DYNAMIC CHARACTERISTICS OF INDUSTRIAL SYSTEMS FOR MEASURING
THE FLOW RATE OF AN OXYGEN BLAST, BASED ON COMPENSATION
DIFFERENTIAL MANOMETERS OF THE DMKK TYPE

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In this paper we shall consider a system for varying the flow of oxygen in industrial systems by means of a
compensation differential manometer of the DMKK type, incorporating additional automatic correction for the con-
centration of oxygen in the blast [1]. When the temperature, pressure, and oxygen content of the gas deviate from
the values specified in the design of the compressing system, the instrument measuring the flow continuously and au-
tomatically solves the equation [1, 2, 3]

\[ Q_{DMKK} = K C \sqrt{\frac{K_p}{K_T} \Delta p}, \]  

where \( Q_{DMKK} \) is the flow of oxygen as given by the scale readings of the differential manometer, \( K \) is a coefficient
of proportionality, \( K_C \) is the correction coefficient relating to the oxygen content of the gas, \( K_p \) is the correction
coefficient relating to the gas pressure, and \( K_T \) is the correction coefficient relating to the gas temperature, while
\( \Delta p \) is the pressure drop in the compressing device.

The structural arrangement of the oxygen-flow-measuring system is shown in Fig. 1. It would be convenient
to study the dynamic and static properties of the measuring system independently along each channel; in this case,
however, the dynamic characteristics of the system studied will be valid only for those working conditions under
which the simultaneous appearance of two or more perturbations in unlikely, and this is unrealistic in industrial mea-
suring systems. The simultaneous deviations of all the parameters from their calculated values exerts a combined
effect on the result of each separate perturbation, so that the principle of superposition is inapplicable when analyz-
ing the static and dynamic properties of the measuring system. It may nevertheless be shown that the infringement
of the aforementioned condition produces errors smaller than the errors of the differential manometer itself when
analyzing the dynamics and statics of the measuring system.

After certain transformations, Eq. (1) may be expressed as

\[ Q_{DMKK} = Q_D - Q_p - Q_T - Q_C + Q_{PT} + Q_{TC} - Q_{PCT}, \]  

where \( Q_D \) is the rate of flow of the blast for the calculated gas parameters, \( Q_p = (1 - \sqrt{K_p}) Q_D \) is the deviation
in the flow resulting from a change in gas pressure, \( Q_T = (1 - \sqrt{K_T}) Q_D \) is the deviation in the flow resulting from
a change in gas temperature, \( Q_C = (1 - K_C) Q_D \) is the deviation in the flow resulting from a change in the oxygen
content of the gas, \( Q_{PT} = (1 - \sqrt{K_T}) Q_p \) is the deviation in the flow resulting from the mutual influence of simultane-
ously changing gas temperature and pressure, \( Q_{PC} = (1 - K_C) Q_p \) is the deviation in the flow resulting from the mutual
influence of simultaneously changing gas pressure and oxygen content, \( Q_{TC} = (1 - K_C) Q_T \) is the deviation in the flow resulting from
the mutual influence of simultaneously changing gas temperature and oxygen content, and \( Q_{PCT} = (1 - \sqrt{K_T}) Q_C \)
is the deviation in the flow resulting from the mutual influence of simultaneously changing gas pressure, temperature,
and oxygen content, all together.

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A calculation based on Eq. (2) shows that, when the gas temperature and pressure deviate simultaneously by the whole calculated range of corrections envisaged by the correction system, and the oxygen content of the gas deviates by 10%, with the effects all acting in the same sense on the result of the measurement, $Q_{DMKK}$, the sum of the last terms in Eq. (2)

$$\Sigma Q_i = Q_{RT} + Q_{RC} + Q_{TC} - Q_{PTC}$$

equals about 2.5% of the flow $Q_{DM}$. If, however, we consider the fact that simultaneous deviations in the gas parameters by the whole of the calculated range of corrections, all in the same sense with respect to the result of the measurement, are very unlikely, then the sum (3) will be several times smaller. If, then, we neglect the last terms in Eq. (2) on account of their smallness, we may write

$$Q_{DMKK} = Q_{DM} - Q_{RT} - Q_{TC}.$$

The structural arrangement of the flow-measuring system set up in accordance with Eq. (4) must allow for the dynamics and statics of exactly the same link (the output compensating circuit of the DMKK computing device) in every channel. In order to simplify the structural arrangement without introducing any errors, it is convenient to allow for the dynamics of the output compensation circuit by a single link, with a transmission factor of unity, and for the statics of the circuit by corresponding coefficients in each channel. A fully developed structure for the system of flow measurement corresponding to Eq. (4) is shown in Fig. 2. In contrast to the arrangement shown in Fig. 1, the later structure enables us to correct the static and dynamic characteristics of the measuring system independently along individual channels (i.e., with respect to individual parameters).

The inertia of the measuring system along the channel “pressure drop in the compressing system $\Delta p$—flow $Q_{DM}$” is determined by the dynamic properties of the pulse line and those of the compensation differential manometer. The dynamic properties of pulse lines having a reasonably small length may be described [4, 5] by the differential equations

$$T_{PL} \frac{d \Delta p_{PL}}{dt} + \Delta p_{PL} = \Delta p (t - \tau_{PL}),$$

where $T_{PL}$ and $\tau_{PL}$ are the dynamic parameters determined by calculation. The equations characterizing the dynamic and static properties of the compensation differential manometer are written

$$Q_{DM} = \int_0^t \mu_{DM} dt, \quad \mu_{DM} = \frac{1}{T_{DM}} \text{sign} \left( \Delta p_{PL} - \frac{1}{K^2} Q_{DM}^2 \right),$$

where $T_{DM}$ is the running time and $\mu_{DM}$ is the running velocity of the differential-manometer scale.

The inertia of measuring system along the channel “gas pressure $p$—deviation in the flow $Q_p$ resulting from a change in pressure” is determined by the dynamic properties of the pulse line of the manometer and by the manometer of the DMKK system itself. Since the DMKK system uses the same pulse line for measuring both the pressure drop $\Delta p$ and the pressure $p$, the dynamic properties of the pulse line of the manometer may be described by an equation analogous to Eq. (5).

The differential equation of the manometer is determined by identifying the mathematical model of the manometer (using an analog computer) with the averaged experimental transient characteristic of the DMKK manometer.