10th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2006, Barcelona-Lloret de Mar, Spain, 11-15 September, 2006

# CUTTING DISTURBANCES IN HARD TURNING PROCESS

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## ABSTRACT
*Assumption of cutting disturbances in hard turning process (caused by variations in depth of cutting, high passive force $F_p$ or small tool nose radius) could be confirmed with several indicators. These indicators can be monitored during turning process(forces, vibrations, sound, etc.) or after process has been finished (roughness, temperature, wear, etc). Variation of depth of cutting as well as its influence on lead edge angle and passive force $F_p$ was therefore calculated on numerical model and procedure was followed by experimental tests .*
*It was found that high chip thickness alteration occur because of cutting depth vary for a value of some 60 % and even more if $F_p$ force signal is analyzing when machine tool has inadequate stiffness.*
*Assuming that a hard turning is a semi finishing or finishing process, surface finish is of big relevance. Surface roughness is a consequence of both cutting disturbances and of tool/workpiece non-uniform loading distribution. Results of test indicates an optimal cutting depth for final pass when minimum surface roughness can be achieved what can be valuable for cutting regime determination. Furthermore, higher machine tool efficiency might be achieved..*
**Keywords:** dynamic properties, depth of cutting, passive force

## 1. INTRODUCTION
Turning of parts with high surface hardness, where small values of cutting speed and chip area in cross section (comparing with soft turning) can be applied, is appearing to be in last few decades a process that substitutes grinding very successfully. This substitution enables higher productivity machining and reduce environment impact (lowering coolant consumption). But, besides these positive effects there are few negative acting effects which are related with hard turning. Hard turning is continuous process of chip removal according to tool engagement and thermal loads, but also dynamic undertaking the cyclic loading condition arising as a result of uncut chip area and depth of cutting variations in particular. Variations in depth of cut (DOC) as a result of prior pass scallops, feedrate, push–off effect, cutting velocity and effective lead angle, along the tool path produce significant dynamic force variations, which induce process disturbances. Besides other, cutting disturbances are besides already mentioned condition associated with the eccentricity of the workpieces, what might lead to self-exited vibration in any component of machine tool. Presence of that kind of vibration can lead to irregularity of machined shape as well as surface damage of machined workpiece. When hard turning process is applied, high precision in dimensions and shape of products is demanded. A lot of factors can affect precision and productivity of machining and one of the most affecting is self-exited vibration. On the other hand vibrations can lead to increased tool wearing and tool breakage as well. Tool nose radius influence cutting energy consumption and surface

quality. Higher nose radius allows finer surface finish, but also increased specific cutting energy [1]. Turn-milling as an alternative process, which reach higher productive rate, still cannot overcome the appearance of vibrations as a result of process kinematics-variations in the chip-cross section, and especially by the entry-exit condition [2].

All the disturbances and instabilities are caused by deflections in machining system (machine-tool-workpiece) [3]. The sources can be one or more of the following [4]:

- machine tool parameters : feed drive instabilities and dynamic behavior of the machine tool
- tool parameters : geometrical variations caused with tool wear,
- workpiece parameters : geometrical deviations (diameter variations) , inhomogenities in workpiece material

It is very difficult to obtain unique separation of the disturbances on its causes but there exists solutions to separate causes e.g. tight and broad measuring signal spectrum.

## 2. TOOL/WORKPIECE INTERACTION IN HARD TURNING

Tool/workpiece load distribution and heat interaction is mostly within tool nose radius what means very narrow area and very high specific pressures. Condition that tool/workpiece contact geometry is fully within tool nose radius is derived after :

$$a_p \le r_\varepsilon (1 - \cos \kappa_{re}) \quad \ldots(1)$$

what for turning condition where CNMA geometry of insert and PCLNR geometry of are applied, means that depth of cutting is smaller than value ($a_p$=0,43 mm). This value is calculated from equation (1) while very small tool nose radius ($r_\varepsilon$=0,4 mm) was used.

Effective lead angle in hard turning can be determined after [5]:

$$\tan \kappa_{re} = 0{,}5053 \tan \kappa_r + 1{,}0473\,(f/r_\varepsilon) + 0{,}4654\,(r_\varepsilon/a_p) \quad \ldots(2)$$

If variation of depth during cutting exists, effective lead angle will vary too, Figure 1.

Lowering the depth, lead angle will decrease and passive force should increase but also to decrease because of lower depth. This theoretic consideration is more complicated because of push-off effect derived by Brammertz [6] in terms of surface roughness.

