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RESEARCH ON MACHINING OF DIESEL ENGINE CRANKSHAFT JOURNALS SURFACES

Promotion work abstract

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GENERAL DESCRIPTION OF THE PROMOTION WORK

Actuality of theme

The theme chosen for promotion work, namely, "Researches on machining of diesel engine crankshaft journals surfaces" is closely related with one of Latvia's significant manufacturing industry branch - ship building and ship repair. When the ship's diesel engine repairs are carried out crankshaft journal (bearing) surfaces must be renewed according very precise geometrical and surface roughness requirements. Currently technologies available for ship repair enterprises are sufficient to ensure these requirements, however, they are very time consuming and consequently expensive. Therefore it is necessary to undertake comprehensive research of the shipboard diesel engines crankshaft journals surfaces machining. This will allow to improve technological processes and to identify respective surface roughness parameters as well as to give adequate technological recommendations. It is important to note that crankshaft bearing surfaces must be seen as three-dimensional object with definition of microtopographical surface roughness parameters which reflect to real surface. To summarise all available scientific researches in this field it is stated that there are no analysis given regarding impact of technological regimes to the shipboard engines crankshaft journals surface microtopography.

Taking into consideration the above mention arguments in the promotion work new technological approach has been used, which significantly simplifies technological work and allows crankshaft journal grinding performing inside the housing without removing it from engine. This technology saves significant financial resources as well as time of engine repair itself.

Promotion work contains actual production assignment with practical implication. Solving problems related with surface accuracy it is possible to considerably improve the crankshaft machining process as well as performance of maintenance operations and consequently overall quality of repair works.

Work objective

Main objective of promotion work is to perform research regarding diesel engines crankshaft journals surface machining. To reach this objective the following tasks were identified:

1. To create the microtopographical roughness model of the crankshaft journal surface;
2. To calculate the most important microtopographical parameters which are based on relatively simple metrological and technological characters as well as able describe the real surface of crankshaft journals;

3. To create appropriate technological equipment for grinding of the crankshaft journals;
4. To investigate the correlation between the three-dimensional surface roughness parameters and technological regimes of crankshaft journals machining;
5. To carry out experiments with new developed grinding device, to establish conclusions and practical recommendations regarding reasonable choice of technological regimes.

Research methodology

Research of the diesel engines crankshaft journals surface roughness was based on theory of contingency fields, which gave opportunity to create the credible (maximally close to the real conditions) model of surface roughness and microtopographical surface roughness parameters related to this model.

Analysis of technological regimes to the microtopographical surface roughness parameters has been done by using methods of experiment planning and with "Microsoft Access" & SPSS v.12.0 assistance.

Scientific innovation and general results

New three-dimensional surface roughness model, and its microtopographical surface roughness parameters, which are suitable for diesel engine crankshafts bearing surfaces were developed in the promotion work.

The novel technological equipment for diesel engines crankshaft bearing surfaces (journals) grinding has been elaborated. With this equipment it is possible to carry out the crankshaft crank pin journals grinding in the engine housing without crankshaft dismantling from engine.

Multifactorial analysis of the impact of technological regimes to the three dimensional surface roughness parameters of the diesel engines crankshaft bearings has been undertaken.

The above mentioned results of promotion work are a new contribution to the mechanical technology science.

Practical value

Technology which is developed in the promotion work is applicable generally to the medium size shipboard diesel engines with crankshaft journal diameter from 100 up to 350 mm. This innovative technology allows repairs to the crankshaft to be carried out without removing it from the engine, and, in addition, making unnecessary to dismount the whole engine.

Furthermore, when the above mentioned technology was used for grinding of the crankshaft journals, the geometrical form and surface roughness of bearings fully complied with the established technical requirements.

Thus promotion work gives efficient solution for crankshaft bearing machining problems which allow significantly decrease maintenance time of ship engines and to save considerable financial resources.

Results of this promotion work can be used in the Latvian ship building and ship repair enterprises for diesel engines repairs.

For defence the following results are taken out:

1. Microtopographical model of the diesel engines crankshaft surface roughness;
2. Elaborated device for crankshaft journals surface grinding and related machining technology;
3. Developed grinding device technological regimes impact to the microtopographical surface roughness parameters R_{aT}, S_{m1}, and S_{m2};
4. Technological recommendations regarding ensuring of the microtopographical surface roughness parameters R_{aT}, S_{m1}, and S_{m2} optimal values.

Approbation of work

The basic scientific achievements and results of promotion work have been reported and have received positive evaluation at the following conferences and seminars:

In Latvia:

- RTU 42nd and 43rd students' scientific and technical conference. RT1 Riga. 2001 and 2002.
- RTU 43rd and 45th international scientific conference. Riga. 2002 and 2004.
- RTU Seminar of the Institute of Mechanical Technology. Riga. 12 May 2005.

Abroad:

- XIX International conference of World Association for Case Method Research and Case Method Application. Long term Responsibility for Sustainable Life. Brno. Czech Republic. August 07. - 11. 2002.
- 47. Internationales Wisseschaftliches Kolloquium. Ilmenau. Germany. September 23. - 26. 2002.

- Fourth International Congress: Mechanical Engineering technologies '04. Varna. Bulgaria. September 23 - 25. 2004.

- 10th International Conference "Metrology and Properties of Engineering Surfaces". Saint Etienne, France, July 4-7, 2005.

- International Conference Polycomtrib - 2005. Gomel, Belarus, July 18-21,2005.

- 4th DAAAM International Conference on Advanced Technologies for Developing Countries. Slavonski Brod, Croatia, September 21 — 24, 2005.

- 9th International Research / Expert Conference: Trends in the Development of Machinery and Associated Technology. TMT 2005, Antalia, Turkey, September 26 - 30, 2005.

Elaborated grinding device has been certified by the Russian Maritime Register of Shipping: certificate No 01.01522.123.

