; sampling frequency 4096 Hz; 4096 samples; DDS software	Mean RMS from 11 records at 1000 RPM; Ch4 used for SKF comparison
SKF QuickCollect	RMS vibration velocity; wireless route-based measurement; magnetic mounting near VA5 Pro Ch4	10-1000 Hz; Fmax 1000 Hz; 1600 spectral lines; Spectrum & Time; 10 Hz high-pass filter	Single RMS value at 1000 RPM; comparison with VA5 Pro Ch4
Siemens Simotics Connect 400	RMS velocity trend indicators in X/Y/Z axes; permanently attached sensor module	10-1600 Hz; sampling frequency 3300 Hz; internal processing in SIDRIVE IQ Fleet	5-min trend data; 9 records used as on-line trend context

Evaluation criteria

To compare the diagnostic approaches used, evaluation criteria were established that focus on their practical applicability in monitoring the technical condition of industrial electric drives. The evaluation focuses not only on the technical parameters of the devices used, but primarily on the nature of the data provided, the possibilities for interpreting that data, and its usefulness for supporting maintenance. Given the pilot nature of the study, a qualitative evaluation scale was chosen. The evaluation criteria used for the qualitative comparison of diagnostic approaches are listed in Table 2.

Table 2

Evaluation criteria used for qualitative comparison of diagnostic approaches

Criterion	Description	Relevance for comparison
Diagnostic depth	The level of detail in diagnostic information and the ability to perform a more in-depth signal analysis	The ability to assess or verify the cause of a change in condition
Data continuity	Frequency and continuity of data collection	The ability to track changes in technical condition over time
Trend capability	Ability to store and compare values over time	Suitability for long-term monitoring of changes
Reaction capability	The ability to detect changes in operational behavior in a timely manner	Suitability for timely deviation alerts
Expert dependency	The extent to which the result depends on the diagnostician's experience	Practical applicability in everyday use
Ease of deployment	The complexity of installation, measurement, and operational deployment	Suitable for use in industrial environments
Practical applicability	Overall applicability of the results in diagnostic and maintenance practice	Support for deciding on the next diagnostic or maintenance step

The individual criteria were evaluated using a qualitative scale of low – medium – high. The “high” level indicates direct and systematic support for the criterion in question; the “medium” level indicates partial support or support that depends on the operational context, measurement frequency, sensor placement, or the diagnostician’s interpretation; and the “low” level indicates only limited or indirect support. The ratings were assigned criterion by criterion by comparing the observed outputs and practical functions of each diagnostic system with the criteria listed in Table 2.

For example, VA5 Pro was rated high in diagnostic depth because it enables configurable multi-channel measurements, frequency spectra, and envelope analysis, but low in data continuity because it is used

periodically. Siemens Simotics Connect 400 was rated high in data continuity and trend capability due to its on-line trend records, but lower in diagnostic depth because it provides mainly processed trend indicators. SKF QuickCollect was rated as an intermediate route-based layer because it supports repeated measurements and trend storage, but does not provide continuous monitoring or detailed expert signal analysis to the same extent as VA5 Pro. The qualitative evaluation was derived from the nature of the available outputs of individual systems, the frequency of data collection, the possibility of trend analysis, the capability for detailed signal analysis, and the complexity of operational deployment. This is neither an objective weighted score nor a metrological classification of systems, but rather an expert role-based assessment consistent with the pilot nature of the case study. This method of evaluation was chosen because the available dataset does not yet allow for a statistically robust quantitative comparison, but it does allow for the identification of practical differences between off-line, on-line, and hybrid diagnostic approaches.

RESULTS

This section summarizes the results obtained by applying three diagnostic approaches to the electric drive under study. The comparison is based on diagnostic indicators, particularly the root mean square (RMS) of vibration velocity.

Examples of diagnostic outputs

The main comparison was performed for a selected measurement window in which data from all three systems were available simultaneously. September 1, 2025, was chosen for the main comparative analysis, when the motor was operating in a steady state at 1000 RPM. This operating condition allowed for a comparison of diagnostic indicators within the same operational context and enabled the use of average values over a short time window. The comparison is performed at the level of diagnostic indicators, specifically RMS vibration velocity and trend variables, rather than as a fault classification or predictive model.

