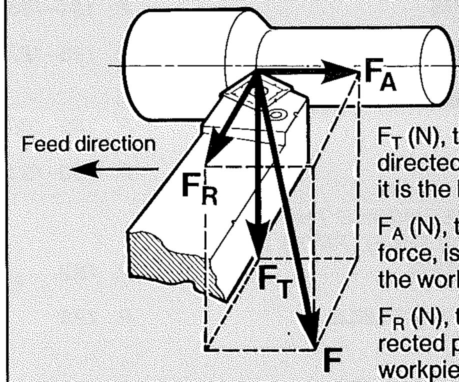
CUTTING FORCE CALCULATION

The main cutting force, F, can be split up into three composants.



F_T (N), the tangential force, is directed downwards. Normally it is the biggest of the three.

F_A (N), the axial force or feed force, is directed parallel to the workpiece centre line.

F_R (N), the radial force,is directed perpendicular to the workpiece centre line.

The approximate relationship of these components to each other is: F_T:F_A:F_R = 4:2:1 but the $F_A$and F_R values are especially influenced by the approach angle and nose radius of the tool.

The tangential cutting force, F_T, can be calculated using the following formula:

$$F_T = k_S \times a \times s$$

and is expressed in Newtons (N)

k_S = *specific cutting force (N/mm²)*
a = *depth of cut (mm)*
s = *feed (mm/r)*

To calculate the F_T-value we need to know the specific cutting force, the k_s-value, of the material to be machined.

Specific cutting force.
***Specific cutting force,* designated k_s and expressed in N/mm², is a material constant, unique for a specific material under certain cutting conditions, which to some degree indicates the machinability of the material.**

The k_s-value is defined as

$$k_s = \frac{F_T}{A} \left(\frac{\text{Tangential cutting force}}{\text{chip area}}\right) \text{(N/mm}^2\text{)}$$

For a specific material, the k_s-value can be determined from the cutting data recommendations in chapter 7, «Selecting insert geometry, carbide grade and cutting data», starting at p. 74.

The k_s-value, however, varies not only with the material but also depends on factors such as;

- ***insert geometry***
- ***entering angle of the tool***
- ***the feed rate choosen***

The following pages give correction factors valid for Coromant insert geometries, entering angles and feed rates, with an example of how cutting forces are calculated.

CORRECTION FACTORS

Multiply the k_S-value given in Chapter 7, with the correction factors for your application, obtained from the three tables below.

k_sCORRECTION FACTORS FOR INSERT GEOMETRIES

	T-MAX P + NEGATIVE/POSITIVE										T-MAX U NEUTRAL			T-MAX COPYING	
INSERT GEOMETRY	TNMG CNMG SNMG DMMG 61	TNMG CNMG SNMG DMMG 15	TNMM CNMM DMN 71	CNMM 62 TMMM 31	TNMM SNMM SNMG 41	TNMG CMMG DNMG VNMG	RNMG SNMN	TNMM CNMM SNMA DNMM	TNMA CNMA DNMA VNMA RNMA	RCMX SCMN	TCMM CCMN SCMN DCMN RCMN 52	TCMN CCMN SCMA DCMN VDMN 53	TCMA -71 KNOX DCMA VBMA	KNMX -12 -11	KNUX
Correction Factor	.95	.95	.85	.87	.85	.97	1.00	1.10	.90	.83	.95	.85	.80		

k_sCORRECTION FACTORS FOR ENTERING ANGLES

ENTERING ANGLE	90°	75°	72°	60°	45°	93° 95°	ROUND
Correction Factor	1.0	.96	.94	.86	.70	1.0	

ROUND:

$\frac{a}{D}$	Factor
.05	.22
.10	.32
.20	.43
.30	.52
.40	.59
.50	.63

k_sCORRECTION FACTORS FOR FEED RATES

Feed rate	0.1	0.15	0.2	0.25	0.3	0.35	0.4
Correction Factor	1.49	1.32	1.22	1.14	1.08	1.03	1.00
Feed rate	0.5	0.6	0.7	0.8	1.0	102	1.4
Correction rate	.94	.89	.85	.82	.77	.72	.69