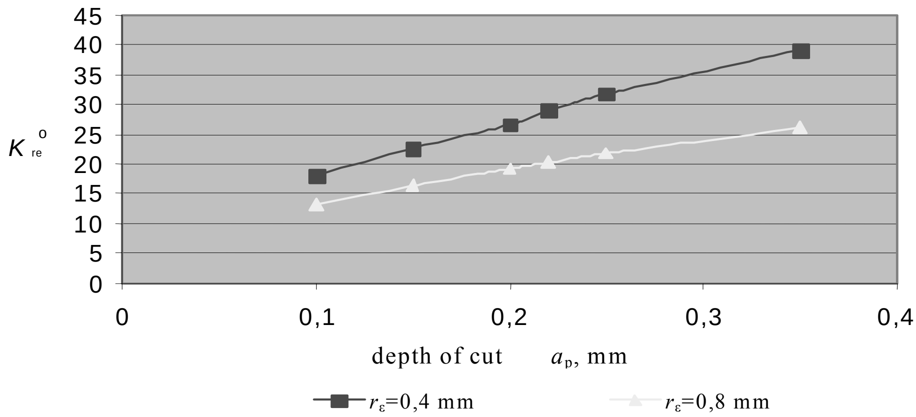


*Figure 1. Influence of DOC on effective lead angle*

As a consequence of uncut chip thickness variation during turning process, which in turning depends on the previous cut profile, variation of cutting force as a result of a nearly subcritical instability in the amplitude versus width-of-cut plane [7]. Hua at all refere the effect of the finishing process on the subsurface residual stress profile related to cutting edge geometry [8].

### 2.1. Depth of cutting influence on cutting dynamics

To check DOC variation during cutting, model of tool/workpiece interface was made , and depth of cutting $a_{min} < a < a_{max}$ was computed in different walley possition according to previous tool pass (p≥0). Figure 2 shows passive force sensing data that confirm variation of DOC (calculated value obtained after geometry analysis i sin the range of some 60%, while in soft steel turning this value is about 10%). In setted DOC of 0,3 mm, these 60 % means roughly ± 0,1 mm .

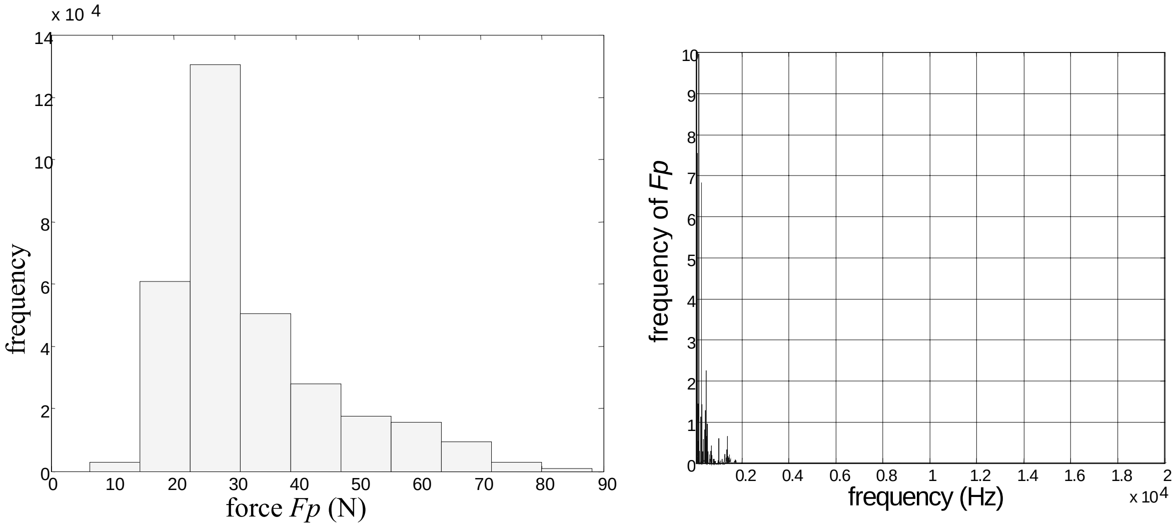


*Figure 2. Verification of DOC variation with $F_p$ measurement*

Depth variation in hard turning could be slightly lower 25-30% (for higher nose radius of priore tool pass, and for smaller feed rate), and slightle higher 10-15% (for other p values).
This DOC variation can be recorded also by acceleration measurement. Passive force $F_p$ variation over 70% can be established. This value is close to the previous consideration (60% variation of DOC), and confirm assumed facts on dynamic behavior of depth of cutting.
Force signals in frequency domain shows peaks only in the range below 2 kHz (observed range was up to 20 kHz), and high power peak at the frequency which correspond to frequency when tool is passing over walley peaks of previous pass. On accelerometer signal (sensor was oriented in the same direction as passive force) frequency peaks are diversed over range 5 and 45 kHz (with not so high dominant peaks at 17 and 31 kHz).

