Analysis regarding Dynamic Parameters of the Milling Head Bearings

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Abstract **– The quality of a lubricant used is a significant factor in the service life of bearings in operation. Nowadays, the development in the field of lubricants is advanced, and opens up additional possibilities for customers to extend the service life of the bearings. This paper deals with the parsing of the high-speed bearing of the milling head in the CNC milling cutter. The state of the bearings and contact surfaces was determined by the measurements and the analysis which was performed in order to assess the abrasion mode.**

Keywords **– Bearings, micro-geometry, vibration.**

1. Introduction

Reliable rolling-element bearings ensure a proper running and performance of machineries. Proper lubrication of rolling bearings largely helps to reach an ideal state of these machineries. A very thin layer of a lubricant is applied during the lubrication of rolling bearings. Therefore, it is very important to check and maintain these bearings regularly, as well as to ensure their long service life.

There are three main principles that need to be followed for prolonging service life of bearings:

- Proper choice of a lubricant,
- Proper application of a lubricant,
- Keeping a lubricant clean.

Failure to comply with one of the principles may lead to an increase in the risk of bearing failure occurrence, and to the violation of trouble-free operation of aparticular machinery. Bearings normally operate at high temperatures and speeds, so the requirements for increasing the accuracy and reliability offered to them mean that, nowadays, the choice of a suitable lubricant for bearings is more decisive than some time ago. With the proper choice of a lubricant we may achieve:

- Reduction of wear and friction thanks to an elastohydrodynamic film of a sufficient thickness and strength to support the load. It ensures the separation of balls from races in order to prevent the contact of metal with metal. Further elastohydrodynamic film:
- Reduces the wear of a cage by reducing sliding friction on surfaces.
- Protects against corrosion.
- Ensures heat transfer.

Up to 36% of all premature failures of machineries occur when an inadequate amount of a lubricant is used. A good lubrication may help improving an increase of no failure operation and productivity. We are able to reduce not only premature failure of bearings, but also to eliminate machinery and manufacture cut offs, which leads to the increase of energy efficiency.

Nowadays, it is possible to choose a wide offer of lubricants which ranges from special to the most modern lubrication systems. [1]

These lubricants are divided into three main categories:

- Oils,
- Fats,
- Solid lubricants.

It is essential to follow operating conditions and limitations of a given structural system when choosing a type of a lubricant for bearings.

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Among these conditions we can bring out the following :

- Viscosity of a lubricant at a temperature during operation.
- Minimum and maximum permissible operating temperatures.
- Speed of a bearing in operation. [1] [2] [3]

2. Diagnostics of bearings

Bearings are used to a precise placement of rotating rolling machine elements. They ensure the desired rotating placement with a small backlash. Any bearing is a machine part in which energy is lost by friction. A bearing, actually its construction, should ensure that these loses are as small as possible. This requirement applies mainly at high speeds.

The important role of bearings is to capture radial or axial load forces or both. It is essential that they ensure the transfer of forces between stationary and rotating parts of the placement.

Division of bearings:

We divide bearings according to the type of friction into rolling and sliding.

Division of bearings according to the orientation of transferred load comprises:

-Radial bearings constructed to transfer radial forces.
-Axial bearings constructed to transfer axial forces.
-Radial – axial for combined load.

Bearings durability can be expressed as a number of speeds or a number of operational hours of a machine for a given speed of rotation, that a bearing may perform before the first sign of material fatigue whichis detected, or its flaking in a rolling object, or on the raceways of an inner or outer ring.

Testing the same bearings under the same operating conditions points to a wide range in a number of cycles or hours until fatigue occurs. Fundamental durability of L10 bearings presents fatigue durability and it is reached or exceeded in 90%. [2]

The reasons why tapered bearings with axial prestress are assembled as follows:

- Increasing the stiffness of the placement (smaller deformation – transfer at loading, mainly – axial or dynamic).
- Reducing vibration and noise.
- Increasing the accuracy of operation (radial and axial run-out).
- Compensation of running in the processes (bearing application during initial operation).
- Increasing the durability of bearings.

