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Development of a Method of Technological Control Proportional Electromagnetic Actuators for Controlling the Process of Production

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Abstract: This study describes the algorithm and the results of the practical implementation of the method of process control proportional electromagnetic actuators to control their production process. method algorithm includes four items: the measurement of the dynamic characteristics of the magnetization of the electromagnetic actuator, reduction of the space dimension of input data using the selected projection method, carrying out the classification into groups of measured characteristics, determining the numerical values of the deviations from the norm of defective products with the selected method of calibration. This approach allows us to determine the type and degree of impairment of the mode of the process that will lead to effective management of the production process electromagnetic actuators.

Key words: Dynamic characteristic of the magnetization, the principal component analysis, a formal independent modeling of class analogies, regression to latent structures, process control, proportional electromagnetic actuator

INTRODUCTION

An important element in the process of production of proportional electromagnetic actuators is to identify deviations from the nominal mode of its occurrence. An urgent task is to develop a method for process control which allows to determine the place and the degree of deviation from the nominal values of the process conditions for further management. Currently, there are two common approaches to this task: rejection of articles on the “fit-unfit” by using checklists and rejection of products by comparing the measured electrical, magnetic, or mechanical energy with exemplary.

Control cards-a tool that allows you to track the progress of the process flow and work on it, preventing its deviation from the requirements to the process requirements. To control the output electromagnetic actuators are used multivariate Hotelling cards, cumulative amounts and exponentially weighted moving averages. If there is a violation of the manufacturing process of the signal must be identified and eliminated the cause of violations, however control cards do not allow this.

Another currently used method for the detection of a marriage is to compare the measured electrical, magnetic, or mechanical energy with exemplary performance during the final inspection. The main characteristics regulated by GOST (1988) are as follows:

- Static traction characteristics $F = f(\delta)$
- Dynamic traction characteristics $F_d = f(\delta)$
- The movement of anchor in time $\delta = f(t)$
- The current in the coil in time $i = f(t)$
- Heating and Cooling in time $\otimes = f(t)$
- The dependence of the magnetic flux from current $\Phi = f(i)$ for fixed values of the gap δ

MATERIALS AND METHODS

For process control these characteristics are not suitable and getting them, it is a long laborious process. This situation encourages the search for integral characteristics (Lankin *et al*., 2015a, b) that allow to obtain information for process control in a short (no >1-2 min) time.

In the study have shown that having a dynamic characteristic of the electromagnetic actuator of the magnetization (Fig. 1) can be calculated most of the characteristics of regulated GOST (Kovalev, 2001).

After the power supply, the current in the coil reaches a value of starting current I_{st} which corresponds to point 1. At that moment, the anchor is set in motion, during which the working gap δ decreases, the winding inductance increases and the current drops toit until the anchor is not attracted to the core which corresponds to point 2. During the movement of anchor flux linkage between ψ and current I is determined 1-2 curve. At the

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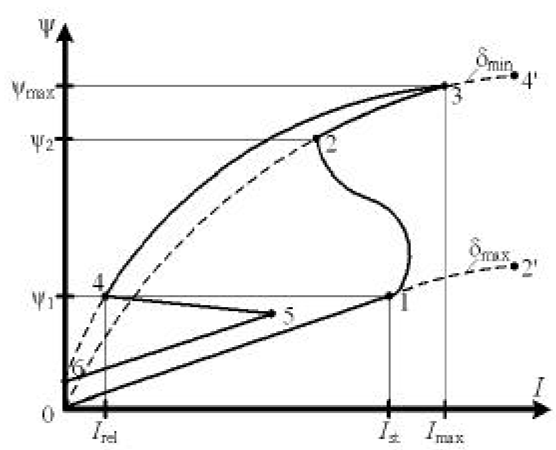

Fig. 1: The dynamic characteristic of the magnetization of the electromagnetic actuator

end of the motion anchor current starts to increase again, reaching a steady-state value at 3. After disconnecting the power supply of the electromagnet, the coil current falls and when the value of current release I_{rel} (Point 4), the anchor is set in motion and working air gap is increased from a minimum δ_{min} to maximum δ_{max}. 5 corresponds to the end point of the motion anchor. Further, the current drops to zero which corresponds to point 6. Because of the residual magnetization of the magnetic flux linkage, corresponding to point 6 above zero.

Kovalev (2001) shown how to determine the electromagnetic force of the dynamic characteristics of the magnetization. The force of attraction of the electromagnetic flux determined by the nature depending on the position of anchor and current in its windings depends on the type of the magnetization characteristics.

