APPLICATION OF TRIBOTECHNICAL DIAGNOSTIC METHODS IN CASE OF DETERMINATION OF COEFFICIENT OF OPERATIONAL RELIABILITY OF MACHINE TOOLS

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The submitted paper analyses the check of operational capacity and of economic efficiency of the selected machines in case of the use of different types of oil, determination of mode of friction and of machine wear and specification of interval of oil change. The object of the paper is a machine park in the industrial company comprising of five machine tools. Particularly, it is the case of two grinding machines, two lathes and one milling cutter. Having been removed from the greasing systems, the oils were used to gain information on technical condition of the respective machines.

KEYWORDS

friction, wear, greasing, tribology

1 INTRODUCTION

Theory of reliability deals with methods and procedures which must be observed in case of design elaboration, production, taking-over, transport and use of products to assure maximum efficiency in the process of the product application [Mascenik 2011]. Basic problem of the theory rests in determination of reliability of components, of products and of complicated machines [Modrak 2011 and 2017]. Therefore, it is inevitable to clarify the term reliability that refers to general property of an object resting in capability to perform required functions with preservation of the values defined by operation coefficients within the frame of specified limits and time according to determined technical conditions [Turygin 2018, Bozek 2021].

1.1 Determination of Machine Wear Mode

It is determined by means of the PMA 87 – 2 direct-counting magnetic analyser of particles in liquid. It applies thin-walled capillaries located in the divergent magnetic field of a special super magnetic type [Turtelli 2006]. The particles occurring in oil split and deposit under the influence of intensively divergent field. Particles Dl are bigger than *15 μm* and dimension of small particles Ds is approximately *2 μm*.

The test tube is filled with *5 ml* of oil diluted with gasoline 1:1 (approximately *5 ml* of oil and *5 ml* of gasoline). The test tube is attached to a holder with the end of the rubber hose in it. The device remains switched on until the gravity flows brings the specimen through the device capillary [Straka 2020a]. Consequently, the values referring to number of big *Dl* and of small *Ds* abrasive particles are read off the device. The values are substituted in the relations and the values of level and intensity of wear are specified.

Relation for determination of level of machine wear:

$$WPC = \frac{Dl+Ds}{1800}.100 \tag{1}$$

Dl – big abrasive particles, *Ds* – small abrasive particles,

Relation for determination of intensity of machine wear:

$$PLP = \frac{Dl.k}{Dl+Ds}.100 \tag{2}$$

Coefficient k indicating intensity of wear will be defined based on the following conditions:

- if number of big abrasive particles is $Dl \leq 100$, then coefficient $k = 0.01$.

- if number of big abrasive particles *Dl* ranges from *100* to *900*, then coefficient *k* ranges from *0.1 to 0.9* (for example, if $Dl = 500$, then $k = 0.5$).

2 METHODS AND MATERIALS

2.1 Data Collection

Collection of specimens of the greasing system requires higher attention to be paid to as the specimen must be representative to allow correct determination of technical condition of the machine [Cacko 2014a,b, Murcinkova 2013, Coranic 2018]. The specimens are collected from the same spot of the greasing system when the machine operation is completed. Number of collected samples equals to 4 in case of every machine, i.e., 20 specimens of oil is analysed. The specimens are collected into glass collection tank with the volume of approximately 1.5 – 2 dcl.

The first specimen of each machine was collected after approximately 350 operating hours. Other specimens were collected every 240 operating hours. It is the case of the following machines: lathe SUI 40; lathe SV 18 RA; grinding machine BDU 80; grinding machine BRH 20.02; milling cutter FGUE 32. In case of the milling cutter FGUE 32 the oil was changed, and the last specimen was collected after 80 operating hours.

Prior to analysis and examination of oil specimens, the specimens must be homogenized as their storage was accompanied by sedimentation of particles. The specimen is simply shaken in collection tank [Smeringaiova 2021a].

2.2 Description of Machine Park

The machine park is located in the company of ZVL TS, Ltd., Presov, in a closed production hall. Five machines were selected out of all machines being at disposal in the company.

Lathe SUI 40

Producer: TOS Trencin

Max. rev. of spindle: *2240 rev. per min* $^{-1}$

The lathes are designed and intended for short-run or single-part production and repair plants or shop-floors for their versatility, working precision and simplicity of structure [Husar 2022]. The machine allows almost all types of machining including lathe turning, boring work, lathe turning of cones, hydraulic copying, milling of grooves and of toothed wheels, face grinding, external and hollow grinding, etc.

Milling Cutter FGUE 32

Producer: TOS Olomouc

Engine of the main drive of a spindle: *1445 rev. per min* $^{-1}$

Engine of feed drive: *1445 rev. per min* $^{-1}$

Universal milling cutter is designed and intended for a wide range of milling, drilling and boring operations.

