3.19 TH PM

Proceedings of The Institute of Acoustics

DIAGNOSTICALLY ORIENTED MEASURES OF THE VIBRO-ACOUSTICAL PROCESSES

C.CEMPEL

TECHNICAL UNIVERSITY OF POZNAŃ, POLAND

INTRODUCTION

Diagnostic application of machinery vibration and noise tends to the description of the whole process by set of fault oriented numbers called discriminants. The simple example of discriminant created in an other area of acoustics is AdB which is common discriminant of the noise risk in industry. But creation of discriminants in applications of vibroacoustical processes to machinery health monitoring is not so simple. For example, the fault oriented division of machinery vibration spectrum [1] gives the good results only for simple machines and under the condition of constant load and speed. The same is true for vibration amplitude discriminants which for simple machinery are in permanent use. In Europe the RMS vibration velocity is used as an indicator of machinery health, while in United States PEAK amplitude measures are prefered. Which one from above the mentioned dimensional amplitude discriminants is better depends on applications, but from the material fatigue point of view, the peak vibration measures are the most appropriate [2].

The great dependence of the vibration amplitude and its spectral lines on machine load and speed instead of on health was the main cause of introducing the dimensionless process discriminants like shape factor, crest factor and kurtosis. According to Drosjack [3], the good ball berings gives vibration with the crest factor less than 8 while the faulty one gives more then 16. Recently Dyer and Steward [10] reported on kurtosis application to the ball bearing vibration. This dimensionless measure of vibration amplitude distribution can distinguish well the running state of the bearing giving the value about 3 for the good one and about 20 for faulty one.
Author of this note has also some analitycal and experimental experience on vibro-acoustical process discriminants. It has been defined and applied the amplitude discriminants [4,5] and new frequency ones [5,6,7]. Following that this note brings the review of their definition and application.

AMPLITUDE AND SPECTRAL PROCESS DISCRIMINANTS

Vibro-acoustical processes, u(t), as stationary, ergodic zero mean time dependent stochastic processes, can be characterized independently in two domains of description, namely in an amplitude domain by means of probability density, p(u), and in a frequency domain by means of power spectral density, $G_{uu}(f)$.
If we take into consideration the amplitude domain, the following dimensional amplitude measures can be defined [8]

$$u_d = \left[\int_{-\infty}^{\infty} |u|^l \, p(u)\, du\right]^{\frac{1}{l}} = \begin{cases} u_r, \text{ for } l = 1/2, \text{ root amplitude}, \\ \bar{u}, \text{ for } l=1, \text{ average amplitude}, \\ u_{RMS}, \text{for } l=2, \text{ RMS amplitude}, \\ \hat{u}, \text{ for } l \to \infty, \text{ PEAK amplitude}. \end{cases} \quad (1)$$

As it is clear from the above the change of the index l gives different sensitivity to the probability density $p(u)$ shape, but the same sensitivity to the overal power of the process [8]. In such a case the first independent amplitude discriminant must be the RMS amplitude, and the next can be defined as dimensionless in the following way [8]:

$$D_u = \frac{\left[\int_{-\infty}^{\infty} |u|^l \, p(u)\, du\right]^{\frac{1}{l}}}{\left[\int_{-\infty}^{\infty} |u|^m p(u)\, du\right]^{\frac{1}{m}}} = \begin{cases} \text{- shape factor, K, for } l=2,\ m=1, \\ \text{- crest factor, C, for } l\to\infty,\ m=2, \\ \text{- impuls factor, I, for } l\to\infty,\ m=1, \\ \text{- clearance factor, L, for } l\to\infty,\ m=1/2, \\ \text{- fourth root of kurtosis, for } l=4,\ m=2. \end{cases} \quad (2)$$

As it was proved [8] they do not depend on change of amplitude scale RMS and time scale of the process as well. The experiences of the author on diagnostic use of K,C,I discriminants indicate that shape factor,K, has no diagnostic abilities because of its small dynamics of variation. From the other hand crest factor,C, and impuls factor,I, are good indicators of machinery running state or quality of a new product. When applied to vibration they can be measured for acceleration, velocity, and displacement independently, and they can carry different diagnostic information about object under investigations.

By analogy to the above considerations we are going now to characterize the spectral contents of ony vibroacoustical process by means of two numbers. The first number has to give an average frequency of the process and the second one has to indicate the spread of the process components around that frequency.