Using the VA5 Pro analyzer, RMS vibration velocity values were recorded in the X, Y, and Z directions, as well as a value from channel Ch4, which was located near the SKF QuickCollect sensor. Channels X, Y, and Z were used to assess the magnitude of the motor's vibration response, while Ch4 was used for a more direct comparison with SKF's hybrid route-based measurement. For the selected time window around the SKF measurement, 11 records were evaluated from the VA5 Pro data. An overview of the values is provided in Table 3. Siemens values are included as on-line trend indicators and are not intended for direct metrological comparison with VA5 Pro values.

Table 3

Basic statistics of VA5 Pro and Siemens Simotics Connect 400 vibration indicators in the selected measurement window

System/ indicator	N	Mean RMS [mm/s]	Standard deviation [mm/s]	Min-Max [mm/s]
VA5 Pro				
Ch1/X	11	0.3461	0.0062	0.3342-0.3545
Ch2/Y	11	0.2183	0.0081	0.2077-0.2283
Ch3/Z	11	0.2773	0.0022	0.2743-0.2808
Ch4 near SKF	11	0.3065	0.0067	0.2963-0.3184
Simotics Connect 400				
X	9	0.01671	0.00915	0.00684-0.03320
Y	9	0.00966	0.00601	0.00293-0.02344
Z	9	0.02235	0.00832	0.00977-0.03516

In addition to RMS values, the VA5 Pro also enables more detailed signal analysis. Fig. 2 shows an example of an envelope spectrum obtained during steady-state motor operation at 1000 RPM. This output was not used for a direct quantitative comparison with SKF QuickCollect and Siemens Simotics Connect 400, but it demonstrates the greater diagnostic depth of off-line measurements, particularly the ability to work with frequency components and envelope analysis.

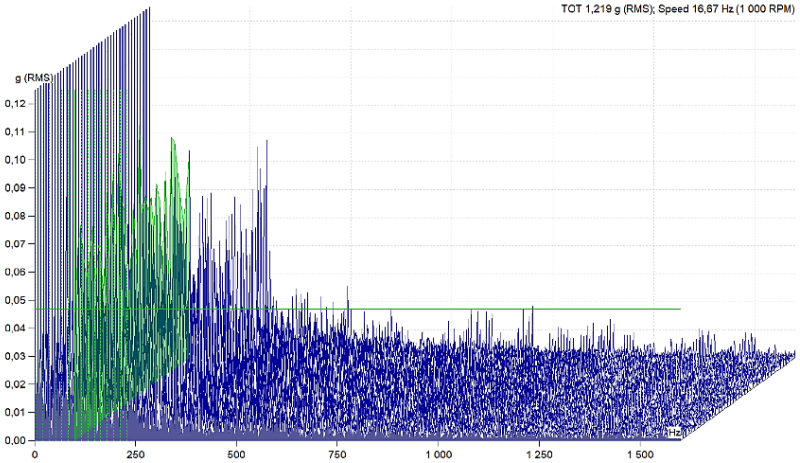


Fig. 2 Example of an acceleration envelope spectrum obtained by VA5 Pro during steady-state operation at 1000 RPM

Alt-text: *Spectrum plot showing vibration amplitude peaks over frequency in the VA5 Pro envelope spectrum during steady-state operation.*

A measurement was also taken using SKF QuickCollect at 1000 RPM under the same operating conditions. The RMS vibration velocity recorded by the SKF sensor at 10:27:47 was 0.310 mm/s. For comparison with the VA5 Pro, the average value of channel Ch4 in the selected time window was used, which reached 0.3065 mm/s. The relative difference between the two values was approximately 1.14%, indicating a similar vibration level at a nearby measurement point under the same operating conditions. However, this result is not interpreted as a metrological validation of the systems, but rather as an indicative comparison of two periodic measurement approaches.

Output from the Siemens Simotics Connect 400 system was used as an on-line trend context. For the same day, the interval 10:15-10:45 was selected, which encompasses the time surrounding the measurements taken using the VA5 Pro and SKF QuickCollect. The values RMS X, RMS Y, and RMS Z – i.e., the RMS vibration velocity in three axes – were used as the main vibration indicators. The basic statistics for these indicators are shown in Table 3, and their temporal evolution is illustrated in Fig. 3.

