Study on the biparametrical transudations circuits with distributed parameters

S F Amirov\textsuperscript{1}, A Kh Sulliev\textsuperscript{1*}, A T Sanbetova\textsuperscript{2}, and I Kurbonov\textsuperscript{1}

\textsuperscript{1}Tashkent State Transport University, Tashkent, Uzbekistan
\textsuperscript{2}Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, 100000 Tashkent, Uzbekistan

\*Email: absaid.sulliev@mail.ru

Abstract. This paper highlights the methods of resenting mode in the transudation with distributed parameters. The transient parameters of the power supply were analyzed. It was discovered that resonance is provided in a small range of movement of the moving component of the sensor in known turbofan engines, indicating that the known techniques of sustaining the resonance mode are flawed. Further study should focus on developing novel methods for preserving resonance mode over the entire range of change of the converted value, general principles of turbojet engine construction, and a complete examination of their resonant circuits, according to the findings.

1. Introduction
Biparametric circuits here are called circuits in which two circuit parameters are variables simultaneously. Most often, the variables are the parameters of the reactive elements of the inductive coil and capacitor.

Some electromagnetic sensors (for example, motion parameter sensors) - primary converters contain biparametric circuits. The advantage of these so-called biparametric sensors is that they combine the advantages of electromagnetic (high output power, stability of characteristics) and capacitive (linearity of the static characteristic, high sensitivity) sensors [1-3]. If in this case the reactive elements form a resonant circuit, the sensitivity of such sensors increases sharply.

The circuits of biparametric resonant sensors are circuits with electrical and magnetic parameters distributed along the coordinate of the moving part. The distribution of parameters leads to the fact that in the operating range of the input value \( x \), the circuit leaves the resonance mode, while sharply reducing the sensitivity of the sensors.

2. Methods
An important requirement for biparametric resonant sensors (circuits) with distributed parameters is the fulfillment of the resonance conditions in the entire range of changes in the parameter values of their reactive elements. The resonance mode can be saved in the following three ways.

1. By satisfying the condition

\[ L(x)C(x) = \text{const} \quad [2, 3, 4], \]  

which is achieved if the parameters of the reactive elements change according to
The advantage of this method of maintaining the resonance mode is that with a known law of change \( L(x) \) or \( C(x) \) you can always find the function \( C(x) \) or \( L(x) \), satisfying the condition (1).

2. By fulfilling the condition \([L_1(x) + L_2(x)]C = \text{const}\) or \([C_1(x) + C_2(x)]L = \text{const}\) [1], where \( L_1(x), L_2(x) \) and \( C_1(x), C_2(x) \) - respectively, the inductance and capacitance of the differential circuits of biparametric resonant motion sensors.

3. By satisfying the condition \( \omega(x) = 1/\sqrt{L(x)C} \) or \( \omega(x) = 1/\sqrt{LC(x)} \) [4], where \( \omega(x) \) - angular frequency of power supply voltage. According to this method, the change in the resonant frequency of the circuit when changing \( L(x) \) or \( C(x) \) automatically "tracked" by a variable frequency generator [3-6].

3. Results and Discussion

As an example, consider a biparametric resonant linear displacement transducer (Figure 1) [6-8]. It consists of a U-shaped fixed magnetic circuit 1, on the base of which the excitation winding 2 and the measuring winding 3 are located.

In the space between the parallel cores 4 and 5 of the magnetic circuit, there is a variable capacitor with a liquid crystal dielectric (LCD), made in the form of extended electrodes 6 and 7, the gap 9 between which is made unevenly in the section (it is smaller up to the movable electromagnetic screen 8, behind it - more) and the LCD is full. The measuring winding and capacitor are tuned to resonance voltages.