For the process under considerations, $u(t)$, the average frequency of positive /or negative/ zero crosing, so called Rice frequency, [9], is

$$f_u = \frac{1}{2\pi}\left[\frac{\int_0^{\infty} f^2 G_{uu}(f)\, df}{\int_0^{\infty} G_{uu}(f)\, df}\right]^{1/2} = \frac{\dot{u}_{RMS}}{2\pi\, u_{RMS}}, \quad (3)$$

where f is the frequency in Hz, $G_{uu}(f)$ - power spectral density of $u(t)$, u_{RMS} and $\dot{u}_{RMS}$ are root mean square of original and derivative processes, respectively. The Rice frequency as dimensional process discriminant, can be calculated or measured for any vibroacoustical process. For example if measured for vibration acceleration of the new ball bearings it can diferentiate bearing quality well. From the other hand the running state of a small electric motor can be described by the Rice frequency of its vibration velocity[8]. As we see location of average process frequency along the frequency axis have the good diagnostic meaning. Besides, it would be interesting to know spectral width of the process under consideration. Such a quantity, dimensionless in nature, was previously defined and used by the author in connection with bearing clearance detection, [7]. This discriminant, called harmonic index /or factor/, was defined as reciprocical of correlation coefficient of the differential and integral processes normalized to the original one. If u(t) is the original process, then after some calculation one can obtain

$$H_u = \frac{(\dot{u}_{RMS})\left(\int^t u dt\right)_{RMS}}{u^2_{RMS}} = \frac{f_u}{f_{\int u}} , \qquad (4)$$

where $(\dot{u})_{RMS}$ and $\left(\int^t u dt\right)_{RMS}$ denote the amplitude of differential and integral processes, respectively, and additionally $f_{\int u}$ is the Rice frequency of the integral processes. It can be proved [8] that harmonic index does not depend on frequency shift but it depends only on shape of the power spectral density. It means that Rice frequency and harmonic index are two independent frequency discriminants of the process. In the author's diagnostic experiments the harmonic index was calculated for two original processes of an electric motor; namely vibration acceleration and velocity. Behaviour of these quantities in terms of motor running time is different, but velocity harmonic index is similar to the Rice frequency change. This conclusion is perhaps strange but one has to remember that quantities independent in terms of process description can be dependent in terms of diagnostic object properties. Recapitulating our process discriminant consideration we can state that for every one process we can create a number of independent discriminant, but their diagnostic ability in every one case must be proved.

VIBRATIONAL QUALITY INVESTIGATION FOR THE NEW BALL BEARINGS

In order to present some possible application of the process discriminants let us consider a ball bearings quality investigation by means of vibration measurements. For the experiment a sample of 38 new bearings /6303/ were taken. Bearing vibrations were measured on the test stand where inner race rotated with 30 Hz frequency and radial vibration signal was received from fixed outer race. For every bearings under investigation the RMS vibration acceleration, a, velocity, v, and displacement, x, as well as its impuls factors, I_a, I_v, I_x, the Rice frequencies, f_a, f_v, f_x, and the harmonic indexes, H_a, H_v, were measured. The results of these measurement were put into computer program for principial coordinate and statistical feature analysis. Due to the computation four significant features in the ball bearing sample were found. This quality features can be described well by linear combination of four vibrational discriminants namely, a, f_a, I_a, H_v, that were found from among eleven ones as most independent and quality oriented. For the purposes of comparison the same acceleration signals were frequency analysed on 12 octaves from the range 16Hz to 31,5Hz, and each octave absolute readings were put into the same computer program. After statistical analysis only two significant features were found. This conclusion confirms the hipothesis that for diagnostic application of vibroacoustical processes, a special diagnostic oriented discriminants must be created.

REFERENCES

1. B.Dawson, Vibration condition monitoring techniques for rotating machinery, The Shock and Vibration Digest, Vol.8,No 12, 1976,p.3-8.
2. C.Cempel, The Fundamentals of Vibro-acoustical Diagnostics, /in Polish, WNT - in print/.
3. M.J.Drosjack, D.R.Hauser, G.W. Hogg, Vibration diagnostics in helicopter power trains, Proceedings of 20-th International Symposium of ISA, May 21-23,1974, Albuquerque,New Mexico.
4. C.Cempel, Dimensionless amplitude discriminants of the vibroacoustical processes. Proceedings of IV Symposium on Machinery Diagnostics, Szczyrk 1978 /in Polish/.
5. C.Cempel, Amplitude and spectral discriminants of vibroacoustical processes for diagnostic purposes, Proceedings of XII Conference on Machine Dynamics, Vysoke Tatry, April 1979, 103-116.
6. C.Cempel, Detection of clearances in machine kinematic pairs by means a coherence method, Journal of Sound and Vibration, 1978 Vol.60, No 3, 1978, p.411-416.
7. C.Cempel, Simple method of clearance detection in kinematic pairs, Proceeding of V World Congres of IFToMM, Montreal, June 1979.
8. C.Cempel, Diagnostically oriented measures of the vibroacoustical processes, /full text/ Applied Mechanics Institute, Internal Reports No 83/79.
9. A.Papoulis, Probability; random variables and stochastic processes, Mc-Graw Hill Inc, 1965.
10. D.Dyer, R.M.Stewart, Detection of rolling element bearing damage by statistical analysis, ASME Publication, Paper No 77 - DET-83.