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Using Matlab to Study of the Response of the System to Oscillatory Influences be an Oscillatory Effect on the Resting Antenna

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Abstract
The purpose of this work is to observe the dependence of the response of a system previously calculated using a linear model to typical actions if they are applied not to a model linear system, but to a real object containing nonlinear elements.
The object of research is a mobile radar antenna. The purpose of object control is to maintain a constant angular velocity of the antenna. Typical impacts on the system are selected based on the characteristics of the object and its scope. Among the operating modes of the object are long-term observation of the entire surrounding space (continuous rotation of the antenna) and observation of a certain sector (periodic rotational movements of an oscillatory nature). Short-term impacts of large amplitude and high-frequency impacts of small amplitude can be applied to the input of the object due to the features of the line that supplies the input signal to the system. Periodic oscillatory effects can be applied to the antenna from the outside, this is due to the specifics of the location of the control object on the ground.

Keywords: Acceleration of the mechanism; Heaviside function; Non-linear system; Matlab

1. Introduction
After analyzing the behavior of the control object based on linear theory, and calculating the necessary control laws, when implementing systems based on the calculations performed, you may encounter some discrepancies between the reactions received from the real object and the expected ones. The properties of the assembled system, built on real elements, can differ significantly from the calculated ones.
So in a stable, according to a linear model, system, undamped oscillations can be observed. A small error in the processing of input actions in the linear model turns out to be much larger or even increases indefinitely. The transient process in a real system can be much longer than in a linear case. An astatic system in a linear approximation can in reality work out actions with a constant steady-state error. The reason for all these phenomena is the discrepancy between the properties of real elements and their linear model adopted in the calculation.
In the first section of this work, the main points related to the linear description of the system and the synthesis of the controller will be listed. In the second section, the virtual linear plant model implemented in the Simulink system will include in turn the nonlinearities that are expected to appear in a real plant. In the third section, observation will be made of the capture by a nonlinear object of forced oscillations of a frequency coinciding with the frequency of the input action.

2. Research Methodology
2.1. Setting tasks
It was necessary to synthesize the control law for the acceleration system of the inertial rotor. It was required to ensure the process of acceleration to a given constant speed, providing a given quality of transient processes in terms of speed, oscillation and overshoot.

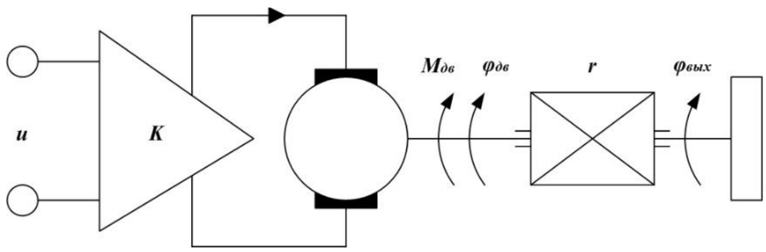

Fig 1: Functional diagram of the installation

2.2. Design scheme

First, it was necessary to build an adequate model of a real system and introduce its parameters:

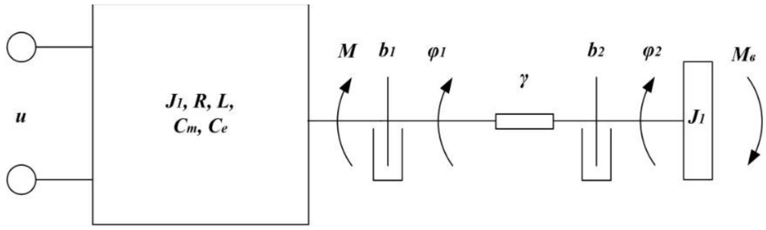

Fig 2: Control object scheme

It was believed that only the first natural frequency is important in the operating frequency range. For the study, the values of the system parameters were set. The control object is a radar antenna mounted on a movable base. The accepted values are given in the table:

Table 1: The study the values of the system parameters were set

Value name	Designation	Meaning	Unit dimensions
The upper limit of the frequency range of processed actions	$\bar{\omega}$	20	1/s
Natural frequency of the system	ω_0	8	1/s
Reduced moment of inertia of the motor	J_1	2,25	Kg.m^2
Reduced load moment of inertia	J_2	2	Kg.m^2
Reduced coefficient of viscous friction of the input shaft	b_1	1,7	N·m·s
Output shaft viscous friction coefficient	b_2	3,4	N·m·s
Electrical analogue of viscosity	h	3,4	N·m·s
Rigidity of the kinematic transmission	γ	67,76471	N·m
Reduced electromechanical gain	d	45	N·m/V
Characteristic time of electrical processes	$\tau_э$	0,01	s

2.3. Mathematical models of the control object

In this problem, the input is the control voltage and the external disturbing moment M_B, the output is the angular velocity of the output shaft. Let's write down the system of differential equations describing the behavior of the object:

$$\begin{cases} J_1\ddot{\varphi}_1 + b_1\dot{\varphi}_1 + \gamma(\varphi_1 - \varphi_2) = M \\ J_2\ddot{\varphi}_2 + b_2\dot{\varphi}_2 + \gamma(\varphi_2 - \varphi_1) = M_B \\ \tau_э\dot{M} + M = du - h\dot{\varphi}_1 \end{cases} \quad (1)$$

In this system: $\tau_э = \dfrac{R}{L}$, $d = \dfrac{KC_m}{R}$, $h = \dfrac{i^2 C_e C_m}{R}$.