![Figure 1. Construction of a biparametric resonant sensor linear displacement](image)

When the excitation winding is powered from an alternating current source I, an EMF is induced in the measuring winding. Moving the screen 8 simultaneously changes the inductance \( L \) and winding 3 and the capacitance \( C \) of the variable capacitor so that the circuit is in resonance at any position of the screen along the length of the cores. With an increase in the \( x \) coordinate of the screen, the inductance \( L_i \) increases, and the capacitance of the capacitor decreases due to the reorientation of the LCD molecules. The inductance of the measuring winding without taking into account the magnetic resistance of steel and the electrical resistance of the screen is determined as

\[
L_n(x) = w^2 \mu_0 \frac{b_1 x}{\delta_1}
\]
and the capacitance of the liquid crystal capacitor

\[ C = \varepsilon_1 \varepsilon_0 \frac{(X_M - x) b_2}{\delta_2(x)} + \varepsilon_2 \varepsilon_0 \frac{b_2 x}{\delta_2(x)} = \varepsilon_0 \frac{b_2}{\delta_2(x)} [\varepsilon_1 (X_M - x) + \varepsilon_2 x], \]  

(2)

where \( w \) is the number of turns of the measuring winding; \( b_1 \) and \( \delta_1 \) - the width of the cores of the magnetic circuit and the gap between them; \( \mu_0 = 4\pi \times 10^{-7} \text{H/m} \) - magnetic constant; \( b_2 \) and \( \delta_2(x) \) - the width of the capacitor electrodes and the gap between them; \( x \) - initial and maximum values of \( x \) respectively \( x_0 \) and \( X_M \); \( \varepsilon_1 \) - dielectric constant of LCD, the molecules of which are not oriented along the magnetic field \( x \); \( \varepsilon_2 \) - dielectric constant of the LCD, the molecules of which are oriented along the magnetic field.

The size of the gap \( \delta_2(x) \) is given by:

\[ \delta_2(x) = \frac{w^2 \omega^2 \mu_0 \varepsilon_0}{\frac{b_2}{\delta_1} \left[ \varepsilon_1 (X_M - x) + \varepsilon_2 x \right]}. \]  

(3)

Substituting expression (3) into equation (1), we get:

\[ C = \left[ \varepsilon_1 (X_M - x) + \varepsilon_2 x \right] \cdot \varepsilon_0 \frac{b_2 \delta_1}{w^2 \omega^2 \mu_0 \varepsilon_0 b_2 \left[ (X_M - x) + \varepsilon_2 x \right] x} = \frac{\delta_1}{b_1 w^2 \omega^2 \mu_0 x}; \]

\[ LC = \frac{w^2 \mu_0}{\delta_1} \frac{b_1 x}{w^2 \omega^2 \mu_0 b_2 x} = \frac{1}{\omega^2}; \quad \omega = \frac{1}{\sqrt{LC}}. \]

The output signal or static characteristic of the sensor will be written as:

\[ E_{\text{wee}} = I_2 x_L = I_2 \frac{w^2 \omega \mu_0 b_1}{\delta_1} x. \]

The last expression shows that the static characteristic of the investigated sensor is linear under the above assumptions. However, the distributed nature of the magnetic resistance of steel and the magnetic conductivity of the gap has a significant effect on the resonance mode. Therefore, below we consider the influence of the distributed parameters of the magnetic circuit and the frequency of the power source on the resonant mode within the range of variation of the parameters \( L(x) \) and \( C(x) \) in the considered biparametric resonant linear displacement transducer. In biparametric circuits with distributed parameters operating in a resonant mode, inductance and capacitance are defined as

\[ L(x) = \frac{w^2}{\gamma ch(\gamma X_M)} \frac{g}{sh(\gamma(x_0 + x))}, \quad C(x) = \varepsilon_0 \frac{S}{x_0 + x}, \]

where \( \gamma = \sqrt{2\mu_0 g} \) - coefficient of propagation of a magnetic field along a magnetic circuit, \( \gamma \) - the quantity is complex, but in the formulas at sufficiently low frequencies and the absence of a surface effect, the coefficient spread by a real number,

\[ g = \mu_0 \frac{b_1}{\delta_1}, \quad \mu = \frac{1}{\mu_0 b_1 n_1} \]

- linear values of the magnetic conductivity of the gap \( \delta_1 \) and the magnetic resistance of parallel cores per unit length \( x \), \( \mu \) is the relative magnetic permeability of the material (steel) of the magnetic circuit, is the thickness of parallel cores, \( S \) - is the active area of the capacitor electrodes.

