Improvement of a work piece quality by suppression of vibration induced by imbalance

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Abstract: *The paper presents current methods of balancing rotors of machine tools in connection with quality of a final product. In the paper there are described different approaches to solution of balancing. The approaches are divided into five categories. Different machines are assigned to those categories including a description of pros and cons. Some automatic possibilities of imbalance elimination on machine tools are introduced as well.*

In the second part of the paper there is introduced case study of imbalance influence to a surface geometry and quality in case of milling.

Key words: *balancing, machine tools, automatic balancer, imbalance influence to surface quality*

1 Introduction - description of current state

The current solution of balancing approaches can be divided into several basic groups
1] Balancing a part performing the main rotary cutting movement is not carried out
2] Balancing is performed only ones while the machine or its part putting into operation
3] Only separable parts of rotating components are balanced. For example when exchanging tools, in case of maintenance, grinding or exchanging the tool holder.
4] Balancing is carried out every time we clamp a new work piece or tool
5] Balancing is checked in the course of machining process and it is possible to balance rotating parts on the machine and continue in machining

1.1 Segmentation of machines and manufacturing processes

Proper decision which balancing approach will be chosen depends on a compromise between the price and the quality of the final product. In other words it depends on if the influence of imbalance can cause justified demands leading to increased focus on balancing.

The important factor is the market and the technology the product is produced for. It is not possible to sort machines to the above mentioned groups according to maximum operational speeds or some other simple value.

There are some important influences such a size and mass of machined rotor (in case of lathes) or rotating tools (in case of milling machines). Another one is what kind of a work piece and tool will be used. Some other important things are static and dynamic compliancy of the machine in junction with the tool and the work piece – especially at the speed of cutting multiplied by number of teeth. On the other hand the very important things are expected surface quality, waviness and geometric accuracy.

Most of conventional machines belong to the first two groups. It is common that during production there is some basic balancing included - depending on the price category of the machine.

Into the third group belong grinding machines and some milling machines. In this case there are mainly balanced grinding wheel and its joining part. For example grinding wheel equipped with a coned flange, which is important for precise settlement on a shaft. Recently - during ingoing of high speed milling machines, the third category has been extended by milling machines. The tools together with tool holders are balanced on special balancing machines which are developed especially for milling tool holders. In this case tools and its tool holders are balanced outside its mother machine.

Into the fourth category there is possible to assign grinding, milling machines and some lathes. As a rule they are machines which allow to hand balancing directly on the machine without disassembly necessity. This method brings great advantage, that the work piece there is balanced together with other rotating parts. The biggest advantage is that there is eliminated an influence of changeover of a tool or the work piece. Except grinding machines it is possible to assign to this category lathes, especially the big ones, by which the imbalance can make an eccentricity of cut rotating surfaces. Disadvantage of the method is a need of skilled staff and a need of repeating balancing procedure every time after changing conditions (grinding wheel wear, mass distribution change caused by cutting etc.).

Into the fifth category are assigned mainly grinding machines, which are determined for the kind of production which is accentuated to high productivity and minimization of nonproductive times, together with elimination of bad influence of the staff performing balancing. Recently there is an effort to assign to this category even lathes and milling machines for high speed machining. In cases of high speed cutting machines, there is visible negative influence of imbalance because of higher speed together with higher demands on surface quality. Leading machine tools producers started to equip their machines with automatic balancing systems. They are more and more integrated into spindles of lathes and milling machines. In case of lathes the situation is obviously interesting because of there is high effort to keep good cutting conditions throughout all the cut diameters. In case of a piece on which there are some very different diameters, the cutting speed has to conform to technological demands. Therefore the speed is higher in case of cutting smaller diameter in comparison to cutting bigger one. Owning to varying speed during cutting the imbalance forces varies as well. The result of different forces is an eccentricity between above mentioned two diameters on the work piece. Another important thing which is needed to take into account is different dynamic compliancy of the machine according to different rotating speed. The case can be even more complicated in the case of a piece which is non-symmetric according to its axes of rotation. Such a work piece is imbalanced by its essence and turning it effectively in high quality without balancing is impossible. Those cases are for example turbine blades, crankshaft components etc..