Publications

Six scientific articles devoted to the promotion work issues and overall results have been published (see page 23).

Structure and volume of work

Promotion work is written in Latvian, consist of the introduction, six chapters, conclusions, list of literature, 2 annexes, 36 figures, 9 tables, all together 106 pages. List of literature contains 124 articles.

CONTENT OF WORK

In **Introduction** the actuality of promotion work theme and its practical application is described. It was stated that if problems related with the surface accuracy are solved, it will be possible to develop crankshaft machining processes and reduce repair costs as well as considerably improve overall quality of crankshaft repairs.

In the **First chapter** the review of literature is done. It contains the following subchapters:

- Analysis of existing surface roughness standards;
- Overview of available scientific researches devoted to the surface micro-topographical roughness parameters;
- Ability of technological equipment to ensure the necessary surface roughness parameters;
- The main objectives of promotion work.

Comparing surface roughness parameters which are included in the world's standards, it is concluded that ISO and industrially developed countries national standards prescribe almost identical surface roughness parameters. Furthermore, above mentioned standards characterise surface roughness only in profile. All these surface roughness parameters can be divided into three groups: *height* parameters, *spacing* and *shape* parameters. The shape parameters often are called also as *hybrid* parameters. It is stated that whole worlds industry in practice so far using parameters which describing surface roughness in the one sectional plane so called profile parameters or two-dimensional surface roughness parameters. Currently in Latvia adapted ISO standards are official ones. The following ISO standards in force covering geometrical products specifications: LVS EN ISO 1302:2002; LVS EN ISO 4287:2002; LVS EN ISO 4288:2002; LVS EN ISO 11562:2002; LVS EN ISO 11562:2002; LVS EN ISO 12085:2002. It is important to note that also these standards characterising surface roughness only in profile.

Furthermore standards, which are devoted to characterize microtopographical surface roughness, currently are only at the development stage. It is foreseen that three-dimensional surface roughness ISO standards will be implemented not earlier that in 2006 / 2007.

Nevertheless, surface of internal combustion engine crankshaft in reality is spatial object. Therefore this particular surface also should be approached spatially - in three dimensions. Topographical method of surface analysis apart of usual surface roughness parameters approach allows to describe particular surface sufficiently and completely, which respects to real surface conditions. Scientists from several countries were researched this issue and many scientific publications, articles and books are written on this subject. The following authors with the most important theoretical researches in the particular field can be distinguished: J. Rudzitis, N. Djomkin, E. Rizov, T. Tomass, V. Likianov, A. Husu, J. Schneider, P. Nayak, D. Whitehouse, Q. Chen, W. Dong, P. Sullivan, K. Stout, L. Blunt, X. Yang and D. Butler. Promotion work contains analysis of scientific publications written by the above mentioned authors and it is stated that none of them have researched shipboard diesel engines crankshaft surface roughness in the three-dimensions. It is concluded that J. Rudzitis and V. Lukianov offering rather simple methodology for determination of surface microtopography. Furthermore these scientists based their theory on the three-dimensional parameters R_{aT}, S_{ml} and S_{m2} which can be measured in practice and are technically realisable. From these three parameters, within the framework of this particular model, it is possible to derive all other necessary three-dimensional parameters. Therefore, in the future researches of crankshaft journals surface roughness parameters, the microtopographical approach oh J. Rudzitis and V. Lukianov has been used.

Several theoretical end experimental researches are available now. The following topics in these researches were explored: grinding processes, grinding stone wear, correlations of macro and micro relief formation, temperature fluctuations in the contact zone between grinding stone and surface, vibrations of grinding stone, etc. Substantial researches in the area of technological ensuring of surface roughness parameters have been done by N. Diomkin, E. Rizov, Z. Prusak, and A. Aleksejev. These authors looked at correlations between parameters of grinding process and grinding technological regimes. Nevertheless, because of complexity of calculations and insufficient analysis of impact to the spatial parameters (S_{m1} and S_{m2}) only researches of E. Rizov and A. Aleksejev can be used. In the sixth chapter of promotion work the formulas offered by these authors were examined as well as their practical applicability to this work.

In the conclusion of the literature overview it is noted that currently scientific researches analysing impact of technological regimes to the shipboard diesel engines crankshaft journals surface microtopography, are not available.

The overview of literature allows formulation of the main tasks of the promotion work. These tasks are already mentioned in the work objectives.

In the **Second Chapter** the model of crankshaft journals surface roughness was determinate. This mathematical model of the surface roughness should be complete enough to describe the real surface and in the same time simple enough to be practically applicable. In order to successfully work out the crankshaft journals surface roughness model, in the promotion work classification of rough surfaces and research of irregular roughness model have been done.

It the promotion work was defined that every type of mechanical machining and surface creation process has their own, unique surface roughness topography. However, all mechanically processed surfaces principally can be divided into two groups: isotropic and anisotropic surfaces. The *Isotropic* surface is surface whose roughness parameters in the all directions are the same but for anisotropic surface the roughness parameters are different depending on measuring direction.

Isotropic roughness structure is typical for details which surface is machined by following methods: electro-erosion, sand or pellet blasting, vibro — abrasive, polishing and scraping. But anisotropic surface structure is characteristic for surfaces machined by different abrasive methods, e.g. grinding, superfinish, rolling and broaching, etc.

Despite the above mentioned classification surfaces with the identical structure can have absolutely different character of surface inequalities. Therefore, in this research the detailed surface irregularities classification were done. Generally by surface roughness mathematical functions these surfaces can be divided into three groups, namely, with regular character, irregular character and mixed type. The regular type of irregularities characterises by periodical bodies of inequalities which are very similar and in the first approximation can be described by the periodical mathematical function. But the irregular type of inequalities characterises with irregular height and form of roughness. Furthermore, mixed type of profile is forming when regular and irregular character factors are combined, in fact this type is allocated between both above described kinds of irregularities.

