Budapest University of Technology and Economics
Faculty of Transportation Engineering and Vehicle Engineering
Kálmán Kandó Doctorate School

Modern Technological Diagnostics of Boundary Surfaces of Composed (Hybrid and Composite) Vehicle Materials

BOOKLET OF THESES

PhD Dissertation

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Introduction

One of the main fields of developments in the automotive industry is the application of various hybrid and composite materials. There are several reports in the publications of the leading manufacturers about the use of these materials. A ***hybrid material*** usually is the application of several materials within a structural unit in order to use their advantageous properties. A ***composite material*** is called a combination of materials that consists of a matrix, and a strengthening material, usually of fibre type. A ***hybrid-composite material*** is usually consisting of several matrices and strengthening materials.

During the cutting of hybrid and composite materials the individual parts have to be processed at the same time. The cutting process and the accompanying events are of macroscopic type, because of the hybrid structure. These dynamic and thermal properties and the geometrical accuracy can have an effect on the quality of the manufactured products. These changing circumstances and their effects on the cutting process are discussed only in a few literatures. That is the reason why the target of this report was set to clear some items on this field.

Review of the literature

According to the goal of the research project the review of the literature has been carried out by the different topics separately, as follows:

- Diagnostics of the cutting process,
- Vibrations of the machine tools (vibration tests),
- Further methods of testing (force, temperature),
- Shape correctness and surface quality of the machined surface,
- Cutting of hybrid and composite materials, testing the boundary surfaces,
- Complex testing.

After reviewing the literature available the T2.1 Table has been compiled. It is providing a survey of the various projects and their complexities. (The full table can be seen in the dissertation under the designation of 2.1 Table.) In this table it can be seen that there is no fully complex study available, providing a complete review of all the methods, presenting all the advantageous and disadvantageous properties of their characters.

Also it can be seen, that the composite materials, according to their micro-structures, have little effect on the dynamic properties of the cutting process. That is the reason why the target of this study has been set on the investigation of the hybrid materials, which have more typical features in the macroscopic world.

T-2.1 table

Authors (see the literature)	Purpose of the study	Tested materials	Testing methods					
			Cutting force	Para-meters of the cutting	Vibration, noise, acoustic emission	Temperature	High speed camera	Shape of geometry, surface roughness
[F33.01-1989]	tool wears	steel	yes		yes			
[F4.19-1999]	industrial application	planet gear system			yes	yes		
[F5.32-2002]	montage accuracy	dynamometers	yes		yes			
[F5.27-2004]	milling	cast iron	yes		yes			
[F6.14-2006]	tool and work piece	simulation	yes			yes		
[F6.17-2008]	milling	industrial robot	yes		yes			
[F5.72-2008]	monitoring	theory			yes	yes		yes
[F5.41-2008]	chips formation	titanium alloy	yes				yes	
[F7.03-2009]	turning	steel	yes	yes				yes
[F7.05-2010]	tool wear	steel		yes	yes	yes		
[F5.51-2010]	cutting parameters	composites	yes	yes				
[F3.26-2010]	machine tool	software	yes			yes		
[F5.54-2010]	milling	milling machine	yes	yes				
[F6.24-2012]	cutting	WINalyse			yes		yes	
[F9.05-xxxx]	surface roughness	MATLAB			yes			yes

Goal of the research project

The goal of the dissertation is to study the behaviour of hybrid materials, regarding the

- cutting force, by a Kistler dynamometer, and data processing by Matlab software,
- vibration test by various methods and instruments (DLI, CSI, SKF, Brüel & Kjaer),
- comparison of the various parameters of vibration, and the the commercially available post-processing methods of various companies,
- tracking of the cutting process by thermo cameras and high speed cameras,
- test of geometrical shape and surface roughness after cutting.

The purpose of all these tests is to study the cutting process of the hybrid materials, and to find a relatively simple method equivalent with the complex series of all these tests, mentioned above.

The goal of the research project is to find an answer to the question whether it is possible to replace the highly complex measurement system by a more simple and cheaper method for the identification of quality parameters of the process. On the basis of this new method it would be possible to identify the time when a replacement of the cutting tool is necessary or when the technology has to be changed.

