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Influence of Mechanical Vibration on Strain Gauge Based Force Transducer Performance

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Abstract

This paper deals with the influence of mechanical vibration on the performance of strain-gauge based force transducers. Force transducers of beam bending with binocular type were used for investigations. The transducers with different capacities varying in the range of 3 – 30 kg were loaded by the calibrated masses and excited by discrete accelerations levels at a certain frequency. The difference in electrical output of transducer caused by mechanical vibration has been determined. Resonance curves of the transducers have been obtained by frequency sweep measurements under loaded conditions.

1. Introduction

Although the strain gauge force transducers were developed and commercialized about 40 years ago, until recently they were mainly used for industrial applications such as process control, heavy machinery, test engineering etc. Electronic scales based on strain gauge force transducers are now commonplace [1]. Force transducers are used for calibration purposes and technical applications, while load cells are the sensing elements of the weighing devices.

According to the bending test beam principle, force transducers are frequently used in the range below 10 kN [2]. The calibration of the force transducers is carried out under static loading conditions. In most applications the transducer used for the force measurement purposes is exposed not only to a static but also dynamic force. Even the level and frequency of the input quantity are small the excitation is composed of static and dynamic forces. For this reason changes in force transducer characteristics under mechanical vibration should be investigated carefully, if the transducer is a critical part of process control equipment.

2. Theoretical Background

The structure of the force transducer should be elastic in the usable dynamic range. Because of its mechanical properties this elastic structure is called as spring element. According to the direction of the applied force resulting in strain, the force transducers are classified as bending, direct stress and shear type transducers. Various kinds of bending type force transducers are widely used in industrial applications.

For the dynamical application the mechanical model of force transducer is simple spring-mass system. The vibration model of the spring-mass system is given in Figure 1. The upper part of the force transducer is called as end-mass. The dynamic excitation can only be applied from the bottom of the transducer. The excitation is sensed by the spring element by means of end-mass. Depending on the mounting technique, relative motion between the force measuring structure, including moving head of the exciter and force transducer end-mass and loads, may occur. This effect should be taken into account in precise measurements. Screwing is the best mounting way for the transducer, used in measurement of mechanical quantities, to the place where the measurement is performed. This approach can be verified by measurement of frequency response of the transducer.

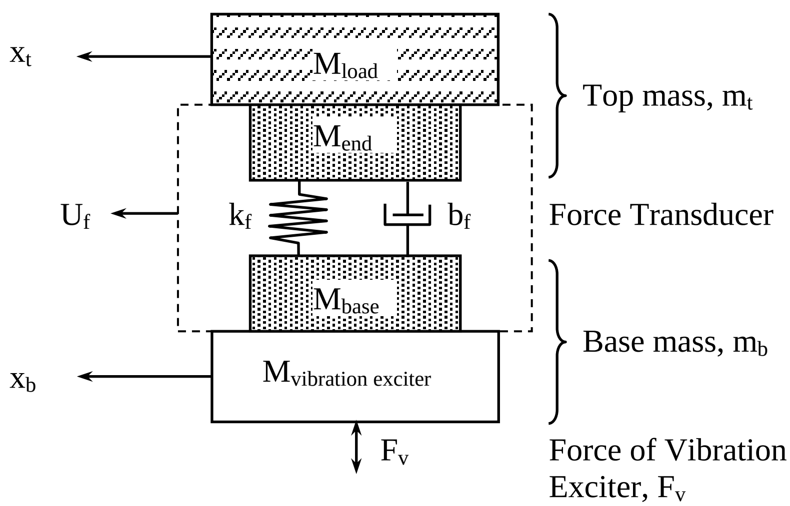

Figure 1. Schematic model of force transducer [3].

For mounting of loads to the force transducer an adapter is used. If the resonance frequency of the coupling between adapter and load mass is high compared with the measurement frequency range, the accelerations of the mass and the adapter are almost identical [3]. Therefore the expression of the force can be written in the simple form:

$$F_v = \left(M_{load} + M_{adapter} + M_{end}\right)\ddot{x}_t \ , \qquad (1)$$

where x_t is displacement amplitude of load mass, F_v is dynamic force, M_{load}, $M_{adapter}$, M_{end} are weights of load, adapter and end-mass respectively.

The sensitivity of a measuring transducer is defined as the ratio of the electrical output U_f to the input quantity F_v. Then the dynamic force sensitivity S_f of a force transducer is given by

$$S_f = \frac{U_f}{F_v} \ . \qquad (2)$$

Substituting F_v into (2), the expression for the dynamic sensitivity can be written as:

$$\frac{U_f}{\ddot{x}_t} = S_f \ . \left(M_{load} + M_{adopter} + M_{end}\right). \qquad (3)$$

3. Description of the Experimental Work

In order to investigate dynamic behavior of strain gauge based force transducer, beam bending type force transducers with binocular spring element were used. Characteristics of four different force trans-ducers with static load capacity of 300 N (two transducers), 100 N and 50 N were investigated. Measurements were carried out using the experimental set-up shown in Figure 2. Load mass, excitation level and vibration frequency were selected as variable parameters during the measurements.