Slivinskaia discloses the preparation of temporal parameters of operation of the same characteristics. The response time of the electromagnets includes: pick-up time and travel time. Breakaway time $t_{br.aw}$ period of time from the filing of the pulse to the coil of the electromagnet to the start of the movement anchor. Moving time t_{mv} interval from the start of anchor movement up to a complete standstill.

Based on the foregoing, it can be concluded that the dynamic characteristic magnetization latent information comprises the majority of the electromagnetic drive parameters. Thus, it can be determined knowing the towing, the time and energy parameters, consequently the dynamic magnetization characteristic can be used as an integral characteristic of the electromagnetic actuator.

However, the dynamic characteristic of the magnetization of the electromagnetic actuator is difficult not unambiguous, making it difficult to analyze, so after determining it is necessary to reduce the dimension of the analyzed information (Shayhutdinov *et al*., 2015). Currently, this is done using projection methods based on the allocation of the principal component and allowing to reduce the dimensionality of the original data.

The essence of the method of principal component (Shayhkutdinov *et al*., 2015a, b) consists of a transition from the original variables to new values, the Principal Components (PC) which are linear combinations of the original variables with the maximum possible dispersion. In this first principal component has the maximum variance is normalized by a linear combination of all possible signs of starting and the second - takes into account the maximum value and the remaining correlation variance is not associated with the first component and so forth up to m (m-number of PC). For the implementation of the algorithm output control required (d+1) training sample products. Each sample contains the same type having q samples and one sample defects conditioned products.

In the first, preparatory stage, measurements q (d+1) the dynamic characteristics of the magnetization of the electromagnetic actuators and made their transformation into the space of the principal components. The result is (d+1) "cloud" of points that integrate products with the same type of defect d and one "cloud" of conditioned products.

In the second, the working stage, the measurement of the dynamic characteristics of the magnetization of the electromagnetic actuators in manufactured products and the conversion of these characteristics to the point in the r-dimensional space. As a result, we obtain the value of the principal component for the training sample and the test product which is produced by the values of further classification and identification of the type of marriage.

Figure 2 shows an example of the conversion of a number of dynamic characteristics of the magnetization electromagnetic actuators having various defects in the space of the principal components. The initial data were taken on 16 characteristics of each of the mechanical defects (defect of the spring, smaller initial gap and clogging of the surface of the anchor), 16 specifications without defects and a characteristic of a closed loop faults.

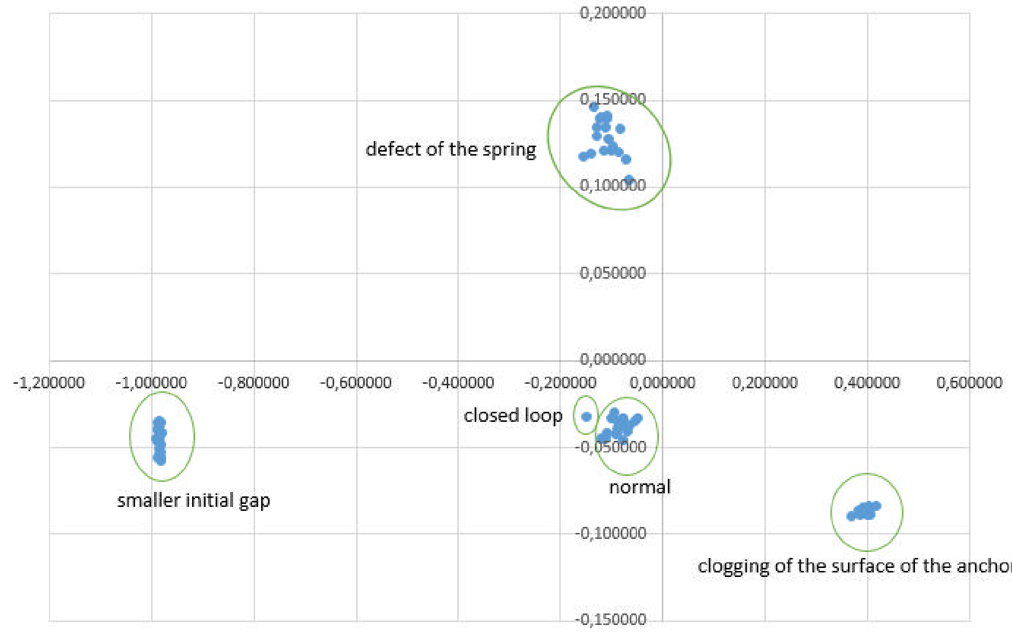

Fig. 2: The dynamic characteristics of the magnetization in the space of two principal components

