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THE CHARACTERISTIC DIFFERENTIAL SPECTRUM OF A CONVENTIONAL SUBSTITUTE SIGNAL SOURCE IN MACHINERY TESTING

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The paper concerns the evaluation of the acoustic signal which carries information on the dynamics of the interaction of machine elements. A method is presented which can be used for the experimental testing of machine characteristics by periodic excitation of the machine. The essence of this method is a new evaluation of the signal in the form of characteristic differential spectra which are dependent on the dynamics of the interaction of elements of the object to be tested and independent of the position of the microphone.

1. Introduction

The testing of machines by acoustic methods may involve attestation, diagnostic and constructional tests. This paper does not deal with attestation tests, the main purpose of which is the evaluation of noise and vibrations in the light of ergonomic criteria. The purpose of constructional tests is to check the tested object for design correctness. The purpose of diagnostic tests is the appraisal of the condition of a tested object. In the tests described here evaluation of the design and condition is made indirectly by evaluation of the dynamics of the interaction of the elements of the tested object. The conclusions will be based on the statement that the acoustic effects and vibrations of the object depend on the dynamics of the interaction of elements. Constructional tests should include several machines while diagnostic tests should cover only a single machine.

It has been assumed that the object to be tested may be described by

$$(K \wedge ST \wedge WD), \tag{1}$$

where K is the design of the tested object determined by the geometrical, material and dynamic features of the construction [3]; it constitutes the input information of the production process whose result is the tested object; ST is the condition of the tested object and describes a set of evaluations of the correctness test of operation and degree of wear of the object; WD are the operating conditions that describe a set of inputs and outputs of the tested object (e.g. speed, power).

The design is understood to be the result of the designing process, but not a direct description of the tested object. For instance, a geometrical constructional feature concerning the shaft determines a permissible deviation of the diameter or the tolerance of the execution of the construction of such products including, among others, the tested object. This feature does not describe the value of the diameter determined by measurement of the tested object. The statement that the tested object corresponds to its design is an assumption that requires verification, which will consists, in part, in checking that the measurement system is within the assumed tolerance field.

One of the basic methods of analysis used in acoustic methods of machinery testing is a frequency analysis of the signals. A *signal* here means the acoustic effect or vibrations of the tested object. Signal spectra are a direct result of experimental tests. A *signal spectrum* in this paper will be the distribution of, the signal power in consecutive frequency bands with constant relative width-determined for a certain frequency range. It has been assumed that the descri bed spectrum is a set of power levels in these bands,

$$W = \{w(f_j),\ j = j_p, \ldots, j_k\}, \tag{2}$$

where W denotes the spectrum as a set, w – the signal power level in the frequency band [dB], f_j – the mid-band frequency [Hz], j – the index (serial number) of the frequency band varying from j_p to j_k for bands of mid-frequencies from f_p to f_k.

We use a simplified notational form for the definition:

(2)
$$W = \{w(j),\ j = j_p, \ldots, j_k\}. \tag{3}$$

The classification of the frequency range into bands of constant relative width and the establishment of indices for the frequency bands has been formulated in order to adopt a uniform system of notation.

It has been assumed that

– 1000 Hz is always the mid-range frequency;

– the index of the band with mid-frequency 1000 Hz equals zero, i.e.

$$\begin{aligned} f_j &= 1000\ \text{Hz} \to j = 0, \\ f_j &< 1000\ \text{Hz} \to j < 0, \\ f_j &> 1000\ \text{Hz} \to j > 0; \end{aligned} \tag{4}$$

– the number which determines the accepted classification into bands and indirectly determines the band width is the so-called *band spacing* x,

$$x = f_{j+1}/f_j.$$

From the above we obtain

$$f_j = 1000\ x^j\ [\text{Hz}]. \tag{6}$$

Experimental tests have been performed for various conditions of the tested object. A limitation has been accepted that the tested objects are machines for which a certain characteristic excitation frequency f_m can be defined. For example, one of characteristic excitation frequencies f_m for gear transmissions is the meshing frequency f_z,

$$f_m = f_z \frac{nz}{60} \text{ [Hz]}, \tag{7}$$

where n is the rotational speed of the toothed element [r.p.m.] and z – the number of teeth on the toothed element.

