研 究 速 報

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MEASUREMENT OF CORRELATION OF FLUCTUATION BETWEEN ROTATIONAL VELOCITY AND FREQUENCY IN MACHINE TOOL VIBRATION

工作機械の振動における回転速度と振動数との変動の相関の測定

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1. Introduction

Nowadays most self-excited vibrations in machining are considered to be caused by the regenerative effect. The theory of regenerative effect is based upon the assumption that a phase difference between the vibratory displacement and the oscillatory cutting force permitting the cutting force to supply the vibratory system with energy is determined only by the rotational velocity of work or tool and the frequency of vibration. The rotational velocity is expected to fluctuate in case that friction transmissions such as belts and pullies are included in the driving mechanism of a machine tool. Therefore, if energy is really supplied by the regenerative effect, a correlated fluctuation must appear in the frequency to maintain a constant phase difference in spite of the fluctuation of the rotational velocity.

To investigate whether the rotational velocity fluctuates or not and whether a correlated fluctuation appears in the frequency or not, the authors devised a measuring apparatus which can detect fast fluctuations of both the rotational velocity and the frequency.

2. Measuring Apparatus

Measurement of fluctuation is carried out by making use of FM techniques.

Two indentical spur gears are used to make a transducer which converts the fluctuation of the rotational velocity into an FM wave. The gears are positioned coaxially in face to face relation with a narrow air gap as shown in Fig. 1, one being fixed to a rotating work and another being stationarily mounted on an insulation material. Capacitance of the air gap between the gears is detected.

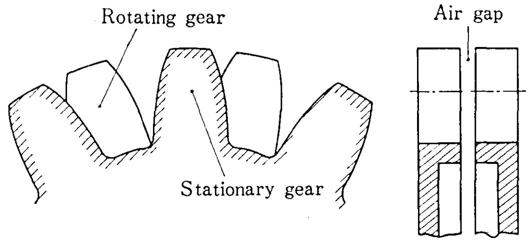

Fig. 1 Arrangement for generating an FM wave.

If the rotational velocity of work varies sinusoidally with time, the angular velocity can be represented by

$$\omega=\omega_0+\Delta\omega\cos pt \quad \cdots\cdots (1)$$

where ω is the angular velocity, ω_0 is the mean angular velocity, $\Delta\omega$ is the amplitude of fluctuation and p is the angular frequency of fluctuation. Integrating Eq. (1) gives the angular position of work as

$$\varphi=\int\omega(t)dt=\omega_0 t+\frac{\Delta\omega}{p}\sin pt$$

Let $\phi=2\pi n$ at the time when the teeth of two gears align as viewed in axial direction where ϕ is the electric phase angle and $n=0, \pm1, \pm2, \cdots\cdots$. Then the capacitance variation is given by $C=C_0\cos\phi$. Since $\phi=z\varphi$ where z is the number of teeth, the capacitance fluctuation is represented by

$$C=C_0\cos\left(z\omega_0 t+\frac{z\Delta\omega}{p}\sin pt\right) \quad \cdots\cdots (2)$$

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It is seen from Eq. (2) that the capacitance variation is an FM wave whose carrier frequency is $z\omega_0$. When z is a large number, the carrier frequency can be larger than two times of the signal frequency $p/(2\pi)$ and thus the fluctuation of the rotational velocity becomes detectable. In the case of the gears used here $z=400$.

The stationary gear is not essential to make a transducer. An FM wave given by Eq. (2) can also be obtained for example by an arrangement in which an electromagnetic pickup is located close to the periphery of the rotating gear as the teeth pass successively by the pickup. In the one gear arrangement, however, possible pitch errors of the gear can be mistaken for the flucturtion of the rotational velocity. Hence, at first a two gear system as shown in Fig. 1 was employed to counterbalance individual pitch errors, but later pitch errors of the gears used here were found to be too small to affect FM waves generated. A disc with radial slits can replace a gear.

No transducer is required for the frequency because a wave whose frequency fluctuates is an FM wave itself.

A pulse counting circuit is employed as a demodulation circuit to cover wide change of the mean frequency of input. The circuit is shown in Fig. 2 in the form of a block diagram. The

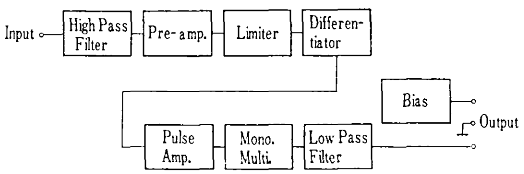

Fig. 2 Block diagram of the demodulation circuit.

multivibrator is adapted to change the width of pulse it generates stepwise by three steps according to the mean frequency of input to achieve higher level of gain. Bias is applied to compensate the DC component of the output of the lowpass filter, which corresponds to the mean frequency.

Fig. 3 shows a static characteristic of the circuit, in which p in Eq. (2) is kept to zero and

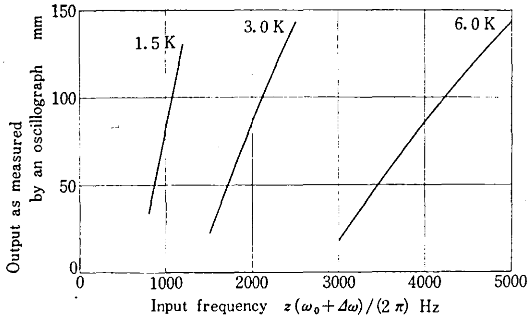

Fig. 3 Static characteristic of the circuit. Numerals on the curves indicate the upper limit frequencies respective curves can cover.

