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Influence of the Cutting Parameters on Vibration Level in Metal Turning

Cutting vibration is a phenomenon that often appears in the process of metal machining, being one of primary factors that affects the processing quality and limits the productivity enhances. The analysis of vibration in the cutting process became very important, because the vibrations may cause the damaging of the machine spindle, cutting tool, or workpiece and leave behind a poor quality machined surface. The present paper intended to study the influence of the cutting parameters on the vibration level of the tool in turning process of mild steel.

Keywords: *metal cutting, vibration, cutting tool, cutting parameters*

1. Introduction

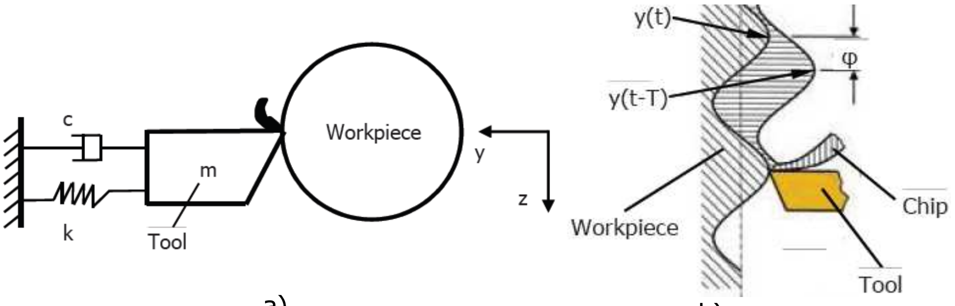
Metal cutting is a complex phenomenon, where the machined surface quality and the productivity are depending on a significant number of cutting parameters, respective tooling conditions. Today, the standard procedure to avoid vibration during the machining process involves a careful planning of the cutting parameters. Machining vibration accompanies every cutting process. Being influenced by many sources, such as machine structure, tool type, work material, etc., the composition of the machining vibration is complex.

However, at least two types of vibrations, forced vibration and self-excited vibration, were identified as machining vibrations [1], [2]. Forced vibration is a result of certain periodical forces that occurs within the machine. The source of these forces are, according to [3], [7], the bad gear drives, unbalanced machine-tool components, misalignments, or motors and pumps, etc.

Self-excited vibration, which is also known as chatter [4], [5], is caused by the interaction of the chip removal process and the structure of the machine tool, which results in disturbances in the cutting zone. Chatter always indicates defects on the machined surface. Especially self-excited vibration is associated with the machined surface roughness.

A mathematical model for turning, considering a single Degree of Freedom

(1DOF) with flexible tool and rigid workpiece is shown in figure 1.



a) b)

Figure 1. 1 DOF orthogonal turning model (a) and mechanism of regeneration (b)

With the notations from figure 1, the dynamic system can be modeled in the radial direction (y) as:

$$m\ddot{y}(t)+c\dot{y}(t)+ky(t)=F_p(t), \tag{1}$$

where, *m*, *k* and *c* are the mass, stiffness and damping coefficient of the tool, respective $F_p(t)$ is the time-varying passive force.

Considering *y(t)* the coordinate of the wave generated during the current revolution and *y(t-T)* the coordinate of the wave generated during the previous revolution of the workpiece, the passive force can be expressed as follows:

$$F_p(t)=K_{F_p}\cdot b\cdot[x(t-T)-x(t)], \tag{2}$$

where K_{F_p} is the passive force coefficient, *b* is the chip width and $T=60/n$, with *n*- the spindle (workpiece) speed.

Substituting Eq. (2) in Eq. (1) and dividing by *m*, Eq. (3) is obtained:

$$\ddot{y}+\frac{c}{m}\dot{y}+\frac{k}{m}y=\frac{K_{F_p}\cdot b}{k}\cdot\frac{k}{m}\cdot[x(t-T)-x(t)], \tag{3}$$

Making the notations: $\omega_0^2=\frac{k}{m}$, $\frac{c}{m}=2\cdot D\cdot\omega_0$ and $\alpha=\frac{K_{F_p}\cdot b}{k}$, Eq. (3) becomes:

$$\ddot{y}+2\cdot D.\omega_0\dot{y}+\omega_0^2 y-\alpha\cdot\omega_0^2\cdot[x(t-T)-x(t)]=0, \tag{4}$$

where ω_0 is the natural frequency of the system, D is the attenuation degree and α is the cutting parameter, being proportional to the chip width (width of cut).

Starting from Eq. (4) and making some mathematical manipulations, it can be drawn the stability lobes diagram (SLD), which is showing the relationship between the limiting width of cut (b_{lim}) and the spindle speed (*n*) for the turning operation. Being a succession of several local minima and maxima, the SLD indicates the regions where the process is stable, respective the regions where chatter appears.

