Engenharia Mecânica
Politécnica • COPPE
UFRJ

# Unidade 3 e 4
# Forças de usinagem
# Rugosidade

CEFCON
CENTRO DE ESTUDOS EM FABRICAÇÃO E COMANDO NUMÉRICO

Grupo de Pesquisa DaVinci Processos de Fabricação

COPPE UFRJ

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Fábio Campos (Doutorando)
Matheus Sartor (Monitor)

# Observações importantes

- O alunos dos dois grupos de cada dia de aula prática serão redivididos em sub-grupos de 3 ou 4 alunos para realizar a atividade.
- Cada sub-grupo será organizado dependendo se você já fez Usinagem I ou se está fazendo Usinagem I.
- Lembrando que alunos que não tenham feito Usinagem, não deveriam estão inscritos e não podem realizar a atividade.

# Objetivos da Unidade

- Aula teórica: Apresentação da unidade, realinhar a teoria de usinagem e apresentar o laboratório de Comando Numérico.
- Ter contato com os equipamentos de forças de usinagem
- Comando Numérico
- Medir a rugosidade da superfície

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# Aula de hoje

Introdução

Ferramenta Monocortante

Forças de Usinagem

Fresamento

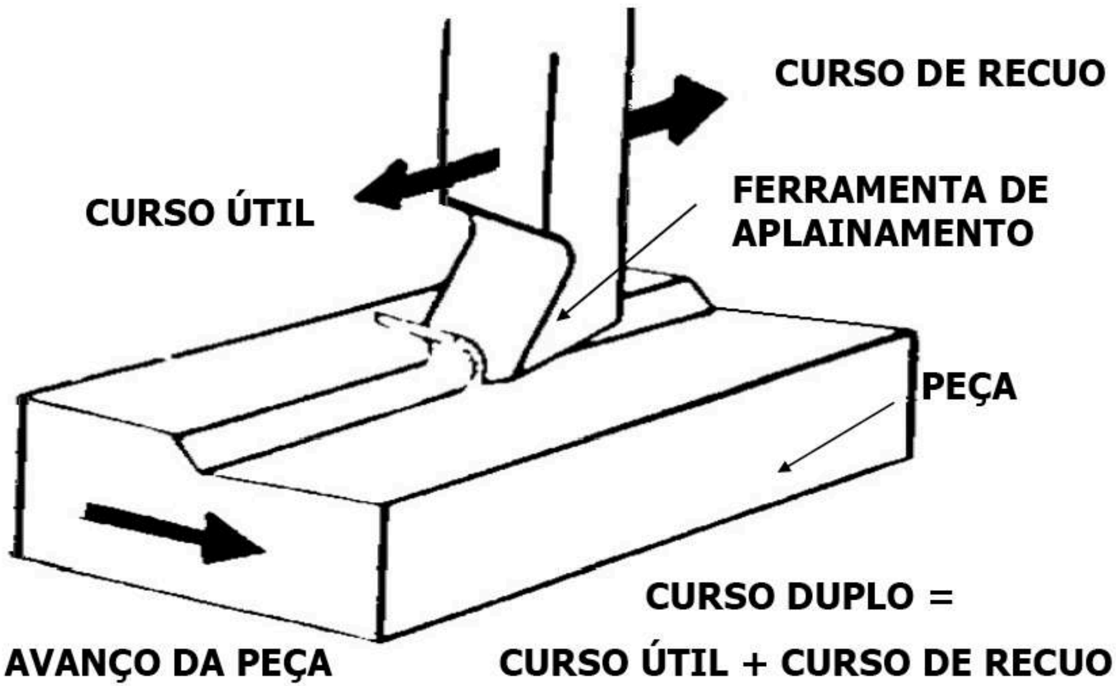
Dinamometria

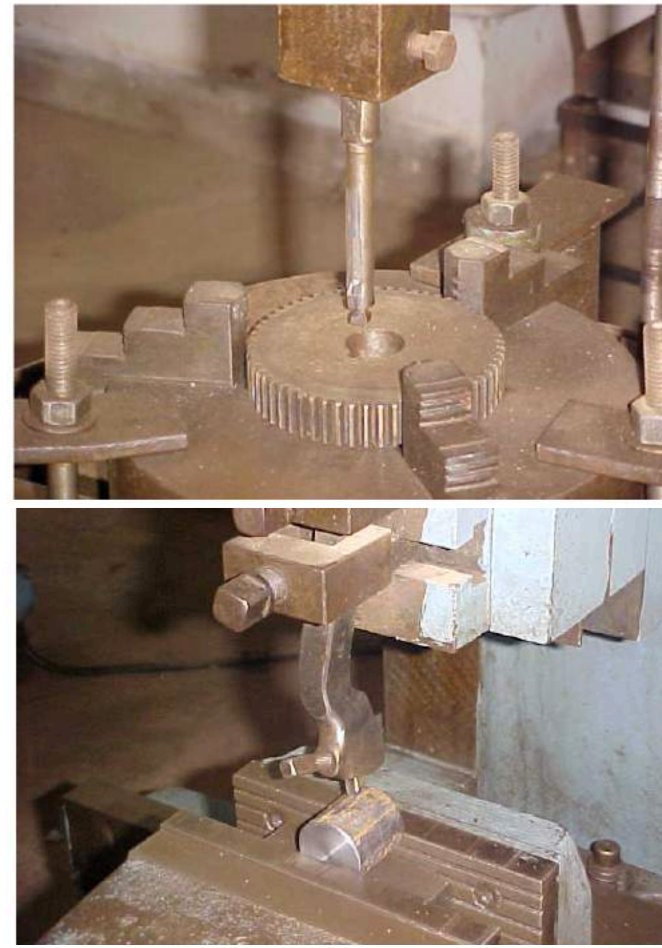
Rugosidade e Ondulação

Medida de Rugosidade

- Parametros de Usinagem com Ferramenta Monocortante
- Força de Usinagem com Ferramenta Monocortante
- Parametros do Fresamento
- Forças de Fresamento
- Medição das forças de usinagem
- Característica da superficie da peça