Because $\tau_э = 0.01 << \tau_м = \dfrac{J_1 + J_2}{b_1 + b_2 + h} = 0.5$, that is, electrical processes in the system proceed much faster than mechanical ones $\tau_э\dot{M}$, in the third equation the first term was taken out of consideration. The system has been rewritten as:

$$\begin{cases} J_1\ddot{\varphi}_1 + (h + b_1)\dot{\varphi}_1 + \gamma(\varphi_1 - \varphi_2) = du \\ J_2\ddot{\varphi}_2 + b_2\dot{\varphi}_2 + \gamma(\varphi_2 - \varphi_1) = M_B \end{cases} \quad (2)$$

Having additionally adopted the notation $b_1' = b_1 + h$, we write the system of equations as follows:

$$\begin{cases} J_1\ddot{\varphi}_1 + b_1'\dot{\varphi}_1 + \gamma(\varphi_1 - \varphi_2) = du \\ J_2\ddot{\varphi}_2 + b_2\dot{\varphi}_2 + \gamma(\varphi_2 - \varphi_1) = M_B \end{cases} \tag{3}$$

2.4. Regulator synthesis

For the system described above, using the compensation method, a controller was synthesized, the transfer function of which is given below:

$$W(p) = \frac{14.76 \cdot \left(p^3 + 3.97p^2 + 67.85p + 128\right)}{p \cdot \left(0.11p^2 + 9.87p + 444.44\right)} \tag{4}$$

It was assumed that the block diagram of a closed system has the form:

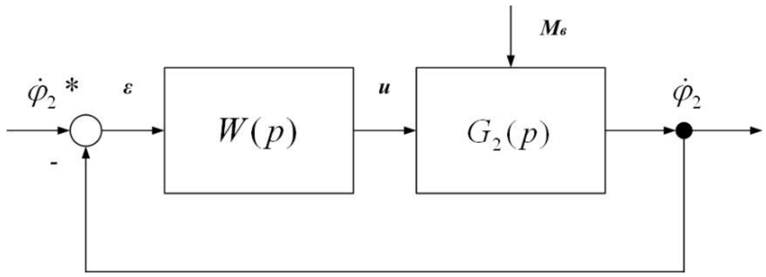

Fig 3: Closed system diagram

In the diagram $G_2(p)$ - the transfer function from the inputs (control voltage u and external torque $M_в$) to the angular velocity of the output shaft (antenna) $\dot{\varphi}_2$.

It makes sense to apply the following typical actions to the system input:

Sinusoidal action of low frequency and high amplitude (sector monitoring mode)

A signal is selected as a sinusoidal input signal of low frequency and high amplitude $1 \cdot \sin(\pi t)$. High frequency signal- $0{,}01 \cdot \sin(25\pi t)$.

As mentioned earlier, in the case of assembling a system designed according to a linear model from real elements, its properties may differ from those expected- the response to input actions may be different. Moreover, the differences can be of a qualitative nature.

In this section, we will check the response of the object to the inclusion of non-linearities in it. The verification will be carried out at different levels of nonlinearities according to the reaction of the resulting system to the input of the Heaviside function to the input of the system.

2.5. Description of the types of nonlinearities

First of all, it makes sense to consider in more detail the types of nonlinearities that take place in a given system.

2.5.1. Dead zone: This nonlinear dependence will be used in the description of the amplifier and kinematic gears. In the case of an amplifier, this dependence means that there is a minimum threshold voltage, only when it is exceeded, a non-zero signal appears at the output. When describing kinematic gears, this dependence makes it possible to take into account gaps. An example of this relationship is shown in the graph below.

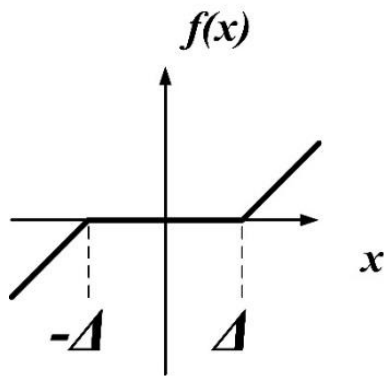

Fig 4: Approximate view of the dependence of the "dead zone" type

2.5.2. Saturation (limitation): This nonlinear dependence will be used in the description of the amplifier. With its help, you can take into account the limitations of the output signal. An example of this dependence is shown in the graph below.

