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Mathematical Models of Displacement Measurement Differential Transformer Sensors with Different Drive Elements and Magnetic Circuits with a Special Structure

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Abstract: In the article, the analysis of the mathematical models of new differential transformer sensors with different moving elements and magnetic circuits with a special structure for displacement measuring, the moving part of which is made in the form of a collective measuring winding, when these sensors are made in such a way that the value of the magnetic capacitance between long ferromagnetic rods changes in the form of a hyperbolic function along the magnetic circuit of the excitation winding it was determined that the inductance does not depend on the coordinates of the driven measuring device and that the working magnetic currents, the mutual inductances between the excitation and the driven measuring device, and the output EMF of the sensors change with an absolutely linear law. It is shown that in new differential transformer sensors in which the excitation element is made in the form of a screen, the operating magnetic currents are a nonlinear function of the screen coordinate, and the inductance of the excitation winding depends on the screen coordinate. In differential transformer sensors, the moving element of which is made in the form of a ferromagnetic core, the distance between the long ferromagnetic rods is much greater than the total distance between the driven ferromagnetic core and the rods, and when the distance between the long ferromagnetic rods does not change along the length of the magnetic circuit, the working magnetic currents, the inductance of the excitation winding and the mutual it is found that the inductance does not depend on the value of the coordinate of the excited ferromagnetic core, and the value of the output signal is a linear function of the coordinate of the ferromagnetic core.

Keywords: differential transformer sensor, differential magnetic circuit, moving element, winding, screen, ferromagnetic core, magnetic circuit with simple structure; distributed parameter chains; magnetic force; magnetic resistance; magnetic capacity, longitudinal and transverse currents, magnetic flux; magnetic tension; linear distribution.

Various models, in particular, differential transformer sensors (DTS), are widely used to obtain information about device displacements in controlled objects in technological processes and automatic production control systems [1,2]. A comparative analysis of the main characteristics of these DTS showed that they have a relatively low sensitivity in the measurement range and a nonlinear conversion function [3,4]. The use of DTS with these shortcomings in automatic control systems leads to a decrease in the quality indicators of the control process.

In order to eliminate the above-mentioned shortcomings, a new design of the DTS measuring the displacement of the magnetic chain with a special structure was developed at the Tashkent State Transport University (Fig. 1) [5]. This is the Pogon values of the magnetic capacities of the air gaps in the middle of the 2nd and 3rd and 3rd and 4th long booms in the DTS construction, unlike the existing constructions of this type of DTS, hyperbolically decreases from the middle section of each half of the DMC to its two edges (between the

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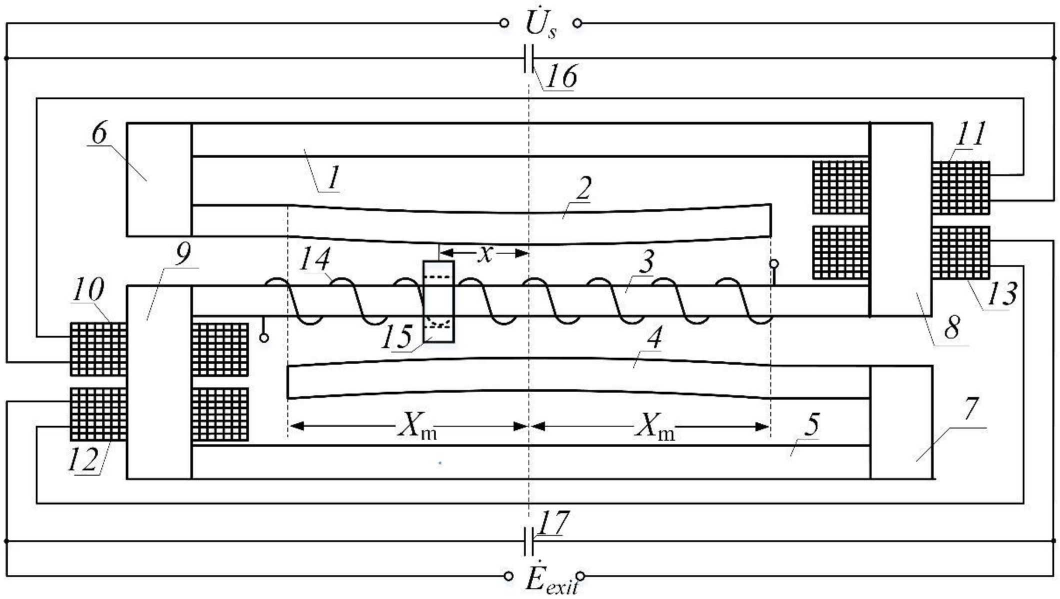
corresponding booms the distance increases with a quadratic law) is made in the form of a gradient. Both sections of the excitation circuit are connected in series and inductively opposite to each other, both sections of the measuring circuit are connected to each other in series and inductively opposite.

