A NOVEL GRINDING TECHNOLOGY AND 3D SURFACE ROUGHNESS PARAMETERS OF CRANKSHAFT BEARINGS

НОВАЯ ТЕХНОЛОГИЯ ШЛИФОВКИ И ТРЕХ-ДИМЕНСИОННЫЕ ПАРАМЕТРЫ ШЕРОХОВАТОСТИ ПОВЕРХНОСТИ ПОДШИПНИКОВ КОЛЕНЧАТЫХ ВАЛОВ

Dr.sc.ing., Assist. Prof. Torims T., Vilcans J., Kravalis K., Zarins M., Ratkus A.
Faculty of Transport and Mechanical Engineering, Riga Technical university, Latvia

Abstract: *Comprehensive study how to improve the renovation of the shipboard diesel engines crankshaft bearings has been done. This particular paper covers calculations of the applied 3D surface roughness parameters as well as description of the novel grinding equipment for the crankshafts bearing surfaces machining. This technology is suitable to the medium size shipboard diesel engines with crankshaft bearing diameter from 100 up to 350 mm. Its advantage is that it permits to do the surface renovation directly in the engine housing, without removing the crankshaft from the engine. It has been determined, 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}. Calculations for statistical surface roughness parameters are covered as well. Furthermore calculations of the chosen 3D surface roughness parameters in discrete measurements and chosen parameters equations applicable to elaborated grinding equipment are covered, too.*

Keywords: CRANKSHAFTS BEARINGS GRINDING, GRINDING TECHNOLOGY, 3D SURFACE ROUGHNESS PARAMETERS, SURFACE ROUGHNESS MODEL, 3D SURFACE TEXTURE

1. Introduction

This article is based on scientific research which has been done with the purpose to improve the renovation of the shipboard diesel engines crankshaft bearings (journals). Renovation of the crankshafts surfaces is one of the main tasks when the diesel engines are undergoing the overhauling works in the ship repair facilities. Sometimes these repair – renovation works have to be done directly on board of the vessel or even at sea. Furthermore, technical requirements for these repair operations are very tight, namely, the high surface quality, geometrical accuracy and surface roughness parameters are stipulated by the Maritime Classification Societies. Although currently available technologies are sufficient to ensure these requirements, they are very expensive and time consuming. On top of that conventional technologies are requiring removal of the crankshaft from the engine and its transportation to the shore ship repair facilities. Finally, highly sophisticated and expensive grinding machinery is needed to renew the above mentioned bearings surfaces.

Aforementioned arguments are clearly indicating a need for the new technology, which could achieve the same technical results (prerequisite parameters) but would be less work and time consuming - thus cheaper. These issues are not new in the ship repair industry and especially in its military domain. Already during the Second World War and in the fifties of the last century Navy began the researches on how to carry out the ships engines crankshafts emergency repairs directly on board, without removing the crankshaft from the engine housing and ship itself. As a result certain technologies were developed and several technical patents were registered with the same basic principle: grinding device is placed on the crankshaft itself and mechanical motion is ensured by compressed air or by chain mechanism or by electrical motor via mechanical redactor/multiplicator. However, these technologies were limited by the following obstacles: 1) they were applicable only to big size crankshafts, with at least Ø 200 mm; 2) they were closely guarded and classified; 3) they required a super-qualified service staff. Nowadays, situation slightly has changed and these in-situ grinding know-how are available also for many commercial ship repair enterprises. Nevertheless, size limitations, industrial application and which is most important the scientific justifications of these particular repair technologies are lagging behind.

Taking into account the above mentioned considerations one Latvian ship repair company has conducted and R&D project with the aim to develop a new grinding machine which would allow the repairing of diesel engines crankshafts with the crankpin bearings diameter from 100 to 350 mm and directly in the engine housing. Furthermore, it has been decided that it is imperative that crankshaft bearing surfaces are seen as spatial three-dimensional (3D) objects with the appropriate definition of the microtopographical surface roughness parameters. Only this approach allows a complete description of the bearing surface properties.

