Theoretical investigation into the influence of a teeth fault to gear train vibrations

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Abstract: *The vibration behavior of a healthy gear train is modelled as a sum of sinusoidal accelerations of a pinion, a gear, and a gear-mesh. A while noise is added trough waveform of normally distributed random numbers. The corresponding time-diagram and spectrogram are obtained. After that, an impulse acceleration waveform is added to simulate a teeth fault. The time-diagram and spectrogram are obtained again and compared. Conclusions are made.*
***Keywords**: GEAR TRAIN, FAULT, ACCELERATION WAVEFORMS, GEAR-MESH FREQUENCY, SIDE BANDS, VIBRODIAGNOSTIC, TIME-DIAGRAMS, SPECTROGRAMS, POWER SPECTRUM, CONDITION MONITORING*

1. Introduction

The gear mesh frequency (GMF) is the rate at which a gear tooth make contact, and it appears in the frequency spectrum regardless of the condition of the gears. ***Gear sidebands (GS)*** are frequency peaks appearing symmetrically around the *GMF* peak in a vibration spectrum. By modulating the *GMF* at the rotational speed of a specific gear, the *GS* indicate issues like wear, eccentricity, or misalignment. Analysing *GS* spacing helps diagnose which gear is faulty. This is because the sidebands are spaced at the faulty running speed, so they can indicate problems and are crucial for **predictive maintenance** in gearboxes.

Predictive maintenance is essential for gearboxes because it allows for the **early detection**. Engineers can identify potential failures before they lead to costly breakdowns. This proactive approach significantly **reduces downtime**, ensuring that production remains steady and efficient. Furthermore, it **extends the service life** of the gearbox components by preventing catastrophic damage to the entire system.

2. Prerequisites and means for solving the problem

The complex and multi-element approach is to model a completely gear transmission (including bearings, shafts, box, etc.) and simulate with the help of FEM [1, 3, 4, 5]. This is problematic for the following reasons:

1. The initial modeling is slow, and the time required for the simulation is long even on clusters of powerful computers. Therefore, changing the values of the parameters again and again, requires a lot of calculation time;

2. Many elements influence each other, their influences are mixed, and the dependencies that are the subject of the current study cannot be separated and analyzed. That is, it turns out that the complex model used is not suitable for the specific investigation.

3. Each of the modeled elements has its own parameters to which values must be assigned. But these values are often: not completely clear; dependable by time, load, temperature, etc., and these dependencies cannot be guaranteed to be linear. All of these uncertainties and inaccuracies are very likely to distance the study from real behavior.

As a consequence of the above, **the aim of this investigation** is to obtain results about the ability to identify a fault, analysing *GS* spacing of a phenomenological vibration model of a gear train with presence of white noise environment disturbance.

Therefore, in this investigation the vibration behavior of a healthy gear train is modelled as a sum of sinusoidal accelerations of a pinion, a gear, and a gear-mesh [2, 7, 6]. The influence of other transmission elements and of other mechanisms in the transmission environment, is taken into account adding while noise trough waveform of normally distributed random numbers. Finaly, an impulse acceleration waveform is added to simulate a teeth fault. The time-diagram and spectrogram are obtained and compared. **This is simple, but powerful method, which has flexibility and rapidity.**

3. Solution of the examined problem

The parameter values used is shown in Table 1.

***Table 1**.* Parameter values

Sample rate, KHz	fs	10
Number of pinion teeth	Np	20
Number of gear teeth	Np	81
Rotation speed of pinion, rps	f_{pin}	50
Pinion acceleration amplitude, m/s^2	A_p	0.4
Gear acceleration amplitude, m/s^2	A_g	0.2
Gear-mesh acceleration amplitude, m/s^2	A_{GM}	1

The pinion acceleration waveform is generated according to

(1) $$a_p = A_p \sin(2\pi\ f_{pin}\ t).$$

The gear acceleration waveform is generated according to

(1) $$a_g = A_g \sin(2\pi\ f_{gear}\ t).$$

The gear-mesh acceleration waveform is generated according to

(3) $$a_{GM} = A_{GM} \sin(2\pi\ f_{mesh}\ t).$$

Then, the healthy acceleration is obtained as a sum of (1), (2), and (3). After that, white noise is added trough waveform of normally distributed random numbers – Fig. 1. The time-diagram of the vibration acceleration of the healthy train model is shown on Fig. 2.

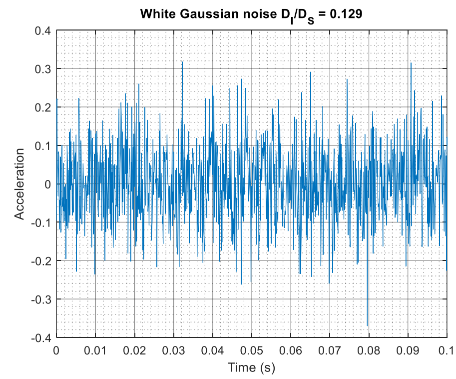

Fig. 1. The time-diagram of the white noise added

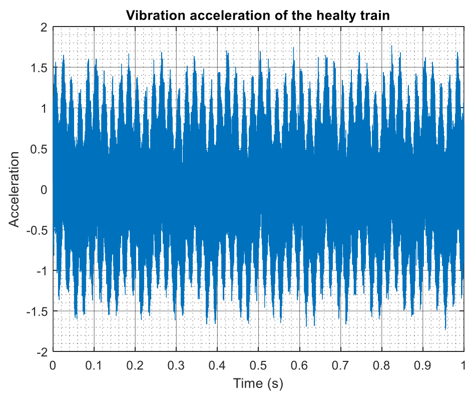

Fig. 2. The time-diagram of the healthy train

The Discrete Fourier Transform is performed according to

(4) $$X(k) = \sum_{n=0}^{N-1} x(t)\ e^{-i\frac{2\pi}{N}kt},$$

where: x is the input signal in the time area, with length n; X – output signal in the frequency area, with length k; $x(t)$ – the value of the input signal at time t; and $X(k)$ – complex number, carrying amplitude and phase information at frequency k.