For the evaluation of the measurement results, apart from the own software of the instruments the following methods have been used

- for the processing and evaluation of the cutting force a special program, made in MATLAB environment, while
- for the determination of the correlation between the various parameters, the special function of the EXCEL software has been used.

In order to realize the project goals the following research plan has been compiled.

3.1 table – research plan

Testing procedure	**Specimen**	**Testing method**				
		Cutting force	**Vibration**	**Temperature**	**High speed camera**	**Shape, Surface roughness**
Preliminary tests on a mill	brazing sheet		DLI analyser	WUHAN Guide thermocamera	iSpeed camera	
Cross turning	Sintered steel, aluminium cylinder, and inside it various plugs with different hardness each (C45 steel, and bronze, and HSS)	KISTLER dynamometer + Matlab data processing	CMVA10 analyser (SKF)	WUHAN Guide thermo camera	iSpeed camera	
				AGEMA thermo camera		
			2135 analyser (CSI)	WUHAN Guide thermo camera		
			CMVA60 analyser (SKF)	FLIR thermo camera		
Orthogonal turning	Aluminium cylinder, and inside it various plugs with different hardness each (C45 steel, and bronze, and HSS)	KISTLER dynamometer + Matlab data processing	CMVA10 analyser (SKF)	FLIR thermo camera	iSpeed camera	shape and surface roughness measurement
			Brüel&Kjaer analyser			

Preparation of the specimens

The series of the research project can be divided into 3 different sections both in time and goal. Specimens, meeting the requirements and the process of preparation can also be divided into 3 groups accordingly.

In the first part of the project the so called "brazing sheets" (plates of various aluminium alloys), widely used in the automotive industry were used as specimens. However, their mechanical properties are not strongly different, and consequently the results were also not very dominant.

In the second part of the project, based on the previous experience specimens, with strongly different mechanical properties were selected.

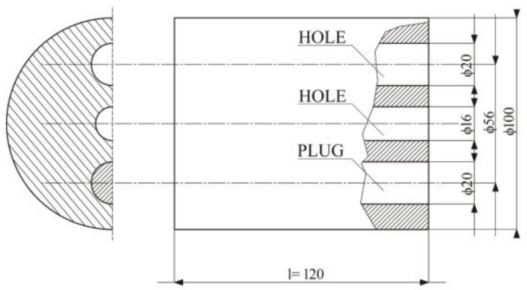

Fig. 4.02 a – Sketch of the specimens, used for the cross turning

Fig. 4.02 b – Photo of the specimens, used for the cross turning

These specimens consisted of a cylinder, and a plug inserted and fixed in the cylinder by thermal shrinkage method. Raw material was supplied by Hungarian sponsors. However, both the chemical composition and the mechanical properties had to be checked. Moreover, the texture of the specimens was checked by metallographic methods, too.

Also the method of cutting procedure has changed, and cross turning has been selected. Specimens have been tested by hardness measurement by the indentation method. It was found, that there is a difference between the extrapolated values of the catalogue and our measurements.

A sketch and the main data of the technology, used in the second section, can be seen on the Fig. 4.09a.

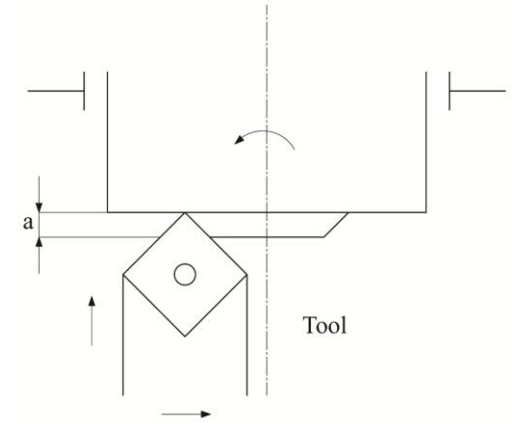

Fig. 4.09 a – Sketch of the cross turning

Main data of the technology:

- EU-400/01 lathe,
- Mitsubishi SEET13T3, AGEN-JL F7030 TIN,
- Feed: v_f = 0,1 mm/turn,
- Depth of cut: a = 0,5 mm,
- Speed n= 530/min, and 1060/min, respectively
- average speed of cut: v_c = 162 m/min (2,7 m/s), and 330 m/min (5,5 m/s) respectively.

