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COMPARATIVE ANALYSIS OF SENSITIVITY OF VIBRATION DAMAGE INDICATORS BY THE RESULTS OF LABORATORY TESTS

Anatoly P. Bovsunovsky

Department of oscillations and vibration reliability
Institute for Problems of Strength
Timiriazevskaia st. 2
252014, Kyiv
Ukraine

ABSTRACT

The results of experimental research of damping, natural frequency and high harmonics of the wave shape of strain and acceleration chosen as vibration damage indicators are presented. The specimens in the form of cantilever beam with closing or open single-sided edge crack were tested at bending and axial vibrations. The comparative analysis of sensitivity of vibration damage indicators being considered are executed.

NOMENCLATURE

L	length of specimen
L_c	crack location (distance of crack from the attachment)
h	height of cross-section
b	width of cross-section
a	depth of crack
m	mass on the end of a specimen
E	Young's modulus
ρ	density
ν	Poisson's Ratio
σ	stress amlitude
f	resonance frequency
f_c	resonance frequency of cracked specimen
δ	decrement of vibrations
δ_c	decrement of vibrations of cracked specimen
F	Fourier series
A_n	sine terms of Fourier series
B_n	cosine terms of Fourier series
R_δ	rate of relative change of decrement
R_f	rate of relative change of natural frequency
R_F	rate of relative change of high harmonics

1 INTRODUCTION

The vibration diagnostics of damage in various structures is a promising way for creation of non-destructive and comparatively inexpensive methods for estimation of theirs quality and reliability. A great number of works, detailed survey of which was performed by Krawczuk and Ostachowicz[1], are devoted to analytical and numerical study of interrelations between dynamic characteristics of cracked structures and parameters of crack (crack depth and location). At the same time, limited number of works are devoted to experimental research of mentioned above problem.

Adams *et. al.*[2] developed a non-destructive test which can be used to detect and locate damage in structures. The method is based on the analysis of first two or three axial modes of vibrations. Axial natural frequency of the piezoelectric ceramics cracked beam was investigated by Chushko[3]. Cawley and Adams[4] studied the possibilities of employment of natural frequency for the detection of damage basing on the data of experiment and FE model.

Cawley and Ray[5] compared the changes in the natural frequencies of a beam produced by cracks with those caused by slots of the same depth and different widths. They showed that the natural frequencies changes increase as the width of the slot is increased. The test of hollow cantilever beam at bending vibration enabled Gounaris *et. al.*[6] to conclude that an open crack causes more essential changes of natural frequency than closing one. This effect was observed earlier by Gudmundson[7]. Dimarogonas and Massouros[8] investigated torsional vibration of cracked shaft. Circumstantial study of different vibration damage indicators (VDI), among which are damping and natural frequency, was performed by Rytter[9].

The aim of present work is to conduct the comparative experimental investigation of the most promising in author's

Metal	Type of crack	L	L_C	h	b	m	E	ρ	ν	f
#	#	mm	mm	mm	mm	kg	GPa	kg/m^3	#	Hz
15H2NMFA	closing	220	6	13.8	4	0.154	200	7800	0.26	81.3
		...	17	...	...	0.259	...	...	...	69.3
		...	30	...	...	...	...	...	...	69.0
		...	34	...	...	0.154	...	...	...	82.5
		...	61	...	...	0.259	...	...	...	70.0
08H18N10	closing	150	30	20	4	3.520	200	7900	0.26	50.6 806.8
VT-8	open	220	20	20	4	0.150	110	4480	0.3	105.3
		...	40	...	...	...	...	...	...	109.7
		...	114	...	...	0.255	...	...	...	88.6

TABLE 1: Geometrical description of the specimens and mechanical properties of the metals.

the virgin state was lower. At the same time, in study of the specimens with open crack the insignificant decrease of decrement takes place. For all types of crack most essential change of damping is observed at lower stress aplitudes.