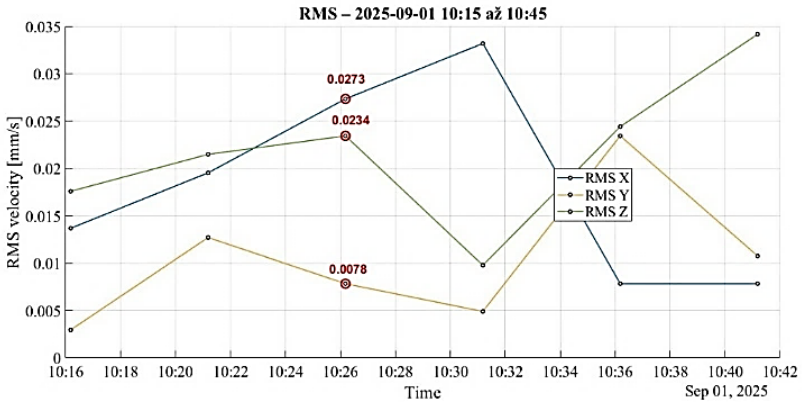


Fig. 3 RMS vibration velocity trends in the X, Y and Z axes measured by Siemens Simotics Connect 400 on 1 September 2025 in the time interval 10:15-10:45

Alt-text: *Line chart with nine records showing small fluctuations of X, Y and Z RMS vibration velocity below 0.04 mm/s from 10:15 to 10:45.*

The values from the Siemens system were not directly compared with those from the VA5 Pro and SKF QuickCollect, as the system differs in terms of sensor position, mounting method, axis orientation, and internal signal processing. In this study, therefore, the output from the Siemens Simotics Connect 400 is interpreted primarily as an on-line trend indicator, not as a direct metrological substitute for local vibration measurements.

To provide additional context, two supporting measurements from other days were also included. On July 29, 2025, at 12:43, the motor was detected in a transient operating state, with the VA5 Pro Ch4 RMS value reaching 0.275 mm/s and the SKF QuickCollect value reaching 0.237 mm/s; at the same time, the RMS X/Y/Z trend from the Siemens system was available. On June 23, 2025, at 14:00, another measurement was performed at 1000 RPM, when the VA5 Pro Ch4 RMS value reached 0.231 mm/s and the SKF QuickCollect value reached 0.1975 mm/s; data from the Siemens system for this day was not available. These measurements serve only as supporting observations to expand the context of the case study and do not replace long-term statistical validation. The main comparative interval in the article is therefore based on September 1, 2025, at 10:27:47 at 1000 RPM, when data from all three systems were available and the motor was operating in a steady state.

Comparative assessment of diagnostic approaches

Based on the results presented in the previous section, a qualitative comparison of the three diagnostic approaches used was conducted. The evaluation was conducted according to the criteria and interpretation scale defined in the Evaluation criteria section. The goal was not to identify a single universally best diagnostic approach, but to define the different roles of each approach in terms of diagnostic depth, data continuity, trend monitoring capabilities, and practical usability. The results of the comparison are presented in Table 4.

Table 4

Qualitative comparative assessment of the diagnostic approaches

Evaluation criterion	VA5 Pro	Simotics Connect 400	SKF QuickCollect
Diagnostic depth	High	Low-medium	Medium
Data continuity	Low	High	Medium
Trend capability	Medium	High	Medium-high
Reaction capability	Low	High	Medium
Expert dependency	High	Low-medium	Medium
Ease of deployment	Medium	Medium	High
Practical applicability	High	High	Medium-high

The evaluation in Table 4 represents a qualitative assessment of the roles of individual systems within this case study and is not intended as a general ranking or metrological classification of the devices used. The comparison shows that VA5 Pro provides the highest diagnostic depth but low data continuity. Siemens Simotics Connect 400, on the other hand, achieves the highest continuity and trending capabilities, but with a lower level of detailed local diagnostics. SKF QuickCollect is a solution that combines periodic measurements with the ability to store data and perform trend analysis. These differences are further interpreted from the perspective of maintenance support in the Discussion.