The natural angular frequency of the circuit is
and the resonant frequency is found as

\[ \omega_p = \frac{1}{\sqrt{L C}} = \frac{1}{w \sqrt{g_x e_0 \delta}}. \] (4)

The relative detuning of the circuit frequency with respect to the resonant frequency is

\[ \Delta = \frac{\omega(x) - \omega_0}{\omega_0} \times 100\% = \sqrt{1 - \frac{\gamma x c h(y X_M)}{sh(y x)}} \times 100\%. \] (5)

The ratio of the current in the circuit to the resonant current can be found as

\[ I^* = \frac{I}{I_{res}} = \frac{R}{\sqrt{R^2 + \left[ \omega_0 w^2 g_{x} e_0 \delta \frac{x}{\omega_0 e_0 \delta^2 x} \right]^2}}. \]

Where \( R \) – active resistance of the measuring circuit of the sensor.

Figure 2 shows the curves of the dependences \( \Delta = f(x^*) \) and \( I^* = f(x^*) \) at different values \( \gamma \), where \( x^* = \frac{x}{X_M} \) - the relative value of the input quantity. The curves show that with increasing \( \gamma \) (due to an increase in the magnetic resistance of steel), the relative detuning increases, and the current in the circuit decreases sharply. The degree of unevenness of the magnetic field in the working gap of the magnetic circuit is determined by the formula [9-15]:

\[ \varepsilon_B, \% = \left(1 - \frac{1}{ch(y X_M)}\right) \times 100\%. \]

Substituting (6) into (5), we obtain the expression for the dependence of the detuning on the degree of unevenness of the magnetic field in the working gap:

\[ \Delta = \sqrt{1 - \frac{(x_0 + x) ch \left[ \frac{100}{100 - \varepsilon_B} \right]}{100 - \varepsilon_B} \left( ch \frac{100}{100 - \varepsilon_B} \right)} \times 100\%. \]

Changing the mains frequency also affects the resonance mode, the current \( I^* \) in this case is calculated as

\[ I^* = \frac{R}{\sqrt{R^2 + \left[ (\omega_0 \pm \Delta \omega)L(x) - \frac{1}{(\omega_0 \pm \Delta \omega)C(x)} \right]^2}}. \]

Dependency Curve Analysis \( I^* = f(x^*) \) at different values \( \pm \Delta \omega \) and \( \gamma \) indicates that with an increase in the frequency of the source voltage by \( \Delta \omega \) the resonance effect is reduced to a greater
extent than by decreasing the frequency by the same amount. This is due to a decrease in the increase in the inductance of the circuit with an increase in the magnetic resistance of the steel [16-20].

Thus, the article describes the methods of maintaining the resonant mode in biparametric circuits with distributed parameters and studies the influence of changing the parameter circuit and the power supply on the resonant mode.

Figure 2. Curves of the dependence of the detuning of the measuring circuit and the current on the coordinates of the moving part of the sensor at different values $\gamma$ and $\Delta \omega$: solid – curves $\Delta$, dotted – curves $I$.

4. Conclusions

It is shown that at present only separate designs of the transformer-type linear displacement turbojet engine have been developed, and inductive turbojet turbojet engines and sensors of this type for converting speed, acceleration and vibration are under development. It was found that in the known turbofan engines, resonance is provided in a narrow range of movement of the moving part of the sensor, which indicates the imperfection of the known methods of maintaining the resonance mode.

It has been established that further research should be aimed at developing new methods of maintaining the resonance mode over the entire range of change of the converted value, general principles of constructing a turbojet engine, a detailed analysis of their resonant circuits, the study of their dynamic properties, a comparative assessment of the technical characteristics of inductive and transformer, conventional and differential turbofan engines, taking into account the type of their moving part.