EXAMPLE

CUTTING DATA:
$V = 130$ m/min
$s = 0.8$ mm/r
$a = 8$ mm

Material:	***Low Alloy Steel (CMC no 02.1)***
Specific cutting force:	***$k_s = 2100$ N/mm² (from p. 79)***
Insert:	***CNMM 16 06 16 - 71 425***
Holder:	***PCLNL 3225 P 16 ($\kappa = 95°$)***

CORRECTED K_S-VALUE

GEOMETRY: 0.85 × 2100 = 1785 (N/mm²)

ENTERING ANGLE: 1.0 × 1785 = 1785 (N/mm²)

FEED RATE: 0.8 × 1785 = 1430 (N/mm²)

THE TANGENTIAL CUTTING FORCE IS

$$F_T = k_s \times a \times s = 1430 \times 8 \times 0{,}8 = 9140 \text{ N}$$

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MACHINE POWER REQUIREMENT

The power required for metal cutting is mainly of interest when roughing, then it is essential to ensure that the machine has sufficient power for the operation. The basic parameters in the power calculation are the tangential cutting force, F_T, and the cutting speed, v. The efficiency factor of the machine is also of great importance. The efficiency factor, η, depends on the type of transmission the machine is fitted with, and the overall condition of the machine. In practice, this means that the cutting data calculated could not be used because of the losses in the machine transmission from motor to spindle. The machine efficiency, η, is normally between 0.6 to 0.9 depending on the machine condition, but generally $\eta = 0.7$ could be used for the power calculation.

$$P = \frac{P_{net}}{\eta}$$

P = available motor effect (kW).
P_{net} = net effect for metal cutting (kW).

$$P_{net} = \frac{v \times F_T}{60 \times 1000} \text{ (kW)} \qquad P = \frac{v \times F_T}{\eta \times 60 \times 1000} \text{ (kW)}$$

or complete

$$P = \frac{v \times a \times s \times k_s}{\eta \times 60 \times 1000} \text{ (kW)}$$

Where:
- v = *cutting speed (m/min)*
- a = *depth of cut (mm)*
- s = *feed (mm/r)*
- k_s = *specific cutting force (N/mm²) (corrected)*

EXAMPLE:

$v = 130$ m/min
$a = 8$ mm
$s = 0.8$ mm/r
$k_s = 1430$ N/mm² (corrected)

Or

$v = 130$ m/min
$F_T = 9140$ N

WITH $\eta = 0.7$
THE POWER NEEDED IS

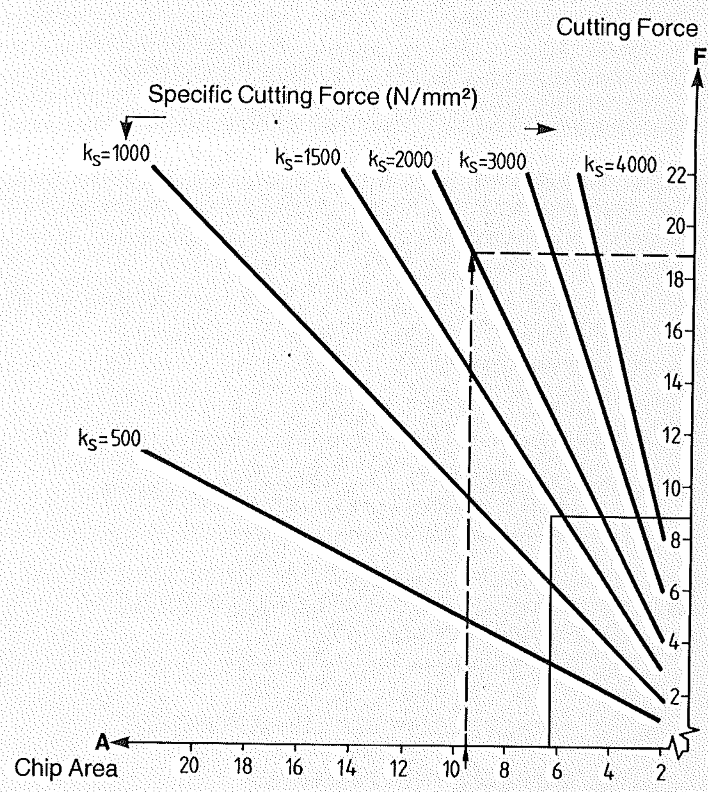
$$P = \frac{130 \times 8 \times 0.8 \times 1430}{0.7 \times 60 \times 1000} = \frac{130 \times 9140}{0.7 \times 60 \times 1000} = 28 \text{ kW}$$