It has been assumed that the characteristic frequency f_m is equal to the mid-band frequency of one of the bands with fixed relative width. This obviously limits the operating conditions which may be established during testing. For instance, if the tested object is a gear transmission, then the rotational speed can be evaluated from the following formula:

$$n_j = 60\,000\, x^j/z \text{[r.p.m.]} \quad \text{for } j = 0, \pm 1, \pm 2, \ldots \tag{8}$$

The index m, in the denotation of the characteristic frequency f_m, is an integer equal to the index j of mid-band frequency f_j equal to f_m. Thus from equation (6)

$$m = \log_x(f_m/1000). \tag{9}$$

2. Spectra of the characteristic and resonance signals

The spectra of signals determined for various operating conditions of a large number of gear transmissions [1, 4, 6] have been compared. Special attention was paid to the occurrence of local maxima of the spectrum caused by resonance phenomena, as well as to the occurrence of maxima that correspond to the harmonics and subharmonics of the meshing frequencies. It has been found [1] that, for a limited range of operating conditions, the signal spectrum can be regarded as the sum of the spectra of three independent signals,

$$W = S + R + L, \tag{10}$$

where W is the spectrum of the analyzed signal, S – the spectrum of a signal called the characteristic signals, R – the spectrum of a signal called the resonance signal, and L – the spectrum of a signal referred to as pink noise.

The characteristic signal depends on the dynamics of the interaction of the elements of the tested object and on the value of the characteristic frequency f_m determined by the design and operating conditions of the object.

A feature of this signal is the stability of its spectrum described on a relative scale of frequency, that is on a frequency scale referred to the characteristic frequency f_m (Fig. 1).

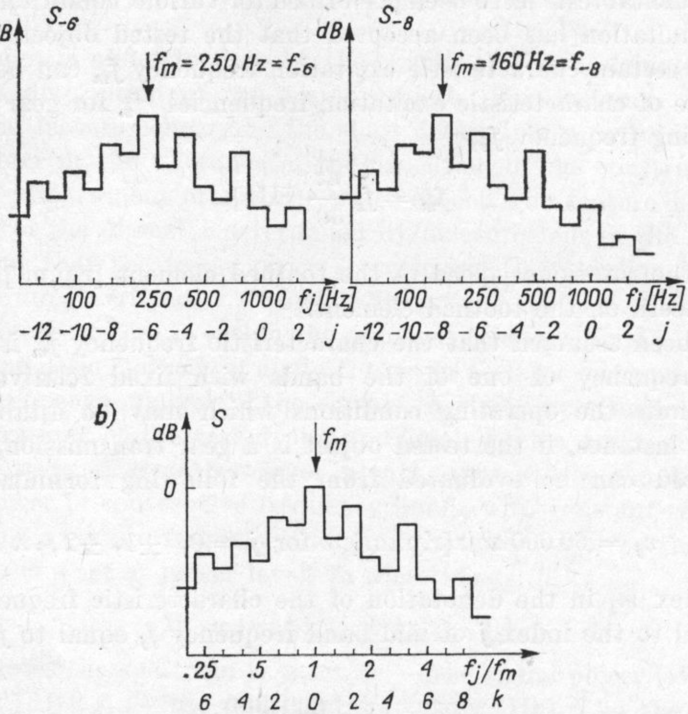

Fig. 1. **Characteristic spectrum: a) in terms of an absolute frequency scale for various characteristic frequencies, b) in terms of a relative frequency scale**

The spectrum of the characteristic signal can be written:

— in terms of an absolute scale of frequency as

$$S_m = \{s_m(j),\ j = j_p, \ldots, j_k\}, \tag{11}$$

where $s_m(j)$ is the value of the power level of a typical signal in the j-th frequency band for a characteristic frequency equal to f_m;

— and in terms of relative scale of frequency as

$$S = \{s(k),\ k = k_p, \ldots, k_k\}, \tag{12}$$

where

$$s(k) = s_m(k+m). \tag{13}$$

The resonance signal does not depend on the operating conditions of the tested object. Its spectrum describes the resonance properties of the object and can be denoted as

$$R = \{r(j),\ j = j_p, \ldots, j_k\}. \tag{14}$$

In view of the necessity to establish reference levels for characteristic and resonance signals it has been assumed that:

— the level of the spectrum of the typical signal $s(k)$ for the mid-band frequency $f_j = f_m$ is equal to 0 dB,

$$s(0) = 0\,[\mathrm{dB}], \tag{15}$$

— and the level of the resonance signal spectrum for the mid-band frequency of 1000 Hz is equal to 0 dB,

$$r(0) = 0\,[\mathrm{dB}]. \tag{16}$$

Bearing in mind the assumptions (15) and (16) and the dependence (10), a third signal in the form of pink noise has been introduced. The spectrum of this signal is described by a constant level l_m of the power in all frequency bands. It can be interpreted as the power $w(j)$ of the analyzed signal in the mid-frequency band (at 1000 Hz) for operating conditions that cause the occurrence of a characteristic frequency $f_m = 1000$ Hz.