The following scientific methodology was used: crankshaft surface research was based on the theory of contingency fields, which gave opportunity to create a credible (maximally close to the real conditions) model of surface roughness and microtopographical surface roughness parameters related to this model.

This research has a real production assignment with practical implication. Naturally, by solving the problems related to the surface accuracy it is possible to improve the crankshaft machining processes considerably. As a result the performance of the maintenance operations and consequently overall quality of repair works could be significantly improved.

2. Research objectives

By conducting the full scale analysis of the available scientific literature, it was found that in the framework of aforementioned problems, there are no comprehensive researches available. More specifically in domain of the shipboard engines crankshaft bearings surface microtopography, there are no available researches at all.

Therefore, the main R&D project objective was to perform comprehensive research on diesel engines crankshaft journals surface machining taking into account the parameters of the 3D surface roughness. To reach this objective the following major 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 crankshaft journals grinding;
4. To investigate the correlation between the 3D 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.

This article mostly is covering objectives No 2 and 3.

3. *Novel grinding technology for ships engines*

Taking into consideration all the arguments given in the introduction, a new technological approach has been developed during the research. The novel technology significantly simplifies machining processes and provides that crankshaft journals grinding can be done directly inside the engine housing. Thus there is no need to remove the crankshaft from engine. This new technology results in significant savings of financial and human resources. On top of that much less overall repair time is needed for the ship diesel engine repairs. The latest is a very important argument for the ships owners and shipping management companies [5].

The designed grinding device is an electro-mechanical hand instrument, the principal construction of which is relatively simple and safe. Its main parts are the following: drive mechanism, reduction gear, positioning and adjustment system, grinding stone (in protective casing), control gauge and complimentary equipment.

Originally the grinding device was designed for the machining of the crankshafts crankpins. The grinding device is based directly on crankshaft crankpin radiuses R (see Figure 1). It requires previous removal of the connection road and bearing liners.

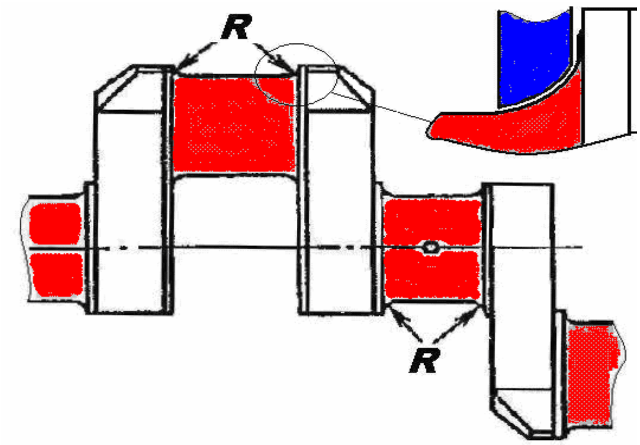
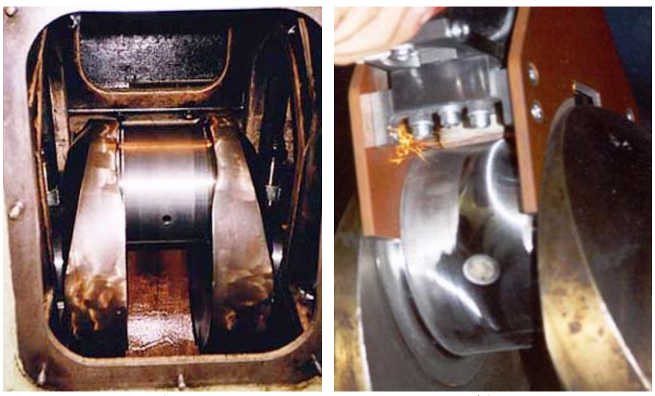


Fig.1. Crankshaft bearings grinding devices' placement

Nevertheless, during experiments the device proved to be easily applicable also for the grinding of crankshaft main bearings. In this case crankshaft should be previously dismantled form the engine and centred in the turning machine.

This grinding device has been extensively tested and the Russian Maritime Register has certified it as capable to ensure that crankshaft bearings surfaces are renewed according the prescribed geometrical and surface roughness parameters.

