Vibration Measurement with Piezoelectric Transducer

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Abstract – **This article discusses piezoelectric transducers and their application for vibration measurement. The functions of conversion are experimentally defined and investigated.**

Keywords – **Vibrations, no electrical measurement, piezoelectric transducer, amplitude, frequency.**

I. VIBRATION – BASICS

A. Definition

Vibration is the motion of a particle or a device or system of connected devices scattered around the balanced position. Most vibrations are undesirable in machines and equipment because they lead to increased loads, fatigue and energy loss, increased bearing loads, creating discomfort for passengers in vehicles and absorbing energy from the system. The rotating parts in machines must be carefully balanced to prevent vibration damage. [1]

Vibrations can be obtained from natural forces, such as earthquake [2]. There are vibrations created by the people who influence the environment. Such vibrations can be caused by industry, transport [3], construction [2] and other activities.

Vibration is a response of the system to internal or external impact, which causes it to fluctuate or pulsate.

Although it is commonly believed that vibrations do damage to the equipment and the machinery, they do not. Instead, the damage is done by dynamic loads, which lead to fatigue and dynamic loads are caused by vibration. [4]

If a vibrating object can be seen in slow motion, it will be found running in different directions. Each vibration has two measurable variables that help to determine the vibration characteristics, how far (magnitude or intensity) and how fast (frequency) the subject is moving. The parameters used to describe this movement are displacement, frequency, amplitude and acceleration. (Figure .1)

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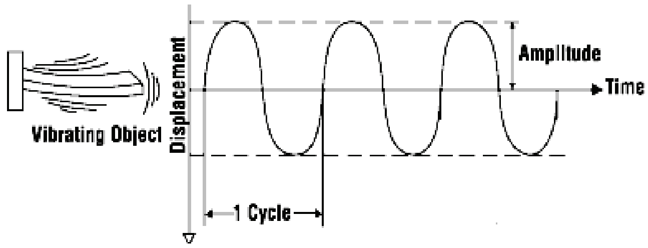

Fig.1 Parameters of vibration

B. Amplitude

The generally accepted term for this how big is the vibration is amplitude, A. The definition of amplitude depends on the systems. One can work in units of distance from the vibrating subject from extreme left to extreme right (double amplitude) but in physics more often is used the distance from the center to one of the extremes.

C.Frequency

Frequency f is the number of cycles that occur per unit of time. [4]. Unit rate is usually 1 cycle/second, which is defined as a special unit 1 Hertz (1Hz). The term frequency is common in determining the vibration.

If one cycle takes time T, then the number of cycles that occur per unit time is:

$$f = \frac{1\ cycle}{T} \qquad (1)$$

D. Units for vibration measurement

<u>Vibration displacement</u> " s "

This is a deviation of the measured point from the equilibrium position. The unit is usually μm . [5]

<u>Vibration velocity</u> " v "

This is the rate at which the measured point moves around its equilibrium position. The unit is mm/s . [5]

<u>Vibration acceleration</u> " a "

This is the acceleration with which the measured point moves about the equilibrium position. The unit is either m/s^2 or g ($1g = 9{,}81 m/s^2$). [5]

II. PIEZOELECTRIC TRANSDUCER

Piezoelectric effect occurs in some crystalline substances - natural quartz, Rochelle salt, lithium sulphate, some ceramics and more. When such a crystal is placed in an electric field it changes its size synchronously with the changes of the field – opposite Piezoelectric effect (used to generate audible and ultrasonic signals). When the crystal is deformed in an appropriate direction an electric charge is generated (straight Piezoelectric effect). [6]

One of the commonly used structures for vibration measurement while controlling the state of the machine is shown in Figure 2. The Piezoelectric transducer is glued strong at the one end of the bending under the forces of inertia plate and the free end is soldered seismic mass. Attenuation is achieved through the oil drops placed in the gap between the seismic mass and the attenuator. When the base is moving downside-up the inertia opposes and deforms the Piezoelectric transducer. This generates an electrical charge that is proportional to the acceleration. Typical values of the sensitivity of these sensors are 0,5-50 mVs^2/m in the frequency range 0,1 Hz to 200 kHz.

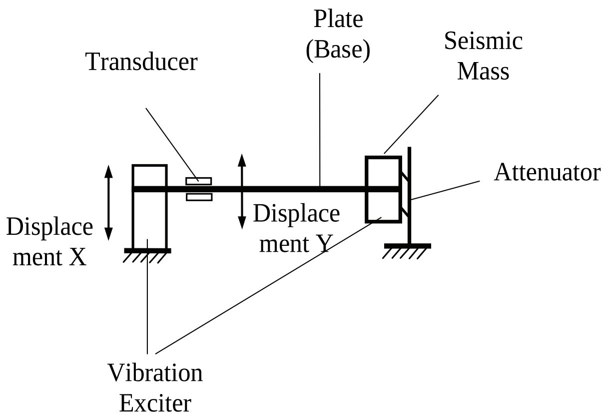

Fig.2 Stand for vibration measurements

Between the vibrational displacement x, absolute displacement of the seismic mass y and its relative movement z exist dependence ($z = x - y$).

