Measurement Techniques, Vol. 52, No. 6, 2009

MECHANICAL MEASUREMENTS

MEASUREMENT OF THE DYNAMIC CHARACTERISTICS OF MACHINE TOOLS BY A PULSE LOADING METHOD

N. A. Kochinev[1] and F. S. Sabirov[2]

UDC 621.9.06.014

A pulse loading method for estimating the dynamic characteristics of the elastic systems of machine tools is considered, which gives considerable advantages compared with harmonic loading, requires the minimum amount of measuring apparatus, is simple to use, and provides a computer representation of the results and need not be changed for tests under production conditions. The original software enables the frequency characteristics of elastic systems to be obtained rapidly and reliably. It can be used successfully for vibroacoustic diagnostics of equipment and technological processes in metal processing.

***Key words**: pulse loading, impact action, frequency characteristics, elastic systems, equipment diagnostics, vibroacoustic signals.*

The dynamic characteristics of elastic mechanical systems, in particular, machine tools, are most often represented in the form of frequency characteristics: amplitude-frequency characteristics, phase-frequency characteristics or complex frequency characteristics, namely, amplitude-phase frequency characteristics. These characteristics largely reflect such important features of a machine tool as its productivity, accuracy and operating capability (reliability), and hence it is an extremely important problem to determine them.

One can obtain the frequency characteristic experimentally by setting up an external force and measuring the response of the system at certain points. For a harmonic force, a considerable set of apparatus and devices are necessary, including a vibrator with fittings to attach it, an audiogenerator, a power amplifier and measuring equipment [1]. Hence, although the harmonic-excitation method also gives reliable and authentic estimates of the characteristics, it is difficult to use under production conditions. A method employing a pulse load, which requires a minimum of apparatus, can be competitive to it. The pulse excitation method has been well recommended for determining the forms of oscillations of machine tools [2] and has obtained further development, which we will indicate below.

To obtain the frequency characteristics of the elastic systems of machine tools, we can use the same apparatus that is employed to estimate the balance of elastic displacements of the supporting system of machine tools [3], and also for the diagnostics and monitoring of the technological processes in metalworking [4]. This consists of a dynamometric hammer, one or two sensors of the absolute oscillations (an accelerometer) with amplification units, an analog-to-digital converter and a computer (notebook) with original software.

[1] ENIMS OAO, Moscow, Russia.
[2] Stankin Moscow State Technological University, Moscow, Russia; e-mail: FANIRA5057@yandex.ru.

Translated from Izmeritel'naya Tekknika, No. 6, pp. 39–41, June, 2009. Original article submitted March 30, 2009.

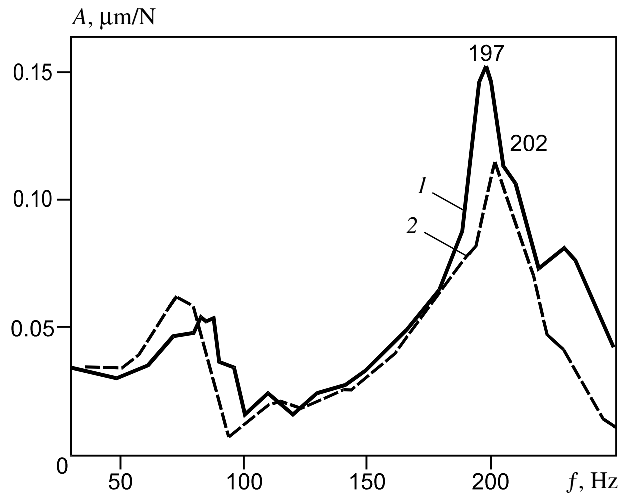

Fig. 1. Amplitude-frequency characteristic of the elastic system, obtained with a harmonic form of excitation (*1*) and a pulse form of excitation (*2*).

TABLE 1. Logarithmic Decrement of the Attenuation of the Oscillations for Different Excitation and Material of the Shock Part of the Dynamometric Hammer

Form of excitation	Material of the hammer face	Logarithmic decrement
Harmonic	–	0.3–0.32
	Rubber	0.6–0.7
Pulse	PTFE	0.37–0.5
	Textolite	0.42–0.45

In the case of harmonic excitation with a vibrator, a load is produced between the branches of the article and the instrument ("relative" loading), which corresponds to the actual load when using the machine tool. The oscillations between the article and the instrument are measured with a sensor of relative oscillations. The frequency characteristic of the machine tool is then

$$W_{yP} = y/P,$$

where y are the relative oscillations, and P is the relative load.