Within the range of the tests performed on gear transmissions [1], a relationship between the tested object, the measuring conditions and the spectra defined (S, R, L), was found to exist (Fig. 2).

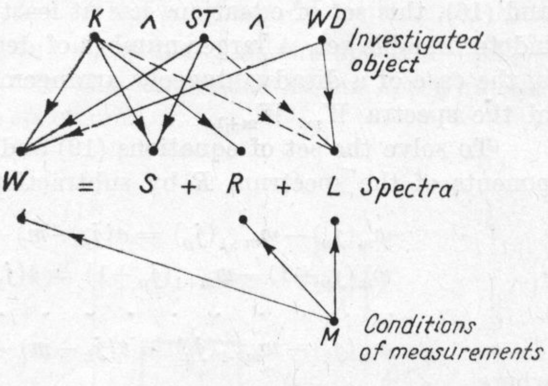

Fig. 2. Relationships encountered between the tested object, the measuring conditions and the defined spectra S,R,L

For the calculation of the spectra S, R and L, it is necessary to measure spectra for various operating conditions, i.e. for various characteristic frequencies. The number of different characteristic frequencies for which spectra W are determined should be at least 2. If the number is greater than 2, it is possible to calculate the spectra to be determined and to define the confidence interval for their components.

3. Determination of the spectra S, R and L-differential spectra

The results of measurements made are spectra W_m determined in the range $f_p - f_k$ at characteristic excitation frequencies f_m equal to successive mid-band frequencies $m, m+1, \ldots$

Let the number of f_m be equal to 2. On the basis of equation (10) we can write

$$W_m = S_m + R + L_m \tag{17}$$

and

$$W_{m+1} = S_{m+1} + R + L_{m+1}. \tag{18}$$

In equations (17) and (18) the unknowns are S_m, S_{m+1}, R, L_m and L_{m+1}. Using (13) we can write equations (17), (18) in the form:

$$\begin{aligned} w_m(j_p) &= s(j_p - m) + r(j_p) + l_m, \\ w_m(j_p+1) &= s(j_p+1-m) + r(j_p+1) + l_m, \\ &\cdots \\ w_m(j_k) &= s(j_k - m) + r(j_k) + l_m; \end{aligned} \tag{19}$$

$$\begin{aligned} w_{m+1}(j_p) &= s(j_p - (m+1)) + r(j_p) + l_{m+1}, \\ w_{m+1}(j_p+1) &= s(j_p+1-(m+1)) + r(j_p+1) + l_{m+1}, \\ &\cdots \\ w_{m+1}(j_k) &= s(j_k - (m+1)) + r(j_k) + l_{m+1}. \end{aligned} \tag{20}$$

It can be proved that after giving consideration to the conditions (15) and (16), this set of equations has at least one degree of freedom, i.e. it is an indeterminable set. A larger number of degrees of freedom can be encountered in the case of a disadvantageous arrangement of the values of the components of the spectra W_m, W_{m+1}.

To solve the set of equations (19) and (20), we remove the unknown components of the spectrum R by subtraction of corresponding equations

$$\begin{aligned} w_m(j_p) - w_{m+1}(j_p) &= s(j_p - m) - s(j_p - m - 1) + d, \\ w_m(j_p+1) - w_{m+1}(j_p+1) &= s(j_p+1-m) - s(j_p - m) + d, \\ &\cdots \\ w_m(j_k) - w_{m+1}(j_k) &= s(j_k - m) - s(j_k - m - 1) + d, \end{aligned} \tag{21}$$

where

$$d = l_m - l_{m+1}. \tag{22}$$

Substituting from (15) into (21) we get

$$\begin{aligned} w_m(m) - w_{m+1}(m) &= 0 - s(-1) + d, \\ w_m(m+1) - w_{m+1}(m+1) &= s(1) - 0 + d. \end{aligned} \tag{23}$$

Thus the solution of the equation set (21) may be obtained in the form of a family of solutions, with family parameter equal to d.

