Estimation of the influence of variations in the dimensional parameters car's generator active zone set of a on its technical characteristics, through elasticity coefficients (influences)

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Abstract the active zone of an electromechanical transducer (ET) contains several tens of geometrical parameters, each of which has a definite influence on the technical characteristics of the generator. When building a computer model, it is impossible to reflect the influence of each single input parameter on the output. Therefore, we propose to introduce a quantitative assessment of the influence of variations in all the geometric parameters of the active zone of an electromechanical transducer on the electromagnetic parameters of technical characteristics, and then select the most significant ones.

Keywords: active zone, car's generator, elasticity coefficient, influences, electromagnetic

1. Introduction

The active zone of the generator consists of a group of dimensional parameters (Figure 1): the outer diameter of the rotor \( D_p \); bore diameter \( D_i \); sleeve diameter \( D_{vt} \); ring height \( h_k \); inner diameter of the pole system \( D_m \); barrel length \( l_{vt} \); pole length \( l_p \); the length of the bevel of the shank of the pole \( l_{пц} \); outer diameter of the coil \( D_k \); The outer diameter of the stator \( D_n \); length stator bore \( l_i \); the width of the bottom of the groove \( b_z \); slot width on the stator's surface \( b_{sh} \); stator tooth height \( h_z \); the gap at the junction \( l_{st} \); slot height \( h_{sh} \); groove size \( h_1 \); slot size \( h_2 \); the diameter of the rounding of the groove on the surface \( a_1 \).

Each of the listed parameters has a definite influence on the formation of the electromagnetic characteristics of the ET. However, not all of them have the same weightage. Some parameters of the ET have a significant impact, while others are less noticeable. [1-3]

A special group of dimensional parameters is determined when calculating the influence coefficients on the basis of the electromagnetic calculation of a three-phase synchronous generator with a beak-shaped rotor. As the operating characteristics of the generator, no-load characteristic (NLC), current-speed characteristic (CSC) is considered.

![Figure 1](image-url) Dimensional parameters of the active part of the ET
a) the size of the magnetic system;
b) the size of the groove of the stator.

2. Research and calculations

The interrelationship between input and output parameters in general can be described by the following expression

\[ y_i = f(x_1, \ldots, x_j), \quad (1) \]

where \( y_i \) – output parameter; \( x_j \) - input parameter.

For a function of several variables, provided it is differentiable by the formula of the total differential, we can write

\[ dy_i = \frac{\partial y_i}{\partial x_1} dx_1 + \frac{\partial y_i}{\partial x_2} dx_2 + \ldots + \frac{\partial y_i}{\partial x_j} dx_j, \quad (2) \]

Passing from differentials to finite increments under the condition of smallness of the latter, we obtain the equation for the absolute error (3) of the output parameter and for the ratio error (4).

\[ \Delta y_i = \sum_{j=1}^{m} \frac{\partial f(x_1, \ldots, x_j)}{\partial x_j} \Delta x_j, \quad (3) \]

\[ \frac{\Delta y_i}{y_i} = \sum_{j=1}^{m} \frac{\partial f(x_1, \ldots, x_j)}{\partial x_j} \cdot \frac{x_j}{f(x_1, \ldots, x_j)} \cdot \frac{\Delta x_j}{x_j}, \quad (4) \]

The expressions that establish the interrelationship between the errors of the input and output parameters in the theory of accuracy are called the equations of error.

The coefficients of the equations facing the errors of the input parameters and determining the degree of influence of these errors on the errors of the output parameters are called influence coefficients.

The accuracy of the output parameters will be described by a system of l error equations, where l is the number of output parameters involved in the consideration. These equations are the source for the analysis of technological errors and the calculation of tolerances. On their basis, it is possible to calculate the deviations of the output parameter by the given deviations of the input parameter — a direct problem, and the calculation of the tolerances of the deviations of the input parameters by a given tolerance on the output — an inverse problem.

From the expression (4) it follows that the reduction in the spread of the output parameter can be achieved in two ways: by reducing the spread of the input parameters, by varying the coefficients of influence.