2. Experimental Set-Up

The cutting experiments were carried out on a precision turning lathe (type SN 560). The work piece material was the mild steel C45. Machining was carried out using standard P30 carbide inserted tools with a 25 mm square shank, without the use of cutting fluid. The starting work pieces diameter was 50mm and 500 mm length. The turning was run until the flank wear of the tool achieved a maximum value VB_{max}= 0,6 mm.

Details of the tests and cutting conditions are listed in table 1.

Table 1. Cutting conditions

Spindle speed [rev./ min]	200, 315, 400 and 630
Cutting speed [m/min]	31,42; 49,48; 62,84and 98,96
Feed rate [mm/ rev.]	0,1; 0,2; 0,315 and 0,4
Depth of cut [mm]	0,5; 0,75; 1, 1,25 and 1,5
Cutting fluid	none

For vibration measurement was used an accelerometer type 4524B from Brüell & Kjaer, which was fixed on the cutting tool as shown in figure 2.

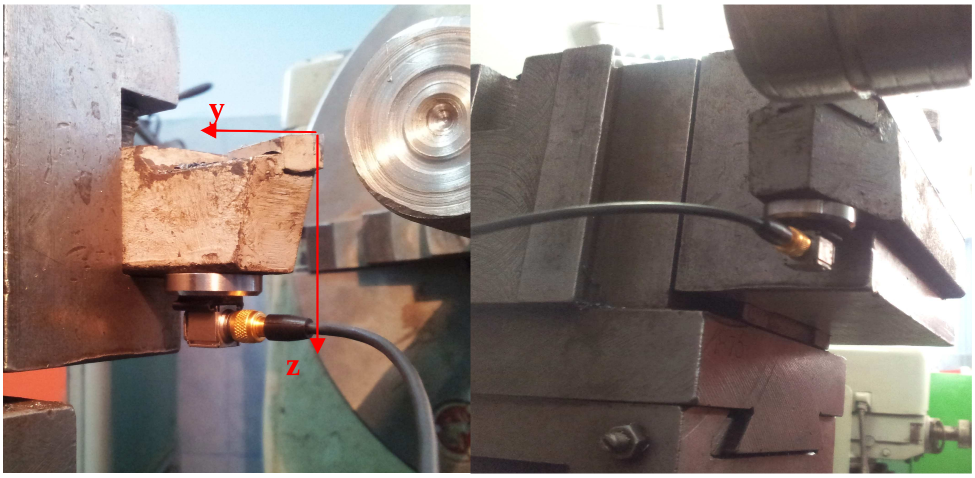


Figure 2. The set-up of the accelerometer on the cutting tool

The vibration of the cutting tool was monitored in two directions: in the direction of the passive force (further noted with index "y") and in the direction of the main cutting force (further noted with index "z").

Schematic diagram of the experimental set-up is shown in figure 3.

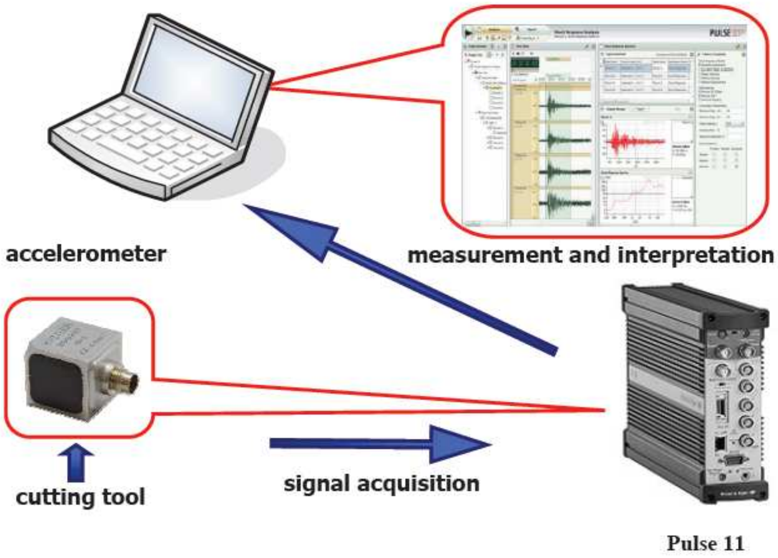


Figure 3. Experimental set-up

3. Experimental Results and Discussion

The cutting parameters and the vibration responses are shown in table 2 and table 3, respective in figures 4 and 5.