When the moving element of the DTS is made in the form of a compact winding, measuring windings 12-14 are not used in the device, when the function of the moving element is an electromagnetic screen, measuring windings 12 and 13 or 14 can be used, and when the moving element is made in the form of a ferromagnetic core, measuring windings 12 and 13 are not used. An oscillation countour consisting of a capacitor connected in parallel (or series) with the excitation winding is supplied from a sinusoidal voltage source and tuned to resonance.

The advantage of the DTS design described above is that the working air gaps are made with a certain regularity, firstly, it ensures that the inductance of the excitation winding does not change even at any value of the coordinate of the driven element (as a result, the resonance mode is maintained in the primary circuit of the DTS and the sensitivity of the sensor is high in its entire measurement range), and secondly, the DTS ensures that the static characterization is linear.



Picture 1. The magnetic chain has a special structure and the working air gap is variable along the length of the chain displacement measuring DTD structural scheme: 1-5 – long ferromagnetic rods; 6-9 – ferromagnetic connectors; 10, 11 – sections of the excitation winding; 12, 13 – sections of measuring winding; 14 – measuring winding wrapped in scattered form; 15 – movable element; 16 – capacitor

In this article, we will create mathematical models of DTSs with high sensitivity of the displacement meter with various moving elements (winding, screen and ferromagnetic core) and magnetic circuits with a special structure on the example of the proposed DTS (Fig. 1). In this case, it is most convenient to calculate distributed parameter magnetic circuits with a moving element, and Professor Zaripov M.F. we use the method "Separation of magnetic chains into certain parts" developed by [3,6].

It is appropriate to start the coordinate head for the DMC from the middle section of the chain (Fig. 2).

1. *A DTS in which the movable element is made in the form of an assembly*. Since this sensor is symmetrical about the midsection of the DMCH, it is sufficient to carry out calculations for

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one half of it, for example, the left half. The equations based on the Kirchhoff equations for the elemental dx_1 part of the upper half of the DMCH are written in the following form.

$Q'_{\mu 2x_1} = U_{\mu x1} C_{\mu c x_1}$, (1) $\quad Q'_{\mu 3x_1} = -U_{\mu x_1} C_{\mu x_1}$,(2) $\quad U'_{\mu x_1} = Z_{\mu c}\left(Q_{\mu 2x_1} - Q_{\mu 3x_1}\right)$,(3)

here $Z_{\mu c}$, $[H^{-1} \cdot m^{-1}]$; $C_{\mu c x_1}, [H \cdot m^{-1}]$ – respectively, the pogon (comparative) values of long ferromagnetic rods 2,3 magnetic resistances and the magnetic capacity of the working gap between them per unit length of these rods; $Q_{\mu 2x_1}$, $Q_{\mu 3x_1}, [Wb]$; $U_{\mu x_1}, [A]$ – are the magnetic currents in the corresponding rods and the magnetic voltage between them, respectively.

