17th IMEKO TC 10 and EUROLAB Virtual Conference
"Global Trends in Testing, Diagnostics & Inspection for 2030"
October 20-22, 2020.

A Maintenance Assessment Measurement-Based Method For SMEs: Case Study of an Italian Mechanical Reality

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Abstract – **The Industry 4.0 enabling technologies offer new opportunities of innovation for many Small and Medium Enterprises (SMEs). More and more, the information deriving from measurements by intelligent and advanced data processing gives possibility of introducing new and smart approaches in many sectors contemporaneously, like production, maintenance, energy saving and supply chain management. Validation of data to be used for this multi-purpose analysis is mandatory, starting from the very preliminary phase. Taking in mind typical operating scenarios of Italian SMEs, in this paper a set of guidelines and requirements are given, in order to take advantage of the data-driven technical solutions for smart maintenance, providing that measurement data are reliable. The most important aspects to be considered for a more reliable analysis are presented, with reference to predictive maintenance projects carried on a complex plant and a specific sub-system. Simple considerations are shown to be able to avoid heavy mistakes.**

Keywords – Measurement uncertainty; On-Condition Maintenance; Preliminary Data Validation.

I. INTRODUCTION

The umbrella of Industry 4.0 scenario offers more and more new opportunities of innovation both in Big Enterprises and in many Small and Medium ones (SMEs) [1]. The whirling development and application of the enabling technologies of Industry 4.0 moves all enterprise toward completely new models of organization and operation in order to fulfil their objectives [2]. Connectivity and fusion of sensors and machines, digitalization, integration, big data processing and artificial intelligence [3], which have been addressed in a first step of this revolution mostly towards solution concerning hardware and physical assets, are now concepts influencing and integrating all the functions of the company; therefore, it seems inadequate to design innovation interventions, able to consider only a part of the organization and of the operations, the measurement data could be useful, if a smart manufacturing is taken into account.

Many innovation proposals could be found in literature, able to suggest innovation in design [4], production [5-6], maintenance [3, 7], sustainability [8], [9-11], safety and reliability [4], supply chain management [12-13].

In all these references it is very interesting to notice that the most recent papers emphasize the possibility of using the information content deriving from measured data to many issues and aspects: in [7,14], a strong attention is paid to the processes by which data-driven maintenance processes can support sustainable production in modern manufacturing; intelligent monitoring by a group of sensors allows to realize high quality production by three-axis CNC machine with savings in cost and energy; a similar result is proposed by [6]; sometimes a sustainable approach in terms of energy and computation load is optimized with respect to the communication devices and solutions [8]; also some techniques, like blockchain, usually used to guarantee that the measurement data remain unchanged and safe, can offer the possibility of employing this programming environment to improve sustainability [13],[11].

Furthermore, sharing the computation load due to big data between edge, fog and cloud computing is not more only the result of the best trade-off of computation applications depending on real time, computation load and cost [15];in fact, a suitable stratification between these layers can be useful to merge efficaciously metrological data deriving from high performance measuring systems [16], to propose new solutions in information management, , service composition and evaluation, for sustainable models of development [15], to propose cloud-based manufacturing process monitoring for smart diagnosis services, sharing resources and duties, according geographical, competence based, computation based criteria [17], to improve data integrity even with reference to extended networks, realizing a merging of requirements by all the involved stake-holders, thanks to blockchain solutions [12].

The described framework and applications are very interesting and promising; anyway, this situation emphasizes more and more the role of accuracy of experimental data deriving from the sensors; this concept seems quite obvious but when the propagation of information involves all the aspects and functions of the company, it has to be highlighted.

In fact, many are the causes able to affect the accuracy of data; some of them are "coarse", that is, they refer to incorrect practices by operators, like incorrect merging of different databases, incorrect managing of the instrumentation, communication mistakes, out of service instruments, timing errors in data series, etc.. These practices should be avoided, but the check of validity of data with respect to these requirements is an unavoidable initial requirement of the above high level services. In SMEs these situations are often acknowledged.

Furthermore, new requirements involve sensors and sensor's networks due to the technological progress, which are coarse and fine: digital calibration and time synchronization for low-cost digital sensors, on line and in line calibration of them when they are embedded into the process elements, and so on.

In [18], Authors identify the requirements for a big data processing pipeline in the different phases of data processing such as data collection, analytics, querying, and storage. They mapped these requirements to the capabilities of open-source technologies for big data and stream processing such as distributed queuing management, big data stream processing platforms, big data storage technologies and streaming SQL engines. However, the data reliability is taken for granted. Similar considerations apply to other powerful solutions like in [19], providing a system design to stream the collected device diagnostic parameters, following the universal data-driven approach, to the cloud for analytics and decision-making, or in [20], where the approach integrates as services in the cloud system, edge gateways, data stores at both the edge and the cloud, and various applications, such as predictive analytics, visualization and scheduling.

