Accuracy of the experimentally obtained values of the dynamic cutting coefficient with the Kals-method

Citation for published version (APA):
Dautzenberg, H. J., & van der Wolf, A. C. H. (1980). *Accuracy of the experimentally obtained values of the dynamic cutting coefficient with the Kals-method.* (TH Eindhoven. Afd. Werktuigbouwkunde, Laboratorium voor mechanische technologie en werkplaatstechniek : WT rapporten; Vol. WT0465). Technische Hogeschool Eindhoven.

Document status and date:
Published: 01/01/1980

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

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ACCURACY OF THE EXPERIMENTALLY OBTAINED VALUES OF THE DYNAMIC CUTTING COEFFICIENT WITH THE KALS-METHOD.

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"Eindhoven University Press" PT-rapport nr. PT-0465.
Note for STC "Machine Tools" Paris, January 1980.

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1. Introduction.

During the discussion of the note: "The imaginary part of the direct inner dynamic cutting coefficient (= Imk_{di}) of the steel SAE 1045 for different feeds measurement with the Kals-method (1)" in the workmeeting of the STC "Machine Tools" of the CIRP in Davos (August 1979), two important problems arose:

- The reality of the big variance in the values of Imk_{di} of steel SAE 1045 for different cutting conditions.This variation was determined (1) by the difference of the maximum and minimum value of Imk_{di} of three tests under the same cutting condition.
- The reality of the frequency variation of the rig during cutting after a hit. At that time, this problem was not fully clear, for there was too little experimental evidence available.

It was promised to investigate the causes for the big variance of Imk_{di} and to measure the variation of the frequency of the rig during cutting after a hit. In order to solve these two problems 25 tests for one cutting condition were made for three different materials (steel C45, free cutting steel, stainless steel). Every test consisted of an idling test followed by a cutting test under exactly the same conditions. From these tests one can derive the Imk_{di} and the frequency variation of the rig during cutting after a hit. These 25 values of both quantities form a statistical distribution on which the statistical rules for the mean value and its variance are applicable. From the measurements it was clear that the frequency variation of the rig after a hit during cutting was small.

The measurements of Imk_{di} made clear that its variance, already indicated in (1), was large. Now, the question was to find out the reasons. First, it was proven that the rig has only one important mode. Next, the absolute error caused by the measuring instruments was determined. This error indicates to be one of the reasons for the big variance of Imk_{di} of the different materials. The main cause is the big sensitivity of Imk_{di} for small variations in the amplitude of the hit rig. Table 2-5 give a collection of the important values of the tests.

2. Experimental Set-Up.

The cutting was carried out on a 25 kW lath mark Lange. The cutting conditions for all tests were: cutting speed 1.5 m/s, depth of cut 3 mm and feed 0.208 mm/rev. These testing conditions were chosen in order to prevent the appearance of a builtup edge. The used tip was a P30 carbide. The following materials are used for the cutting tests:

1. steel C-45 (in bar and tube form).
2. stainless steel 5 Cr Ni Mo 18 12 (in tube form).
3. free cutting steel 9 S Mn 28 (in bar form).

For the dimensions of the tests piece see table 1. The tests on steel C-45 were carried out on a bar and on a tube. This was done for determining the influence of the secondary cutting edge. The maximum admissible flank wear of the tool was less than 0.2 mm. The displacement signal of the hit rig during idling and cutting was stored in a solid state memory with a 8-bit wordlength (resolution $\frac{1}{127}$) and 1024 words (sampling time 50×10^{-6}s). After storage the memory was read out with a xy - recorder which has a maximum deflection in the x-direction of 354 mm (44 mm is used for one timeperiod of the vibration of the hit rig) and in the y-direction of 250 mm (two times the maximum amplitude of the vibration of the hit rig).

See table 1.

$\bar{\xi}_{oi}$ = The mean of 25 measurements of the damping coefficient of the rig during idling and the i period after hitting the rig.

$\bar{\nu}_{oi}$ = The mean of 25 measurements of the frequency of the rig during idling and the i period after hitting the rig.

$\bar{\xi}_{ci}$ = The mean of 25 measurements of the damping coefficient of the rig during cutting and the i period after hitting the rig.

$\bar{\nu}_{ci}$ = The mean of 25 measurements of the frequency of the rig during cutting and the i period after hitting the rig.

$\mathrm{Im}\bar{k}_{di}$ = The mean of 25 measurements of the imaginary part of the direct inner cutting coefficient.

C = Proportional factor = $\dfrac{\xi_c \nu_c - \xi_o \nu_o}{\xi_c \nu_c}$

Table 1. Survey of measured and computed values of the different used materials.