It follows from the results shown in Figure 4 that any type of crack causes considerable change of bending natural frequency. The axial natural frequency is less sensitive to crack growth. A comparison between the data of experiment for steel 15H2NMFA and alloy VT-8 specimens enables to conclude that the open crack causes more essential change of natural frequency than closing one. This conclusion is in a good agreement with the published results[6-8]. All curves shown in Figure 4 are the result of approximation using the method of least squares.

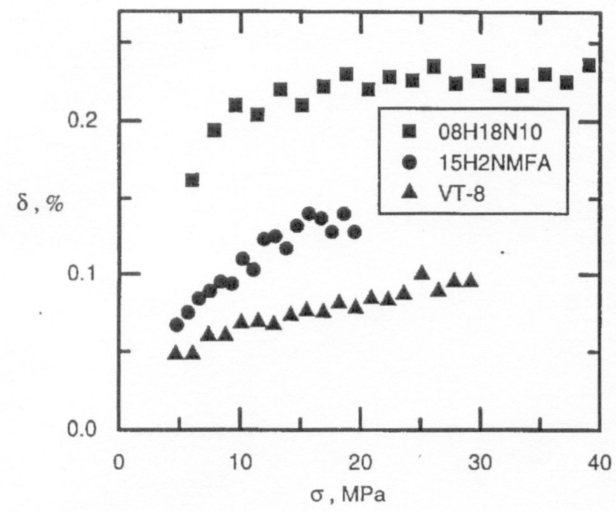

Figure 2: Stress amplitude dependencies of logarithmic decrement of bending vibrations for tested specimens.

More clearly the effect of crack type is demonstrated in Figure 5. In addition, it is evident from Figure 5 that the farther the crack from the attachment, the lesser its influence on the first natural frequency of bending vibrations.

The crack in a specimen causes the deviation of wave shape of strain and acceleration from rigorously harmonic. This deviation increases with crack growth and may be determined by the representation of the wave shapes in a Fourier series:

$$F = \frac{A_0}{2} + \sum_{n=1}^{N}\left(A_n \cdot \mathrm{Cos}\, n\omega t + B_n \cdot \mathrm{Sin}\, n\omega t\right).$$

Harmonic analysis of the wave shapes makes it possible to establish the relationships between the parameters of crack and the amlitudes of high harmonics (high harmonics method).

As the investigations showed, the amplitudes of zero and even-numbered (first of all second) harmonics are subjected to the most considerable change. Certain of the most interesting results are presented in Figure 6. Solid lines correspond to the strain and dash lines - to the acceleration. The curves are the result of approximation using the method of least squares.

In the case of closing crack high harmonics essentially change with crack growth as well as with change of crack location. It must be emphasized that the harmonic A_2 manifests itself considerably for the strain and harmonic B_2 - for the acceleration. In study of the specimens with large closing crack (a/h>0.4) it might be seen even on the screen of oscilloscope that the wave shapes of signals from the