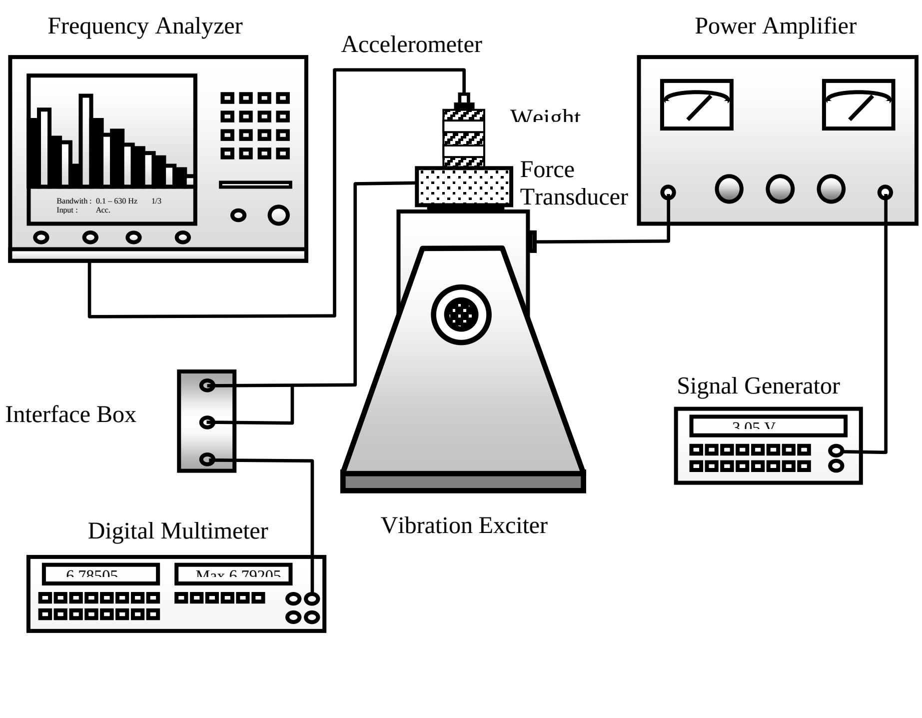

Figure 2. Experimental set-up and instrumentation

Force transducers were mounted on an electrodynamics exciter. The exciter was driven by an AC signal generator through a power amplifier. The transducers were loaded up to 4.5 kg according to their capacities. The set of calibrated weights consisting of ten masses, each of 510 g were used as load. The transducers were excited at 10 Hz and discrete acceleration levels starting from 1 to 10 m/s² with 1 m/s² step for each load. To take care of the transverse motion influence caused by motion of exciter, the loads were screwed on force transducer by using an adapter

coincident to the centerline to the force transducer. The excitation level of the transducer was measured by calibrated accelerometer. The force transducer was conditioned by using a 10 V (DC) power supply and electrical signal from output of the transducers were measured by a digital multimeter. The measurements were repeated for the remaining transducers. For analyzing measurement results the transducers were also calibrated under static loading conditions.

Resonance curves of force transducers were determined by frequency sweep measurements under loaded condition. Transducers were excited under 3.7 kg loading conditions at the 1/3-octave band center frequencies in the frequency range of 5 – 2000 Hz. Two identical type accelerometers were used in measurements while one of them was mounted on the top of the load mass and another on the moving head of the exciter. The frequency responses of the transducers were obtained calculating the ratio of accelerations of top mass a_{top} to base mass a_{base}.

4. Experimental Results

The linearity of the electrical output of the transducers was investigated under static loaded condition and different accelerations. The linearity curve is given in Figure 3. It can be seen that the force transducer electrical signal in static and dynamic conditions are linear under different loads. For the same load there is a slight deviation between the output of transducer under static loading and output at 10 m/s² acceleration. However the reasonable deviation occurs at higher loads.

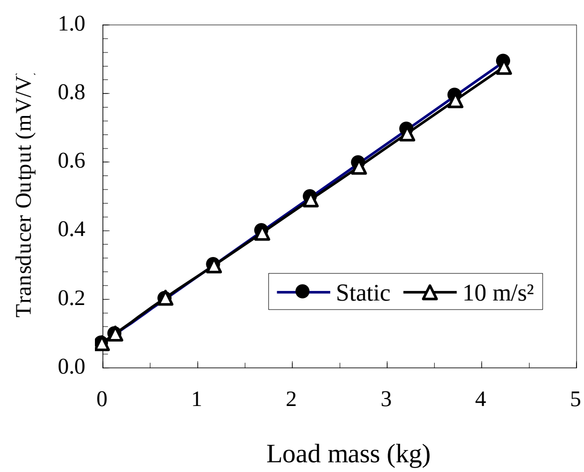

Figure 3. Force transducer electrical output under static and dynamic conditions with different loads.