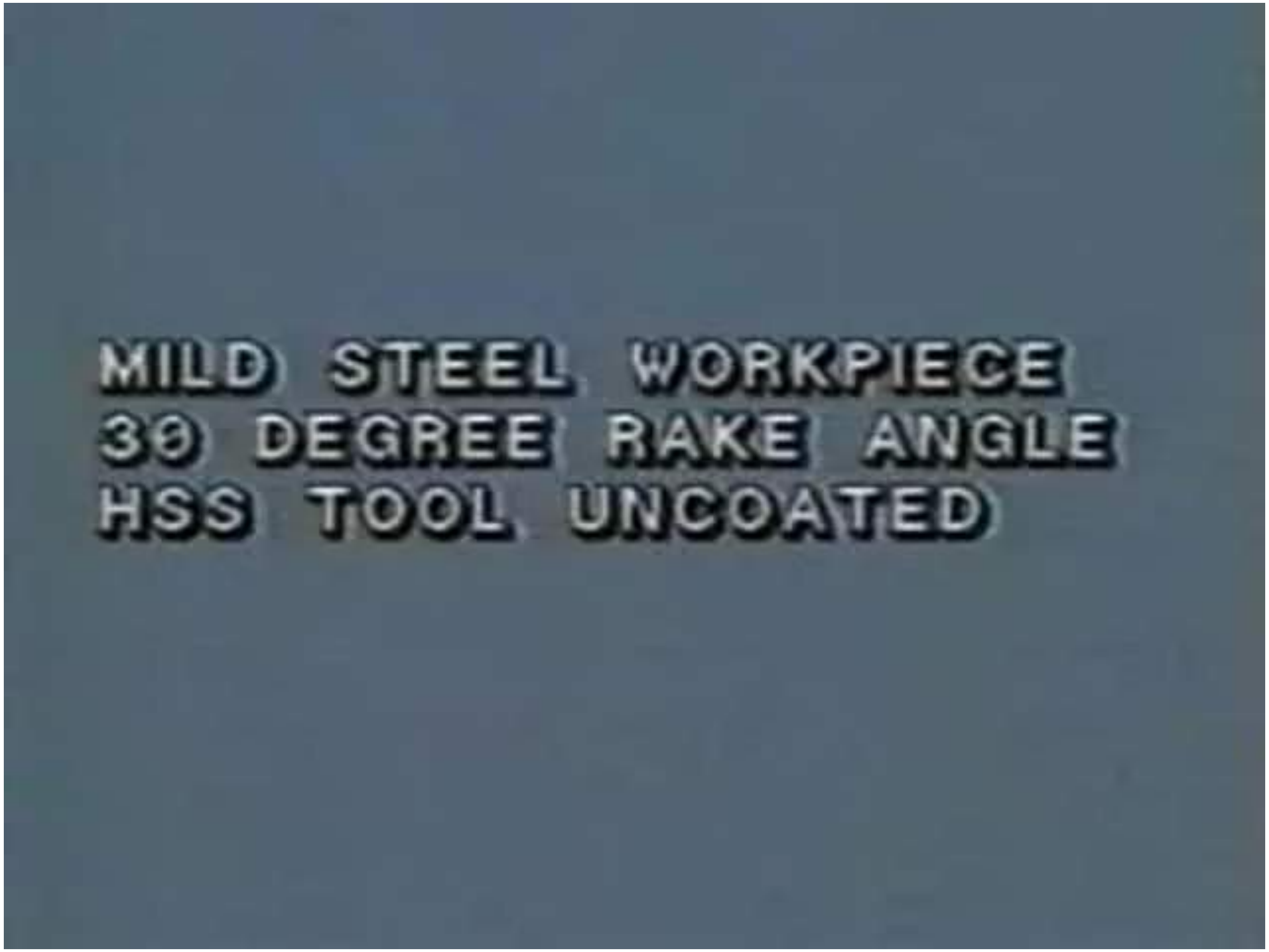
# Ferramenta Monocortante



**Rasgo de Chaveta (Mov. Horizontal)**

# Mecânica do