APPLYING TAGUCHI METHOD FOR CONTROL PARAMETERS OF AN INDUCTION MOTOR

Catalin Silviu NUTU[1], Mihai Octavian POPESCU[2]

This paper is intended to provide a model for the study of the quality of squirrel cage induction motor, based on the Taguchi Method. By measuring the values of the considered quality characteristic - the rated current (I_N) as being dependent of the control parameters: rated rotation speed (n_N), rated torque (M_N), rated phase voltage (U_{phN}), efficiency (η) and power factor ($\cos\varphi$) of the analyzed induction motors, one can conclude about the combination of the control factors which produces the best quality result.

Keywords: Squirrel cage induction motor, Taguchi Method, nominal is the best quality loss function, S/N ratio, ANOVA, Regression Analysis

1. Introduction

In the present scientific literature the Taguchi Methods were used mainly to assess one or more of the quality characteristics considering a set of control factors deemed to influence the respective quality characteristic/ characteristics.

Much of the published scientific material regarding the Taguchi methods refers to processes within the area of mechanical processes such as welding, drilling, end milling or hard machining in general. The purpose of such works is to determine the optimal combination of process parameters leading to the best values for the quality characteristic. (See [1]&[2] from Bibliography)

In order to determine the best combination of control factors the steps usually performed in the Taguchi methods are:

1. Identify the quality characteristic or characteristics
2. Identify the control factors also named control parameters or process parameters.
3. Identify the objective function (quality loss function) to be optimized by selecting it from the available three alternatives: smaller the better, nominal the best or larger the better.

[1] Assist. Prof., Faculty of Electromechanical Engineering, Constanta Maritime University Romania, e-mail: catalin.nutu@cmu-edu.eu

[2] Prof., Faculty of Electrical Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: mo_popescu@rectorat.pub.ro

4. Selection of the Taguchi design - orthogonal array (OA) which determines the matrix of experiments to be conducted.
5. Conducting the matrix experiment according to selected design.
6. Calculation of the S/N ratios for each experiment pertaining to the matrix and determination of the optimal combination of the control factors.

Sometimes, with a view to decide with regard to the importance (magnitude) of the control factors it is useful to apply ANOVA technique.

Regression analysis is used, usually, additionally to ANOVA, in order to determine the relationship between the analyzed quality characteristic/ characteristics and the control parameters.

2. Application of Taguchi Method for the control parameters of an induction motor

The Taguchi Method consists, in general, in the conducting of the afore mentioned five main steps, already presented in the introduction chapter of this paper.

Now, in our case for an induction motor, in order to apply the presented five stages of the Taguchi Method, we have to choose a quality characteristic or quality attribute which can be measured during the experiments conducted. The chosen quality characteristic used in the paper is the rated current (I_N) of the motor.

For the induction motor, this quality characteristic is deemed to be influenced by a set of chosen control factors (control parameters). The main idea behind the Taguchi Method, thus applied for the induction motor, is to calculate the signal to noise ratio (S/N ratio) corresponding to the measured values of the quality characteristic and values of control factors.

The calculation of the S/N ratio, thus follows for every experiment conducted. These experiments, for the Taguchi Method, are conducted respecting a certain design of experiments (DOE), which in the case of the Taguchi Methods has the form of an orthogonal array (OA).

The OA's, discovered and applied by Genichi Taguchi, are one of the most important point in application of the Taguchi Methods, and their main advantage is that OA's are reducing the number of the experiments necessary to be conducted in a full factorial design of experiments.

The best (optimal) control factor combination is that combination from the Taguchi OA, for which the S/N ratio has the maximal value.

The considered motor's batch within the research is a batch of 180W rated power three phase squirrel cage induction motors.

There were selected five control factors (parameters) determining the value of the quality characteristic: rated rotation speed (n_N), rated torque (M_N), rated phase voltage (U_{phN}), efficiency (η) and power factor (cosφ), the last two of them being parameters depending on the performance of the construction of the induction motor.

The selected levels of the identified control parameters are presented in the following Table 1:

Table 1

Control factors and their levels

No.	Control factor/notation/description/ measurement unit	Level 1	Level 2
1	**A** (n_N: rated rotation speed) [rpm]	2700	2800
2	**B** (M_N: rated torque) [Nm]	0,60	0,65
3	**C** (U_{phN}: rated phase voltage) [V]	230	240
4	**D** (η: efficiency) n.a.	0,65	0,70
5	**E** (cosφ: power factor) n.a.	0,75	0,80

The selected quality loss function refers to the loss derived by deviation from the targeted value of the chosen quality characteristic, rated current (I_N), and it is consequently the nominal the best alternative.

