XVI IMEKO World Congress
Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

A NEW TWO-DIMENSIONAL TRANSDUCER FOR SENSORS SENSITIVE TO INFLUENCE QUANTITY

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Abstract: In this paper the important problem in measuring system: "How to eliminate the sensitivity of sensors to the influence quantity?" is replaced by the question: "How to ***use this sensitivity*** *to measure both the main and the influence quantities?" As a solution of the second problem the frequency balanced bridges as primary signal processing circuit for parametric sensors are proposed. Structure of such a two-dimensional transducer and possibilities of its realization are described. An example of transfer functions, parameters of linear model, nonlinearity errors is given when typical semiconductor pressure sensors are assumed. Some practical aspects are discussed.*

Keywords: 2-D transducers, parametric sensors, frequency output transducers

1 INTRODUCTION

The parametric sensors are sensitive not only for the quantity aimed to be measured. It is not possible to avoid the impact of other quantities. To minimize their influence the designers put a lot of effort. Different methods are applied: proper construction (technology), using of a suitable primary signal conditioning circuit (e.g. differential, self-compensation [1]) or correction of the results. The two last methods require an additional sensor sensing the influence quantity.

In this paper an another conception is proposed. Instead of eliminating, the **using** of the sensor's sensitivity to the additional quantity to measure that one – together with the main measured quantity, of course. In this way two quantities: the main and the influence compose the measurand.

By the use two or more sensors of the some type and a circuit proposed below a two-dimensional (2-D) measuring transducer can be realized.

The idea of such a transducer is explained in Fig. 1.

Following properties of that transducer are distinctive:

(i) two input quantities X_1 and X_2 are converted into two output quantities Y_1 and Y_2 simultaneously,

(ii) both of input quantities are measured, neither of them is treated as an influence quantity,

(iii) the reconstruction of measured quantities X_1 and X_2 (inversion of the realized conversion) is possible

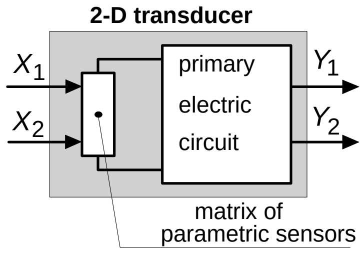

Figure 1. 2-dimentional transducer

From the third of above conditions an important problem arises: How to realize the inversion with sufficient accuracy?

Different methods of reconstruction are known [2, 3], the results however, are limited by the properties of the transducer (e.g. linearity) and precision of calibration procedure.

2 STRUCTURE OF THE PROPOSED 2-D TRANSDUCER

The proposed circuit of 2-D transducer belongs to the class of frequency output transducers [4] and is realized as a frequency balanced bridge [5,6]. A block diagram of such a circuit is shown in Fig. 2.

For any values of X_1 and X_2 the bridge circuit is balanced by tuning the frequency f to reach the minimum value (e.g. RMS) of the output voltage $u(t)$. It could be performed automatically. When the balancing procedure is completed the obtained frequency $f=f_r$ and actual value U_0 of voltage $u(t)$ are the values of output quantities. In consequence the 2-D transducer described above realize following conversion:

$$\mathbf{Y} = \mathbf{F}(\mathbf{X}) \qquad \text{where} \quad \mathbf{X} = [X_1, X_2]^{\mathrm{T}}; \quad \mathbf{Y} = [f_r, U_0]^{\mathrm{T}} \tag{1}$$

It is worth to notify that there is only one output signal of that transducer – voltage *u(t).*
During the calibration procedure it is possible to obtain the output voltage U_0 equal to zero while X_1=0, X_2=0 and f_r=f_{r0}. The tuning of additional parameters Z_1 and/or Z_3 is necessary.

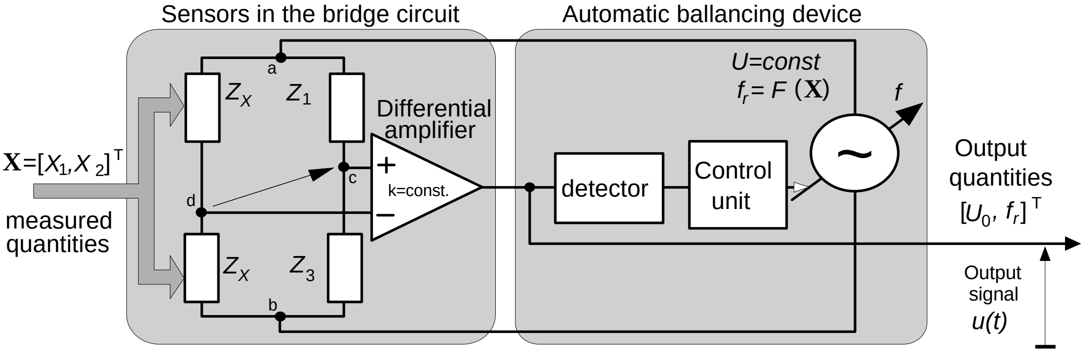

Figure 2. Block diagram of 2-D transducer based on frequency balanced bridge with two sensors Z_X

Different structures of frequency depended bridges have been analyzed [5,7]. Not all of them are applicable to the 2-D transducers.

