ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1216386

EXPERIMENTAL STUDY ON THE INFLUENCE OF BURNISH PARAMETERS ON THE SURFACE ROUGHNESS REDUCTION INDEX

Stanisław Polanowski
Wojciech Labuda

Gdynia Maritime University, Faculty of Marine Engineering
Morska 83, 81-225 Gdynia
tel.: +48 586901549, fax: +48 586901399
e-mail: wlabuda@am.gdynia.pl

Abstract

The paper presents the research results of relationship between surface roughness reduction index K_{Ra} and three input parameters: burnishing speed V_n, feed f_n and burnishing force F_n., and all combinations of levels of yields N measured for 48 points of experiment. The experiment was repeated 3 times. In order to select the model describing the results of tests, the stepping approximation analysis was performed. It relayed at incorporated into the model in following steps approximation elements function, giving the biggest decrease of the sum of squared deviations. The first approximation was based on the ternary monomial of the powers from 0 to 3 for each input value. This approximation aim was to show, that the index of surface roughness reduction does not depend on the burnishing speed in the made in the area of research. The reduced input parameters to two, i.e. f_n and F_n. The plan of the experiment was brought to N = 12 and M = 12. The best approximation of test results obtained in the case of Laurent polynomial with stepping selection of elements. The biggest contribution to the decrease in the sum of squared deviations was element $f_n{}^{-1} \cdot F_n{}^3$, and then f_n^2. The article shows that in the range f_n {0.6:1.2} there was not information on the successful model and the lack of influence of f and F_n on the results of the experiment. It is postulated to retry the experiment for the feed f <0.6.

Keywords: *burnishing process, surface roughness parameter, stainless steel elements*

1. Introduction

Vessels and warships propulsion plants consist of main propulsion engines, electro generators and numerous auxiliary machinery, which are placed in the engine room as well as on the deck. Seawater pumps belong to a group of centrifugal angular momentum pumps. Centrifugal angular momentum pumps are working in the cooling systems of high and medium speed engines, water systems supplying boilers, in bilge systems, ballast systems and in firefighting installations. Due to their hard service conditions, marine pumps working in seawater environment are made of corrosion resistant materials. Despite the fact that pump shafts are made of an expensive material, it is not possible to avoid service damage. This damage includes cracking, plastic deformation, excessive wear of pins in places of mounting rotor discs and sealing chokes, corrosive wear, friction wear, erosive wear and splineways knock outs. According to long time service experience, the most commonly observed problem is excessive wear of pins, causing their diameter decrease as well as exceeding the permissible shape deviations in place of chokes mounting. The research work effort has been focused at improvement of the shafts service durability and was based on carrying out tests for contact fatigue, friction wear and electrochemical corrosion [1 - 6]

The process of burnish of shafts proposed here, aimed at increasing the service durability of marine pump shafts of seawater installations, what should give economic benefits in comparison with traditional methods. Burnish process enables the achievement of high smoothness of machined surface together with the surface layer hardening. The final formation of dimensions and service properties with the use of burnishing constitutes a chipless and dustless treatment, which allows classify burnish as ecological tooling methods. Burnishing technology can be used in machines production plants. It allows eliminating traditional finish machining such as: lathing, grinding, super finishing, honing and polishing.

2. Goal and results of research

The paper presents results of tests, aimed at determination how burnish main parameters have an influence on lowering of roughness of surface and determination of optimum conditions of treatment. As a parameter of surface roughness, level was taken index K_{Ra}, which was initial value of research.

Input parameters of tests were as follows:

V_n– burnish speed,
f– advance
F– burnish force.

Plan of the experiment consisted of N = 48 levels of input parameters (Tab. 1). Number of repetitions at every level was M = 3 (Tab. 2).

