Measurement of Resonant Frequency of Radio Frequency Converter under Conditions of Significant Electromagnetic Losses

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Abstract: -The measurement of resonant frequency in radio wave converter under conditions of high electromagnetic losses presents a formidable challenge. This frequency serves as a crucial parameter directly linked to non-electronic quantities, such as spatial separation thresholds or substance consumption levels. Consequently, accurate measurement of these non-electric variables necessitates precise determination of the transmitter's resonant frequency. However, when electromagnetic losses escalate due to control environment properties, achieving such precision becomes daunting. Common methodologies often hinge on assessing resonant frequency via the transmitter's amplitude-frequency characteristic. However, conventional approaches, typically reliant on electron beam tubes with intricate control mechanisms, falter in accuracy amidst substantial electromagnetic transmission losses. This inadequacy undermines the efficacy of current devices. This paper introduces an unconventional method for resonance frequency measurement and underscores the benefits of the device developed through this novel approach compared to existing ones. The proposed method ensures sustained high measurement accuracy even in the face of significant transmitter electromagnetic losses. Central to this method is the measurement of frequencies ω_1 and ω_2 proximate to the resonant circuit's extreme value at points characterized by identical transmission coefficients. Resonant frequency is then determined as the half-sum of these frequencies during symmetrical frequency modulation. This innovative approach promises to overcome the limitations of traditional resonance frequency measurement methods, offering enhanced precision and reliability in challenging electromagnetic environments.

Key-Words: - Resonant frequency measurement, Frequency modulation, Amplitude-frequency characteristic, Q factor

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1 Introduction

The radio frequency transmitter converter functions as a distributed-parameter oscillating system (RS), characterized by several key parameters such as resonance frequency, electromagnetic losses (measured by the Q factor), passband, amplitude, and shape of the resonance curve. Among these, the primary parameter of interest is the resonance frequency. This is because, owing to the nature of electromagnetic waves, the resonant frequency of the oscillating system directly correlates with the significance of the controlled non-electric quantity. For instance, it plays a crucial role in delineating boundaries between different environments or quantifying substance consumption (1). Consequently, when employing a radio frequency converter, the measurement of non-electric quantities essentially boils down to determining the resonant frequency of the radio frequency oscillating system. However, under conditions where electromagnetic losses of the radio frequency converter increase—often due to the properties of the controlled environment—achieving precise measurements of the resonant frequency becomes a challenging task.
[1] [2].

2 Problem Formulation

One common method frequently employed in practice involves determining the resonance frequency through the amplitude-frequency characteristic [2], [3]. To achieve this, in many cases, an oscilloscope or an electron-ray tube with its intricate control scheme is utilized. These devices allow for the visual determination of research information parameters on the screen. However, they often lack the capability to provide high accuracy, especially when confronted with significant electromagnetic transmission losses. This limitation restricts the usefulness of existing devices. [3].

3 Problem Solution

This paper proposes an unconventional method for measuring resonance frequency and highlights the advantages of the device developed through this approach compared to existing ones.

