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ERROR PROPAGATION IN INTERFACE ELECTRONICS FOR PASSIVE SENSORS.

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Abstract: Contemporary interface electronics for passive sensors may be divided into three groups according to the output variable: frequency output, voltage output and pulse duration modulated output. The paper presents the basic principles of error propagation for only two groups. The error propagation depends mostly on the sensor properties ("m" coefficient) and on the structure of the interface electronics (nondifferential or differential one). For sensors with low "m" values the similarity of error propagation for both investigated groups has been found in spite of the great differences in their design. Specific properties of quasi-differential strictures - like bridges – are presented too.

Keywords: Passive sensors, error propagation, interface electronics.

1. INTRODUCTION

The interface electronics forms that part of the measuring system which is necessary to convert the sensor output to the digital signal processed further in the system. In the case of active sensors such as thermoelectric and thermopiles sensors, piezoelectric accelerometers, photovoltaic sensors etc, the only task of the interface electronics is to amplify the signal to the level high enough for an A/D converter. The required accuracy, stability and noise protection should be taken into account. For passive sensors like thermoresistors, photoresistors, strain gages, piezoresistors, capacitive and inductance displacement sensors, humidity sensors and many others, the design of interface electronics is more complicated because the sensor does not generate any signal and the change of the electrical circuit parameter has to be measured. Two different methods are commonly used in practice for that purpose. In the first one the wave oscillator is designed with the frequency following the changes of the sensor parameter P. Then the frequency is converted into the digital signal by the use of simple counters normally incorporated into microprocessor system and controlled by the appropriate program. In that kind of interfacing electronics, known as the frequency – output design, no A/D converter is needed. The second method consists in the supplying the sensor from the current or voltage source and the use of the voltage drop over the sensor parameter as the signal for further amplification and A/D conversion. In the both methods the sensor parameter P is that one sensitive to the measured quantity (resistance, capacity, mutual impedance or other). Such a parameter always consists of two parts: P_0 and P_X, where only P_X depends on the measured quantity X.

For the purpose of that paper two relative coefficients have been introduced: The first one is $r(x) = P_X/\Delta P_X$ where ΔP_X is the span of the sensor parameter corresponding to the ΔX span of the measured quantity. The r(x) represents the level of the actually measured quantity and changes its value from 0 to 1. The other, and more important coefficient is defined as $m = \Delta P_X/P_0$. The "m" value depends on the sensor used. In the strain gage sensors "m" is very small, about $2*10^{-3}$, in capacitive humidity sensors -approximately 10^{-1}, and in Pt 100 RTD's reaches up to 3.5.

The paper is focused on the error analysis of the basic methods mentioned above and used in the interface electronics circuits. The aim of the paper is to compare the results of the error propagation analysis in order to reject wrong solutions just at the beginning of the measuring system design process.

2. ERROR PROPAGATION.

The analysis of each measuring structure consists in the examination of the measurement function $V_{out} = F(P, V_1, V_2, ...V_i, ...V_k)$ in order to determine the error propagation rules. V_i are the variables influencing the transducer output V_{out} but not sensitive to the measured quantity X. The law of error propagation describes how the errors of all variables V_i and P influence the error at the system output. Such an analysis forms the background for error compensation and error correction procedures. For the purpose of that paper only additive E^A and multiplicative E^M errors will be considered. Other kind of errors like higher order errors and interaction errors will be neglected. Multiplicative errors are considered for sensor parameters P only, because in the measurement function all other variables have nominally constant values and therefore there is no need to introduce their multiplicative errors to the performed analysis.

$$E_P = E^A + E^M = \varepsilon^A P_0 + \varepsilon^M P_X \qquad E_i = \varepsilon_i V_i \tag{1}$$

