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"Eindhoven University Press" PT-report nr. PTO-458

Note for STC "Machine Tools" DAVOS, August 1979

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1. Introduction

In general it is known, that in cutting chatter is an important problem especially when one is interested in optimizing cutting conditions, i.e. the material has to be removed for the lowest cost.
An analysis of the chatter phenomenon (1) shows, that the imaginary part of the direct inner dynamic cutting coefficient (= $\mathrm{Im}K_{di}$) of the chip formation process is one of the most important quantities. In the past a lot of work has been done in this field. In CIRP a cooperative work was started in order to determine this quantity for several kinds of materials under various test conditions. As can be read in ref. (1), there were a lot of differences amongst the values of $\mathrm{Im}K_{di}$ for the same material and the same cutting conditions as measured by the different laboratories.
These differences have lead to the proposal to measure (2) this quantity again in different laboratories. The same proposal also included an other method for measuring of $\mathrm{Im}K_{di}$. It is a simple one, known as the Kals method (3). The next chapter will shortly deal with a variant of this method.
In the present work the tests were carried out on steel SAE 1045 by a carbide tool (P30) with different cutting speeds and three different feeds.

2. Kals method

The Kals method is based on the phenomenon that during cutting the process adds damping and stiffness to the system. The magnitude of this supplementary damping can be obtained by subtracting the damping during and before cutting.

If the damping during cutting is C_c and before cutting C_o (that means while the lathe is idling or is cutting with a depth of cut equal to zero), the process damping C_p can be written as:

$$C_p = C_c - C_o \qquad (2.1)$$

For measuring these magnitudes an oil-damped rig is used which has a natural frequency ν_o, mass m and damping ratio ξ_o before cutting and ν_c and ξ_c during cutting.

For a vibrational system of one degree of freedom it holds in general (4):

$$C = \frac{4\pi\xi_o m\nu_o}{\sqrt{1-\xi_o^2}} \qquad (2.2)$$

Equations (2.1) and (2.2) give for the different conditions:

$$C_p = \frac{4\pi\xi_c m\nu_c}{\sqrt{1-\xi_c^2}} - \frac{4\pi\xi_o m\nu_o}{\sqrt{1-\xi_o^2}} \qquad (2.3)$$

The imaginary part of the direct inner dynamic cutting coefficient (= ImK_{di}) is defined by:

$$ImK_{di} = \frac{2\pi\nu_c C_p}{b} \qquad (2.4)$$

with b = width of cut.

With the aid of equation (2.3) ImK_{di} can be written as:

$$ImK_{di} = \frac{8\pi^2\nu_c m}{b}\left(\frac{\xi_c\nu_c}{\sqrt{1-\xi_c^2}} - \frac{\xi_o\nu_o}{\sqrt{1-\xi_o^2}}\right) \qquad (2.5)$$

3. Experimental set-up

The orthogonal cutting tests are performed on a 10 KW lathe, make Lange. The rig with a mass m = 20,5 kg and a natural frequency of 143 Hz has a principal direction of motion perpendicular to the cut surface. This principal direction of motion is parallel to the axis of the testpiece. The rig has an automatic device in order to peel the workpiece with a high stiffness. During measuring the damping, this device lowers the stiffness and hits the rig. The thickness of the damping oil film in the rig was 2.75 mm.

One can calculate with (5) that the influence of the static deflection (under these conditions up to a maximum of 0.5 mm) on the damping during idling of $\xi_o = 0.05$ is neglegible low. These calculations are confirmed by measurements.
The vibration of the rig is registrated with an U.V. recorder. The amplitude of the displacement signal (sensitivity 1.33 $^{mm}/\mu m$ and a maximum displacement of 0.09 mm) was measured with a vernier.
The frequency of the rig was determined by comparising the displacement signal of the rig with an at the same time recorded signal of a stabilized frequency source. The testpiece was a bar of steel SAE 1045, with a length of 500 mm and a diameter of 106 mm. The width of cut was 3 mm.
The maximum admissible flank wear of the tool was 0.1 mm. The magnitude of ξ_o and $\bar{\nu}_o$ was determined from the average of three idling test. The $Im\bar{K}_{di}$ value was determined as the average of ImK_{di} of three hits. The cutting tests were carried out immediately after the idling tests. Also the minimum and the maximum value of the three values of ξ_o, ν_o, ξ, ν and ImK_{di} were recorded. The cutting tool was a P30 tip.