The following equation is appropriate for the magnetic circuit under study [7]:

$Q_{\mu 2x_1} + Q_{\mu 3x_1} = Q_{\mu м}$, (4)

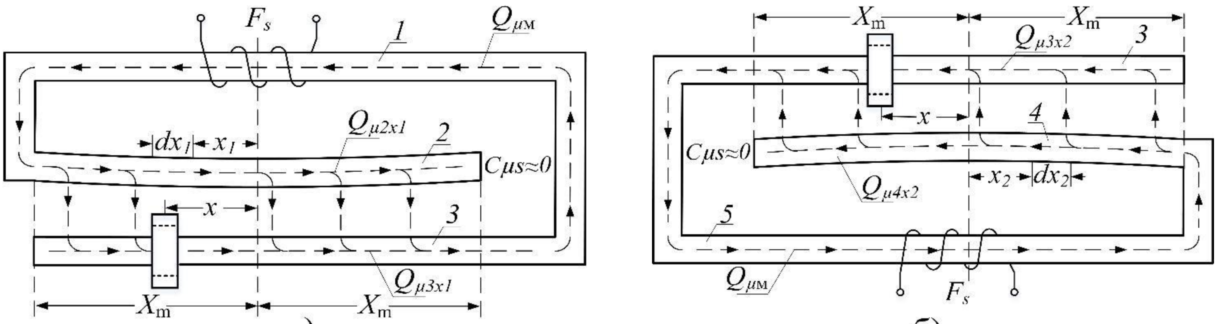
where $Q_{\mu м}$ – is the maximum value of the magnetic flux in half of the DMCH.

For magnetic fluxes $Q_{\mu 2x_1}$ ва $Q_{\mu 3x_1}$ to be linearly distributed along the coordinate x_1, the condition $Q''_{\mu 2x_1} = 0$ and $Q''_{\mu 3x_1} = 0$ (5) must be fulfilled [3].

Based on this condition and the fact that $C_{\mu c x_1} = const$, we solve the differential equations (1)-(3) together.

In this case, the differential equation (1) and its solution are written as follows:

$Q''_{\mu 1x_1} = \left(U_{\mu x_1} C_{\mu c x_1}\right)' = 0$, (5) $\qquad U_{\mu x_1} C_{\mu c x_1} = A_1$. (6)



a) б)

Fig 2. The upper (a) and lower (b) halves of the DMC with a special structure consisting of a moving element

Deriving the equation (3) constructed for the magnetic circuit under study, putting (1) and (2) into the result, and taking into account (4) the resulting differential equation, we make the following expression:

$U_{\mu x_1} = Z_{\mu c} A_1 x_1^2 + A_2 x_1 + A_3$. (7)

The magnetic fluxes $Q_{\mu 2x}$ and $Q_{\mu 3x}$ found on the basis of (3), (4) and (7) are equal to:

$Q_{\mu 2x_1} = A_1 x_1 + \frac{A_2}{2Z_{\mu c}} + \frac{1}{2} Q_{\mu м}$, (8); $\qquad Q_{\mu 3x_1} = -A_1 x_1 - \frac{A_2}{2Z_{\mu c}} + \frac{1}{2} Q_{\mu м}$. (9)

The pogon value of the magnetic capacitance of the working air gap by the length of the magnetic circuit is found as follows:

$C_{\mu c x_1} = \frac{A_1}{\left(Z_{\mu c} A_1 x_1^2 + A_2 x_1 + A_3\right)}$ (10)

The integration constants A_1, A_2 and A_3 are found on the basis of the following boundary conditions, which are appropriate for the half of the studied DMCH (Fig. 2, a):

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$$Q_{\mu 3x_1=0} = \frac{1}{2}Q_{\mu\text{м}};\ C_{\mu c x_1=0} = C_{\mu c0} = \frac{A_1}{A_3};\ Q_{\mu 3x_1=X_m} = Q_{\mu\text{м}}. \qquad (11)$$

From this $A_1 = \frac{Q_{\mu\text{м}}}{2X_m};\ A_2 = 0;\ A_3 = \frac{Q_{\mu\text{м}}}{2C_{\mu c0}X_m}.$ (12)