According above described classification, the shipboard diesel engines crankshaft journals machining with the mechanical grinding method, can be looked as anisotropic surface with irregular character of surface roughness. This kind of surface can be described by the normal distribution (Gaussian) low. It was determinate, that the optimal microtopographical model of the particular surface is composed by the following parameters: roughness height parameter R_{aT} and two spacing parameters S_{m1} and S_{m2}. Moreover, the measurement basis for these roughness parameters is a mean plane of overall roughness. More detailed analysis of the chosen three-dimensional roughness model is given in the future chapters of promotion work.

In the **Third chapter** topographical parameters of the crankshaft journals surfaces are defined. None of these parameters are currently foreseen in the any of technical standards. Therefore, mathematical calculations of these surface roughness parameters were done, based on real metrological and technological surface parameters of the crankshaft journals.

The formulas of the surface roughness parameters R_{aT}, S_{m1} and S_{m2} (basic parameters) were determinate. The microtopographical surface roughness height parameter:

$$R_{aT} = \frac{1}{A} \iint_{\Omega} |h(x,y)| dxdy \ ,$$

where: A — area of the viewed surface, mm^2;
$h(x,y)$ - surface roughness (points) deviation from the mean plane, in coordinates x and y.

Topographical spacing parameters S_{m1} and S_{m2}:

$$S_{m1,2} = \frac{2}{n(0)_{1,2}} \ ,$$

where: $n(0)_{1,2}$- number of ,,zeros" within one length unit, when the profile crosses the mean plane in the two perpendicular directions to each other.

In the Fourth chapter the overall correlations between crankshaft journals surface roughness parameters and its grinding technological regimes have been done. Furthermore, technical requirements for the shipboard diesel engines crankshaft journals repairs were defined.

Naturally, the crankshaft is one of the most important internal combustion engine parts. Nevertheless, the crankshafts have very high geometric and tolerance precision requirements:

- R_a = 0,32 μm — for crank pins with diameter up to 100 mm;
- R_a — 0,63 μm — for crank pins with diameter above 100mm;
- R_a = 1,25 μm — for the all crank /main/ journals.

It is stated, that ensuring of the necessary surface roughness values is based on researches of the theoretical and experimental connectedness. Several works offered the empirical connections between the technological regimes and the number of surface roughness parameters. Nevertheless, the most appropriate for the real working conditions of crankshafts grinding are the empirical formulas of the microtopographical surface roughness parameters offered by Prof. E. Rizov and A. Aleksejev.

Abbreviations of the technological regimes in the formulas were substituted according to the real regimes for crankshaft grinding. Thus the formulas of A. Aleksejev are following:

$$R_{aT} = 0,44 \frac{S_{rad}^{\ 0,34} t^{0,17} Z^{0,43}}{V_{\det}^{\ 0,01}} \ ;$$

$$S_{m1} = 0{,}083 \frac{S_{rad}^{\ 0{,}22} t^{0{,}2} Z^{0{,}09}}{V_{\det}^{\ 0{,}07}};$$

$$S_{m2} = 0{,}037 \frac{S_{rad}^{\ 0{,}18} t^{0{,}21}}{V_{\det}^{\ 0{,}42} Z^{0{,}9}},$$

where: S_{rad} -radial feeding of the grinding stone (mm/move);
t - grinding depth (mm);
Z — grinding stone graininess;
V_{det} - longitudinal feeding speed of detail /device/ (m/min).

Analysis of these formulas is given in the sixth chapter of the promotion work, but respective principal schema of the grinding process is shown in the Figure 1.

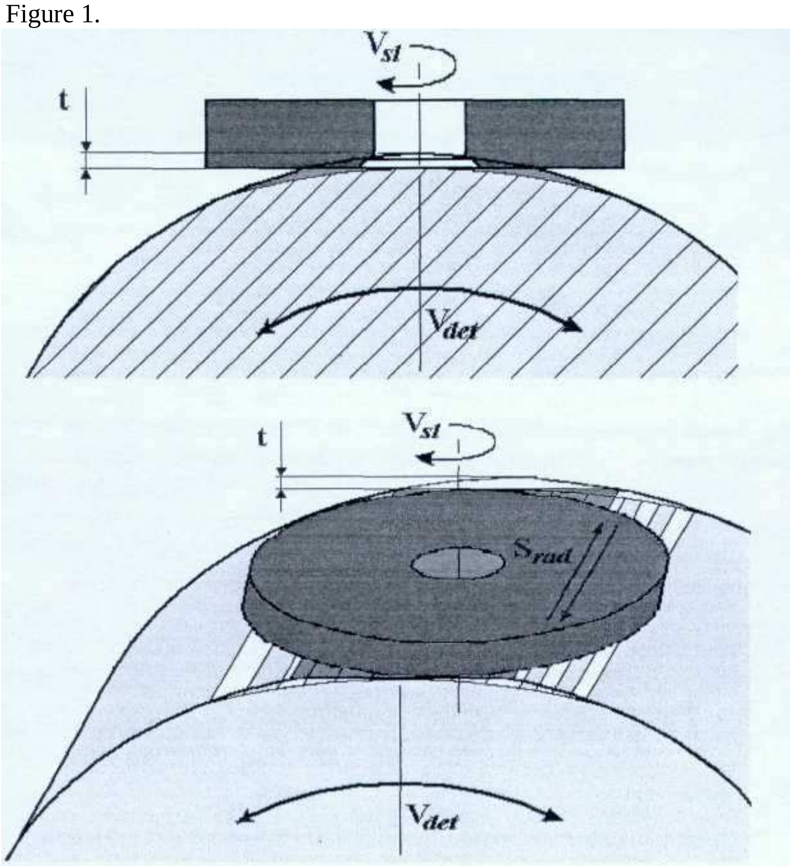

Figure 1. Principal scheme of grinding process.