In principle by simple constructive adjustments this grinding device can be applied eventually to any type of crankshafts. However additional difficulties occur when very small or very large (bearings with Ø > 350 mm) crankshafts have to be renewed. Actually due to the spatial limitations this device cannot be used for bearings less than 100 mm in diameter (see fig. 2.).

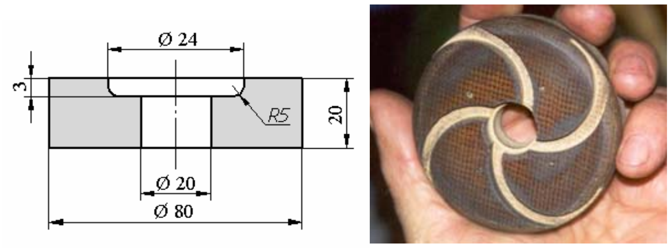


a) b)

Fig. 2. a) Middle size crankshaft placement in the engine housing; b) In-situ crankshafts grinding device in work

The renewable crankshaft bearing surface is abrasively processed by the flat surface of grinding stone. This kind of abrasive stone position is rather unusual for grinding operations. However, only in this manner it is possible to carry out crankshafts grinding in the very limited space of the engine housing. This is the main advantage of this elaborated equipment in comparison with other available grinding devices in the ship repair facilities. Relatively small diameter and specific position is compensated by the very high rotation speed of the grinding stone.

Feeding motion of grinding device is ensured manually by an operator, who steady moves the device in parallel to machining surface and in the same time performs 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 it is necessary to achieve a smooth surface it is possible to use the special polishing discs and polishing wax (see Fig. 3.).



a) b)

Fig. 3. a) grinding stone design, b) polishing disc

Elaborated grinding device is innovative and delivered the required results. Therefore its exact impact to the grinded surface properties should be investigated too. This includes not only the geometrical tolerances but also the microtopographical surface roughness parameters. For this very reason the 3D crankshaft bearings surface model has been elaborated [4].

4. *Determination of 3D surface roughness parameters of the crankshafts bearings*

Determination of the 3D surface roughness parameters is directly related to the actual surface roughness model of the surface. Although this article does not cover the development of this model, more information on it can be found in [1 and 4]. The research revealed that the shipboard diesel engines crankshaft journals machining with the mechanical grinding method can be regarded as anisotropic surface with irregular character of surface roughness. This kind of surface can be described by the normal distribution (Gaussian) law. Therefore, it was decided, that the optimal 3D 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}. The measurement basis for these roughness parameters is a mean plane of overall roughness. Detailed calculations of spatial, height and statistical crankshaft surface roughness parameters are given below. One should bear in mind that currently none of these parameters is covered by any existing international of national standard. Although the theoretical background and scientific justification is available for some time already, these standards are still incomplete and delayed. For instance standard ISO/DIS 25178-2 is in draft stage and can be expected to become official soon. Therefore, mathematical calculations of the crankshaft 3D surface roughness parameters, as far as it is possible, should be done based on the same theoretical approach which was used in draft surface texture standards. In the same time, all calculations have to be based on real metrological and technological surface parameters of the crankshaft journals. It means parameters which exist not only in theory but which can be measured in practice by currently available technical hardware in the ship repair industry. Furthermore, it is crucial to maintain the mathematical correlation between parameters which are calculated and those parameters which are already predefined by actual surface roughness model, namely, R_{aT}, S_{m1} un S_{m2}.

4.1. Spatial and height face roughness parameters

Root-mean-square deviation of the microtopographical surface roughness σ_T can be calculated by the following equation:

(1) $$\sigma_T = \frac{1}{A}\sqrt{\iint_{\Omega} h^2(x,y)dxdy},$$

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

But surface roughness height parameter R_{aT} mathematically can be described in the following manner [1]:

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

Furthermore, mathematical expectation of parameter R_{aT} can be fixed too:

(3) $$E\{R_{aT}\} = \frac{1}{A}\int_0^A E\{|h(x)|\}dx$$

Equation 3 can be changed to a more suitable form:

(4) $$E\{R_{aT}\} = \frac{1}{A}\int_0^A\int_0^{\infty} yf(y)dydx,$$

where: $y = |h(x)|$.