The relative coefficient of influence of the \( j \)-th input parameter on the \( i \)-th output can be determined analytically

\[ c_{yi} = \frac{\partial f_i(x_1, \ldots, x_j)}{\partial x_j} \cdot \frac{x_j}{f_i(x_1, \ldots, x_j)}, \quad (5) \]

Substituting into the expression (5) the calculated nominal values of the parameters, we obtain the numerical value of this coefficient of influence.

In order to provide an objective and most complete analysis, we subdivide the calculation stages: the magnetic conductivity of the interpolar scattering \( G_{\sigma p} \); magnetic conductivity of the stray field across the stator sheets \( G_{\sigma s} \); magnetic conductivity of external scattering \( G_{\sigma u} \); the magnetic conductivity of the scattering of the excitation coil \( G_{\sigma k} \); axial scattering magnetic conductivity \( G_{\sigma a} \); magnetic voltage of the air gap \( F_{\delta} \); magnetic voltage of the stator teeth \( F_z \); magnetic voltage of the stator yoke \( F_j \); magnetic stator voltage \( U_{11} \); magnetic stress of the scattering surfaces \( U_{14} \); magnetic bending stress of the sleeve \( F_{ivrt} \); magnetic voltage joint \( F_{st} \); magnetic voltage of the \( F_{vt} \) sleeve; the total magnetizing force of the excitation winding \( F_v \); inductive resistance to phase dissipation of the stator winding \( X_{s} \); load current at a given frequency of rotation of the rotor \( I_d(n) \).
The output of analytical expressions for calculating the influence coefficients is organized on the basis of a group of mathematical programs written in the MathLab environment. The algorithm of the programs is shown in Figure 2. Entering the numerical values of the input dimensional parameters is carried out directly into the program window. The program determines the analytical dependencies of one or several output parameters on the input \((f(x_i))\) group. In the cycle, the obtained dependences are differentiated for each considered dimensional parameter \((df(x_j))\) and an expression is determined for calculating the influence coefficients. [9-12]

![Figure 2](image)

**Figure 2**  Algorithm of the program that calculates the influence coefficient

The last operation of the program for calculating the influence coefficients is the calculation of the numerical values of the influence coefficients \((c_j)\). The coefficients are displayed on the working screen in the form of arrays.

The numerical values of the coefficients of the influence of the input parameters on the scattering conductivity of the rotor (Figure 3) are presented in Table 1.

| Input parameters | \(G_\sigma p\) | \(G_\sigma i\) | \(G_\sigma vn\) | \(G_\sigma k\) | \(G_\sigma a\) |
|------------------|---------------|---------------|---------------|---------------|---------------|
| \(D_p\)          | 0.195         | 14.93         | 1.36          | 0             | 0             |
| \(D_i\)          | 0             | -14.14        | 0             | 0             | 0             |
| \(D_{vt}\)       | 0             | 0             | -1.608        | 0             | 0             |
| \(h_k\)          | 0             | 0             | -0.157        | 0             | 0             |
| \(D_m\)          | 0             | 0             | 0             | -2.68         | -1            |
| \(l_{vt}\)       | 0             | 0             | -0.207        | -1            | -1            |
| \(l_p\)          | 0.804         | 0.189         | 0             | 0             | 0             |
| \(l_{rc}\)       | 0             | 0.0206        | 0             | 0             | 0             |
| \(D_k\)          | 0             | 0             | 3.608         | -22.66        | -22.66        |

The calculation of the numerical values of the coefficients of the influence of the input parameters on the scattering conductivity of the rotor showed that:

- the stator bore diameter and outer diameter of the rotor have the greatest influence on the formation of the magnetic conductivity of the stray field across the stator sheets, the effect of these parameters is approximately the same and opposite in sign;
- the magnitude of the magnetic conductivity of the scattering of the excitation coil is most influenced by the diameter of the excitation coil and the internal diameter of the pole system;
Dk and Dm have the largest numerical and opposite in sign values of the coefficients of influence, calculated relative to the magnetic conductivity of axially scattering.

Figure 3  Rotor Scattering Flows

The calculation of the coefficients of the influence of the group of input parameters on the magnetic voltages of the circuit and the total magnetizing force was carried out at a phase voltage \( U_{f0} = 6.43 \) V, \( n = 1100 \text{ min}^{-1} \). In this case, the calculations require the use of magnetization curves for the steels from which the stator and rotor packs are made. The magnetization curves are approximated by the least squares method. [13-17]

The numerical values of the influence factors of the input dimensional parameters on the magnetic stresses of the gap, the tooth and the stator yoke are presented in Table 2.