In the third section of the project – in order to separate the individual parameters – orthogonal cutting had been selected. Arrangement of the specimens was as before, in the second section. However, the raw material has been purchased from authorized dealers. Consequently, there was no need for checking the chemical composition. The material of the cylinder was AlMgSi1F30 aluminium alloy, ϕ110 bar, while the plug was made of ϕ22 diameters, C45 quality steel. The prepared specimens can be seen on the Fig. 4.10a and 4.10b.

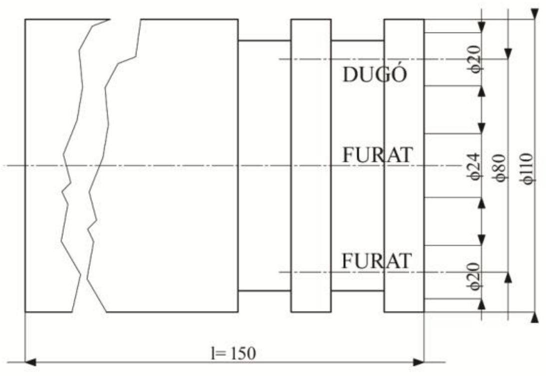

Fig. 4.10 a - Sketch of the specimens, prepared for orthogonal cutting

Fig. 4.10 b – Photo of the specimens, prepared for orthogonal cutting

The hardness difference of the individual plugs was achieved by thermal processing. On the Fig. 4.13 the hardness of the plugs can be seen, as a function of the distance from the outer surface. The Fig. 4.14 shows the location of the hardness measurement.

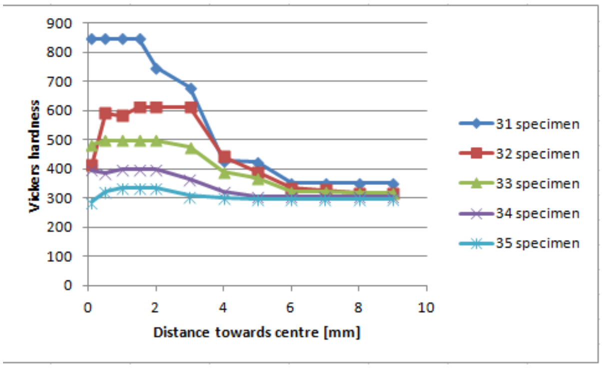

Fig. 4.13 – Micro-hardness of the plugs

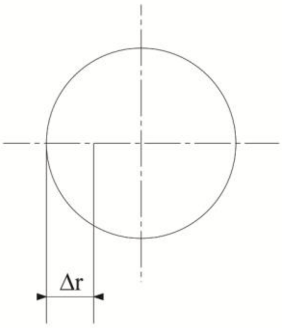

Fig. 4.14 – Sketch of measurements for Micro-hardness inside of the plug

The sketch arrangement and the main data of the technology used in the third section of the project can be seen on the Fig. 4.18.

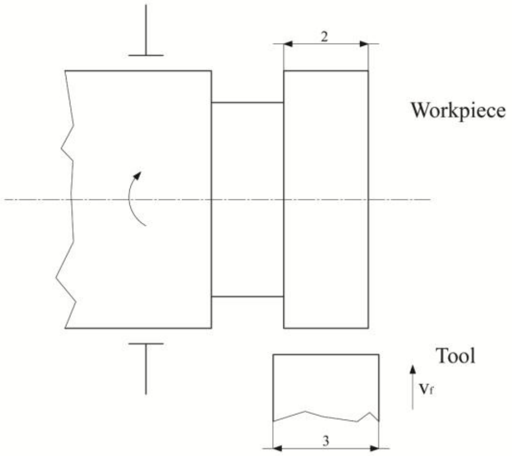

Fig. 4.18
Sketch of the orthogonal cutting

Main data of the orthogonal cutting:

- Lathe: EU-400/01
- Speed: n = 265/min,
- Feed: v_f = 0,1 mm/turn
- Cutting speed: v_c = 78 m/min (1,3 m/s)
- Tool-1: L151F SAFM/P25 MT-5 Mircona
- Tool-2: Sandvik COROMANT R154.91-25-25-30 R154.91-3300-S18810

Methods and tools of the experiments

There are several methods available for the measurement of the average ***temperature*** of the contact surface of the tool and the chips (calorimeter, thermo elements, thermo colours, and thermography). Based on the recommendations of the literature, and on the experience and equipment available at the department, the thermo camera has been selected.