DISCUSSION

The results of the case study show that the diagnostic approaches evaluated provide different types of information and cannot be considered interchangeable measurement options. Each system supports a different aspect of maintenance decision-making: detailed diagnostic verification, long-term trend monitoring, or repeated condition checks at selected measurement points. The interpretation of diagnostic data should therefore not be based solely on the absolute value of a single indicator but should also consider the method of data collection, the location and mounting of the sensor, the operating condition

of the equipment, internal signal processing, and the role of the system in the maintenance process. This supports the need to interpret diagnostic data within a broader operational and maintenance context rather than in isolation.

From a maintenance support perspective, the three approaches under review can be viewed as complementary diagnostic layers with different practical applications. VA5 Pro represents an expert off-line layer with the highest level of diagnostic depth, as it enables detailed analysis of vibration signals, including time histories, frequency spectra, and envelope analysis. In maintenance practice, it is therefore particularly suitable for detailed diagnostics, condition verification following an alarm or the detection of a deviation, and for supporting condition-based maintenance. Siemens Simotics Connect 400 represents an on-line layer for long-term trend monitoring. In this study, it is not interpreted as a direct metrological replacement for local vibration diagnostic measurements, but rather as a source of trend context and early indication of changes in operational behavior. Its use is particularly suitable within the framework of condition-based maintenance and predictive maintenance, where it is important to monitor the development of selected indicators over the long term and to identify trend changes in a timely manner. SKF QuickCollect represents an intermediate layer of route-based diagnostics, suitable for repeated measurements at selected points and local verification of changes indicated by on-line monitoring. In practice, it is used primarily in route-based maintenance, to support total productive maintenance (TPM) activities, and during regular equipment inspections.

The practical value of combining these approaches lies in the ability to gradually escalate diagnostic activities based on the observed condition of the equipment. If the on-line trend remains stable, the equipment can be left in operation without immediate intervention. If Siemens Simotics Connect 400 indicates a deviation or an increasing trend, a route-based verification using SKF QuickCollect may follow. If the deviation is not confirmed, it is advisable to continue monitoring. If the elevated value is confirmed or the deviation recurs, detailed off-line diagnostics can be performed using VA5 Pro. Based on this interpretation, a decision can then be made whether to keep the equipment in operation, continue monitoring, or schedule a maintenance intervention. The proposed decision-making process is illustrated in Fig. 4.

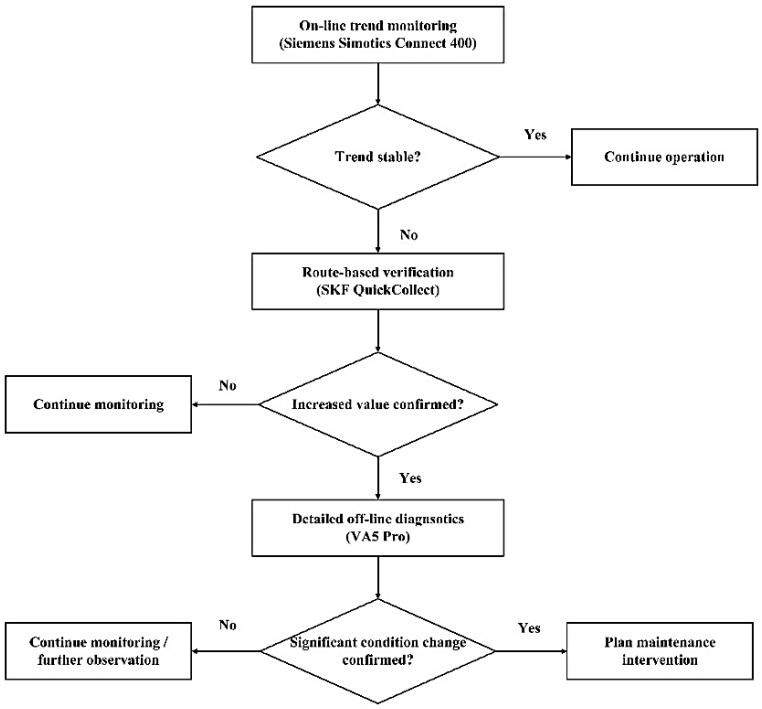


Fig. 4 Proposed workflow linking on-line monitoring, route-based verification and off-line diagnostics for maintenance decision support

Alt-text: *Top-down decision flowchart: stable trends lead to monitoring; deviations lead to SKF verification, VA5 diagnostics, or maintenance decisions.*

This multi-level diagnostic strategy combines trend monitoring, route-based verification, and expert interpretation. In industrial maintenance settings, this approach can help reduce the risk of misinterpreting isolated measurements and promote a more systematic prioritization of diagnostic and maintenance interventions. However, the proposed workflow should be understood as a practical support procedure derived from a pilot case study, not as a statistically validated decision-making model. Its further validation requires a longer time series, various operating conditions, and application to a broader set of machines.