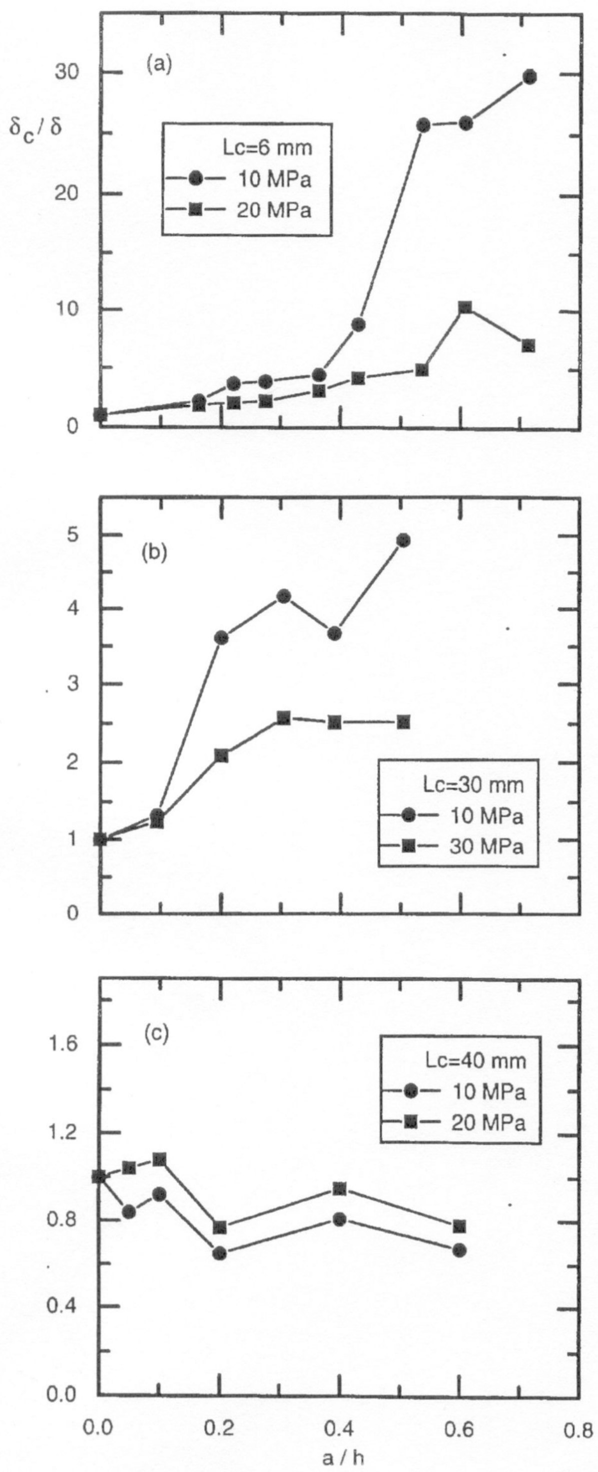

Figure 3: The effect of crack depth on the damping capacity of steel 15H2NMFA (a), steel 08H18N10 (b) and alloy VT-8 (c) specimens.