Corte



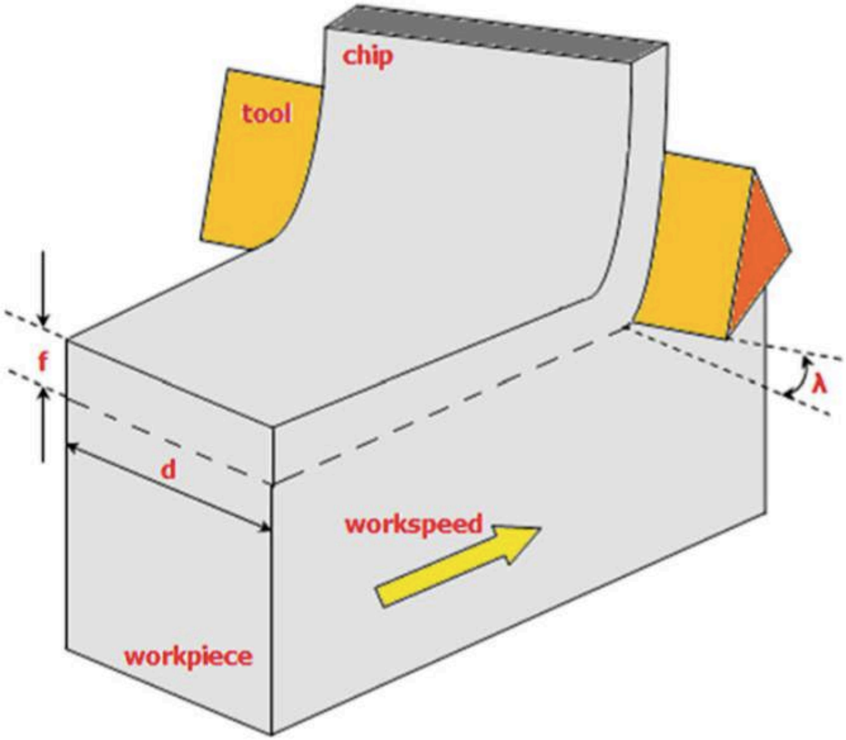
# Usinagem Mecânica

Principais parâmetros para o processo de usinagem:

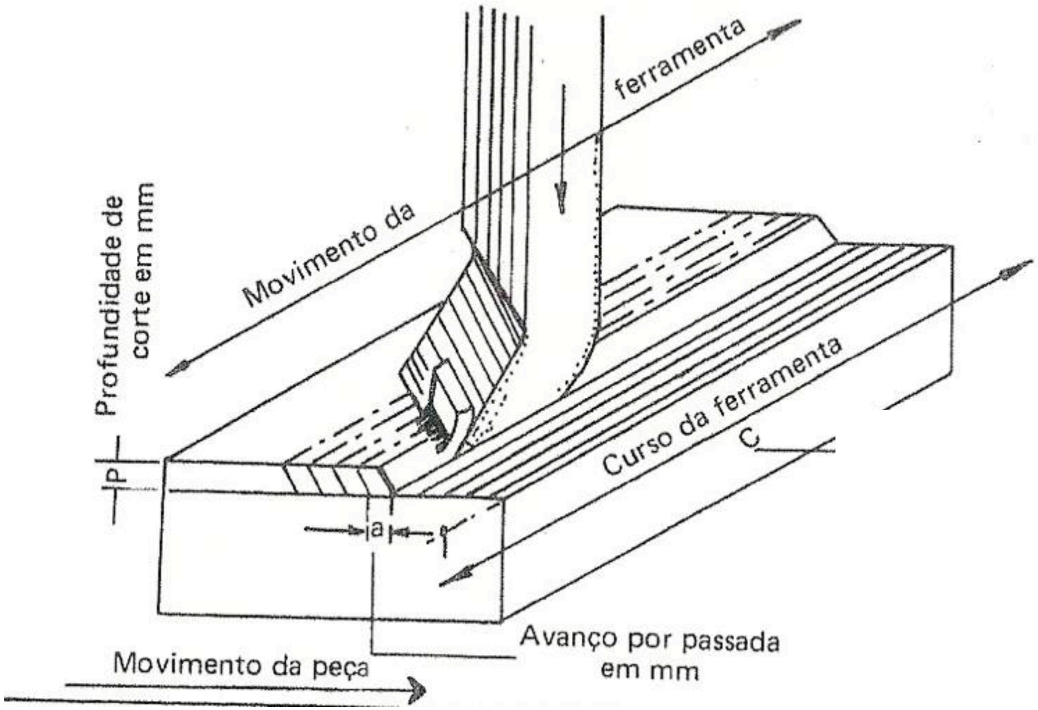
Velocidade de Corte

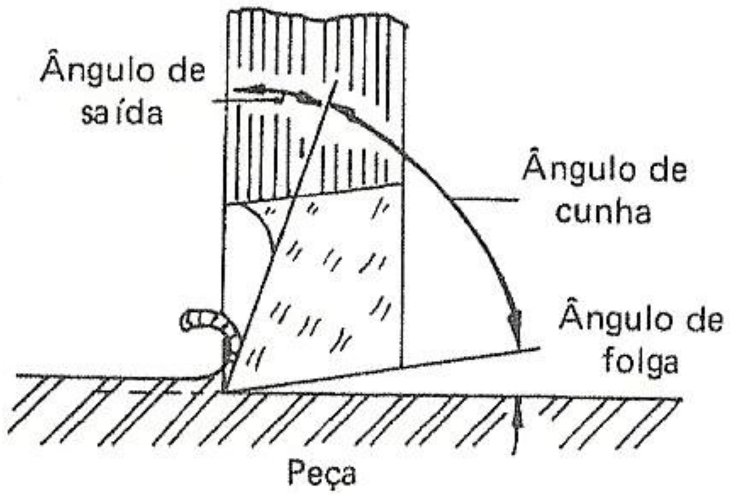
Avanço por aresta (espessura do cavaco)

Profundidade de corte (comprimento cortante da aresta)



# Ferramenta monocortante




**Como calcular a área de corte?**

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# Força de Usinagem



**Força = Pressão Esp. x Area de corte**

**(usinagem 1) Consultar Tabela de acordo com o material da peça e da ferramenta**

prof.corte x avanço

**Potência = Força x Velocidade de Corte**

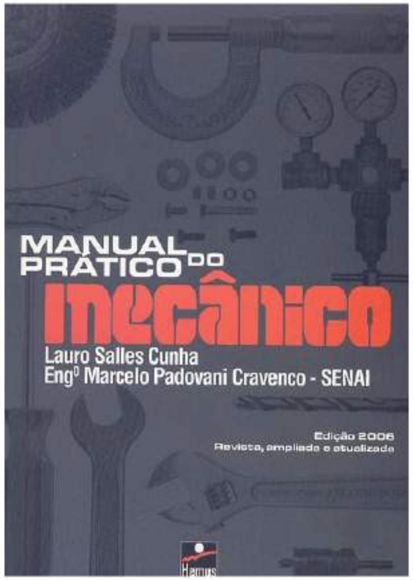
**Consultar tabela para definir na máquina**