1.2 Detailed description of commonly used balancing methods

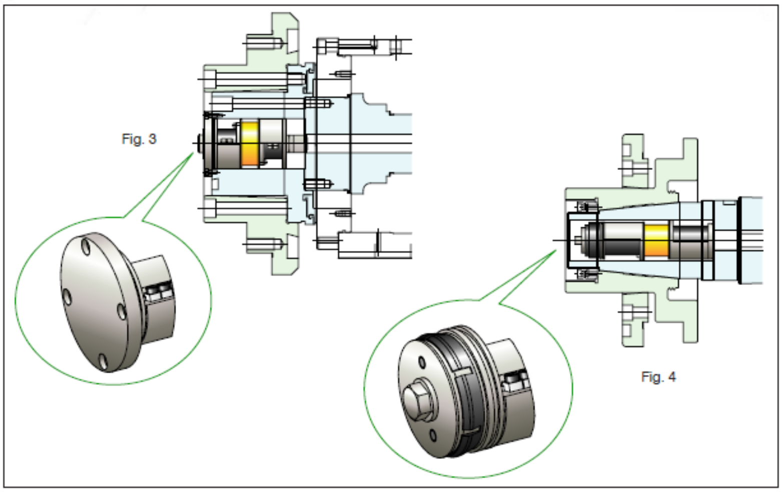
For category no 2 there are generally used instruments for rotor balancing outside of their mother machines. They are produced for example by Cemb, Schenck, Best Balance, Tira, Hofmann etc.

***Picture 1** Balancing machine for common use and a specialized balancer for tool holders*

The typical instrument for balancing rotors of machines belonging to category 2 is a balancer Schenck Pasio 50. It is used before assembling rotors.

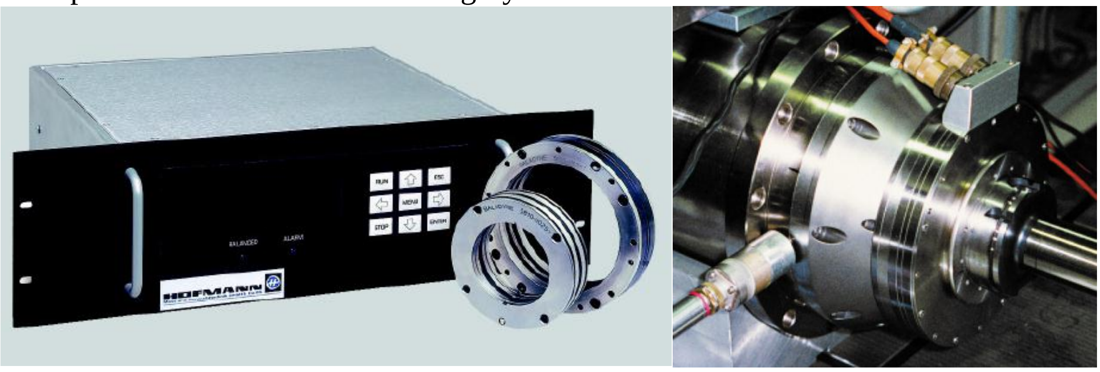
For machines and productions belonging to category 3 it is widely used balancing machines which are specialized for the rotors shapes (for example tool holders). A typical representative is a balancing machine PTB32.2 of Hofmann producer.

For machines and productions belonging to category 4 and 5 balancing equipment which is integrated into machine tools is used. This balancing equipment is represented by producers like Dittel, MPM, Marpos, Best Balance, Balancing System, Lord etc. A typical representative is balancing equipment Marposs ST which is developed for integration into a hole in a shaft is at the next picture. See Picture 2.