Putting (12) into (7)-(10), we get the following expressions:

$$Q_{\mu 2x_1} = \frac{1}{2}Q_{\mu\text{м}}\left(1+\frac{x_1}{X_m}\right), \quad (13) \qquad Q_{\mu 3x_1} = \frac{1}{2}Q_{\mu\text{м}}\left(1-\frac{x_1}{X_m}\right), \quad (14)$$

$$U_{\mu x_1} = \frac{Q_{\mu\text{м}}(Z_{\mu c}\, C_{\mu c0}x_1^2+1)}{2C_{\mu c0}X_m}, \quad (15) \qquad C_{\mu c x_1} = \frac{C_{\mu c0}}{(Z_{\mu c}\, C_{\mu c0}x_1^2+1)}. \quad (16)$$

In order to find the maximum value of the working magnetic current $Q_{\mu\text{м}}$, which is generated due to the MFF source in the magnetic circuit under study, we use the following equation formulated for a closed circuit:

$$F_s = Z_{\mu 0}Q_{\mu\text{м}} + Z_{\mu c}\int_0^{X_m} Q_{\mu 2x_1}dx_1 + Z_{\mu c}\int_0^{X_m} Q_{\mu 3x_1}dx_1 + U_{\mu x_1=0}, \qquad (17)$$

From (17) we determine the following value of $Q_{\mu\text{м}}$:

$$Q_{\mu\text{м}} = \frac{2F_s\, C_{\mu c0}X_m}{(2Z_{\mu 0}\ C_{\mu c0}X_m+3Z_{\mu c}\ C_{\mu c0}X_m^2+1)} = \frac{2F_s\, C_{\mu c0}X_m}{\Delta_1}. \qquad (18)$$

If (18) is taken into account, then expressions (13)-(15) are written as follows:

$$Q_{\mu 2x_1} = \frac{F_s\, C_{\mu c0}X_m}{\Delta_1}\left(1+\frac{x_1}{X_m}\right), \quad (19) \qquad Q_{\mu 3x_1} = \frac{F_s\, C_{\mu c0}X_m}{\Delta_1}\left(1-\frac{x_1}{X_m}\right), \quad (20)$$

$$U_{\mu x_1} = \frac{F_s(Z_{\mu c}\, C_{\mu c0}x_1^2+1)}{\Delta_1}. \qquad (21)$$

Calculations for the lower half of the DMC are carried out in the same sequence as above (Fig. 2, b). We limit ourselves to the following final expressions of the magnetic fluxes (the Pogon value of the magnetic voltage and the magnetic capacitance are the same as (15) and (16)):

$$Q_{\mu 3x_1} = \frac{F_s\, C_{\mu c0}X_m}{\Delta_1}\left(1-\frac{x_2}{X_m}\right), (22) \qquad Q_{\mu 4x_2} = \frac{F_s\, C_{\mu c0}X_m}{\Delta_1}\left(1+\frac{x_2}{X_m}\right), (23)$$

$$U_{\mu x_2} = \frac{F_s(Z_{\mu c}\, C_{\mu c0}x_2^2+1)}{\Delta_1}. \qquad (24)$$

The inductances of the special structural DTS excitation (primary) circuit sections under investigation are determined in the form of the following expressions [8]:

$$L_s^h = \frac{w_e.Q_{\mu 2x_1=X_m}}{I_s} = L_s^l = \frac{w_e.Q_{\mu 4x_2=X_m}}{I_s} = 2w_.^2\frac{C_{\mu c0}X_m}{\Delta_1} = const, \quad (25)$$

where $w_{e.}$, I_e is the number of windings of the excitation coil section and the current passing through it.

The mutual inductance between the sections of the excitation winding and the measuring winding is determined accordingly as:

$$M^h = w_{meas.}w_m\frac{C_{\mu c0}X_m}{\Delta_1}\left(1+\frac{x_1}{X_m}\right) \quad (26) \qquad M^l = w_1w_2\frac{C_{\mu c0}X_\text{м}}{\Delta_1}\left(1-\frac{x_2}{X_m}\right). \quad (27)$$

where $w_{meas.}$ is the number of windings of measuring tape.