WE ARE JUST UNDER THE MAX POWER AVAILABLE IN OUR MACHINE. A POSSIBLE INCREASE OF CUTTING DATA SHOULD BE MADE AS FOLLOWS:

1. ***INCREASE DEPTH OF CUT IF POSSIBLE.***
2. ***INCREASE THE FEED RATE.***
3. ***INCREASE THE CUTTING SPEED.***

When we are above the max power available, decrease the above values.

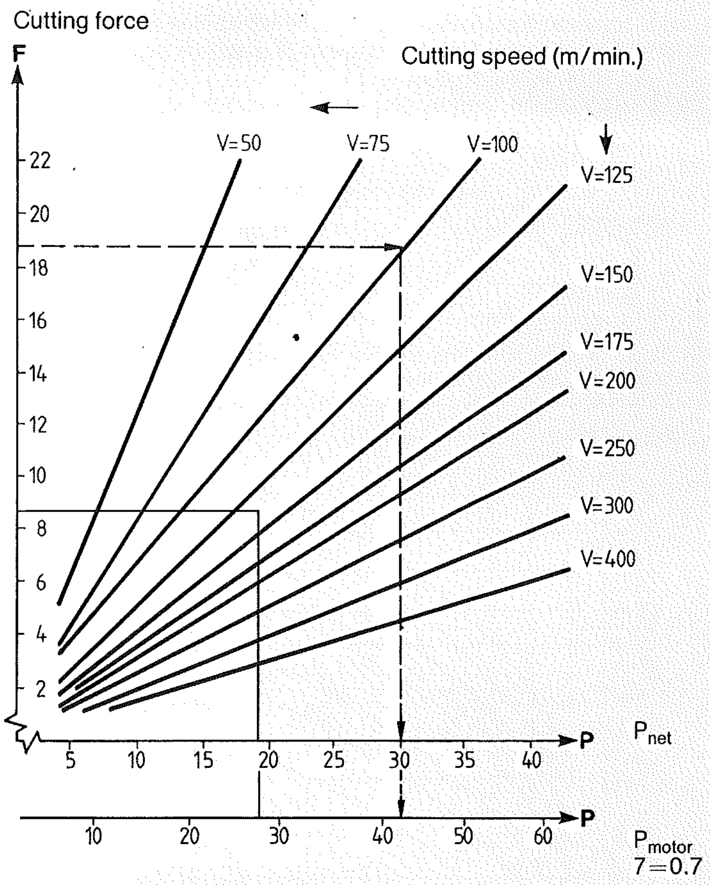
DIAGRAM FOR DETERMINING THE MACHINE POWER



EXAMPLE:

A = s x a = 0.8 mm/r × 8 mm = 6.4 mm²
K_s = (NON ALLOY STELL) ≃ 1430 N/mm²
V = (CUTTING SPEED) = 130 m/min.