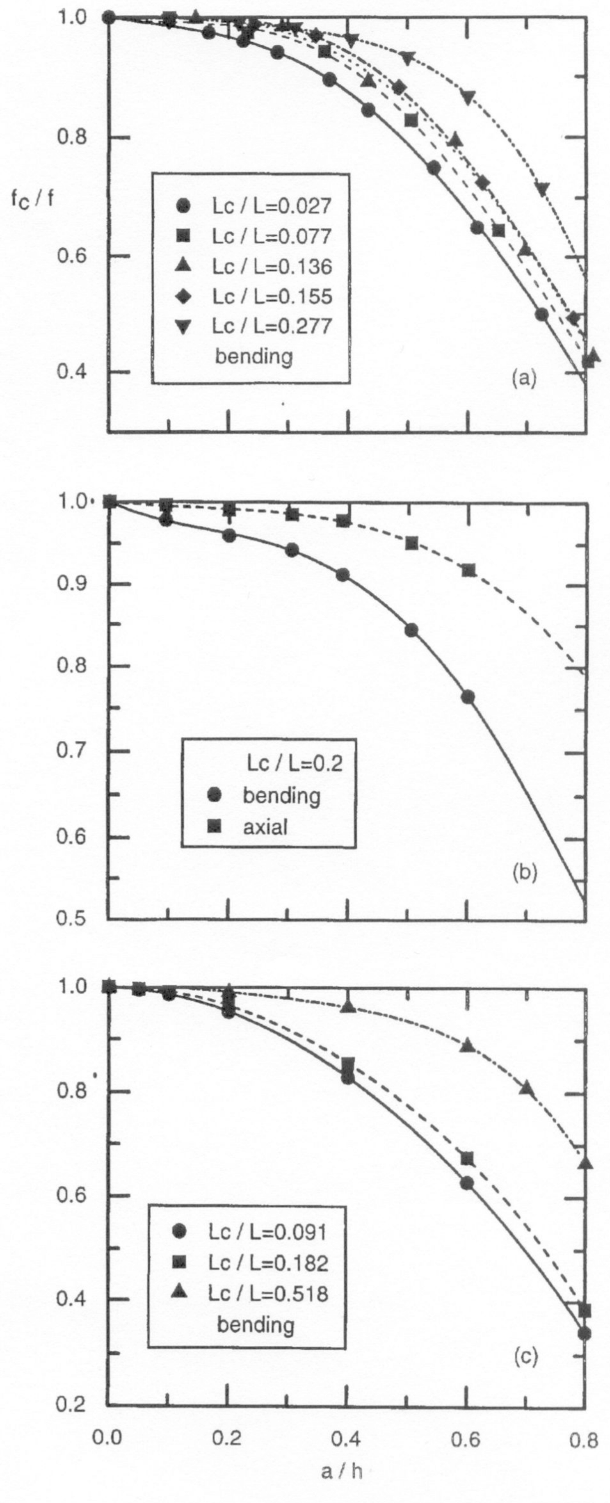

Figure 4: The effect of crack depth on the first natural frequency of steel 15H2NMFA (a), steel 08H18N10 (b) and alloy VT-8 (c) specimens.

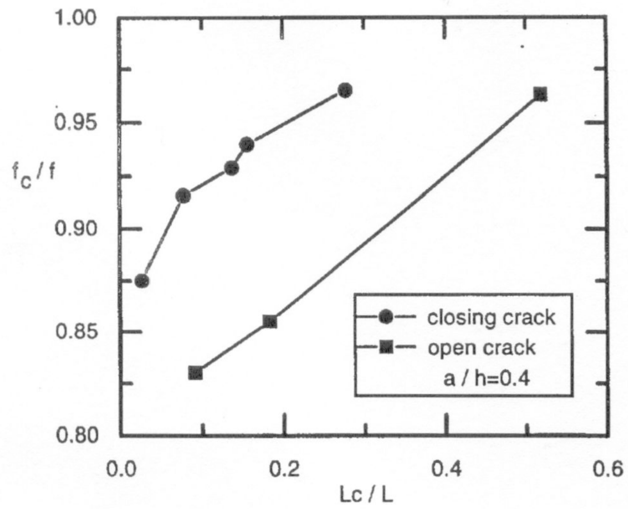

Figure 5: The effect of crack location on the first natural frequency of bending vibrations for specimens with closing (15H2NMFA) and open (VT-8) crack.