In the Fifth chapter the description of crankshaft journals grinding devise was given; it contains the following subchapters:

- application and working principles of the grinding device;
- principal construction and main technical parameters of the grinding device;
- safe and effective usage of the grinding device.

The grinding device (see figure 2) is elaborated for crank pin journals grinding to the next "repair" dimensions or into any other dimension when geometrical and surface roughness parameters should be renewed. Furthermore, when the grinding operations are carried out the grinding device is based directly on crankshaft journal, with previous dismantling of the connection road and bearing liners. It is important to note that grinding device also can be used for machining of the crankshaft main journals - in this case crankshaft should be centred in the stationary turning machine.

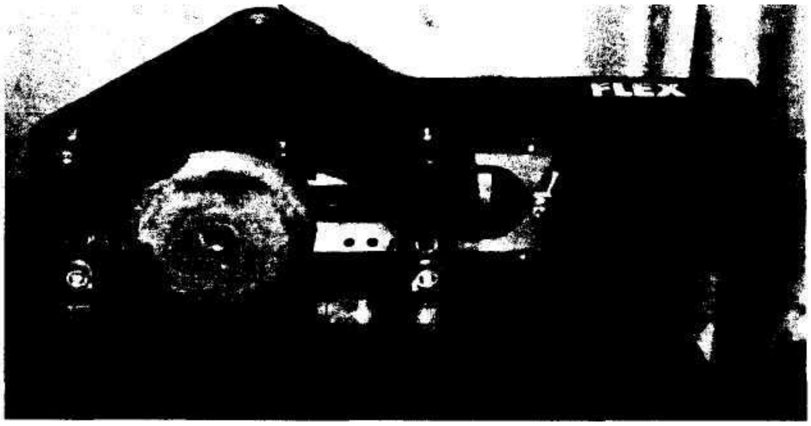

Figure 2. Modification of grinding device for machining of Ø120 mm journals

In principle by changing of the base rings and liners of the grinding device (depending of journal dimensions) it is possible to use this grinding device for machining of any type of diesel engines crankshafts. However additional difficulties occur when is necessary to process very small (journal Ø < 100 mm) and very large (journal Ø > 350 mm) crankshafts.

The renewable crankshaft journal surface is abrasively processed by the flat surface of grinding stone. Such kind of abrasive stone placement is unusual for grinding operations, however, only in this way it is possible to carry out crankshaft journals grinding in very limited space (inside the engine housing). Nevertheless, relatively small diameter and specific position is compensated by the high rotation speed of the grinding stone.

Feeding motion of grinding device is ensured manually by operator, who steady moves the device in parallel to machining surface and in the same time performing cyclic round-shape motions. The grinding depth is fixed by the special adjustment plates and screws. In exceptional cases, when at the end of machining is necessary to achieve the very smooth surface it is possible to use the special polishing discs and polishing pastas. Furthermore, the grinding device fully ensured necessary accuracy of the geometrical and surface roughness parameters in accordance with the technical requirements for this type of repair operations. The elaborated device is experimentally tested in production and fully proved its efficiency.

The grinding device is electro-mechanical hand instrument, whose principal construction is relatively simple and safe. Its main parts are following: drive mechanism, reduction gear, base plate, regulation and basing system, grinding stone, fixing mechanism and iron ring of grinding stone, load control gauge, as well as complimentary equipment.

The grinding stone placed in the iron ring by assistance of the bronze bushing is fixed on the drive shaft of mechanical reduction gear. Sufficient and tight connection between grinding stone and drive shaft is achieved by usage of special fixation nut. The drive mechanism is connected with the basic plate of grinding device on which in its turn is fixed regulation and basing system. Thus the orientation of the grinding stone towards the crankshaft journal surface is ensured.

Elaborated grinding surface is innovative, there are no known analogical in the ship repair, therefore it is important to understand and follow to the specific requirements which are foreseen for the work with this device as well as scrupulously perform the technical maintenance of equipment. In order to ensure successful and safe machining of crankshafts, description of technological principles and the most important safe-work requirements are given in the promotion work.

The analysis of the technological regimes impact is made in the **Sixth chapter.** The main purpose of this chapter is to evaluate and crosscheck the microtopographical roughness model (chosen in the previous chapters) and its mathematical calculation formulas compliance with real conditions of the crankshaft journals machining, grinding technology and elaborated special equipment.

In the promotion work it was stated, that for this research most appropriate grinding technological regimes and surface roughness parameters correlations have been created by A. Aleksejev and E. Rizov. In this chapter applicability of above mentioned correlations to shipboard diesel engines crankshaft journals grinding with elaborated grinding device were analysed.

This kind of basic parameters calculation formulas examination allows adapting these equations to the real working conditions. The basic parameters calculation formulas were exanimate by computer programmes with creation of respective graphical images. These graphs clearly illustrate impact of technological regimes to formation of the roughness parameters R_{aT}, S_{m1} and S_{m2}. Thus it is possible to define the technological regimes which have the most important role in the formation of basic parameters as well as to identify those parameters which are not so important.

To fulfil above mentioned complex examination of R_{aT}, S_{m1} and S_{m2} calculation formulas it is necessary to put in place the real values of this specific grinding process. Respective values of grinding device's technological regimes were obtained in practical work at „Rēdertehserviss" Ltd. These values are following: t = 0,01 mm ÷0,1 mm, Z = 6 ÷ 50, V_{det} 5 ÷25 m/min and S_{rad} 1 ÷10 mm/move; but the principal scheme of grinding process is shown on figure 1. The same values of the technological regimes were used when grinding device was certified by Russian Maritime Register of Shipping. The technological design of the grinding device foresees the mechanical setting of the t and Z values, but V_{det} and S_{rad} are manual regimes.