For pulse loading, an "absolute" load is produced by the shock method and, as a rule, absolute oscillations are measured. In this case, to obtain the complete characteristic W_{yP} it is necessary to measure the following four quantities:

$$W_{11} = y_1/P_1; \quad W_{12} = y_1/P_2; \quad W_{21} = y_2/P_1; \quad W_{22} = y_2/P_2;$$

where y_1 and y_2 are the absolute oscillations, measured on the article and the instrument, and P_1 and P_2 are the absolute loads on the article and the instrument.

The overall characteristic is found from the formula

$$W_{yP} = W_{11} + W_{22} - W_{12} - W_{21}.$$

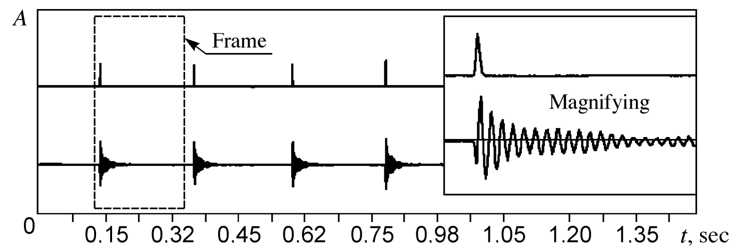

Fig. 2. Series of pulses on the elastic system and the responses to them.

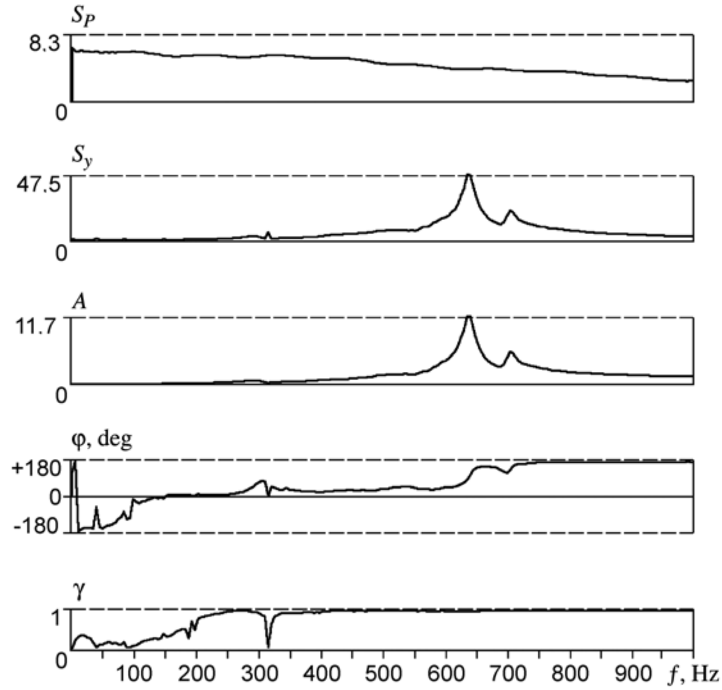

Fig. 3. Characteristics of the elastic system: *I*) spectrum of the input action (pulse); *II*) response spectrum; *III*) amplitude-frequency characteristic; *IV*) phase-frequency characteristic; *V*) coherence function.

The pulsed force is produced by a dynamometric hammer. The force is measured using a piezoelectric dynamometer, built in to the hammer. The additional mass and material of the shock part can change the duration of the pulse, and, of course, also the frequency range of the perturbation spectrum. They must be chosen so as to ensure a fairly high level of the excitation spectrum over the working frequency band.

The operating capability of the method and the reliability of the data obtained were estimated by comparing the frequency characteristics obtained using harmonic and pulse loading. As mentioned above, the frequency characteristic obtained for harmonic excitation was taken as the standard. The amplitude-frequency characteristics of the same elastic system under the same conditions, obtained by harmonic and pulse loading are shown in Fig. 1, from which it can be seen that there is fairly good agreement between them. However, in practice, in all cases, when pulse excitation was used the fundamental resonance amplitude was somewhat less (by 20–25%), i.e., the decrement of the oscillations is greater (see the table).

The complexity of the calibration of the force and vibration channels in the pulse method is due to the fact that piezoelectric sensors, as a rule, do not react to the constant component. The force sensor can be calibrated by a shock from

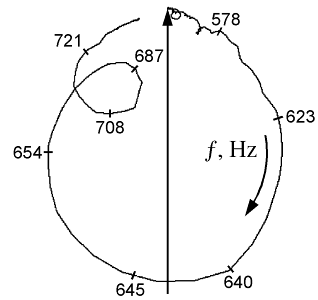

Fig. 4. An example of the amplitude-phase frequency characteristic of the elastic system of a lathe, obtained using pulses.

a standard dynamometer and by recording two signals on a computer, the calibration of absolute-oscillation sensors on a standard vibration bench.