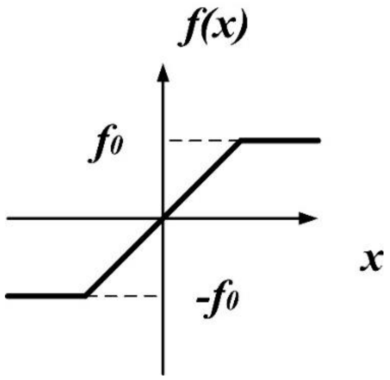

Fig 5: Approximate type of dependence of the "saturation" type

2.5.3. Coulomb friction (relay): This type of non-linear dependence makes it possible to describe the effect of Coulomb friction. An example of this relationship is shown in the graph below.

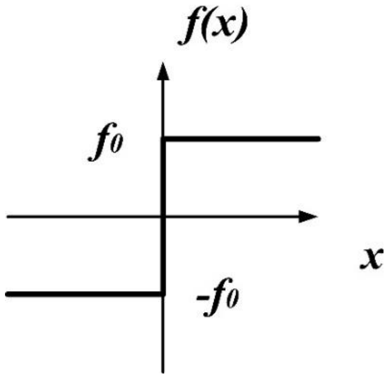

Fig 6: Approximate type of "relay" dependency

2.5.4. Friction with Stribeck effect (friction model): This type of nonlinear dependence corresponds to the Stribeck friction model. The peculiarity of this model is that at the beginning of the movement, the friction moment first decreases, starting from the static friction moment, and then begins to increase nonlinearly with an increase in the speed of movement. An approximate view of this non-linear dependence is shown in the graph below.

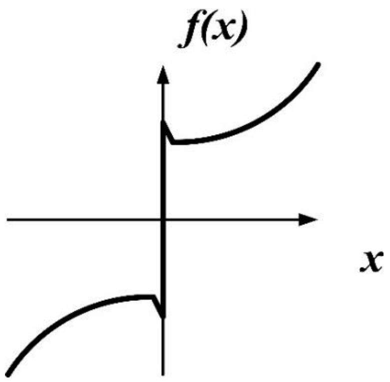

Fig 7: Approximate view of the dependence of the type "friction with the Striebeck effect"

3. Results and discussion

3.1. System response to oscillatory inputs

In this section, a study of the response of the system to oscillatory influences will be carried out. These actions will be an oscillatory effect on the resting antenna and a sinusoidal control action.

3.1.1. System response to noise impacts

As a noise signal (high-frequency low-amplitude signal) $0{,}01 \cdot \sin(25\pi t)$, the influence supplied to the system as a disturbing moment was chosen. Graphs of the time dependence of the input signal and the response of the systems - linear and non-linear - are shown below. On the given graphs: light line - linear system, dark line - non-linear system.