Table 2.  The influence coefficients of dimensional parameters of the active zone of the ET on the magnetic stresses of the gap, the tooth and the yoke of the stator

| Input parameters | \( F_\delta \) | \( F_z \) | \( F_j \) |
|------------------|-------------|-------------|-------------|
| Dn               | 0           | 0           | -17,367     |
| Dp               | -111.78     | 0           | 0           |
| Di               | 112.68      | 0           | 13,321      |
| li               | -1          | -1,599      | -1,468      |
| bz               | 0           | -1,599      | 0           |
| bsh              | 0.368       | 0           | 0           |
| hz               | 0           | 1           | 3,577       |

According to the results of the calculation of the coefficients of influence of dimensional parameters on the magnetic voltage of the working air gap, the tooth and the yoke of the stator, it can be noted that:

- the size of the magnetic voltage of the air gap is determined by the outer diameter of the rotor and the diameter of the stator bore, these parameters determine the size of the air gap between the rotor and the stator;
- the magnitude of the magnitude of the magnetic voltage of the stator yoke is most influenced by the outer diameter and diameter of the stator bore.

The stator diameter and outer diameter of the rotor have the most significant influence on the magnetic voltage of the air gap. These parameters form the working air gap. Their influence on the magnetic voltage is opposite, as with increasing \( D_p \), with a constant value of all other parameters, the value of \( F_\delta \) decreases, and with increasing \( D_0 \), the magnetic voltage of the air gap increases.

The equal value of the coefficients of influence of \( l_i, b_z \) on the magnetic voltage of the stator teeth is characteristic. The greatest influence on the magnetic voltage of the yoke of the stator has its outer diameter.

Table 3 presents the coefficients of the influence of the magnetic voltage of the gap, the tooth and the yoke of the stator on the magnetic voltage of the stator (\( U_{11} \)).
From the analysis of the data in Table 3, it can be concluded that the magnetic voltage of the air gap is decisive in the formation of the magnetic stator voltage.

The inner diameter of the pole system ($D_m$) and the outer diameter of the rotor ($D_p$) have the largest opposite coefficients calculated for the magnetic voltage of the scattering surfaces ($U_{44}$). These parameters are also characterized by the highest values of the coefficients calculated relative to the magnetic bending stress of the sleeve ($F_{vt}$), the joint ($F_{st}$) and the sleeve ($F_{vt}$) (table 4).

| Intermediate parameters | U11  |
|-------------------------|------|
| $F_8$                   | 0.938|
| $F_z$                   | 0.029|
| $F_j$                   | 0.0325|

Table 3. The influence coefficients of the magnetic voltage of the gap, the tooth and the yoke of the stator on the magnetic voltage of the stator

The calculation of the influence coefficients of intermediate parameters on the total magnetizing force showed that the greatest contribution to the formation of $F_v$ is made by the magnetic voltage of the scattering surfaces and the magnetic voltage of the sleeve.

Using the numerical values of the coefficients of influence of intermediate values calculated for the total magnetizing force of the excitation winding (table 5), we single out a special group of input dimensional parameters that significantly affect the NLC: rotor diameter, inner diameter of the pole system, sleeve length, bushing diameter, stator bore diameter joint clearance.

| Input and intermediate parameters | U44  | Fizvt | Fst  | Fvt  |
|---------------------------------|------|-------|------|------|
| U11                             | 0.801| 1.001 | 0.499| 0.768|
| $F_t$                           | 0.363| 0.3902| 0.194| 1.299|
| $G_\sigma$                      | 0.429| 0.601 | 0.3033| 0.461|
| $D_p$                           | -4.571| -5.009| -2.5002| -3.844|
| $D_m$                           | 4.602| 4.392 | 2.192 | 3.37  |
| $h_k$                           | -0.962| -1.041| -0.262| -0.403|
| $G_\sigma$                      | 0.279| 0.505 | 0.252 | 0.387  |
| $D_vt$                          | -1.332| -3.186| -2.346| -3.607|
| $G_\sigma_v$                    | 0.032| 0.0843| 0.042 | 0.0647 |
| $G_\sigma_k$                    | 0    | 0.508 | 0.253 | 0.3904|
| $G_\sigma_a$                    | 0    | 0.012 | 0.00603| 0.00927|
| $F_{st}$                        | 1    |       |       |       |
| $F_{vt}$                        | 0    |       |       |       |

