Measurement 126 (2018) 1–12

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

A smart and intuitive machine condition monitoring in the Industry 4.0 scenario

G. Dinardo*, L. Fabbiano, G. Vacca

Politecnico di Bari University, via Orabona 4, Bari 70125, Italy

ARTICLE INFO

Keywords:
Internet of Things
Decision making
Machine condition monitoring
Signal analysis and processing
Vibration acceleration measurements
Laser Doppler Vibrometry

ABSTRACT

In the smart industry philosophy, continuous monitoring of the machinery condition is crucial to follow up the decision-making strategy. In this context, the purpose of the paper is to elaborate a simple procedure aimed at rotating machine condition monitoring and prognosis. The general assessment of the machine operating condition goodness is indeed crucial for a smart and efficient industrial processes running. Any incipient defect manifests itself in an alteration of the component vibratory status. The proposed procedure is based on the continuous monitoring of the energetic features of the vibration signals acquired from the equipment under analysis. The considered parameter is the vibration velocity RMS value. It is representative of the amount of the fatigue stress affecting the machine. By means of a continuous monitoring of such energetic features, the user is able to plan the maintenance of the equipment, prior to impeding failures. The case study provided in this paper, can illustrate how the data from a monitored process can lead to the machine system self-awareness and, eventually, self-maintenance. Such an approach allows for a self-assessment of health and degradation status of the machine system, in the framework of the Industry 4.0 scenario, one of the pillars of the Smart City.

1. Introduction

The predictive maintenance technique has attracted great interest in the last 30 years in both academia and industry.

In the industrial processes, often plant out-of-service times are mainly due to machinery faults. Their systematic prediction and assessment deals with the maintenance aspects concerning both the present and past machines' operation. In order to inspect the machine's operation condition, sensors are installed in such a way that relevant information about the machine's health condition can be controlled and monitored.

Industry 4.0 aims at creating the so-called "smart industry", that is an industry in which every element of the system communicates and cooperates with each other and with humans in real time, through the Internet of Services. Smart industry indeed is defined as "the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and societal outcomes" [1,2]. In this prospective a continuous monitoring of the machinery condition is imperative.

There are numerous techniques commonly used to diagnose any defect occurring during the machine operation: vibration monitoring, thermography, ultrasonic analysis, and many others [3,4]. However, only a few of these techniques allow a continuous analysis of the machines operating parameters. The continuous screening of specific parameters of the machine allow detecting its incipient fault [5,6].

A strategy to make an accurate detection of machine incipient faults requires a prognostic approach. As defined in [1], prognostic is to monitor and detect the initial indications of degradation in a component, in order to make accurate and consistent predictions. The focus of this approach is to predict an incipient fault before its occurrence, avoiding the eventual catastrophic consequences for the production cycle and/or the integrity of the machine itself. The issue of prognostics has been widely studied and many papers are available in the scientific literature [2,7–14].

Obviously, a more accurate condition monitoring requires highly accurate measurement systems (in terms of deployed sensors and adopted measurement procedures) [15]. However, it is essential to have significant indexes that could serve as warning, in order to predict early failures. Therefore, the key elements of monitoring are the continuous analysis of the operating parameters and the definition of the proper indices.

Ref. [16] highlights how the smart city concept grounds on six key areas: Smart People, Smart Economy, Smart Living, Smart Governance, Smart Mobility and Smart Environment and that the same six key areas belong to Industry 4.0 context. In the specific case, Internet of Things, Internet of Services, Internet of People and Internet of Everything (in

* Corresponding author.
E-mail addresses: giuseppe.dinardo@outlook.it (G. Dinardo), laura.fabbiano@poliba.it (L. Fabbiano), gaetano.vacca@poliba.it (G. Vacca).

https://doi.org/10.1016/j.measurement.2018.05.041
Received 9 January 2018; Received in revised form 27 March 2018; Accepted 9 May 2018

the frame of the Cyber-Computational Space) [17], can be considered as elements that can create a connection between Smart City Initiatives and Industry 4.0. Therefore, Industry 4.0 can be seen as a part of Smart City. The authors, within the context of the Industry 4.0, propose a prognostic approach to the detection of incipient faults of rotating machines by means of their vibrational status monitoring. The Data Mining (DM) is an important component of Industry 4.0 as it allows the extraction, through intelligent methods, of information or knowledge from large amounts of data and the scientific, industrial or operational use of this information. Decisions are based on both data, and the ability to retrieve the significant data at the relevant time, in appropriate format, accessible to the specific operators. Decision-making process is a function of DM. Industry 4.0 formalizes the data driven decision approach. Decision-making process is performed on the bases of a large amount of data, which describe the operating condition of the process under analysis. In this paper, the authors better focus the importance of the decision-making strategy by means of the definition of the proper damage index, that explains the condition of incipient fault.

2. Theoretical background

In this paper, the authors define an energy index based on the energy features of vibrational signals acquired from rotating machines, with the purpose of performing an accurate and valuable diagnostics and prognostics of the analyzed system. Indeed, an analysis approach aimed at preventing the occurrence of progressive defects allows for a drastic reduction of shut-down times inevitably occurring during maintenance phases.

The definition of such an energy index involves the so-called Root Mean Square (RMS) value of the acquired vibrational signal [18].

The energy index requires the definition of the relative vibration physical quantity.