	STEEL C45 BAR	STEEL C45 TUBE	STAINLESS STEEL TUBE	FREE CUTTING STEEL BAR
WORK PIECE LENGTH	300 mm	150 mm	150 mm	295 mm
WORK PIECE DIAMETER	Ø 100 mm	Ø 86 mm WALLTHICKNESS 3 mm	Ø 84 mm WALLTHICKNESS 3 mm	Ø 84 mm
STEEL	C45	C45	5 Cr Ni Mo 18 12	9 S Mn 28
$\bar{\xi}_{01}$	0.0667 ± 0.0028	0.0740 ± 0.0026	0.0727 ± 0.0029	0.0666 ± 0.0028
$\bar{\xi}_{02}$	0.0564 ± 0.0050	0.0619 ± 0.0044	0.0591 ± 0.0028	0.0691 ± 0.0025
$\bar{\xi}_{03}$	0.0547 ± 0.0057	0.0587 ± 0.0048	0.0532 ± 0.0068	0.0660 ± 0.0046
$\bar{\xi}_{04}$	0.0483 ± 0.0056	0.0625 ± 0.0065	0.0534 ± 0.0067	0.0584 ± 0.0070
$\bar{\xi}_{05}$	0.0562 ± 0.0080	0.0518 ± 0.0090	0.0476 ± 0.0082	0.0542 ± 0.0083
$\bar{\nu}_{01}$ $[s^{-1}]$	152.6 ± 1.0	153.9 ± 1.3	154.5 ± 1.3	156.1 ± 1.4
$\bar{\nu}_{02}$ $[s^{-1}]$	153.4 ± 1.1	154.5 ± 1.6	154.5 ± 1.2	155.6 ± 1.5
$\bar{\nu}_{03}$ $[s^{-1}]$	154.2 ± 0.9	157.2 ± 1.6	157.4 ± 1.9	155.0 ± 1.6
$\bar{\nu}_{04}$ $[s^{-1}]$	156.9 ± 1.8	158.5 ± 2.0	159.4 ± 1.6	157.4 ± 1.6
$\bar{\nu}_{05}$ $[s^{-1}]$	157.6 ± 1.4	159.8 ± 1.9	159.6 ± 1.9	158.3 ± 1.6
$\bar{\xi}_{c1}$	0.1183 ± 0.0093	0.1248 ± 0.0176	0.1003 ± 0.0109	0.0739 ± 0.0050
$\bar{\xi}_{c2}$	0.0928 ± 0.0345	0.1321 ± 0.0222	0.0920 ± 0.0147	0.0662 ± 0.0057
$\bar{\xi}_{c3}$	0.0782 ± 0.0454	0.1016 ± 0.0705	0.0753 ± 0.0263	0.0688 ± 0.0076
$\bar{\nu}_{c1}$ $[s^{-1}]$	162.4 ± 3.0	162.4 ± 2.7	159.7 ± 2.6	161.0 ± 1.2
$\bar{\nu}_{c2}$ $[s^{-1}]$	168.8 ± 4.2	168.6 ± 7.4	160.9 ± 3.5	161.7 ± 1.5
$\bar{\nu}_{c3}$ $[s^{-1}]$	165.6 ± 7.6	178.2 ± 17.7	163.5 ± 5.9	161.8 ± 1.7
$\overline{Imk}_{di}$ $[10^{8} \frac{N}{m2}]$	6.6 ± 2.4	9.9 ± 5.9	4.8 ± 1.9	1.2 ± 0.6
Correlation coefficient normal distribution of Imk_{di}.	0.95	0.97	0.98	0.98
C proportional factor	0.444 ± 0.094	0.491 ± 0.139	0.368 ± 0.095	0.124 ± 0.059

The vibration of the rig was measured by the xy - recorder in the x-direction with an accuracy of 0.2 mm/period and in the y-direction with an accuracy of 0.5 mm. In order to prove that the rig has only one mode, an analysis was made with an HP 5420A data analyzer. Figure 1. shows the displacement signal during idling in the time domain. Figure 3. shows the same signal after Fourier transformation in the frequency domain. Figure 2. shows the displacement of the rig during cutting of free cutting steel in the time domain (for the rest the same conditions as figure 1). Figure 4. shows the same signal as in figure 2. but now after Fourier transformation. These four figures prove that the rig has one mode.

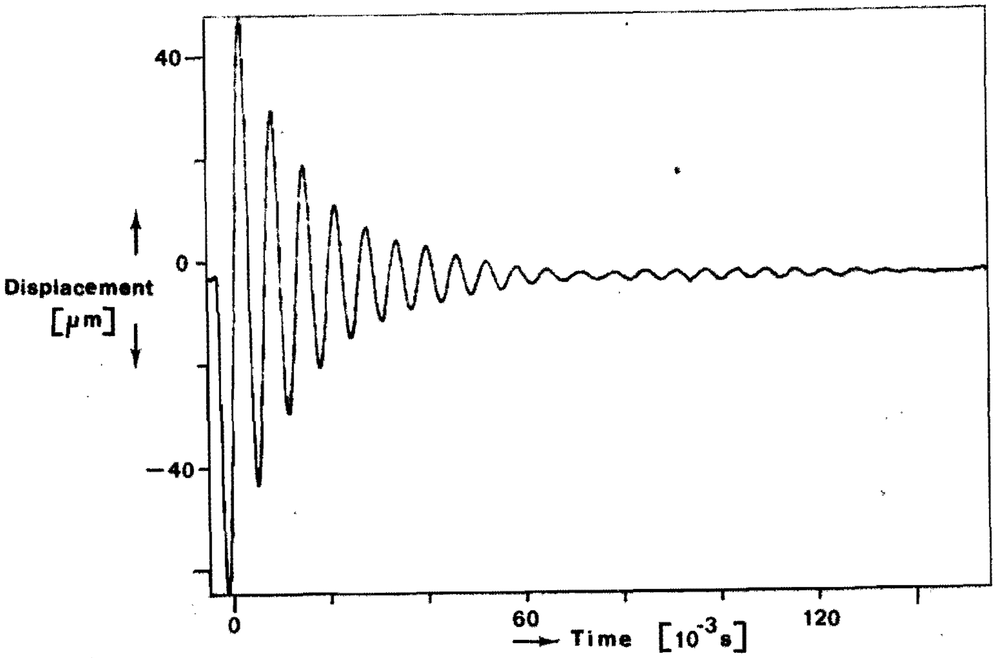

Fig. 1. The displacement signal of the hit rig as a function of time during idling (for the rest same conditions as in figure 2).