The form of the solutions is

$$S = \{s(k),\, k = j_p - m - 1, \ldots, j_k - m\}, \tag{24}$$

where $s(k)$ is defined by the recurrence relations

$$s(k) = s(k-1) + w_m(m+k) - w_{m+1}(m+k) - d, \tag{25}$$

and

$$s(k) = s(k+1) + w_{m+1}(m+k+1) - w_m(m+k+1) + d. \tag{26}$$

Proceeding in a similar manner it is possible to determine the spectrum R.

The concept of differential spectra ΔS and ΔR, defined as invariants of the family of solutions of the set of equations (21) may be introduced. For the form of these spectra we have

$$\Delta S = \{\Delta s(k), \quad k = j_p - m, \ldots, \quad j_k - m - 1\}, \tag{27}$$

$$\Delta R = \{\Delta r(j), \quad j = j_p + 1, \ldots, \quad j_k - 1\}, \tag{28}$$

where

$$\Delta s(k) = s(k) - \tfrac{1}{2}[s(k-1) + s(k+1)], \tag{29}$$

$$\Delta r(j) = r(j) - \tfrac{1}{2}[r(j-1) + r(j+1)]. \tag{30}$$

Substituting from (25) and (26) into (29) we obtain:

$$\Delta s(k) = \tfrac{1}{2}[w_m(m+k) - w_m(m+k+1) + w_{m+1}(m+k+1) - w_{m+1}(m+k)]. \tag{31}$$

Similarly:

$$\Delta r(j) = \tfrac{1}{2}[w_m(j) + w_{m+1}(j) - w_m(j-1) - w_{m+1}(j+1)]. \tag{32}$$

The graphical representation of the components of the spectrum ΔR is shown in Fig. 3. It should be stressed that the components of this spectrum are very sensitive to local extremes of the spectrum.

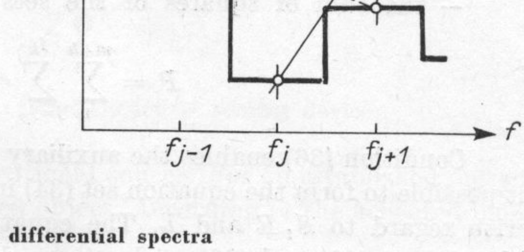

Fig. 3. Component $\Delta r(j)$ of a differential resonance spectrum

4. Deviation of differential spectra

The above method of determining the spectra ΔS, ΔR on the basis of knowledge of the spectra W_m, W_{m+1} does not permit the determination of the deviations and confidence interval for components of the spectra ΔS, ΔR that are looked for.

To determine the deviations of the spectra of interest, it is necessary to know the set of spectra $W_m, W_{m+1}, \ldots, W_{m+h}$, where h is higher than unity.

The determination of the spectra ΔS and ΔR now involves solving the following equations:

$$\begin{aligned} W_m &= S_m + R + L_m, \\ W_{m+1} &= S_{m+1} + R + L_{m+1}, \\ &\cdots\cdots\cdots \\ W_{m+h} &= S_{m+h} + R + L_{m+h}. \end{aligned} \tag{33}$$

Attention should be called to the fact that the spectra $W_m, W_{m+1}, \ldots,$ are determined by measurement and as such involve a certain deviation due to the measurement itself. These deviations cause the spectra ΔS, ΔR, determined according to equations (31) and (32), from successive pairs of equations of (33), to be different and thus to cause a variance in this equation system. An additional reason for the variance of the equation set (33) may be ascribed to the fact that the assumptions on which it is based have not been fully satisfied.

To obtain the most reliable solution ΔS, ΔR, the so-called «agreement» of the equation set (33) is found in the form

$$\begin{aligned} W_m + E_m &= S_m + R + L_m, \\ &\cdots\cdots\cdots \\ W_{m+h} + E_{m+h} &= S_{m+h} R + L_{m+h}, \end{aligned} \tag{34}$$

where

$$E_m = \{e_m(j),\ j = j_p, \ldots, j_k\}, \tag{35}$$

$e_m(j)$ denoting the random values that indicate the existence of some slight measurement deviations.

In order to solve the equation set (34), two conditions are assumed:

– the equation set (34) is compatible;

– the sum of squares of the sets $E_m, E_{m+1}, \ldots,$ is the least possible:

$$P = \sum_{i=m}^{m+h} \sum_{j=j_p}^{j_k} e_i^2(j) \Rightarrow \min. \tag{36}$$

Condition (36) enables the auxiliary unknowns e_i to be removed and makes it possible to form the equation set (34) into a compatible set of linear equations with regard to S, R and L. The equation set obtained in this manner has, like the set (19) and (20), at least one degree of freedom. The solution can be determined in the form of invariants of a family of solutions, that is, in the form of differential spectra ΔS, ΔR. This procedure permits the definition of deviations of the determined magnitudes of ΔS and ΔR. A disadvantage of this method is the necessity to solve very large sets of linear equations.

