SOME QUESTIONS OF THE ADJUSTMENT OF INSTRUMENTS

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The adjustment is the *displacement* of one of the essential elements of an instrument into the position required for ensuring the prescribed function. Adjustment is realized by a *geometrical change* in any instrument, whatever the working principle may be. By the displacement of material bodies having certain physical characteristics (electrodes, radiators, armatures, etc.), namely, instrument characteristics can be influenced what is essentially the aim of the above mentioned operation.

Instruments fulfil their function through the suitable choice of the physical characteristics of their elements and the suitable design of the position and arrangement of the elements. Adjustment is necessary since the mentioned elements have not the prescribed characteristics, and their positioning and arrangement has not been or could not have been successful. Let J_i designate, in accordance with Hansen [1], the physical characteristics of an instrument consisting of i elements, E their arrangement, K_i the positioning parameters. Then the resultant functioning of the instrument can be described by the expression

$$R = f\,[J_i, K_i, E] \tag{1}$$

what is a symbolic form of the functional correlation named "instrument equation" [2]. One part of the characteristics figuring in (1) are not alterable given things (a), while the others are suitable for adjusting the instrument, since they are influencing the resulting output signal without affecting basically its character (quality). Let v designate the second, variable group of the characteristics.

$$R = f\{[K_i, J_i]_a,\ [J_i, E]_v\}. \tag{2}$$

From the point of view of adjustment the given things are of no interest, only the changes of characteristics having the subscript v should be considered.

$$\Delta R = F\,[J_i, E]_v = G(L)\,. \tag{3}$$

The characteristics of both the types J_i and E can equally be influenced by a *geometrical displacement*, therefore their symbolic reduction into the displacement parameter L is justified.

Instrument equation

Relationship between the various instrument parameters is expressed by the instrument equation (3), what can be conveniently used for presenting the questions connected with adjustment.

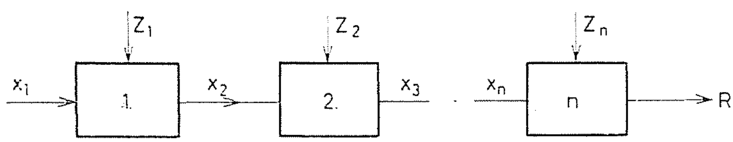

Fig. 1. Block diagram of an instrument consisting of series units

The equation of an instrument having a structure formed by n units connected in series (see the figure) consists of the intercontained functions of the following type.

$$x_{i+1} = f_{(i)}(x_i, a_i, b_i, \dots z_i); \qquad i = 0, 1, 2, \dots n. \tag{4}$$

In case of an instrument consisting of three units what frequently occurs in practice (primary element, amplifier, indicating element).

$$\begin{aligned} &\text{the equation of unit 1 is} && x_2 = f_1(x_1, a_1, b_1, \dots z_1); \\ &\text{that of unit 2 is} && x_3 = f_2(x_2, a_2, b_2, \dots z_2); \\ &\text{that of unit 3 is} && R = f_3(x_3, a_3, b_3, \dots z_3). \end{aligned} \tag{5}$$

The reduced instrument equation is found to be

$$R = f_3 \left\{ f_2 \left[f_1(x_1, a_1, b_1, \dots z_1), \ a_2 \, b_2, \dots z_2 \right] a_3, b_3, \dots z_3 \right\}; \tag{6}$$

where x_n is the input signal,
x_{n+1} the output signal,
$a_n, b_n, \dots$ the construction parameters characterizing the nth unit,
z_n the disturbing variable of the nth unit,
R the indicated (resultant) value of the quantity x_1 to be measured.

The equation of the ideal instrument is given by the relationship

$$R^* = k \cdot x_1, \tag{7}$$

where k designates the constant transfer coefficient of the instrument.

The *task of adjustment* can accordingly be formulated also in that form that the value ΔR indicated in Eq. (3) and obtained in the course of adjustment should continuously take such a value that the equation

$$R - R^* = -\Delta R \tag{8}$$

is satisfied.