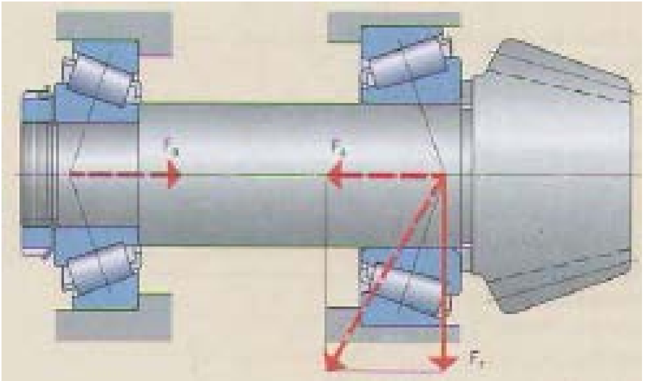

Figure 1. Assembly of the bearing with axial prestress

3. Characteristics of the researched problem

The subject of the review is high-speed bearing placement of a milling head in CNC milling cutter.
During an operation the operator of a machine tool reaches:

- Low durability of bearings, placement of a milling head.
- Increase of radial and axial backlash in a bearing placement after a short operation period (3 – 6 months), loss of placement stiffness.
- High oscillation of a mill clamp, vibrations and high dynamic effects.
- Gear cutter mainly while machining reaches high dynamic induction from variable cutter force.
- Machined area shows low quality and high geometry and micro geometry deviations, the values are above the allowed limit (roughness, dimensional tolerance, flatness).

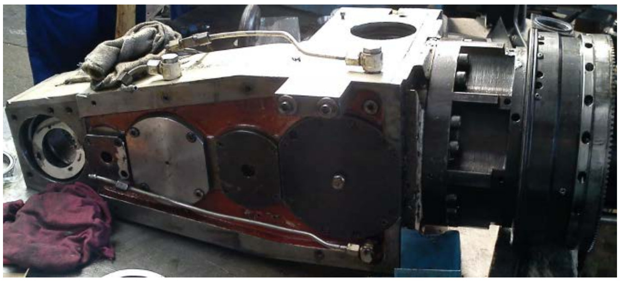

Figure 2. Dismantled milling head

4. Realized experiments and the results of the measurements

Figure 2 displays a dismantled milling head. We performed the following measurements at our workplace during the dismantling of individual parts:

- Bearing set analysis,
- Evaluation of the bearings conditions and contact surfaces,
- Lubricant analysis and friction assessment.

Subsequently, the roller-element bearing was dismantled into individual bearing components, while the check of the micro geometry regarding the chosen surfaces – contact surfaces was performed. Figure 2 shows the scheme of bearing placement of the milling head. The holder for the cutting machine fastening (milling cutter, drill bit, and so on) is placed in two tapered roller bearings of the following types:

- Timken LL714649/LL714610
- Timken L116149/L116110

The bearings are assembled with axial prestress to increase the stiffness of the placement. The reduction of deformation/oscillation of a cutting tool from high dynamic induction thus from the cutting force during machining is reached by this.

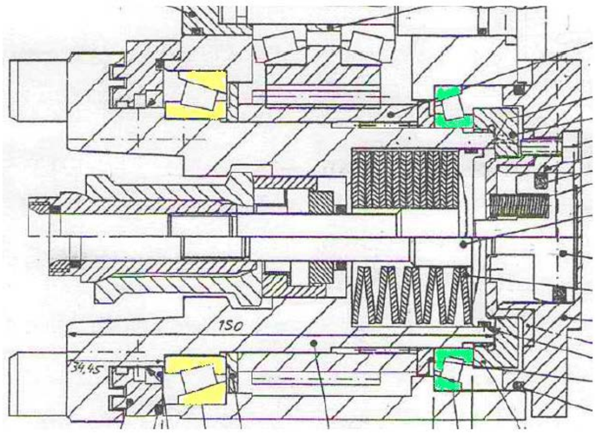

Figure 3. Tapered roller bearings

5. Diagnostics of the rolling – element bearings – the calculation of power ratios and current measurements

We performed the calculation of power ratios – parameters for used cutting conditions during the milling. The calculated results are shown in Table No. 1. At the same time, we carried out the current measurement – power in the main electric motor, propulsion of the milling head for various machining conditions:

Table 1. Power ratios and current measurements

Rated engine power	**37 kW**		
Rated motor current	**107 A**		
The measured main motor current / power values			
Operation number 1	**Mill 114**	44 %	16,3 kW
Operation number 2	**T21 circular**	46 %	17,0 kW
Operation number 3	**Mill F160**	45 %	16,7 kW
Operation number 4	**Hole 67 mm**	25 %	9,3 kW
Operation number 5	**Dimension 39**	30 %	11,1 kW
Operation number 6	**Hole 32 mm**	28 %	10,4 kW

Input data:

Used tool	Sandvik Coromant R245-160Q40-12 L
Cutting blate	Sandvik Coromant R245-12T3E-PL 4030
Tool diameter (Dc)	160 mm
Number of cutting boards (z)	7 pieces
Setting angle (Kr)	45°
Spindle speed (n)	550 rpm/min
Width of the milled area (ae)	137 mm
1. Splinter – thickness (ap)	4,5 mm (maximum)
1. Splinter – feed (vf)	450 mm/min
2. Splinter – thickness (ap)	1,5 mm
3. Splinter – feed (vf)	880 mm/min

Computed data:

Cutting speed (v) – 276,32 m/min
Feed rate – 1. Splinter (fz) – 0,117 mm
Feed rate – 2. Splinter (fz) – 0,229 mm

Spindle power (Pc) :

$$Pc = \frac{ap.ae.vf.kc}{6\,0000\,000} \quad (1)$$

ap - Splinter thickness
ae - Width of the milled area
vf - Feed mm/min
kc - The coefficient of a specific cutting force

$$kc = kc1.hm^{-mc}.\left(\frac{1-\infty}{100}\right) \quad (2)$$

Kc1- Coefficient for steel = 1300-3050 N/mm^2 (We consider - kc1 = 2000 N/mm^2)

hm - Average splinter thickness

mc - Coefficient (mc=0,25)

co - Front angle of cutting blade (6°)

$$hm = \frac{180.\sin Kr\ x\ ae.fz}{3{,}14.Dcap.\arcsin(\frac{ae}{dcap})} \quad (3)$$

Kr - Setting angle
fz - Feed rate
Dcap – max. ф Tool in cut

$$Dcap = \frac{Dc + 2.ap}{\tan Kr} \quad (4)$$

Dc - Tool diameter

Then for the first splinter is valid		Then for the second splinter is valid	
Dcap	165,56 mm	Dcap	161,85 mm
hm	4,841 mm	hm	9,350 mm
kc	1 267,459	kc	1 075,102
Pc	5,86 kW	Pc	3,24 kW

Spindle torque:

$$Mc = \frac{Pc.30\ 000}{3{,}14.n} \quad (5)$$

Then for the first splinter is valid		Then for the second splinter is valid	
Mc	101,80 Nm	Mc	56,29 Nm

6. Diagnostics of the rolling – element bearings – Surface state assessment, micro geometry

Figure 4. Local surface corrosion on the shell of the rolling element

The local surface corrosion on the shell of the rolling element, as well as on the raceway of the outer ring can be seen in Figure No. 4. This is a sign of the penetration cutting emulsion (water) into the space of the bearing placement and the plastic lubricant.