Authors in [21] defer to future work a full metrological analysis, stating that, for their application, the accuracy of the measurement chains based on calibration data and combined uncertainties, seems adequate to reproduce results of similar accuracy in the prototype field trials as in the laboratory-based test results; therefore, it is reasonable to expect similar validation procedure have to be applied if several and ongoing databases and monitoring platforms need to be merged in-field.

Digitization and digitalization are also of concern, for the correct implementation and application of data fusion techniques meeting the requirements of I4.0 principles [22].

Taking in mind the above considerations, in this paper a set of guidelines and requirements are given, in order to take advantage of the data-driven technical solutions for smart maintenance, provided that measurement data are reliable.

II. MATERIALS AND METHODS

According to previous experimental work of the Authors [23-24], the methodology can be split into two main phases. The first phase aims at checking data availability and accessibility with reference to the following aspects:

- Typology, position and functionality of the instrumentation
- Management of measurement systems
- Other information

For each of them, the guidelines see the following checks:

Typology of the instrumentation:

- Bulk sensors
- Smart sensors
- Embedded sensors
- network of sensors

Instrumentation mapping:

- Position and connections
- Functionality:
    - Safety
    - Product/process control

Other information:

- Historical data and alarms
- Faults/failures
- Maintenance activities

As far as the management of measurement systems, the following have to be verified:

- Operating state and connection to the monitoring system:
    - Working and connected
    - Working but not connected
    - Not working and connected
    - Not existing but considered by the monitoring system (e.g. available input of the Programmable Logic Controller (PLC) acquired by the monitoring system).
- Calibration state of the critical instrumentation
- Typology of the available data:
    - Historical timeseries
    - Data resolution
    - Measurement uncertainty
- Database consistency:
    - Coherence between data that are supposed to be correspondent

- Homogeneity of temporal discretization of data
- Bias correction in sensitivity data

The second phase refers to the identification of some action plans, in order to solve the criticalities arising from the previous step, also considering eventual operating priorities. In this phase, the Pareto analysis may help to two aims:

1) Analysis of the main causes of the problem (e.g. failure, fault, defect, and so on)
2) Evaluation of the need of intervention on sensors and measurement chains, considering the most relevant problems identified in 1).

The analysis carried out by means of these two macro-phases, if equipped by a positive assessment of the experimental information available, allows arranging the technological solutions for predictive maintenance, provided that further and widespread validation actions are set-up within the data processing flow, in the whole.

The data permanence through blockchain technology may be a further preliminary element to implement in those circumstances where controversies between subjects sharing information may happen.

III. RESULTS

In this Section, two test cases are described concerning the need of preliminary data validation and assessment, with reference to the need of preparing predictive maintenance strategies for both complex systems and specific devices.

A. Test Case 1

Data retrieving and awareness. The test case refers to an energy production plant, provided by a turn-key solutions farm, called *Subject A* in the following.

Subject A aims at realizing a remote monitoring system for predictive maintenance of all the sub-systems of the plant. The available data refer to the whole plant, including electrical, mechanical, thermal quantities monitoring the working on the plant; these sensors have been installed by Subject A. Other databases available refer to the engine and to the boiler and they have been realized by different manufacturers. The available information allows managing the plant efficaciously and in a reliable way but the capability of realizing predictive maintenance procedures has to be checked.

The first step consists of comparing the Piping and Instrumentation (P&I) Diagram, the remote monitoring software and the available archives, concurrently, with the aim of associating each quantity to the correspondent sensor. In fact, for a firm providing turn-key plants it is worth checking that databases assumed identical between provider and end-user are effectively coincident.

For a deeper analysis and knowledge of these data, the expert in the field for *Subject A* supports in comparing the parameters in the archives, by means of the remote monitoring platform connected to the plant itself. Each entry is associated to the correspondent sensor, simultaneously evaluating archives, P&I and software.

The expert in the field lets useful information for the analysis be known:

- Data are available in a database, which is automatically filled during the processes monitoring;
- Maintenance activities are available on reports realized manually by the operators and filled in parallel;
- Future energy production plants will be equipped by technologically advanced sensors, capable of more powerful performances in terms of auto-diagnosis and possibility of automatically transferring measurements into transverse databases;
- The calibration data are owned by the customer managing the plant.

Analysis of criticalities and action plans. The following criticalities can be summarized:

- Entries on the archive with inappropriate values for the conveyed quantities;
- Duplicated quantities on the general archive and the electrical quantities archive, with values not-corresponding due to reprocessing along the transmission line;
- In the general archive 13 on 95 parameters reported some anomalies: n. 2 not-working sensors; n. 6 not-existing sensors, but considered by the monitoring systems; n. 3 occasionally working sensors on auxiliary circuits; n.2 sensors with a coarse resolution for condition monitoring applications.
- In the electrical quantities archive, on a total of 56 measurement channels n.2 not-existing sensors but considered by the monitoring system and n.2 sensors with a coarse resolution for condition monitoring applications have been found.