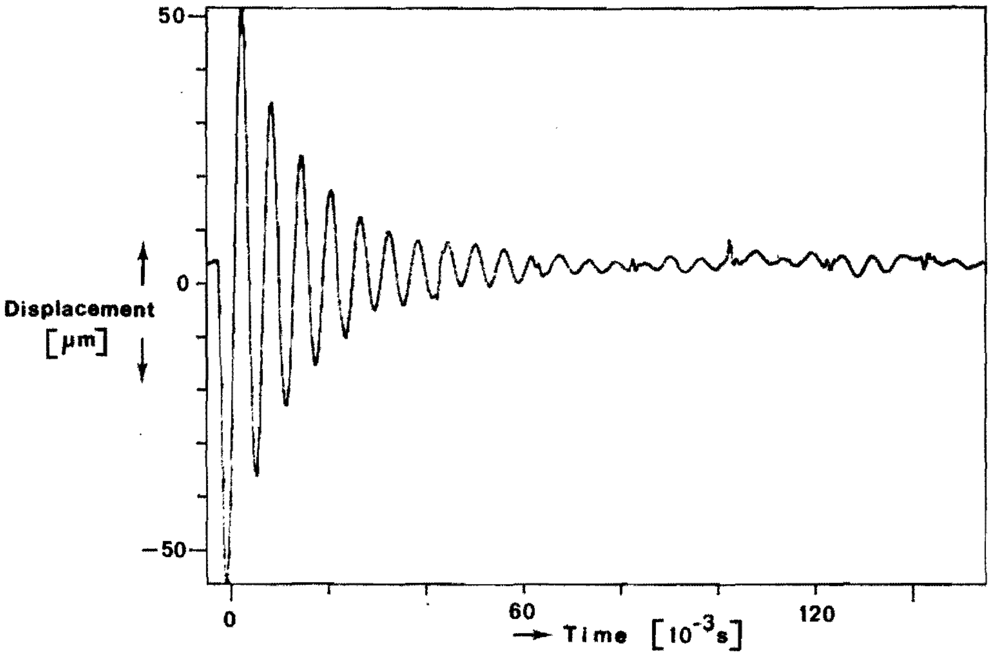

Fig. 2. The displacement signal of the hit rig as a function of time during cutting of free cutting steel 9 S Mn 28 (cutting speed 1.5 m/s, depth of cut 3 mm and feed 0.208 mm/rev.).

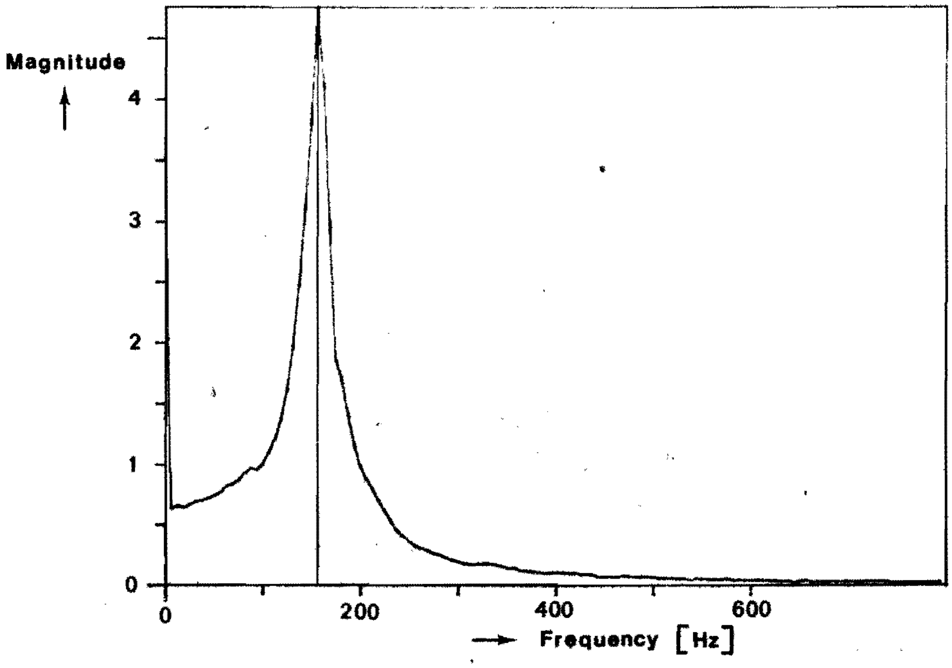

Fig. 3. The magnitude of the Fourier transformed displacement signal of the hit rig during idling as a function of the frequency (for the rest the same conditions as in figure 4).