Lathe SV 18 RA

Producer: TOS Trencin

Max. revolutions of a spindle: *2240 rev. per min* $^{-1}$

The scope of utilization of the lathes is similar to the one of the lathes of the SUI series.

Grinding machine BDU 80

Producer: Motorcycle racing, Strakonice

The machine is designed and intended for precise grinding of external and hollow cylindrical and conical areas by longitudinal or in-feed method. It is possible to use the machine in series or single-part production with the application of its versatility.

Grinding machine BRH 20.02

Producer: ZVL, consolidated company, Povazska Bystrica

Max. automatic transversal continual feed: *2.5 m per min* $^{-1}$

Fast up feed: *0.5m per min* $^{-1}$

Machine type: Horizontal spindle surface grinding machine.

Horizontal spindle surface grinding machine with a grinding spindle and square table is designed for grinding of the planar and shaped areas of the components made of steel, cast iron and other metal materials in case of which high precision and quality of machining is required. Grinding is performed by means of peripheral part of the grinding wheel. It is fitted with both manual and power drive of perpendicular and transversal feed.

Lathe SUI 40

In analysis of the first specimen the oil contained adhesive and silicon particles non-ferrous metals the amount of which is small. The analysis of the second specimen detected a little water which, probably, leaked into the greasing system out of the cooling system of the machine. But the greasing system contains inbuilt filter which should eliminate the water when the oil flows through it. The filter retained silicon and adhesive particles, too because in case of the third specimen no silicon particles were detected and the amount of the adhesive ones was rather smaller yet a little water could be observed. Despite the aforementioned fact, the overall condition of oil is good. The analysis of the fourth specimen detected small number of adhesive and silicon particles which occurred in oil under the influence of dust. The dust entered the greasing system along with filter fibres [Vahovsky 2019]. Due to its possible contamination, the filter is recommended to be replaced. In spite of this, the condition of oil is good, mode of friction and wear is standard, technical condition of the machine is unsatisfactory and according to all indicators the overall condition of the machine is normal. Further machine operation should be free from serious complications. Interval of oil charge replacement should remain unchanged based on recommendation of the machine producer, yet it is advised to subject the oil to tribotechnical diagnostics to prevent needless oil charge replacement if the oil is still possible to be used in operation. The results of oil specimen analysis are presented in Table 1.

Table 1. Results of oil specimen analysis

Lathe SUI40	*number of oper. hours*	*OI (%)*	*water content (%)*	*DI*	*Ds*	*PLP*	*WPC*
1st specimen	350	1.4	0	20	8	0.71	1.55
2nd specimen	240	1.5	0.1	50	10	0.83	3.33
3rd specimen	240	1.55	0.1	26	9	0.74	1.94
4th specimen	240	1.55	0	30	12	0.71	2.33

OI – overall impurities

Milling Cutter FGUE 32

During evaluation of the first oil specimen of the milling cutter, a large number of adhesive particles was traced in the oil along with abrasive particles and low volume of water. That is why the oil was filtered. Analysis of the second specimen detected occurrence of many adhesive particles. The second specimen contained abrasive particles as well and water volume was higher. The oil was added in greasing system. Obvious improvement could be observed in case of the third specimen as the oil contained fewer adhesive particles which were only submicronic ones and at the same time water volume decreased. The fourth specimen was taken from the oil which had already been changed. Currently, the number of overall impurities is small in the oil yet a large number of paramagnetic particles could be detected which penetrated into the greasing system from the external environment when the cap was opened. It is recommended to filter the oil again. Presumably, the oil was under higher stress contrary to previous situation because a complicated component was machined which means that the machine was more loaded than in the cases before. Based on the date given herein it can be assumed that the overall condition of the machine is critical due to occurrence high PLP and WPC values. The mode of friction and wear is normal and oil condition should be good after re-filtration. Table 2 presents the results of oil specimen analysis.

Table 2. Results of oil specimen analysis

Milling cutter FGUE 32	*number of oper. hours*	*OI (%)*	*water content (%)*	*DI*	*Ds*	*PLP*	*WPC*
1st specimen	350	1.3	0.2	320	15	28.65	18.61
2nd specimen	240	1.55	2	430	20	38.22	25
3rd specimen	240	1.55	0.2	80	12	0.86	5.11
4th specimen	80	0.1	0.3	266	15	18.93	15.61

