Developing of model for vibroacoustic signals of roller bearing

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Abstract. At present, the automated systems for vibroacoustic diagnostics (ASVD) are being used more widely. They are intended to rapidly assess the technical condition of the machinery as such and its particular mechanisms. The ASVD’s assembled according to a modular principle consists of sub-systems for collecting and switching information on the vibration state of an object, primary analog processing subsystems, and secondary digital processing and control. The current state of microprocessor technology makes it possible to create small-size ASVD’s capable of not just making a decision on the operability of a diagnosed node, but also recognizing the type of the defect and the degree of its danger to the mechanism.

1. Introduction
The development of algorithms for the digital identification of defects is a particularly complex task, requiring a large number of full-scale tests conducted with various possible combinations of defects in the construction, which is being diagnosed [1]. The amount of on-site tests and the costs of conducting such tests could be significantly reduced if digital mathematical modeling of signals generated by various combinations of defects is applied in the development of identification algorithms.

Figure 1 shows the section of a roller bearing consisting of an inner ring (hereinafter referred to as a “ring”) and an outer collar (hereinafter referred to as “collar”) in-between of which the rolling bodies are “located-rollers”. Those are enclosed in a separator (not shown in the picture). The bearing collar is fixed in a stable case.

**Figure 1.** Mechanism design of the roller bearing.
2. Materials and methods

Acoustic vibration caused by the interaction of the surface of the defective element with other moving parts of the bearing is converted by the piezoelectric sensor-accelerometer into an electrical signal.

Considering the fine structure of the signal when defining the processing algorithm leads to some significant computing costs, therefore, our paper mostly concentrates on the model of vibroacoustic (VA) signals corresponding to the formula 1 [2]:

\[
x(t) = \sum_{k=1}^{n} a_k \cdot [1(t - t_k) - 1(t - t_k + \tau_k)].
\]  

(1)

Figure 2 shows the signal received during the defective bearing testing. As the diagram shows, the electrical signal is formed by the sequence of high-frequency pulses.

![Piezoelectric sensor signal](image)

Figure 2. Piezoelectric sensor signal.

Analyzing BA signals, we will use the information about the amplitude of radio pulses envelope and the time of their arrival.

The presence of the defect in the bearing can be identified via estimating the amplitude or power of the VA signal and comparing the obtained value to some numerical threshold. In the simplest case, the value of the threshold can be selected experimentally. We may determine whether the defect belongs to a specific bearing element - thus, solving the identification problem - by knowing the characteristic features of the signal generated by the defect of this element [3].

Let us set up mathematical models of signals caused by the most common defects of bearing elements: roller, ring and a collar.

If the possible slippage of the rollers in the bearing is neglected, then the appearance of impulses caused by the defects on the working surfaces of the elements must be determined by the angular velocities of the bearing elements rotation at a constant speed of rotation of the ring. This is illustrated in the Figure 3, which shows the amplified and detected signals obtained during the full-scale tests of standard bearings with a defect in the roller (Fig. 3a), rings (Fig. 3b) and collars (Fig. 3c). The geometric dimensions of the bearing elements and the number of rollers are shown in Table 1.
Table 1. Major characteristics of the experimental bearing

|                    | Ring diameter, mm. | Clips diameter, mm. | Rollers diameter, mm. | Amount of rollers, number of items |
|--------------------|--------------------|---------------------|-----------------------|-----------------------------------|
|                    | 158,5              | 222,5               | 32                    | 14                                |

As being measured, the bearing was located vertically. In each bearing there was only one defective element: roller, ring or collar. All defects were made artificially - by applying of the transverse groove on the working surface of the element with the depth and width of 1 mm. During the recording of signals, the period of rotation of the bearing inner ring was $T_B \approx 0.25$ s.

Let us determine the moments of appearance of impulses caused by a defect on the working surface of the roller. For this we turn to Figure 2. We assume that the cage is absolutely stable, the bearing ring rotates around the O-axis, and there is no slippage of the links observed.

The defect on the surface of the roller is marked by the “P” point. If the ring rotates counterclockwise at an angular velocity of $\omega_B$, then the rollers will rotate clockwise around the $C_i$-axes and simultaneously move counterclockwise around the O-axis due to frictional interaction with the stationary collar.

Moving rollers will entrain the bearing separator [4]. The angular velocity of the axes of the rollers ($\omega_c$) coincides with the angular speed of rotation of the bearing separator around the fixed O-axis. When the defect “P” touches the working surface of the collar or the ring, a vibroacoustic signal will be generated, which, in its turn, causes an electric impulse at the output side of the piezoelectric sensor.

3. Conclusion
Calculated and experimental values of the interval between neighboring pulses for the defects of the roller, the ring and the clip.

The experimental values are obtained by averaging the time intervals between neighboring pulses for the signals. As we see, the calculated values closely correspond to the experimental values.
Table 2. Periods of rotation of the ring $T_\theta = 0.25 \phi$

| Interval | $T_p$, s | $T_B$, s | $T_H$, s |
|----------|---------|---------|---------|
| Estimated value | 43.21 | 30.57 | 42.92 |
| Experimental value | 43.9 | 29.5 | 41.4 |

Using the BA signal model (1), let us list the expressions for the signal models from the roller, the ring and the collar defects:

$$S_p(t) = A_p \left[ t - t_{p}^k \right] - \left[ t - t_{p}^k + \tau \right]$$  \hspace{1cm} (2)

$$S_g(t) = A_g \left[ t - t_{g}^k \right] - \left[ t - t_{g}^k + \tau \right]$$  \hspace{1cm} (3)

$$S_H(t) = A_H \left[ t - t_{H}^k \right] - \left[ t - t_{H}^k + \tau \right]$$  \hspace{1cm} (4)

where $A_p, A_g, A_H$ are the amplitudes of signals from the roller defects, the rings and the collars, respectively; $\tau$ - the time constant of the piezoelectric sensor; and $t^k$ - the moments of appearance of pulses from the corresponding defects.

These analytical relationships are shown in figure 4.

Figure 4. Periodic sequences of impulses from defects: a) roller; b) rings; c) clips.

However, the comparison of the signals in Fig. 3 and 4 shows that the structure of the signals caused by real defects of the roller and ring differs significantly from those based on the formulas (2), (3) and (5).

References

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