The self-induction EMF generated in the sections of the DTS excitation coil is found as follows:

$$\dot{E}_s = -j\omega w_s\dot{Q}_{\mu 2x_1} - j\omega w_s\dot{Q}_{\mu 4x_2} = -j\omega w_s^2\dot{I}_s\frac{C_{\mu c0}}{\Delta_1}4X_m. \qquad (28)$$

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Due to the mutual induction between the DTS excitation and the measuring circuits, the mutual inductance EMF, which is formed in the measuring circuit, is found as follows:

$$\dot{E}_{meas.} = -\left(j\omega w_{meas.}\dot{Q}_{\mu 3x_1=x} - j\omega w_{meas.}\dot{Q}_{\mu 3x_2=-x}\right) = -j\omega 2 w_s w_{meas.}\dot{I}_s \frac{C_{\mu c0}x}{\Delta_1}. \quad (29)$$

The analysis of the mathematical models (20)-(29) created for the DTS, which has a special structure and distributed parameter DMCH, which is made in the form of a winding with a moving part, and is designed to measure the displacement, shows that the pogon value of the magnetic capacitance between its corresponding long ferromagnetic rods along the magnetic circuit (16) due to the change in the form of the function, the inductances of the sections of the excitation winding in these windings, the self-induction, which creates the working magnetic currents in the excitation winding connected in series and inductively to each other, does not depend on the coordinate of the excited element (winding), and their value remains unchanged in the entire measuring range of the DTS is maintained, the working magnetic fluxes, the mutual inductance between the excitation winding and the excited measuring winding, and the output EMF of the DTS change with a completely linear law within the limits accepted in the calculation of these magnetic circuits. (25) it can be seen from the expression that the inductance of the sections of the excitation coil does not change its value even at any value of the coordinate of the excitation winding.

It follows that the resonant condition $\left(L_{1s}^{h} + L_{1s}^{l}\right) \cdot C = const$ created in the excitation circuit of the DTS is maintained in the entire measurement range of the sensor, and the sensitivity is high.

2. *DTS, the moving element of which is made in the form of an electromagnetic screen (Fig. 3).* For this *DMZ,* $U_{\mu x_2}$, $Q_{\mu 3x_2}$, $Q_{\mu 2x_2}$ and $C_{\mu c x_2}$ are written in the following form*:*

$$U_{\mu x_2} = Z_{\mu c}\, A_1 x_2^2 + A_2 x_2 + A_3, \qquad (30)$$

$$Q_{\mu 3x_2} = A_1 x_2 + \frac{A_2}{2Z_{\mu c}} + \frac{Q_{\mu\text{м}}^{h}}{2}, \quad (31) \qquad Q_{\mu 2x_2} = -A_1 x_2 - \frac{A_2}{2Z_{\mu c}} + \frac{Q_{\mu\text{м}}^{h}}{2}. \quad (32)$$

$$C_{\mu c x_2} = \frac{A_1}{\left(Z_{\mu c}\, A_1 x_2^2 + A_2 x_2 + A_3\right)}, \qquad (33)$$

where $Q_{\mu\text{м}}^{h}$ is the maximum value of the magnetic flux generated by F_s MFF in the upper half of the DMC.

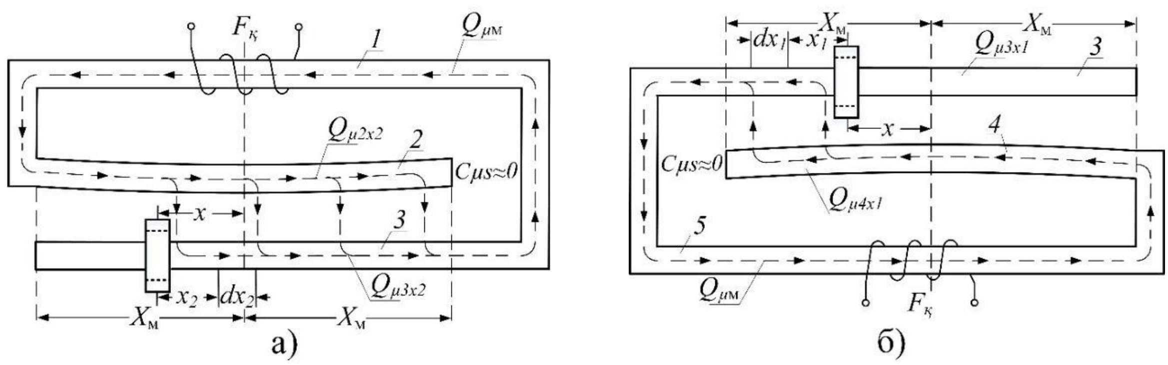

Figure 3. The upper (a) and lower (b) halves of a specially structured DMC, the moving element of which is an electromagnetic screen