(Correct formula can be found on p. 185)



P_{net} = 19 kW, P_{motor} = 28 kW

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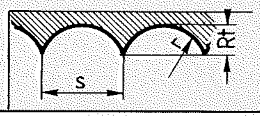
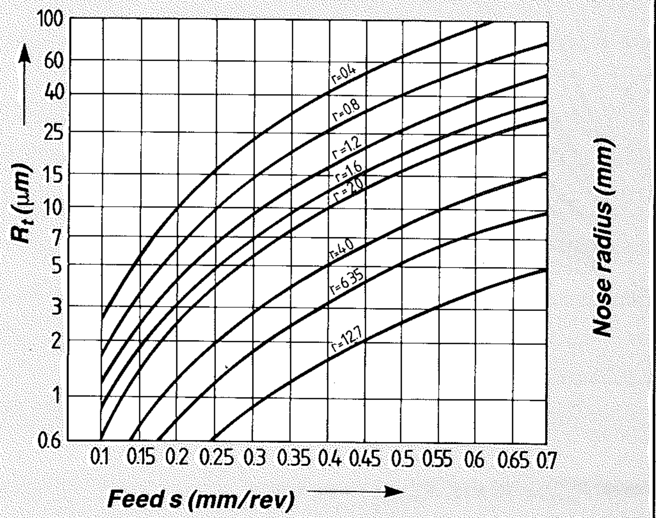
SURFACE FINISH

The profile depth is symbolized by R_t and indicated in µm or µin (1 µm = 40 µin).
A more common expression of surface finish is «The arithmetical mean surface roughness» expressed as R_a which is approximately $1/4 \times R_t$.
The R_t-value can be theoretically calculated from the formula:



$$R_t = \frac{s^2}{8r} \times 1000\ (\mu m)$$

The diagram below shows theoretical R_t-values from given feed and nose radius combination.

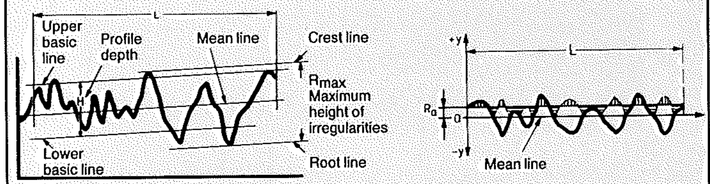


Other common surface finish standards are:

CLA (Centre Line Average) = R_a
AA (Arithmetical Average) = R_a
RMS (Root Mean Square) = $1.11 \times R_a$

The table shows the conversion between different measuring systems.

R_t	Ra = CLA = AA		RMS	
µm	µm	µin	µm	µin
1.6	0.30	11.8	0.30	11.9
1.8	0.35	13.8	0.35	14.0
2.0	0.40	15.7	0.41	16.0
2.2	0.44	17.5	0.46	18.0
2.4	0.49	19.2	0.51	20.0
2.6	0.53	20.8	0.58	23.0
2.8	0.58	22.7	0.64	25.0
3.0	0.63	24.6	0.67	26.5
3.5	0.71	27.8	0.77	32.0
4.0	0.80	31.4	0.96	38
4.5	0.90	35.2	1.07	42
5.0	0.99	38.8	1.24	48
6.0	1.2	47.2	1.40	55
7.0	1.4	55.1	1.65	65
8.0	1.6	63.0	1.91	75
9.0	1.8	71	2.14	83
10.0	2.0	79	2.51	91
15.0	3.2	126	3.20	130
20.0	4.4	173	4.45	175
25.0	5.8	238	5.44	214
30.0	7.4	292	6.70	260
35.0	8.8	346	7.61	300
40.0	10.7	422	8.73	344
45.0	12.3	485	10.2	400
50.0	14.0	552	11.5	450



