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A QUARTZ RESONATOR FORCE TRANSDUCER

M. WERSZKO

Technical University of Wrocław
(50-370 Wrocław, Wyb. Wyspiańskiego 27)

The prototype of force transducer with the *AT*-cut quartz resonator serving as the sensitive to force element is described. The operating principle of this transducer is based on the relation between the resonator vibration frequency and the force acting on this resonator.

Since the quartz resonator is sensitive to ambient temperature, the force transducer has been also equipped by the *LC*-cut resonator, which plays the role of temperature sensor with frequency output signal. This signal is used to compensate the thermal influences.

1. Introduction

Currently, the force transducers with strain gauge are most often used in industry. Despite their many advantages they also have some disadvantages: relatively small sensitivity, analogue output signal not easily digitised. To avoid these disadvantages, the force transducers with quartz resonator representing the force-sensitive element are being developed today by some companies [1], [2], [3].

As we know, the resonance frequency of the resonator depends on Young's modulus E and density ϱ of quartz, and on the dimension of the resonator. For the AT-cut resonator this dependence is given by

$$f = 0.5\, n/h\sqrt{E/\varrho}, \tag{1}$$

where: n – vibration mode number, h – quartz thickness.

Parameters E, ϱ and h depend on the temperature, but modulus E additionally depends on the applied force F. This relation between modulus E and force F serves as a basis for the operating principle of the force transducer with quartz resonator (Fig. 1).

The steady-state characteristic of such force transducer (relation between the resonator frequency f and the measuring force F, applied to the resonator along the

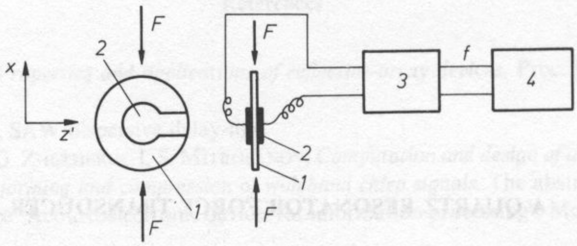

FIG. 1. Operating principle of the transducer. 1 — resonator, 2 — electrode, 3 — oscillator, 4 — frequency meter.

X-axis) is given by

$$f = f_0\sqrt{1+kF} \tag{2}$$

where: f_0 — resonator frequency at the starting point, when the measuring force is equal zero $F=0$, $k=$ scale factor.

The frequency deviation $\Delta f = f - f_0$ plays the role of the transducer output signal. For the AT-cut resonator the maximal value of this deviation (conditioned by the limiting range stress) referred to frequency f_0 equals about 0.5%.

Main advantages of the force transducer with quartz resonator are as follows:
- high sensitivity,
- frequency output signal; interference resistant and easily digitised,
- excellent stability,
- little drift, small hysteresis and time constant.

Disadvantages: sensitivity to changes of ambient temperature, steady-state characteristic non-linearity.

2. Force transducer design

The force transducer, developed at the Technical University of Wrocław, consists of an elastic frame *1* (Fig. 2), the AT-cut resonator *2* for the force measurement, the LC-cut resonator *3* for the temperature measurement, two oscillators *4* and *5*, the housing *6* and a microprocessor-based electronic unit *7*. The AT-cut resonator in form of the plane-convex plate is fitted into the steel frame *1* which reduces the measuring force F and transmits it to the resonator *2*. Under the action of this force the resonant frequency f of the resonator, connected with oscillator *4*, is changed. This frequency f is the output signal of the transducer.

In order to avoid the vapour condensation, air pressure inside the transducer housing *6* is reduced to the value of 7 kPa.

