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TRIBOLOGICAL PROCESS OF BRUSH WEARING

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ABSTRACT
The brushes are used for transmission of electric current from or to rotating surfaces depending on the type of electrical machines.
Besides the process of current transmission, what is significant for the brushes is the tribological process, which is the subject of the experiment.
The brush was exposed to a planned experiment and a regression and correlation analyses of tribological process of brush wearing relative to the time were undertaken.
The interdependency has been tested and determined by regression analysis and by correlation analysis, the connection between the length of wearing Y of the examined brush and observing time X, taken in mode of statistics agglomerates.
The wearing of brushes in practice varies relative to the time. The variations may result in extreme wearing of brushes, changes in the current transmission - arcing of brushes and the like.
Keywords: Experiment, brush, tribological process, regression, correlation, analysis, wearing.

1. INTRODUCTION
When doing a process research, the first step is to identify one or more magnitudes best applicable in describing the effects of the process or the object of the experiment at issue.
That magnitude is a result of behaviour of the overall system. It is referred to as the dependant variable or the brush wear - Y. The next step is to identify those magnitudes whose changes affect the dependant variable. They are referred to as the independent variables or factors, particularly the
X magnitude – the time. The experiment planned represents a methodology for establishing the relationships between the factors and the response for any process with measurable parameters.
The statistic feature (variable) is a property common to all the units of a statistical set.
In the example of the tribological process of the brush wear, the statistic feature are the results of measuring the brush A wear in time intervals.
The statistic set or population is a set of all the potential values of the brush A wear in time intervals.
The population subset is the number of measurements performed on the brush A or the results of the measurements conducted on a greater number of brushes by taking one sample, A, B, C etc. from each primary set of brushes.
Experiment is one of the fundamental methods of discovery. It is a procedure applied to induce a phenomenon for the purpose of observation, research or interpretation [1].

2. REGRESSION AND CORRELATION ANALYSIS

When determining the linear regression parameter, the least square method – LSM – is applied.
The theoretical form of the mathematical model of the simple linear regression used in this analysis is: $Y = \beta_0 + \beta_1 X + \varepsilon$, where β_0 and β_1 are the theoretical coefficients or regression parameters, whose values based on the data for y_i and x_i (i=1,2,...,n) can be obtained through the values of the regression coefficients b_0 and b_1 in the equation of the regression straight line,
$\bar{y} = b_0 + b_1 x + e$, where ε_1, ε_2, ...ε_n are random independent uncorrelated magnitudes conditioned by the measurement errors for example, while the error e is the statistic evaluation for ε.
When applying the least square method, the condition is set that the sum of the square deviations of the observed values y_i from the regression straight line yˆ is minimal.

$$\min \sum_i^n \varepsilon_i^2 = \sum_i^n (y_i - b_0 - b_1 x_i)^2 = \sum_i^n e_i^2 \qquad \text{i=1,2,...,n [2].}$$

From the above expression one can mathematically determine from the minimum condition the most probable values of the coefficients b_0 and b_1.
In this paper, we shall limit ourselves to the linear correlation.