References

[1] Ashrafi S, Golnabi H 1999 A high precision method for measuring very small capacitance changes The Review of scientific instruments 70(8) 3483-3487.

[2] Anufriev DP, Zaripova VM, Lezhnina YuA, Petrova IYu, Khomenko TV, Shikulskaia OM 2015 Designing elements of information-measuring and control systems for intelligent buildings, State Autonomous Educational Establishment of Astrakhan Civil Engineering Institute, Astrakhan.

[3] Yakubov MS, Baratov RZh, Sulliev AKh 2000 Patent of the Republic of Uzbekistan No. IAP-04362. Linear displacement transducer, Rasmium of the Achborotnoma 3.
[4] Amirov SF, Sulliev AKh 2015 Biparametric resonance sensors for train speed control systems. Publishing house “ADAD PLYUS” LLC, Tashkent.
[5] Amirov SF, Sulliev AKh 2008 Biparametric resonant sensors with distributed parameters Sensors and Systems Magazine 10 41-43.
[6] Sulliev AKh 2017 Biparametric resonant circuits with distributed parameters, IX International Symposium on Breakthrough technologies for electric transport Eltrans-2017, St. Petersburg.
[7] Amirov SF 1997 Pseudo-resonant mode in DC circuits Problems of Informatics and Energy 4 27-28.
[8] Amirov SF 1997 Method of synthesis of positive and negative parameters of circuits of different physical nature Problems of Informatics and Energy 5 23-35.
[9] Yakubov MS, Sulliev AKh, Rakhmanov M 2011 Analysis of static and dynamic characteristics of autoresonant electromagnetic converters Chemical Technology. Control and management 1 58–63.
[10] Baratov RZh, Shoyimov YYu, Sulliev Akh 1998 Ensuring constancy in high sensitivity of electromagnetic converters of mechanical quantities used in agricultural water supply Collection of Scientific. Tr. TIIIMSKH 138-145.
[11] Shabanov VA, Bashirov MG, and Khlyupin PA 2018 Diagnostics of the technical condition of electrical equipment of power supply systems: 2 part, In: Methods for diagnosing the technical condition of electrical equipment, MEI Publishing House, Moscow.
[12] Yakubov MS, Fayzullaev ZhS 2018 Diagnosis of the operating mode of the traction asynchronous electric motor Bulletin of ANRuz “Problems of Informatics and Energy” 4 33-41.
[13] Yakubov MS, Fayzullaev ZhS 2018 Optimization of the periodicity of technical diagnostics of maintenance and repair of traction electrical equipment of electric locomotives Energy and Resource Saving 6 24-32.
[14] Amirov SF, Zhuraeva KK, Turdibekov KKh, Boltaev OT, Fayzullaev ZhS Magnetoelastic force transducer, Invented patent, No. IAP 20180333, Intellectual Property Agencies of the Republic of Uzbekistan.
[15] Yakubov MS, Mukhamedova SG 2018 Continuous diagnostics of the state of the traction induction motor to based on the spectral analyses first current Journal of Tashkent Institute of Railway Engineers 16 86-92.
[16] Yakubov MS, Mukhamedova SG 2018 Analysis of optimal periodicity of the preventive maintenance of rail service captaining into account operational technology European Science Review 1 167-171.
[17] Yakubov MS, Mukhamedova ZG, Isroilov US, Fayzullaev ZhS 2018 Methodological aspect of continuous monitoring of traction electrical equipment diagnostics using spectral analysis methods Chemical Technology Control and Management 3 67-73.
[18] Amirov S, Yakubov M, Turdibekov K, Sulliev A 2020 Resource-saving maintenance and repair of the Traction transformer based on its diagnostics International Journal of Advanced Science and Technology 29(5) 15001504.
[19] Sanbetova A, Sulliev A, Kasimov Sh 2020 Research on Biparametric Resonant Displacement Sensors Deviation IOP Conf. Series Materials Science and Engineering 883 012150.
[20] Sulliev Akh 2011 Biparametric resonant motion sensors for monitoring and control systems, Candidate of Technical Science Dissertation, Tashkent.