Tab. 1. Experiment's plan: n- number of the input parameters level

i	V_{ni}	f_i	F_i	i	V_{ni}	f_i	F_i	i	V_{ni}	f_i	F_i
1	35	0.13	720	17	56	0.54	930	33	88	0.94	1140
2	35	0.13	930	18	56	0.54	1140	34	88	1.20	720
3	35	0.13	1140	19	56	0.94	720	35	88	1.20	930
4	35	0.54	720	20	56	0.94	930	36	88	1.20	1140
5	35	0.54	930	21	56	0.94	1140	37	112	0.13	720
6	35	0.54	1140	22	56	1.20	720	38	112	0.13	930
7	35	0.94	720	23	56	1.20	930	39	112	0.13	1140
8	35	0.94	930	24	56	1.20	1140	40	112	0.54	720
9	35	0.94	1140	25	88	0.13	720	41	112	0.54	930
10	35	1.20	720	26	88	0.13	930	42	112	0.54	1140
11	35	1.20	930	27	88	0.13	1140	43	112	0.94	720
12	35	1.20	1140	28	88	0.54	720	44	112	0.94	930
13	56	0.13	720	29	88	0.54	930	45	112	0.94	1140
14	56	0.13	930	30	88	0.54	1140	46	112	1.20	720
15	56	0.13	1140	31	88	0.94	720	47	112	1.20	930
16	56	0.54	720	32	88	0.94	930	48	112	1.20	1140

Tab. 2. Measurements results of K_{Ra}: j – number of repetitions at level i

	j				j				j		
i	1	2	3	i	1	2	3	i	1	2	3
1	1.50	1.57	1.53	17	2.33	2.44	2.17	33	1.55	1.73	1.80
2	7.82	8.18	8.09	18	1.84	2.14	2.53	34	1.30	1.11	1.17
3	10.60	10.73	10.78	19	1.19	1.21	1.29	35	1.95	1.62	1.65
4	1.20	1.29	1.00	20	1.92	1.83	1.79	36	2.04	1.91	1.88
5	1.88	2.00	1.59	21	1.95	1.85	1.85	37	1.57	1.47	1.59
6	1.43	1.37	1.49	22	1.21	1.15	1.32	38	6.80	6.25	6.25
7	1.31	1.11	1.25	23	1.62	1.66	1.76	39	10.00	10.22	11.00
8	2.46	2.05	1.80	24	1.77	1.91	2.15	40	1.17	1.15	1.29
9	2.11	2.24	2.29	25	1.34	1.38	1.37	41	2.51	2.57	3.21
10	1.22	1.42	1.27	26	6.69	5.56	5.25	42	1.83	1.79	1.88
11	1.66	1.42	1.56	27	9.89	10.21	10.45	43	1.26	1.25	1.01
12	2.08	2.42	2.42	28	1.55	1.41	1.10	44	2.38	2.28	2.14
13	1.38	1.37	1.37	29	1.89	2.03	1.89	45	2.23	2.06	2.20
14	5.36	6.45	5.85	30	1.90	2.14	1.98	46	1.22	1.18	1.29
15	11.02	10.73	11.36	31	1.15	1.03	1.18	47	1.70	1.81	1.72
16	1.69	1.24	1.51	32	1.92	2.13	2.09	48	2.39	2.22	2.57

Standard deviation value for experiment for $2 \cdot N = 96$ steps of freedom was 0.223. In the case of level n = 26 (Tab. 2), maximum deviation from mean value was 0.857, what more than three times oversteps the value of calculated standard deviation. Further analysis showed that rejection of that measurement was a mistake.

3. Approximation of research results using polynomial functions based on ternary monomials

Due to abeyance of physical model, in order to establish a mathematical model, statistical methods based on least squares were implemented. In case when physical form of the model is unknown, most common approximation way using polynomial functions or other linear functions of model's coefficients. In our case, firstly was considered approximation by polynomial in form of formula:

$$K_{WQ} = \sum_{q=1}^{Q} a_q \cdot V_n^{w_{Vq}} \cdot f^{w_{fq}} \cdot F^{w_{Fq}}, \tag{1}$$

where:
K_{WQ} – approximation function,
Q – number of elements of approximation function (approximation level).
a_q – coefficients (constant) determined by way of least square,
w_{Vq}, w_{fq}, w_{Fq} – indexes defined for element q.

As criteria of efficiency of approximation, were used values of sum of square deviations from mean $\overline{K}_i$ for level of realisation of experiment:

$$S_{WQ} = \sum_{i=1}^{N} \left(\overline{K}_i - K_{WQi}\right)^2, \tag{2}$$

where:

$$\overline{K}_i = \frac{1}{M} \sum_{j=1}^{M} \widetilde{K}_{ij}, \tag{3}$$

where:
$\overline{K}_i$ – mean value of results for i[th] point of experiment's realisation. Furthermore, symbol characterising mean value was omitted,
M – number of experiments of every amongst i- points of experiment's realisation,
$\widetilde{K}_{ij}$ – result of single measurement.