Limitations and Future Work

This pilot study should be interpreted as an initial comparison of three diagnostic approaches applied to a single industrial electric drive. The objective was not to perform metrological validation of the systems used or to detect a specific fault, but rather to assess the nature of the diagnostic information and its usefulness in supporting maintenance decision-making.

The main limitation of the study is the limited scope of available measurements. The main comparison was performed for a selected steady-state operating condition at 1000 RPM, when data from all three systems were available. This condition allowed for a basic comparison of diagnostic indicators, particularly the RMS vibration velocity for VA5 Pro and SKF QuickCollect; however, it does not permit long-term statistical validation or the generalization of results to other operating conditions or other types of equipment.

Future work will focus on extending measurements over longer time periods and to other electric drives. It will be important to include both steady-state and transient operating conditions, verify the repeatability of measurements, and quantitatively compare selected diagnostic indicators. The next step will be to formalize and validate the proposed decision-making procedure using longer-term data and a broader set of equipment.

CONCLUSIONS

The article presented a pilot comparison of off-line, on-line, and hybrid route-based diagnostic approaches applied to an industrial electric drive. The comparison was performed using the VA5 Pro vibration analyzer, the Siemens Simotics Connect 400 system, and the SKF QuickCollect sensor. The objective was to assess the different nature of the diagnostic outputs and their usefulness in supporting maintenance decision-making. Within the scope of this pilot case study, the results support the interpretation that the evaluated systems provide different types of diagnostic information. The VA5 Pro is suitable for detailed expert analysis of the vibration signal, the Siemens Simotics Connect 400 for long-term trend monitoring of selected operational and diagnostic indicators, and the SKF QuickCollect for route-based inspections and repeated condition verification at selected measurement points. The outputs of the individual systems should therefore not be interpreted as interchangeable, but as complementary sources of information for maintenance decision-making.

The main contribution of the study is the practical definition of off-line, on-line, and route-based diagnostics as complementary layers of maintenance decision support. On-line monitoring can indicate trend changes, route-based diagnostics can verify the local condition, and off-line diagnostics can provide detailed interpretation of probable causes. In this way, the study contributes to a better understanding of how different diagnostic outputs can be used within an industrial maintenance system rather than as isolated measurements. However, the proposed interpretation should be regarded as an initial practical framework derived from one industrial case study, rather than as a generally validated model. Future work should verify the proposed approach over longer time periods, under different operating conditions, and on a broader set of equipment, with a focus on quantitative comparison of diagnostic indicators, measurement repeatability, and validation of the proposed decision-making procedure.

ACKNOWLEDGEMENTS

This research was funded with the financial support of the Faculty of Mechanical Engineering, Brno University of Technology, grant number FSI-S-26-8983.

REFERENCES

[1] Jardine, A.K.S., Lin, D. and Banjevic, D. (2006) 'A review on machinery diagnostics and prognostics implementing condition-based maintenance,' *Mechanical Systems and Signal Processing*, 20(7), pp. 1483-1510. https://doi.org/10.1016/j.ymssp.2005.09.012.

[2] Zonta, T. *et al.* (2020) 'Predictive maintenance in the Industry 4.0: A systematic literature review,' *Computers & Industrial Engineering*, 150, p. 106889. https://doi.org/10.1016/j.cie.2020.106889.

[3] Tidriri, K. *et al.* (2016) 'Bridging data-driven and model-based approaches for process fault diagnosis nd health monitoring: A review of researches and future challenges,' *Annual Reviews in Control*, 42, pp. 63-81. https://doi.org/10.1016/j.arcontrol.2016.09.008.

[4] Hammer, M. and Nahodil, P. (2020) 'Electrodiagnostics as a part of multiparametric diagnostics in industrial practice', *DIAGNOSTIKA 11*, pp. 11-15.

