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Calculation of parameters of control induction support

***Abstract**. Control induction supports are widely used in the automation of technological processes for measuring the created mechanical forces, determining the mass and movement of working mechanisms, as well as for automatically controlling the movement and maintaining a certain vertical position of the working mechanism. In all cases, increasing the range of the electromagnetic lifting force created by the support is the primary scientific and technical problem and the purpose of the presented work. Theoretical methods of electromagnetic lifting induction support for steady state are investigated. The development of a calculation methodology and methods for expanding the range of forces of an induction support reflects the novelty of the work.*

Streszczenie.** Sterowanie podporami indukcyjnymi znajduje szerokie zastosowanie w automatyzacji procesów technologicznych do pomiaru powstających sił mechanicznych, określenia masy i ruchu mechanizmów roboczych, a także do automatycznego sterowania ruchem i utrzymywania określonego położenia pionowego mechanizmu roboczego.We wszystkich przypadkach Podstawowym problemem naukowo-technicznym i celem prezentowanej pracy jest zwiększenie zasięgu elektromagnetycznej siły nośnej wytwarzanej przez podporę. Badano teoretyczne metody elektromagnetycznego wspomagania indukcji podnoszenia dla stanu ustalonego. Opracowanie metodologii obliczeń i metod poszerzania zakresu sił podpory indukcyjnej odzwierciedla nowość pracy.* (Obliczanie parametrów wspomagania indukcji*** sterującej)

Key words: induction support, control, electromagnetic force, lifting force, range, working mechanism, movement, vertical position.
Słowa kluczowe: wsparcie indukcyjne, sterowanie, siła elektromagnetyczna, siła podnoszenia, zasięg, mechanizm roboczy, ruch, położenie pionowe.

Introduction

The research method of the presented work is theoretical methods for studying the electromagnetic force of an induction support for a steady state. The development of a calculation methodology, as well as methods for expanding the range of forces of an induction support, reflects the characteristic features of the work and novelty. The main objectives are the development and research of functional dependencies, restrictions on parameters and dimensions, structures, magnetic system and structural diagram of the induction support; determination of optimal size values; calculation of the influence of thermal processes on the main parameters [1-20]. The induction support consists of a force transducer, a levitation element of the excitation winding and a load. The external force acting on the force converter pushes down the levitation element, as a result of which the levitation height *h* decreases. The levitation height *h* is the distance between the levitation element and the excitation winding. Therefore, the force acting on the levitation element *P* with a decrease in the levitation height *h* reduces the inductive resistance of the excitation winding $x_1=\omega L_1$ and increases the current flowing through the excitation winding I_1. Due to the magnetic coupling between the field winding and the load, the current I_{load} flowing through the load Z_{load} also increases. According to the levitation condition:

(1) $$P + P_{gravity} = F_e$$

Where $P_{gravity}$ and F_e –respectively, the force of gravity of the levitation element and the electromagnetic force acting on the levitation element.

Since the load is placed at the bottom of the field winding, therefore, the currents flowing through the field winding and the load are determined through the magnetic interconnections of these windings [15-18]:

(2) $$I_1(h) = \frac{k_u U_1}{\omega L_1(h)}$$

(3) $$I_{load} = k_{12} I_1(h)$$

Methods for increasing the force range from a theoretical point of view contribute to the development of induction supports. From a practical point of view, the results obtained, used in the automation of technological processes, provide control of the vertical movement of the working mechanism, as well as taking measurements. According to the expressions for electromagnetic force and current, we can write [1-7]:

(4) $$F_e = \frac{1}{2}\lambda\left(I_1 W_1\right)^2$$

(5) $$I_1 = \frac{k_u U_1}{x_1} = \frac{k_u U_1}{\omega\lambda\left(h_{12} + x_p\right)W_1^2}$$

Hence the inductive reactance:

(6) $$x_1 = \omega L_1 = \omega\lambda\left(h_{12} + x_p\right)W_1^2,$$

where x_p - working stroke, h_{12}- equivalent height.

(7) $$h_{12} = \frac{1}{3}\left(h_1 + h_2\right)$$

h_{12} is determined by the height of the excitation and levitation windings.

(8) $$I_2 = b_2 I_1 \frac{W_1}{W_2} = \frac{b_2 k_u U_1}{W_1 W_2 \omega\lambda\left(h_{12} + x_p\right)},$$

here $k_u \approx 0.96 \div 0.98$; $b_2 \approx 0.97 \div 0.98$.

According to expressions (4) and (5), for the electromagnetic force we can write [17-19]:

(9) $$F_e = \frac{\left(k_u U_1\right)^2}{2\lambda\left(\omega W_1\right)^2\left(h_{12} + x_p\right)^2}$$

Based on the obtained mathematical expressions, it is possible to determine ways to increase the force values: increasing the voltage at the terminals of the field winding U_1, decreasing the frequency ω, the working stroke x_p, the equivalent height h_{12}, the number of turns of the field winding W_1, the specific magnetic conductivity of the working air gap λ [8-16].

Statement and solution of the problem..

Calculation of functional dependencies of electromag thread force $F_e(x_p;W)$ is carried out according to expression (9).The initial data are: U_1=220V; k_u=0.96; λ=9.09×10^{-6} Hn/m.;h_1=40×10^{-3}m.; h_2=80×10^{-3}m.; c_2=20×10^{-3}m.; Δ_2=2×10^{-3}m.;c=22×10^{-3}m.;$n_{e2}=h_2/c_2$=4;h_{12}=(20+40)/3;x_p=(10÷40)×10^{-3}m.; W_1=500÷800.