Fig. 1 illustrates the relationship between displacement, velocity and acceleration amplitudes and it provides an useful guidance about which quantity should be adopted for the analysis of the vibrational status affecting the equipment under analysis. An approach based on the vibration frequency ranges promptly suggests the kind of measurement and analysis technique to be employed. From Fig. 1, the vibration displacement acquire significant importance at very low frequencies. The acceleration amplitudes become more significant than displacement and velocity for frequency ranges over 1 kHz.

For frequencies ranging from 10 Hz up to 1 kHz, the vibration velocity is the quantity yielding significant and detectable amplitudes. Since the majority of defects affecting rotating machinery are in 10 Hz–1 kHz range, the vibration velocity is used for vibration signal analysis [5,6].

In addition, machinery failures due to vibrations are fatigue failures. The time required to achieve fatigue failure is due to both vibration motion (in terms of vibration displacement) and the number of stress cycles, i.e. the rate at which the component under analysis is deflected (vibration frequency). Therefore, the product of vibration displacement and its characterizing frequency (nominally the vibration velocity) is a direct measure of the fatigue stress induced by the vibratory status, symptom of a possible machine defect.

The authors developed an experimental setup, involving a rotating disk (whose specifications are going to be introduced in Section 4), mounted on a proper shaft, which is driven by a DC motor. The kind of defect is an uneven mass distribution of the rotating disk. The disk uneven mass distribution causes an eccentricity between its centre of mass and the shaft axis. Since the disk thickness is very low, any dynamic misalignments due to possible principal axes of inertia misalignment are negligible. Thus, in the case study presented in this paper, the sole dynamic phenomenon considered is the static misalignment due to the disk mass eccentricity. Static misalignments influence the operating condition of the analyzed rotating equipment. Such a defect clearly influences the machine vibrational status and the importance of such an influence clearly varies as the current machine operating condition (i.e. the machine rotating speed). The detection and a possible prognosis of such anomaly can be carried out by monitoring the vibration signal, acquired at specific points. Then, in order to detect a possible incoming failure or in order to assess the acceptability of the operating condition, a reliable and effective signal processing must be performed.

Figs. 2 and 3 show, respectively, the vibrational velocity signal, acquired at a specific measurement point for a given machine operating condition, and the signal Fast Fourier Transform (FFT).

A preliminary signal analysis can be performed by means of a visual inspection of the time-domain signal and its frequency spectrum.

A static misalignment induces a centrifugal force, which rotates at the rotor speed. Therefore, the most significant harmonic is the 1X RPM component and its amplitude is proportional to the centrifugal force due to the unbalance. Fig. 3 shows the signal frequency spectrum, which exhibits a series of harmonics at 1X RPM, 2X RPM, 3X RPM and so forth.

In the early studies, the FFT has been widely used for the detection of possible fault and defect footprints and it is considered the dominating signal analysis tool for vibrations due to its implementation and interpretation simplicity. However, there exist some critical issues regarding the use of the FFT. These issues become crucial whenever the

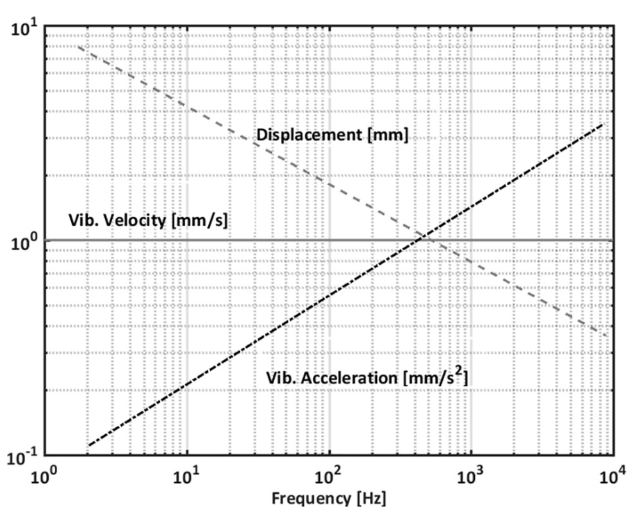

Fig. 1. Relationship between vibration displacement, velocity and acceleration at constant velocity.

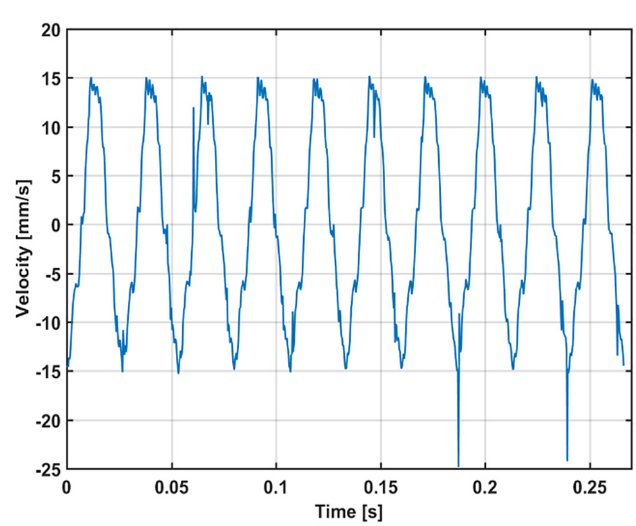

Fig. 2. Vibration velocity signal.