Methods of calculations of the ***cutting force*** usually provide a static formula, although the cutting force depends on time, too. Consequently, the cutting force as a function of the time shall be determined by measurements. For this a modern KISTLER dynamometer has been used. Data of the cutting force were processed by an A/D converter, and then stored as txt files by the computer. These files were processed by the Matlab software. The results were obtained as a time function, and FFT spectra, spectrograms.

For the ***vibration measurement*** and data processing several methods have been used. One of them is the direct analysis of the registered time signals (acceleration and velocity). The other one is the Fast Fourier Transform (FFT) of the signals and the analysis of the spectra. The third one is the series of post processing methods of the signals, offered by the different companies (SKF Envelope Acceleration, CSI PeakVue, etc.). In order to make the analysis easier, the special methods of demonstration (ZOOM, waterfall diagrams, SKF Palogram, etc.) have been used.

A high speed camera has been selected for the study of the chip formation instead of the methods used before (visual observation of engraved lines on the surface of the workpiece, optical stress measurement, etc.). The task of this observation is to register the real process and to replay it at low speed in order to observe the process later on.

Methods for the measurement of deformation of the workpiece (form deviation) and the surface roughness are determined by international standards. Out of the given parameters the roundness deviation (radial deformation) and the surface roughness parameters have been selected and analysed as functions of the mechanical properties of the specimens.

Fields and process of the research

The duration of the research project spreads over 2 years. During this time several methods have been tested. Various types of thermo cameras and vibration analysers have been used. Details of the equipment are given in the relevant chapters of the dissertation.

Results of the research project

During the test of cross-turning by thermo camera a specimen, made of SD11 sintered steel cylinder, and AZ91 magnesium alloy plug have been tested by an AGEMA thermo camera, set to line detection mode of application. (Fig. 7.3).