The second criteria of efficiency evaluation was standard deviation, in our case with number of steps of freedom described as follows N – Q.

In order to reveal the polynomials of approximation of researches results, a rule of stepping appending to an approximating function, subsequent monomials, giving maximum diminishing of sum of square deviations in considered step of approximation [7].

At every step, data set consisting of all monomials for every combination of power indexes w_{Vq}, w_{fq}, w_{Fq} from range 0÷3, and in some cases efficiency of the 4[th] power was verified.

Taking under consideration tendency of diminishing of values S_{WQ} or s_{WQ} approximation can be finished for $Q = 3$ or $Q = 6$ (tab. 3) depending on undertaken requirements concerning accuracy. For $Q > 6$ approximation was found as not efficient.

Very important observation was that for every subsequent step of approximation (tab. 3) happens $w_{Vq} = 0$, what means that is lack of influence of parameter V_n at results of experiment.

Coefficients of correlations calculated for input values databases took values as follows: -0.0083 for V_n; K_{Ra}, -0.58 for f; K_{Ra} and 0.42 for F; K_{Ra}, what confirms above stated observation.

Tab. 3. Results of approximations by polynomial functions K_{WQ}, using way of stepping selection of optimal monomials, S_{WQ} – sum of squared deviations

q, Q	1	2	3	4	5	6	7	8	9	10	11
w_{Vq}	0	0	0	0	0	0	0	0	0	0	0
w_{fq}	0	1	3	2	0	3	0	3	1	2	1
w_{Fq}	2	2	2	1	0	1	3	0	0	3	3
S_{WQ}	294	122	55	52	40	13.9	12.3	10.6	10.1	6.0	5.3
s_{WQ}	2.50	1.63	1.11	1.09	0.96	0.57	0.55	0.51	0.51	0.40	0.38

4. Reduction of the experiment plan and statistical evaluation of results

Due to the lack of impact at research results, in further analysis of results, input value V_n was rejected. Plan of experiment was reduced to $N = 12$ points, in which performed $M = 12$ experiments (repetitions). Models of the process became two-dimensional.

Subsequently was carried out evaluation of results of new plan experiments. Analysis of deviations from mean values in all 12 points of experiment did not confirmed justification of classification them as inordinate.

For valuation of the variance, criterion *G* [8] in form of formula (4) was used:

$$G_i = \frac{s_{Ki}}{\sum_{i=1}^{N} s_{Ki}}, \tag{4}$$

Comparison of G value with critical values G_{kr} revealed significant deviations of variance for point 2 from variances other points (fig. 1). Taking under consideration lack of inordinate deviations in point 2, that point was not excluded from further calculations.

