THE INFLUENCE OF BURNISHING PARAMETERS ON THE ROUGHNESS, PLASTIC STRAIN AND SHAPE DEVIATIONS OF MARINE PUMPS CRANKSHAFT PINS IN FRESH WATER INSTALLATIONS

WPLYW PARAMETRÓW NAGNIATANIA NA CHROPOWATOŚĆ, ODKSZTAŁCENIE PLASTYCZNE I ODCHYLEKI KSZTAŁTU CZOPÓW WAŁÓW POMP OKRĘTOWYCH INSTALACJI WODY MORSKIEJ

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Abstract: Angular momentum pumps are frequently applied in marine installations. Due to hard working conditions of these pumps, special corrosion wear resistant materials as well as the ones resistant to electrochemical corrosion caused by sea water are used for their production. In case of pump shafts the most frequent inefficiency is the pin wear (corrosive wear, friction wear and contact wear) in place of sealings assembly (throttle).

Burnishing as finish plastic tooling method enables obtaining machine elements of proper technological quality. Bearing in mind numerous advantages of using burnishing, it is suggested to apply it instead of machining (finish turning, grinding, polishing) to the shafts of marine angular momentum pumps.

The burnishing process was carried out by SRMD single roll burnishing tool by Yamato. The object of the paper was to determine the influence of burnishing parameters and the number of burnishing tool passes on the improvement of roughness, plastic deformation and the shape deviation of marine pumps crank pins.

Keywords: burnishing, surface layer, stainless steel, angular momentum pump

Streszczenie: W instalacjach okrętowych często wykorzystywane są pompy wirowe. Ze względu na trudne warunki ich pracy do budowy tego rodzaju pomp stosuje się materiały odporne na zużycie erozyjne oraz korozję elektrochemiczną wywołaną przez wodę morską. W przypadku wałów pomp najczęstszą niesprawnością jest zużycie czopów (korozyjne, cierne i zmęczenie stykowe) w miejscu montażu uszczelnień (dławic). Obróbka nagniataniem jako metoda wykańczająca obróbki plastycznej umożliwia uzyskanie elementów maszyn o odpowiedniej jakości technologicznej. W związku z licznymi korzyściami stosowania obróbki nagniataniem proponuje się jej zastosowanie w zamian za wykańczającą obróbkę skrawaniem (toczenie wykańczające, szlifowanie, polerowanie) do wałów okrętowych pomp krętnych. Proces nagniatania przeprowadzono nagniatakiem jednorolkowym SRMD firmy Yamato. Celem pracy było określenie wpływu parametrów nagniatania i liczby przejść nagniataka na poprawę chropowatości, odkształcenie plastyczne i odchyłki kształtu czopów wałów pomp okrętowych.

Słowa kluczowe: nagniatanie, warstwa wierzchnia, stal nierdzewna, pompy krętne.

1. Introduction

Pump shafts operating in sea water conditions are subjected to wear corrosion, friction corrosion and erosion corrosion due to difficult working conditions. That is why they are made of materials resistant to corrosion. The application of an expensive material does not prevent its operating damages. The main shaft damages comprise: cracks, plastic deformations, excessive pin wear in rotor disc mounting and in throttles seal, corrosive wear, erosion wear as well as key grooves knock out. Operating experience shows excessive wear of journals which causes the decrease of their diameter and exceeding of permissible shape deviations.

The burnishing process recommended here aims at increasing the operating life of marine pump shafts for fresh water installations which should also give economic effect. Burnishing is one of the mechanical methods of finish treatment which enables achieving surface layer of exceptionally advantageous quality. The review of professional publications has demonstrated three basic aims of applying burnish treatment in the production process of machine elements [1, 2, 3, 4]: smoothness working, strengthening treatment and dimensional – surface finish machining.