# Qual a Velocidade de Corte?

Tabela 48

**NORMA PARA VELOCIDADE DE CORTE E AVANÇO PARA PLAINA LIMADORA**

| Materiais | Ferramentas | | | | |
|---|---|---|---|---|---|
| | Aço carbono | | Aço rápido | | Metal duro |
| | Vc m/min | Avanço mm | Vc m/min | Avanço mm | Vc m/min |
| Aço fundido | 5 a 10 | 0,1 a 8,0 | 10 a 25 | 0,2 a 12 | 15 a 70 |
| Aço doce 35 a 60 kg/mm² | 6 a 12 | 0,1 a 8,0 | 10 a 30 | 0,2 a 12 | 20 a 100 |
| Ferro fundido | 5 a 8 | 0,1 a 8,0 | 10 a 20 | 0,2 a 12 | 15 a 70 |
| Aço fundido macio | 5 a 10 | 0,1 a 8,0 | 5 a 10 | 0,2 a 12 | 10 a 60 |
| Aço semi-duro (5o a 60) | 5 a 10 | 0,1 a 8,0 | 12 a 15 | 0,2 a 12 | 15 a 80 |
| Aço duro 60 a 90 | 5 a 10 | 0,1 a 15,0 | 10 a 12 | 0,2 a 12 | 10 a 60 |
| Bronze | 10 a 18 | 0,1 a 10,0 | 20 a 30 | 0,2 a 12 | 30 a 200 |
| Latão | 10 a 20 | 0,1 a 10,0 | 20 a 30 | 0,2 a 12 | 50 a 350 |
| Metais leves | 10 a 25 | 0,1 a 10,0 | 25 a 50 | 0,2 a 12 | 50 a 350 |
| Cobre | 10 a 25 | 0,1 a 10,0 | 25 a 50 | 0,2 a 12 | 50 a 350 |



# Qual a Velocidade de Corte?

**TABLE 4-1 Speed and Feed for Planers**

| Work material | High-speed steel: Speed, fpm | High-speed steel: Max feed, in | Cast alloys: Speed, fpm | Cast alloys: Max feed, in | Carbides: Speed, fpm | Carbides: Max feed, in |
|---|---|---|---|---|---|---|
| Aluminum | 200–300 | 0.125 | * | * | † | 0.125 |
| Brass (soft) | 150–250 | 0.250 | * | * | † | 0.125 |
| Bronze (medium) | 75–125 | 0.075 | * | * | 150–300 | 0.050 |
| Bronze (hard) | 30–60 | 0.050 | 50–100 | 0.040 | 150–200 | 0.050 |
| Cast iron (soft) | 50–80 | 0.125 | 90–120 | 0.050 | 110–225 | 0.050 |
| Cast iron (hard) | 30–50 | 0.060 | 50–80 | 0.050 | 100–200 | 0.050 |
| Malleable iron | 50–90 | 0.090 | 80–120 | 0.050 | 150–250 | 0.050 |
| Cast steel (30% C) | 25–60 | 0.050 | 60–80 | 0.040 | 100–180 | 0.040 |
| Steel (soft) | 70–100 | 0.050 | * | * | 180–300 | 0.050 |
| Steel (medium) | 60–70 | 0.060 | * | * | 180–250 | 0.050 |
| Steel (hard) | 20–35 | 0.035 | * | * | 100–180 | 0.035 |

Note: Data based on an average depth of cut of ½ in. Speed increases up to 50 percent are frequently possible on light finishing cuts.
*This tool not recommended for this application.
†Maximum speed of the planer.


TOOL AND MANUFACTURING ENGINEERS HANDBOOK

Fourth Edition

VOLUME I
MACHINING

A reference book for manufacturing engineers, managers, and technicians

Thomas J. Drozda, PE, CMfgE
Editor-in-Chief

Charles Wick, CMfgE
Managing Editor

Revised under the supervision of the SME Publications Committee in cooperation with the SME Technical Divisions

**“Tool and Manufacturing Engineers Handbook” - SME (Society of Mechanical Engineers) - 3a edição (1976) / Hoje: 4a edicao (1986)**