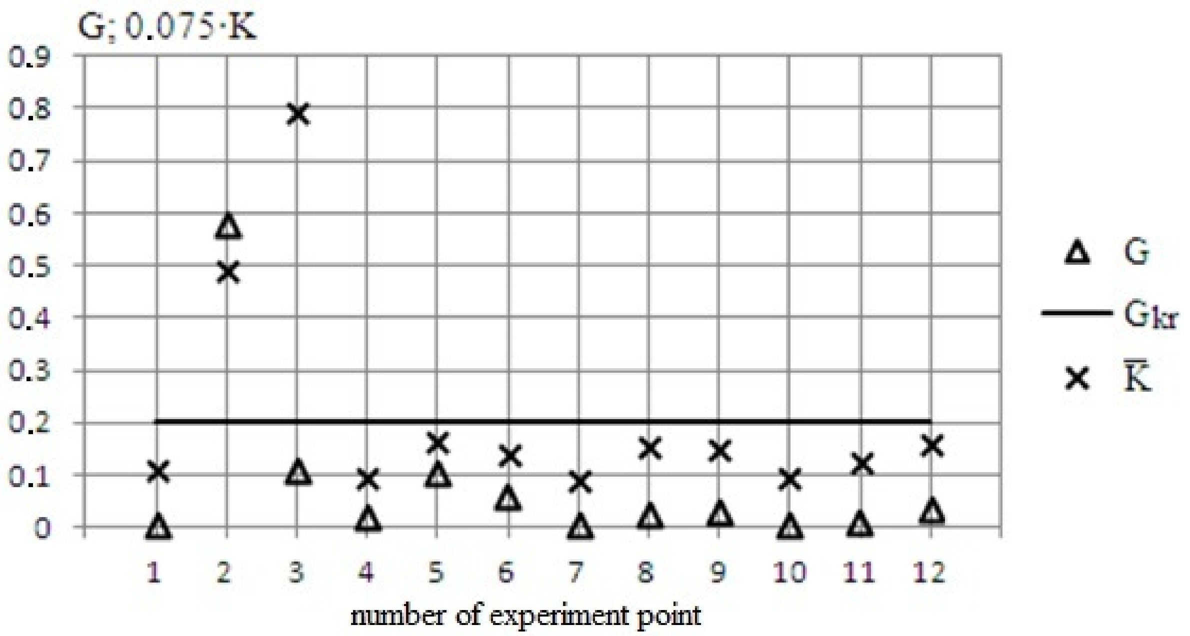

Fig. 1. Comparison of criterion G_i with critical values G_{kr} [1] in points of experiment: $\overline{K}_i$ – mean values in points of experiment

5. Approximation with functions based at binary Laurent's monomials

Utilisation of Laurent's polynomials means extension of database of exponents w_{fq} and w_{Fq} at set of integers. In searching process, the same method of stepping selection of monomials was used, because of biggest diminishing of sum of square deviations in subsequent step of approximation (tab. 4).

Tab. 4. Results of approximation by polynomial functions K_{LQ} based at binary polynomials of Laurent, S_{LQ} – sum of square deviations, s_{LQ} – standard deviation, F – criterion of Snedecor [2], Fkr – critical value of criterion F

q, Q	1	2	3	4	5	6	7	8	9
w_{fq}	-1	2	-1	-1	0	1	1	2	3
w_{Fq}	3	0	-3	0	3	1	2	2	0
S_{LQ}	9.1	3.9	3.4	1.8	1.6	0.24	0.23	0.23	0.23
s_{LQ}	0.91	0.63	0.61	0.47	0.47	0.20	0.21	0.24	0.27
F	66.4	31.7	30.1	17.9	18.1	3.19	3.66	4.56	6.06
$Fkr095$	1.87	1.91	1.96	2.01	2.08	2.17	2.29		
$Fkr099$	2.4	2.5	2.55	2.66	2.79	2.95	3.17		

Models revealed for subsequent Q are characterised by significantly higher decrease of sum of squared deviations S_{LQ} (tab. 4) in comparison to values S_{WoQ} (tab. 3).

The closest approach to results of test is given by polynomial K_{L6}, for which lowest value of standard deviation s_{L6} was obtained (Tab. 4) and value of criterion F close to required for fulfilling the condition of statistical adequacy of the model.

The contour line graph shown at Fig. 2 presents, that K_m values in points of experiment, are practically identical with values K_{L6} received from approximation (Fig. 7)