Burnishing technology can be utilized in machine production plants for both single and series production. In industrial environment the burnishing process is performed on universal machine tools and on CNC machines but is rated among plastic treatment. It allows to eliminate traditional finish machining such as: super finishing, grinding, honing and polishing. Therefore the final dimensions shaping and functional properties formation by burnishing is a chipless and dustless treatment which qualifies it for ecological treatment method [5]. Burnishing process enables surface working at high dimensional precision (accuracy class 7 and 6) which makes it possible to achieve many advantages such as :

- ability to reach low roughness surface ($R_a = 0,32 - 0,04 \mu m$) and high bearing surface of roughness profile (90%),
- surface hardness increase,
- wear resistance increase,
- increase of abrasive and mashing wear resistance,
- corrosion resistance increase,
- no abrasive grain, sharp and hard built-up edge fragments and chips on burnished surface,
- application of burnish tools on universal lathes (the concept of one stand working),
- elimination or decrease of the time consuming operations such as: honing, lapping, grinding and polishing,

- ability to eliminate heat treatment in specific cases,
- high process efficiency (one working transition of a tool) and production costs reduction,
- high durability of burnishing tool.

Burnishing treatment research and its influence on surface layer are being conducted in many scientific centres all over the world and their research programs deal with matters related to burnishing of cast iron [6], some heat resisting alloys, stainless steels, copper and aluminium alloys [3,4], titanium and its alloys [7] as well as galvanic coatings, diffusive and padded coatings and parts produced by sintering metal powders.

Within the research an optimization of technological parameters of burnishing was performed and the influence of the number of burnishing tool passes on the stereometric parameters of centrifugal pumps shaft pins was determined. The burnishing process is to be conducted thanks to the reduction of roughness index R_a . Another essential condition of technological process is to define the influence of burnishing parameters on plastic deformation and shape deviations of steel used for marine pump shafts.

2. Samples preparation

The rollers of X5CrNi1810 stainless steel were initially machined in order to prepare the shaft pins for burnishing. The turning process was carried out on a lathe TUC 40 type by a cutting tool with removable plates WNMG 080408 WF type by Sandvik Coromant (Fig.1) During turning the following machining parameters were applied: machining speed $V_c=112$ m/min, rate of feed $f=0,27$ mm/rev and machining depth $a_p=0.5$ mm.

Fig.1. The view of working assembly (machine tool, fixture, object, tool):
1-TUC 40 lathe, 2- catch plate, 3- machined object, 4- turning tool, 5 – tool post

3. Research methodology

The process of burnishing was conducted by a one roll burnish SRMD type by Yamato. Shaft pins of ϕ 39 mm diameter were burnished. The technological process parameters applied for surface plastic treatment are shown in Table 1.

Tab. 1. Technological parameters of burnishing process

Parameter		Values
Burnishing force - F	[kN]	0,7; 0,9; 1,1
Burnishing speed - V_c	[m/min]	35; 56; 88; 112
Feed - f	[mm/rev]	0.13; 0.54; 0.94; 1.2

The surface roughness was measured by HOMMEL TESTER T 1000 profile meter. The measuring length of test sample amounted to 4,8 mm, while the sampling length was 0.08 mm. On the basis of the results achieved, the surface K_{Ra} roughness reduction index was define:

$$K_{Ra} = \frac{R_a'}{R_a} \quad (1)$$

where:

K_{Ra} - surface roughness reduction index

R_a' - material surface roughness,

R_a - material surface roughness after surface plastic treatment.

The R_a parameter measurement was conducted in order to carry out research on the choice of burnishing parameters leading to the achievement of best roughness surface. However parameter R_t was to define the influence of the burnishing tool on plastic deformation and consequently on the smoothness of surface roughness peaks.

Establishing the influence of the number of burnishing tool passes on the change of surface roughness reduction index K_{Ra} will be carried out by means of experimental research based on Hartley system [8, 9,]. The research plan system utilizes three values of each quantity measured. The maximum value is marked "+1", the middle value is "0", and the minimum value is "-1".