Table 1: The classification methods and their basic properties

Property/ classification method	Ability To work with a large array of data source	Setting the error level first and of second kind	The result depends on the type distribution	Requires pre-regulari-zation and regression analysis	It requires training set samples in the training set	Poor working with a small number of PC	Sensitive to releases	The result depends on the amount data into clusters	It is difficult to divide the input	Deviations from the requirements
Linear Discriminant Analysis (LDA)	-	-	+	+	+	-	+	+	-	5
Quadratic Discriminant Analysis (QDA)	-	-	+	+	+	-	+	+	-	5
PLS discrimination	+	-	-	+	+	+	+	+	-	4
Soft Independent Modeling of Class Analogy (SIMCA)	+	+	-	+	+	+	-	+	-	2
K-nearest neighbors	-	-	-	-	+	+	-	-	-	3
Clustering using k-medium	+	-	-	-	-	-	-	-	+	2
Required	+	+	-			-	-	-	-	

RESULTS AND DISCUSSION

One of main steps of this method is to join in a group of points from the training sample in the space of the principal components and classification of marriage investigational product or its absence. This requires an analysis of existing methods of classification. In this case, the classification is a procedure in which the objects are divided into groups (classes) in accordance with the numerical values of the variables characterizing the properties of these objects. Table 1 shows the classification methods and their basic properties. Soft independent modeling of class analogy has some features:

- First, each class is modeled separately, independently of the others. Therefore one class a SIMCA method
- Secondly, SIMCA classification is a multi-valued each sample can be assigned simultaneously to several classes
- Thirdly, in SIMCA have a unique opportunity to set the error value of the 1st and 2nd kind and build the appropriate qualifier. In the methods discussed above, the error of the 1st and 2nd kind arise as a reality which can not be changed

After separation of the training sample into groups and assigning the test product to one of them is

Table 2: Methods of calibration and their basic properties

Property method/method of calibration	Calibration results in underestimation or overestimation	Can be used for multiple responses matrix values	Taken into account multicollinearity	Taken into account the correlation between the values of the response matrix	It should be a small amount of PC	Small values of systematic deviations	Deviations from the requirements
Calibrate one channel	+	-	-	-	-	-	4
Firordt method	+	-	-	-	-	-	4
Indirect calibration	+	-	-	-	-	-	4
Multiple calibration	+	-	-	-	-	-	4
Step calibration	-	-	-	-	-	-	4
Principal component Regression	-	-	+	-	-	+	2
Regression to latent structures-1	-	+	+	-	+	+	0
Regression to latent structures-2	-	+	+	+	+	+	0
Required	-	+	+	-	+	+	

necessary to define the numerical values of defective products abnormalities using the selected method of calibration. The essence of the methods of calibration is to establish a quantitative relationship between the variables x (matrix previously obtained principal components for products from the training sample, recognized defective) and the response *y* (matrix values of numerical parameters of electromagnetic actuators), depending on:

$$y = f(x_1, x_2, x_3,\ldots | a_1, a_2, a_3,\ldots)+\epsilon$$

In practice this means estimate the unknown parameters a_1, a_2, a_3,... in the calibration curve. Of course, the calibration can not be built exactly. The calibration curve is always present errors ϵ, the sources of which measuring, modeling, etc. Consider the most common methods of calibration and analyze the subject put forward requirements (Table 2).

Classification method should allow to work with large data sets, to be able to control errors of the first and second kind (an error of the first kind the false rejection of acceptable products, an error of the second kind a false pass defective products), the result should not depend on type distribution method should work with the lowest number of samples in the training set, should not be sensitive to outliers. As a result, the most suitable were: formal independent modeling of class analogies and clustering using k-means. Given the fact that in order to control the process of production is important to have the ability to set the level of errors of the first and second kind, the most urgent to solve the problem is soft independent modeling of class analogy.

Most suitable for solving calibration problem were regression methods to latent structures and regression on principal components because they take into account the phenomenon multicollinearity in the matrix x and give the most accurate solution of the problem. Metod regression is used to latent structures fewer PC for the same result as when using principal component regression it was preferred. Comparing regression to latent structures-1 and regression to latent structures-2, it should be noted that the second can be used in the correlation between the response matrix values y but in this case the advantage is not used.

Thus, chosen a method of regression on latent structure-1. After it is possible to determine the matrix a, containing the coefficients for conversion by which point the coordinates of the investigated product in the space of PC can be seen on the numerical values of the defective items abnormalities.

CONCLUSION

As a result, it proposed to date for the modern production process of the electromagnetic actuators process control method. It allows you to determine the type and degree of impairment of the mode of the process which will increase the efficiency of the production process control of electromagnetic actuators.

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