The complex analysis of the technological parameters impact to the surface roughness height parameters clarifies, that the main technological objective (for crankshafts with diameter above 100 mm) is to achieve values of basic parameters which are not bigger than: R_{aT} < 0,63 urn, and to maintain the empirical connectedness $R_{aT} / S_{m1} \leq 200$. Thus it is known what should be results of R_{aT} calculations.

All possible (5000) technological regimes combinations were applied to the R_{aT} calculation formula. Furthermore, the appropriate data base was created and results were analysed with the "Microsoft Access" and graphs were created too. These graphs illustrate how technological regimes of grinding influence the formation of R_{aT}. According graphs in conformity with the empirical formula of A. Aleksejev it is clear that values of R_{aT} by result of complex impact of technological regimes are fluctuating in the limits from 0,42 to 3,44 microns. Theoretically the minimal value of R_{aT} = 0,42 (im is achievable by applying the following grinding regimes: V_{det} = 25 m/min, S_{rad} = 1 mm/move, t = 0,01 mm, Z = 6. But the maximal value of R_{aT} = 3,44 um appears by the technological regimes combination: V_{det} = 5 m/min, S_{rad} =10 mm/move, t = 0,1 mm and Z = 50. However, only very limited combinations of technological regimes ensure the necessary microtopographical surface roughness height values.

Analysing the results of R_{aT} calculation formulas it is possible to affirm that the main technological factors influencing formation of R_{aT} are radial feeding S_{rad} and graininess of grinding stone Z. Additionally, only minimal values of the crankshaft journals grinding regimes gives the appreciated result - achieving of necessary R_{aT} values. However, taking into account that formulas offered by A. Alksejev are empirical, the compliance with the exact crankshaft machining conditions can be incomplete. Therefore when in the promotion work the theoretical analysis of technological regimes impact were carried out, the additionally R_{aT} calculation formulas offered by E. Rizov were analysed. This analysis had shown that in conformity with E. Rizov's calculation formula of R_{aT} almost all combinations of technological regimes ensure condition R_{aT} 0,63 μm. Naturally, the maximal values of R_{aT} - can be exceeded only when proceeding is realised with radial feeding S_{rad} = 9 ÷ 10 mm/move and in the same time using medium graininess grinding stones (Z = 32, 40 un 50) and maxima grinding depth *(t* = 0,09 ÷ 0,1 mm).

Based on the analysis of Prof. E. Rizov empirical formula for R_{aT} calculation was deducted that theoretically condition $R_{aT} \leq 0{,}63$ um will be maintained by any combination of technological regimes when the following conditions are fulfilled $S_{rad} \leq 8$ mm/move and Z = 6 ÷ 25. Nevertheless, the bigger radial feed and graininess values are not recommendable. Furthermore, analogically like in case of A. Aleksejev formula the biggest impact to the R_{aT} formation has radial feeding S_{rad} and girding stone graininess Z; grinding depth *t* and longitudinal feeding speed V_{det} have rather small influence.

When <u>the analysis of complex impact of the technological regimes to the surface roughness spatial parameters</u> was made, it is concluded that technical rules for crankshaft repairs did not regulate maximum values of parameters S_mj and S_{m2}. Nevertheless, it is important to maintain proportional balance between spatial parameters and basic values of R_{aT} , namely: $S_{m]}$ / R_{aT} and $c = S_{ml} / S_{m2}$.

In conformity with Prof. J. Rudzitis researches for grinding operations these proportions are following: S_{ml} / R_{aT} =10÷190 and c = 0,5 ÷ 0,7. Furthermore proportion $c = S_{m1} / S_{m2}$ usually is named: the anisotropy or heterogeny of the microtopographical spatial parameters. Thus theoretically is known what should be the ratio between the S_{m1} and S_{m2} calculation formulas results.

Analogically like in case of R_{aT} calculation formulas, also complex theoretical analysis of technological regimes impact to formation of S_{m1} and S_{m2} were made. The real grinding technological regimes (see table 1 and figure 1) were used in A. Alekseev' formulas. It was cleared up, that according A. Aleksejevs' empirical formulas the average values for surface spacing parameters between the peaks S_{m1} are fluctuating between 0,03 and 0,11 millimetres. The minimal values of S_{m1} = 0,03 is possible achieve when the following grinding regimes are applied: V_{det} = 10 m/min, S_{rad} 1 mm/move, *t* = 0,01 mm, Z = 6. But the maximal value of $S_{m]}$ = 3,44 mm arose by following combination: $V_{det} = 5$ m/min, S_{rad} =10 mm/move, *t* = 0,1 mm and Z = 50. Additionally it is possible to conclude that technological regimes which theoretically ensure the minimal and maximal values of S_{m1} are analogical like for parameter R_{aT}. Furthermore in conformity with researches of J. Rudzitis, the achieved results of S_{m1} comply with common engineering practice and are reliable.

Clarified that the most important technological factors influencing creation of S_{m1} are radial feeding S_{rad} and grinding depth *t*. By increasing of radial feeding and grinding depth values, the values for S_{m1} increases too. In this case the grinding stone graininess Z and grinding longitudinal feeding impact to the S_{m1} are not important.

The complex impacts of the technological regimes to Sm2 have been fulfilled by "Microsoft Access". Respective graphs were created, and it is concluded that the most important impact to the S_{m2}, contradictory to S_{m1}, have longitudinal feeding speed V_{det} and grindstone graininess Z. These differences are explainable by the fact that these two spatial parameters were measured in two perpendicular directions to each other. Furthermore from graphs it is clear that grinding depth and radial feeding have minor impact to the formation of S_{m2}.

The individual impact of technological regimes to the average values of surface roughness parameters R_{AT}, S_{m1} and S_{m2}, were carried out. Using ,,Microsoft Access" programme the respective graphs were created. From these graphs it is possible to evaluate dynamics of the average values changes depending on grinding device's technological regimes, namely from S_{rad}, *Z*, *t* and V_{det}. Thus overall tendencies were elucidate, by creation of the average values curves for each separate technological parameter.