To avoid this problem, the following method for the determination of the solution of equation set (33) may be used:

– to divide the given spectra W into pairs of successive spectra $(W_m, W_{m+1})_1 (W_{m+1}, W_{m+2})_2, \ldots;$

– to determine for each pair according to (31), (32) the solution $(\Delta S, \Delta R)_1 (\Delta S, \Delta R)_2, \ldots,$ which should be interpreted as approximate solutions;

– to accept the mean approximate solution as a solution of the set (33);

– and to determine the deviation of the solution obtained by comparing it with the approximate solutions.

5. Substitute signal source

The method described above for the evaluation of acoustic signals, is convenient for tests performed in laboratory conditions with negligible participation of the background. Full advantage is taken of the measurement results obtained for one location of the sensing device.

As it is necessary to conduct investigations in industrial conditions, a model of the system: object-sensing device (Fig. 4) has been used, and the notion of a substitute source introduced.

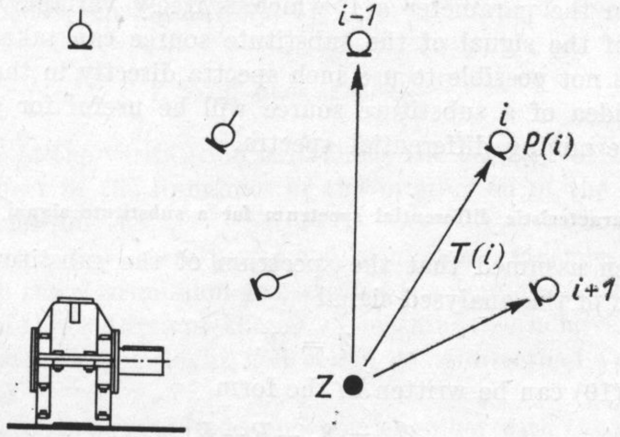

Fig. 4. Model of the system: tested object – sensing devices

The substitute source is a conventional source. For an established measuring point system it replaces the tested object. According to the accepted model for each measuring point i we may write

$$P(i) = Z - T(i), \tag{37}$$

where $P(i)$ is the spectrum of the signal at the measuring point i,

$$P(i) = \{p(i,j), j = j_p, \ldots, j_k\}, \tag{38}$$

Z – the spectrum of the substitute signal source,

$$Z = \{z(j), j = j_p, \ldots, j_k\}, \tag{39}$$

and $T(i)$ – the attenuation spectrum between the substitute source and the measuring point i,

$$T(i) = \{t(i, j), j = j_p, \ldots, j_k\}. \tag{40}$$

For any frequency band j, as well as for successive measuring points i, it is possible to write equation (37) in the form

$$\begin{aligned} z(j) - t(i_p, j) &= p(i_p, j), \\ z(j) - t(i_p+1, j) &= p(i_p+1, j), \\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ &\cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot \\ z(j) - t(i_k, j) &= p(i_k, j), \end{aligned} \tag{41}$$

where $I = \{i_p, i_{p+1}, \ldots, i_k\}$ denotes a set of indices for the measuring points.

The solution of the equation set (41) can be represented in the form of a family of solutions with one parameter $a(j)$

$$z(j) = [z^*(j) + a(j)], \quad t(i, j) = [t^*(i, j) + a(j)], \tag{42}$$

where $z^*(j)$, $t^*(i, j)$ is any pair of solutions satisfying the set (41).

From formulae (42) it can be seen that since the solution of the set (41) is dependent on the parameter $a(j)$ which is freely variable with frequency, the spectrum of the signal of the substitute source can take any form. For this reason it is not possible to use such spectra directly in the investigations. However, the idea of a substitute source will be useful for generalizing the method of determining differential spectra.

6. Characteristic differential spectrum for a substitute signal source

It has been assumed that the spectrum of the substitute signal source is the spectrum of the analysed signal

$$Z = W. \tag{43}$$

Equation (10) can be written in the form

$$Z_m = S_m + R + L_m, \tag{44}$$

where, from (37),

$$Z_m = P_m(i) + T(i). \tag{45}$$

The index m is defined by formula (6).