Future goals have been identified:

- Evaluation of the most influencing parameters using Pareto diagrams and previous experience
- Analysis of the parameters behaviors and possible correlations with extern conditions
- Analysis of the alarms file, evaluating the type of alarms, how many times they have occurred and from what sensors.

Taking into account complex systems, where several subjects act with different temporal stratification of the interventions, the correct building of the starting database is strongly affected by a suitable integration of different informative contributions, which are *per se* irregular.

B. Test Case 2

The second test case refers to the embedding of condition monitoring tools in automatic packaging lines [25]. In fig. 1, a specific area fitted with instruments, as a part of a motorized mechanism aiming at the alternate rotation of a pulley suited for the item handling. The simplified scheme shows the nomenclature and the location of the external sensors (accelerometers) used for the analysis: ACC1-Y e ACC2-X are the initially prepared sensors for monitoring purposes; ACC3-XYZ is the sensor used for the validation of the procedure itself.

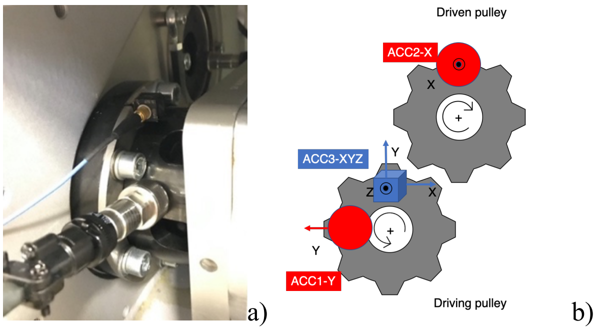

Fig. 1. Test case 1: a) Picture of the machine area of interest; b) Sketch of the instrumented area. Please note that the accelerometers are installed on the still parts of the support.

An important improvement derives from the ability of using internal and external sensors to the motor, provided that the correct data saving is granted, together with the synchronization of data acquisition systems among internal and external sensors and among the external sensors themselves, if acquired through different platforms.

The synchronization has been realized by means of a digital output signal from the PLC to the data acquisition system of external sensors. The sampling frequencies still remain different, so are the lengths of the acquisition intervals and, therefore, the characteristics of the synthetic indicators that can be obtained from these signals.

One of the preliminary checks, which is needed for the external sensors, is their correct positioning and installation. This may be accomplished through straightforward controls, like the FFT analysis, as shown for the auxiliary accelerometer ACC3_XYZ in Fig. 2 and Fig. 3, in reference and failure conditions, respectively.

The sensitivity of the spectrum to the presence of a defect appears evident in the frequency range (300-500) Hz.

Fig. 4 shows that the signals coming from the internal sensors to the motor provide interesting information as well, with respect to the presence of the failure. In particular, the band power of the Feedback Current in the frequency range (0-500) Hz appears capable of indicating the occurrence of failure, over other traditional signals like Current and Tracking Deviation and over other traditional features like Root Mean Square (RMS), Kurtosis and difference of maximum and minimum values in one cycle (MAX-MIN).

Nevertheless, in order to exploit the information form internal sensors, the informative content of accelerometer data should be optimal in the common frequency range, i.e. (0-500) Hz. This fact depends on the sensors dynamic characteristics, on the accelerometer signal transmission line characteristics and on the acquisition duration.