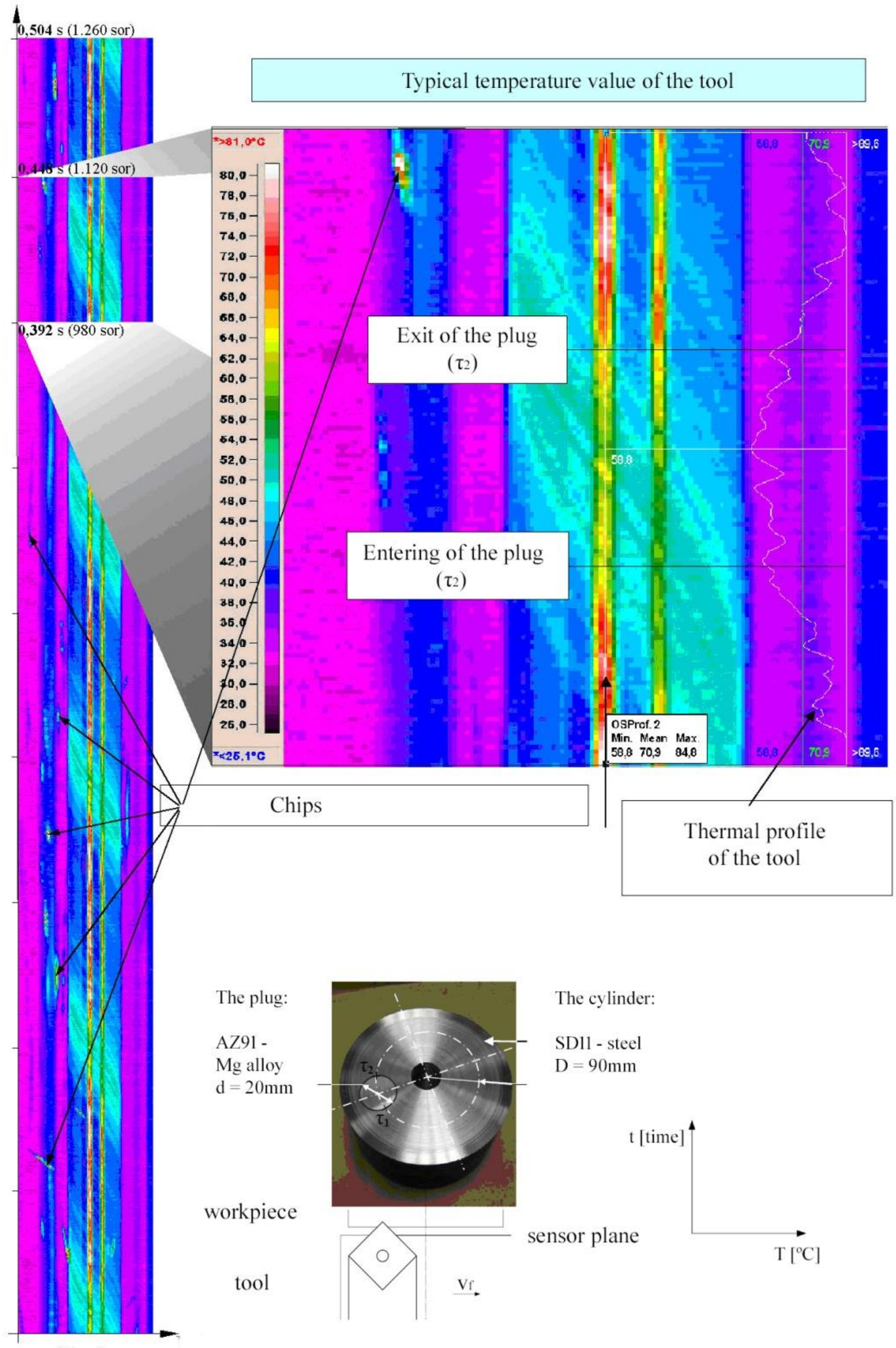

Fig. 7.3 – Investigation of the cross turning process by thermo camera (registration of data in line detection mode of operation)

The plane of sensing the signal is perpendicular to the axis of rotation, and is at ca. 1 mm distance in front of the workpiece. Temperature is demonstrated in a quasi 3 dimensional picture. The horizontal axis is the geometrical distance, while the vertical axis is the time. Temperature is designated by the different colours. On the left hand side of the picture there are several cycles, while a quadrant section of it is shown on the right hand side of the picture. The chips in the scanning plane can also be traced. Temperature as the function of time can be seen in the upper right hand side corner of the Fig. 7.3. It has been observed, that the temperature is changing periodically with the time.

Results of the temperature measurements of the orthogonal cutting can be seen on the picture 7.21. It can be observed, that in case of harder plugs the temperature is changing periodically. The period of time is obviously related to the rotational speed (specimens 31 and 32). The distance between the individual peaks on the horizontal axis is ca. 0,1 s, which is nearly equivalent with the value calculated of the rotational number (530/60=8,83 Hz, 1/8,33=0,12 s).

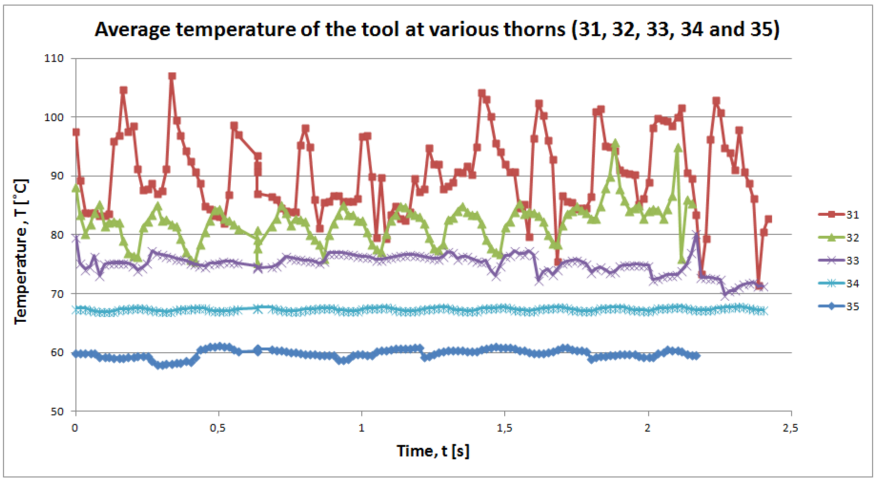

Fig. 7.21 – Temperature of the cutting plate during the orthogonal cutting process of the various specimens

The cutting force has been measured both in case of cross turning and orthogonal cutting by a KISTLER dynamometer. The received data have been processed by the MATLAB software. As it can be seen on the Fig. 7.8, the time signal has a periodicity, related to the number of revolution. The hits of the cutting tool to the plugs can be identified very clearly. Time of period is ca. T=0,1 s. The individual components can be identified as well. On the vertical axis the dimensionless value of the F_c cutting force component can be seen.