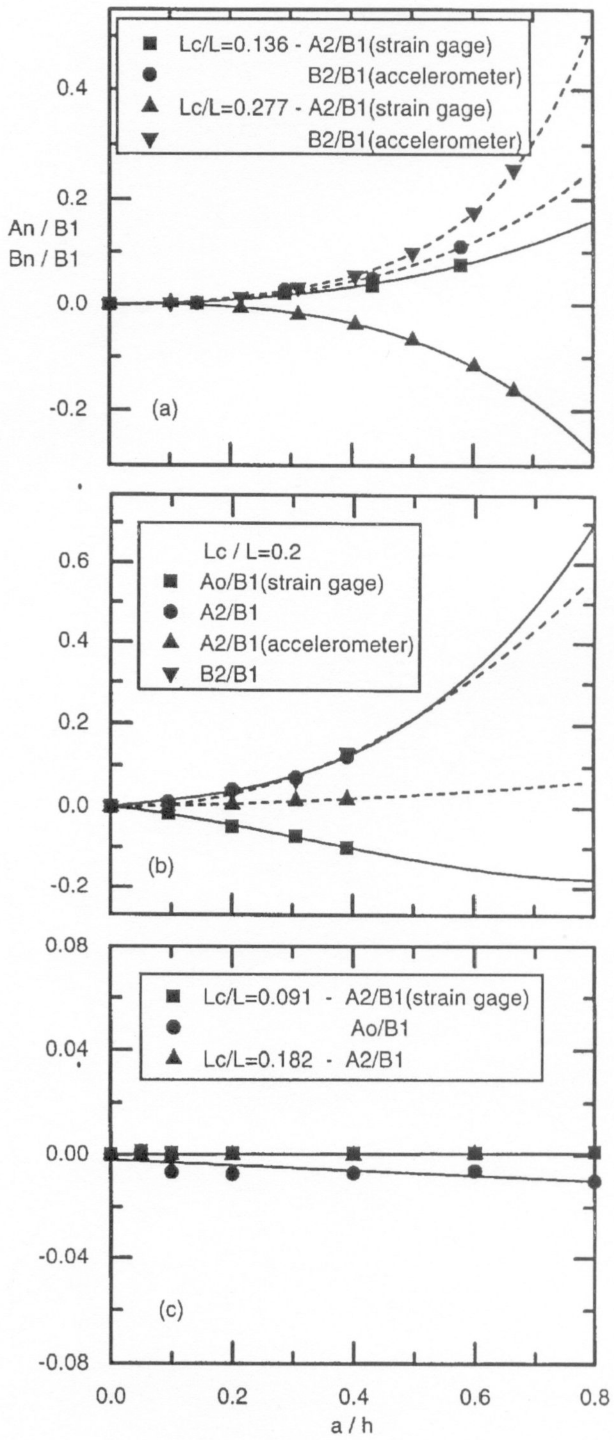

Figure 6: The relationships between the crack depth and the high harmonics of strain (solid lines) and acceleration (dash lines) for steel 15H2NMFA (a), steel 08H18N10 (b) and alloy VT-8 (c) specimens.

strain gage and accelerometer are distorted and differed from each other. The distortion of the wave shape of stain depends on the location of the strain gage relatively crack. The location of crack relatively strain gage may be judged by the sign of certain high harmonics.

For the specimens with the open crack the wave shapes of strain and acceleration practically did not deviate from harmonic.

4 DISCUSSION

The immediate comparison of the presented VDI is a problem inasmuch as one of the functions is a from-zero function. Because of this, the rates of relative changes of decrement (R_δ), natural frequency (R_f) and high harmonics (R_F) were compared. This functions were calculated using the results of approximation of the experimental data.

The functions R_δ, R_f and R_F which were determined from the most significant relationships between the relative changes of decrement, natural frequency and high harmonics and the crack depth are shown in Figure 7. Comparative analysis of this curves leads to the conclusion that for the detection of crack the damping is most preferable. Of two remaining VDI for the steel 15H2NMFA specimens the high harmonics method is more sensitive. As it was observed, the location of strain gage relatively crack essentially effects on the wave shape of strain. On the steel 08H18N10 specimen the strain gage was located in the immediate vicinity to the crack. Contrary to the expectations, the degree of manifestation of

The natural frequency is perhaps one of the most investigated VDI having sufficiently high sensitivity. In tests the results of which are presented above the author of this report always first observed the changes of natural frequency and only then detected the crack. At the same time, in practice there is not simple to provide the identical conditions of tests because of long intervals between them.

From the practical point of view the employment of the accelerometer in the measuring system is preferable. This is true also for the high harmonics method in spite of the fact that the wave shape of signal from the strain gage is more sensitive to crack propagation, all other factors being equal. However, the high harmonics method requires further experimental and analytical investigations.

Each of the presented VDI possesses the advantages and drawbacks. In connection with this the variant of employment at least two VDI simultaneously is a very promising way. On the one hand, the reliability of crack detection increases. On the other hand, such a variant enables to determine the parameters of crack analytically as well as to obtain the additional information on type of crack. For example, joint employment of natural frequency and high harmonics method among other factors enables to determine uniquely the type of crack: open or closing one (see Figure 7). The knowledge of type of crack is important for the correct analytical solution of the problem.

5 CONCLUSIONS

From the VDI being investigated in the case of closing crack most sensitive VDI is damping. In the case of open crack most sensitive VDI is natural frequency.

If the damping can not be used as the VDI the high harmonics method is more preferable. The depth and location of closing crack can be judged by the value and sign of amplitudes of high harmonics.

From the practical point of view the joint employment of two or several VDI is a promising way for the reliable detection of crack and for the determination of crack parameters.

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