Main sources of the transducer errors are: ambient temperature and hysteresis. Variation of temperature influences, first of all, the resonator parameters E, ϱ, h (see Equation 1); moreover since the thermal expansion coefficients of the quartz resonator

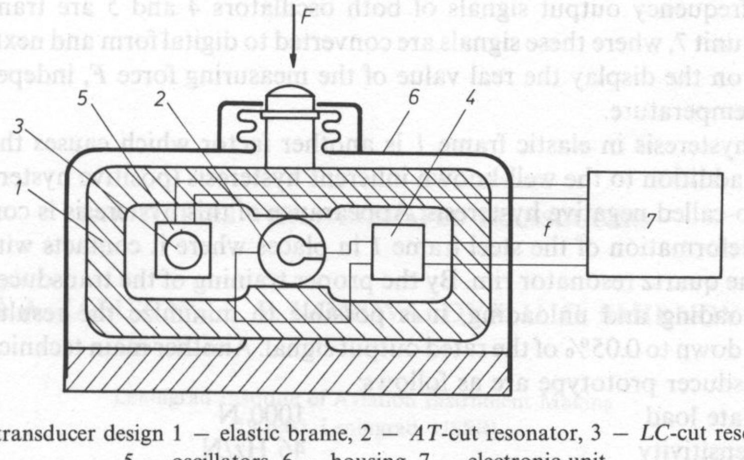

FIG. 2. Force transducer design 1 — elastic brame, 2 — *AT*-cut resonator, 3 — *LC*-cut resonator, 4 and 5 — oscillators, 6 — housing, 7 — electronic unit.

and the steel frame *1* are different, variation of ambient temperature produces additional tension in the quartz resonator and appropriate frequency change. As the steady-state characteristic shows (Fig. 3), the transducer error set up by ambient temperature can reach 0.2% of the rated output per 1°C.

The ambient temperature influence is compensated by means of the correction of the steady state transducer characteristic in the electronic unit 7. For this purpose serves the *LC*-cut resonator, which plays the role of the temperature sensor with frequency output signal. This resonator, connected with oscillator *5*, is placed near by the *AT*-cut resonator *2*.

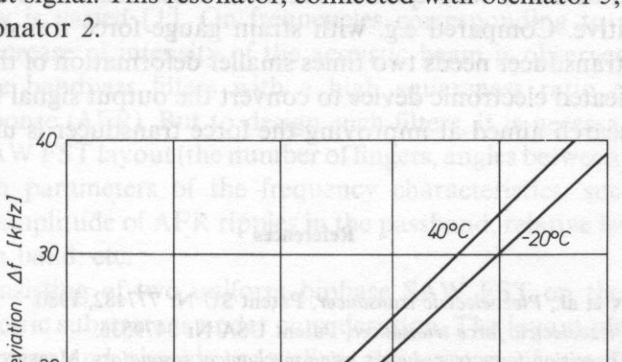

FIG. 3

The frequency output signals of both oscillators *4* and *5* are transmitted into electronic unit 7, where these signals are converted to digital form and next reprocessed to obtain on the display the real value of the measuring force *F*, independent of the ambient temperature.

The hysteresis in elastic frame *1* is another factor which causes the transducer errors. In addition to the well-known inherent hysteresis (positive hysteresis), there is also the so-called negative hysteresis. Appearance of this hysteresis is connected with inelastic deformation of the steel frame *1* in places where it contacts with very small areas of the quartz resonator rim. By the proper training of the transducer, its mutiple safe overloading and unloading, it is possible to minimize the resulting value of hysteresis down to 0.05% of the rated output signal. Another main technical data of the force transducer prototype are as follows:

– Rate load	1000 N
– Sensitivity	46 Hz/N
– Calibration accuracy	0.2% of rated output
– Compensated temperature range	−20 to +40°C
– Temperature effect	0.04% of rated output per 1°C.
– Rated output	46 kHz.

3. Conclusion

The force transducer with quartz resonator described above seems to be very stable and sensitive. Compared e.g. with strain gauge force transducer, the quartz resonator force transducer needs two times smaller deformation of the elastic element and less sophisticated electronic device to convert the output signal to a digital form.

Further research aimed at improving the force transducer is under way.

References

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[2] F. A. Norris, *Piezoelectric force transducer*, Patent USA Nr 3479536.
[3] T. Ueda et al., *Precision force transducers using mechanical resonators*, Measurement, 3, Nr 2, 89–94 (1985).