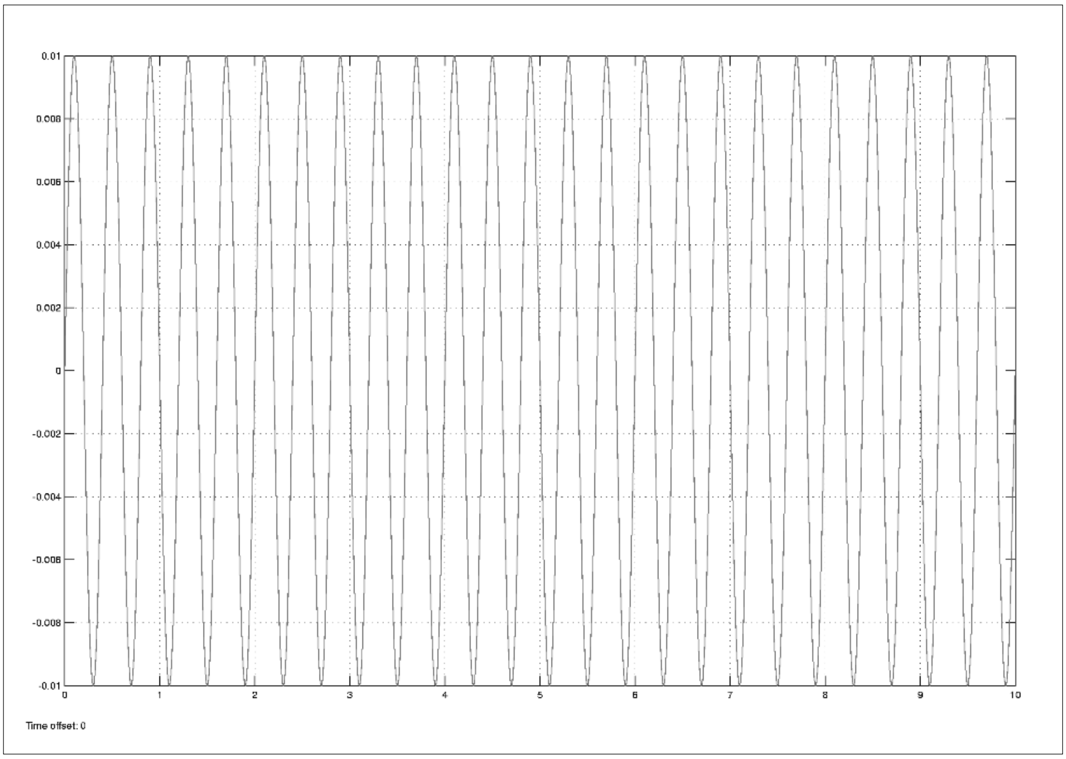

Fig 8: Input action $0,01 \cdot \sin(25\pi t)$ (sinusoidal noise)

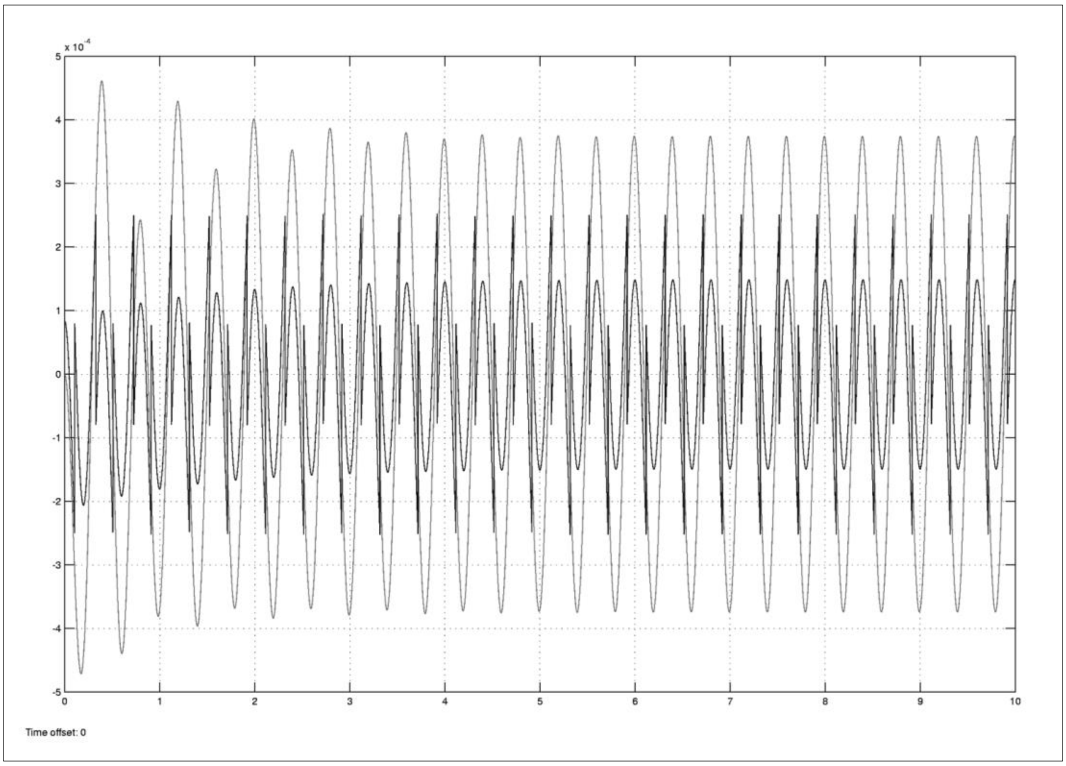

Fig 9: Response of systems to input action $0,01 \cdot \sin(25\pi t)$ (sinusoidal noise)

It can be seen from the graphs that the reactions of the full and linear models are characterized by greater fluctuations in comparison with the input action. In addition, the oscillatory processes in these systems are similar in terms of period. However, the linear model response is larger and less oscillatory compared to the full model response.

3.1.2. Observation of the phenomenon of capture of forced oscillations

Now let's try using the nonlinear system studied in the previous sections to observe the phenomenon of capture of forced oscillations.

To do this, we will apply to the input a control action of the form $1 \cdot \sin(\omega t)$, where ω - we will vary. The set will be used for observation $\omega = \left\{ \frac{\pi}{10}; \frac{\pi}{5}; \frac{\pi}{2}; \pi; 2\pi; 3\pi; 4\pi; 5\pi; 8\pi; 16\pi \right\}$.