The basic relation for the error propagation is then

$$\varepsilon_{out} = \frac{E_{out}}{\Delta V_{out}} = \frac{\partial V_{out}}{\partial P}\frac{E_P}{\Delta V_{out}} + \sum_{i=1}^{k}\frac{\partial V_{out}}{\partial V_i}\frac{E_i}{\Delta V_{out}} = \frac{\partial V_{out}}{\partial P}\frac{\varepsilon^A P_0}{\Delta V_{out}} + \frac{\partial V_{out}}{\partial P}\frac{\varepsilon^M P_X}{\Delta V_{out}} + \sum_{i=1}^{k}\frac{\partial V_{out}}{\partial V_i}\frac{E_i}{\Delta V_{out}} \tag{2}$$

where E are absolute errors, ε are relative errors and ΔV_{out} is the span of the output variable.
The coefficients present in (2) are the sensitivities to the changes of variables P or V_i and constitute the error propagation factors K.

$$\varepsilon_{out} = K_P^A \varepsilon^A + K_P^M \varepsilon^M + \sum_{i=1}^{k} K_i \varepsilon_i \,. \tag{3}$$

Let us analyse the simplest linear structure (an example will be presented in section 3)

$$V_{Out} = S(P_0 + P_X)\,, \tag{4}$$

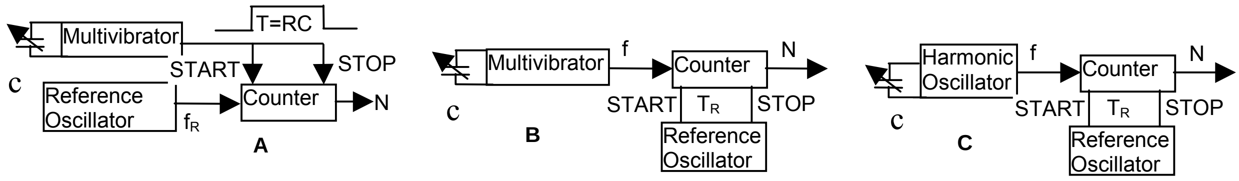
where S is the transducer sensitivity.
The relative error is then

$$\varepsilon_{out} = \frac{E_{out}}{\Delta V_{out}} = \varepsilon_S[\frac{1}{m} + r(x)] + \varepsilon^A \frac{1}{m} + \varepsilon^M r(x) \tag{5}$$

The additive error propagation factor is equal to 1/m and achieves very high value in the case of low m coefficient. The multiplicative error according to its nature remains multiplicative one with the propagation factor changing from 0 to 1. The sensitivity error ε_S is multiplicated by both factors. The results presented above ought to be taken as a reference for any other structures analysed below.
A specific problem appears in all systems with passive sensors regardless to the method used for obtaining the digital signal N_X at the output of interfacing electronics. The problem is related to the necessity of cutting off the initial offset value N_0 corresponding to the P_0 and therefore to the initial (or zero) value of the measured quantity. The value of N_0 is fixed during the calibration process and its error influences the output N_X with the propagation factor K = 1

3. FREQUENCY OUTPUT INTERFACE STRUCTURES

The use of the parameter controlled oscillator as interface electronics is the simplest method to transform the passive sensor output variable (R, C, L, M) into the frequency. It may be done in many different structures but three basic structures shown in Fig. 1 will be investigated below: It has been assumed that the sensor capacitance C is that parameter sensitive to the measured quantity X.



$N = N_0 + N_X = Af_R T = Af_R R(C_0 + C_X)$

$N = N_0 + N_X = \frac{Af_R}{RC} = \frac{Af_R}{R(C_0 + C_X)}$

$N = N_0 + N_X = \frac{T_R}{2\pi\sqrt{LC}} = \frac{T_R}{2\pi\sqrt{L(C_0 + C_X)}}$

Fig. 1. Three examples of interface electronics structures with parameter controlled oscillators. Multivibrator structure with the period output A, multivibrator structure with the frequency output B, and harmonic generator structure with frequency output C.

Due to the mostly low values of capacitances or inductances of the sensors the frequencies obtained from both oscillators and multivibrators are rather high. Hence, from the technical point of view it is more convenient to measure the oscillation frequency rather than the period. However, if the linear relation between the digital output and the sensor parameter is demanded the structure presented in Fig. 1A ought to be used. The analysis of this structure is extremely simple because the structure corresponds to the basic law of error propagation presented in section 3 and therefore needs no additional comments. The propagation factors for this structure are depicted in Fig. 2.