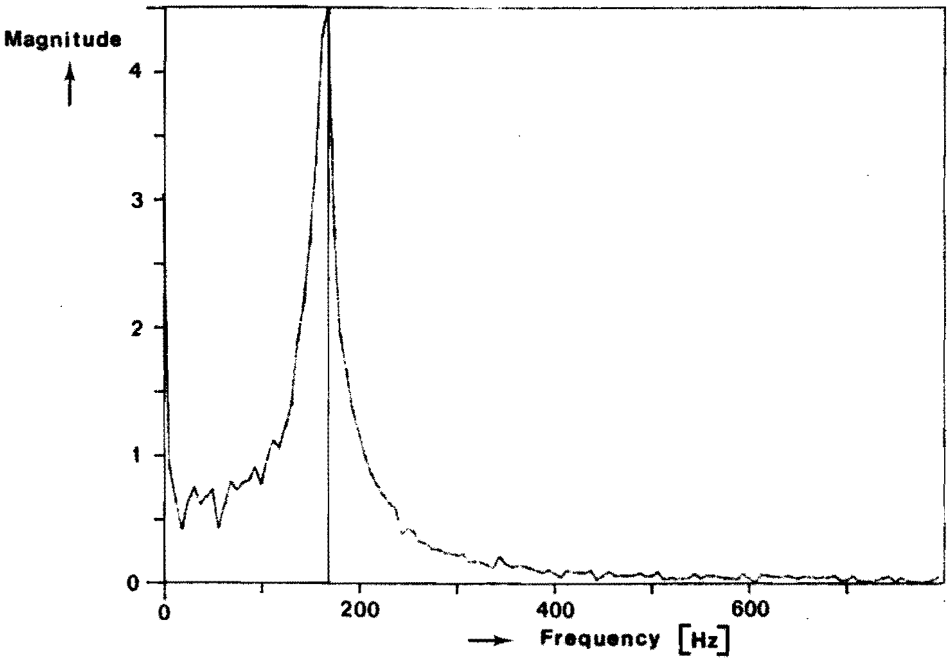

Fig. 4. The magnitude of the Fourier transformed displacement signal of the hit rig during cutting of free cutting steel 9 S Mn 28 (cutting speed 1.5 m/s, depth of cut 3 mm and feed 0.208 mm/rev.) as a function of the frequency).

3. Results.

3.1 Frequency variation of the rig during cutting after a hit.

The frequency during idling (= $\bar{\nu}_o$) for every of the 25 tests (that is the mean value and ist variance during 5 periods) can be found in Table 2-5. The frequency during cutting (= $\bar{\nu}_c$) for every test (that is the mean value and its variance during 3 periods) can also be found in Table 2-5. Table 1 shows the mean frequency and its variance of 25 tests during idling. The five frequencies of one hit are denoted by $\bar{\nu}_{01}$ to $\bar{\nu}_{05}$. The same applies for the frequencies during cutting: $\bar{\nu}_{c1}$ to $\bar{\nu}_{c3}$. By comparison of the values of $\bar{\nu}_{oi}$ with $\bar{\nu}_{ci}$ it is clear that the mean values of $\bar{\nu}_{ci}$ and $\bar{\nu}_{oi}$ show the same variation. Only the variance of the values during cutting is higher than during idling. This variance during cutting enhances from the first to the third period. This holds for the three materials (Table 1). Summarizing for these cutting conditions and these three materials the frequency variation of the rig after one hit is relatively small.

See table 2-5.

$\bar{\xi}_o$ = The mean quantity and its variance of the damping coefficient of the rig for 5 periodes during idling for one tests.

$\bar{\nu}_o$ = The mean quantity and its variance of the frequency of the rig for 5 periodes during idling for one test.

$\bar{\xi}_c$ = The mean quantity and its variance of the damping coefficient of the rig for 3 periodes during cutting for one test.

$\bar{\nu}_c$ = The mean quantity and its vairance of the frequency of the rig for 3 periodes during cutting for one test.

Imk_{di} = Imaginary part of the direct inner cutting coefficient for one test.

C = Proportional factor $= \dfrac{\xi_c \nu_c - \xi_o \nu_o}{\xi_c \nu_c}$

TABLE 2. Measuring values of steel C45 (bar).

TEST NR.	$\bar{\xi}_0$	$\bar{\nu}_0$ [s^{-1}]	$\bar{\xi}_c$	$\bar{\nu}_c$ [s^{-1}]	Imk_{di} [$10^8 \frac{N}{m2}$]	C
04127929	0.0662 ± 0.0050	155.4 ± 3.0	0.1074 ± 0.0222	168.6 ± 5.2	7.19	0.434
04127928	0.0638 ± 0.0070	154.5 ± 2.5	0.1020 ± 0.0052	165.2 ± 4.6	6.29	0.417
04127927	0.0507 ± 0.0086	154.0 ± 1.7	0.0874 ± 0.0295	163.1 ± 3.6	5.71	0.453
04127926	0.0507 ± 0.0074	155.1 ± 1.6	0.1188 ± 0.0281	173.2 ± 9.0	12.01	0.620
04127925	0.0524 ± 0.0090	154.7 ± 2.3	0.0854 ± 0.0273	163.3 ± 1.5	5.18	0.420
04127924	0.0518 ± 0.0074	154.7 ± 2.6	0.0918 ± 0.0325	165.5 ± 5.6	6.46	0.474
04127923	0.0551 ± 0.0055	156.1 ± 3.1	0.1107 ± 0.0179	165.5 ± 6.2	8.77	0.533
04127922	0.0536 ± 0.0096	154.5 ± 2.5	0.0866 ± 0.0363	163.3 ± 3.1	5.20	0.416
04127921	0.0531 ± 0.0080	154.2 ± 1.8	0.0899 ± 0.0350	165.9 ± 4.4	6.06	0.452
04127920	0.0563 ± 0.0075	155.0 ± 3.3	0.0912 ± 0.0495	168.2 ± 3.3	6.05	0.433
04127919	0.0560 ± 0.0057	155.4 ± 3.0	0.0862 ± 0.0319	165.4 ± 1.7	4.99	0.391
04127918	0.0569 ± 0.0045	155.0 ± 1.4	0.0990 ± 0.0145	168.7 ± 3.6	7.24	0.476
04127917	0.0582 ± 0.0084	155.3 ± 3.3	0.0917 ± 0.0184	164.8 ± 6.7	5.44	0.403
04127916	0.0552 ± 0.0084	154.5 ± 4.0	0.0801 ± 0.0387	169.9 ± 3.0	4.69	0.375
04127915	0.0554 ± 0.0055	155.1 ± 2.7	0.0890 ± 0.0177	165.8 ± 3.7	5.55	0.419
04127914	0.0604 ± 0.0082	155.1 ± 2.2	0.1078 ± 0.0778	173.0 ± 7.8	8.75	0.500
04127913	0.0608 ± 0.0058	155.3 ± 2.3	0.0796 ± 0.0839	168.4 ± 7.0	3.62	0.296
04127912	0.0605 ± 0.0077	155.3 ± 3.0	0.1025 ± 0.0323	166.1 ± 4.7	6.90	0.450
04127911	0.0644 ± 0.0073	155.1 ± 2.7	0.0748 ± 0.0374	166.2 ± 5.7	2.20	0.197
04127910	0.0639 ± 0.0027	155.2 ± 2.3	0.0981 ± 0.0366	165.4 ± 5.6	5.68	0.390
04127909	0.0535 ± 0.0088	155.1 ± 2.1	0.0880 ± 0.0336	163.3 ± 2.6	5.39	0.424
04127908	0.0523 ± 0.0091	154.3 ± 2.1	0.1391 ± 0.0852	155.4 ±13.8	11.53	0.630
04127907	0.0521 ± 0.0070	155.0 ± 2.5	0.1348 ± 0.0386	157.9 ± 3.4	11.41	0.623
04127906	0.0502 ± 0.0093	154.8 ± 1.7	0.0797 ± 0.0312	164.4 ± 3.2	4.76	0.407
04127905	0.0576 ± 0.0081	155.0 ± 2.2	0.1012 ± 0.0100	164.8 ± 2.8	6.95	0.466