The concept of a resonance spectrum $R(i)$ can be introduced. For a measuring point i it is defined as

$$R(i) = R - T(i), \tag{46}$$

where

$$R(i) = \{r(i, j), j = j_p, \ldots, j_k\}, \tag{47}$$

$$r(i, j) = r(j) - t(i, j). \tag{48}$$

A similar dependence can be written for several measuring points $i, i+1, \ldots$ Hence we obtain:

$$
\begin{aligned}
P_m(i) &= S_m + R(i) + L_m, \\
P_{m+1}(i) &= S_{m+1} + R(i) + L_{m+1}, \\
&\cdots\cdots\cdots \\
P_m(i+1) &= S_m + R(i+1) + L_m, \\
P_{m+1}(i+1) &= S_{m+1} + R(i+1) + L_{m+1}. \\
&\cdots\cdots\cdots
\end{aligned} \tag{49}
$$

These equations can be solved in a similar manner to equations (33), i.e. by averaging successive approximated solutions. Accordingly, we obtain differential spectra ΔS, $\Delta R(i)$. The spectrum ΔS is the characteristic differential spectrum for the substitute signal source. The spectrum $\Delta R(i)$ is the differential spectrum of the resonance spectrum determined for the i-th measuring point.

According to the assumptions introduced, the spectrum ΔS is conditioned by the dynamics of the interaction of elements of the tested object. The analysis of this spectrum can be very effective in the diagnostic and constructional testing of machines. It should be stressed that the spectrum ΔS is not dependent on the location of the sensing device.

7. Verification of method

The purpose of the verification is to check the validity of the assumption regarding the effect of the dynamics of the interaction of the elements upon the shape of spectrum ΔS.

The verification tests were performed using gear transmissions [1] as the tested objects. In the transmission gears tested the dynamics of the interactions involved in the of three different shapes of meshing teeth have been differentiated. Transmissions with straight, helical and straight teeth of a different height have been tested.

The tests were performed in an anechoic chamber with the aid of standard Brüel and Kjaer apparatus. The microphone was placed at three different measuring points. The operating conditions were such as to obtain at least three values of meshing frequency. The signal spectra were measured in third octave bands.

Figure 5 shows characteristic differential spectra of the substitute signal source calculated for the three different shapes of teeth that determine the different dynamics of intermeshing. In Fig. 5 the broken line indicates the confidence intervals of component levels of the spectrum. These intervals are calculated by assuming a significance level of 0.9. Comparing the spectra shown, and taking into consideration their confidence intervals, it can be demonstrated [1] that

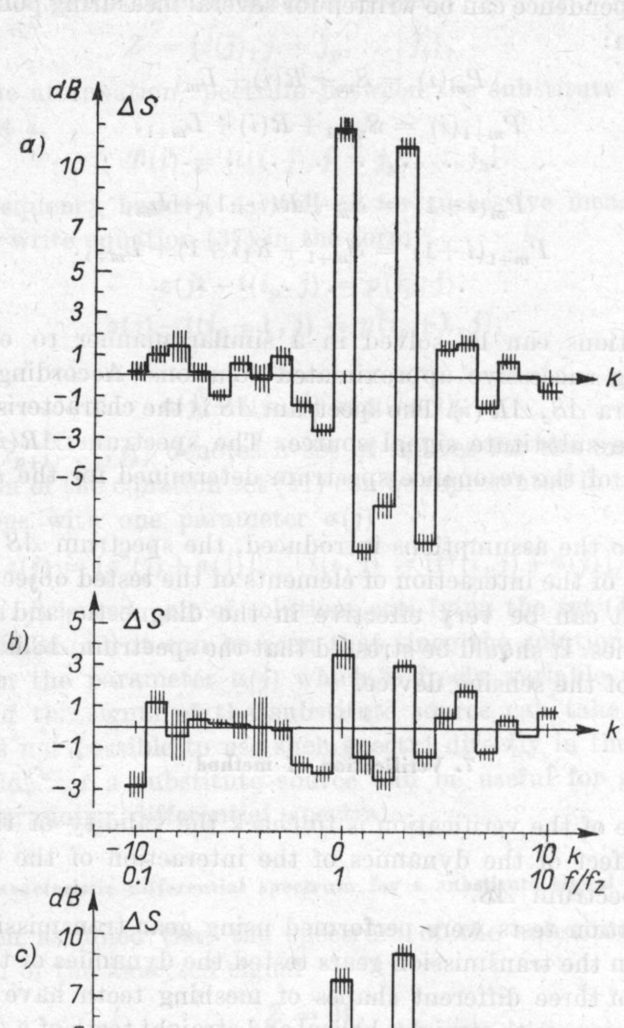

Fig. 5. Typical differential spectra for transmission gears of differently shaped teeth
a) straight teeth, b) helical teeth, c) straight teeth of a different height

they have essential differences. The conclusion can be drawn that different shapes of the spectrum ΔS correspond to different dynamics of intermeshing.