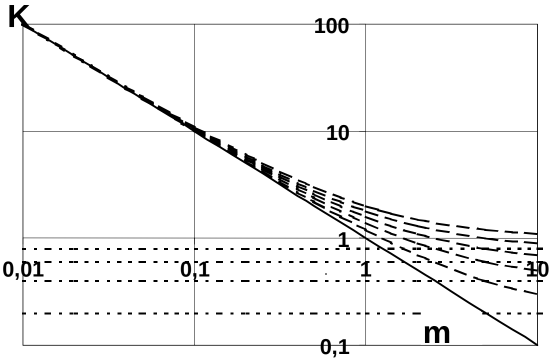


Fig.2. Error propagation factors K for sensor parameter additive errors (full line), for sensor parameter multiplicative errors (dotted lines), and for all other variables A, f_R, R_1, (dash lines). Data are related to the structure presented in Fig. 1A.

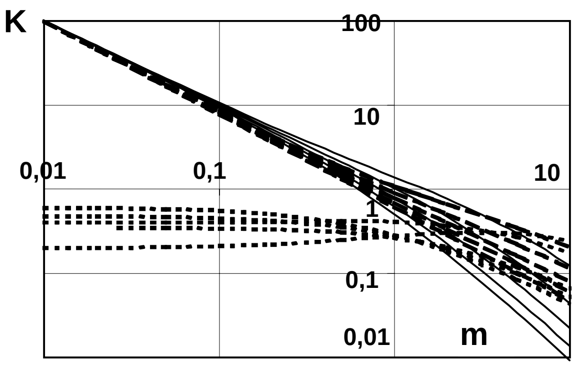


Fig. 3. Error propagation factor related to the structure presented in Fig. 1B. The meaning of the line styles is the same as in Fig. 2.

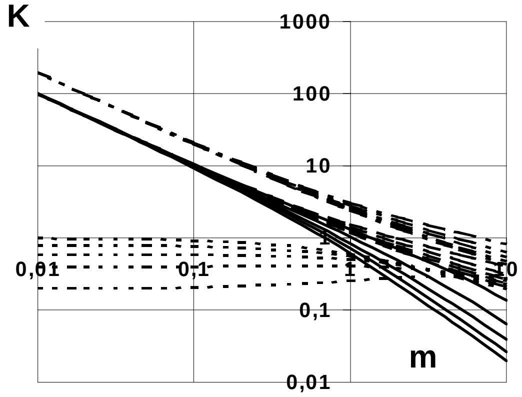


Fig. 4. Error propagation factors related to the structure presented in Fig.1C. The meaning of the line styles is the same as in Fig. 2.

Error propagation factors for structures B and C are presented in Fig. 3 and 4. It should be emphasised that for the m value lower than 0.2 all investigated structures have almost the same properties. For higher values of m multiplikative errors become greater and additive errors smaller in comparison with the reference situation illustrated in Fig. 2. Additionally, the output errors caused by the period T_R in the structure C are always twice greater than all the other errors due to the nonlinear calibration function of that structure.(Fig. 4. –dotted-dash line).A very effective method for the K factor diminishing is the use of the differential structure. Unfortunately, the practical realisation of that structure infrequency output interface electronics is complicated for technical reasons and therefore the problem will not be presented here.

4 STRUCTURES WITH THE A/D CONVERETERS

As the A/D converter needs a voltage signal the interface electronics has to convert the change of the sensor parameter into the voltage. It may be performed by nondifferential or differential structures (Fig.5). In order to simplify the further presentation it is assumed that the sensor resistance R is sensitive to the measured quantity. The basic difference between the both structures consists in the manner how the N_0 value is rejected from the measurement result. That cutting off process may be performed either in the analogue part of the electronic circuit by the use of differential structure or in nondifferential structure by an appropriate algorithm after the A/D conversion. The algorithm method seems to be more effective, especially if the cutting–off algorithm forms a part of the other digital signal conditioning. Error analysis shows, however, that better results may be sometimes achieved if some tasks are performed rather in an analogue than in a digital way.