In figure 3 the average values of technological regimes impact to the *Raj* are shown, according A. Aleksejevs' empirical formula. On the *x* axis mathematical values of the looked technological regimes are placed, but on *y* axis the respective R_{aT} values. Graphs which are elaborated according Prof. E. Rizov's empirical formulas for R_{aT} calculations are not shown in the promotion work because they are identical to curves which are shown in figure 3, only R_{aT} numerical values are different. Analysing figure 3 it is possible to conclude that by increasing of radial feeding S_{racl} and grinding stone graininess Z, also R_{aT} values proportionally increases. By increasing of grinding depth *t* also growth. But when grinding longitudinal feeding speed V_{det} growth, the values R_{aT} decreasing.

In the figure 4 impact of grinding technological regimes to the pattern of the roughness spatial parameters are illustrated. These graphs were made by using the average values of the S_{m1} and S_{m2} calculation formulas. On the *x* axis the scale of technological regimes are place but on *y* axis the values of S_{m1} and S_{m2}. The following conclusions have been made from these graphs: by increasing of radial feeding S_{racl} and grinding depth *t* values, both the values of S_{m1} and S_{m2} increasing (curves are gently sloping).Furthermore, by increasing of the grinding stone graininess Z and longitudinal feeding speed V_{det}, the average values of S_{m1} did not change, but values of S_{m2} has tendency to the rapid decrease.

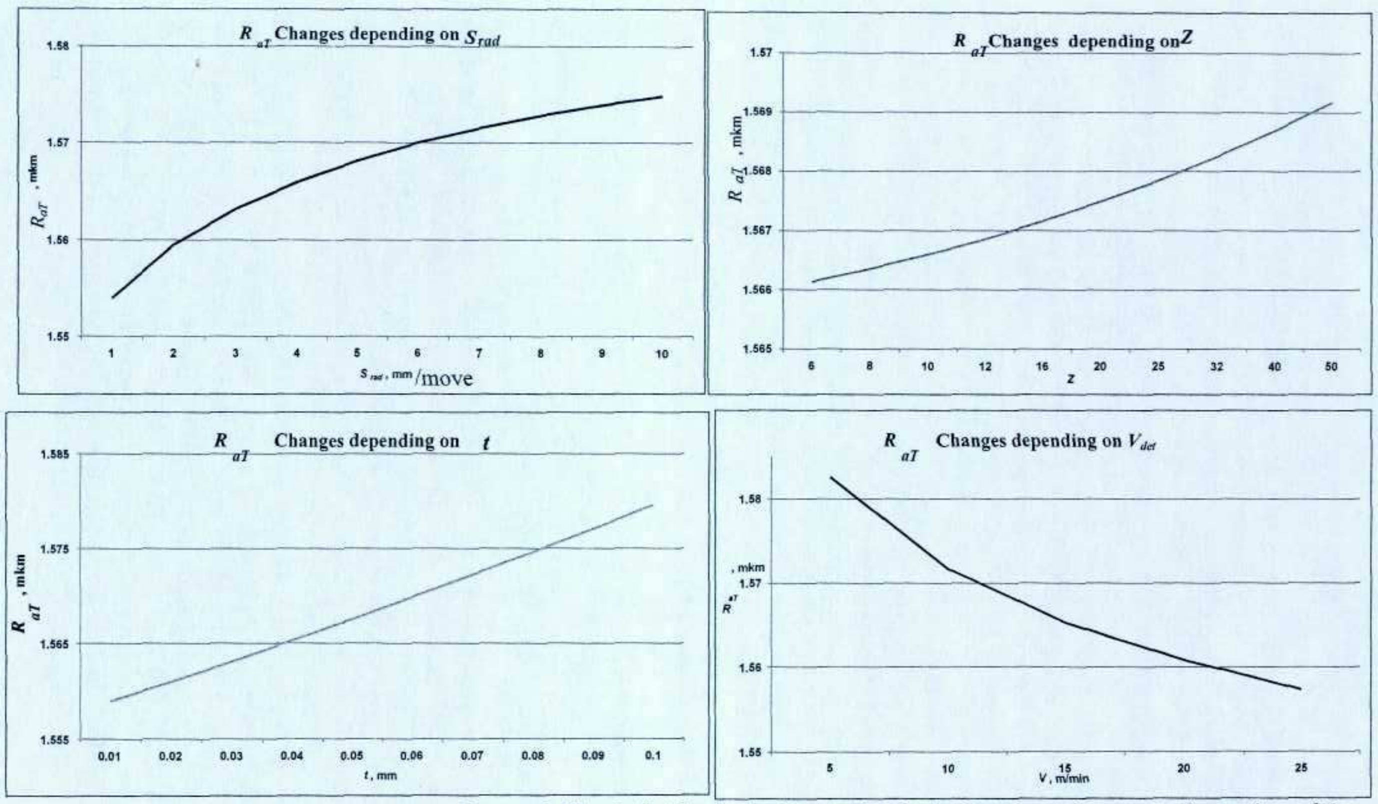

Figure 3. The individual grinding technological regimes impact to formation of R_{aT}.

