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Fault detection in rotating machines with beamforming: Spatial visualization of diagnosis features

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ABSTRACT

Rotating machines diagnosis is conventionally related to vibration analysis. Sensors are usually placed on the machine to gather information about its components. The recorded signals are then processed through a fault detection algorithm allowing the identification of the failing part. This paper proposes an acoustic-based diagnosis method. A microphone array is used to record the acoustic field radiated by the machine. The main advantage over vibration-based diagnosis is that the contact between the sensors and the machine is no longer required. Moreover, the application of acoustic imaging makes possible the identification of the sources of acoustic radiation on the machine surface. The display of information is then spatially continuous while the accelerometers only give it discrete. Beamforming provides the time-varying signals radiated by the machine as a function of space. Any fault detection tool can be applied to the beamforming output. Spectral kurtosis, which highlights the impulsiveness of a signal as function of frequency, is used in this study. The combination of spectral kurtosis with acoustic imaging makes possible the mapping of the impulsiveness as a function of space and frequency. The efficiency of this approach lays on the source separation in the spatial and frequency domains. These mappings make possible the localization of such impulsive sources. The faulty components of the machine have an impulsive behavior and thus will be highlighted on the mappings. The study presents experimental validations of the method on rotating machines.

1. Introduction

Since the development of signal processing, surveillance and diagnosis of rotating machines have been topics of main interest. Although mechanical components health can be estimated, the uncertainties brought by the operating conditions variation possibly lead to unexpected breakdowns. Machine monitoring allows following the evolution of the signals generated by its mechanical parts. In practice, the calculation of scalar features is a way to estimate the parts health. Such information is provided by accelerometers placed on strategic location of the machine, nearby the components of interest. The aim of this study is to replace the vibration sensors by a microphone array. Acoustic based monitoring of gears is shown to be successful by Baydar and Bawl [1,2]. Some works have used acoustic imaging to deal with fault detection. Coutable et al. [4] used Nearfield Acoustic Holography to identify the sound field radiated by different bearing faults while Choi et al. [3] proposed a modified beamforming formulation to localize impulsive sources. Despite these works, diagnosis of machines by means of acoustic imaging has received little attention.

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The need of an expensive microphone array and the heavy computational time might explain this lack of investigation. However, the development of MEMS microphone arrays equipped with embedded acquisition devices will facilitate the use of acoustic imaging in the future. Moreover, acoustic-based diagnosis can be seen as an improvement of vibration-based diagnosis.

One advantage is that the measurement no longer requires the contact with the machine. Vibration-based diagnosis is sensitive to the distance between the sensors and the mechanical components. In some cases, the machine geometry prevents the sensors from being placed close enough to the parts which possibly leads to misleading results. Acoustic measurement does not suffer from this since the identified signals can be chosen at any point of the machine. Hence, it is possible to obtain a continuous spatial information over the whole machine surface while the vibration sensors provide information about discrete points only.

Acoustic imaging is generally used to visualize the source strength layout as a function of space and frequency. This can be relevant for source localization purposes but has many limitations in a fault detection approach. Actually, the fault acoustic radiation is rarely dominant among the overall acoustic field. In this paper, diagnosis features will be considered in order to highlight the fault signature instead of simply visualizing the radiated energy. The spectral kurtosis (SK) is a signal processing tool that computes the kurtosis of a signal as a function of frequency. It has been shown relevant in diagnosis of rolling element bearing and in extracting impulsive signals buried in noise [5–8,12]. Since faulty gears and bearings generate impulsive signals, the SK makes possible the identification of the frequency band containing the fault information and its isolation. Here, the SK is combined with acoustic imaging in order to visualize the impulsive sources on the machine surface. Since the faulty parts of the machine most likely have an important impulsive feature, they will be emphasized on such mappings. Benefits of this approach are twofold: the sources will be localized in space and the high kurtosis frequency band will be identified. Focusing at one point and bandpass filtering is a way to separate the sources and makes possible the extraction of the fault signature.

This paper is organized as follows. In the first section, beamforming – which is the acoustic imaging technique used in this work – is presented. Then, the theory of SK is explained. In the next section, a way to combine the SK with beamforming in order to visualize the impulsive sources as a function of space and frequency is introduced. Finally, two experimental applications are presented to validate the proposed method.

2. Beamforming

Beamforming can be considered as one of the oldest acoustic imaging methods. This source location technique was inspired by telecommunication methods and is often referred to as “acoustic telescope” [9]. In spite of its age, beamforming is still used in the industrial field [10] because of its many advantages compared to other methods. Nearfield Acoustic Holography or Source Equivalent Method for instance are both sensitive to noise and usually need a regularization step which is time consuming. Moreover, they do not provide time varying signals which are useful in a diagnosis approach. Although beamforming has a low spatial resolution at low frequencies, the previously listed conveniences make it adapted to diagnosis purposes. The aim of this paper does not lay on the acoustic imaging improvement. Saying so, beamforming is presented as a tool in its classical formulation.

The principle of source location lays on the numerical focusing of the microphone array toward a direction (or point). The amplitude of planar (or spherical) waves coming from this direction (or point) is estimated. Choosing a set of different directions will allow the mapping of the source strength distribution over a surface.

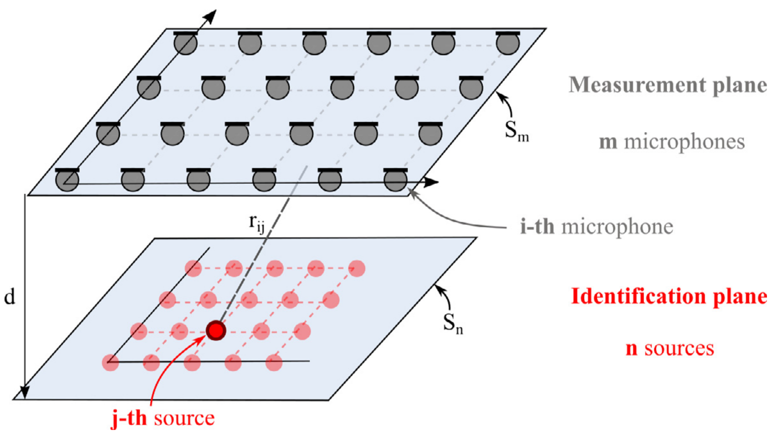

Fig. 1. Theoretical setup.