The results that define surface roughness underwent statistic analysis of multiple regression in order to determine their influence on the properties measured. The calculations were made by computer program Statistica 5.5. Due to different independent variables, the influence of particular

parameters was analyzed on the basis of standardized regression index (BETA). The diameter was measured by transameter at the measuring accuracy of 0,002 mm in longitudinal and transversal cross-sections shown in figure 2.

Fig. 2. Measurement of marine pumps shafts pins

Microscope examinations of pins transversal sections were done by scanning electronic microscope (SEM) Philips XL30.

4. Research results

It is possible to conduct a burnishing process of a corrosion resistant steel X5CrNi1810 for the purpose of decreasing the value of mean arithmetic roughness profile R_a [10]. The technological process aiming at achieving low surface roughness should be performed with the greatest burnishing force possible and the lowest feed.

The research program and the determination of the influence of burnishing tool passes number on the change of surface roughness reduction index K_{Ra} was presented in table 2.

Tab. 2. The research program of the influence of chosen burnishing parameters on roughness reduction index value (K_{Ra})

Test No.	Hartley plan system			Hartley plan completion		
	x_F	x_{LP}	x_f	Force F [N]	Number of burnishing tool passes LP	Feed [mm/rev]
1	-1	-1	-1	720	1	0.13
2	+1	-1	-1	1140	1	0.13
3	-1	+1	-1	720	4	0.13
4	+1	+1	+1	1140	4	1.20
5	-1	0	0	720	2	0,54
6	+1	0	0	1140	2	0,54
7	0	-1	0	930	1	0,54
8	0	+1	0	930	4	0,54
9	0	0	-1	930	2	0,13
10	0	0	+1	930	2	1,20
11	0	0	0	930	2	0,54

According to Hartley plan for the K_{Ra} parameter, the technological burnishing process was carried out at constant burnishing speed value $V_n = 35$ m/min. Other parameters used in the burnishing process are shown in table 3.

Tab. 3. Technological parameters of burnishing process for K_{Ra} according to Hartley

Parameter		Values
Burnishing force - F	[kN]	0.7; 0.9; 1.1
Feed - f	[mm/rev]	0.13; 0.54; 1.2
Number of passes - LP	[-]	1; 2; 4

The influence of burnishing parameters on the surface roughness reduction index was defined by means of multiple regression analysis. Table 4 contains the values of standard regression indices (BETA), multiple regression indices (B), and the levels of importance. Constant coefficients take the following respective values: correlation coefficient $R=0,67$, coefficient of determination $R^2=0,46$ and estimation error $R^2=0,46$.

Tab. 4. The results of K_{Ra} parameter statistic analysis for variables presented in table 3

	BETA	B	level p
Free term		-4.87	0.53
Burnishing force – F	0.51	0.01	0.13
Number of passes - LP	-0.02	-0.08	0.94
Feed- f	-0.65	-7.09	0.07

Feed shows the greatest influence of the analyzed burnishing process parameters on K_{Ra} value, which is reflected in the value of standard regression index (BETA) that equals -0,65. The lower the feed value applied in the burnishing process, the lower the value of mean arithmetic roughness profile R_a . The second significant parameter having an impact on the quality of the surface achieved and as a result on the parameter K_{Ra} is the burnishing force. It can be demonstrated by the value obtained for standard regression index (BETA = 0,51). When the value of burnishing force increases the value of parameter R_a drops. The BETA value = -0,02 for the number of passes indicates its lowest influence on the value of surface roughness reduction index. The results obtained prove a considerable influence of the burnishing parameters on the optimization process of burnishing technology for parameter K_{Ra} .

