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WIRELESS SENSOR ACCELERATION OF MOVING ELEMENTS FOR CONDITION MONITORING OF MECHANISMS

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***Abstract* - Comprehensive analysis of the angular and linear accelerations of the moving elements (shafts, gears) allows to increase quality of the condition monitoring of the mechanisms. However, existing tools and methods measure either linear or angular acceleration with postprocessing. The research suggests a new construction design of the angular acceleration sensor for the moving elements. Besides, the authors introduce the method for the received information processing, that makes it possible to divide the measured acceleration into the angular and linear components. The study has shown that this method provides a definite separation of the measured acceleration on linear and angular components even in noise. The research contributes to the range of methods and tools for condition monitoring of the mechanisms.**

Keywords: angular acceleration, wireless sensor, rotating shaft, condition monitoring

1. INTRODUCTION

The reliability of the machines and mechanisms directly affects the efficiency of production and technological processes. Rotation in mechanisms such as motors and pumps, gearboxes and turbines is the basic type of movement. The translational vibrations of the moving elements (shafts, gears) appear due to the structural features and defects in mechanisms. Therefore, the measurement and comprehensive analysis of the angular and linear accelerations can improve the quality of the condition monitoring of the mechanisms.

The issues related to the measurement of the angular acceleration, are the most significant. The existing measurement methods are divided into two groups: direct and indirect measurement [1]. There is a direct measurement method implemented with special sensors [2, 3] or angular accelerometers of different constructions [4, 5, 6]. Besides, there is an indirect evaluation, where the angular acceleration is calculated using different algorithms from the angular velocity and displacement [7, 8]. However, indirect methods of assessment are sensitive to a high level of noise. The direct measurement is not always possible on the equipment in operation due to the constructive peculiarities of its sensors. A linear acceleration can also be measured and evaluated directly or indirectly with the help of linear accelerometers or using special sensors. However, none of the above studies describe angular and linear accelerations simultaneous measuring and processing.

Furthermore, in the study [9] the authors propose to mount accelerometer directly to the rotating shaft. This method allows to increase the sensitivity of the measuring system to the occurring defects. However, this approach does not allow to value the angular accelerations of the shaft separately from the linear accelerations.

The present research suggests a model of wireless sensor which is able to measure angular and linear accelerations simultaneously directly from the rotating shaft or gears, expanding the idea expressed in [10, 11]. Moreover, the authors suggest a method which allows to divide the measured accelerations to the angular and the linear components.

2. WIRELESS SENSOR

The sensor construction is designed as a disk rigidly mounted on the shaft or on the side surface of gear. The disk contains three one-axis accelerometer equidistant from the center of the central angle of between 120 degrees and tangentially oriented sensitivity axes (Fig. 1). The power supply and data transmission are performed wirelessly.

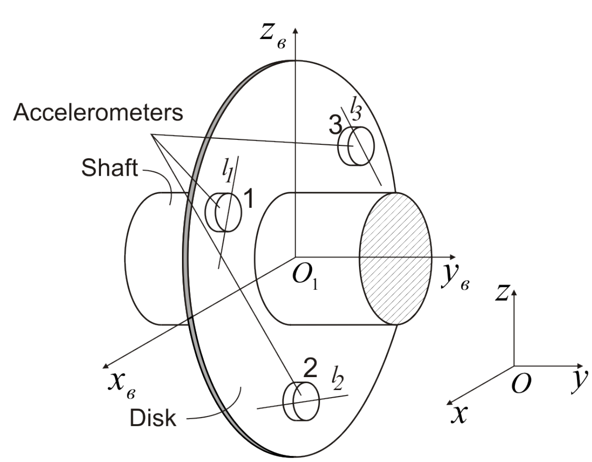

Fig. 1. Sensor model.

For the mathematical description we take the case when the sensor is mounted on the spur gear which is coaxially fixed to a shaft located horizontally. The shaft is turning around its axis (around axis O_1y_b) and two-dimensional motion with acceleration in the diametral plane (in the plane Oxz). Such movements are typical for spur transmission and are often considered in the models of the total mesh stiffness estimation made for technical diagnosis [12, 13].