Figure 5. Local surface corrosion on the inner ring

The same state is detected on the inner ring of the bearing Fig. No. 5, the local surface corrosion occurs in radial direction (raceway) as well as in axial direction (a ball bearing – a support face of the inner ring).

Figure 6. Abrasion on the faces of the rolling elements and on the face of the inner ring

Abrasion – the running in track in a contact point, Fig. No. 6 is clear on the faces of the rolling elements, as well as on the bearing face of the inner ring. Wear (loss of material) on these surfaces is directly related to the decrease of axial prestress set during the bearing assembly.

7. Diagnostics of the rolling – element bearings - the friction and lubricant condition assessment

During the dismantling of the bearings, we took samples of the plastic lubricant and analysed it. Table No. 2 shows the detected values and a comparison with the recommended limit.

Table 2. Lubricant condition

Plastic lubricant Isoflex NBU – 15, main bearing	**Recommended limit (max)**	**Detected values**	**Valuation**
Solid impurities DL+DS	200	340	Inconvenient
Abrasion particles Fe (ppm)	100	274	Inconvenient
Corrosion particles - Alfa Hematit Fe2O3	absent	20 % present abrasions	Inconvenient

The number of the solid particles, the number of the **Fe** abrasion particles, as well as the number of the corrosion particles (red iron oxide) shows an unsatisfactory friction mode and the lubricant condition. The sample of the plastic lubricant contains water – cutting emulsion.

In Fig. No. 7 and in Fig No. 8 we can see the graphs with individual dependencies:

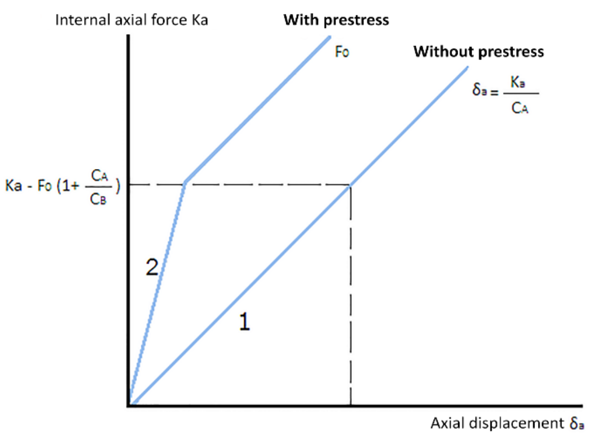

Figure 1. Dependence between axial load and deformation

The dependence between axial load and deformation or displacement is shown in Graph No 7. The displacement is significantly eliminated in case of assembly with axial prestress.

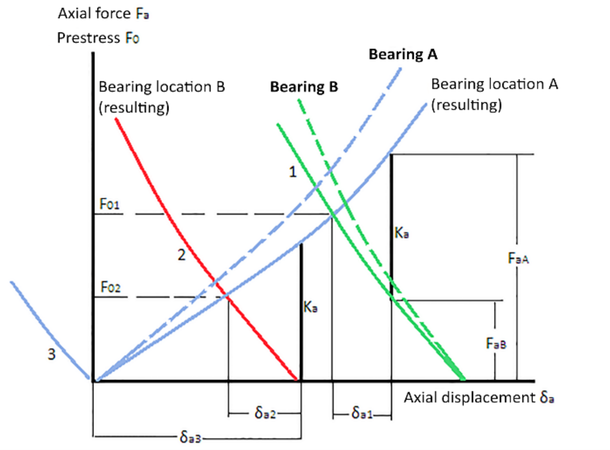

Figure 2. Dependence between axial displacement and prestress

Graph No. 8 points out the change in the bearings position due to axial displacement. The size of the location change is important for:

- Exact setting of the shaft location in axial direction.
- Determining the size of a washer.

The check of axial prestress:

There is adependence between axial prestress of a bearing and friction in a bearing. The friction increases with the increase of prestress. The measurement of a frictional moment within a pair of assembled bearings is used for setting the prestress. During the assembly we increase the prestress of bearings until we reach the prescribed friction moment.