**2.2. Tool nose radius influence on cutting dynamics**

Tool nose radius has, as mentioned above, strong influence on DOC variation, and on lead angle what implicate cutting dynamics. It seems reasonable to verify influence of nose radius on cutting dynamic in frequency domain.
The concept and arrangement of measurements is shown in Figure 3 [9]. One can see from Figure 3 that direction of accelerometer sensitivity is coincided with direction of passive force in X-axis. It is also evident that the applied CNC lathe (Mori Seiki SL-153) has a relatively large revolver head where our experimental tool holder with accelerometer at one end and with cutting insert (geometry CNMA 1204 TN3) at another end was fixed.
As shown in fig. 4 the useful length of a test workpiece (heat treatable steel Ck35 E) was slightly less than 350 millimeters. This length was divided into several sections and for each two neighboring sections machining was performed under the same conditions (the same cutting parameters). For each section 10 single signals for acceleration in X-axis were recorded and after that transformed and averaged in frequency domain. Thus, the presented results are average spectra of 10 single spectra, obtained with discrete Fast Fourier Transformation. Sampling frequency during the signal recording was 100 kHz and number of discrete points was 8192. According to relations between sampling frequency, number of discrete points and time of recording, the latter was 0.08192 s. This means that frequency resolution of average frequency spectra was approximately 12.207 Hz .
The analysis of the effect of nose radius shows that the amplitude peak at 4 kHz is inversely proportional to the nose radius $r_\varepsilon$. Therefore, one can conclude that the amplitude peak at 4 kHz is a reliable criterion for identification of cutting nose radius. There is an additional prominent peak at 10 kHz, however its amplitude is higher for larger nose radius, which is not in agreement with conclusions from the first amplitude peak (see above). Therefore, it is reasonable to conclude that

only the first resonant peak has physically logical meaning: Smaller nose radius results in smaller tool holder stability (stronger vibrations) at this frequency in comparison to larger nose radius.

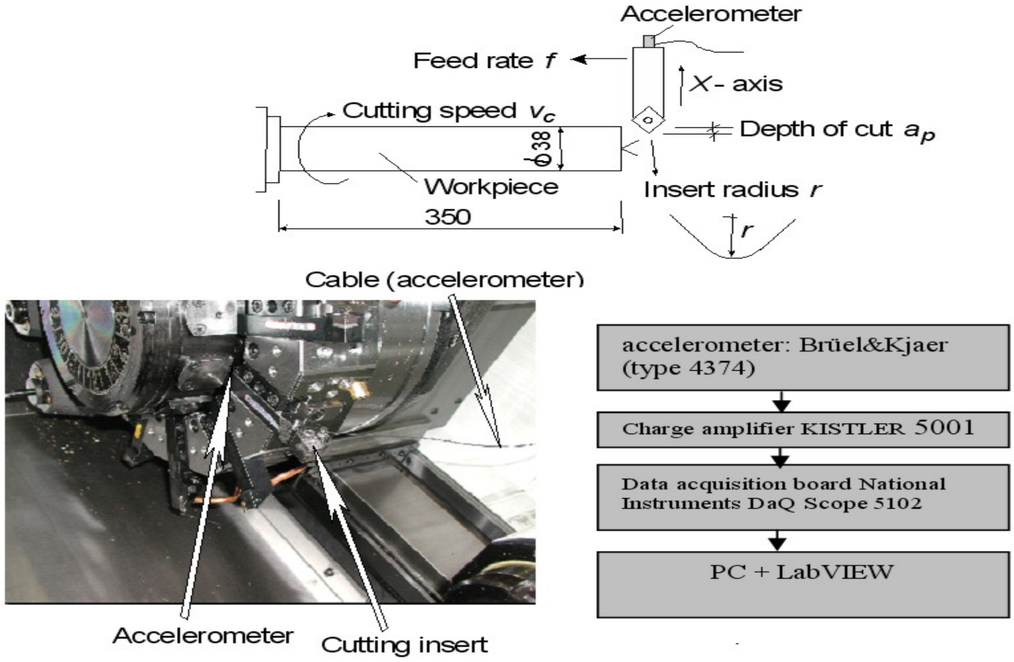


*Figure 3. Testing concept for tool nose radius influence on dynamic characteristics of hard turning*

## 3. CONCLUSION

An approach for identification of cutting disturbances in hard turning process has been presented. It was found DOC variation, by tool/workpiece interface obtained on numerical model and it was verified with passive force measurement. Since the chip-area geometry vary along the tool path, the tool path for several revolutions is considered when presenting the force/accelerometer sensing data. Under the given circumstances the amplitude peak at 4 kHz is a reliable criterion for identification of cutting nose radius influence, and acceleration amplitude at this frequency was inversely proportional to the tool nose radius $r_\varepsilon$. The achievements can be employed to increase productivity by guiding the judicious choice of cutting conditions and tooling geometry, and/or by regulating the spindle speed.

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