Lathe SV 18 RA

From the analysis of all specimens, it was detected that the condition of oil was good and it was capable of further operation. The analysis of the first specimen proved that the oil was in good condition and contained only small amount of submicronic adhesive and silicon particles. Water in oil was not traced [Rewers 2017]. However, apart from adhesive and silicon particles, the second specimen contained paramagnetic particles as well. At the same time, low volume of water was traced in oil which should be eliminated after oil filtration. The third specimen taken from the respective machine proved to contain only small amount of adhesive and silicon particles which is considerably influenced by the greasing system filter. However, the water content slightly increased. Again, the fourth specimen contained adhesive and silicon particles along with fibres of the filter [Trojanowski 2019]. It is advisable to replace the filter in the greasing system to eliminate the fibres and silicon particles which occurred in the oil under the influence of dust entering the greasing system. The overall condition of the machine is good which can be proved by the results based on analysis of all specimens. Technical condition of the machine is unsatisfactory. Oil condition is good as well. Mode of friction and wear is normal. The results of oil specimen analysis are presented in Table 3.

Table 3. Results of oil specimen analysis

Lathe SV 18 RA	*number of oper. hours*	*OI (%)*	*water content (%)*	*DI*	*Ds*	*PLP*	*WPC*
1st specimen	350	1.2	0	12	8	0.6	1.11
2nd specimen	240	1.4	0.2	25	10	0.71	1.94
3rd specimen	240	1.5	0.5	45	12	0.78	3.16
4th specimen	240	1.57	0	45	14	0.76	3.27

Grinding Machine BDU 80

In case of the grinding machine BDU 80, transmission oil Madit SPINOL 3 was analyses. The analysis of the first specimen proved that the oil was extremely contaminated. The oil contained large number of adhesive particles as well as adhesive and silicon particles and non-ferrous metals. The water was not traced in the oil. However, in case of other specimen the number of adhesive particles remained unchanged and number of adhesive particles increased. Little water was traced in oil which could be probably caused by the component cooling. It is recommended to replace the contaminated filter with the new one. The third specimen contained fewer adhesive, abrasive and silicon particles presumably due to the filter replacement. Further decrease of adhesive particles could be observed in case of the fourth specimen, however, their number is still large. Based on the aforementioned facts it can be concluded that the technical condition of the machine is alarming, condition of oil is normal, mode of friction and wear is unsatisfactory [Husar 2021]. The interval of oil charge replacement remains unchanged, yet each replacement should be preceded by tribotechnical diagnostics of exploited oil. Preventive repair of the machine is recommended to be performed in order to avoid larger failures which could result in high economical losses [Man 2011]. The results of oil specimen analysis are shown in Table 4.

Table 4. Results of oil specimen analysis

Grinding machine BDU 80	*number of oper. hours*	*OI (%)*	*water content (%)*	*DI*	*Ds*	*PLP*	*WPC*
1st specimen	350	1.5	0	375	15	28.84	21.66
2nd specimen	240	1.3	0.2	375	32	27.64	22.61
3rd specimen	240	1.43	0.2	300	20	28.13	17.77
4th specimen	240	1.53	0	200	20	18.18	12.22

Grinding Machine BHR 20.20

Analysis of the first specimen proved occurrence of large number of adhesive particles due to influence of water. At the same time, the specimen contained silicon and paramagnetic particles which entered the oil from the external environment. The oil must be filtrated to eliminate water and silicon and paramagnetic particles. The oil was filtered by means of thick filter and therefore the water content remained unchanged in case of the second specimen. However, the ferrographic analysis showed that content of adhesive and silicon particles considerably decreased.

Table 5. Results of oil specimen analysis

Grinding machine BRH 20.02	*number of oper. hours*	*OI (%)*	*water content (%)*	*DI*	*Ds*	*PLP*	*WPC*
1st specimen	350	1.56	3	550	25	47.82	31.94
2nd specimen	240	1.3	3	160	12	9.30	9.55
3rd specimen	240	1.43	0.2	60	12	0.83	4
4th specimen	240	1.5	0	70	12	0.85	4.55

Required amount of oil was added into oil tank. Without any further recommendations the oil can be used with possible filtration by means of fine filter. In case of the fourth specimen, the water was not traced in the oil and number of DI and Ds particles is standard which refers to normal machine wear. However, secondary impurities were traced in the oil which entered the oil from the external environment when the cap of the oil tank was opened. Therefore, the oil must be filtered. The condition of oil is good and technical condition of the machine is unsatisfactory. Mode of friction and wear is normal. Interval of oil charge replacement remains unchanged as recommended by the machine producer. The results of oil specimen analysis are shown in Table 5.

3 DETERMINATION OF RELIABILITY COEFFICIENT

When determining the reliability coefficient in case of the individual machines, it is inevitable to take into consideration the data gained through the analysis of the particular specimens. In general, the following is applicable: the higher the wear intensity, the lower the probability of failure-free operation and lower the reliability coefficient [Bun 2022]. Determination of reliability coefficient stems from parameters of static characteristics of mode of friction, i.e., WPC and determination of probability of failure-free operation stems from the parameters of dynamic characteristics of mode of friction – PLP with mean value being taken into consideration [Cacko 2014a, Coranic 2021].