Each accelerometer 1 – 3 is affected by the forces caused by the accelerated plane motion of the shaft, centrifugal force, the force caused by the accelerated rotation of the shaft and the force of gravity. To assume that accelerometers are identical, internal components transitional processes of the accelerometers and the impact of centrifugal forces on the measurement result are negligible, the positive direction of the sensitivity axes is counterclockwise. Thus, the acceleration sensed by accelerometers is

$$\begin{cases} a_1 = \ddot{\varphi}r + \ddot{x}\cos\left(\varphi + \dfrac{\pi}{3}\right) + \\ + (g - \ddot{z})\sin\left(\varphi + \dfrac{\pi}{3}\right), \\ a_2 = \ddot{\varphi}r - \ddot{x}\cos(\varphi) + \\ + (\ddot{z} - g)\sin(\varphi), \\ a_3 = \ddot{\varphi}r + \ddot{x}\cos\left(\varphi - \dfrac{\pi}{3}\right) + \\ + (g - \ddot{z})\sin\left(\varphi - \dfrac{\pi}{3}\right), \end{cases} \quad (1)$$

where a_1, a_2, a_3 – acceleration measured by accelerometers 1 – 3, in accordance, r – the distance among the rotational axis of shaft and the accelerometer, g – gravitational acceleration of the earth, $\ddot{\varphi}$ – angular acceleration of the shaft around axis O_1y_b, $\ddot{x}$ – linear acceleration of the shaft along axis Ox, $\ddot{z}$ – linear acceleration of the shaft along axis Oz, φ – the angle of rotation of the shaft.

The solution of (1) allows to calculate the angular and linear accelerations of the shaft at a mount point of the sensor. The calculation is performed on each time sample.

The rotation angle of the shaft is found by numerical integration of $\ddot{\varphi}$, assuming that at the zero time the shaft has been in the rest. The uniqueness of solution of (1) follows from the fact that the equation determinant is always nonzero.

3. MEASUREMENT PROCESSING

To value the measurement accuracy of $\ddot{\varphi}$, $\ddot{x}$ and $\ddot{z}$, we simulate the sensor operation with the following conditions: $r = 0.04$ m, $g = 9.81$ m/s^2, $t = [0; 5]$ s, $\Delta t = 0.0005$ s, $\dot{\varphi}(0) = 0$ rad/s, $\varphi(0) = 0$ rad, $\dot{x}(0) = 0$ m/s, $x(0) = 0$ m, $\dot{z}(0) = 0$ m/s, $z(0) = 0$ m.

Let us assume that the shaft does motions with accelerations

$$\begin{cases} \ddot{\varphi} = 10 + \sin(100\pi t) + 0.5\sin(200\pi t) + \\ \quad + 0.5\sin(900\pi t) + 0.25\sin(910\pi t), \\ \ddot{x} = 0.5\sin(750\pi t) + 0.25\sin(760\pi t), \\ \ddot{z} = 0.5\sin(820\pi t) + 0.25(800\pi t). \end{cases} \quad (2)$$

Additionally, the random white noise is added to each acceleration (5% of acceleration amplitude). The accelerations graphs of the shaft (2) are shown in Fig. 2.

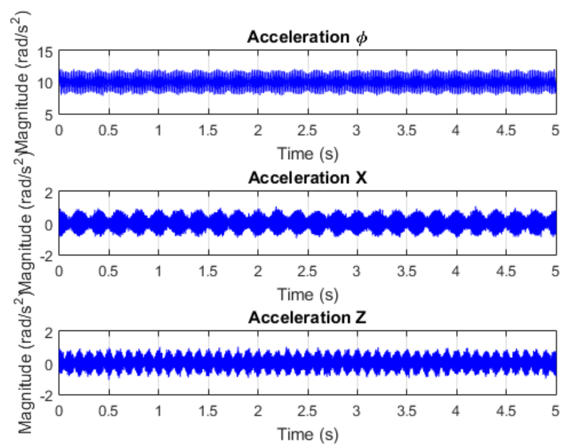

Fig. 2. Defined accelerations.