In case of normal distribution Law (Gaussian Law) function $f(y)$ is dividing equally:

(5) $$f(y) = \frac{2}{\sigma_T\sqrt{2\pi}}\exp\left\{-\frac{y^2}{2{\sigma_T}^2}\right\}$$

Taking into account that field distribution pattern is homogeneous (as it is mentioned before – Gaussian Law), namely, distribution of $h(x,y)$ is rather independent from coordinates x un y, the following equation is obtained:

(6) $$E\{R_{aT}\} = \sqrt{\frac{2}{\pi}\sigma_T},$$

Spatial parameters of microtopographical surface roughness can be calculated in the following manner:

(7) $$S_m \approx \frac{2}{n(0)}$$

These spatial parameters should be measured in two mutually perpendicular directions. Bearing in mind that "zeros" (or crosses with the mean plane) in the observed base length certainly will be bigger than 10 ($n(0)>10$), one can assume that:

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

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.

To obtain the mathematical expectancy values of S_{m1} and S_{m2} these spatial parameters should be considered as a random value function. In general cases characteristics of the function $y=f(x_1,x_2,...,x_n)$ can be obtained by ranging this function in a row, and maintaining the first two particles of this row. According to the previous researches [1 and 4] the mathematical expectation of this function can be determinate:

(9) $$E\{y\} \approx f(E_1, E_2, ..., E_n),$$

where: $E_1,E_2,...,E_n$ are mathematical expectation values of $x_1,x_2,...,x_n$.

Taking into account that S_{m1} and S_{m2} are functions of the same parameter $n(0)_{1,2}$, and adapting equation 9 to need of correlation 8, the following coherence is obtained:

(10) $$E\{S_{m1;2}\} \approx \frac{2}{E\{n(0)_{1,2}\}},$$

4.2. Statistical parameters of the rough surface

Additional information on microtopography of the rough cylindrical surface (like diesel engine crankshaft journals surface is) can be obtained by employing the so called statistical parameters. Statistical science has huge number of different parameters and calculation methods, therefore the most appropriate ones should be chosen for the 3D surface roughness researches. Such handy parameter for example is relative surface footing field η_u. Index u indicates that this footing field is in distance u from the mean plain.

(11) $$\eta_u = \frac{1}{A}\iint_{\Omega}\xi(h,u)dxdy,$$

where: $\xi(h,u)$ – random value which is dependant on surface peaks and level u; the mean plane is taken as a reference base:

(12) $$\xi(h,u) = \begin{cases} 1, if & h(x,y) > u \\ 0, if & h(x,y) \le u \end{cases},$$

The mathematical expectancy of the relative surface footing field, in case of Gaussian Law, by the following equation:

(13) $$E\{\eta_u\} = \frac{1}{A}\iint_{\Omega} E\{\xi(h,u)\}dxdy = 1 - \Phi\left(\frac{u}{\sigma}\right),$$

where: Φ - Laplace transform:

(14) $$\Phi(x) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{x}\exp\left(-\frac{t^2}{2}\right)dt,$$

Very important statistical indices also are the skewness of the scale limited surface in the observed plane R_{sk} and the kurtosis of the scale limited surface R_{ku} [2]. These field parameters can be calculated by using these equations:

(15) $$R_{sk} = \frac{1}{A}\iint_{\Omega} h^3(x,y)f(x,y)dxdy,$$

(16) $$R_{ku} = \frac{1}{A}\iint_{\Omega} h^4(x,y)f(x,y)dxdy,$$

where: $f(x,y)$ – density of the function distribution.

In normal distribution (Gaussian Law), which is a case here, obtained function is always symmetric [3]. Thus the skewness indicator R_{sk} = 0 and kurtosis R_{ku} = 3. It is important to mention that these parameters also are foreseen in the draft standard ISO/DIS 25178-2.