4. Results

Tables 1, 2 and 3 give the different magnitudes which are necessary to calculate ImK_{di} for different feeds and cutting velocities. Figure 1 gives a graphical view of these tables. This figure also shows the minimum, maximum and average values of ImK_{di}. It also demonstrates very clearly the great scatter in the value of ImK_{di} at low cutting velocities.

5. Discussion

1. The great variation of ImK_{di} for the one cutting condition shows that the calculation of b_{crit} from these data will be very inaccurate. One must put a question mark behind these b_{crit} values.

2. The variation of the values of ImK_{di} shows clearly the big differences found by the different laboratories.

3. In a lot of cutting conditions we found the frequency of ν_c of the motion during one hit of the rig changing almost continuously.

4. Relation (2.5) shows that if ξ_c and ξ_o have nearly the same value, ImK_{di} is fully unreliable.

5. Hitting of the rig with an automatic device which has a mechanical connection with the rig disturbs the signal.

Acknowledgements

The authors wish to thank mr. A. van Sorgen who carried out the experimental work.

Table 1, 2 and 3

The different measured constants for calculating the imaginary part of the direct inner dynamic cutting force coefficient

$\bar{\xi}_o$ = the average of the damping coefficient of the rig for idling.

$\xi_{o\ min-max}$ = the minimum and maximum of the damping coefficient of the rig for idling.

$\bar{\nu}_o$ = the average of the frequency of the rig during idling

$\nu_{o\ min-max}$ = the minimum and maximum of the frequency of the rig during idling.

$\xi_{c\ min-max}$ = the minimum and maximum of the damping coefficient of the rig during cutting.

$\nu_{c\ min-max}$ = the minimum and maximum frequency of the rig during cutting.

$Im\bar{K}_{di}$ = the average of the imaginary part of the direct inner cutting coefficient.

$ImK_{di\ min-max}$ = the minimum and maximum of the imaginary part of the direct inner cutting coefficient.

m = mass of the rig (20.5 kg).

Table 1

Speed [m/s]	Feed [mm/Rev.]	$\bar{\xi}_o$	ξ_o min-max	$\bar{\nu}_o$ $[s^{-1}]$	ν_o min-max $[s^{-1}]$	ξ_c min-max	ν_c min-max $[s^{-1}]$	Im $[10^8 \frac{N}{m^2}]$ $\bar{K}_{di}$	K_{di} min-max
0,2	0,104	0,067	0,066 -0,069	148,1	147,3-149,2	0,148-0,236	154,1-170,5	20,3	13,1-34,6
0,3	0,104	0,066	0,0657-0,0658	150,0	146,4-153,2	0,110-0,120	152,6-163,6	8,5	8,1- 9,1
0,4	0,104	0,068	0,067 -0,069	147,8	144,3-150,6	0,080-0,102	146,2-152,6	4,0	1,6- 5,6
0,5	0,104	0,069	0,068 -0,070	148,2	147,0-149,4	0,088-0,123	147,8-163,5	5,3	2,7-10,6
0,75	0,104	0,065	0,064 -0,066	145,1	142,1-149,2	0,095-0,102	146,4-156,7	5,6	5,0- 6,7
1,0	0,104	0,0612	0,060 -0,063	148,4	145,0-153,5	0,051-0,067	151,7-164,1	0,2	-1,0- 1,2
1,5	0,104	0,059	0,056 -0,062	149,0	148,6-149,4	0,031-0,055	166,1-174,3	-0,89	-3,9- 0,7
2,0	0,104	0,058	0,057 -0,058	149,5	146,3-153,2	0,086-0,113	157,7-167,9	8,1	5,8-11,4
2,5	0,104	0,058	0,057 -0,059	149,6	145,6-151,7	0,099-0,106	156,8-162,8	7,9	7,4- 8,5