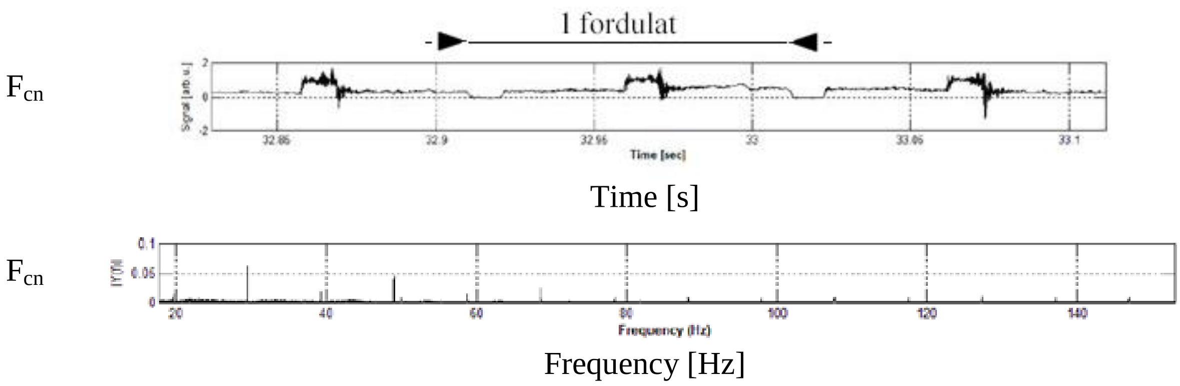

Fig. 7.8 – Time signal and frequency spectrum of the F_{cn} cutting force component, taken during the orthogonal cutting of specimen Nr. 2.5
(Kistler dynamometer + Matlab software [T.04-2011])

Vibration measurements were carried out partly by a CMVA 10 (SKF) analyser, partly by a CMVA60 analyser (also SKF), partly by a CSI2130 (Emerson) vibration-analyser, a DLI instrument, and a Brüel & Kjaer PULSE measurement system. On the fig. 7.12 the results of the vibration measurements, taken during the cross turning. On the vertical axis the Envelope Acceleration is shown. The hit of the tool into the plug can be well identified.

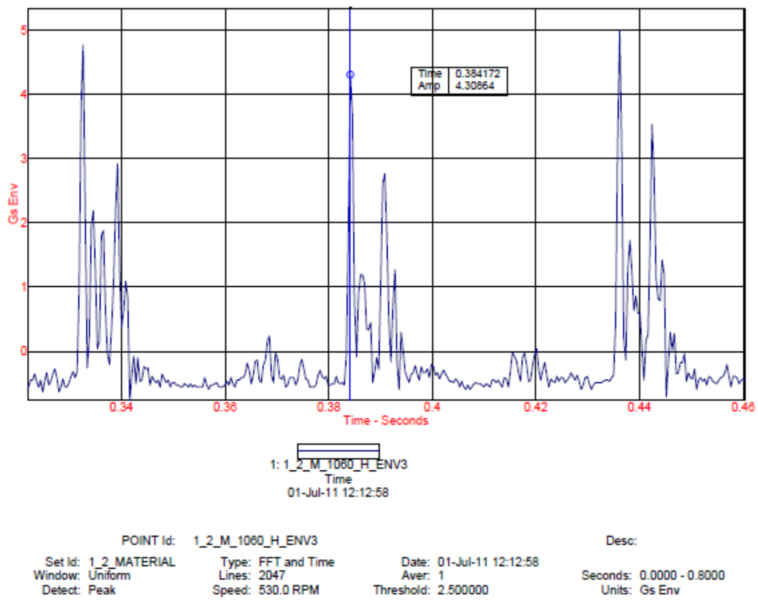

Fig. 7.12 – Time signal of the vibration, measured during the cross turning of the Nr. 1.2 specimen (CMVA10 analyser, F_f direction, time signal)

On the Fig. 7.13 the frequency spectra of the vibration signal taken during the cross turning of various specimens, shown in a so called Palogram type waterfall diagram. It can be seen, that the homogeneous specimens (Nr.1.1 and Nr.2.1) generate much lower vibration amplitude vibrations, than the inhomogeneous specimens (Nr.2.2 and Nr.2.3 specimens).