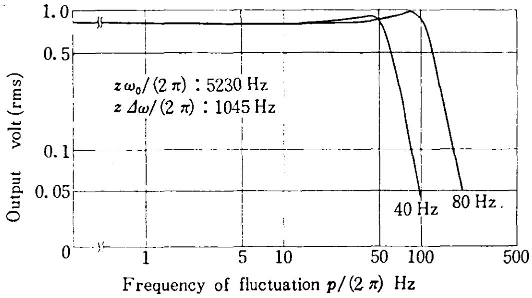

Fig. 4 Dynamic characteristic of the circuit. Numerals on the curves indicate the cutoff frequencies of the low pass filter.

$z(\omega_0+\Delta\omega)$ is varied. A suitable pulse width is selected according to the frequency band of input. Fig. 4 shows a dynamic characteristic of the circuit, in which $z\omega_0$ and $z\Delta\omega$ are kept constant and p is varied. FM waves required to get the dynamic characteristic are easily obtained by making use of a modulation circuit in a data recorder.

3. Results of Measurement

Fig. 5 shows fluctuations of both the rotational velocity of work and the frequency of vibration of work in a self-excited vibration in cylindrical plunge grinding. Close correlation of fluctuation between the rotational velocity and the frequency can be seen. The authors consider that the close correlation implies the existence of a synchronization effect. A similar close correlation is shown in Fig. 6 which was obtained when a self-exited vibration occurred in turning of brass. Since the time

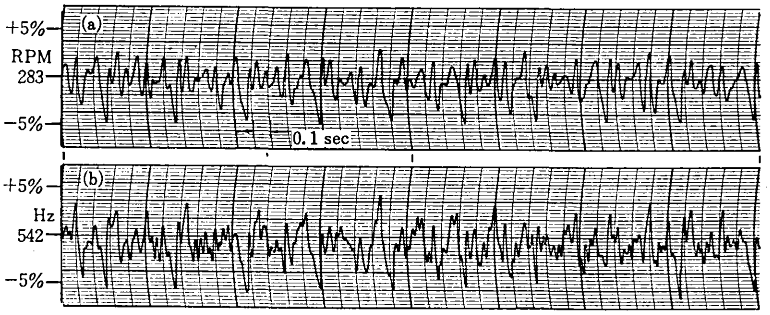

Fig. 5 Correlation of fluctuation in cylindrical grinding.
(a) rotational velocity of work
(b) frequency of self-excited vibration of work

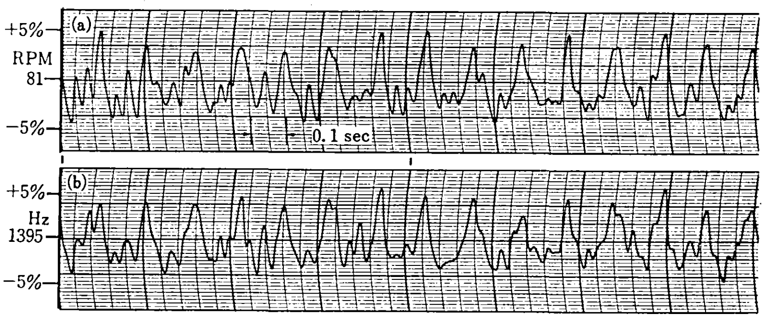

Fig. 6 Correlation of fluctuation in turning of brass.
(a) rotational velocity of work
(b) frequency of self-excited vibration of tool

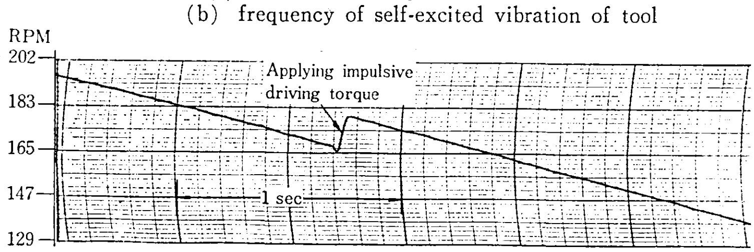

Fig. 7 Decreasing rotational velocity of a freely rotating spindle as measured by the apparatus

interval of noticeable drops in the rotational velocity coincides with the period of circulation of a driving belt in both cases, it is obvious that the variation of the rotational velocity is caused by the varying conditions of engagement between belts and pullies. In Fig. 5 ripples in frequency variation whose period is nearly 0. 03 second are considered to be caused by the varying properties of the grinding wheel around the periphery because the period coincides with the period of rotation of the wheel.

The measuring apparatus has variety of applications in measuring the rotational velocity. Fig. 7 shows a decreasing rotational velocity of a spindle after cutoff of driving torque. A sudden increase in velocity due to applying impulsive driving torque is detected.

4. Conclusions

Fast fluctuations of both the rotational velocity and the frequency were detected by a measuring apparatus the authors devised.

Close correlation of fluctuations was found between the rotational velocity of work and the frequency of vibration when self-excited vibrations occurred in grinding and turning.

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