It was established experimentally that absolute-oscillation sensors may introduce considerable phase distortions. Hence, it is necessary to carry out phase calibration of the measurement channels, including the vibration sensor, the amplifier, the channel multiplexor and the analog-to-digital converter.

To record and process the data, we developed a special program called nkRecorder. The signals were recorded using an automatic recorder. The duration of the recording was set by the program. The maximum duration is determined in practice by the amount of free disk storage space. For a large volume of input data, the signals are scanned frame by frame, the size of which depends on the computer parameters (primarily, on the video memory capacity and the required discreteness in representing the signal on the screen). The following signal processing is possible in the time domain: cutting out, storage of the fragments, statistical processing (calculation of the mean, moments of the distribution up to the third order, filtering (low-pass, high-pass and octave), trend, automatic sampling of a specified length and level, and construction of the phase portraits for two signals).

A fast Fourier transform is carried out, the spectral power densities are calculated, as well as the mutual spectral powers, and an estimate of the coherence, as well as single and double integration of the signals (when recording vibration velocity or vibration acceleration).

For random and pulse excitation, the frequency characteristics can be obtained using a spectral analysis of a number of signal samples. In accordance with the theory of random-signal processing, a Fourier transformation of a transient pulse characteristic gives its frequency characteristic [5].

An example of the recording of the signals on the computer is shown in Fig. 2. By setting the frame to a certain duration (the frame should cover the whole transient, but not be superimposed on the next one), samples are produced. For each sample, a fast Fourier transform is carried out and the autospectra of the channels S_{PP}, S_{yy}, the real part R_{yP} and imaginary part I_{yP} of the parts of the mutual spectrum $S_{yP} = R_{yP} + iI_{yP}$ are calculated from the formulas

$$S_{PP} = R_P^2 + I_P^2; \quad S_{yy} = R_y^2 + I_y^2; \quad R_{yP} = R_p R_y + I_P I_y; \quad I_{yP} = I_p R_y - I_y R_P.$$

The spectra are then averaged over all the samples SS_{PP}, SS_{yy}, RR_{yP}, II_{yP}. The spectra obtained are used to calculate the real part (Re) and the imaginary part (Im) of the amplitude-phase frequency characteristic

$$\mathrm{Re} = RR_{yP}/SS_{PP}, \quad \mathrm{Im} = II_{yP}/SS_{PP}$$

and the coherence function.

The coherence function (Fig. 3) provides the means for estimating the degree of linearity of the relation between the input and output signals: $-\gamma^2 = |SS_{yP}|^2/SS_{yy}SS_{PP}$, where $0 \le \gamma^2 \le 1$.

The limiting values of the coherence functions are “1” when there is no noise and “0” when pure noise is present. The coherence function for each frequency indicates the extent to which the signals at the input and output of the system are related linearly. It is similar to the square of the correlation coefficient, used in statistics. For dynamic investigations, it is this important property that is used to reveal a whole series of possible errors. It should be borne in mind that the physical meaning of this function only appears when several samples, corresponding to individual pulses, are available. A meaningless result is obtained for a single sample [5], since the coherence function will be equal to unity for all frequencies.

Often, when constructing the amplitude-phase frequency characteristic of elastic systems, the hodograph in the region of the resonance frequencies is a broken line due to the large frequency step, which, in turn, depends on the sample length. A smoothing procedure is provided in the nkRecorder program based on linear interpolation of the inverse value of the hodograph for a specified number of points. In Fig. 4 we show, as an example, the smoothed amplitude-phase frequency characteristic of the elastic system of a lathe.

Hence, the pulse method of measuring the frequency characteristics of elastic systems can be used successfully to investigate and test machine tools under production conditions. It requires the minimum amount of apparatus, is fairly accurate, and the computer representation of the results of the analysis increases its convenience considerably.

REFERENCES

1. *Determination of the Amplitude-Phase Frequency Characteristics of Machine Tools of Average Dimensions and Their Analysis*, ONTI, ENIMS, Moscow (1974).
2. N. A. Kochinev, *Stanki i Instrument*, No. 6, 6 (1987).
3. N. A. Kochinev and F. S. Sabirov, *Izmer. Tekhn.*, No. 6, 32 (2006); *Measur. Techn.*, **49**, No. 6, 572 (2006).
4. M. P. Kozochkin, N. A. Kochinev, and F. S. Sabirov, *Izmer. Tekhn.*, No. 7, 30 (2006); *Measur. Techn.*, **49**, No. 7, 672 (2006).
5. J. Bendat and A.Peirsol, *Applications of Correlation and Spectral Analysis*, Wiley, New York (1983).