TABLE 3. Measuring values of steel C45 (tube).

TEST NR.	$\bar{\xi}_o$	$\bar{\nu}_o$ [s^{-1}]	$\bar{\xi}_c$	$\bar{\nu}_c$ [s^{-1}]	$\mathrm{Im}k_{di}$ [$10^8 \frac{N}{m2}$]	C
10127900	0.0673 ± 0.0109	155.2 ± 5.5	0.1346 ± 0.0100	166.5 ± 7.6	10.91	0.537
10127901	0.0596 ± 0.0073	155.0 ± 3.1	0.1080 ± 0.0646	176.1 ± 16.2	9.38	0.516
10127902	0.0648 ± 0.0079	158.0 ± 4.1	0.0752 ± 0.1023	164.9 ± 1.0	1.94	0.175
10127903	0.0616 ± 0.0088	155.6 ± 2.3	0.1304 ± 0.0068	167.9 ± 8.0	11.3	0.565
10127904	0.0599 ± 0.0100	156.5 ± 2.9	0.1961 ± 0.0826	193.2 ± 43.2	30.5	0.757
10127905	0.0556 ± 0.0097	156.1 ± 3.3	0.1239 ± 0.0370	168.7 ± 7.5	11.3	0.589
10127906	0.0699 ± 0.0031	156.2 ± 2.3	0.1092 ± 0.0115	164.1 ± 7.1	6.27	0.393
11127900	0.0676 ± 0.0076	155.3 ± 1.8	0.0776 ± 0.0926	175.0 ± 9.2	2.93	0.228
11127901	0.0629 ± 0.0063	155.7 ± 2.0	0.1158 ± 0.0209	169.0 ± 5.5	9.02	0.502
11127902	0.0634 ± 0.0084	156.9 ± 3.1	0.1419 ± 0.0266	170.3 ± 12.1	13.3	0.593
11127903	0.0651 ± 0.0086	156.6 ± 2.5	0.0895 ± 0.0462	168.5 ± 7.4	4.48	0.325
11127904	0.0619 ± 0.0078	157.9 ± 2.8	0.1086 ± 00.271	168.9 ± 10.5	7.89	0.469
11127905	0.0547 ± 0.0191	158.5 ± 3.8	0.1087 ± 0.0266	168.2 ± 6.9	8.81	0.528
11127906	0.0606 ± 0.0091	156.0 ± 1.9	0.1839 ± 0.0812	172.1 ± 12.7	21.1	0.706
11127907	0.0604 ± 0.0080	158.2 ± 3.2	0.1113 ± 0.0431	174.3 ± 8.9	9.36	0.510
11127908	0.0663 ± 0.0104	157.0 ± 1.9	0.1108 ± 0.0090	168.7 ± 7.5	7.62	0.445
11127909	0.0574 ± 0.0098	156.9 ± 2.4	0.1348 ± 0.0379	171.6 ± 4.6	13.3	0.615
11127910	0.0609 ± 0.0065	156.0 ± 2.5	0.0958 ± 0.0123	158.5 ± 1.9	4.91	0.376
11127911	0.0617 ± 0.0073	157.5 ± 2.9	0.0821 ± 0.0169	159.8 ± 1.8	2.96	0.261
11127912	0.0626 ± 0.0072	157.5 ± 2.0	0.1141 ± 0.0230	152.9 ± 10.4	6.34	0.438
11127913	0.0620 ± 0.0140	158.2 ± 3.0	0.1343 ± 0.0453	165.4 ± 8.1	11.2	0.560
11127914	0.0626 ± 0.0071	157.9 ± 3.8	0.1195 ± 0.0169	168.9 ± 3.2	9.50	0.513
11127915	0.0621 ± 0.0077	156.9 ± 3.2	0.1273 ± 0.0483	172.6 ± 4.7	11.5	0.557
11127916	0.0575 ± 0.0112	157.1 ± 2.7	0.1124 ± 0.0335	174.9 ± 7.4	10.1	0.541
11127917	0.0562 ± 0.0107	156.8 ± 1.9	0.1220 ± 0.0371	174.2 ± 11.4	11.8	0.586

TABLE 4. Measuring values of stainless steel 5 Cr Ni Mo 18 12 (tube).