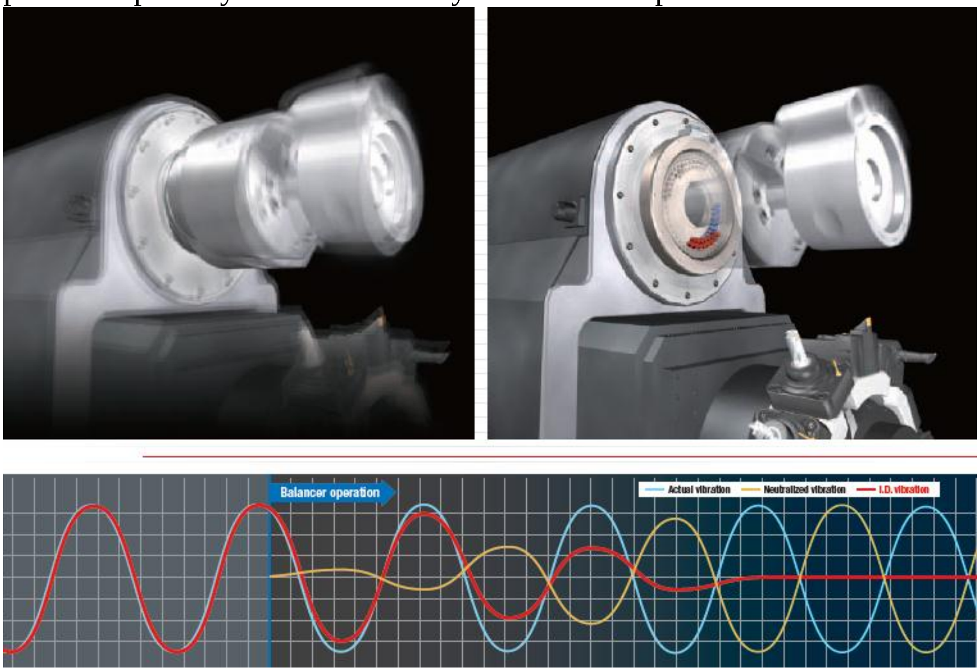
***Picture 2** Balancing heads*

It is possible to use a system which is determined for outside use of rotating shaft. The example is mentioned as a Balancing System EMB 7000. See Picture 3.



Picture 3 *Automatic balancing ring by Hofmann*

The balancing equipment EMB 7000 produced Balancing Systems (or Lord in now days) is optionally used on Mori Seiki Lathes for balancing main spindle. It is used during cutting process especially to balance non symmetric work pieces.



Picture 4 *Automatic balancing system for lathes Mori Seiki*

2 Case study: Influence of a tool imbalance to a work piece surface quality

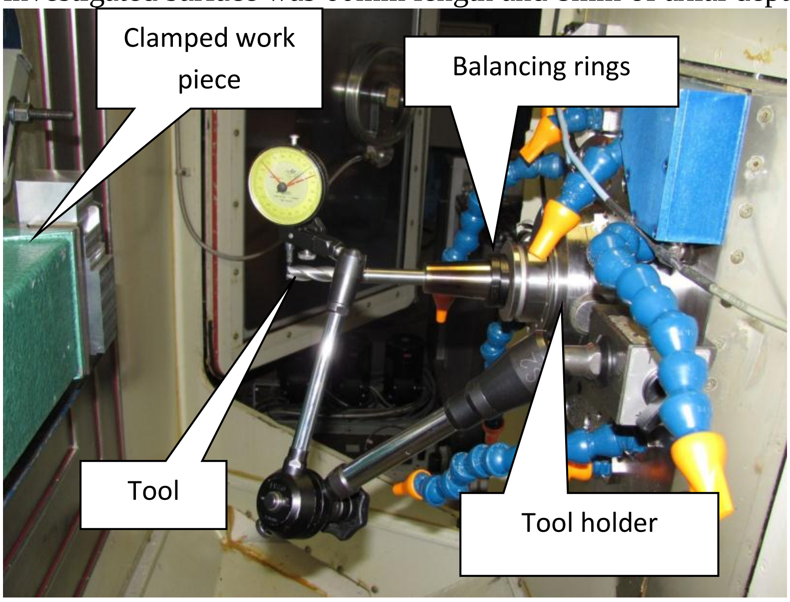
In order to determine the influence of a tool imbalance to a surface quality there were performed experimental measurements in a laboratory of VCSVTT at CVUT on the LM-2 experimental machine tool.