3. CONDUCT OF AND RESEARCH INTO THE EXPERIMENT CONCERNING BRUSH WEAR PROCESS

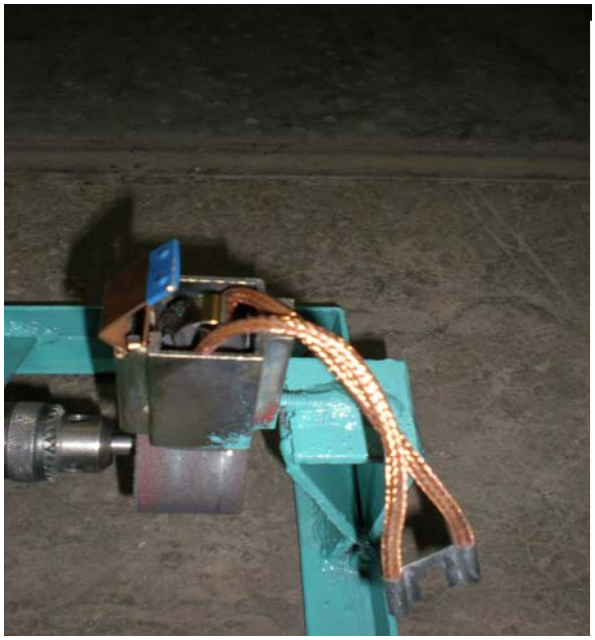

Figure 1. Disk drive, brush holder, brush, spring

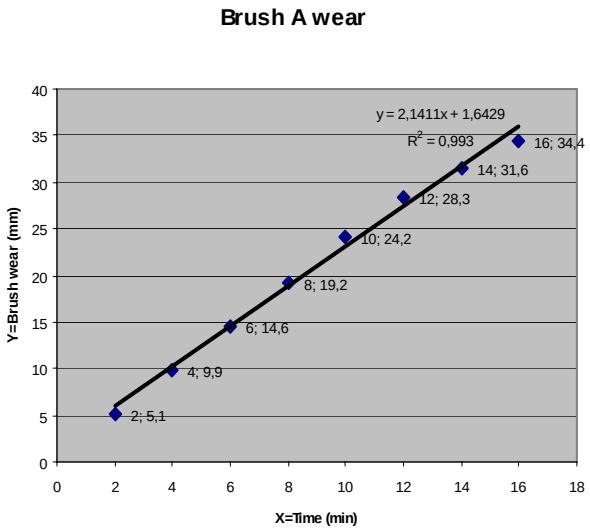

Figure 2. The function of the brush A wear

The following was used during the experiment concerning the brush A wear tribological process:
- A device suiting the purpose, device drive (drill of "Iskra" 1000 o/min made; during the load n=900 rot/min).
- Disk under investigation (D=56 mm in diameter).
- Emery paper (KSE22 P80 ALOX PAPER ZIA Electro Coated Made in Croatia).
- Brush A (HM axbxHč=32x25x64 mm), brush holder (MEZ Type).
- Spring gauge (RINGSDORFF WERKE GmbH MEHLEM 0-2,5 kg Made in Germany).
- Vernier caliper (MITNt 0y0 Made in Japan 17128 IN).
- Rotation measuring instrument (DEMO 2, Berlin Made in Germany).
- Time measuring device (the one installed on the Nokia mobile phone was applied).

The brush A length (a=32 mm) "follows" the curvature of the circular ring circumference.

The spring force F=-k (Hč-Ht), where Hč-is the total brush length, while Ht- is the length of the section worn as a result of the tribological process during the experiment time. It would be ideal to have F=constant.
The pressure on the brush should be 18-20 mN/mm^2 or 180-2000 g/cm^2 [3].
In our case, the pressure on the brush is 18.7-23.4 mN/mm^2 or 187-234 g/cm^2.
It is possible to design the sampling of brushes A, B, C... on the collector, machine sliding rings, production or supply packages or any basic type of brushes, calculate the arithmetic means, the common arithmetic mean, and do an analysis the same as the one applied in the case of a single brush A sample, as presented in the paper.

4. THE ANALYSIS OF THE EMPIRICAL DISTRIBUTION OF THE BRUSH A WEAR

The linear regression of the brush A wear is: y=2.1411x+1.6429
The regression direction may be calculated and the regression analysis done using the programme tools of MS Excel and menu options: Insert (Tools),Chart (Data Analysis).

Table 1. Brush A wear calculation results (Regression)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,996470502
R Square	0,992953461
Adjusted R Square	0,991779038
Standard Error	0,954407071
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	770,1433929	770,1433929	845,481866	1,0963E-07
Residual	6	5,465357143	0,910892857		
Total	7	775,60875			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1,642857143	0,743667998	2,209127119	0,06922645	0,176832892	3,462547178
x	2,141071429	0,073634104	29,07717088	1,0963E-07	1,960895267	2,32124759

RESIDUAL OUTPUT

Observation	*Predicted y*	*Residuals*	*Standard Residuals*
1	5,925	-0,825	-0,933670625
2	10,20714286	-0,30714286	-0,347600319
3	14,48928571	0,110714286	0,125297789
4	18,77142857	0,428571429	0,485023701
5	23,05357143	1,146428571	1,2974384
6	27,33571429	0,964285714	1,091303327
7	31,61785714	-0,01785714	-0,020209321
8	35,9	-1,5	-1,697582954