TEST NR.	$\bar{\xi}_o$	$\bar{\nu}_o$	$\bar{\xi}_c$	$\bar{\nu}_c$	$Imk_{di} [10^8 \frac{N}{m2}]$	C
11127825	0.0634 ± 0.0074	156.8 ± 3.7	0.0721 ± 0.0304	162.4 ± 4.3	1.56	0.152
11127926	0.0653 ± 0.0086	156.2 ± 3.1	0.1159 ± 0.0035	164.9 ± 2.7	8.02	0.468
11127927	0.0587 ± 0.0107	156.6 ± 2.9	0.0990 ± 0.0137	163.2 ± 5.2	6.19	0.433
11127928	0.0599 ± 0.0081	154.9 ± 2.3	0.1221 ± 0.0099	162.9 ± 2.0	9.44	0.536
11127929	0.0557 ± 0.0100	157.5 ± 2.8	0.0810 ± 0.0507	167.4 ±11.5	4.35	0.354
11127930	0.0637 ± 0.0088	156.9 ± 3.8	0.0830 ± 0.0326	157.6 ± 4.4	2.65	0.237
11127931	0.0590 ± 0.0106	157.8 ± 3.0	0.0837 ± 0.0155	159.4 ± 1.1	3.49	0.303
11127932	0.0561 ± 0.0115	157.3 ± 2.5	0.0876 ± 0.0178	164.6 ± 3.5	5.01	0.390
11127933	0.0593 ± 0.0105	157.3 ± 3.2	0.1043 ± 0.0131	159.8 ± 0.8	6.39	0.442
11127934	0.0594 ± 0.0131	157.0 ± 3.8	0.0904 ± 0.0136	164.3 ± 1.3	4.94	0.374
11127935	0.0584 ± 0.0090	157.6 ± 3.5	0.0898 ± 0.0097	162.0 ± 3.0	4.71	0.369
11127936	0.0563 ± 0.0115	155.9 ± 3.0	0.0808 ± 0.0082	159.5 ± 4.7	3.56	0.320
11127937	0.0553 ± 0.0112	157.7 ± 2.9	0.0848 ± 0.0413	164.8 ± 6.9	4.70	0.377
11127938	0.0535 ± 0.0105	156.6 ± 1.8	0.0895 ± 0.0147	160.8 ± 3.6	5.26	0.420
11127939	0.0567 ± 0.0107	157.5 ± 2.3	0.0981 ± 0.0246	164.6 ± 8.1	6.47	0.449
12127900	0.0636 ± 0.0098	158.4 ± 3.5	0.0904 ± 0.0065	158.2 ± 2.2	3.64	0.297
12127901	0.0607 ± 0.0097	156.7 ± 3.7	0.0818 ± 0.0112	158.1 ± 1.5	2.94	0.266
12127902	0.0566 ± 0.0126	156.2 ± 2.7	0.0918 ± 0.0203	160.0 ± 4.3	5.09	0.400
12127903	0.0544 ± 0.0148	158.0 ± 2.2	0.1099 ± 0.0168	159.1 ± 1.2	7.71	0.511
12127904	0.0526 ± 0.0152	158.2 ± 2.3	0.0941 ± 0.0067	158.1 ± 2.0	5.64	0.442
12127905	0.0507 ± 0.0115	157.9 ± 2.8	0.0738 ± 0.0157	162.4 ± 3.9	3.51	0.333
12127906	0.0562 ± 0.0097	157.3 ± 2.6	0.0692 ± 0.0271	156.3 ± 3.1	1.68	0.184
12127907	0.0564 ± 0.0098	156.8 ± 2.1	0.1009 ± 0.0092	159.8 ± 2.4	6.34	0.454
12127908	0.0517 ± 0.0117	157.8 ± 2.9	0.0766 ± 0.0047	160.4 ± 3.2	3.59	0.337
12127909	0.0527 ± 0.0101	156.4 ± 2.5	0.0772 ± 0.0139	162.0 ± 2.1	3.75	0.342

TABLE 5. Measuring values of free cutting steel 9 S Mn 28 (bar).