The integration constants A_1, A_2 and A_3 are found based on the following boundary conditions, which are appropriate for the magnetic circuit under study:

$$Q_{\mu 3x_2=0} = 0;\; C_{\mu c x_2=0} = C_{\mu c x} = \frac{A_1}{A_3};\; Q_{\mu 3x_2=X_m+x} = Q_{\mu\text{м}}^{h}, \quad (34)$$

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here $C_{\mu cx} = \frac{C_{\mu c0}}{(Z_{\mu c} C_{\mu c0} x^2+1)}$.

From (34) : $A_1 = \frac{Q^h_{\mu M}}{(X_m+x)}$; $A_2 = -Z_{\mu c}\, Q^h_{\mu M}$; $A_3 = \frac{Q^h_{\mu M}}{[\,C_{\mu cx}(X_m+x)]}$. (35)

Putting the values of A_1, A_2 and A_3 in (35) into (30)-(33), we form the following expressions:

$$Q_{\mu 3x_2} = \frac{Q^h_{\mu M} x_2}{(X_m+x)}, \quad (36) \qquad Q_{\mu 2x_2} = Q^h_{\mu M}\left[1-\frac{x_2}{(X_m+x)}\right], \quad (37)$$

$$U_{\mu x_2} = \frac{Q^h_{\mu M}}{C_{\mu cx}(X_m+x)}\left[Z_{\mu c}\, C_{\mu cx} x_2^2 - Z_{\mu c}\, C_{\mu cx}(X_m+x)x_2 + 1\right], \quad (38)$$

$$C_{\mu cx_2} = \frac{C_{\mu cx}}{(Z_{\mu c}\, C_{\mu cx} x_2^2 - Z_{\mu c}\, C_{\mu cx}(X_m+x)x_2+1)}. \quad (39)$$

To find the maximum value of the working magnetic current $Q^h_{\mu M}$ generated due to the MFF source in the magnetic circuit under study, we use the following equation created for a closed circuit:

$$F_e = Z_{\mu 0} Q^h_{\mu M} + Z_{\mu c}(X_m - x) Q^h_{\mu M} + Z_{\mu c}\int_0^{X_m+x} Q_{\mu 2x_2} dx_2 + U_{\mu x_2 = X_m+x}. \quad (40)$$

From (40) we determine the following value of $Q_{\mu M}$:

$$Q^h_{\mu M} = \frac{F_s\, C_{\mu cx}(X_m+x)}{\Delta_2}, \quad (41)$$

here $\Delta_3 = Z_{\mu 0} C_{\mu cx}(X_m + x) + Z_{\mu c}\, C_{\mu cx}\left({X_m}^2 - x^2\right) + \frac{Z_{\mu c}\, C_{\mu cx}(X_m+x)^2}{2} + 1.$

The corresponding magnitudes and parameters for the lower half of the investigated DMC are also found in the above sequence. We limit ourselves to quoting their final expressions below:

$$Q_{\mu 3x_1} = \frac{Q^l_{\mu M} x_1}{(X_m-x)}, \quad (42) \qquad Q_{\mu 4x_1} = Q^l_{\mu M}\left[1-\frac{x_1}{(X_m-x)}\right], \quad (43)$$

$$U_{\mu x_1} = \frac{Q^l_{\mu M}}{C_{\mu cx}(X_m-x)}\left[Z_{\mu c}\, C_{\mu cx} x_1^2 - Z_{\mu c}\, C_{\mu cx}(X_m-x)x_1 + 1\right], \quad (44)$$