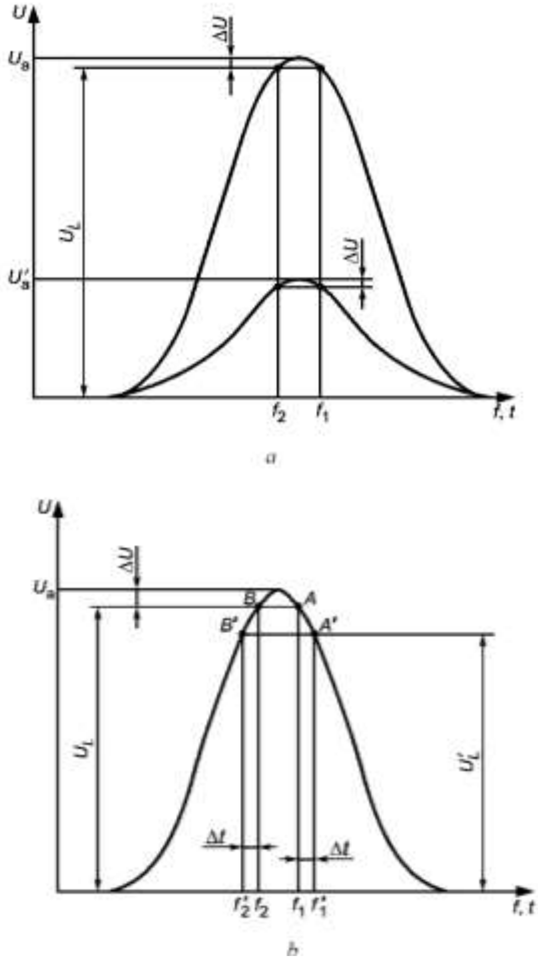

Figure 1 Factors affecting the result of measuring OS resonant frequency: a) effect of a change in OS Q-factor and its maximum AFC on measurement accuracy;
b) effect of time delays operating for individual units of the layout on the measured result.

The proposed method ensures the maintenance of high measurement accuracy under conditions of substantial electromagnetic losses of the transmitter[4] [5]. The essence of this method lies in measuring frequencies ω_1 and ω_2 near the extreme value of the resonant curve at points with the same transmission coefficient and determining the resonant frequency as their half-sum during symmetrical frequency modulation.

Fig. 1a depicts the core concept of the proposed method, while Fig.2 demonstrates how the resonance curve of the radio frequency converter alters with an increase in electromagnetic losses (where suitability is small with $Q_1 \leq 20$ and amplitude is 6-10 times). The visible frequency measurement cycle comprises two stages: firstly, measuring the frequency ω_1 while linearly increasing the output frequency of the driving generator, and secondly, measuring the frequency ω_2 while decreasing linearly at the same rate as point a and point b of ω_2. At both the first and second U_0 levels, recorded by the peak detector integrated into the device.

The device, based on the proposed method, presents several advantages over existing ones, notably: the elimination of non-linearity resulting from the error of the linear variable generator due to direct measurement of frequencies ω_1 and ω_2.

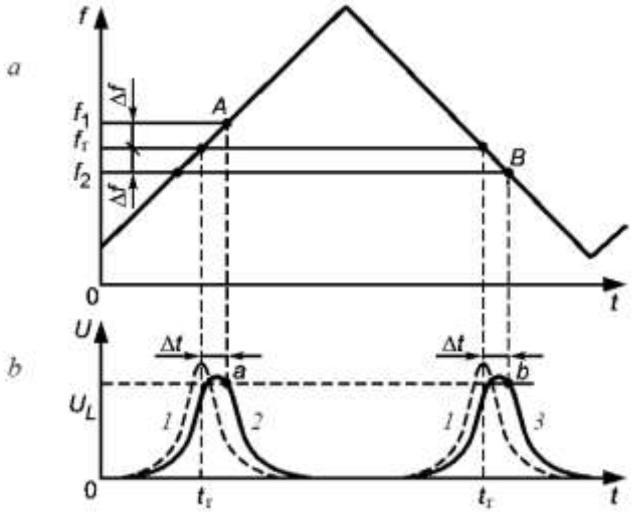

Figure 2 Measurement of resonant frequency with symmetrical frequency modulation of the controlled voltage oscillator: a) dependence of tuning frequency on time; b) signal corresponding to the OS AFC in a dynamic regime; 1) static resonance curve that on the frequency scale corresponds to a static OS AFC; 2, 3) dynamic OS AFC.

The change in the amplitude of the resonant curve of the transmitter has less effect on the result of gas heating because the peak detector included in the device always detects the extreme dimness in the vicinity of the amplitude value, and the closer the extreme value is to the amplitude mark, the smaller the difference, which in turn reduces the error caused by non-peaking of the modulation characteristic of the controlled generator.