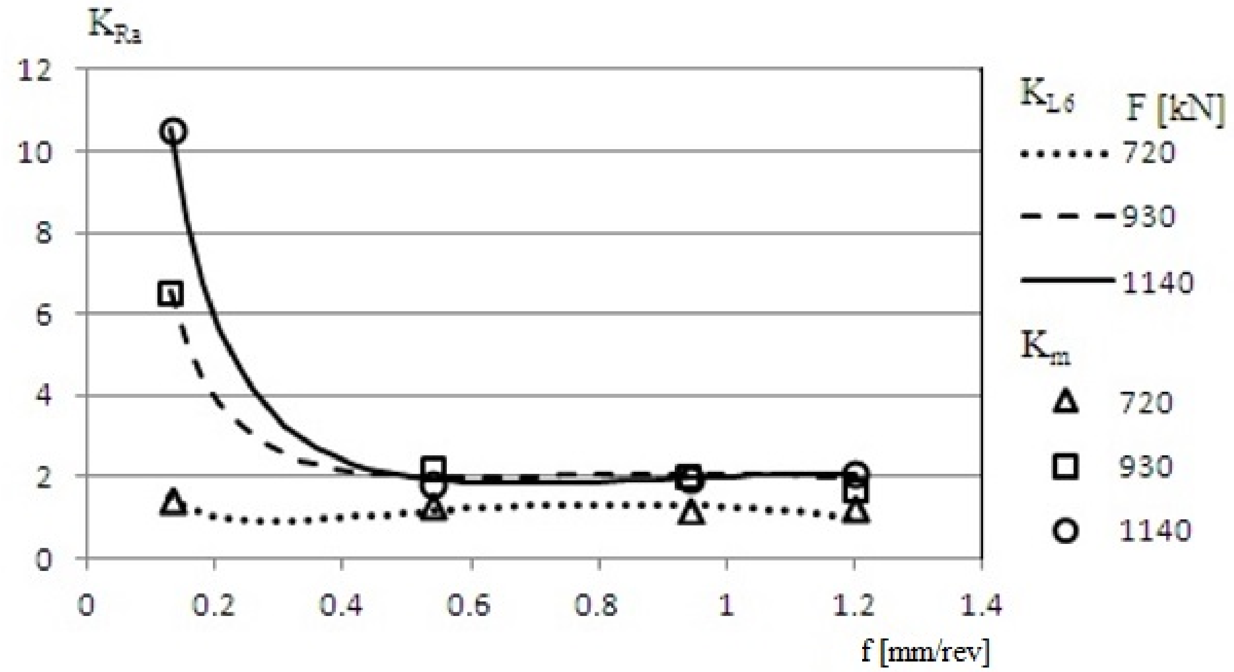

Fig. 2. Contour line graph of polynomial of approximation function K_{L6}: K_j – mean values K_{Ra} in experiment's points

The basic approximating element of considered polynomial is polynomial K_{L1}, which gives well approximation of high values K_{Ra} (fig. 3).

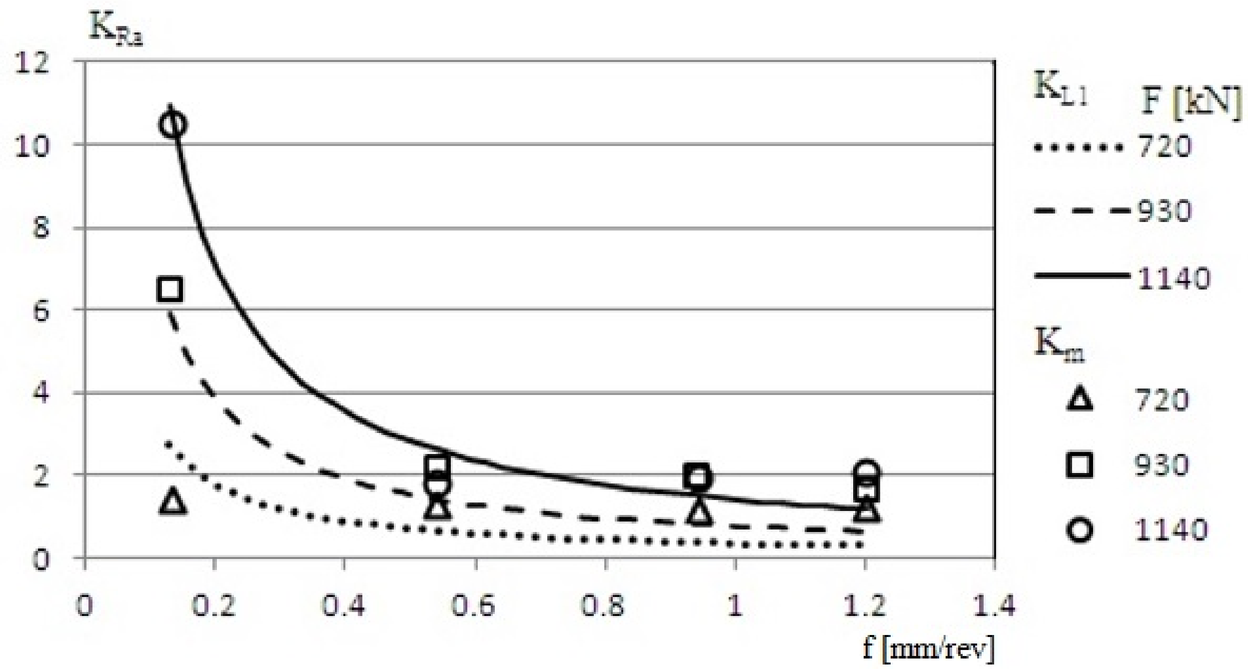

Fig. 3. Contour line graph of polynomial of approximation K_{L1}: K_j – mean values K_{Ra} in points of experiment

6. Revelation of burnish process model

Presented above analysis of approximating models lets declare that optimum model is the one K_{L6} and its submodels for lower values Q.

