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Complex Predict Fault Diagnostics of Electromagnetic Actuators Based on the Principle Component Analyses

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Abstract: The study describes a method of complex predict diagnosis of electromagnetic actuators based on their magnetic flux-current characteristics. Principle Component Analyses (PCA) is used as a diagnostic algorithm, it allows to reduce the source data dimension. Particular defect of the electromagnetic actuator is assessed by accumulation of points in a certain region of space. To predict possible failures of investigated actuators regression model is used.

Key words: Electromagnetic actuators, flux-current characteristics of the operating cycle, predict diagnostics, principle component analyses, diagnosis

INTRODUCTION

Fault diagnosis of electromagnetic actuators is important not only in the production of such devices (Shaykhutdinov *et al*., 2015) but also for their further use. To assess the state of the electromagnetic actuators are used a number of different approaches such as the analysis of the current characteristics or traction but the determination of the type of fault of a variety of one such characteristic often lacking.

We propose to use during diagnostic weber-ampere characteristic of the operating cycle of the electromagnetic actuators (Gorbatenko *et al*., 2015). This allows you to define an integral characteristic of the majority of faults without additional testing. As a mathematical basis for building a forecast diagnostic algorithm will use the main component analysis.

MATERIALS AND METHODS

Consider the essence of the method of main components (Ayvazyan, 1983) to determine the defects of electromagnetic actuators. Experimentally obtained sample composed of dots weber-ampere characteristics $X_j = \{x_1, x_2, ..., x_m\}$ at various defects are listed. We find the transformation of values X_j a new set of values $Z_i = \{z_1, z_2, ..., z_p\}$. Elements Z_i are polynomials consisting of m terms:

$$Z_1 = b_1x_1 + b_2x_2 + ... + b_mx_m \quad (1)$$

The first principal component for m = 2 may be written as:

$$Z_1 = \alpha_1x_1 + \alpha_2x_2 \quad (2)$$

where, α_1 and α_2 unknown. For j (j = 1, ..., n) sample can find the value of $h_j^2 = x_{1j}^2 + x_{2j}^2$ which can be defined through the main component:

$$h_j^2 = (b_1x_{1j} + b_2x_{2j})^2 + d_j^2 = z_{1j}^2 + d_j^2 \quad (3)$$

where, d_j random component corresponding to sample j, b_1 and b_2 estimates α_1 and α_2 which is found by minimizing the equation:

$$\sum_{j=1}^{n} d_j^2 = \sum_{j=1}^{n} [h_j^2 - (b_1x_{1j} + b_2x_{2j})^2] \quad (4)$$

It is imperative $b_1^2 + b_2^2 = 1$, representing the main component (Eq. 2) in the form:

$$Z_1 = \alpha_1(x_1 - \mu_1) + \alpha_2(x_2 - \mu_2) \quad (5)$$

where, μ_1 and μ_2 unknown true mean values of random variables x_1 and x_2. With regard to (Eq. 5), Eq. 4 has the form:

$$\sum_{j=1}^{n} d_j^2 = \sum_{j=1}^{n} \{h_j^2 - [b_1(x_{1j} - \bar{x}_1) + b_2(x_{2j} - \bar{x}_2)]^2 \quad (6)$$

where, $\bar{x}_1$ and $\bar{x}_2$ sample means x_1 and x_2:

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$$h_j^2 = (x_{1j}-\bar{x}_1)^2 + b_2(x_{2j}-\bar{x}_2)^2$$

The second main component: $Z_2 = \beta_1x_1+\beta_2x_2$ it is similar. Coefficients α and β must meet the following requirements:

$$\alpha_1^2 + \alpha_2^2 = 1, \beta_1^2 + \beta_2^2 = 1, \alpha_1\beta_1 + \alpha_2\beta_2 = 0$$

These conditions mean that vectors (α_1, α_2) and (β_1, β_2) orthogonal. In the case of m variable (m>2) is the main component:

$$Z_i = \sum_{j=1}^{n} b_{ij}x_i, i = 1,\ 2, ..., m; j = 1, 2, ..., n$$

Equation 6 takes the form:

$$\sum_{j=1}^{n} d_j^2 = \sum_{j=1}^{n}\sum_{i=1}^{m}(x_{ij}-x_i)^2-[\sum_{i=1}^{m} b_i(z_{ij}-\bar{x}_i)]^2 \text{ where, } \bar{x}_i = \frac{\sum_{j=1}^{n} x_{ij}}{n}$$

Ideally, the number of main components equal to the number of initial parameters but the processing of magnetic characteristics the first two main components describe over 80% of the variability of initial data and specifically in this case, 99.8%.

The result of the algorithms is a set of points in the new space of the main components. Moreover, may highlight certain groups of points, responsible for various defects electromagnetic actuators.