The selected orthogonal design for the experiments to be conducted is an L8 orthogonal array, having the form presented in the Table 2, beneath.

Table 2

L8 orthogonal array

No.	A	B	C	D	E
1	1	1	1	1	1
2	1	1	1	2	2
3	1	2	2	1	1
4	1	2	2	2	2
5	2	1	2	1	2
6	2	1	2	2	1
7	2	2	1	1	2
8	2	2	1	2	1

This table, representing the L8 orthogonal array (L8-OA), presents the experiments to be conducted for the induction motors, the first column is representing the experiment number, the letters from A to E are representing each, one of the five control factors, the values 1 and 2 from the table are representing the chosen level of the control factors. Thus, for the example, the row No.1 is representing the first of the eight experiments conducted for the chosen L8-OA, where the control factors A, B, C, D, E of the induction motors are all on the level 1, according to the Table 1 above. For each of the 8 experiments five values of the rated current were measured. Results can be found in the following Table 3.

Table 3

Results for the matrix of experiments conducted

No.	Mesured rated current value (I_N)					Mean	Standard deviation	S/N ratio
	N1	N2	N3	N4	N5			
1	0.52	0.54	0.57	0.54	0.56	0.55	0.02	28.9465
2	0.49	0.48	0.51	0.55	0.56	0.52	0.04	23.2535
3	0.54	0.56	0.57	0.58	0.56	0.56	0.01	31.5713
4	0.55	0.56	0.58	0.54	0.55	0.56	0.02	31.2811
5	0.53	0.52	0.51	0.53	0.56	0.53	0.02	29.0430
6	0.57	0.59	0.58	0.6	0.58	0.58	0.01	34.1898
7	0.62	0.61	0.60	0.59	0.59	0.60	0.01	33.2860
8	0.60	0.58	0.59	0.61	0.57	0.59	0.02	31.4378

The results are showing that the optimal control parameter combination is corresponding to the sixth factor combination from the Table 2.

On deciding about the importance of the control factors we use the ANOVA technique applied for the measurements performed, taking into account that there are 5 control factors it follows that the total sum of squares may be expressed as addition of the sum of squares corresponding to each of the 5 control factors, plus the term corresponding to the error.

Table 4

ANOVA/ Significance of the control factors

No.	SS	Values	Importance
1	SS1	0.01346	31.63%
2	SS2	0.01541	36.21%
3	SS3	0.00216	5.08%
4	SS4	0.00216	5.08%
5	SS5	0.00616	14.47%
6	SSe	0.00321	7,54%
7	SST	0.04256	100%

Regression analysis on the measured data can be also performed with the purpose to identify the relationship between the measured values of the current and the values of the control factors.

Regression analysis allows one to establish relationships between the dependent (in our case, the quality characteristic) and independent variables (in our case, the control factors) or to make predictions about the numerical dependent variable based on one or more numerical independent variables.

There are two possible outcomes: if such a relation is found, it is consistent with the hypothesis of a causal influence between the dependent and independent variables, if instead no relation is found then the result suggests that there is no causal influence between the dependent and independent variables. However, in both cases the presence or the absence of the causal influence is not proved.

In the regression analysis one has to check whether there is a linear relationship between the output and input, or between the dependent and independent variable or between the response and explanatory.

The regression model has the form:

$$y = \beta_0 + \beta_1 x + e \quad (1)$$

where β_1 is called the regression coefficient or the slope of the line and e is the error term.

The parameters β_0 and β_1 need to be estimated and their estimations will be denoted as b_0 and b_1 and hence the equation is

$$y\hat{} = b_0 + b_1 x \quad (2)$$

b_0 and b_1 are to be calculated by minimizing the sum of square errors

$$\text{SSE}=\sum_1^n e_i^2=\sum_1^n (y_i - y\hat{}_i)^2=\sum_1^n (y_i - b_0 - b_1 x_i)^2 \quad (3)$$

The regression line obtained by performing of the above mentioned regression analysis is:

$I_N = -0.295 + 0.000310\ n_N + 0.660\ M_N - 0.00060\ U_N + 0.040\ \eta_N - 0.380\ \cos\varphi$

Having the coefficient of determination (R^2) equal to 0.802.