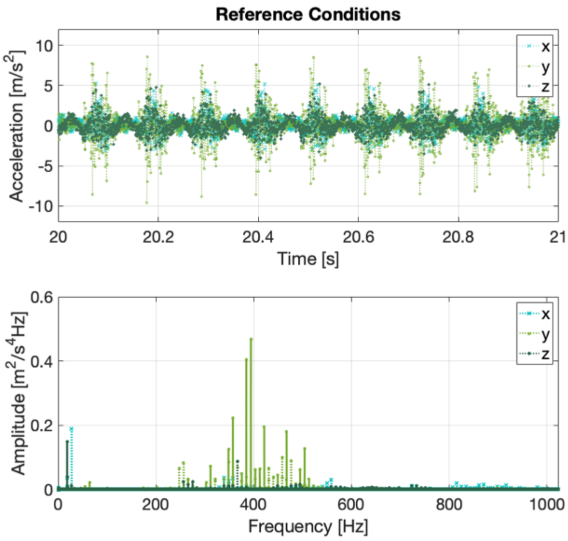

Fig. 2. Time and frequency behaviors for ACC3-XYZ in the reference conditions

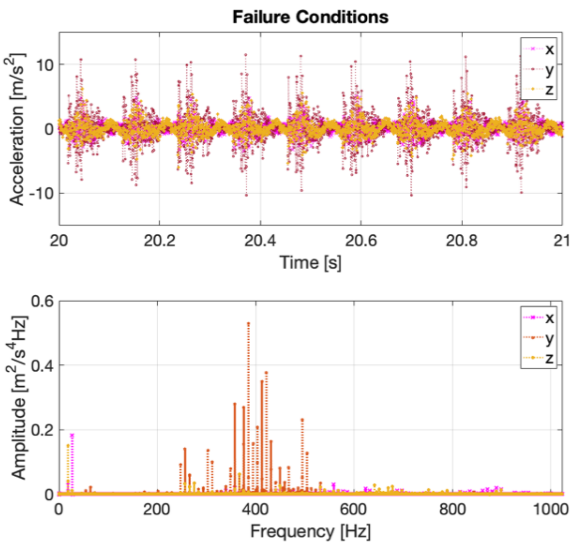

Fig. 3. Time and frequency behaviors for ACC3-XYZ in the failure conditions.

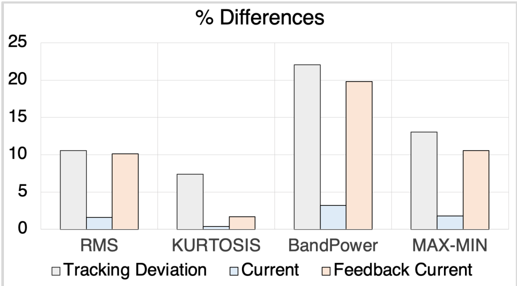

Fig. 4. Comparison of features values based on internal sensors: percentage differences between faulted and reference values.

Fig. 5 and 6 show the accelerometers ACC1_Y e ACC2_X provide information in frequency ranges different from those of interest and different between each other, due to the choice of the installation in which the transmission line of the vibration signal plays an important role.

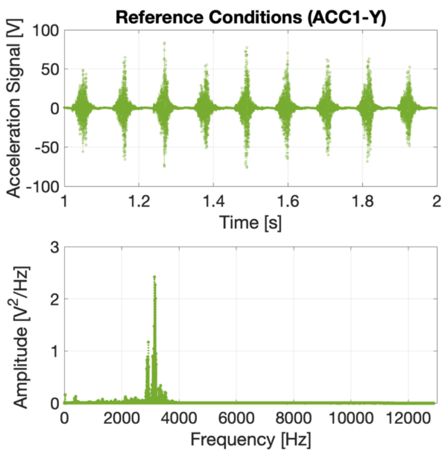

Fig. 5. Time and frequency behaviors for ACC1-Y in the reference conditions.

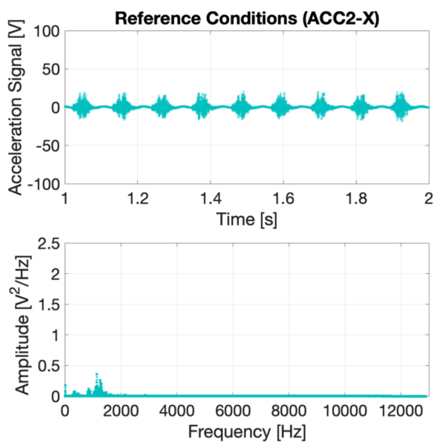

Fig. 6. Time and frequency behaviors for ACC2-X in the reference conditions.

In this test case, the most critical point is related to the positioning and connection of sensors. An accurate analysis of the transmission line is needed, otherwise the difference are evident. Some quantities provided by the sensors internal to the motor are very sensitive to the defects, however the data have to be managed adequately.

Even when the analysis focuses on a sub-system and, therefore, it is presumable that the organization is known and managed by a unique subject, the correct integration of different databases resulted as a preliminary but fundamental aspect, clearly linked to different manners.

IV. CONCLUSIONS AND OUTLOOK

The more the experimental data may be the base for the most disparate analyses, the more the preliminary controls have to be conducted in a systematic and rigorous manner, even though the controls appear trivial.

Some examples have been provided in this paper: (1) in a preliminary analysis the steps of the methodology resulted very important in the monitoring and diagnostic finalized to the predictive maintenance of a thermal energy production plant; (2) in a specific example for defect diagnosis of elements in alternate motion of a packaging line, the issues linked to the data saving and to the sensor positioning have been highlighted.

This work confirms that paying the due attention to a preliminary validation of the data on which maintenance, and reliability analyses are based is mandatory, being these aspects many, various, multi-disciplinary, and often neglected by the involved operators Furthermore, they strongly depend on the specific application.

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