Table 4. The influence coefficients of dimensional parameters of the core of the ET, the conductivity of the scattering of the rotor, the magnetic stator voltage on the magnetic stresses of the scattering surfaces, bending of the sleeve, the joint and the sleeve

The calculation of the influence coefficients of intermediate parameters on the total magnetizing force showed that the greatest contribution to the formation of $F_v$ is made by the magnetic voltage of the scattering surfaces and the magnetic voltage of the sleeve.

Using the numerical values of the coefficients of influence of intermediate values calculated for the total magnetizing force of the excitation winding (table 5), we single out a special group of input dimensional parameters that significantly affect the NLC: rotor diameter, inner diameter of the pole system, sleeve length, bushing diameter, stator bore diameter joint clearance.

Table 5. The influence coefficients of magnetic stresses of the scattering surfaces, the bending of the sleeve, the joint, the sleeve on the total magnetizing force of the excitation winding

| Intermediate parameters | $F_v$ |
|-------------------------|-------|
| U44                     | 0.42  |
| Fizvt                   | 0.027 |
| Fst                     | 0.0509|
| Fvt                     | 0.5   |

Table 6. The influence coefficients of input parameters on CSC. The calculated values of the influence coefficients of the group of dimensional parameters on the inductive resistance of the phase dissipation of the stator winding are presented in Table 6.
Table 6. The influence coefficients of dimensional parameters of the active zone of the ET on the inductive resistance of the phase of the stator winding

| Input parameters | Xs   |
|------------------|------|
| Dp               | 28.96|
| Di               | -29.2|
| li               | 0.747|
| bsh              | -0.093|
| lal              | 0.347|
| h1               | 0.192|
| h2               | 0.156|
| a1               | -0.39 |
| hsh              | 0.091|

From the data analysis of table 6, it should be noted that the largest numerical values of the influence coefficients on the inductive impedance of the stator winding phase have dimensional parameters - Dp and Di.

The influence coefficients of the inductive resistance of the phase dissipation of the stator winding and the total magnetizing force of the excitation winding on the electrochemical capacity at a given frequency of rotation are opposite in sign, approximately equal in absolute value (Table 7). This means that a rising in Xs decreases, and a rising in Fb increases the generator’s electrochemical capacity at a given rotor revolution rate almost equally.

Table 7. The influence coefficients of the inductive resistance of the stator winding phase and the total magnetizing force of the excitation winding on the generator electrochemical capacity

| Intermediate parameters | Id(n) |
|-------------------------|-------|
| Xs                      | 0.418 |
| Fv                      | -0.393|

Table 8. Tendencies of influence of dimensional parameters of the core of the ET on the generator electrochemical capacity

| Dimension parameter | Parameter change | Tendency              |
|---------------------|------------------|-----------------------|
| Interface gap (1st) | Increase         |                       |
| Rotor outside diameter (Dp) | Decrease     |                       |
| Stator bore diameter (Di)  | Increase       |                       |
| Internal diameter of the pole system (Dm) | Increase | Decrease of electrochemical capacity |
| Bushing diameter (Dvt)    | Decrease        |                       |
| Bushing length (lvt)      | Increase        |                       |
| Stator bore length (li)   | Decrease        |                       |
| Interface gap (1st)       | Decrease        |                       |

The group of input dimensional parameters that determine the formation of the NLC and CSC generator is as follows: outer diameter of the rotor, internal diameter of the stator bore, length of the stator package, internal diameter of the pole system, sleeve length, sleeve diameter, gap in the joint.

Table 8 shows the trends in the influence of the selected group of dimensional parameters on the generator electrochemical capacity in the design mode of operation.
Conclusion

In the article, we proposed to introduce a quantitative assessment of the effect of variations of all geometric parameters of the active zone of the electromechanical converter on the electromagnetic parameters of technical characteristics to select the most significant. This will help to choose the most significant geometric parameters when building a computer model.

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