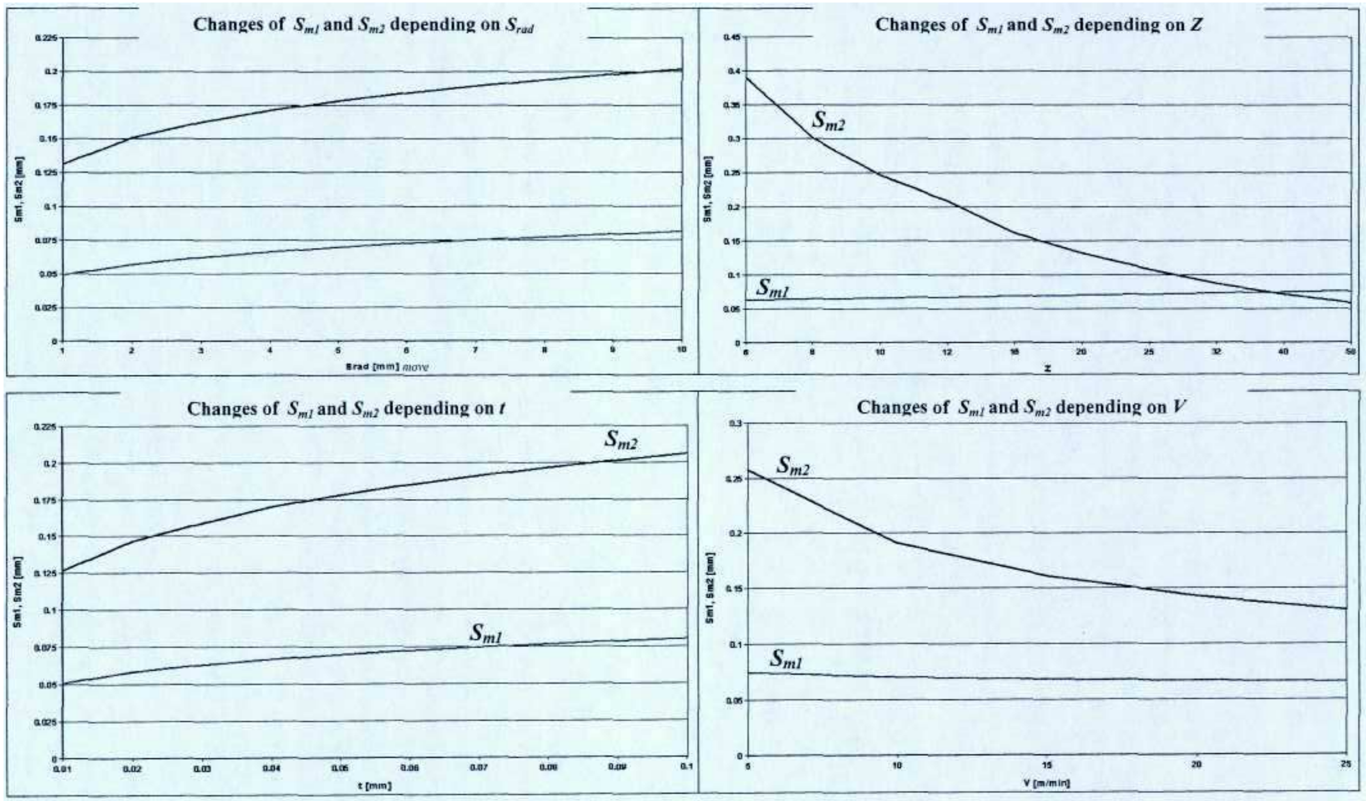

Figure 4. The individual technological regimes impact formation of S_{m1} and S_{m2}.

The experimental examination of the crankshaft surface roughness parameters has been made. The elaborated grinding devices' technological regimes impact to the crankshaft journals surface roughness parameters R_{aT}, S_{m1} and S_{m2} experimentally were evaluated in ,,Rēdertehserviss" Ltd.

This examination was carried using values which were obtained during the previous technological regimes complex impact examinations. Furthermore, to not complicate the experiment, in the experimental evaluations were used only the minimal maximal an average values (see table 1). These values of technological regimes according to the previous analysis should ensure necessary values of R_{aT}, S_{m1} and S_{m2}.

Values of technological regimes used in the experimental tests

Table 1

	t (mm)	Z	V_{det} (m/min)	S_{rad} (mm/move)
Minimal	0,02	6	5	3
Average	0,05	16	15	6
Maximal	0,1	40	25	8

The logical assumption was moved out: if the values given in table 1 ensure the necessary numerical values ($R_{aT} \leq 0{,}63$ µm, S_{m1} I R_{aT} = 10 ÷ 190 and S_{m1} I S_{m2} = 0,7 ÷ 0,5), then analogically all other values within margins given in table 1 will provide desirable results. Naturally, the amount of these grinding regimes combinations defined the total number of experiments -81. Two shipboard diesel engines, type 6Ч - 18-22 crankshafts with bearing diameter 120 mm were removed from engines. All the main and crank pin journals geometrical and surface roughness parameters have to be renewed (in this research only renovation of surface roughness parameters were covered). The control of the surface roughness parameters was made applying two different methods: using "roughness samples" and companies' ,,Feinpruf Perthen GmbH" crankshafts journals surface measurement device PFK2 together with electronical block S3P. These last mentioned devices ensure reading of most of surface roughness parameters foreseen in the existing standards as well as reading of parameters R_a, and S_m. Nevertheless, it is important to note that S3P allows reading only the profile parameters and did not ensure recording of microtopographical parameters R_{aT} , S_{m1} and S_{m2}.

To obtain microtopographical values of these parameters the discrete method were applied by breakdown of observing surface to several separate profiles. Calculation of the microtopographical values of R_{aT}, S_{m1} and S_{m2} have been done using discrete values recorded by S3P. The looked surface was divided to the ten (N=10) separate profiles with length of measuring trace l = 4,0 mm. Acquired values were placed into the following formulas determinate in the promotion work:

$$R_{aT} = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M} R_a(i,j);$$

$$S_{m1} = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M} S_{m1}(i,j);$$

$$S_{m2} = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M} S_{m2}(i,j),$$

Where: *M* -number of measurements within single profile;
N - number of profiles examined;
i - the examined profile;
j - the measurement within profile.

Note: measurement S_{m1} and S_{m2} should be done in the perpendicular directions to each other.

Naturally, these formulas allow making transition from discrete values of R_a, S_{ml} *and* S_{m2} measured in profile to the surface roughness microtopographical parameters.