2.1 Measurement conditions

At the beginning was the geometric position respectively the difference between them measured at the Mitutoyo coordinate machine. Unfortunately the accuracy of the measurement wasn't sufficient. So it was decided to perform relative measurement by use of Tessa LVDT sensor which allowed measurement with better accuracy.

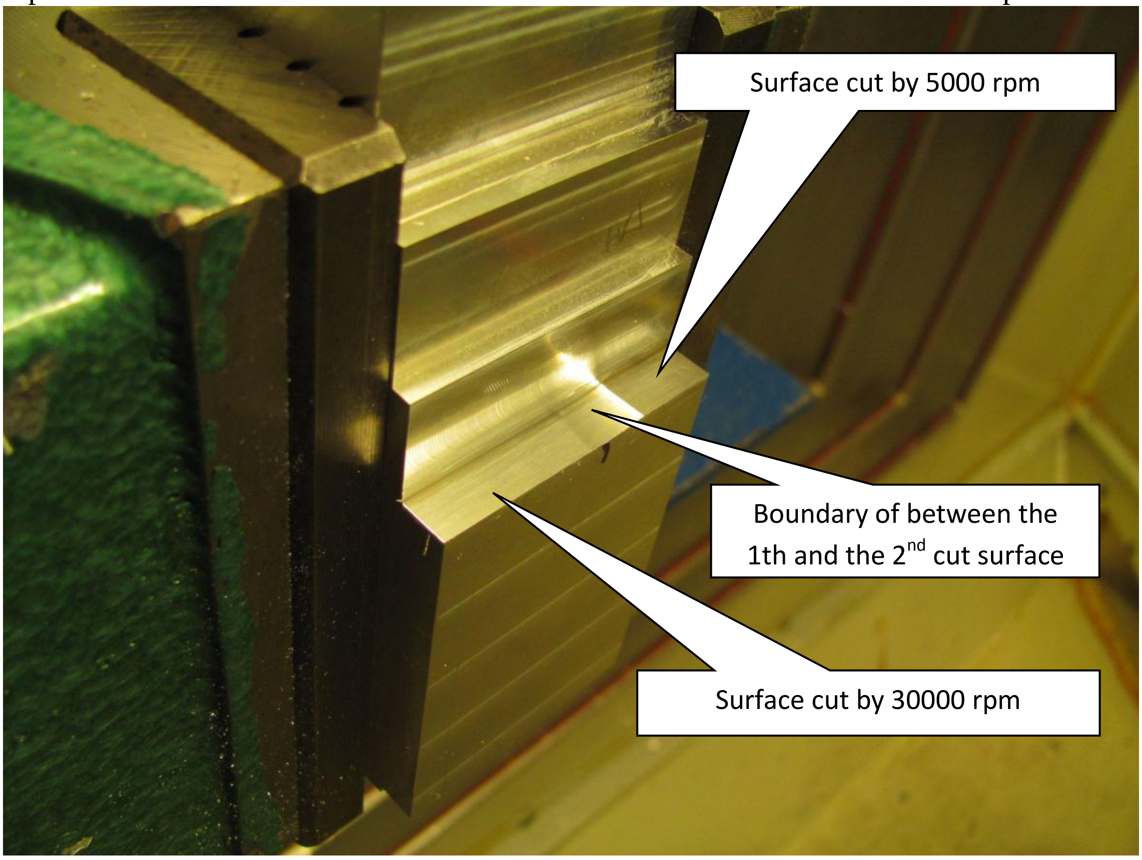
Picture 5 *Measurement of cut surface by use of Tesa LVDT displacement sensor*