The random white noise is added to each a_1, a_2, a_3 (3% of a_1, a_2, a_3 amplitude) for simulated noise of accelerometers. Considering the finite bitness of an analog-to-digital converter, a_1, a_2, a_3 have been rounded to the 4th decimal place.

The measured accelerations graphs of the shaft are shown in Fig. 3.

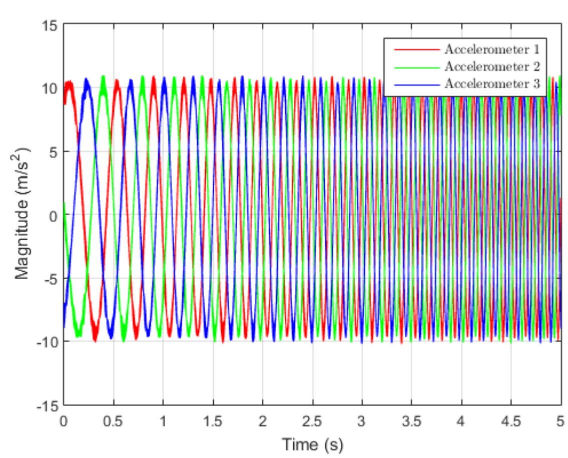

Fig. 3. Acceleration mesuared by accelerometers.

Due to the fact that the shaft is located horizontally, the gravitational acceleration occurs in the measured signals. Thus, the Fig. 3 shows the period of measured acceleration corresponds to the shaft revolution. Also, the Fig. 3 shows that the angular speed of the shaft increases. The speed is increasing due to the presence of the constant component in the $\ddot{\varphi}$.

We apply the fast Fourier transform (FFT) to value the frequency components of $\ddot{\varphi}$, $\ddot{x}$ and $\ddot{z}$, which are calculated from the measured accelerations (Fig. 3). The frequency spectrums of acceleration are shown in Fig. 4.

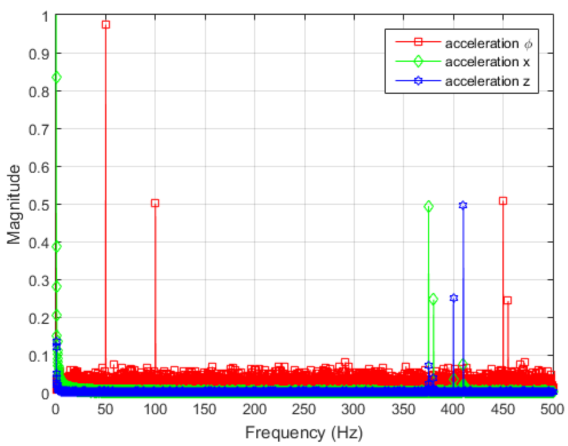

Fig. 4. The measured accelerations in frequency domain

The Fig. 4 shows that the components defined in (2) are distinctly visible. Moreover, the amplitudes error of the defined frequencies of the angular and the linear accelerations is less than 0.027 rad/s^2 and 0.007 m/s^2, respectively.

The results of simulating show that the applied method allows to divide the measured accelerations to the angular and the linear parts. Besides the method divide the linear part to the orthogonal axes.

These features allow to increase the quality of technical diagnostic mechanisms when components of an external vibration sources are occurring in the measured signal. Moreover, their amplitudes and frequencies are comparable to the desired signal components. As an example, the sensor and the method can provide the diagnostic of actuators with several independent drives which are running at the closely spaced frequencies.

However, the application of the proposed sensor is complicated due to it should be mounted on the shaft or on the side surface of gear.

4. CONCLUSIONS

The proposed wireless sensor and processing method of received signals can measure and divide the accelerations of the moving elements of mechanisms onto the angular and linear parts. The study contributes to the range of methods and tools for diagnosing the technical condition of machines and mechanisms.

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