ROTATIONAL VIBRATIONS OF DIGITALLY CONTROLLED DRIVING UNITS RUNNING AT IDLE

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Abstract: The paper deals with the measurements of rotational vibrations of a lathe gearbox excited by driving units equipped by digital control systems. Angular vibration of the gearboxes input shaft of running at idle was identified as a source of no acceptable noise.

Key words: Rotational vibrations, angular vibrations, digital control systems

1. INTRODUCTION

The paper deals with noise and vibration measurements that were performed on driving system of a newly built lathe. The trouble-shooting task is to establish the cause of excessive non-machinery noise emitted by a lathe running at idle and subsequently to propose a possible cure for the problem at hand.

The lathe transmission system consists of a digitally controlled electric motor, propelling a gearbox by means of a belt. An arrangement of the lathe transmission system and analysis instrumentation is shown in Fig. 1.

![Arrangement of the lathe transmission system and the measurement instrumentation](image)

As the noise problem shall be solved at its very source, the first task is to verify uniformity of rotation. The reason for it is that the discrete control system is based on sampling of continuous signals and the finite wordlength for the input, internal and output variables of the discrete control system. In this case the steady-state rotation of the gearbox wheels is corrupted by rotational speed variation. Then the contact of unloaded free-running gears occurs on both the tooth flanks.

2. MEASURING ROTATIONAL VIBRATIONS

Measuring rotational vibrations of rotating shafts is a notoriously difficult problem (Angelo, 1987). The easiest way how to determine instantaneous rotational speed after each revolution is using a tacho probe giving one pulse per shaft rotation. Rotational speed in Hz equals to the inverse of the length of the time interval between consecutive tacho-pulses (tacho interval) as it is shown in Fig. 2. The tacho interval is determined by the trigger-level-crossing interpolation some 50 times more accurately than indicated by the actual sampling interval.

![Tacho signal generated by a tacho probe](image)

Variations of the input shaft rotational speed in RPM versus the current number of revolutions from a beginning are shown in part of Fig. 3 designated a). As the time axis of this plot is scaled in revolutions the FFT spectrum of the RPM-variations, shown in part b) of the same figure, is measured in orders. The component of 0.27344 orders, corresponding to 3.617 revolutions in average, is dominating in this order spectrum.

![Rotational speed variation, RPM vs. number of revolutions, order spectrum](image)

The instantaneous RPM is changing three levels in a non-regularly way, but no quite randomly or chaotic. Other measurement shows that the number of the RPM levels can be equal to two through four with one or two components dominating in the order spectrum.

As the above-mentioned digital control system is in fact a non-linear system the self-oscillations are excited. A phase trajectory in the RPM – ΔPRM plane tends to a limit cycle.

![Phase trajectory of the RPM variations](image)

3. MEASURING HOUSING VIBRATIONS

To examine the relationship between the RPM-variations and noise emitted by gearbox the acceleration signal of the gearbox housing is recorded. A strip-plot of the acceleration signal divided into 22 revolutions of the gearbox input shaft is shown.
in Fig. 5.

![Phase trajectory in a phase plane](image)

**Fig. 4. Phase trajectory in a phase plane**

![Acceleration signal vs. number of the input-shaft revolutions](image)

**Fig. 5. Acceleration signal vs. number of the input-shaft revolutions**

The bursts on this plot are distributed quite randomly along the revolution axis. Any regularity of their location during the input shaft, intermediate shaft and spindle cannot be determined.

![Order spectra](image)

**Fig. 6. Order spectra, a) order spectrum averaged in the frequency domain, b) order spectrum of the time signal averaged in the time domain averaged signal**

Averaged order spectra, corresponding to the time signal in Fig. 5, are shown in Fig. 6. The spectrum designated by a) is averaged in the frequency domain while the spectrum designated by b) is evaluated as the FFT of the time signal averaged synchronously in the time domain (Tuma, 1998).

The dominating components are harmonics of the base frequency equaling to the toothmeshing frequency of the 25-tooth gear mounted on the input shaft. Both the spectra differ in the level of their background. The level of the background in the order spectrum in Fig. 6a is higher than this level in the order spectrum in Fig. 6b. Noise with a spectrum, which is similar to one in Fig. 6b, is designated as tonal and it is emitted by geared axis systems. The synchronously averaged time signal, corresponding to the time signal shown in Fig. 5, is shown in Fig. 7. The time domain averaging is a result of 200 revolutions of the gearbox input-shaft. In comparison the averaged acceleration signal is much uniform than the bursted signal in Fig. 5.

![Synchronously averaged acceleration signal during a gear revolution](image)

**Fig. 7. Synchronously averaged acceleration signal during a gear revolution**

Mentioned non-machinery noise is caused by spectrum components out of synchronism with the frequency or rotation. These components are vanished from the order spectrum by averaging in the time domain.

The proposed cure consists in improving of:
- uniformity of running of driving electric motor
- accuracy of tooth geometry.

4. CONCLUSION

The topic discussed in the paper is focused on the noise emitted by gearboxes running at idle while they are driven by digitally controlled electric motors. The effect of uniformity of rotation speed on noise is highlighted. It can be concluded that the variations of rotational speed are required to be as smooth as it is possible.

5. REFERENCES


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