Experimental results presented in Figure 4 show that the behaviour of a force transducer changes when vibration applied on it. In Figure 4 it is clearly seen that the tendency in behaviour of all four force transducers with three different capacities is similar. The deviation from the static value of one of the 300N force transducers signal decreases up to 1.5%, while the other one decreases up to 2.4%. The signal of force transducer with a capacity of 50N deviates 2.3% and the signal of force transducer with a capacity of 50N deviates up to 2.8% when they are vibrated at 10 m/s^2.

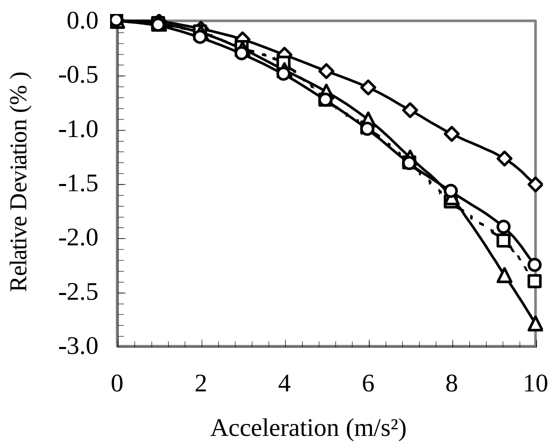

Figure 4. Relative deviations of four different force transducers with three different capacities under vibration at vertical direction.

(◇ - FT 1-300N, □ - FT 2-300N,

Δ - FT 3-100N, O - FT 4 - 50N)

Although the deviation of transducer signal from static behaviour changes, one can not generalize that the decrease in transducer output of different type but the same capacity force transducers has comparable value. On the other hand, two force transducers from the same manufacturer but different capacity also shows different deviations.

Typical frequency response curves are given in Figure 5. The axial resonance frequency of the transducers mentioned above varies between 20-90 Hz depending on the load applied.

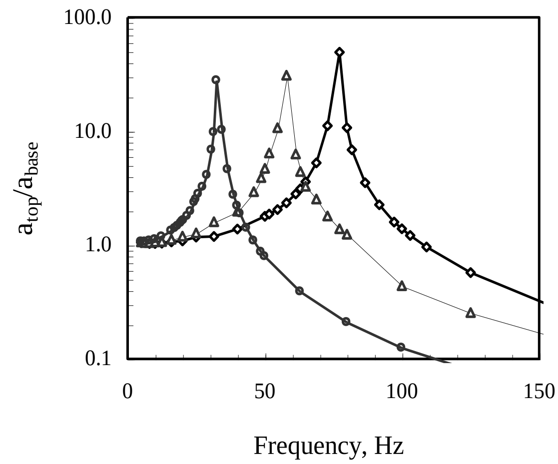

Figure 5. Resonance curves of three different force transducers under 4.2 kg load.

(O- FT 2-300N, Δ - FT 1-300N, ◇ - FT 3-50N)

Although the measurements were carried out under 4.2 kg load in the frequency range of 5-2000 Hz in 1/3 octave band center frequencies, only results in the frequency range of 5-150 Hz is presented. In order to find resonance peak more precisely, the region where the resonance occurs was scanned in 1/12-octave band steps. The resonance frequencies of two similar force transducers with 300N capacity and one force transducer 50N capacity have been determined. From the Figure 5, it is seen that the resonance frequency of two same capacity force transducers is different. They are 77.2 Hz and 57.9 Hz. Resonance peak of small capacity force transducer was found in lower frequency range, 32.5 Hz.

5. Conclusion

Influence of mechanical vibration on strain gauge based force transducer performance was investigated. It was found that even high quality force transducers could show behavior significantly different from static performance. The vibration effect on force transducer increases with higher loads. As the force transducers are used not only in static measurements but also in dynamic measurements, some errors may occur in these measurements. Since uncertainty of force measurements with such transducers typically is less that 0.5 %, in the case of measurements performed in uncontrolled environment with random vibration at low frequencies, the knowledge of described peculiarity of force transducer is very important for obtaining reliable results.

If the measurements are performed in uncontrolled environment with random vibration at frequencies around resonance frequency, the resonance frequency of the force transducer must be taken into account for correct evaluation of measurement results.

6. References

[1]. *Strain Gage Based Transducers, Their Design and Construction*, Measurement Group, Inc. North Carolina, USA, 1988

[2]. Kumme R.., *The Main Influences on the Dynamic Properties of Force Measuring Devices*, Proceedings of the XIV IMEKO World Congress, 1997, Vol. 3, p. 102-107

[3]. Kumme.R., *Error Sources in Dynamic Force Calibration*, Proceedings of the XIII IMEKO World Congress, 1994, Vol. 1, p. 259-264.

[4]. Sawla A., Kumme R., *Dynamic Behavior of Strain-Gauge Force Transducers in Fatigue Testing*, Proceedings of the IFToMM-jc International Symposium on Theory of Machines and Mechanisms, 1992, Vol. 3, p. 56-60.

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