Through (4), the spectrogram of the healthy vibration acceleration is obtained and presented on Fig. 3. With red vertical lines are marked gear sidebands frequencies. On Fig. 3, one can observe that there are **six peaks**, that matches with sideband frequencies – they are marked with green circles.

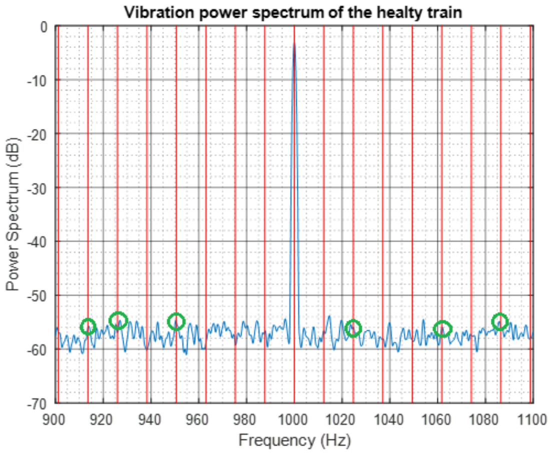

Fig. 3. The spectrogram of the healthy train

The next step is to add an impulse waveform to simulate a teeth fault – Fig. 4.

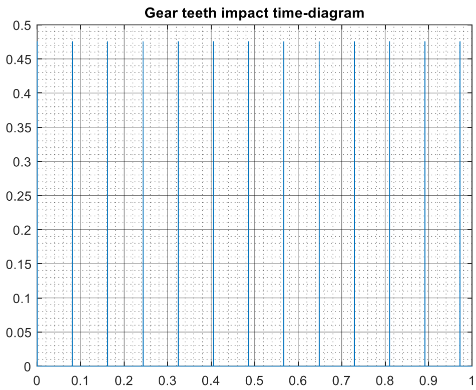

Fig. 4. The time-diagram of the impulse used

The resulting acceleration is shown on Fig. 5. One can observe and compare the time-domain signals from Fig. 2 and Fig. 5. There are not visible differences that indicates signal change and fault presence.

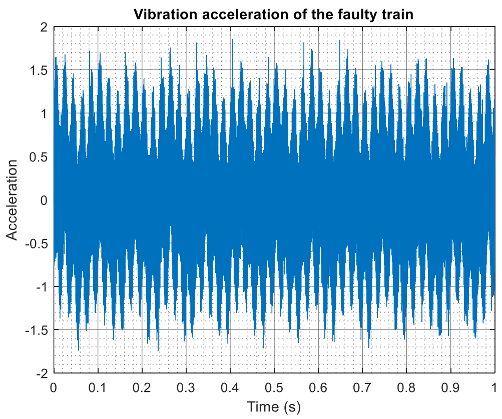

Fig. 5. The time-diagram of the faulty train

After that, the Fourier transform is performed again and the spectrogram of the faulty train is obtained – Fig. 6. One can observe that there are **thirteen peaks**, that matches with sideband frequencies – they are marked with green circles.

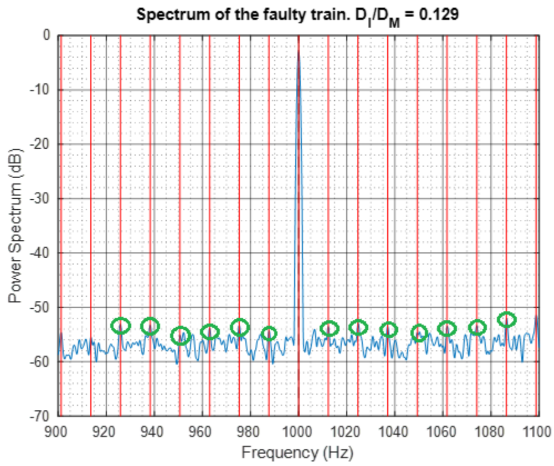

Fig. 6. The spectrogram of the faulty train

4. Conclusions

This investigation shows that by comparing the spectrogram of the healthy gear train model (Fig. 3) and the faulty train model (Fig. 6), one can identify the problem presence. But an interesting question is what is the influence of the white noise density and of the faulty impulse amplitude on this ability the problem presence to be identified. So, this can be marked as a topic for the future investigation.

A basis for this future investigation is the deviation indicator shown in the titles of Fig. 3 and Fig. 6. The standard deviation of the white noise used are calculated and marked with D_I. The standard deviation of the healthy acceleration (obtained as a sum of equations (1), (2), and (3)) are also calculated and marked with D_M. On Fig. 3 and Fig. 6 titles, one can see the indicator obtained by dividing of these deviations. By varying the values if this indicator, the influence of above-described factors will be investigated in the future researches.

5. References

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