LATHE SUI 40

The mean value of wear level in case of the lathe SUI 40 equals to 2.2875. Probability of failure-free operation is 97.71%.

$$WPC_{STR-1} = \frac{\sum_{i=1}^{n} WPC}{n} = 2.2875 \tag{3}$$

$$k_{sp-1} = 97.71 / 100 = 0.9771$$

MILLING CUTTER FGUE 32

The mean value of wear level in case of the milling cutter FGUE 32 equals to *15.83*. Probability of failure-free operation is *84.17%.*

$$WPC_{STR-2} = \frac{\sum_{i=1}^{n} WPC}{n} = 15.83 \tag{4}$$

$$k_{sp-2} = 84.17 / 100 = 0.8417$$

LATHE SV 18 RA

The mean value of wear level in case of the lathe SV 18 RA equals to *2.37*. Probability of failure-free operation is *97.63%.*

$$WPC_{STR-3} = \frac{\sum_{i=1}^{n} WPC}{n} = 2.37 \tag{5}$$

$$k_{sp-3} = 97.63 / 100 = 0.9763$$

GRINDING MACHINE BDU 80

The mean value of wear level in case of the grinding machine BDU 80 equals to *18.565*. Probability of failure-free operation is *81.435%.*

$$WPC_{STR-4} = \frac{\sum_{i=1}^{n} WPC}{n} = 18.565 \tag{6}$$

$$k_{sp-4} = 81.435 / 100 = 0.81435$$

GRINDING MACHINE BRH 20.02

The mean value of wear level in case of the grinding machine BRH 20.02 equals to *12.51*. Probability of failure-free operation is *87.49%.*

$$WPC_{STR-5} = \frac{\sum_{i=1}^{n} WPC}{n} = 12.51 \quad (7)$$

$$k_{sp-5} = 87.49 / 100 = 0.8749$$

Overall mean value of wear level in case of the aforementioned machines equals to *10.3125*.

4 CONCLUSIONS

Calculation of coefficients required analysis of all specimens which were at disposal in case of all machines in question. Four oil specimens were taken from each machine [Straka 2020b]. Analysis of specimens were performed with the machines located in the company of ZVL TS, Ltd. in Presov. The specimens were taken from the greasing systems on regular basis during three quarters of the year which allows making a diagnosis and prognosis in case of the respective machining tools.

Firstly, water content in oil was examined and water was traced in case of at least two specimens with each machine. Therefore, it was assumed that water entered the oil due to product cooling and because of that, the oil had to be filtered or replaced by the finer one. In case of the last specimens taken from four machines the water was not traced which proved the recommendations to have been correct [Smeringaiova 2021b,c]. The water appeared only in the milling cutter FGUE 32 in case of which the oil had to be filtered or even changed and at the same time the sealing rings of the greasing system had to be replaced to prevent the water from entering the system.

Further and rather extremely significant indicator was the value of overall impurities content in the oil. Maximum acceptable value is CN of up to *3 %*. In case of the machines mentioned herein the CN values ranged from *0.1* to *1.57 %* which proved that overall impurities content did not considerably influence operating capability of the machines.

At the same time, number of large *Dl* and of small *Ds* particles was detected out of which mode of wear was calculated, i.e., level and intensity of wear of the individual machines. Mode of friction and wear was proved to be good or satisfactory in case of lathe SUI 40, SN 18 RA, and grinding machine BRH 20.02. Mode of friction and wear in case of milling cutter FGUE 32 and grinding machine BDU 80 is unsatisfactory therefore, preventive maintenance must be conducted with both types of machines to prevent high economical losses. The individual particles could be observed with a ferrograph which allows watching all visible magnetic particles.

In case of the grinding machine BRH 20.02 it is recommended to use, instead of applied hydraulic oil OTHP 32, the oil with better physical and chemical properties. It is more expensive contrary to the first of the aforementioned oils, however, its usage in hydraulic system would result in increase of operating hours from *2 000* to *3 000* which proves that oil replacement may lead to considerable saving of oil use because the length of the application increases by a half. In case of other machines, it is not necessary to replace transmission oil.

The conclusion which can be drawn based on the observations and analysis is that the machines subjected to tribotechnical diagnostics are capable of further operation, however, the milling cutter FGUE 32 and the grinding machine BDU 80 require preventive repair. Therefore, tribotechnical diagnostics must be conducted in case of all other machines located in the shop floor which might probably prevent losses in the event of small or bigger or even general repairs of machines.

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