Variant 1: W_1=800

$$x_p = 16\times10^{-3}\,m;\ x = h_{12} + x_p = (20+16)\times10^{-3} = 36\times10^{-3}\,m.$$

According to the formula (9):

$$F_e = \frac{(0.96\times220)^2}{2\times9.09\times10^{-6}\times314^2\times(20+16)\times10^{-6}\times0.64\times10^6} = 30\,N.$$

In general, the $F_e(x_p;W)$ dependence can be written as:

(10) $$F_e = \frac{24884.828}{X^2\times Y^2}$$

Where $X^2 = \left(h_{12}+x_p\right)^2 = (20+16)^2 = 36^2;$

$$Y^2 = W^2\times10^{-6} = 800^2\times10^{-6} = 0.64$$

Variant 2: W_1=800

$$X^2 = \left(h_{12}+x_p\right)^2 = (20+20)^2 = 40^2;$$

$$Y^2 = W^2\times10^{-6} = 800^2\times10^{-6} = 0.64$$

According to (10) we calculate:

$$F_e = \frac{24884.828}{40^2\times0.64} = 24.3\,N.$$

Variant 3: W_1=500

$$X^2 = \left(h_{12}+x_p\right)^2 = (20+20)^2 = 40^2;$$

$$Y^2 = W^2\times10^{-6} = 500^2\times10^{-6} = 0.25$$

According to (10) we calculate:

$$F_e = \frac{24884.828}{40^2\times0.25} = 62.212\,N.$$

Variant 4: W_1=500

$$X^2 = \left(h_{12}+x_p\right)^2 = (20+16)^2 = 36^2;$$

$$Y^2 = W^2\times10^{-6} = 500^2\times10^{-6} = 0.25$$

According to (10) we calculate:

$$F_e = \frac{24884.828}{36^2\times0.25} = 76.805\,N.$$

Variant 5: W_1=500

$$X^2 = \left(h_{12}+x_p\right)^2 = (20+10)^2 = 30^2;$$

$$Y^2 = W^2\times10^{-6} = 500^2\times10^{-6} = 0.25$$

According to (10) we calculate:

$$F_e = \frac{24884.828}{30^2\times0.25} = 110.599\,N.$$

Variant 6: W_1=800

$$X^2 = \left(h_{12}+x_p\right)^2 = (20+10)^2 = 30^2;$$

$$Y^2 = W^2\times10^{-6} = 800^2\times10^{-6} = 0.64$$

According to (10) we calculate:

$$F_e = \frac{24884.828}{30^2\times0.6425} = 43.202\,N.$$

The calculation results are shown in Table 1, and the dependency graphs in Fig. 1. Based on the above, to increase the range, the electromagnet greater effort, it is necessary to increase the number of turns W_1 and the working stroke of the x_p.

Table 1. Dependency values *F(X;Y)*

y(x)	30	32	34	36	38	40
500	39.816	36.812	34.136	31.741	29.590	27.650
600	27.650	25.564	23.705	22.042	20.548	19.201
700	20.314	18.782	17.416	16.194	15.097	14.107
800	15.553	14.380	13.334	12.399	11.558	10.801

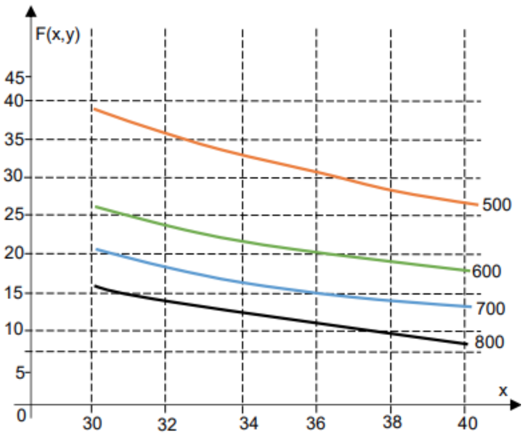

Fig 1. Dependency graphs *F(X;Y)*

As a result of the analysis of methods for increasing the range of electromagnetic force, it was found that by regulating the network voltage, the range of force can be expanded within a wide range. In this case, it is also necessary to take into account thermal conductivity, impact force, magnetization characteristics, temperature rises, ratios of sizes and parameters, and the thickness of the levitation element. The optimal dimensions of the controlled induction support are determined by the overheating temperature of the windings (excitation and levitation), as well as magnetic losses in the steel core. For this purpose, a method for calculating the magnetic system has also been developed, which will be presented in subsequent works. Determining the overall dimensions of the support ensures a reduction in the working air gap and dimensionless aspect ratio coefficients. The dependence of the gain on the permissible overheating temperatures [17-20] is also observed.

Conclusions

Development and research of functional dependencies of electromagnetic forces, restrictions on parameters and dimensions, design features and structural diagrams of a control induction support are a primary task. Along with the above, we also determine the optimal size values and calculate the influence of the heating process on the main parameters.

The theoretical and practical significance of the work comes down to methods for increasing the range of forces, which in turn makes it possible to develop induction supports. The application of the obtained results in the automation of technological processes ensures control of the vertical movement of working mechanisms, as well as carrying out measurements with a support.

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