Ratiometers designed as shown in the structural schematic of Fig. 1 are widely used in three-phase phase meters. It has been shown in [1] that the measurement range of a phase meter based on such a design principle does not normally exceed 120°. Nevertheless, it is often desirable to have phase meters with a wider measurement range extending up to 180°. The demand for such instruments, especially of medium precision, is rising in connection with the increasing use of moving iron circular-scale phase meters.

It will be shown below that it is possible to manufacture double-range three-phase phase meters with a medium precision whose measuring mechanism is made according to the structural schematic shown in Fig. 1. This instrument is provided with two subranges. One subrange serves to measure phase angles of 0 to 90° with inductive loading, and the other angles of 0 to 90° with capacitive loading.

When these ratiometers are used, the tested-circuit load current is made to flow through the phase-meter stationary coils which are connected in series, whereas the currents in moving coils I and II are functionally coupled to the tested circuit voltage.

Figure 2 shows a vector diagram of currents in the phase-meter circuits. Here, \( i_1 \) and \( i_2 \) denote currents in the moving coils; \( I_0 \) is the current in the series circuit for \( \cos \varphi = 1 \) (ind); \( I_{90} \) is the current in the series circuit for \( \cos \varphi = 0 \) (ind).

It is obvious that for current operation of the phase meter provided with a measuring mechanism shown in Fig. 1, it is necessary that currents \( i_1 \) and \( i_2 \) should have a certain phase angle \( \beta \) between them, and should be oriented with respect to their phase, as shown in the figure, i.e., they should lie within the range bounded by vectors \( I_0 \) and \( I_{90} \).

If the measuring range of a three-phase phase meter is required to cover phase angles of 0 to 90° (\( \cos \varphi = 0-1 \)), the vector diagram of such an instrument should be of the type shown in Fig. 3.

In order to obtain, in a general case, two currents \( i_1 \) and \( i_2 \) which are independent both with respect to their magnitude and phase, it is necessary to use six supplementary resistors. Taking advantage of the fact that the line voltage \( U_{31} \) has a phase angle of 60° with respect to voltage \( U_{10} \) (see Fig. 3), moving coil II can be connected to line voltage \( U_{31} \). In such a case, it is possible to reduce the number of supplementary resistors to four.

Let us derive balance conditions for the moving part of the phase meter at the extreme points of the scale.

For \( \cos \varphi = 1 \), vectors \( I_0 \) and \( U_{10} \) coincide in phase and, therefore,

\[
k_1 i_1 B_1 \cos 30° = k_2 i_2 B_2 \cos (30° + \beta),
\]

where \( k_1 \) and \( k_2 \) are the design constants of the two elements, and \( B \) is induction.

Vectors \( I_{90} \) and \( U_{31} \) coincide in phase for \( \cos \varphi = 0 \) (ind) and, therefore,

\[
k_1 i_1 B_1'' \cos 60° = k_2 i_2 B_2'' \cos (60° - \beta).
\]

In actual measuring mechanisms of this type, inevitably \( k_1 = k_2 \), and

\[
\frac{B_2'}{B_1'} = \frac{B_2''}{B_1''} = \frac{B_{\text{max}}}{B_{\text{min}}},
\]
Taking into consideration the above relationships, we find from (1) and (2) the basic system of equations
\[
\frac{i_1 \cdot \cos 30^\circ}{i_2 \cdot \cos (30^\circ + \beta)} = \frac{B_{\text{max}}}{B_{\text{min}}}, \quad \frac{i_1 \cdot \cos 60^\circ}{i_2 \cdot \cos (60^\circ - \beta)} = \frac{B_{\text{min}}}{B_{\text{max}}}.
\]

Let us denote \(B_{\text{max}}/B_{\text{min}}\) as
\[
\frac{B_{\text{max}}}{B_{\text{min}}} = a
\]
call it the design parameter of the measuring instrument, and denote the current ratio as
\[
\frac{i_1}{i_2} = k_i.
\]

By solving Eq. (4), we obtain the value of the angle and the current ratio in moving coils \(k_i\), expressed in terms of the measuring mechanism's design parameter \(a\):
\[
\tan \beta = \sqrt{3} \cdot \frac{a^2 - 1}{a^2 + 3},
\]
\[
k_i = \frac{2a}{\sqrt{a^4 + 3}}.
\]

The schematic of the instrument's parallel circuit is shown in Fig. 4, and the vector diagram for this circuit in Fig. 5.

Voltage \(U_3\) can be represented as
\[
U_3 = U_{31}Y_1 + U_{32}Y_2 + U_{33}Y_3.
\]

Admittances \(Y_1, Y_2,\) and \(Y_3\) of the star circuit can be selected arbitrarily. Let us choose their values so that \(Y_2 = mY_1\) and \(Y_3 = Y_1\), where \(m\) is a certain positive number.

Assuming that \(U_{32} = U_T e^{j\theta}\), we obtain
\[
U_{32} = U_T e^{j240^\circ} = U_T(-0.5 - j0.866),
\]
\[
U_{31} = U_T e^{j120^\circ} = U_T(-0.5 + j0.866),
\]
where \(U_T\) is the line voltage of the three-phase circuit. By substituting the above values for \(U_{33}\) and \(U_{31}\) in (9), we obtain
\[
U_3' = U_T \left( \frac{0.5 (1 - m) - j0.866 (1 + m)}{2 + m} \right).
\]

The angle between vectors \(U_{32}\) and \(U_3'\) we find from the expression
\[
\tan \theta_i = -\frac{0.866 (1 + m)}{0.5 (1 - m)} = -\sqrt{3} \frac{(1 + m)}{m - 1}.
\]

It will be seen from the vector diagram shown in Fig. 5 that \(\varphi_3 = 60^\circ + \beta\); however, in using this equality, it is necessary to take into consideration that in passing from angles smaller than 90° to those larger than 90°, their tangent reverses its sign.

An analysis of (7) provides a correct estimation of the tangent sign.

For ratiometers used in practice, invariably \(a > 2\), hence \(\tan \beta > \varphi_3\)
and, therefore, the angle is always larger than 30°.