The error caused by the asymmetry of the transmission resonance curve is reduced.

The following graph (Fig. 3) shows the results of the methodical error analysis of the existing (Fig. 4, curve-1) and proposed (Fig. 3, curve 2) methods for reducing the suitability of the supplier (4≤Q≤20).

The analysis is carried out taking into account the following ratio:

The approximate equation of the amplitude-frequency characteristic of the transmitter is:

$$U(w) = \frac{U_m}{\sqrt{1+\frac{2Q(\omega-\omega_{0)}}{\omega_0^2}}} \qquad (1)$$

Asymmetry coefficient

$$L = \frac{\omega_{2,3}-\omega_0}{\omega_0-\omega_{1,3}} \qquad (2)$$

where U_m is the transmitter resonance curve amplitude, $\omega_{1,3}$and $\omega_{2,3}$frequencies, at the start and end points of the radio transmitter's passband.

If the resonance curve of the transmission is symmetrical, then the coefficient of asymmetry is equal to L=1, and in the case of asymmetry, L≠1. The analysis was carried out for the case when the asymmetry coefficient was equal to L=0.5. The extreme value that was obtained experimentally corresponded to the level K=0.25-0.5 dB. From the obtained graph, it can be seen that the methodological error caused by the asymmetry of the resonance curve based on the existing method reaches 4% when reducing the suitability of the transmitter (4≤Q≤20). When the methodological error of the proposed method does not exceed 1% under the same conditions.

In the proposed method, the use of symmetric frequency modulation in the realization device allows compensation for the dynamic error.

Dynamic errors stem from the delay threshold time of individual device blocks and the displacement of the amplitude-frequency characteristic. In dynamic mode, the relative change of the displacement concerning the static resonance curve is directly proportional to the frequency rate of change β and the transmitter's suitability Q, calculated by the formula:

$$\frac{\delta\omega}{\omega_0} = 4\beta \times \frac{Q}{\omega_0^2};$$

And the relative change of the transmission band is proportional to the square of the frequency and the fourth power of the fit, which is calculated by the formula:

$$\frac{\delta(w)}{w} = 40 \times \beta^2 Q^4/\omega_0^4$$

where ω is the conduction band of the transmitter in static mode and $\delta\omega$) is the displaced conduction band in dynamic mode.The device based on the existing method has the errors defined by formulas in dynamic mode, and in the device based on the discussed method, such errors are compensated, which is shown in Figure 3 below. This can be explained as follows:

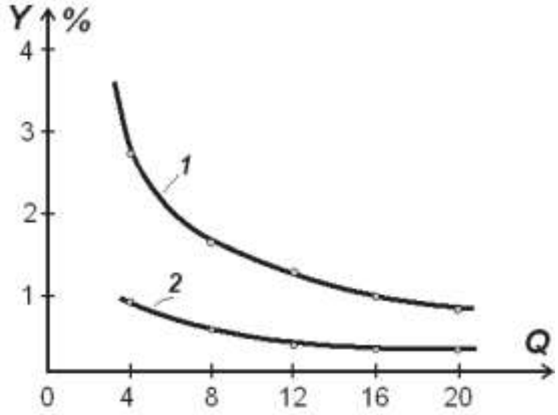

Figure 3

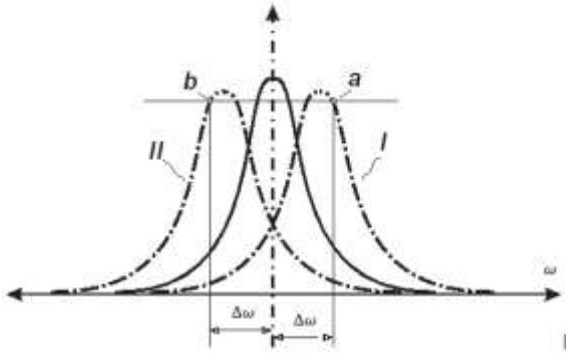

Figure 4

In the proposed device (4) symmetric frequency modulation is used, and in both stages of measurement, the frequency of the controlled generator is changed at the same rate B. The deviation of the dynamic resonance curve of the transmitter with respect to the static one and the delay of the individual blocks included in the device are the integral quantities in both I and II measurement stages (see Fig. 3).