We propose to predict the occurrence of defects electromagnetic drive technique of adaptive regression diagnostics. Diagnostic algorithm is as follows:

- First, by repeated experiments to the normal operating state of the electromagnetic actuator without defects and with possible defects and according to the procedure described above define the coordinate system of the space of main components
- In accordance with the rules verify that the electro-magnetic actuator at times t_1 and t_2 are determined by the first two points of the space of main components with the coordinates $f_1 = (Z_{11}; Z_{21})$ and $f_2 = (Z_{21}; Z_{22})$
- In order to predict the next point, we use regression (n-1) extent at this stage is the linear regression type:

$$Z_{11} = k_0^{(Z_1)} + k_1^{(Z_1)}t_1, \qquad Z_{21} = k_0^{(Z_2)} + k_1^{(Z_2)}t_1$$
$$Z_{12} = k_0^{(Z_1)} + k_1^{(Z_1)}t_2, \qquad Z_{22} = k_0^{(Z_2)} + k_1^{(Z_2)}t_2$$

- Solving of item 3, we obtain the regression equation for the next projected point as:

$$Z_{13} = k_0^{(Z_1)} + k_1^{(Z_1)}t_3, \quad Z_{23} = k_0^{(Z_2)} + k_1^{(Z_2)}t_3$$

- Calculate the state of the electromagnetic actuator at time t_3. If the defect is not expected that upon the occurrence of time t_3 define the next point and compare with the forecast. If the deviation from the forecast of the result is immaterial, i.e., does not exceed the predetermined threshold then use the resulting model is the following steps. If the deviation of the result from the forecast significantly, it increases the degree of regression in the unit and re-organize the construction of a regression model of the form:

$$Z_{1n} = \sum_{1}^{n} k_{n-1}^{(Z_1)} \times t_n^{n-1}, \qquad Z_{2n} = \sum_{1}^{n} k_{n-1}^{(Z_2)} \times t_n^{n-1}$$

Thus, the new point of the space of main components regression procedure increases, in the case of an incorrect forecast which in turn improves the accuracy of prediction of future changes in the function $f(Z_1, Z_2)$ from state $f(Z_{11}, Z_{21})$ in $f(Z_{1n}, Z_{2n})$. Since, the function $f(Z_1, Z_2)$. It describes a high degree of reliability defects electromagnet applying the described algorithm will allow for the timely forecasting of faults.

RESULTS

A number of experiments were conducted using the method of main component analysis (Lawley and Maxwell, 1962), confirming a successful search for the required defect. The experiment was conducted using an apparatus CEC-03-MSM-50 (Shirokov *et al*., 2013) which allows to determine the weber-ampere characteristics of electromagnetic actuators. As an electromagnetic actuator used proportional electromagnet type KTS P25A00-24. For the selected electromagnet were investigated three defects sticking anchor in the initial position, incomplete operation and activated position. For the implementation of principal component package was used statistica 10 (Marques, 2003). Figure 1 shows the results of two similar studies of electromagnetic actuators EM1 and EM2 as a main component of the space obtained. The abscissa reflects the first main component values of x and the ordinate y-second for each sample.

Figure 1 shows that every defect is localized in a separate quadrant of the two-dimensional main component space where in the electromagnetic actuator

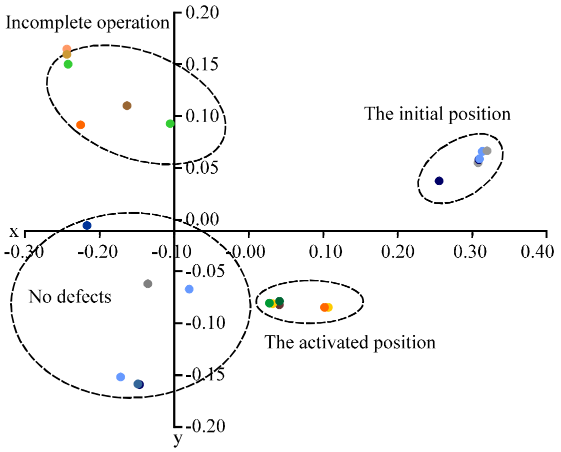

Fig. 1: Application method of main components for the EM1 and EM2

Table 1: Dependence coordinates of defects in the space of main components

Status of the electromagnetic actuator	The polarity of the first main component x	The polarity of the second main component y
No defects	-	-
The initial position	+	+
Incomplete operation	-	+
The activated position	+	-

without defects are located in the third quadrant. The advantage of this approach can be considered that each defect has its own marks of the axes in two-dimensional space (Table 1), i.e, sticking of the armature in the initial position ($Z_1>0$; $Z_2>0$), the incomplete operation ($Z_1<0$; $Z_2>0$), sticking of the armature in tripped position ($Z_1>0$; $Z_2<0$). This facilitates the search for defects and eliminates the need for constructing points in space during diagnosis.

DISCUSSION

The advantages of the proposed approach are: simplicity, speed, low hardware costs in forecasting, acceptable accuracy.

CONCLUSION

The advantage of this approach is not only the performance of diagnostic algorithms but also the ability to predict various malfunctions.

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