The results of the study can be illustrated by the graphs below. On them: the light curve is the input action, the dark curve is the system's response to the given action.

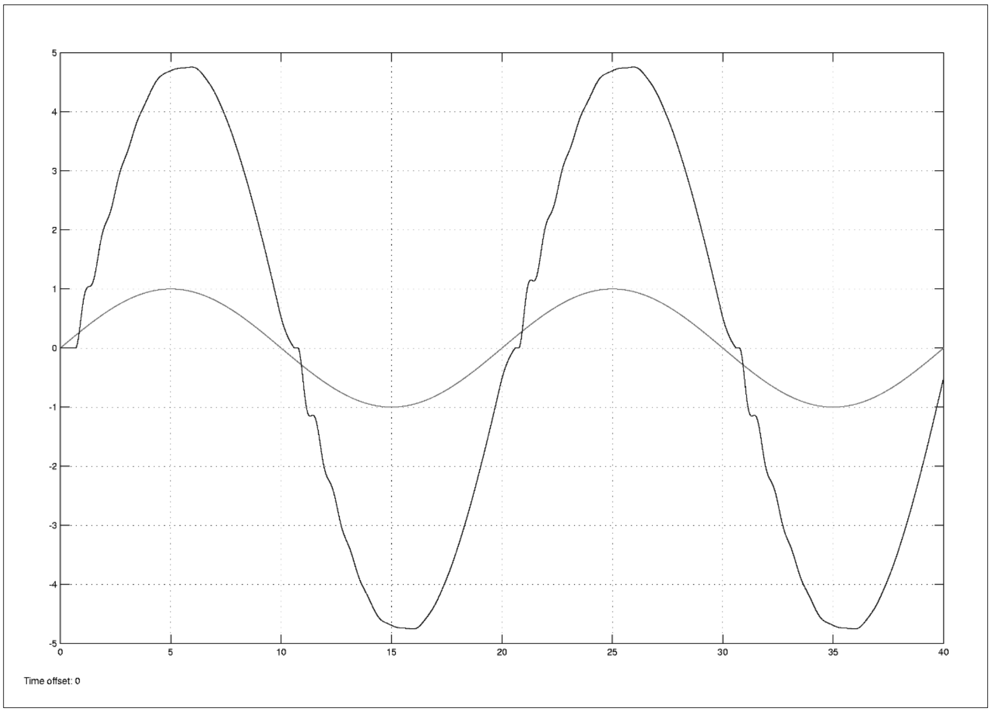

Fig 10: Input and output signals at $\omega = \frac{\pi}{10}$

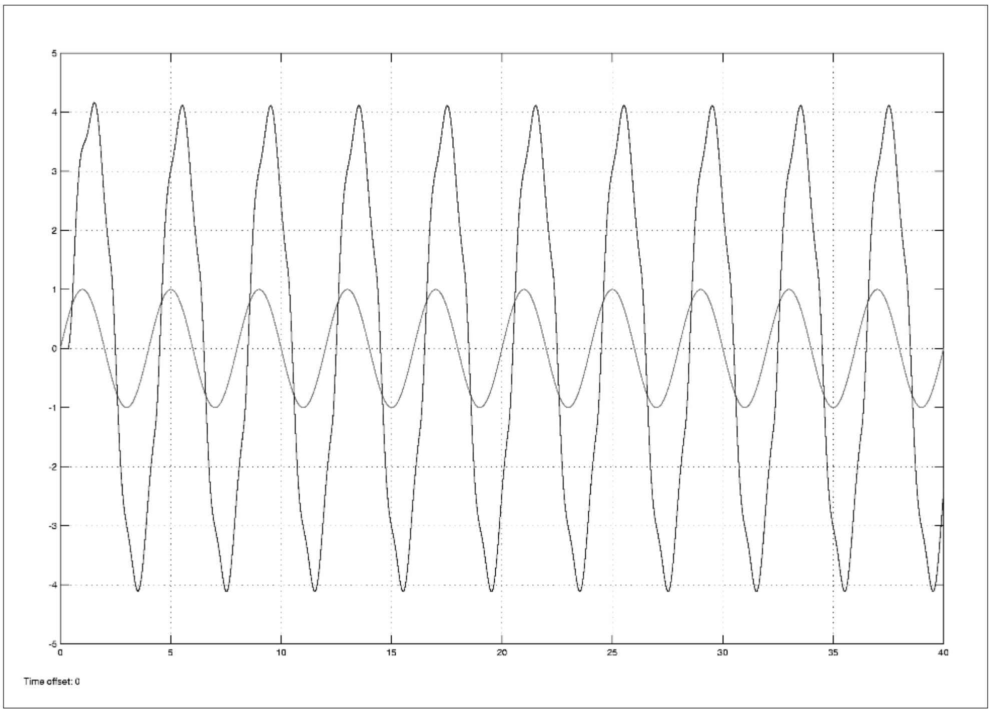

Fig 11: Input and output signals at $\omega = \frac{\pi}{2}$

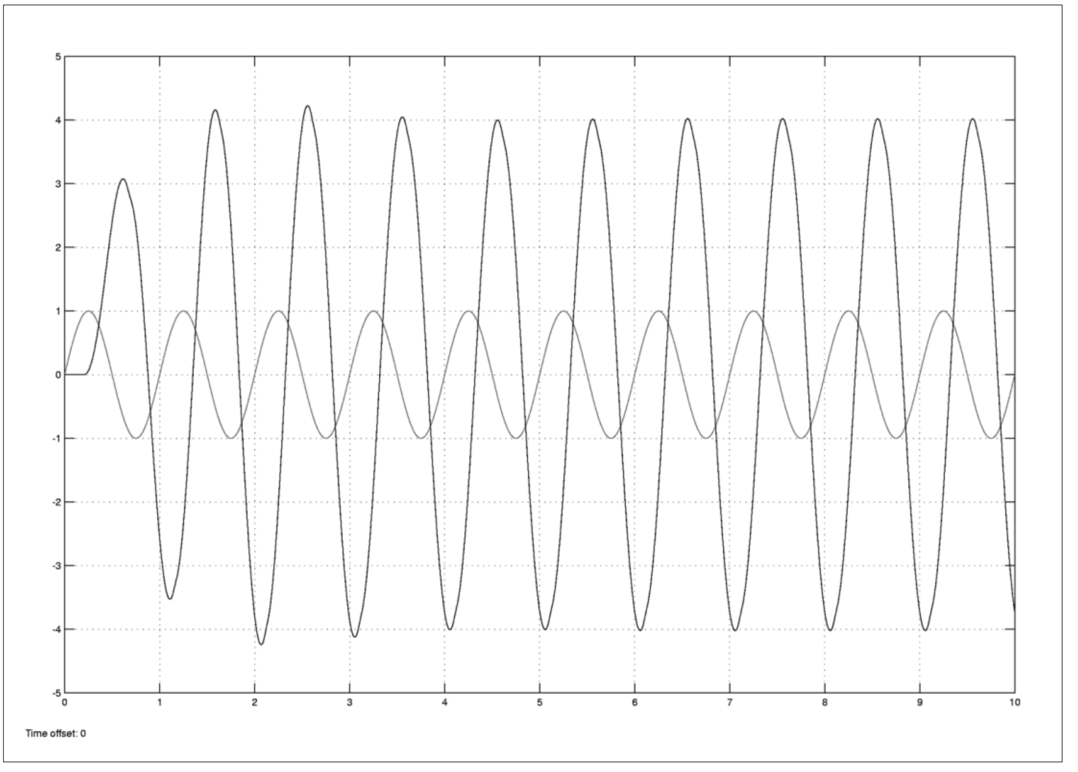

Fig 12: Input and output signals at $\omega = 2\pi$

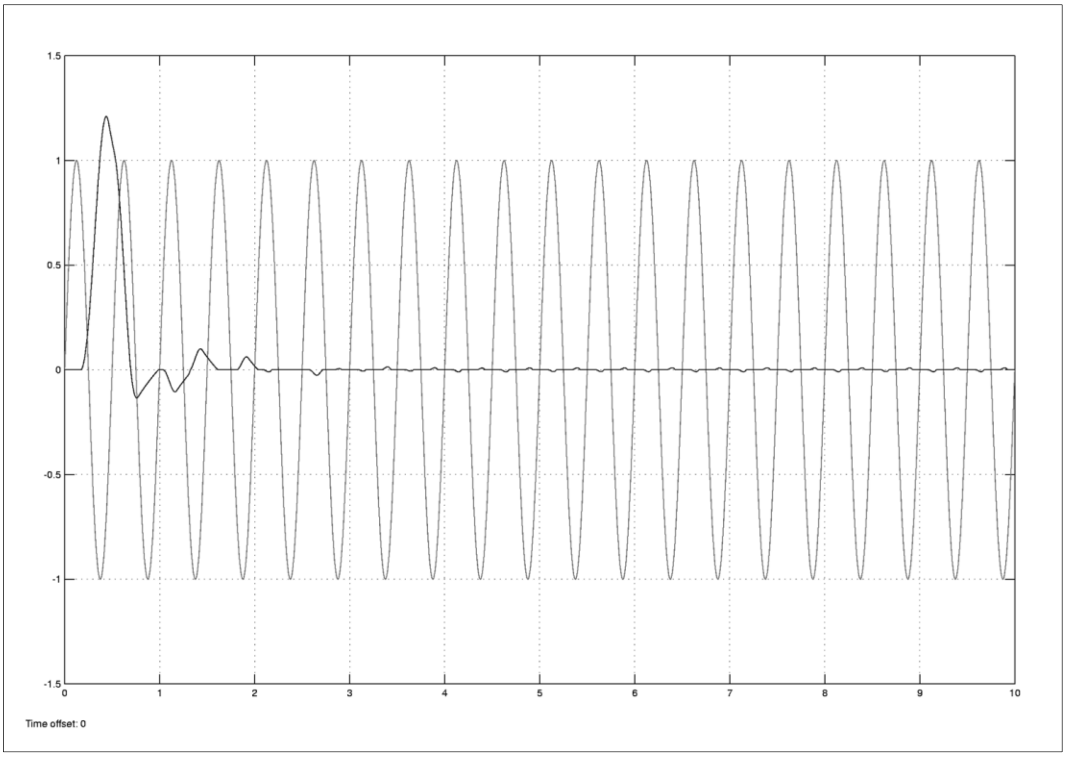

Fig 13: Input and output signals at $\omega = 4\pi$

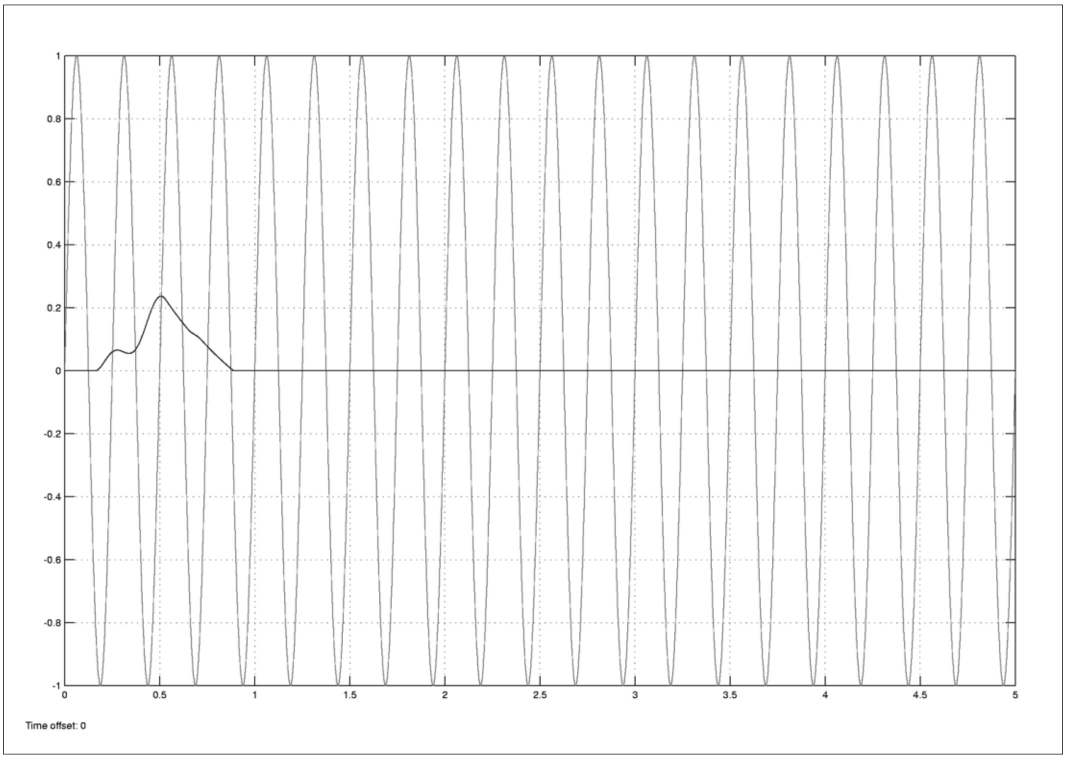

Fig 14: Input and output signals at $\omega = 8\pi$

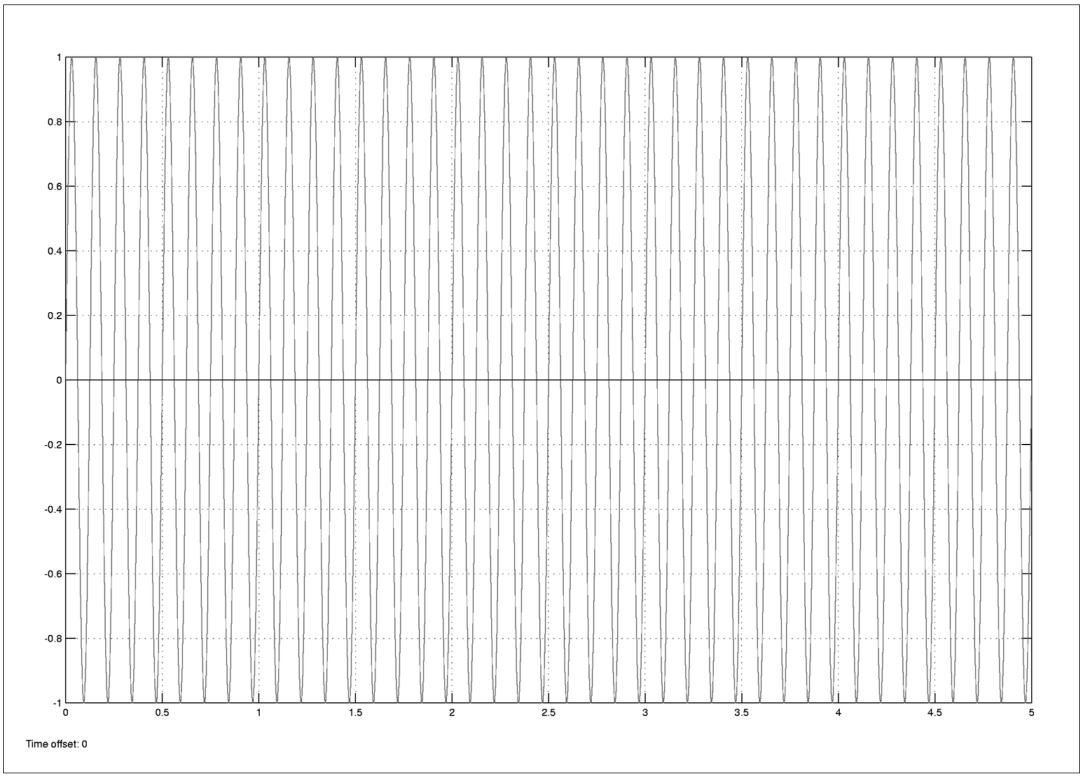

Fig 15: Input and output signals at $\omega = 16\pi$

It can be seen from the above graphs that in this system, at the first seven frequencies, the capture of forced oscillations of the frequency coinciding with the frequency of the input action is observed. At the last three frequencies from the considered