In fact the theoretical relationship between the used control factor and the value of the rated current is well known from the theory of three phase induction motors.

3. Conclusions

The conclusion that can be drawn from the above study is that the optimal combination of control factors in order to obtain the best value of the rated current is for rated rotation speed n_N=2800 rot/min, rated torque M_N=0,60 Nm, rated phase voltage U_{phN}=240 V, efficiency η=0,70 and cosφ=0,75. The chosen quality loss function alternative is “the nominal the best” alternative. Perfoming ANOVA technique it results the importance of each considered control parameter. It follows that the most significant parameters for the value of the rated current are the rated rotation speed n_N and rated torque M_N with contributions of 31,63% respectively 36,21% and the least important control factors are the rated phase voltage U_{phN} respectively efficiency η each of them with a contribution of 5,08%.

R E F E R E N C E S

[1]. *S.S. Mahapatra, Amar Patnaik*, Optimization of electrical wire discharge machining process parameters using Taguchi method (International Journal of Advanced Manufacturing Technology, 2006
[2]. *P.G. Kochure, K.N. Nardurkar*, An approach for selection of process parameters of induction hardening of EN8 D steel (International Journal of Advanced Research in Science, Engineering and Technology, Vol.01, Issue 02, pp 22-27
[3]. *W. Haerdle,L. Simar*, Applied Multivariate Statistical Analysis, Second Edition, Editura Springer-Verlag Berlin 2007.
[4]. *I. Bacivarov, A. Bacivarov, T. Tiplica*, Ingineria calitatii. Initiere in Metodele Taguchi. (Quality Engineering. Initiation into Taguchi's methods) Euroqualrom, 1996
[5]. *U. Esme*, Application of Taguchi Method for the optimization of resistance of spot welding process, The Arabian journal for science and engineering, Vol.34, No. 2B, 2009
[6]. *L.P. Sullivan*, The power of Taguchi methods to impact change in the U.S. companies
[7]. *S. Kamaruddin, A.Z. Khan, K.S. Wan*, The use of the Taguchi method in determining optimum plastic injection moulding parameters for the production of a consumer product, Jurnal Mekanikal, pp 98-110, 2004
[8]. *S. Kamaruddin, A.Z. Khan, S.H. Foong*, Application of the Taguchi method in the optimization of injection moulding parameters for manufacturing products from plastic blend, IACSIT International journal of engineering and technology, vol.2, no.6, 2010
[9]. *C.A. Anoop, P.Kumar*, Application of Taguchi methods and ANOVA in GTAW process parameter optimization for aluminum alloy 7039, International journal of engineering and innovative technology (IJEIT), vol.2, issue 11, 2013
[10]. *A. Al-Refaie, T.H. Wu, M.H. Li*, An effective approach for solving the multi-response problem in Taguchi method, Jordan journal of mechanical and industrial engineering, vol.4, no.2, 2010
[11] *Kreyszig Erwin*, Statistische Methoden und ihre Anwendungen, 7. Auflage, Vandenhoeck&Ruprecht
[12] *Christian Walck*, Hand-book on Statistical Distributions for experimentalists, University of Stockholm 2007
[13] *Mohammed A. Shayib*, Applied Statistics, 1st edition 2013, downloaded free from bookboon.com
[14] http://psych.colorado.edu/~carey/Courses/PSYC5741/handouts/GLM%20Theory.pdf – The general linear model
[15] http://www.fil.ion.ucl.ac.uk/spm/doc/books/hbf2/pdfs/Ch7.pdf, S.J. Kiebel, A.P.Holmes – The general linear model
[16] http://www.stat.wisc.edu/~mchung/teaching/MIA/reading/GLM.2004.pdf, Thomas D. Wickens, Department of psychology, University of California Berkeley – The general linear model
[17] *Jeff Miller, Patricia Haden* – Statistical Analysis with the general linear model, 2006
[18] http://stat511.cwick.co.nz/lectures/26-regression-anova.pdf, Anova&Regression
[19] http://www.math.smith.edu/sasr/excerpt-3.pdf, Linear regression and ANOVA
[20] http://www.public.iastate.edu/~dnett/S401/wreganova.pdf, Analysis of variance (ANOVA) for simple linear regression