Table 2. Acceleration a_y [mm/s^2]

feed rate s [mm/ rev]	Cutting speed v= 31,42 m/ min				Cutting speed v= 49,48 m/ min			
Depth t [mm]	0,1	0,2	0,315	0,4	0,1	0,2	0,315	0,4
0,5	2,13	2,35	2,98	3,01	3,14	4,53	4,75	4,8
0,75	2,4	2,65	3,05	3,2	3,54	4,66	4,92	4,89
1	2,65	3,05	3,23	3,35	3,65	4,54	5,03	5,02
1,25	2,92	3,25	3,52	3,7	3,98	4,64	5,22	5,33
1,5	3,05	3,25	3,6	3,85	4,11	4,49	5,5	5,55
feed rate s [mm/ rev]	Cutting speed v= 62,84 m/ min				Cutting speed v= 98,96 m/ min			
Depth t [mm]	0,1	0,2	0,315	0,4	0,1	0,2	0,315	0,4
0,5	4,25	4,89	5,2	6,15	4,65	5,55	6,83	7,55
0,75	4,33	4,95	5,54	6,55	4,98	5,75	7,53	8,94
1	4,66	5,05	6	7,12	5,1	6,2	8,2	9,7
1,25	4,9	5,7	6,3	7,65	5,8	7,13	8,88	10,4
1,5	5,12	6,35	7,2	8,24	7,2	8,45	10,15	11,95

Table 3. Acceleration a_z [mm/s^2]

feed rate s [mm/ rev]	Cutting speed v= 31,42 m/ min				Cutting speed v= 49,48 m/ min			
Depth t [mm]	0,1	0,2	0,315	0,4	0,1	0,2	0,315	0,4
0,5	2,03	2,2	2,75	2,9	3,14	3,9	4,75	4,6
0,75	1,9	2,5	3,05	3	3,54	3,95	4,92	4,8
1	2,5	2,8	3,1	3,1	3,65	4,3	5,03	4,9
1,25	2,85	3,25	3,4	3	3,98	4,4	5,22	5,3
1,5	2,8	3,25	3,6	3,1	2,9	4,5	5,3	5,45
feed rate s [mm/ rev]	Cutting speed v= 62,84 m/ min				Cutting speed v= 98,96 m/ min			
Depth t [mm]	0,1	0,2	0,315	0,4	0,1	0,2	0,315	0,4
0,5	3,9	4,4	5,13	5,9	4,44	5,3	6,83	7,3
0,75	4,1	4,95	5,54	6,55	5,2	6,5	7,2	8,8
1	4,66	5,05	5,89	7,12	5,25	6,8	8	9
1,25	4,82	5,71	6,28	7,65	5,6	7,13	10,4	10,5
1,5	5,05	6,12	6,95	7,92	7,2	8,45	11	11,8

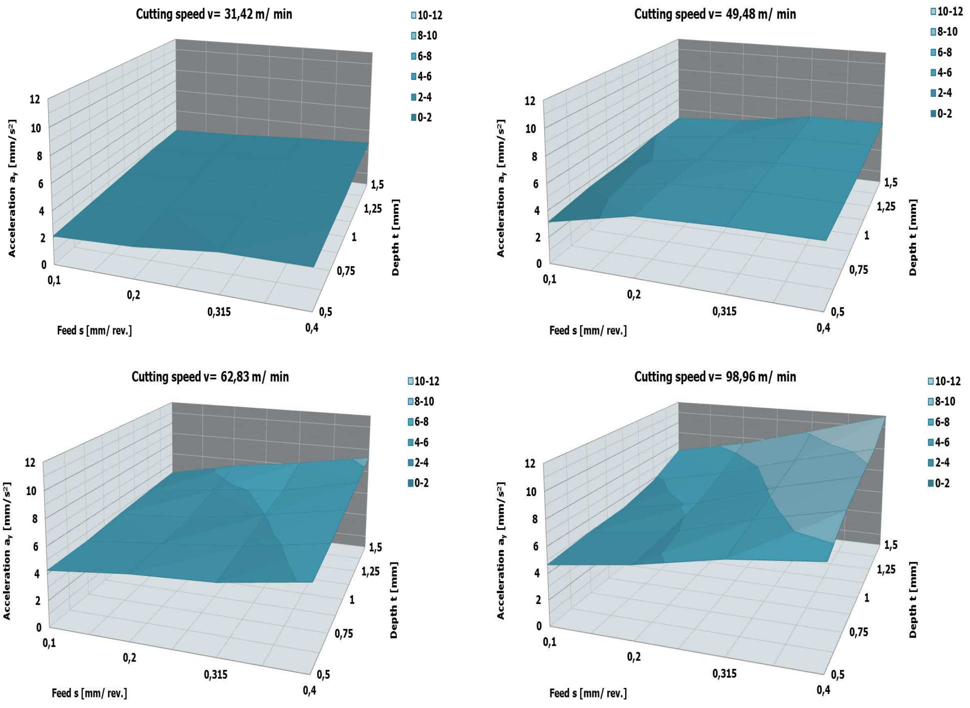


Figure 4. Influence on cutting parameters on vibration measured in direction of passive force (a_y)

