LINEAR MEASUREMENTS

SELECTION OF PARAMETERS FOR PNEUMATIC MEASURING SYSTEMS
ACCORDING TO GIVEN METROLOGICAL CHARACTERISTICS

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Pneumatic instruments for automatic control in engineering have been rapidly developed in recent years both in our country and abroad.

The majority of these instruments are based on the principle shown in Fig. 1, where \( H \) is the supply overpressure, \( h \) is the measured overpressure, \( d_1 \) is the diameter of the input nozzle, \( d_2 \) is the diameter of the measuring nozzle, \( z \) is the measuring gap between the face of nozzle \( d_2 \) and the surface of the tested component.

The characteristic of a given measuring system determines the relationship between the measured pressure \( h \) and gap \( z \).

The design of a pneumatic measuring system consists in selecting the diameters of the input and measuring nozzles and the pressure which would provide the system with the following required metrological characteristics.

1) A measuring system's transfer characteristic \( K_z \) \([\text{N/m}^2/\text{mm}]\) which is equal to the ratio of the measured pressure increment to that of the measuring gap:

\[
K_z = \frac{dh}{dz}
\]

2) Measuring range \( R_z = z_1 - z_2 \) [mm] defined as the range of measuring gaps for which the deviation of the system's characteristic from linearity does not exceed a given error \( \delta_z \)%.

3) The system's error \( \delta_z \) evaluated as the maximum discrepancy in millimeters between the system's characteristic \( h = f(z) \) and its linearizing straight line, expressed in percentages of the full-scale deflection.

The linearizing straight line passes through the inflection point of the curve \( h = f(z) \) which has a slope equal to the maximum transfer ratio of the system.

4) Middle point \( z_m \) [mm] of the linear section of the measuring system's characteristic.

Computations have shown that for small errors \( \delta_z \)% the value of \( z_m \) coincides with sufficient precision with the inflection point of characteristic \( h = f(z) \).

The computation of the measuring system is greatly simplified by introducing dimensionless quantities of:

\[
\zeta = \frac{h}{H}; \quad \psi = \frac{4d_2z}{d_1^2}.
\]

The relationship between the pressure and the gap

\[
h = \frac{H}{1 + \left( \frac{f_3}{f_1} \right)^2},
\]
where \( f_1 \) and \( f_2 \) respectively the port cross sectional areas of the input nozzles and the annular gap, can now be expressed in terms of the dimensionless quantities as:

\[
\zeta = \frac{1}{1 + \varphi^2}.
\]

Thus, by using the dimensionless quantity \( \varphi \) it is possible to obtain the unique characteristic \( \zeta = f(\varphi) \) for various values of \( d_1 \) and \( d_2 \) and for a definite operating pressure \( H \), instead of a multiplicity of characteristics \( h = f(z) \), each of which is determined for different values of \( d_1 \) and \( d_2 \).

It will be shown later that it is also convenient to express the operating pressure \( H \) in terms of a dimensionless quantity

\[
\varepsilon_a = \frac{P_a}{H + P_a},
\]

where \( P_a \) is atmospheric pressure.

It is possible to compile for characteristic \( \zeta = f(\varphi) \) the following set of dimensionless metrological characteristics which are equivalent to the dimensionless characteristics examined above.

1) \( k = \frac{d\zeta}{d\varphi} \) is a dimensionless transfer ratio.
2) \( R_\varphi = \varphi_1 - \varphi_2 \) is the dimensionless measuring range.
3) \( \delta \varphi \) is the dimensionless linearization error.
4) \( \varphi_m = \varphi_1 \) is the middle of the linear section of characteristic \( \zeta = f(\varphi) \), which coincides with a sufficient degree of precision with the inflection point.

The following are the relationships existing between the dimensional and dimensionless metrological characteristics. For the transfer ratio

\[
k = \frac{d\zeta}{d\varphi} = \frac{d\zeta}{4d_2H} \cdot \frac{dh}{dz} = \frac{d_1}{4d_2H} \cdot K_z,
\]

for the measurement range

\[
R_\varphi = \varphi_1 - \varphi_2 = \frac{4d_2}{d_1} (z_1 - z_2) = \frac{4d_2}{d_1} \cdot R_z.
\]

for the linearization error it is the same for both characteristics owing to the converter's linear characteristics (1)

\[
\delta \varphi = \delta z.
\]

and for the linear segment it is

\[
\varphi_m = \frac{4d_2}{d_1} \cdot z_m.
\]

It will be seen from relationships (3) - (6) that

\[
k R_\varphi H = K_z \cdot R_z,
\]

\[
k \varphi_m H = K_z \cdot z_m,
\]

moreover, these dimensional combinations depend only on the value of \( \varepsilon_a \) and the linearization error \( \delta z \).

Thus, the entire design problem is reduced to evaluating the relationship of the maximum dimensionless transfer ratio and the position of the inflection point on characteristic \( \zeta = f(\varphi) \) to the value of \( \varepsilon_a \), and the relationship of the dimensionless measuring range \( R_\varphi \) to the linearization error \( \delta \varphi \) and the value of \( \varepsilon_a \).