When determining the half-sum of $\omega_1$and ω_2, the shifted quantities included in them have opposite signs, which are canceled during summation, and the dynamic resonant frequency ω_0 of the transmission will be equal to the static resonant frequency ω_0.

$$\omega_0^1 = \frac{(\omega_1 + \omega_2)}{2} = (\omega_0 - \Delta\omega + \omega_0 + \Delta\omega)\ /\ 2 = \omega_0$$

which proves dynamic error compensation.

Thus, the considered method and the resonant frequency measuring device based on it have a number of advantages, compared to the existing ones, and these advantages are especially evident when using a radio wave transmitter.

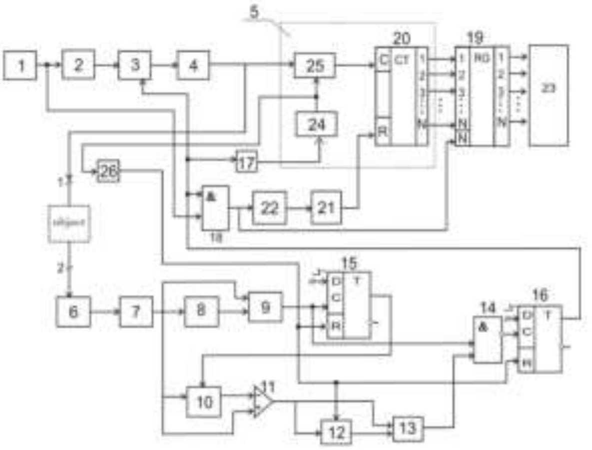

Figure 5 Functional scheme of the device implementing the resonance frequency determination method.

Fig.5 presents the functional scheme of the device implementing the improved method of determining the resonant frequency, the principle of operation of which is based on the above-mentioned algorithm. Fig. 6 shows the time diagrams explaining the working principle.

The diagram shows the following components: 1: rectangular meander generator; 2: triangular pulse shaper; 3: "select-store" elements; 4: controlled (high-frequency) generator; 5: frequency measuring block, which includes measuring time interval generator 24, key 25, and pulse counter 20; research object - an oscillating system connected to the device by means of the first and second clamps; 6: amplitude detector; 7: amplifier; 8: peak detectors; 9: comparators; 11: differential amplifier; 15: "D" triggers; 17, 22: delay lines; 14, 18: "and-not" logical elements; 21, 26—differentiators; 19: memory register; 23: indicator block.

The device described above determines the resonance frequency with high accuracy, even with low suitability, in the case of a symmetrical amplitude-frequency characteristic and a linear function characteristic of voltage-controlled generator conversion into frequency. In practice, the characteristic of the controlled generator is non-linear, making it difficult to determine the exact value of the resonant frequency with high accuracy. To eliminate this shortcoming, it is necessary to approach the extreme value of the resonant frequency and measure the frequencies f_1 and f_2 in its vicinity. However, near the extreme value, the instability of the comparator is revealed, caused by the sharp smoothness of the resonance curve, ultimately leading to the instability of the measurement result.

In the proposed device (Fig. 5), the oscillating system is supplied with a frequency signal that increases linearly over time, which is modulated according to the amplitude-frequency characteristic of the oscillating system. After detection, in the first stage, the extreme value of the amplitude-frequency characteristic of the oscillating system is "roughly" fixed and stored. The difference signal between the stored value and the extremum is amplified in amplitude, resulting in a steep waveform corresponding to the smooth amplitude-frequency characteristic caused by the low suitability of the oscillating system in the extremum region. In the second stage, the "exact" value of the extremum of the obtained amplitude-frequency characteristic is fixed, followed by the fixing of the instantaneous value of the frequency acting on the oscillating system at that moment. The first frequency f_1 is set and the value is memorized.