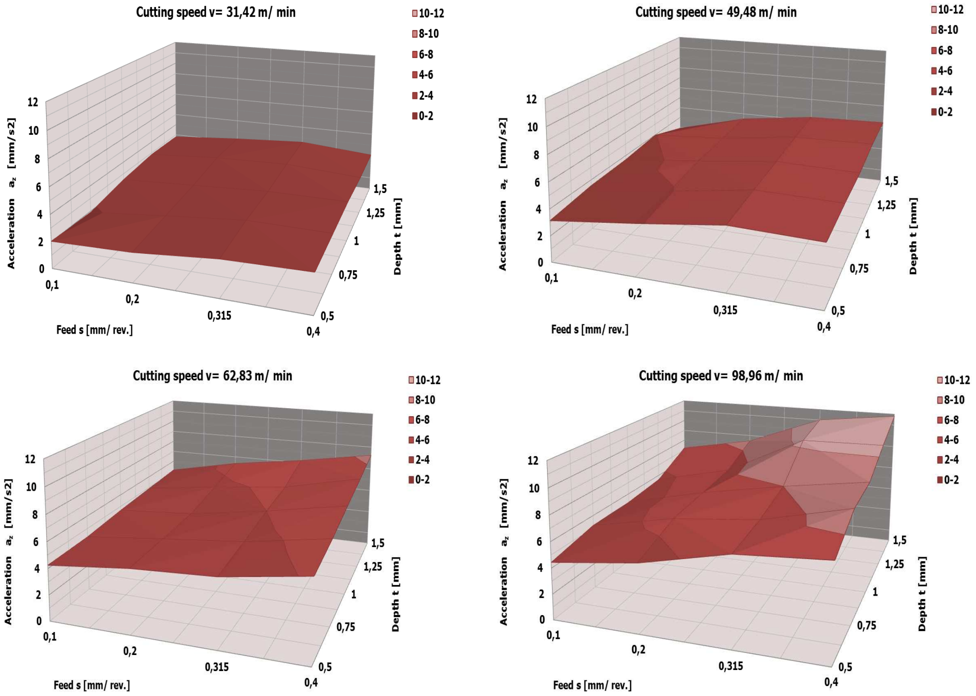


Figure 5. Influence on cutting parameters on vibration measured in direction of main cutting force (a_z)

The results presented in figure 4 and 5 are showing the effect of the cutting parameters (cutting speed, feed rate and cutting depth) on the evolution of the vibrations measured in direction of the passive force (a_y), respective the main cutting force (a_z). As it can be observed, the acceleration values measured in the two directions have close values

By increasing the feed rate and the cutting depth, the section of sheared chips is increasing. Therefore the removal of material requires higher forces and, consequentially, the vibration level is increasing. It can be noticed that, by turning with low cutting speed (v= 31,42 m/ min), the increase of the feed rate from 0,1 to 0,4 mm/rev, respective the increase of the depth of cut from 0,5 to 1,5 mm, results in an increase of the vibration acceleration of 80,75% (for a_y), respective of 52,71 % (for a_z).

However, by increasing the cutting speed, the higher depth of cut, respective the higher feed rate, are influencing more strongly the measured vibration level. Thus, at the cutting speed of v= 62,83 m/min, the increases of the measured vibrations are of 93,88% (for a_y), respective of 103,07 % (for a_z), while at the highest cutting speed (v= 98,86 m/ min), the increases of the measured vibrations are of 156,99% (for a_y), respective of 165,77 % (for a_z).

4. Conclusions

The tests of longitudinal turning, carried out on C45 grade steel, using carbide inserted tools, without the use of cutting fluid, enabled us to study the influence of the cutting parameters on the vibration level.

It could be concluded that, by raising the feed rate (s), the depth of cut (t) and the cutting speed (v), the technological system (machine – tool - piece) becomes unstable and the vibration level (a_x and a_y) is increasing.

The stability of the technological process can be improved by reducing the depth of cut the feed rate and the cutting speed. But these reductions should not be used for vibration damping, because they lead to the decrease of cutting process productivity.

Therefore, the cutting parameters have to be chosen in following order: first of all, the optimal cutting depth is determined, then the feed rate so that the cutting process remains stable and finally, the cutting speed, outside the critical area, where chatter vibrations could appear.

Acknowledgment

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