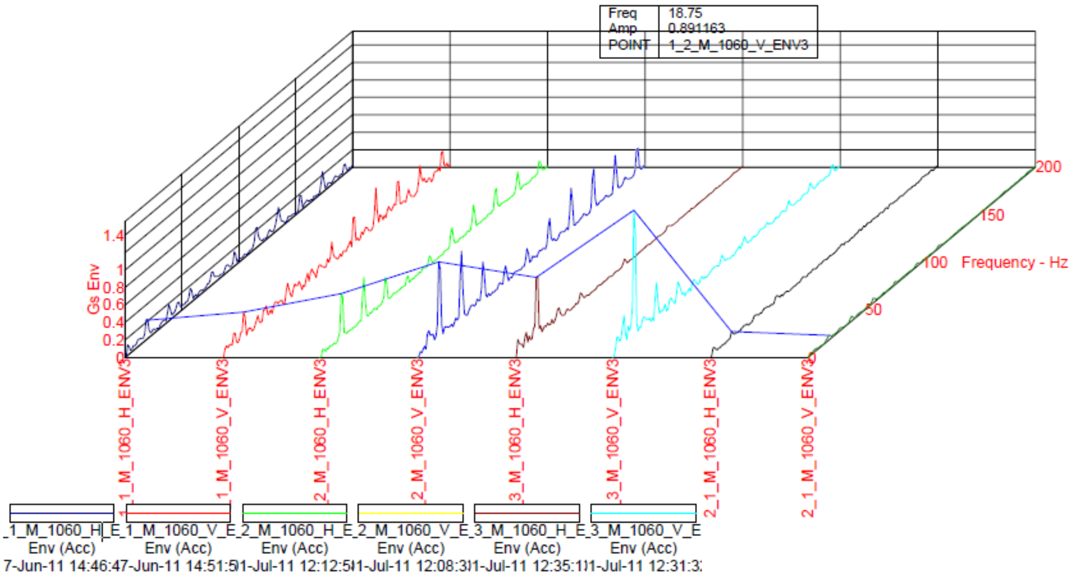

Fig. 7.13 – Frequency spectra of the vibration signal taken during the cross turning of various specimens, shown in a so called Palogram type waterfall diagram (SKF Palogram^{TM}, 1060/min) [T.02-2011]

The goal of ***geometry measurements*** was to identify the effect of plug hardness on the geometrical form of the specimens (deviation of circularity), and surface roughness after the cutting process. Detailed data can be found in the attachment Nr12 to the dissertation. Here only a little detail is shown. According to Fig. 7.37 there is a deviation of circularity, as the 7 measurement points demonstrate (around 3 o'clock position).