During all the measurements there was used tool holder Diebold HSK 63-F together with milling tool of 16mm diameter. The tool was equipped with three carbides inserts every 120deg around the tool. The work piece was made form AlCuMg4 alloy. The work piece was clamped into the machine and the surface coming under investigation was aligned. The size of investigated surface was 60mm length and 8mm of axial depth.



Picture 6 *The performed test scheme and a run out measurement*

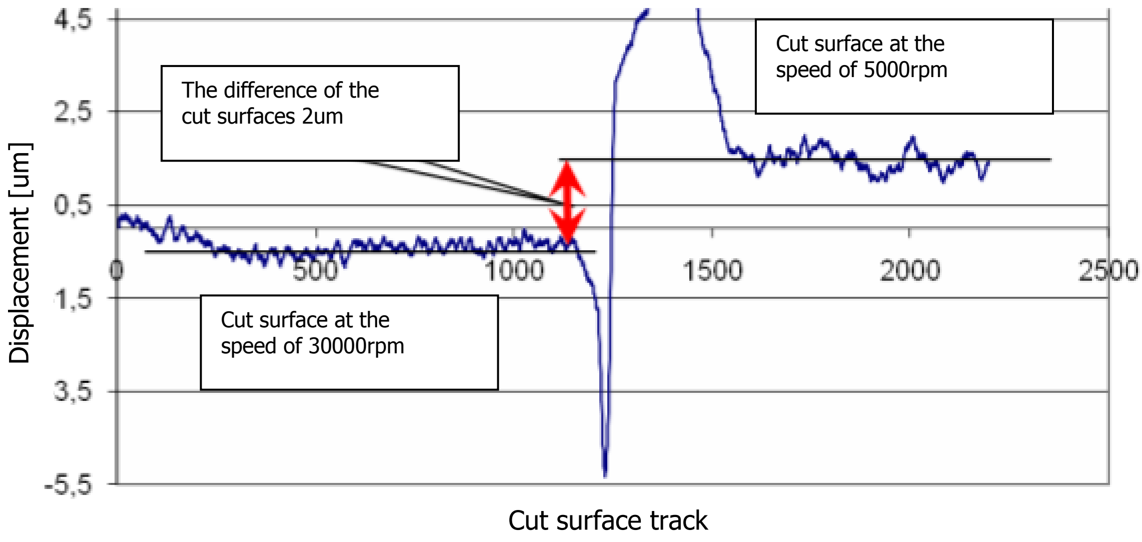
The cutting process was performed in two stages. Fist 2/3 of cutting length was cut by spindle speed of 30000rpm, the resting 1/3 was cut by speed of 5000rpm. Consequently was performed measuring of the surfaces and an offset between them was evaluated. The offset represents the influence of imbalance forces. The cut surface is showed at the picture



Picture 7 *Tested work piece*

2.2 The measurement with an unbalanced tool

At the first part of the measurement the tool holder with the tool was clamped into LM-2 machine spindle. By using of two balancing rings (specific imbalance of every of them is 46gmm) was the rotor assembly balanced. Balancing quality was evaluated by vibration speed measurement at the rotating speed of the spindle. The measured residual value was 0,02mm/s. First cut was performed with the tool of mentioned imbalance. At the Picture 5 it is illustrated the way how the test was performed. Both two surfaces was measured by LVDT sensor connected to measurement central Dewetron 3000. After measurement and filtration the offset between the two surfaces was evaluated. See Picture 8.