8. An example of the method application

The possibility of using the above method may be shown by an example. The tested object will be a single-stage transmission gear. The number of teeth of the pinion is $z_1 = 32$, and of the wheel $z_2 = 49$. The condition of the transmission is unknown. The possibility of performing the tests in laboratory conditions with the background being neglected, will be assumed.

The purpose of the investigation is the evaluation of the condition of the transmission gear in operating conditions that limit the pinion speed from 1000 to 1500 r.p.m. To determine the spectra a third octave analyser was used, with the microphone in a fixed position. Accoording to formula (5) for third octave bands

$$x = \sqrt[10]{10} = 1.2589.$$

The speed of the pinion in the transmission gear required during testing can be evaluated from formula (8). For the condition $1000 \leqslant n \leqslant 1500$ r.p.m. the following values have been calculated:

$$n_{-2} = 60\,000 \times 1.2589^{-2}/32 = 1183 \text{ r.p.m.},$$

$$n_{-1} = 60\,000 \times 1.2589^{-1}/32 = 1489 \text{ r.p.m.}$$

According to formula (7) these speeds correspond to excitation frequencies

$$f_{-2} = \frac{1183 \times 32}{60} = 630.9 \text{ Hz},$$

and

$$f_{-1} = \frac{1489 \times 32}{60} = 794.3 \text{ Hz}.$$

Investigation of the acoustic effect was carried out for the calculated rotational speeds. The microphone was provided at a measuring point located over the contract area at a distance of 1 m from the transmission gear box. The signal spectra obtained shown in Fig. 6. Typical differential spectra have been calculated according to formula (31) and are shown in Fig. 7.

Analysis the spectrum ΔS reveals maxima for frequencies f_z, 4 f_z, 0.25 f_z, 0.0315 f_z, 0.02 f_z. The frequency f_z is the meshing frequency. The frequencies 0.0315 f_z and 0.02 f_z correspond to the frequencies of the pinion and the wheel f_{01}, f_{02} calculated from the formulae