set of oscillations, no oscillations are observed at the output of the system. At the last frequency from the set, the system output generally has a zero signal - the antenna is stationary.

Thus, in the considered nonlinear system, the capture of forced oscillations (for a given amplitude of the input signal) is observed at low frequencies. At a high frequency of the input action, a zero signal is observed at the output of the system.

4. Conclusions

In this work, we compared the performance of two models of a real system, linear and non-linear. To simulate the processes occurring in both systems, the Simulink software package was used. Based on the results of the research, it can be concluded that a linear system is only an approximation to a real object and in fact allows you to reproduce only a small part of the effects that take place in a real nonlinear system.

Thus, taking into account the specifics of the scope of the physical object under consideration - a mobile radar antenna, it should be noted that taking into account nonlinear effects is extremely important when designing such objects. This is due to the fact that this system is prone to self-oscillations, the appearance of which can adversely affect the quality of the final product. It is also important to take into account nonlinearities when considering the mode in which the control signal is a harmonic function (sinusoidal signal), since oscillation capture phenomena take place in a nonlinear system. In addition, when a sinusoidal signal is applied to the input, the movement of the rotor (antenna) in a non-linear system will be described by a law other than harmonic, which, of course, can affect the quality of the final signal received using a radar antenna.

5. Conflicts of Interest

The author declare no conflict of interest.

6. References

1. Pervozvansky A. A Course in the Theory of Automatic Control. Moscow: Nauka; c2016.
2. Dorf RK, Bishop RH. Modern Control Systems. Moscow: Laboratory of Basic Knowledge; c2014.
3. Nguyen H-D, Huang S-C. The uniaxial stress-strain relationship of hyperelastic material models of rubber cracks in the platens of papermaking machines based on nonlinear strain and stress measurements with the finite element method. Materials. 2021;14(24):7534.
4. Nguyen H-D, Huang S-C. Designing and calculating the nonlinear elastic characteristic of longitudinal–transverse transducers of an ultrasonic medical instrument based on the method of successive loadings. Materials. 2022;15(11):4002.
5. Nguyen H-D, Huang S-C. Using the extended finite element method to integrate the level-set method to simulate the stress concentration factor at the circular holes near the material boundary of a functionally-graded material plate. Journal of Materials Research and Technology. 2022;21C:4658-73.
6. Nguyen H-D. Use of XTFEM based on the consecutive interpolation procedure of quadrilateral element to calculate J-integral and SIFs of an FGM plate. Theoretical & Applied Mechanics Letters. 2023;127:103985.