The values of importance factors (level p) on independent variables of coefficient K_{Ra} are over 5 %. This results from a small number of

measurements results that underwent statistic analysis. In order to prove the influence of burnishing tool passes number on the surface layer, a test of 4 burnishing passes was conducted at optimum burnishing parameters obtained during optimization research. And so, for the technological process aiming at achieving the highest surface roughness reduction index K_{Ra} – it is necessary to apply the highest burnishing force possible ($F = 1140$ N), and the lowest feed ($f = 0,13$ mm/rev). The influence of burnishing tool passes number on parameter R_a value is shown in figure 3. The results obtained confirm the assumed experiment plan according to Hartley showing little influence of burnishing tool passes number on the surface smoothness obtained. The first pass of burnishing tool demonstrates the greatest influence on roughness reduction index K_{Ra} . Consecutive passes also cause the reduction of R_a parameter but are not as significant as in the first cycle.

Fig. 3. The influence of burnishing tool passes number on roughness reduction index value (K_{Ra})

The mean value obtained for parameter $R_t = 5,12$ μm after initial machining and the mean value after burnishing $R_t = 0,72$ μm prove the planishing of surface roughness peaks. The burnishing tool triggers plastic deformation of material roughness peaks causing its indentation in surface roughness valleys.

After burnishing operation the surface roughness R_a obtained for all shaft pins was in the range of $0,06 \div 0,87$ μm . The diameter measurements

obtained for burnishing parameters aiming at reaching the lowest surface roughness value ($R_a = 0,06 \div 0,09 \mu\text{m}$) are presented in table 5.

Tab. 5. Mean diameter value for lowest R_a value

Burnishing speed [m/s]	Feed [mm/rev]	Force [N]	Mean diameter value before burnishing [mm]	Mean diameter value after burnishing [mm]
35	0.13	1140	39.452	39.450
56	0.13	1140	39.588	39.586
88	0.13	1140	39.584	39.582
112	0.13	1140	39.582	39.578

The cross section structure of the sample examined, for which the highest surface roughness reduction index K_{Ra} was obtained is shown in figure 4. The metallographic research results analysis did not prove any changes in surface layer structure. The diameter micrometer changes of pins subjected to burnishing are most probably connected with low plastic strain of surface roughness peaks.

Fig. 4. View of sample surface section a) before burnishing b) after burnishing

The measurements of diameter and shape deviations obtained after lathing process are presented in table 6 whereas measurements of diameter and shape deviations after burnishing for the roughness highest surface reduction index K_{Ra} are presented in tab. 7.

Tab. 6. Shape deviations before burnishing

Diameter before burnishing [mm]			Ovality deviation	Rolling deviation	
				Cross section	
section	I-I	II-II		I-I	II-II
A-A	39.584	39.584	0.000	0.005	0.005
B-B	39.588	39.588	0.000		
C-C	39.594	39.594	0.000		

Tab.7. Shape deviations after burnishing for the highest K_{Ra}

Diameter before burnishing [mm]			Ovality deviation	Rolling deviation	
				Cross section	
section	I-I	II-II		I-I	II-II
A-A	39.582	39.580	0.000	0.005	0.005
B-B	39.586	39.584	0.000		
C-C	39.592	39.590	0.000		

5. Conclusions

The application of burnishing process for corrosion resistant steel X5CrNi1810 with the use of single roll burnishing tool SRMD by Yamato makes it possible to decrease the value of mean arithmetic surface roughness profile R_a . The technological process aiming at reaching the lowest surface roughness value should be conducted with the highest burnishing force possible and the lowest feed. The number of burnishing tool passes does not have a considerable influence on the technological process trying to obtain the highest K_{Ra} value. The first pass of a burnishing tool has proved to be the most effective for roughness reduction index. K_{Ra} . The application of burnishing process for corrosion resistant steel X5CrNi1810 enabled the reduction of roughness value without surface layer plastic deformations which was reflected in the results of diameter measurements and metallographic examinations. The technological process of marine pumps shaft pins production by means of burnishing does not require big allowances for finish tooling which constitutes maximum 0,006 mm. The pins should be manufactured at their assumed accuracy class before burnishing with SRMD tool. Moreover, the burnishing process does not influence the shape deviations, which do not change considerably before and after burnishing or are in the range of measuring error.

6. References

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