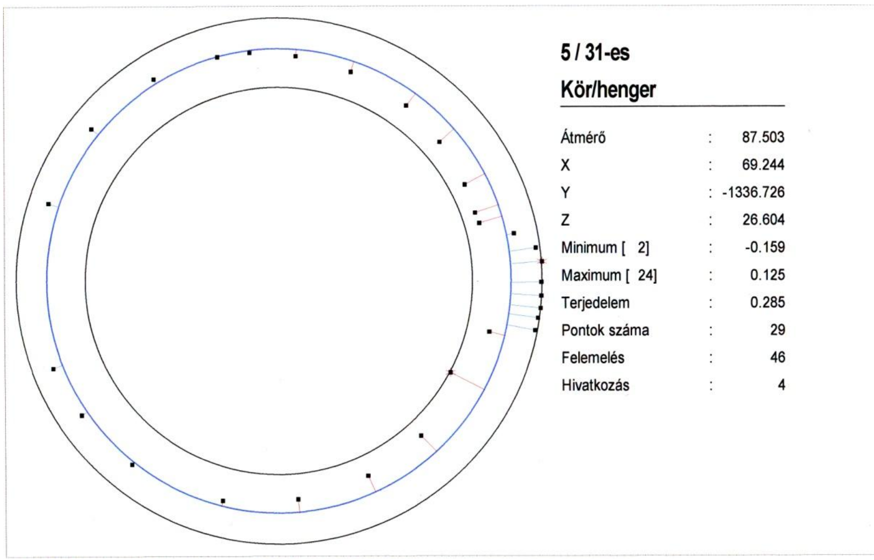

Fig. 7.37 – Nr. 31. specimen, deviation of circularity

Summary of the scientific results in theses

T-1. THESIS: In case of cutting hybrid materials, if there is an optical view to the object, then the thermo camera is capable to track the high speed cutting procedure of the hybrid materials in line observation mode. This can be proved by the periodic changing of the temperature, when entering the hard core material of the specimen. The elaborated new method made it possible to demonstrate the effect of the different features of the hybrid materials on the temperature of the cutting plate of the tool. Based on this investigation it can be stated, that the temperature is falling when cutting magnesium plug (compared to the cutting of sintered steel). The reason for this is the better heat conductivity and the less resistance to cutting. The amount of the reduction and the difference can be observed in the thermal profile diagram. [T.05-2012], [T.10-2013]

T-2. THESIS: By the heat treatment of the plugs, and by the micro hardness measurement afterwards it has been found, that the micro hardness distribution within the plug is not uniform. That is the reason why – based on data from the literature, and on my own measurements - the category of typical hardness was introduced. It has been found, that the temperature amplitude changing depends on the typical hardness of the plug. The harder the plug, the higher is the amplitude. In case of quenched plugs (700 HV typical hardness), the temperature variation amplitude can reach a value of 30 ^{0}C. However, in case of annealed plugs of 300 HV typical hardness the amplitude variation of the temperature can hardly reach the value of 2-3 ^{0} C. [T.05-2012], [T.09-2013], [T.10-2013]

T-3. THESIS: It has been found, that in case of orthogonal turning of hybrid materials there is a good correlation (0.920686) of F_c main cutting force and the Vickers hardness of the plug. It has been found, that the measured values of the main cutting force fit well on the regression line. This is a proof for the extension for the transient case of the previously widely used formula, according to which the main cutting force is proportional to the strength (hardness) of the material of the workpiece. [T.04-2013], [T.05-2013]

T-4. THESIS: A special combination of vibration measurement methods (parameter setup) has been developed, that is capable to test the boundary surface of hybrid materials during the cutting procedure. It has been found, that the directly recorded vibration signals (displacement/velocity/acceleration) are not suitable to trace the vibration during the cutting procedure. It has been found, that the most effective testing procedures are the so called post processing methods. It has been found, that out of these ones the best results can be achieved by the so called Envelope Acceleration method. The correlation is the highest by using this method. [T.09-2013], [T.11-2013], [T.12-2013]

T-5. THESIS: In case of cutting hybrid materials – by measuring the cutting force and the vibration at the same time – the direct relation of the force and vibration measurements have been combined. This means, that within the common measurement range of the two sensors (piezoelectric accelerometer, and piezoelectric force transducer) the signals are nearly identical. Evaluating the dynamic signals there can be found boundary conditions, which can prove the validation of the process modelling procedures. [T.11-2013], [T.12-2013]

T-6. THESIS: In case of cutting hybrid material specimens it has been found, that there is a strong correlation between the hardness of the plugs of the specimens, and the range of the radial runout (circularity, roundness tolerance). This means, that there might be a considerable circular runout, due to the machine-workpiece-tool interaction, and the force variation within one turn of the workpiece. [T.11-2013], [T.12-2013]

T-7. THESIS: For the diagnostic characterization of the cutting process of hybrid materials apart from the parameters of the force, and temperature measurements as dynamic values (shape of the signal, run up and periodicity) the relatively simple vibration measurement methods (features of the acceleration envelope signal processing) can be used effectively. [T.06-2013], [T.07-2013], [T.08-2013], [T.09-2013], [T.10-2013], [T.11-2013], [T.12-2013],

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[T.12-2013] **Dömötör F.** et al: Some Features of the Vibration and Temperature Diagnostics of Cutting Hybrid Metal Structures**,** 30th International Colloquium on Advanced Manufacturing and Repairing Technologies in Vehicle Industry, Visegrád, Hungary, 22-24 May 2013., ISBN: 978-963-313-079-7

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