$$C_{\mu cx_1} = \frac{C_{\mu cx}}{Z_{\mu c}\, C_{\mu cx} x_1^2 - Z_{\mu c}\, C_{\mu cx}(X_m-x)x_1+1}. \quad (45) \qquad Q^l_{\mu M} = \frac{F_e\, C_{\mu cx}(X_m-x)}{\Delta_3}, \quad (46)$$

here $\Delta_3 = Z_{\mu 0} C_{\mu cx}(X_m - x) + Z_{\mu c}\, C_{\mu cx}\left({X_m}^2 - x^2\right) + \frac{Z_{\mu c}\, C_{\mu cx}(X_m-x)^2}{2} + 1.$

The inductances of the investigated DTS excitation winding sections are determined in the form of the following expressions, respectively [9]:

$$L^h_s = \frac{w_1 Q_{\mu 2x_2=0}}{I_s} = 2w_s^2 \frac{C_{\mu cx}(X_m+x)}{\Delta_2}, \quad (47) \qquad L^l_s = \frac{w_1 Q_{\mu 4x_1=0}}{I_s} = 2w_s^2 \frac{C_{\mu cx}(X_m-x)}{\Delta_3}, \quad (48)$$

The mutual inductance between the excitation and measurement windings is respectively determined as follows.

$$M^h = w_s w_{meas.} \frac{C_{\mu cx}(X_m+x)}{\Delta_2}, \quad (49) \qquad M^l = w_s w_{meas.} \frac{C_{\mu cx}(X_m-x)}{\Delta_3}. \quad (50)$$

The self-induction EMF generated in the sections of the DTS excitation winding is found as follows [10]:

$$\dot{E}_s = -j\omega w_s \dot{Q}^h_{\mu M} - j\omega w_e \dot{Q}^l_{\mu M} = -j\omega w_s^2 \dot{I}_s\, C_{\mu cx}\left[\frac{(X_m+x)}{\Delta_2} + \frac{(X_m-x)}{\Delta_3}\right]. \quad (51)$$

Due to the mutual induction between the DTS excitation and the measuring circuits, the

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mutual inductance EMF, which is formed in the measuring circuit, is found as follows:

$$\dot{E}_{meas.} = -j\omega w_s w_{meas.} \dot{I}_s \, C_{\mu cx} \left[\frac{(X_m + x)}{\Delta_2} - \frac{(X_m - x)}{\Delta_3}\right] \qquad (52)$$

3. DTS, whose moving element is made in the form of a ferromagnetic core (Fig. 4).

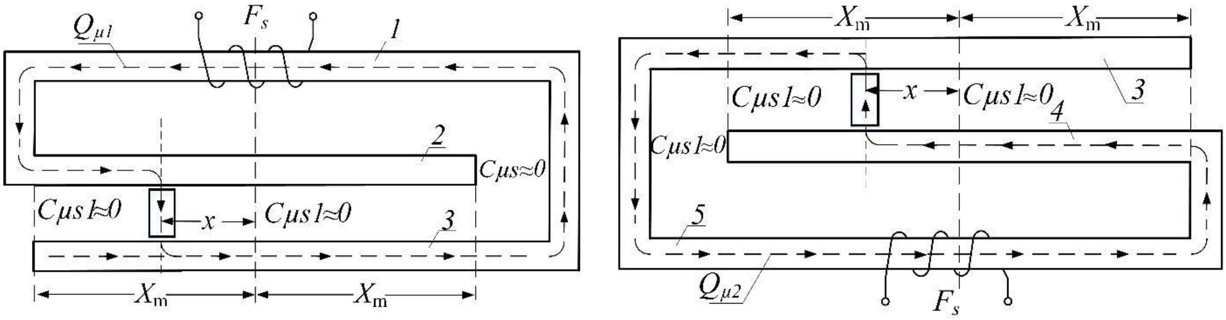

Figure 4. Upper (a) and lower (b) halves of a specially structured DMC with a moving element consisting of a ferromagnetic core

If the distance δ_x between two adjacent long ferromagnetic rods is greater than the total distance between the movable ferromagnetic core placed between these rods and the rods $\Delta_{x.com.}$, for example, $\delta_x > 10\Delta_{x.com.}$, then, in fast engineering calculations, it will be possible to ignore the magnetic fluxes connecting to the right and left of the driven ferromagnetic core through the air gap d, i.e. $C_{\mu s1} = 0$ and $C_{\mu s2} = 0$.