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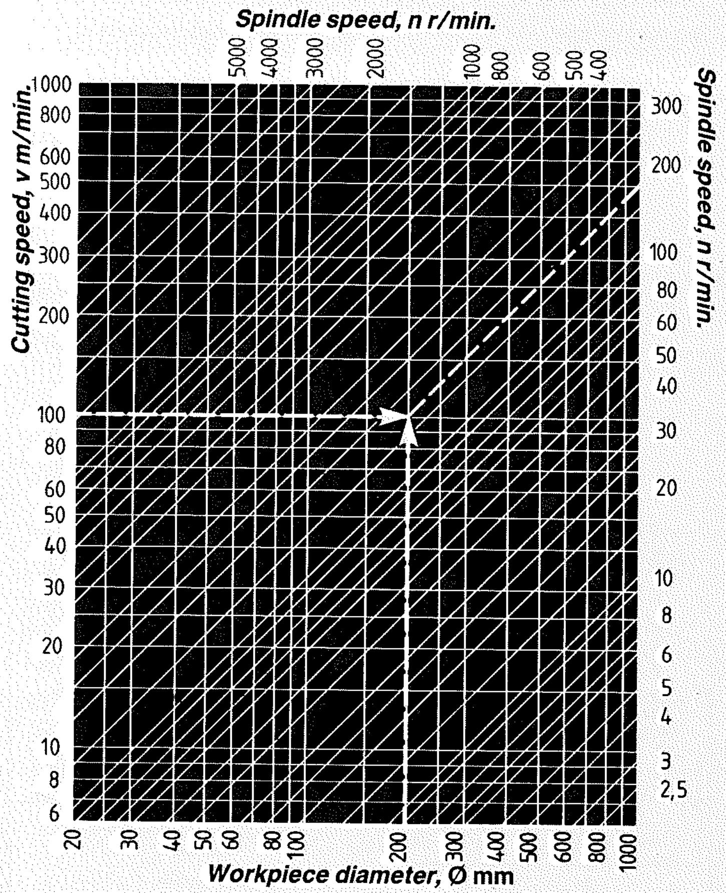
NOMOGRAM FOR DETERMINING THE SPINDLE SPEED, CUTTING SPEED FROM THE WORKPIECE DIA.



HARDNESS COMPARISON TABLE

B Steel kg/mm²	Vickers HV	Brinell HB	Rockwell HRC	Shore "C"
70	200			28
74	210			29
77	220			30
81	230		19.2	31
84	240		21.2	33
88	250		23.0	34
91	260		24.7	35
95	270		26.1	36
98	280		27.6	37
102	290		29.0	39
105	300		30.3	40
109	310		31.5	41
112	320		32.9	42
115	330		33.8	43
119	340		34.9	44
123	350		36.0	45
126	360	359	37.0	46
130	370	368	38.0	47
133	380	373	38.9	48
137	390	385	39.8	49
140	400	393	40.7	50
144	410	400	41.5	51
147	420	407	42.3	52
151	430	416	43.2	53
154	440	423	44.0	54
158	450	429	44.8	55
161	460	435	45.5	56
165	470	441	46.3	57
168	480	450	47.0	58
172	490	457	47.7	59
175	500	465	48.3	60
179	510	474	49.0	61
182	520	482	49.6	62
186	530	489	50.3	63
189	540	496	50.9	64
193	550	503	51.5	65
196	560	511	52.1	66
200	570	520	52.7	67

B Steel kg/mm²	Vickers HV	Brinell HB	Rockwell HRC	Shore "C"
203	580	527	53.3	68
207	590	533	53.8	69
210	600	533	54.4	70
214	610	543	54.9	71
217	620	549	55.4	72
221	630	555	55.9	73
224	640	561	56.4	74
228	650	568	56.9	75
231	660	574	57.4	75
235	670	581	57.9	76
238	680	588	58.7	77
241	690	595	58.9	78
245	700	602	59.3	79
248	710	609	59.8	80
252	720	616	60.2	81
255	730	622	60.7	82
259	740	627	61.1	83
263	750	633	61.5	83
266	760	639	61.9	84
270	770	644	62.3	85
273	780	650	62.7	86
277	790	656	63.1	86
280	800	661	63.5	87
284	810	666	63.9	87
287	820	670	64.3	88
291	830	677	64.6	89
294	840	682	65.0	89
298	850		65.3	90
301	860		65.7	90
305	870		66.0	91
308	880		66.3	91
312	890		66.6	92
315	900		66.9	92
319	910		67.2	
322	920		67.5	
326	930		67.7	
329	940		68.0	