$$f_{01} = \frac{n}{60}, \quad f_{02} = \frac{nz_1}{60\,z_2}. \tag{50}$$

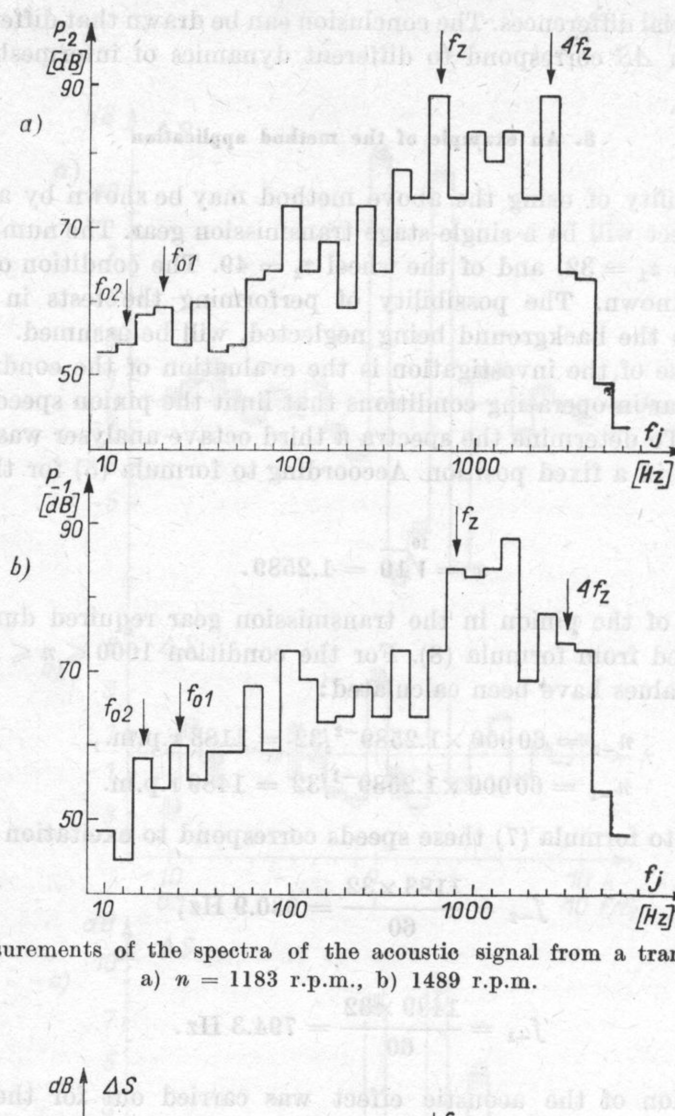

Fig. 6. Measurements of the spectra of the acoustic signal from a transmission gear; a) $n = 1183$ r.p.m., b) 1489 r.p.m.

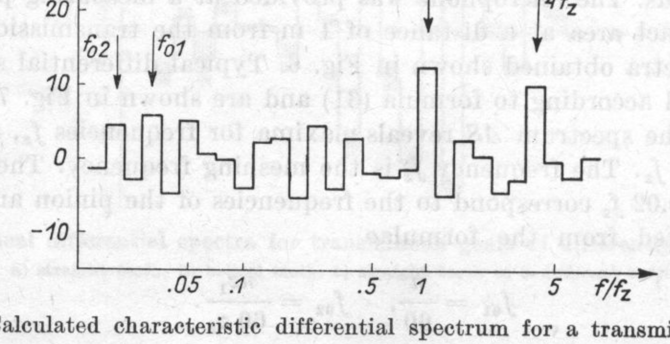

Fig. 7. Calculated characteristic differential spectrum for a transmission gear

On the basis of investigations of transmission gears over many years, it can be said, in virtue of the occurrence in a spectrum of local maxima at relevant frequencies, that it is possible to determine the probable condition of the tested object in accordance with the following data:

f_z – nonlinear entering of teeth into contact causes an excessive dynamic in the intermeshing,

$4f_z$ – eccentricity of the base circle of cut teeth,

$0.25f_z$ – unevenness of execution deviations on the circumference of the toothed element,

$f_{01} = 0.0315f_z$ – no balancing of the pinion,

$f_{02} = 0.02f_z$ – no balancing of the wheel.

The description of the maxima occurring on the basis of the measurement results alone (Fig. 6) is not explicit, and alone they cannot provide the above conclusions.

It should be stressed that in practice it is necessary to measure the spectra in bands narrower than third octave bands. The method described imposes no limitations in this respect.

9. Conclusions

The method described for evaluating a signal in the form of typical differential spectra can be used in constructional and diagnostic tests of machine characteristics for some periodic excitation.

The typical spectrum introduced is independent of the position of the microphone or the vibration sensing device. This independence is of great importance in drawing conclusions about the state of the tested object.

The method proposed can be used with advantage when introducing automation of the measuring system and results of the spectrum analysis are obtained in a form permitting the direct input of these results as data for calculation on a digital machine. This requires the use of a spectrum analyser with an output via a digital-analoque converter to the paper punch, or of a spectrum analyzer operating on-line with a digital machine, or a special analyzer with an analogue input which can rapidly perform Fourier transforms.

References

[1] W. Cholewa, *A method for the evaluation of the acoustic signal of transmission gears for constructional testing* [in Polish], Institute of Fundamental Design of Machines, issue 22/56, Gliwice 1974.

[2] W. Cholewa, W. Moczulski, *An investigation into the analysis of signals during constructional tests; and cooperation with industry in this field* [in Polish], Institute of Fundamental Design of Machines, issue 21/55, p. 21-35, Gliwice 1974.

[3] J. DIETRYCH, *Designing and construction* [in Polish], WNT, Warszawa 1974.

[4] J. DIETRYCH, Z. JASKÓŁA, M. MAKOMASKI, *Frequency characteristics and correlation function in the evaluation of the construction and state of gear transmissions* [in Polish] KOPKM Silesian Technical University, issue 30, Gliwice 1969.

[5] Z. JASKÓŁA, *Acoustic analysis of the effect of constructional features of transmission gears* [in Polish], KOPKM Silesian Technical University, issue 21, Gliwice 1966.

[6] M. MAKOMASKI, *Investigation of the effects of constructional features of transmission gears upon propabilistic characteristics of acoustic effects* [in Polish], IMiPKM Silesian Technical University, issue 4/38, Gliwice 1972.

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