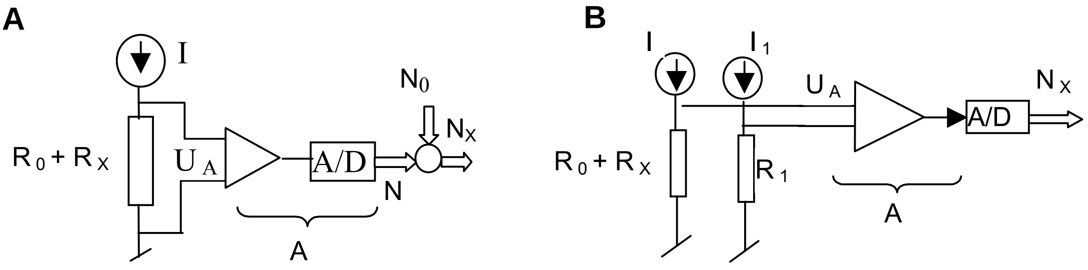


Fig.5. Basic nondifferential A, and differential B structures with voltage output followed by the A/D converter.

4.1. NONDIFFERENTIAL STRUCTURE

The simplest non-differential structure consists of a current source, sensor, amplifier and A/D converter (Fig.3a). The coefficient A represents both the amplification factor and the conversion coefficient of the A/D converter. For that structure the K factors related to all variables are equal to 1/m or even higher which means that the structure is extremely sensitive to all errors especially if the used sensor has a low value of m coefficient. By the use of an A/D converter with the reference input the additive error ε_R^A becomes the miltiplicative one and its value is many times reduced.

4.2. DIFFERENTIAL AND QUASI-DIFFERENTIAL STRUCTURES

Basic differential structure is presented in Fig. 4B. It is possible to cut off the offset voltage IR_0 when matching $R_0 = R_1$ and $I = I_1$. There is no need to subtract N_0 value in the digital part of the instrument. It is well known that all ideal differential structures eliminate additive errors and preserve multiplicative errors. When $\varepsilon_I = \varepsilon_{I_1}$ and $\varepsilon_R^A = \varepsilon_{R_1}^A$, all errors are reduced to the multiplicative components only. It is the greatest advantage of the differential structure.

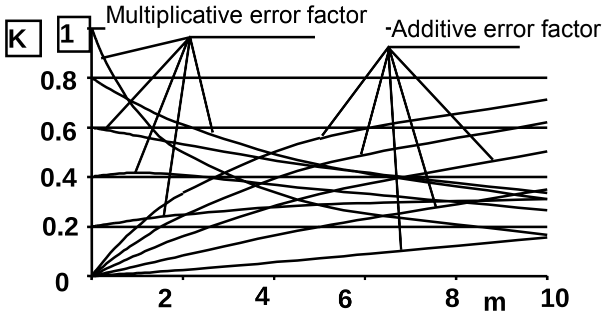


Fig.6. Error propagation factors for current supplied bridge

Unbalanced bridges used very often in interface electronics circuits belong to quasi-differential structures. If the sensor parameter “m” is low their error propagation properties are the same as those of the ideal differential structures. The most spectacular difference appears at high values of “m”. There is also a difference between the voltage and current supplied bridges. A current supplied bridge does not cancel the additive errors like the ideal differential structure but only reduces their values. The K factor for multiplicative errors, however, is also reduced (Fig.6). In the voltage supplied bridges K factors have the opposite signs for additive and for multiplicative errors which gives the opportunity for mutual error reduction. Such an opportunity does not exist in the ideal differential structures. The analysis of error propagation gives the possibility for a proper choice of the interfacing electronics structure in accordance to the dominated errors.

CONCLUSION

The aim of that paper is not to analyse the error propagation of all interface electronics structures. It needs a book not a paper. The main conclusion may be summarised as follows: Not the design and technical realization but the sensor properties and signal conditioning structures decide on the error propagation. The technical realization decides only on the values of each particular error which appears in the measurement system.

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