[5] Hajkova, A. and Hammer, M. (2024) 'Application of Modern Approaches to Solving Diagnostic Tasks in Industry,' *21st International Conference on Mechatronics – Mechatronika (ME)*, pp. 1-7. https://doi.org/10.1109/me61309.2024.10789654.

[6] ČSN ISO 13372 (2012) *Condition monitoring and diagnostics of machines – Vocabulary.* Prague: Czech Office for Standards, Metrology and Testing.

[7] Lee, J., Bagheri, B. and Kao, H.-A. (2014) 'A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems, *Manufacturing Letters*, 3, pp. 18-23. https://doi.org/10.1016/j.mfglet.2014.12.001.

[8] Lei, Y. *et al.* (2020) 'Applications of machine learning to machine fault diagnosis: A review and roadmap,' *Mechanical Systems and Signal Processing*, 138, p. 106587. https://doi.org/10.1016/j.ymssp.2019.106587.

[9] Hoffmann, M.A. and Lasch, R. (2025) 'Unlocking the Potential of Predictive Maintenance for Intelligent Manufacturing: a Case Study On Potentials, Barriers, and Critical Success Factors,' *Schmalenbach Journal of Business Research*, 77(1), pp. 27-55. https://doi.org/10.1007/s41471-024-00204-3.

[10] Benhanifia, A. *et al.* (2025) 'Systematic review of predictive maintenance practices in the manufacturing sector,' *Intelligent Systems With Applications*, 26, p. 200501. https://doi.org/10.1016/j.iswa.2025.200501.

[11] Bousdekis, A. *et al.* (2015) 'Review, analysis and synthesis of prognostic-based decision support methods for condition based maintenance,' *Journal of Intelligent Manufacturing*, 29(6), pp. 1303-1316. https://doi.org/10.1007/s10845-015-1179-5.

[12] Vogl, G.W., Weiss, B.A. and Helu, M. (2016) 'A review of diagnostic and prognostic capabilities and best practices for manufacturing,' *Journal of Intelligent Manufacturing*, 30(1), pp. 79-95. https://doi.org/10.1007/s10845-016-1228-8.

[13] Tomeh, E. (2015) *Technical diagnostics: vibration diagnostics of machinery and equipment.* Liberec: Technical University of Liberec.

[14] Randall, R.B. and Antoni, J. (2010) 'Rolling element bearing diagnostics – A tutorial,' *Mechanical Systems and Signal Processing*, 25(2), pp. 485 -520. https://doi.org/10.1016/j.ymssp.2010.07.017.

[15] ISO 13373-1 (2002) *Condition monitoring and diagnostics of machines – Vibration condition monitoring – Part 1: General procedures.* Geneva: International Organization for Standardization.

[16] ISO 20816-1 (2016) *Mechanical vibration – Measurement and evaluation of machine vibration – Part 1: General guidelines.* Geneva: International Organization for Standardization.

[17] Hashemian, H.M. (2010) 'Wireless sensors for predictive maintenance of rotating equipment in research reactors,' *Annals of Nuclear Energy*, 38(2-3), pp. 665-680. https://doi.org/10.1016/j.anucene.2010.09.012.

[18] Cachada, A. *et al.* (2018) 'Maintenance 4.0: Intelligent and Predictive Maintenance System Architecture,' *2018 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA)*, pp. 139-146. https://doi.org/10.1109/etfa.2018.8502489.

[19] Augustyn, D. and Fidali, M. (2023) 'Identification and evaluation of the characteristics of a selected commercial MEMS based vibration sensor for the machine condition monitoring,' *Diagnostyka*, 24(4), pp. 1-8. https://doi.org/10.29354/diag/172581.

Alena Hajkova (corresponding author)
ORCID ID: 0009-0006-3621-2699
Institute of automation and computer science
Faculty of Mechanical Engineering
Brno University of Technology,
Brno, Czech Republic
e-mail: Alena.Hajkova@vutbr.cz

Milos Hammer
ORCID ID: 0000-0001-7291-2330
Institute of automation and computer science
Faculty of Mechanical Engineering
Brno University of Technology,
Brno, Czech Republic
e-mail: hammer@fme.vutbr.cz