Requirements for the adjustment

In instrument equation (6) the structural parameters are those which form the characteristics $[J_i, E]_v$. *Any* of these parameters may come into question during adjustment, since their change causes a durable modification of R. Among the possible parameters those should advisably be chosen which can suitably ensure

(a) the independence,
(b) the invariance, and
(c) the effectiveness of adjustment.

An adjustment is *independent*, if the influenced construction characteristic is *altering only the output signal* and not touching the effect of the other construction parameters.

If Eq. (6) is written in the simplified form

$$R = f(x_1, a, b, \ldots z), \tag{6a}$$

then the adjustment effected by the help of construction parameter a is independent only if

$$\Delta R = \frac{\partial f}{\partial a} \cdot a. \tag{9}$$

This is equivalent to the independence of $\frac{\partial f}{\partial b}$, $\frac{\partial f}{\partial c}$, etc. from a, i.e. the adjusting effect is independent of the other construction parameters.

A requirement more difficult than independence is the *invariance*, the ensuring of which is a very heavy task, even in case of the adjustment of a single parameter. If adjustment is effected by the help of two or more construction parameters of an instrument, the ensuring of simultaneous invariance for these is in general impossible or uneconomical.

An adjustment is *invariant* if in spite of *all changes* occurring in the course of the operation of the instrument

$$\Delta R = \text{const.} \tag{10}$$

It is usual to interpret the invariance also in a narrower sense when the constancy of ΔR is required only with respect to *external disturbing* effects (parameters z).

Since the ΔR_c initial value of ΔR is altered by both the construction parameters and the disturbing effects, invariance can be realized only by *compensating devices.*

The condition of invariance in the narrower sense, when adjustment is made by the parameter a, is that

$$\Delta R(x_1, a, \Delta a, b, c, \ldots z) = \Delta R(x_1, a, \Delta a, b, c, \ldots z, \Delta z). \tag{11}$$

The compensation should ensure that

$$\frac{\partial f}{\partial z} \Delta z + K(z) = 0,$$

that is

$$K(z) = -\frac{\partial f}{\partial z} \Delta z\,, \tag{12}$$

where $K(z)$ is the function describing the compensating effect depending on the disturbing parameter.

The most suitable among the parameters which can be taken into consideration from the point of view of adjustment should be chosen advisably on the basis of the alteration of the output signal brought about by them. The *effectiveness* of adjustment understood in this sense can be judged in such a way that all parameters are changed by the *same* value and the obtained partial ΔR_i values are compared with $\sum_1^n \Delta R_i$ [4].

The course of the process can be given as follows.

According to (6a) $\qquad R = f(x_1, a, b, c, \ldots z)$

On the basis of the law of propagation of errors we can write that

$$\Delta R = \frac{\partial f}{\partial x_1} \Delta x_1 + \frac{\partial f}{\partial a} \Delta a + \frac{\partial f}{\partial b} \Delta b + \ldots + \frac{\partial f}{\partial z} \Delta z\,. \tag{13}$$

Since $\frac{\partial f}{\partial z} \Delta z$ cannot be taken into consideration from the point of view of adjustment, let us transfer this member to the left side of the equation.

$$\Delta R - \frac{\partial f}{\partial z} \Delta z = R^* . \tag{14}$$

According to the above we assume that

$$\Delta x_1 = \Delta a = \Delta b \; \dots = \Delta j \tag{15}$$

and with this

$$\Delta R^* = \left[\frac{\partial f}{\partial x_1} + \frac{\partial f}{\partial a} + \frac{\partial f}{\partial b} + \dots \right] \Delta j . \tag{16}$$

Eq. (16) gives the possibility of evaluating the effect of the individual parameters, including that of the input signal. By regarding the value in brackets as 100%, the individual adjustment possibilities can even be classified. The construction parameters figuring in the obtained partial expressions contain valuable information also on the dependence or independence of adjustment.

Summary

The theoretical aspects of the adjustment of instruments, especially measuring instruments are treated in the paper. The selection of those construction parameters is discussed, the adjustment of which promotes the correct functioning of the instrument. A calculation method is proposed for the assessment of the independence, invariance, and effectiveness of adjusments.

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