TEST NR.	$\bar{\xi}_o$	$\bar{\nu}_o$ [s^{-1}]	$\bar{\xi}_c$	$\bar{\nu}_c$ [s^{-1}]	$\mathrm{Imk}_{di}[10^8 \frac{N}{m2}]$	C
04018000	0.0594 ± 0.0118	155.3 ± 1.8	0.0641 ± 0.0056	161.9 ± 2.4	1.01	0.111
04018001	0.0649 ± 0.0080	156.9 ± 1.1	0.0635 ± 0.0045	161.5 ± 1.2	0.06	0.007
04018002	0.0610 ± 0.0099	155.1 ± 1.6	0.0682 ± 0.0013	160.8 ± 3.0	1.31	0.137
04018003	0.0640 ± 0.0074	156.3 ± 2.4	0.0698 ± 0.0036	162.4 ± 2.1	1.17	0.118
04018004	0.0570 ± 0.0104	155.3 ± 2.0	0.0734 ± 0.0003	161.0 ± 0.4	2.59	0.252
04018005	0.0600 ± 0.0065	156.5 ± 2.5	0.0719 ± 0.0036	160.9 ± 1.4	1.90	0.189
04018006	0.0620 ± 0.0098	156.3 ± 2.4	0.0738 ± 0.0090	160.9 ± 1.4	1.91	0.185
04018007	0.0638 ± 0.0060	158.1 ± 2.0	0.0677 ± 0.0068	160.9 ± 1.8	0.70	0.074
04108008	0.0608 ± 0.0099	155.8 ± 1.8	0.0729 ± 0.0125	161.4 ± 1.7	2.01	0.196
04018009	0.0621 ± 0.0080	155.1 ± 1.3	0.0685 ± 0.0061	160.3 ± 1.1	1.17	0.123
04018010	0.0600 ± 0.0106	156.0 ± 1.8	0.0670 ± 0.0130	162.5 ± 1.0	1.35	0.141
04018011	0.0598 ± 0.0093	156.9 ± 1.6	0.0666 ± 0.0062	160.3 ± 1.3	1.12	0.121
04018012	0.0633 ± 0.0104	157.7 ± 2.4	0.0708 ± 0.0042	161.3 ± 0.8	1.26	0.126
04018013	0.0656 ± 0.0040	157.4 ± 2.3	0.0669 ± 0.0076	161.4 ± 0.7	0.41	0.042
04018014	0.0649 ± 0.0054	155.6 ± 1.1	0.0793 ± 0.0034	163.4 ± 2.1	2.54	0.222
04018015	0.0625 ± 0.0078	155.8 ± 1.5	0.0678 ± 0.0050	161.0 ± 0.8	1.03	0.108
04018016	0.0624 ± 0.0150	157.9 ± 1.6	0.0721 ± 0.0087	161.7 ± 0.9	1.59	0.156
04018017	0.0648 ± 0.0088	157.2 ± 0.2	0.0675 ± 0.0077	161.2 ± 1.3	0.61	0.064
04018018	0.0659 ± 0.0050	157.3 ± 2.8	0.0648 ± 0.0090	161.3 ± 0.6	0.07	0.008
04018019	0.0653 ± 0.0047	157.1 ± 0.7	0.0722 ± 0.0069	160.8 ± 2.0	1.18	0.117
04018020	0.0627 ± 0.0070	155.6 ± 1.7	0.0697 ± 0.0109	162.2 ± 2.0	1.36	0.137
04018021	0.0651 ± 0.0046	156.0 ± 2.2	0.0718 ± 0.0095	160.5 ± 1.1	1.19	0.119
04018022	0.0623 ± 0.0071	157.1 ± 2.2	0.0710 ± 0.0098	162.8 ± 1.0	1.56	0.153
04018023	0.0660 ± 0.0031	156.5 ± 2.5	0.0706 ± 0.0068	162.6 ± 2.0	1.01	0.100
04018024	0.0659 ± 0.0060	156.9 ± 1.8	0.0695 ± 0.0024	162.2 ± 1.7	0.82	0.083

3.2 Variance of Imk_{di}.

The quantity Imk_{di} is defined by:

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

with b = width of cut

m = mass of the rig (=20.5 kg).

ξ_c = damping coefficient of the rig during cutting.

ξ_o = damping coefficient of the rig during idling.

For every of the 25 tests of each material Imk_{di} was computed for $\bar{\xi}_o$ and $\bar{\nu}_o$ as the mean of five periodes and $\bar{\xi}_c$ and $\bar{\nu}_c$ as the mean of three periodes of each test. (Table 2-5). The value of Imk_{di} for every test is in Table 2-5. The mean value of Imk_{di} and the variance of 25 tests are in Table 1. Also the correlation coefficient of the normal distriburion of Imk_{di} values was determined (Table 1). These correlation coefficients prove that the rules of the statistical theory for normal distributions are applicable. From Table 1 can be derived that the relative variance of the value of Imk_{di} is very high. It means that determination of Imk_{di} under these conditions has a chance of 68% to be in an range which is determined by the mean value and its variance. For a chance of 90% the variance has to multiplied by a factor 2. It is clear that this variation is too high and not very useful for determination of the critical width of cut. In the next chapter this big variance will be explained.

4. Estimation of the variation of Imk_{id} caused by a measuring error.

The variation of Imk_{di} caused by a measuring error can be written with equation (1) as:

$$d\mathrm{Imk}_{di} = \frac{8\pi^2 m}{b}\left\{\frac{2\nu_c\xi_c d\nu_c}{\sqrt{1-\xi_c^2}} + \frac{\nu_c^2 d\xi_c}{\sqrt{1-\xi_c^2}} + \frac{\nu_c\xi_c d\nu_o}{\sqrt{1-\xi_o^2}} + \frac{\nu_c\nu_o d\xi_c}{\sqrt{1-\xi_o^2}}\right\} \qquad (2)$$

In equation (2) the variation of the terms $\sqrt{1-\xi_o^2}$ and $\sqrt{1-\xi_c^2}$ is neglected because the variation of these terms is small in comparison with the other variable terms in equation (2). The relation variation of Imk_{di} can be written with equation (1) and (2) as:

$$\frac{d\mathrm{Imk}_{di}}{\mathrm{Imk}_{di}} = \frac{\dfrac{2\nu_c\xi_c\, d\nu_c}{\sqrt{1-\xi_c^2}} + \dfrac{\nu_c^2 d\xi_c}{\sqrt{1-\xi_c^2}} + \dfrac{\nu_c\xi_o d\nu_o}{\sqrt{1-\xi_o^2}} + \dfrac{\nu_o\nu_c d\xi_o}{\sqrt{1-\xi_o^2}}}{\dfrac{\nu_c^2\xi_c}{\sqrt{1-\xi_c^2}} - \dfrac{\nu_o\nu_c\xi_o}{\sqrt{1-\xi_o^2}}} \qquad (3)$$

For $$\frac{\sqrt{1-\xi_o^2}}{\sqrt{1-\xi_c^2}} = 1 \qquad (4)$$

and $$C = \frac{\xi_c\nu_c - \xi_o\nu_o}{\xi_c\nu_c} \qquad (5)$$

Equation (3) holds:

$$\frac{d\mathrm{Imk}_{di}}{\mathrm{Imk}_{di}} = \frac{1}{C}\left\{\frac{2d\nu_c}{\nu_c} + \frac{d\xi_c}{\xi_c} + \frac{\xi_o d\nu_o}{\xi_c\nu_c} + \frac{\nu_o d\xi_o}{\xi_c\nu_c}\right\} \qquad (6)$$

The definition of ξ is:

$$\xi = \frac{\ln\dfrac{A_1}{A_2}}{(n-1)\ 2\pi} \qquad (7)$$

With A_1 = the amplitude during the first period.