The model K_{L6} put down with round off giving error of calculations less than ±0.001 *K* is presented by formula (10):

$$K_{L6} = 0.0009365 \cdot f^{-1} \cdot F^3 - 2.833 \cdot f^2 - 295.3 \cdot f^{-1} \cdot F^{-3} + 0.725 \cdot f^{-1} + -0.003475 \cdot F^3 + 0.7095 \cdot f \cdot F, \tag{10}$$

where in standard deviation is $s_{L6} = \mp 0.20$.

During experiment models K_{LQ} type achieve high values of correlation coefficients for all Q values (Tab. 5).

Tab. 5. Values of correlation coefficients Wk_{LQ} between results of of experiment (mean for points) and results of approximation by models K_{LQ}

Q	1	2	3	4	5	6
Wk_{LQ}	0.968	0.977	0.981	0.990	0.991	0.998

Must be spotted that (Fig. 2) for $f > 0.5$ values K not depends of value f, and very weakly depends of value F. It creates the question which model is approximating results of experiment the best way. In order to find the answer, analysis of that problem was carried out, doing optimum approximation for points of experiment 4÷12 (Tab. 4), using polynomial elements of Laurent. The set consisted of 9 points. Doing above, one came to conclusion that in the range $f > 0.5$ values K depends only on parameters F (tab. 6).

Tab. 6. Results of approximation for experiment points 4÷12 (Tab. 4) by optimum polynomials at base of binary polynomials of Laurent,S_{9LQ} – sum of squared deviations, s_{9LQ} – standard deviations

q, Q	1	2	3	4	5	6
w_{fq}	0	0	0	1	1	1
w_{Fq}	1	2	0	0	2	1
S_{9LQ}	0.466	0.454	0.199	0.184	0.190	0.026
s_{9LQ}	0.241	0.255	0.182	0.192	0.144	0.093
F	8.67	9.67	4.94	5.48	5.36	1.30
F_{kr095}	2.03	2.10	2.17	2.39	2.44	2.68

Taking under consideration values w_{fq} and s_{9LQ} in subsequent steps of approximation, one can state that in range f $>$ 0.5 walues K depends on walue of parameter F. That relation can be presented in form of monomial second power:

$$K_{9W3} = a_1 + a_2 \cdot F + a_3 \cdot F^2 \tag{11}$$

or

$$K_{9W6} = b_1 + b_2 \cdot F + b_3 \cdot f + b_4 \cdot F \cdot f + b_5 \cdot F^2 + b_6 \cdot F^2 \cdot f. \tag{12}$$

What can be observed comparing criterions F (Tab. 6), model (12) fulfils condition of statistical adequacy, but has to be noticed, that in the range of experiment, number of points can be not sufficient (Fig. 4).