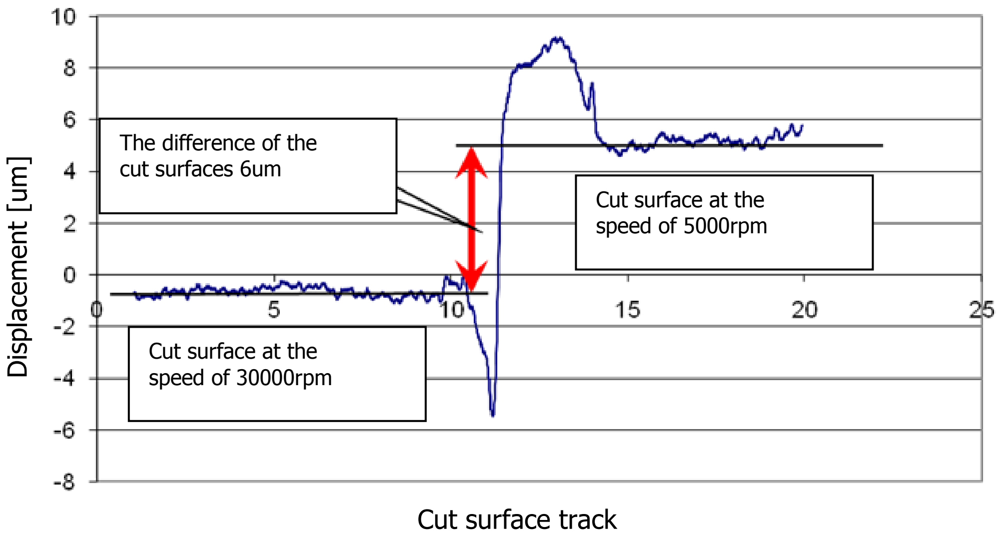


Picture 8 *Cutting with a balanced tool*

The difference (offset) between the cut surfaces was 2um. After the measurement the work piece surface was aligned and therefore got ready for next cut.

2.3 Milling and successive measurement in an opposite direction of the tool holder

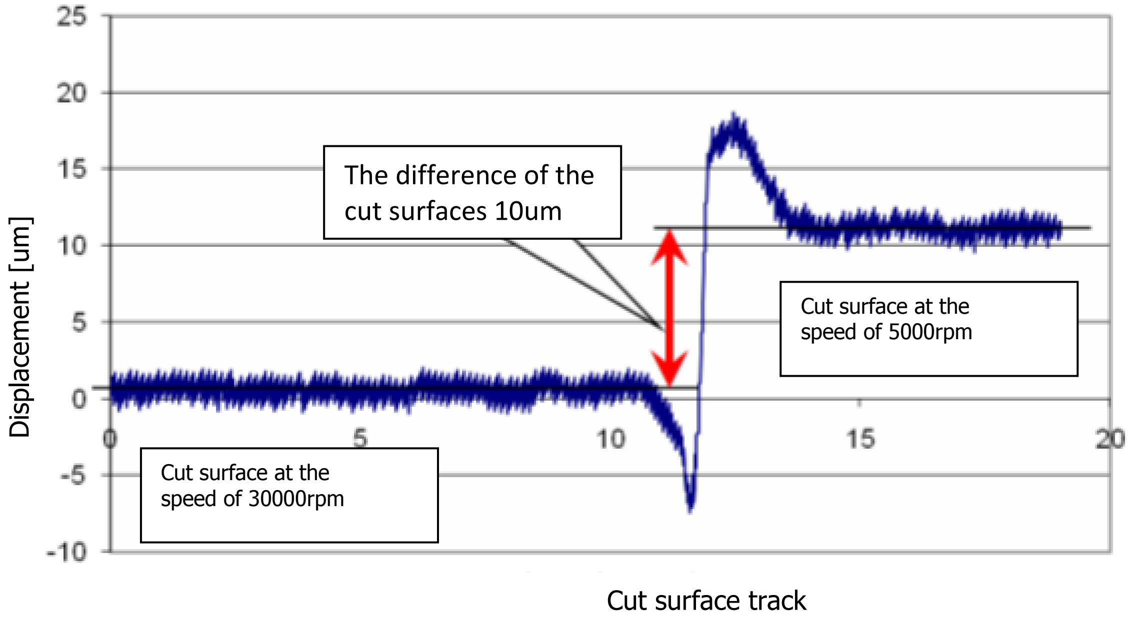
During second measurement was the tool holder rotated by 180deg. Balancing rings stayed at the same position as they were during the first measurement. By small angular movement of the tool holder and successive vibration measurement at the speed of 11500rpm, there was found the angular position at which the vibration was the maximal. The maximum value of vibration speed was 0,47mm/s. It is important to accent that this is the position which can be considered as a position of balanced rotor, just by switching-over the tool holder to the different position. The right position is not signed in the way of common use. The cut was performed with the unbalanced rotor. Cutting condition and whole the process was the same like during the first cut. The value measured after cutting between the first (30000rpm cut), and the second (5000rpm cut) was 6um. For detail see Picture 9