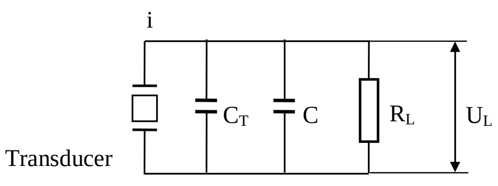

Fig.3 Equivalent replacement scheme

Piezoelectric vibration transducer generates an electrical charge that is proportional to the deflection of the piezoelectric transducer.

$$q = S_q z \qquad (1)$$

where S_q the sensitivity of Piezoelectric vibration transducer for amount of electricity.

The equivalent replacement scheme of the structure from Fig. 2 is shown in Fig. 3, in which with C_T is marked the capacity of the converter with C - the additional capacity with R_L - the output load resistance of Piezoelectric vibration transducer. The current is $i = \frac{d\alpha}{dt}$. The output voltage of the vibration transducer in harmonic mode is:

$$\dot{U}_n = \frac{j\omega S_q \dot{z}}{j\omega C_\Sigma + \frac{1}{R_L}} \approx \frac{S_q}{C_\Sigma}\dot{z} \qquad (2)$$

Here $C_\Sigma = C_T + C$

The approximate equation is valid when $R_L \succ\succ \frac{1}{\omega C_\Sigma}$.

Sometimes this condition is achieved with the given shunt of the transducer with additional capacitor with significant capacity. This, however, reduces the voltage sensitivity of the scheme:

$$\dot{U}_n \approx \frac{S_q}{C_T + C}\dot{z} = S_U \dot{z} \qquad (3)$$

Construction of the piezoelectric transducer is such that any additional resonant frequencies are much higher than the primary. It is assumed that there is only the main resonance. It is determined by the equivalent vibrating mass m, the equivalent elastic counteraction with constant W and without hysteresis friction with constant P. The parameters own frequency of oscillation $f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{W}{m}}$, decay $\beta = \frac{P}{2\sqrt{mW}}$ and relative frequency $\nu = f / f_0$ are obtained.

The condition for the use of piezoelectric transducer as a vibrator for measuring the amplitude of the vibration is given by:

$$\dot{U}_n \approx \frac{S_q}{C_\Sigma}\dot{x}\frac{\nu^2}{\left(1-\nu^2\right) + j2\beta\nu} \qquad (4)$$

To one of the two working ends of the vibrator is attached piezoelectric transducer (Fig. 2).

When $\nu \succ\succ 1$, amplitude-frequency response and phase-frequency response of the piezoelectric transducer tend to:

$$(U_n)_{\nu \succ\succ 1} = \frac{S_q}{C_\Sigma} x \qquad (5)$$

$$(\varphi)_{\nu \succ\succ 1} = \arg\frac{\dot{U}_n}{\dot{x}} = arctg\frac{2\beta}{\nu} \to 0 \qquad (6)$$

Therefore in the above resonant area it is received a signal for the amplitude of the vibration.

If $\dot{X}$ in Eq. (1) is replaced by $\frac{1}{\omega^2}\frac{d^2}{dt^2}(\dot{x})$ it is obtained:

$$\dot{U}_n = \frac{1}{4\pi^2 f_0^2}\frac{S_q}{C_\Sigma}(\dot{x})\frac{1}{\left(1-\nu^2\right)+j2\beta\nu} \qquad (7)$$

For $\nu \prec\prec 1$, amplitude-frequency response and phase-frequency response tend to:
and the frequency response FCHH tend to express:

$$(\dot{U}_n)_{\nu \prec\prec 1} \to \frac{S_q}{C_\Sigma} x'' \qquad (8)$$

$$(\varphi)_{\nu \prec\prec 1} = \arg\frac{\dot{U}_n}{x''} \to 0 \qquad (9)$$

Therefore in the under resonant area it is received a signal for the amplitude of the vibration acceleration.

III. Description of the experimental setup

The setup for vibration measurement and processing of results is shown in Figure 4. It includes the following blocks:

- Frequency Generator - Philips GM 2315. Frequency range of 20Hz to 20kHz. Range from 0 to 10V.
- Digital Multimeter - Fluke 83 Multimeter
- Amplifier - Bruel & Kjaer power amplifier type 2712
- Vibration exciter - Bruel & Kjaer, permanent magnetic vibration exciter type 4808. Maximum acceleration 71g.
- Sensors for measuring vibration acceleration - Piezoelectric - Kistler K-Shear accelerometer Type 8704B500M1. Frequency range of 1Hz to 10kHz. Measuring range ± 500g.
- Power supply for the piezoelectric sensor - Kistler power supply/coupler, type 5134.
- Amplifier - Hottinger Baldwin messtechnic, type spider 8
- Computer
- Software - Catman Professional 5.0