Table 2

Speed $[^m/_s]$	Feed $[^{mm}/_{Rev.}]$	$\overline{\xi}_o$	ξ_o min-max	$\overline{\nu}_o$ $[s^{-1}]$	ν_o min-max $[s^{-1}]$	ξ_c min-max	ν_c min-max $[s^{-1}]$	Im $[10^8 \frac{N}{m^2}]$ $\overline{K}_{di}$	K_{di} min-max
0,1	0,208	0,064	0,063 -0,065	147,1	146,7-147,5	0,155-0,210	151,7-154,8	18,0	14,1-23,8
0,2	0,208	0,070	0,069 -0,071	149,0	148,1-149,7	0,158-0,209	150,3-165,0	18,0	13,2-26,5
0,3	0,208	0,067	0,067 -0,068	149,8	148,9-150,3	0,151-0,167	144,0-153,8	13,5	11,1-16,0
0,4	0,208	0,074	0,073 -0,075	149,7	148,0-151,4	0,105-0,138	148,6-160,1	7,3	4,4-11,7
0,5	0,208	0,071	0,069 -0,072	148,0	145,6-149,4	0,095-0,097	152,9-157,7	4,4	4,0- 4,9
0,75	0,208	0,074	0,072 -0,075	147,5	145,9-149,7	0,152-0,186	143,8-178,7	16,4	10,4-20,9
1,0	0,208	0,052	0,051 -0,053	153,9	152,3-156,1	0,057-0,073	156,5-167,6	2,33	1,6- 3,5
1,5	0,208	0,063	0,0630-0,0635	155,6	150,6-159,1	0,110-0,159	162,7-165,7	12,2	9,2-17,2
2,0	0,208	0,057	0,056 -0,057	148,1	142,4-154,0	0,080-0,107	148,3-152,3	4,8	3,8- 7,8
2,5	0,208	0,054	0,053 -0,055	151,0	144,5-154,4	0,085-0,088	152,0-154,1	5,0	4,8- 5,3

Table 3

Speed $[m/s]$	Feed $[mm/Rev.]$	$\bar{\xi}_o$	ξ_o min-max	$\bar{\nu}_o$ $[s^{-1}]$	ν_o min-max $[s^{-1}]$	ξ_c min-max	ν_c min-max $[s^{-1}]$	Im $[10^8 \frac{N}{m^2}]$ $\bar{K}_{di}$	K_{di} min-max
0,1	0,288	0,0725	0,0724-0,0726	143,4	142,6-144,2	0,168-0,271	150,6-177,7	31,3	14,8-45,6
0,2	0,288	0,073	0,071 -0,074	144,2	140,4-147,2	0,198-0,242	148,6-156,8	24,5	18,8-29,0
0,3	0,288	0,050	0,049 -0,050	151,4	148,0-153,5	0,150-0,168	169,6-187,9	24,6	21,5-29,8
0,4	0,288	0,073	0,070 -0,076	148,8	148,1-149,7	0,149-0,194	144,3-161,9	16,4	10,2-19,7
0,5	0,288	0,072	0,071 -0,074	145,7	140,0-149,2	0,113-0,145	157,1-157,8	11,0	7,4-13,0
0,75	0,288	0,051	0,051 -0,052	155,5	153,7-156,5	0,050-0,079	157,4-171,8	2,8	-0,1- 6,3
1,0	0,288	0,049	0,049 -0,050	153,3	152,9-153,8	0,112-0,128	156,5-166,6	12,6	11,1-13,4
1,5	0,288	0,053	0,052 -0,054	148,9	147,3-151,7	0,074-0,082	157,5-171,8	5,4	4,3- 6,9
2,0	0,288	0,050	0,049 -0,051	160,3	157,9-163,7	0,073-0,096	160,3-163,9	5,4	3,8- 8,0
2,5	0,288	0,055	0,054 -0,056	153,6	152,9-154,1	0,074-0,083	155,8-167,0	4,4	3,1- 5,4