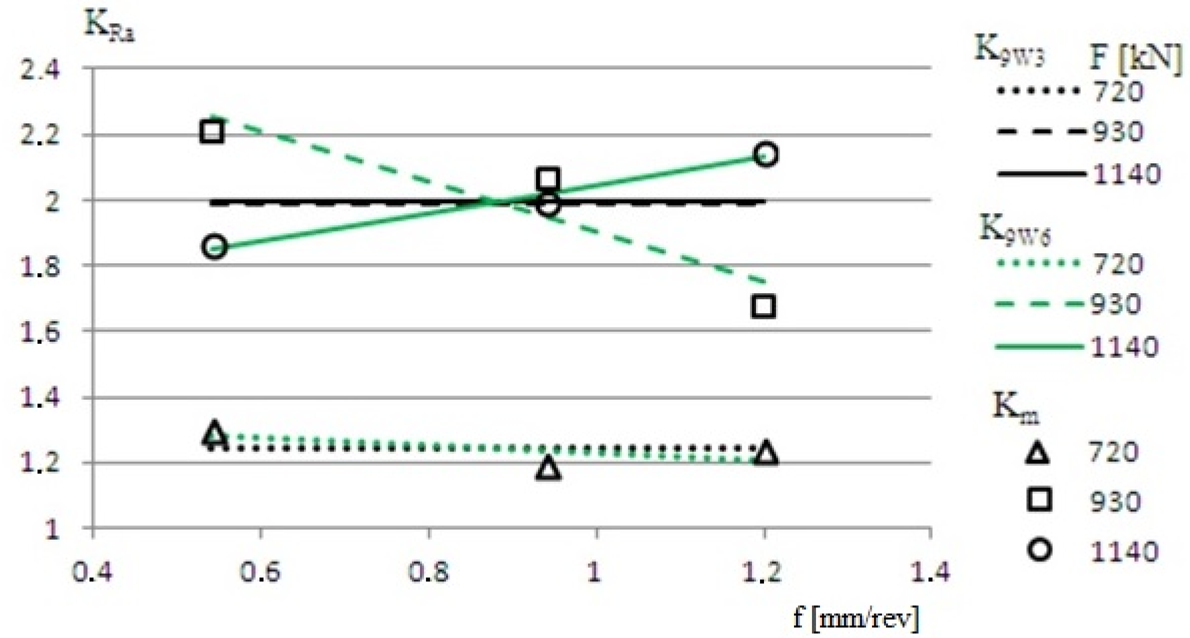

Fig. 4. Comparison of graphs of models K_{9W3} and K_{9W6} for approximation of points in range f >0.5: K_j – mean value K_{Ra} in points of experiment

It seems to be obvious that main part of experiment does not include basic information about models type K_{LQ}, and also about exponential models. That model describes measurement set generally in mathematical sense but not physical aspect. It is possible that physical aspect is also included but its revelation requires additional experiments.

7. Conclusions

In area of experiment, speed of burnish V_n does not affect the value K and model of process is two-dimensional.

Revealed model K_{L6} describing relation K from parameters f and F is linear combination of binary monomials of Laurent. For that model, lower value of standard deviation and lower distance from the critical value of criterion of statistical adequacy was obtained.

In the range $f > 0.5$ values *K* practically do not depend on the parameter *f* and depend weakly on F. Repetition of experiment for $f > 0.5$ is pointless.

In order to get more reliable model one has to increase number of experiments in the range $f < 0.5$.

In experiment (point) 2 significant value of variation occurred. The reason of that could be caused by factors not considered during experiment, for example vibrations.

References

[1] Charchalis, A., Labuda, W., *The analysis of finishing tooling influence on friction factor researched by T-05 tester,* Solid State Phenomena, Trans Tech Publication, Vols. 220-221, part 2, pp. 615-620, Switzerland 2015.

[2] Charchalis, A., Labuda, W., *The analysis of finishing tooling influence on corrosion properties researched by potentiodynamic method,* Journal of KONES Powertrain and Transport, Vol. 19, No. 2, pp. 283-288, Ryn 2012.

[3] Charchalis, A., Labuda, W., *The analysis of finishing tooling influence on corrosion properties researched by EIS,* Journal of KONES Powertrain and Transport, Vol. 19, No. 1, pp. 237-244, Ryn 2012.

[4] Charchalis, A., Labuda, W., *The analysis of finish tooling influence on wear intensity of marine pump shaft,* Journal of KONES Powertrain and Transport, Vol. 20, No. 1, pp. 163-170, Jurata 2013.

[5] Charchalis, A., Starosta, R., Labuda, W., *The analysis of finish tooling influence on contact fatigue of steel applied to sea water pump shafts,* Journal of KONES Powertrain and Transport, Vol. 18, No. 2, pp. 85-92, Kraków 2011.

[6] Charchalis, A., Starosta, R., Labuda, W., *The analysis of the influence of the burnishing process on corrosion propertied of steel applied to sea water pump shafts*, Journal of KONES Powertrain and Transport, Vol. 18, No. 4, pp. 221-228, Kraków 2011.

[7] Enslein, K., Ralston, A., Wilf, H. S., *Statistical Methods for Digital Computers.* John Wiley & Sons, 1977.

[8] Rumszyskij, Ł. E., *Matematiczeskaja obrabotka rezultatow ekspierimenta*, Nauka, Moskwa 1971.