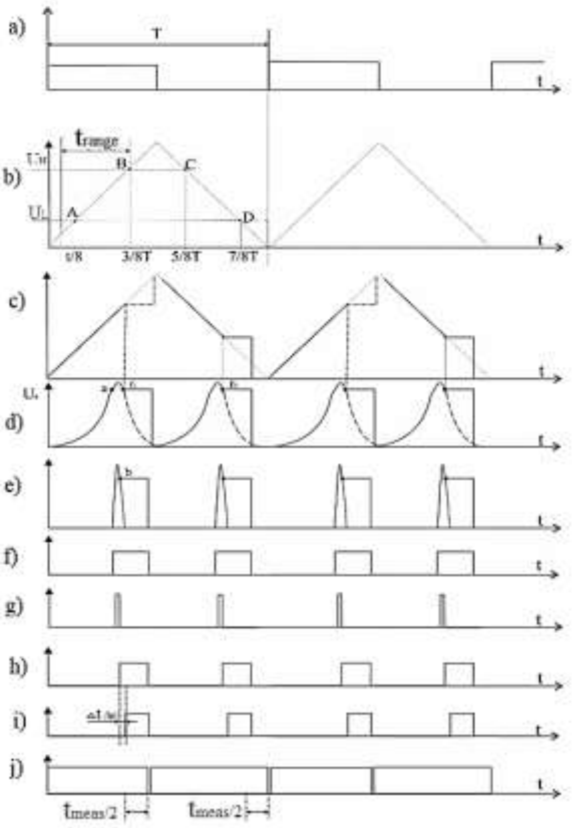

Figure 6 Timing Diagrams Explaining the Working Principle of the Resonant Frequency Determination Device

In the second cycle, a similar process occurs, and the second frequency f_2 is determined, with the difference that the frequency of the signal acting on the oscillating system decreases linearly. The average value of the determined frequencies f_1 and f_2 determines the natural frequency of the oscillating system.

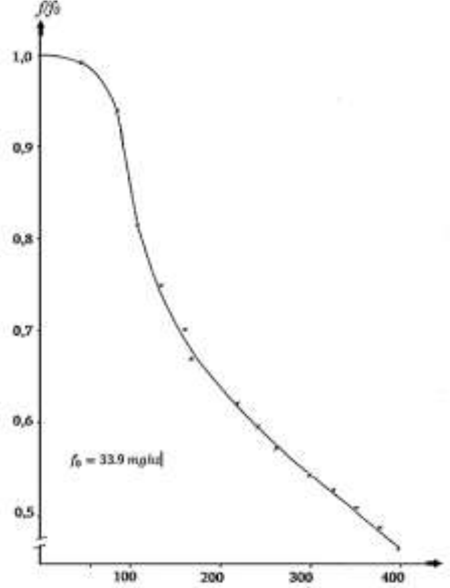

Figure 7 Experimental output characteristic of the object

The device described above was realized and implemented in a factory producing plastic products, where the object was a chemical reactor with axial mixing. In this reactor, a liquid chemical (high-temperature plastic substance) was placed, and the technological process (synthesis) occurred under high pressure.

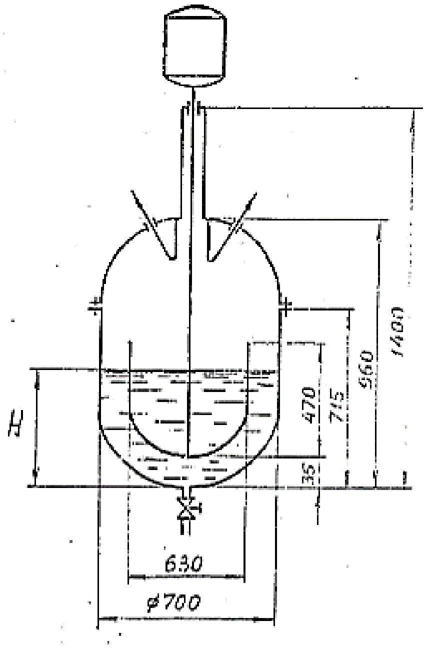

Figure 8 Construction of the object (chemical reactor)