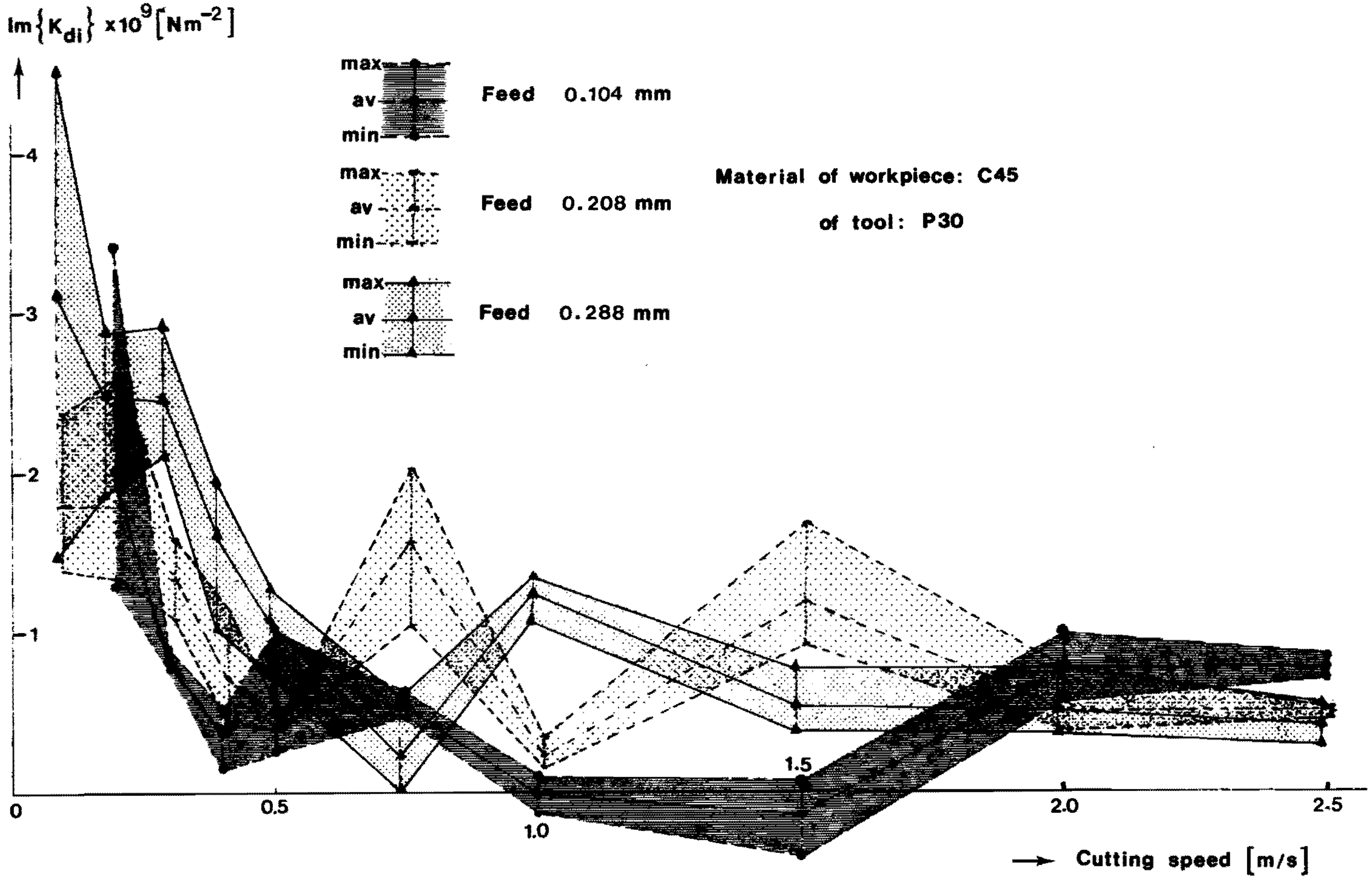

Figure 1. Relation between the imaginary parts of the direct inner dynamic coefficient and the cutting speed for three feeds, showing the spread in measurements.

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