4.3. Calculation of the chosen 3D surface roughness parameters in discrete measurements

Although the above described surface roughness parameters are the most appropriate for the crankshaft surface grinding, it can be difficult to measure them in practice, e.g. in the limited space of the diesel engine housing on board of vessel. Furthermore 3D surface texture parameters measurement equipment is rather expensive and the measurement techniques standardisation process is at development stage. Therefore, to obtain microtopographical values of above mentioned parameters the discrete method was developmed, by breakdown of observing surface in to the several separate profiles. Thus calculations of the 3D values of R_{aT}, S_{m1} and S_{m2} have been done using discrete values recorded in two dimension profile by ordinary measurement technique. For this purpose the following formulas were introduced:

$$R_{aT} = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M} R_a(i,j) \quad (17)$$

$$S_{m1} = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M} S_{m1}(i,j) \quad (18)$$

$$S_{m2} = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M} S_{m2}(i,j), \quad (19)$$

where: M – number of measurements within one single profile;
N – number of examined profiles;
i – the examined profile;
j – the measurement within profile.

N.B.: measurements S_{m1} and S_{m2} should be done in the perpendicular directions to each other. Then, these equations allow to do transition from discrete values measured in profile to the surface roughness microtopographical parameters.

5. Surface roughness parameters calculation formulas applicable to elaborated grinding equipment

The principal scheme of crankshaft grinding by using the flat surface of the grinding stone is given in Fig. 4.

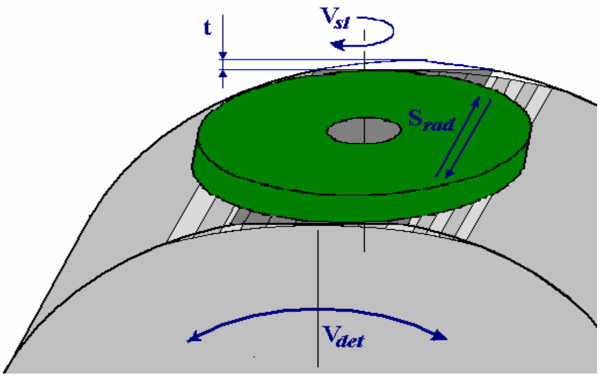


Fig. 4. Principal scheme of crankshaft grinding process

Research has confirmed that the exact grinding technological regimes and surface roughness parameters correlations can be calculated by the following equations:

$$R_{aT} = 0{,}44\frac{S_{rad}^{0,34} t^{0,17} Z^{0,43}}{V_{det}^{0,01}}, \quad (20)$$

$$S_{m1} = 0{,}083\frac{S_{rad}^{0,22} t^{0,2} Z^{0,09}}{V_{det}^{0,07}}, \quad (21)$$

$$S_{m2} = 0{,}037\frac{S_{rad}^{0,18} t^{0,21}}{V_{det}^{0,42} Z^{0,9}}, \quad (22)$$

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 (m/min).

6. Conclusions

A new 3D surface roughness model, and its microtopographical surface roughness parameters, which are suitable for diesel engine crankshafts bearing surfaces were developed. Also a novel technological equipment for diesel engines crankshaft bearing surfaces (journals) grinding has been elaborated.

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

These results of the research are the new contribution to the manufacturing engineering in particular to the domain of mechanical technology. Naturally, this work can be used in the EU ship building and ship repair enterprises for diesel engines repairs.

The following empirical and theoretical conclusions can be driven from "Research on machining of diesel engine crankshaft journals surfaces":

1. Available scientific and technological literature overview reveals that there are apparently no scientific publications available on the grinding technological regimes impact on 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. Original crankshaft journals grinding device 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. Technology is applicable generally to the medium size shipboard diesel engines with crankshaft journal diameter from 100 up to 350 mm.
3. The model of the microtopographical surface roughness was elaborated. This model is based on mean arithmetical deviation of surface - Ra_T and two spacing parameters Sm_1 and Sm_2 - 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 the research and its parameters can be obtained in practical work.
4. The microtopographical surface roughness parameters necessary to characterise crankshaft journals were developed. The equations were provided allowing to switch from discrete profile surface roughness parameters to the microtopographical parameters R_{aT}, S_{m1} and S_{m2}.

This research and the developed technology is granting the 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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