In this case, 2, 3 and 4 long ferromagnetic rods in the DMC can be made parallel to each other. The values of the operating magnetic fluxes in the upper and lower halves of this DMC are found as follows:

$$Q_\mu^h = Q_\mu^l = \frac{F_e}{Z_{\mu\Sigma}} = \frac{F_e}{\left(\frac{\delta}{\mu\mu_0 bh} + \frac{2X_m}{\mu\mu_0 bh} + \frac{2\Delta}{\mu_0 bh}\right)} = const. \qquad (53)$$

The inductances of the DTS excitation winding sections under investigation are determined in the form of the following expressions, respectively:

$$L_s^h = \frac{w_s Q_\mu^h}{I_s} = L_s^l = \frac{w_s Q_{\mu\text{M}}^l}{I_s} = \frac{w_s^2}{Z_{\mu\Sigma}} = const, \qquad (54)$$

The mutual inductance between the excitation windings and the measuring winding is determined accordingly as:

$$h = w_s w_{meas.l} \frac{1}{Z_{\mu\Sigma}} (X_m - x), \quad (55) \qquad M^l = w_s w_{meas.l} \frac{1}{Z_{\mu\Sigma}} (X_m + x). \quad (56)$$

The self-induction EMF generated in the sections of the DTS excitation coil is found as follows: $\dot{E}_s = -\left(j\omega w_s \dot{Q}_{\mu\text{M}}^h + j\omega w_s \dot{Q}_{\mu\text{M}}^l\right) = -j\omega w_s^2 \dot{I}_s \frac{2}{Z_{\mu\Sigma}} = const.$ (57)

Due to the mutual induction between the DTS excitation and the measuring windings, the mutual inductance EMF, which is formed in the measuring winding, is found as follows [11]:

$$\dot{E}_{meas.} = -j\omega w_{meas.l} \dot{Q}_{\mu\text{M}}^h + j\omega w_{meas.l} \dot{Q}_{\mu\text{M}}^l = -j\omega w_s w_{meas.l} \frac{2x}{Z_{\mu\Sigma}}, \qquad (58)$$

where $w_{meas.l}$ - is the pogon (comparative) value of the number of windings of the measuring coil per unit of length of the magnetic chain.

The analysis of the equations (53)-(58) created for the special structural DTS, where the magnetic fluxes connecting through the air gap d to the right and left of the excited ferromagnetic core are negligible, shows that the values of the inductances of the sections of the excitation coil and the values of the working magnetic fluxes to the coordinate of the

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excited ferromagnetic core independent, the mutual inductances between the excitation and measurement coils and the output signal of the DTS are linear functions of the coordinate of the excited ferromagnetic core.

In DTSs with a special structure, in which the excitation element consists of a ferromagnetic core and the magnetic fluxes connecting through the air gap d to the right and left of it are negligible, the inductance of the excitation winding is constant, so the resonance mode created in the excitation coil of these DTSs is preserved in their entire measurement range, DTS although the static characteristics of DTSs are ensured to be linear, increasing the air gap between parallel long ferromagnetic rods in order to drastically reduce the values of the non-working magnetic currents increases the overall dimensions of this type of DTSs. In addition, since the mass of the driven ferromagnetic core is greater than the mass of the driven winding, this DTS has a negative effect on the dynamic properties of the applied object [12].

Thus, it follows from the above analysis that the inductance of the excitation element does not depend on the coordinate of the excitation element, the strictly linear distribution of the working magnetic currents along the length of the magnetic circuit, and the smallness of the mass of the excitation element are ensured by special structural DTSs, in which the excitation element is made in the form of a compact measuring winding.

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