Picture 9 *Cut surface and its offset after angular rotating of balanced tool holder*

3 Milling and successive measurement with purposely unbalanced rotor

The last test was performed with purposely unbalanced rotor assembly. The imbalance was made by usage of only one balancing ring with a specific imbalance of 46gmm. The worst position, the combination of imbalance of spindle shaft and imbalance of the tool holder was found out by angular movement and consecutive measurement in the same way like during the previous case. In this way it was found that the maximum imbalance generates the vibration speed of 0,66mm/s. The tested surface (after its alignment) was cut and measured the same way like before. Resulting offset was 10um.



Picture 10 *Cut surface and its offset after cut with purposely unbalanced rotor assembly*

3.1 The imbalance influence to the surface roughness

Except the measurement of geometric position of cut surfaces there was measured roughness as well. There is a theory that there is only one tooth finishing the surface careless the imbalance. The theory is based on the knowledge, that one of the teeth is every time bigger than the others. If there is an imbalance added this condition doesn’t change. The only parameter which changes is the radius of the biggest tooth. In some cases if the heavy imbalance weight in the rotor is in the opposite to the biggest tooth an increasing of the speed can swop the biggest tooth. It is needed to say that this case is very rare. Results of tests are mentioned at the tab Tab 1.

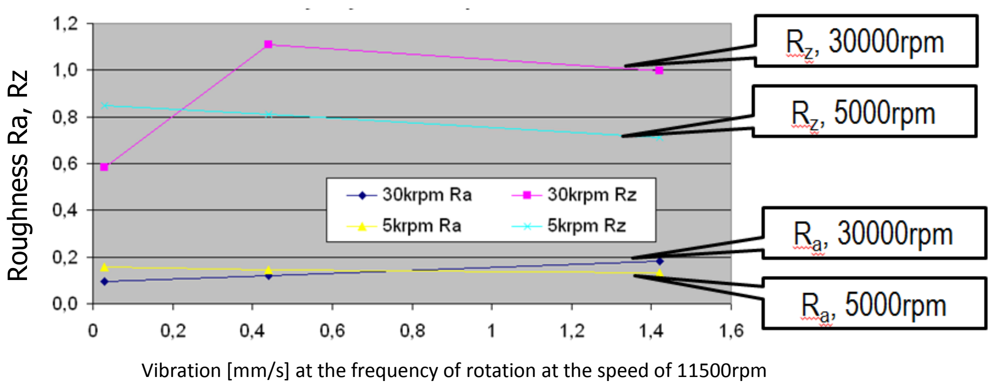


Chart 1 *Imbalance influence to the surface roughness*

Spindle speed [rpm]											
30000						5000					
Vibration [mm/s] at the frequency of rotation at the speed of 11500rpm											
0,03		0,44		1,42		0,03		0,44		1,42	
Roughness											
R_a	R_z	R_a	R_z	R_a	R_z	R_a	R_z	R_a	R_z	R_a	R_z
0,09	0,54	0,02	1,18	0,20	1,07	0,15	0,83	0,21	1,11	0,13	0,62
0,07	0,42	0,17	1,18	0,16	0,87	0,17	0,82	0,14	0,78	0,12	0,68
0,13	0,80	0,17	0,97	0,18	1,06	0,17	0,90	0,09	0,54	0,15	0,83
0,10	**0,59**	**0,12**	**1,11**	**0,18**	**1,00**	**0,16**	**0,85**	**0,15**	**0,81**	**0,13**	**0,71**

Tab 1 *Imbalance influence to the surface roughness*