PROBABILITY OUTPUT

Percentile	*y*
6,25	5,1
18,75	9,9
31,25	14,6
43,75	19,2
56,25	24,2
68,75	28,3
81,25	31,6
93,75	34,4

- The SUMMARY OUTPUT Table presents the correlation coefficients.
The regression representativeness indicator is the determination coefficient R^2.
The closer the determination coefficient to one, the more representative the model.
- Table ANOVA shows the variance analysis results.
The adequacy of the simple linear regression model is examined applying the F-test. For the freedom degrees $v_{reg}=1$, $v_{rez}=6$ and the significance threshold $\alpha=0.05$ the table or the critical value is
$F_{(1, 6, 0,05)}=5.99$ Table 3 from reference [2].
It is much less than the value obtained by calculation $F_0=845.481866$.
The conclusion is that the simple linear regression model is appropriate.
-The Table with the linear regression model parameter values
$b_0=1.642857143$ (Intercept) $b_1=2.141071429$ (x)
Standard Error of parameters b_0 and b_1 as follows:

s_{b0}=0.743667998 s_{b1}=0.073634104
t Statistic –The Student t-test values,
t_{0b0}=2.209127119 t_{0b1}=29.07717088
The Student distribution enables us to evaluate the expectation μ of the variable y of the basic set Y from which the sample originates based on a small number of samples
If we choose t_0 so as to have P{ t| >t_0 }=α, with the probability of (1- α) the inequation may be applied.

$-t_0 \lhd \frac{\bar{x}-\mu}{s_{\bar{x}}} \lhd t_0$, where $s_{\bar{x}} = \frac{s}{\sqrt{n}}$, and s – is the standard sample deviation,

The above inequation presents the expectation evaluation interval.
For the reliability given in advance and the degree of freedom v, t_0 may be read directly from the table for the Student distribution. Based on the overview of Table 2 from references [2].
The critical value $t_{(o,o5,\ 6)}$=2.447 and based on $|t_{(0b1)}| > t_k$ we evaluate the significance of the regression parameters
Because $|t_{(0b0)}| < t_k$ |2.209127119| < 2.447 free member b_0 of the regression straight line is insignificant.
Parameter b_1 of the regression straight line is significant because $|t_{(0b1)}| > t_k$ |29.07717088| > 2.447.
$\bar{y} = b_0 + b_1 x + e$, $\bar{y} = b_0 + b_1 x$ = (1.642857143 ± 1.81964) + (2.141071429 ± 0.18)x
The significance and other correlation coefficients may be tested using the expression for the coefficients in question.
-Tables RESIDUAL OUTPUT and PROBABILITY OUTPUT are the results of the regression analysis using MS Excel programme tools.
Using the MS Excel tools the following diagrams may be obtained:
Residuals Plot, Line Fit Plot (Prediced y), Normal Probiliti Plot, as well as other diagrams.

5. CONCLUSION

The dissipation diagram is used to show the variation relative to the time of the output variable characteristics of the brush wear quality.
The experimental data related to the brush wear relative to the time for the given conditions may be approximated by linear regression.
The planned experiment of the brush wear relative to the time represents a methodology for establishing the relationships of the brush wear in the tribological process with measurable parameters.
For a quality selection of brushes it is necessary to present the results of the regression and correlation analysis and/or other analyses as the results of the experiment planning.
The experimental data and analyses of empirical distribution may be a good foundation for contracting supplies, warranty period, arbitration procedures and brush exploitation monitoring.
Regardless of the latest trends of developing the rotating excitement sets for electric machines brushes will continue to be used.
To improve the monitoring of the machine brush wear, the regression analysis may be used in addition to visual on site inspection. The information about the brush wear may be forwarded by means of the sensor or other signalling devices to the software programmes for calculation, processing and distance data transfer.

6. REFERENCE

[1] http://hr.wikipedia.org/wiki/Eksperiment
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