In many cases, it is difficult to control the technological process inside such reactors, necessitating the use of methods involving external exposure to harmful radiation, which is challenging, environmentally unjustified, and harmful to service personnel. The proposed method is environmentally justified, and the determination of technological parameters is simpler and more reliable.

On the mentioned object, the mechanical construction of which is shown in Fig. 8, studies were conducted, resulting in the experimental (output) characteristic of the dependence of the amount (level) of the liquid medium in the chemical reactor on the resonance frequency .

The maximum value of the resonance frequency was $f_{01}=33.9MHz$, which corresponded to the state of the chemical reactor without a liquid medium. In the case of the reactor fully filled with liquid medium, the resonance frequency was $f_{02}=15.4MHz$. The advantage of this approach is the use of the mechanical construction of the research object itself as a source of primary information. There is practically no need to use special sensors, which simplifies the process of converting a non-electrical physical quantity into an electrical quantity and increases the reliability of determining technological parameters.

4 Conclusion

The measuring devices based on the proposed radio frequency method feature straightforward functionality, employing simple iron or steel constructions as sensitive elements. Implementation of this method in practical applications ensures the maintenance of requisite measurement accuracy for informational parameters, even when the sensitive element exhibits significant electromagnetic losses and operates under challenging conditions. Moreover, the proposed approach offers the advantage of utilizing the mechanical structure of the research object itself as a primary source of information. This minimizes the need for specialized sensors, simplifying the process of converting non-electrical physical quantities into electrical ones and enhancing the reliability of technological parameter determination. This method can be applied in situations where existing methods fail to provide sufficient accuracy or are generally unsuitable. Particularly, it finds utility in scenarios involving elevated or low temperatures, aggressive environments, increased vibration intensity, and other challenging conditions, such as radiation exposure, determining technological parameters of liquid metals and low-temperature cryogenic substances, monitoring the volume of loose matter, as well as assessing geometric dimensions, among others.

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References

[1] Z Azmaiparashvili, N Otkhozoria (2021) "Mathematical Model for Studying the Accuracy Characteristics of Devices for Measuring the Resonant Frequency of scillatory Systems New Approaches in Engineering Research" 121-131 doi.org/10.9734/bpi/naer/v5/10242D.

[2] Zaal Azmaiparashvili, Nona Otkhozoria, Alexander Maltsev. Analytic-Imitation Model for Determination of the Natural Frequency of Oscillatory Systems and Its Research. Engineering and Technology. Vol. 4, No. 6, 2017, pp. 82-87. http://www.aascit.org/journal/archive2?journalId=896&paperId=5986

[3] A. Akhmedova. Determination of oscillating circuit resonance frequency with account for eddy current losses. Russian Electrical Engineering, Volume 82, Issue 12, (2011) 688-690

[4] N. Otkhozoria, Z. Azmaiparashvili, L. Petriashvili, V. Otkhozoria, & E. Akhlouri. (2023). Labview In The Research Of Fractal Properties Of The Topology Of Networks And Stochastic Processes. World Science, (3(81). https://doi.org/10.31435/rsglobal_ws/30092023/8020

[5] Bernard P. Zeigler, Hessam S. Sarjoughian, Guide to Modeling and Simulation of Systems of systems (Simulation Foundations, Methods and Applications) Springer-Verlag, 2012.

[6] Lunkin B. V. Mishenin V. I. Azmaiparashvili Z. A. Efendiev I. M., (1991). Patent No. 1673862 A1. Devices for measuring the liquid level in a tank with an axial stirrer.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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