Similar results was reached by Prof. H.Schulz, Darmstadt University of Technology, who tested cutting of aluminum alloy AlSi8Cu3 at condition: spindle speed 16000rpm, tool 2 teeth, tool diameter 10mm, feed per tooth 0,1mm, radial depth 2mm. Detailed results are at Chart 2

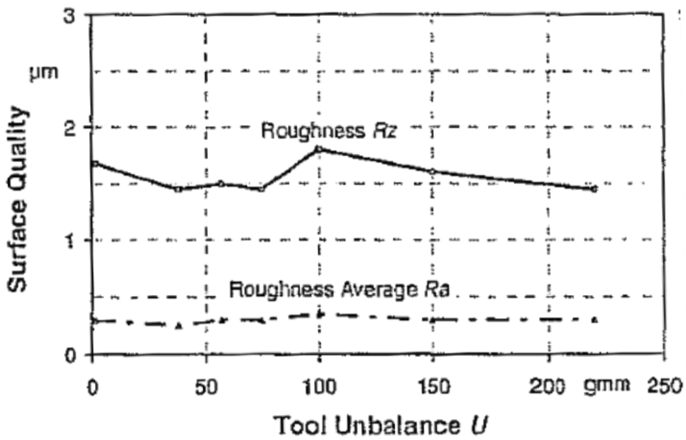


Chart 2 *Imbalance influence to the surface roughness.*

3.2 Conclusion

From the performed set of measurement it is possible to derivate a conclusion, that imbalance has demonstrable influence to the geometric accuracy of cut surface. Perfectly balanced assembly showed 5 times lower value of the difference between cut surfaces at speeds of 30000rpm and 5000rpm then the assembly which was unbalanced by 46gmm. It is possible to say that this imbalance was really high and it should not be present at the machines like the tested one. Nevertheless it the stuff is not precise enough, or if the balancing machine doesn't operate well, it is possible to reach values even higher as is mentioned. What is may be even more interesting is the result of rotating perfectly balanced tool holder to its opposite direction. In this case the increase was almost 3 times in comparison with balanced rotor. This can happen very easily, even if the outside balancing machine is in good condition. By the only rotating of the tool holder to its opposite direction the speed of vibration increased form 0.02mm/s to 0.43mm/s at the rotating speed of 11500rpm.

Performed tests confirm the thought that the accurate balancing is possible to achieve only by balancing of whole the rotor assembly. In industrial conditions it is hard to effectively establish particular imbalances of every part of rotor. Therefore the most effective way leads to balance the rotor assembly directly on the production machines after every switching over the tool or tool holder. In high capacity industrial productions it is possible to comply those demands only by use of automatic balancing systems integrated directly into production machines.

List of symbols:

n	rotating speed	[rpm]
Ra	roughness	[um]
Rz	roughness	[um]
v	vibration velocity	[mm/s]

References: Prof. H.Schulz, Darmstadt University of Technology

Companies materials: *Cemb, Schenck, Best Balance, Tira, Hofmann, Lord, Balance Systems*