From the frequency generator we are setting the frequency and the amplitude of the signal. We are monitoring these values with a multimeter. The signal from the generator passes through the amplifier 2712 and is succumbed to the vibration exciter. It produces in turn a vibration that is measured by the transducer. The piezoelectric transducer is powered externally. It produces a signal proportional to ground acceleration g. The signal from the transducer passes through the amplifier - Hottinger Baldwin messtechnic Type spider 8, where it is transformed in appropriate form and is fed to the computer. The results are displayed using the program Catman Professional. The program is dedicated measurement software that provides great opportunities for visualization and analysis of signals. The program allows to measure frequencies and amplitudes.

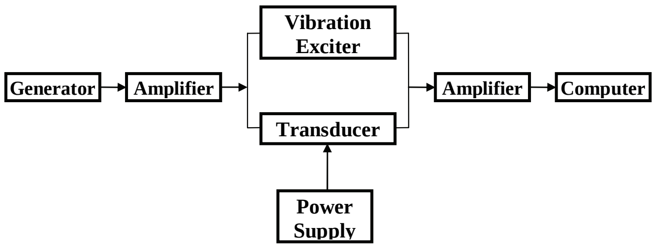

Fig.4 Block diagram of the stand for measuring vibration

IV. Results from the measurement

1. Testing the transducer on measuring frequency. The amplitude of the signal coming from the piezoelectric transducer is maintained constant with the amplifier - Bruel & Kjaer power amplifier Type 2712 with values - 5g and 10g. The results are presented in Table I. There are very small differences (from 0 to 1.2%) between the one from the generator and the measured from the transducer.

TABLE I
DEPENDING ON THE FREQUENCY OF THE PIEZO TRANSDUCER FROM FREQUENCY GENERATOR

Frequency from the generator, Hz	Frequency from the piezoelectric transducer, Hz
20	20
30	30,303
40	40
50	50
60	60,606
70	71,428
80	80
90	90,909
100	100

2. Study on the dependence of the amplitude of the vibration frequency against the frequency signal from the generator, $A = f(f)$. The measurements were made at frequencies from 20 Hz to 500 Hz over 10 Hz (Table II). The

measurement was conducted in the same gain.

The change of amplitude against frequency is shown in Fig. 5. The figure shows that the vibration exciter has resonance at 100 Hz.

TABLE II
AMPLITUDE OF THE TRANSDUCER AS A FUNCTION OF FREQUENCY

Frequency from the generator, Hz	Amplitude from the transducer, g	Frequency from the generator, Hz	Amplitude from the transducer, g
20	3,5		
30	4,4	270	3,2
40	6,0	280	2,85
50	7,3	290	2,85
60	8,5	300	2,45
70	9,0	310	2,45
80	9,75	320	2,05
90	9,75	330	2,05
100	9,75	340	1,6
110	9,2	350	1,6
120	8,9	360	1,6
130	8,5	370	1,2
140	8,0	380	1,2
150	7,7	390	1,2
160	7,3	400	1,0
170	6,9	410	1,0
180	6,5	420	0,8
190	6,5	430	0,8
200	6,0	440	0,8
210	5,6	450	0,8
220	5,2	460	0,8
230	4,8	470	0,4
240	4,4	480	0,4
250	4,0	490	0,4
260	3,6	500	0,4

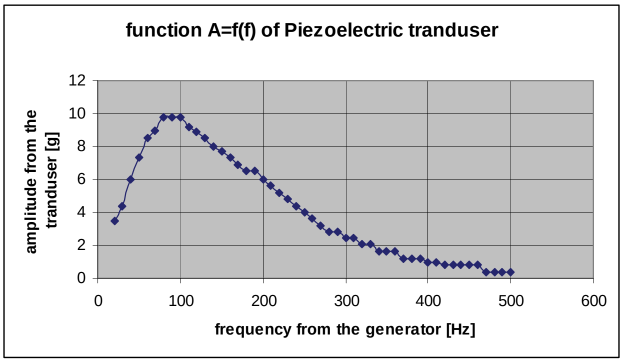

Fig.5 Function of the converting of the piezoelectric transducer from frequency of the generator

V. CONCLUSIONS

The piezoelectric transducer measures frequency very accurate. There are differences in some of the results between the transducer and the report of the assigned frequency of the generator, the biggest difference is 1,4 Hz. This difference is caused by the rounding made when reporting the actual data from the transducer. The transducer has a large frequency range.

Piezoelectric transducer measures better signals with larger amplitudes and around the resonant area. For signals with very small amplitudes, the sensor may not report them.

ACKNOWLEDGEMENTS

The researches, the results of which are presented in this publication are funded by internal competition TU-2012 contract to support PhD student № 122 RP 0074-08 "Study and optimization of processes for measuring vibration".

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