However, it should be noted that the friction moment of bearings:

- Changes for individual bearings (a range is reported by a bearing manufacturer),
- Changes from lubrication conditions (preservatives, oils lubrication etc.),
- Bearing speeds.

We recommend the assembly of bearings with axial prestress in the range of 1.5 to 2.5 Nm for the milling head placement in a pair of tapered roller bearings.

Analysis of the micro geometry regarding the bearings dismantled from the milling head placement

The rolling-element bearings were subsequently dismantled into individual bearing components, and the check of micro geometry of the chosen areas was performed – contact surfaces. The device Roundtest RA120 was used for the measurement. Figures No. 9, 10, 11, 12 illustrate the measurement of the individual bearing parts, the measurement of the circularity on the raceways of the inner and outer ring. Both bearings were measured:

- Timken LL714649/LL714610
- Timken L116149/L116110

Bearing 1:

Figure 9. Measurement of the circularity on the raceways of the inner and outer ring

Bearing 2:

Figure 10. Measurement of the circularity on the raceways of the inner and outer ring

The measured circularity values for the raceways of the inner and outer ring are displayed in the following figures:

Bearing 1:

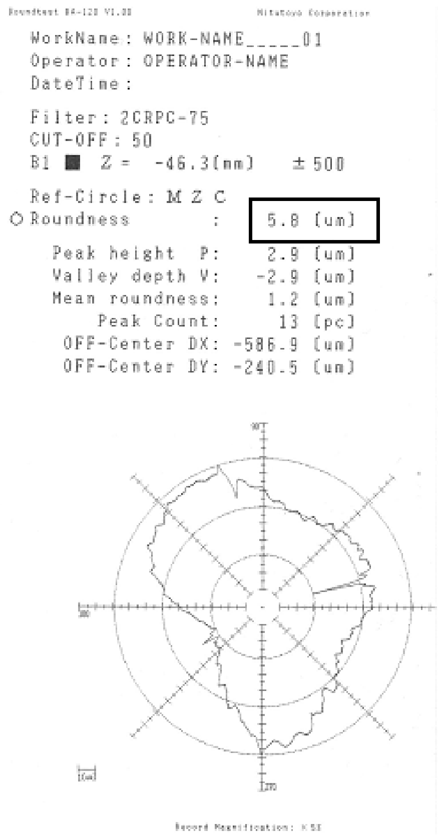

Figure 11. Roundtest RA120 results

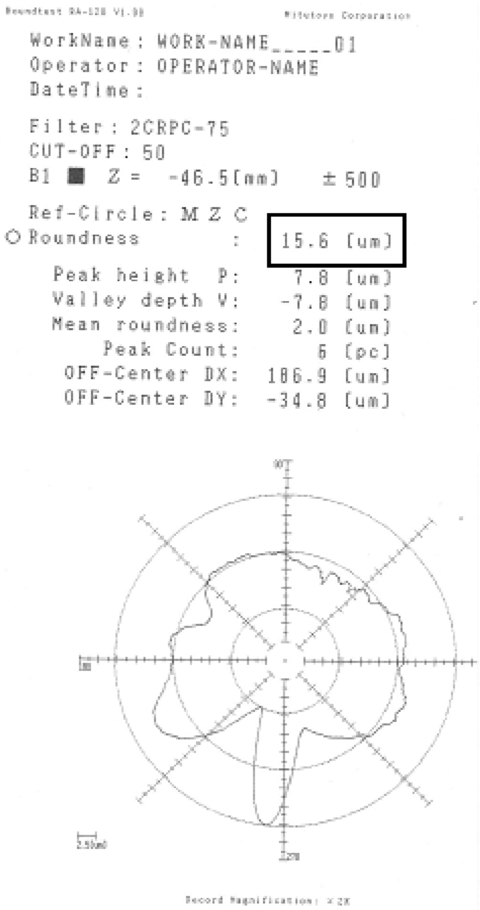

Figure 12. Roundtest RA120 results

Bearing 2:

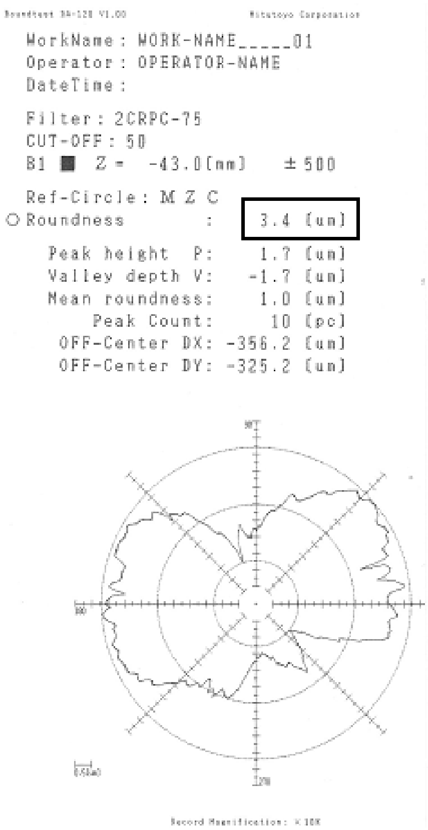

Figure 13. Roundtest RA120 results

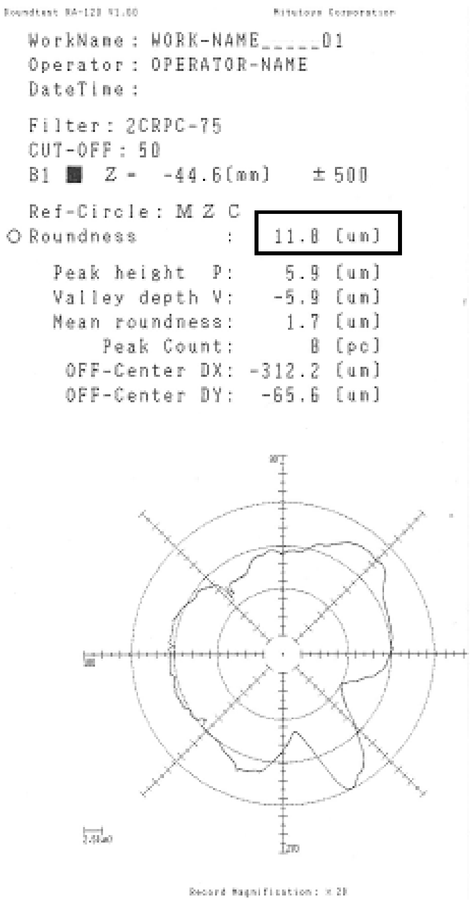

Figure 14. Roundtest RA120 results

The measured values of the circularity confirm inappropriate operating conditions. Due to the penetration of the cutting emulsion into the space of bearing set and into the plastic lubricant, the particular lubricant is not fulfilling its purpose properly and consequently, the bearing is not functioning properly. As a result, the circularity of raceways is also aggravated. This state applies to both monitored bearings [2],[3].

8. Conclusion

The performed measurements of the circularity with reference to the raceways confirmed the damage of the bearing, and thus the correlation between the monitored parameters and the bearing durability in the milling head placement was also confirmed. The performed measurements and the lubrication condition assessment has shown a clear correlation between the monitored parameters (the lubrication condition – the friction mode, abrasion and abrasion particles – axial prestress and set stiffness) and the durability (reliability) of the bearings in the milling head placement.

Based on the obtained results, we recommend carrying out measurements and analysis of dynamic signal in the milling head in the following phase, in an idle mode, as well as during machining, in a state after assembly, and after three months of a machine working in a proper operation (in order to monitor the oscillation increase, and therefore the deformation during machining) [4],[5].

Acknowledgements

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