A_n = the amplitude during the n-th period.

The variation of ξ is:

$$d\xi = \frac{1}{2\pi(n-1)}\left\{\frac{dA_1}{A_1} + \frac{dA_n}{A_n}\right\} \qquad (8)$$

The relative variation of ξ is:

$$\frac{d\xi}{\xi} = \frac{\frac{dA_1}{A_1} + \frac{dA_n}{A_n}}{\ln \frac{A_1}{A_n}} \qquad (9)$$

Equation (9) holds for the variation of ξ_o and ξ_c.
Let us assume that the value $d\xi_o$ and $d\xi_c$ are determined by the following two errors:

- the resolution of the solid state memory: $\frac{1}{127} * 55\ \mu m = 0.43\ \mu m$.
  - because 55 μm is the maximum amplitude for the applied range, which can be stored by the memory.
  - $\frac{1}{127}$ is the resolution of a 8 bit memory (see section 2: Experimental Set-up).
- the inaccuracy in measuring the amplitude is 0.22 μm (0.5 mm on a maximum of 250 mm; see section 2: Experimental Set-up).

Combination of both errors gives:

$$dA_1 = dA_o = 0.65\ \mu m \qquad (10)$$

These values together with the measured amplitudes for idling and cutting (Table 6) give with equation (9), $\frac{d\xi_o}{\xi_o}$ and $\frac{d\xi_c}{\xi_c}$.

Let us assume the value of $d\nu_o$ and $d\nu_c$ are determined by the same errors as $d\xi_o$ and $d\xi_c$.
It means:

- the resolution of the solid state memory for the frequency is 10^{-4}s (time resolution of the memory is 50×10^{-6}s).
- the accuracy for the determination of one period of the vibration after printing the displacement versus time signal is 3×10^{-5}s.

The total time error is 13×10^{-5}s. That means for a mean frequency of 150Hz for idling and cutting: (Table 2-5)

$$\frac{d\nu_c}{\nu_c} = \frac{d\nu_o}{\nu_o} = 2\% \qquad (11)$$

Equation (6), (9), (10) and (11) together with the values in Table 6 give $\frac{dImk_{di}}{Imk_{di}}$. This value is reported in Table 6 for the different materials.

Table 6. Survey of measured and computed values of the different used materials.

	STEEL C45 (BAR)	STEEL C45 (TUBE)	STAINLESS STEEL (TUBE)	FREE CUTTING STEEL (BAR)
A_{o1}[μm]	48.5 ± 4.7	28.5 ± 5.1	47.9 ± 4.5	47.0 ± 3.9
A_{o6}[μm]	8.5 ± 1.4	7.0 ± 0.9	8.0 ± 1.1	6.6 ± 0.9
A_{c1}[μm]	42.1 ± 3.2	42.0 ± 4.6	42.2 ± 4.0	47.8 ± 5.3
A_{c4}[μm]	7.1 ± 2.0	5.1 ± 2.5	8.1 ± 2.1	12.9 ± 1.7
$\frac{dImk_{di}}{Imk_{di}}$	38.4 %	36.3 %	47.7 %	157 %

$\frac{dImk_{di}}{Imk_{di}}$ = Relative error in the determination of the imaginary part of the direct inner cutting coefficient for some given measuring errors.

A_{o1} = The amplitude of the first period after hitting the rig during idling.

A_{o6} = The amplitude of the sixth period after hitting the rig during idling.

A_{c1} = The amplitude of the first period after hitting the rig during cutting.

A_{c4} = The amplitude of the fourth period after hitting the rig during cutting.

The relative error for these really relative small errors are very high especially in the case of free cutting steel. This is in agreement with the variance of Imk_{di} in Table 1 but not fully comparable. At this point, we have to bear in mind that the variance of $Im\bar{k}_{di}$ in Table 1 is the result of a statistical approach, while the relative error of Imk_{di} in Table 6 comes from a deterministic way of calculating errors. Moreover, in Table 6 we still have to account for the neglected errors. These are much higher than the assumed. For instance, the noise on the displacement signal of the rig during cutting without hitting, which is superimposed on the displacement time signal is bigger than the assumed o.65 µm.

It means that in reality the relative error is much higher and thus comparable with the variance of Imk_{di}. These errors or disturbances, which are inevitable, together with the very high sensitivity of the value of Imk_{di} for these variations, may be the main cause for the large variance of Imk_{di} for the different materials. It also means that this method of determining the damping coefficient is only suitable for a global determination of Imk_{di}.

5. Conclusions:

- The frequency of the rig during cutting is nearly constant after a hit.
- The big sensitivity of the value of Imk_{di} for a small deviation of the amplitude of the displacement of the rig may be the main cause for the big variance of Imk_{di} for the different materials.

Acknowledgements:

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

References.

(1) J.H. Dautzenberg and A.C.H. van der Wolf.
The imaginary part of the direct inner dynamic cutting coefficient of steel SAE 1045 for different feeds measured with the Kals-method.
"Eindhoven University Press" PT report nr. PT-458.
Note fore STC "Machine Tools" Davos, August 1979.