The multifactorial analysis of collected data were analysed using computer programme SPSS v. 12.0. Practically the mathematical correlations between technological regimes values (used in the experiment) and obtained surface roughness parameters R_{aT}, S_{m1} and S_{m2} were established. Thus by multifactorial analysis the empirical formulas for surface roughness parameters calculation formulas were determinate. The following formulas correspond to the shipboard diesel engines crankshafts journals machining with the elaborated grinding device:

$$R_{aT} = 0{,}42\,\frac{Z^{0{,}3}\,t^{0{,}29}\,S_{rad}^{0{,}11}}{V_{\det}^{\;0{,}01}};$$

$$S_{m1} = 0{,}09\,\frac{Z^{0,1} t^{0,3} S^{0,18}}{V_{\text{det}}^{\;0,03}}\,;$$

$$S_{m2} = 8{,}9\,\frac{t^{0,22} S^{0,16}}{V_{\text{det}}^{\;0,4} Z}\,.$$

The empirical formulas for calculation of the R_{aT} , S_{m1} and S_{m2}, obtained in the promotion work are directly applicable in cases when the grinding of crankshafts journals will be carried out by the elaborated grinding device. Even more when in the practical work it is necessary from technological regimes values to prognoses the microtopographical values of the mean arithmetical deviation of surface R_{aT} and the perpendicular spacing parameters S_{m1} and S_{m2} - surface spacing parameters between the peaks.

CONCLUSIONS

The following conclusions were achieved in the promotion work "Research on machining of diesel engine crankshaft journals surfaces":

1. As a result of literature overview it is stated that at the time of the promotion work writhing there are no scientific publications available on the grinding technological regimes impact to the shipboard diesel engines crankshaft journals microtopography. Also it is stated that existing international standards contain profile parameters of surface roughness, but standards covering microtopographical surface roughness parameters are only at the development stage.
2. The model of the microtopographical surface roughness was elaborated. This model is based on mean arithmetical deviation of surface - R_{aT} and two spacing parameters S_{m1} and S_{m2} - surface spacing parameters between the peaks. These two spacing parameters are measured in the perpendicular directions to each other. Moreover, this model fully complies with grinding technology analysed within promotion work and its parameters can be obtained in practical work.
3. The microtopographical surface roughness parameters necessary to characterise crankshaft journals were developed. The formulas were provided allowing switch from discrete profile surface roughness parameters to the microtopographical parameters R_{aT}, S_{m1} and S_{m2}.
4. Original crankshaft journals grinding device without known analogues in ship repair was elaborated. This novel grinding device allows carrying out crankshafts crank pin journals machining without removing it from the engine, thus costs of repair jobs can be considerably reduced. Complete description of elaborated device for crankshafts journals grinding, its construction, application and functional principles were made. Also the detailed using instructions were provided.
5. The technical requirements for shipboard diesel engines crankshafts have been summarised. The technological regimes of elaborated grinding equipment were determinate as well as appropriate formulas for calculations of the microtopographical surface roughness parameters.
6. The complex multifactorial analysis of the technological regimes impact on the crankshafts journals microtopographical surface roughness parameters has been done.
7. The individual technological regimes *(t, Z, S_{rad} and V_{det})* impact analysis on the three dimensional surface roughness parameters R_{aT} , S_{m1} un S_{m2} formation led to the following conclusions:

- The most important and influential technological regimes for the mean arithmetical deviation of surface roughness *(R_{aT})* are grindstone graininess (Z) and axial feed *(S_{rad})*. Grinding depth *(t)* is less influential but longitudinal feeding speed *(V_{det})* has minimal impact to R_{aT} . By increasing of Z, S_{rad} and *t* values also R_{aT} increasing, but when V_{det}, increasing the R_{aT} decreases;
- The surface spacing between the roughness peaks *(S_{m1})* is mainly dependent on grinding depth *(t)* and radial feed *(S_{rad})*. By increasing of *t* and S_{rad} accordingly S_{m1} values increase. Grindstone graininess (Z) and longitudinal feeding speed *{V_{det})* has no influence on the S_{ml};
- The perpendicular surface spacing between the roughness peaks *(S_{m2})* is mainly influenced by grindstone graininess (Z) and longitudinal feeding speed *{V_{det})* but grinding depth (t) and radial feed *{S_{rad})* are less important. It was concluded that by increasing of Z and $V_{det,}$ S_{m2} .have tendency to decrease.

8. The experimental researches with the elaborated technological equipment have been made. Thus determinate the real impact of technological regimes to the microtopographical surface roughness parameters R_{aT}, S_{m1} and S_{m2}. Results achieved during these experiments were analysed multifactorially and this analysis allowed to determinate the empirical formulas for calculation of above mentioned parameters. Obtained formulas exactly reflect to the elaborated equipment for grinding of crankshafts journals. Therefore these formulas will be applicable to the ships' engines repairs, when the impact of *t, Z,* S_{rad} and V_{det} to the R_{aT}, S_{m1} and S_{m2} needs to be evaluated.
9. To ensure required values microtopographical surface roughness parameters R_{aT}, S_{m1} and S_{m2}, the following technological recommendations were given:
   - Grinding depth and grinding stone graininess is recommended to chose within the margins: *t* = 0,02 - 0,09 mm, Z = 6, 8, 10, 12, 16, 20,25, 32, but $S_{rad} = 3 \div 8$ mm/move and V_{det}, = 5 ÷ 25 m/min;
   - Combinations of technological regimes using simultaneously big grinding depth *(t* > 0,07 mm) and grinding stone graininess (Z > 20), are not recommended.

Elaborated grinding device is applicable to medium size shipboard diesel engines crankshafts grinding for renewing of the crank pin journals geometrical and surface roughness parameters. Researches carried out in the promotion work and the developed technology grants efficient solutions of crankshaft processing problems. Thus considerably improving the grinding quality of crankshafts journals as well as reducing overall ships' engines repair time.

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