Figure 3 presents some examples of useful bridge structures with resistance and capacitance elements only.

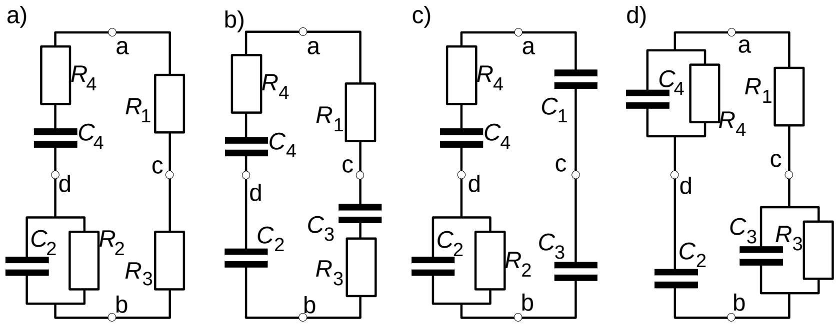

Figure 3. Frequency depended bridges with only resistance and capacitance elements

The proper choice of the bridge type and location of the sensors have to be done with respect to the balance equations and the character of the sensors.
For each of the bridge structure shown above the output voltage U_o depends on the frequency of supply source and on the parameters of elements R_i and C_i (including sensors):

$$\frac{U_o}{U} = j_U(R_i, C_i, f) = F_U(X_1, X_2) \qquad (2)$$

where U is the voltage of supply source.
The balance frequency f_r could be derived from that equation with assumption that U_o reaches the minimum value:

$$f_r = j_f(R_i, C_i) = F_f(X_1, X_2) \qquad (3)$$

The two equations (2) and (3), after the balancing procedure is completed (f=f_r), describes in detail the transfer function (1) of the considered 2-D transducer. The following restrictions have to be fulfill:
a) at least two sensors should be used,
b) their parameters should occur simultaneously in both equation (2) and (3).

3 EXAMPLE OF THE 2-D TRANSDUCER

The elements in semiconductor piezoresistive bridge-strain pressure sensors are usually more sensitive on the influence of temperature than on the main measured quantity. Such a type of sensor is suitable to apply in the considered 2-D transducers to convert two quantities (pressure and temperature) into voltage and frequency of the output signal.

As an example the transfer functions for transducer with the bridge shown in Fig. 2a have been derived. Equations (2) and (3) in this case have the following form:

$$u = \frac{U_o}{U} = \left| \frac{R_3}{R_3 + R_1} - \frac{i \cdot 2p\ f_r \cdot C_4 R_2}{i \cdot 2p\ f_r \cdot C_4 R_2 + (1 + i \cdot 2p\ f_r \cdot C_2 R_2)(1 + i \cdot 2p\ f_r \cdot C_4 R_4)} \right| \qquad (4)$$

$$f_r^2 = \frac{1}{4p^2 C_2 C_4 R_2 R_4} \qquad (5)$$

where *i* is the imaginary unit.

It was assumed that all of the sensor elements are linear: $R_i = R(1+s_1X_1+s_2X_2)$. Typical values of coefficients are R=5000Ω, s_1=0.05 [1/Pa] (X_1 is the pressure), s_2=0.15 [1/K] (X_2 is the temperature). The value of resistance R_1 was tuned to obtain U_0=0 for X_1=X_2=0. The scheme of considered transducer in detail is shown if Fig. 6.

When considering the problems of 2-D transducers the term “transfer curve” have to be replaced by “transfer surfaces”. The obtained transfer surfaces in relative units are shown in Fig. 5. In this example the maximum range of voltage change reaches 5% of supply voltage, when amplification of the amplifier is equal to one (k=1).

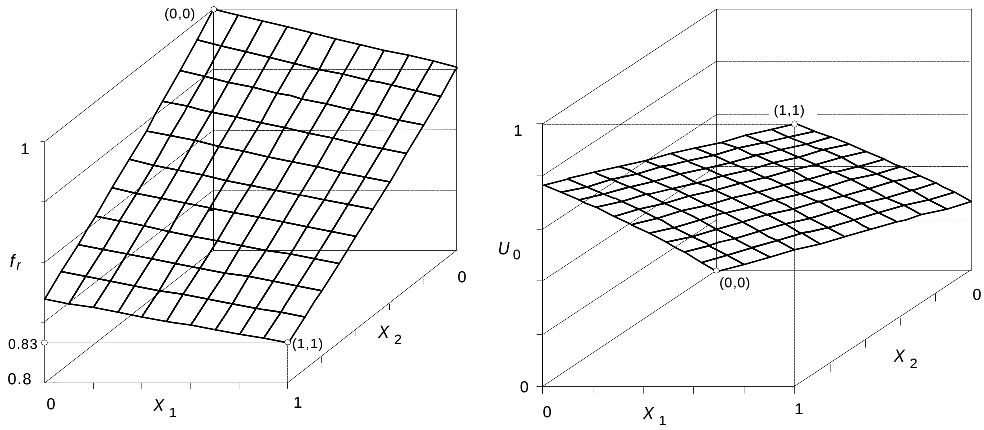

Figure 4. The transfer surfaces of considered 2-D transducer

The following linear model may approximate these transfer surfaces:

$$\begin{bmatrix} f_r \\ u \end{bmatrix} = \begin{bmatrix} s_{f1} & s_{f2} \\ s_{u1} & s_{u2} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} f_{r0} \\ u_0 \end{bmatrix} \qquad (6)$$

with coefficients s_{f1}=-0.0415, s_{f2}=-0.1246, f_{r0}=1-0.00393, s_{u1}=0.2495, s_{u2}=0.7505, u_0=-0.0012.
The nonlinearity errors of above linear model are shown in Fig. 5.

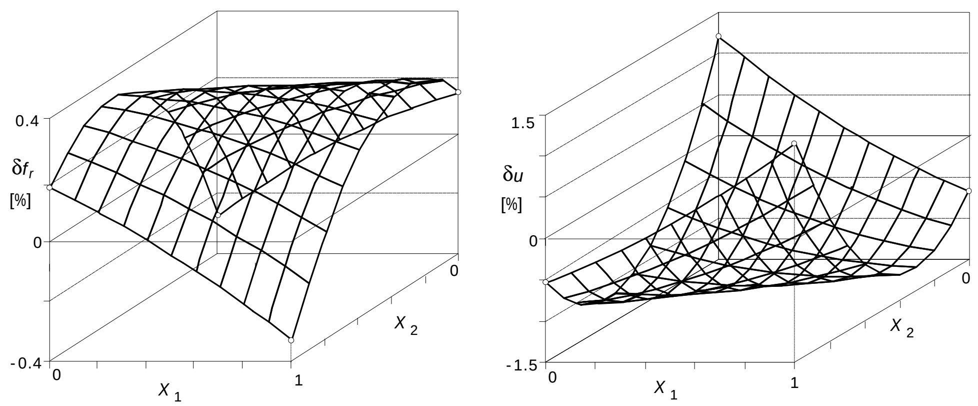

Figure 5. Nonlinearity error of considered 2-D transducer

4 REMARKS ON PRACTICAL REALIZATION

The above given 2-D plots of transfer functions have been obtained by numerical calculation. It allows presenting in a clear way the properties of the method of conversion. The obtained results shown that described transducer fulfills the three conditions (i, ii, iii) given in point 1.
An example of practical realization of considered transducer is shown in Fig. 6.

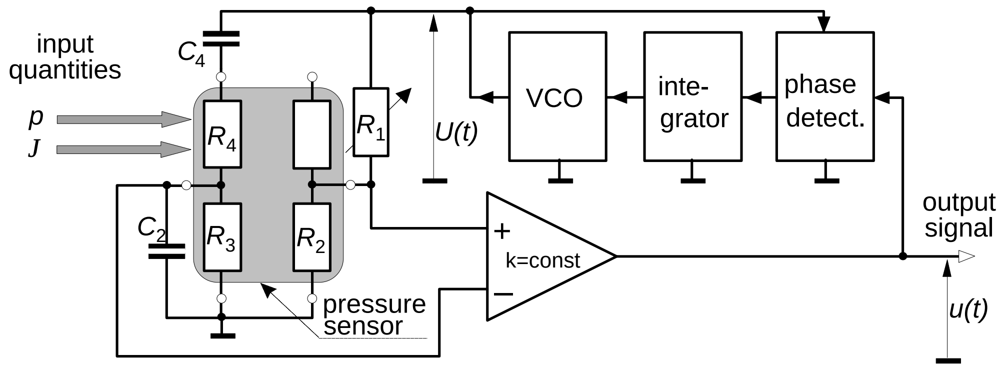

Figure 6. The scheme of considered transducer

Properties of all elements in this device influence to the final form of transfer function and to the uncertainty of realized conversion. Practically the most important of them are the following:

a) the frequency is tuned precisely to balance the bridge - it could be executed when: the VCO output signal has enough low nonlinear distortion, the phase detector has enough high sensitivity and the amplifier with band filter is applied,
b) the additional elements in the bridge have optimal values, matched to the values of sensors parameters,
c) the electromagnetic interference is reduced.

5 CONCLUSIONS

Frequency-balanced bridges are the useful primary signal processing circuits for 2-D parametric sensors. They make possible to utilize the sensitivity of the sensors to both the influence quantity and to the main measured quantity. The new type of 2-dimentional transducer is obtained in this way. Such type of transducers has some good properties: comparatively high level of output signal, high sensitivities to both measured quantities. Good linearity of their transfer functions makes that the reconstruction of measured quantities may be realized with high accuracy. Processing of the output signal to digital form of output quantities is very simple - rectifier and A/D converter to "U_o-code" conversion and counter to "f_r-code" conversion are necessary.

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