# Qual a Velocidade de Corte?

**Table 1 Recommended speeds and feeds for planing with high-speed steel or carbide tools**

| Work metal | Hardness, HB | Depth of cut: 3.2 mm (⅛ in.) Speed, m/min (sfm) | Depth of cut: 3.2 mm (⅛ in.) Feed, mm (in.) per stroke | Depth of cut: 6.4 mm (¼ in.) Speed, m/min (sfm) | Depth of cut: 6.4 mm (¼ in.) Feed, mm (in.) per stroke | Depth of cut: 13 mm (½ in.) Speed, m/min (sfm) | Depth of cut: 13 mm (½ in.) Feed, mm (in.) per stroke | Depth of cut: 25 mm (1 in.) Speed, m/min (sfm) | Depth of cut: 25 mm (1 in.) Feed, mm (in.) per stroke | Finishing speed(a), m/min (sfm) |
|---|---|---|---|---|---|---|---|---|---|---|
| **High-speed steel tools** | | | | | | | | | | |
| Cast iron | 230 | 15 (50) | 2.3–3.2 (0.090–0.125) | 15 (50) | 1.5–2.3 (0.060–0.090) | 12 (40) | 1.1–1.5 (0.045–0.060) | 11 (35) | 0.8–1.1 (0.030–0.045) | 12 (40) |
| Cast iron | 175 | 21 (70) | 2.3–3.2 (0.090–0.125) | 18 (60) | 1.5–2.3 (0.060–0.090) | 15 (50) | 1.1–1.5 (0.045–0.060) | 12 (40) | 1.1–1.5 (0.045–0.060) | 18 (60) |
| Steel | 270 | 11 (35) | 1.5–2.3 (0.060–0.090) | 9 (30) | 1.5–2.3 (0.060–0.090) | 7.6 (25) | 1.1–1.5 (0.045–0.060) | 6 (20) | 1.1–1.5 (0.045–0.060) | 6 (20) |
| Steel | 200 | 11 (35) | 2.3–3.2 (0.090–0.125) | 11 (35) | 1.5–2.3 (0.060–0.090) | 9 (30) | 1.5–2.3 (0.060–0.090) | 8 (25) | 1.1–1.5 (0.045–0.060) | 9 (30) |
| Steel | 130 | 18 (60) | 2.3–3.2 (0.090–0.125) | 15 (50) | 2.3–3.2 (0.090–0.125) | 12 (40) | 1.5–2.3 (0.060–0.090) | 9 (30) | 1.1–1.5 (0.045–0.060) | 15 (50) |
| Bronze | Hard | 18 (60) | 2.3–3.2 (0.090–0.125) | 18 (60) | 2.3–3.2 (0.090–0.125) | 15 (50) | 2.3–3.2 (0.090–0.125) | 12 (40) | 1.5–2.3 (0.060–0.090) | 18 (60) |
| Bronze | Soft | 45 (140) | 4.0–4.8 (0.156–0.188) | 35 (120) | 3.2–4.0 (0.125–0.156) | 30 (100) | 3.2–4.0 (0.125–0.156) | 30 (100) | 2.3–3.2 (0.090–0.125) | 45 (140) |
| **Carbide tools** | | | | | | | | | | |
| Cast iron | 230 | 60 (200) | 2.3–3.2 (0.090–0.125) | 60 (200) | 1.9–2.3 (0.075–0.090) | 60 (200) | 1.5–1.9 (0.060–0.075) | 60 (200) | 1.1–1.5 (0.045–0.060) | 55 (180) |
| Cast iron | 175 | 90 (300) | 2.5–3.2 (0.100–0.125) | 90 (300) | 2.3–2.5 (0.090–0.100) | 90 (300) | 1.9–2.3 (0.075–0.090) | 90 (300) | 1.5–1.9 (0.060–0.075) | 65 (220) |
| Steel | 270 | 75 (250) | 1.5–1.9 (0.060–0.075) | 75 (250) | 1.5–1.9 (0.060–0.075) | 75 (250) | 1.1–1.5 (0.045–0.060) | ... | ... | 75 (250) |
| Steel | 200 | max | 1.5–2.3 (0.060–0.090) | max | 1.5–1.9 (0.060–0.075) | 90 (300) | 1.5–1.9 (0.060–0.075) | ... | ... | 90 (300) |
| Steel | 130 | max | 1.5–2.3 (0.060–0.090) | max | 1.5–2.3 (0.060–0.090) | max | 1.5–2.3 (0.060–0.090) | ... | ... | 90 (300) |
| Bronze | Hard | max | 2.3–3.2 (0.090–0.125) | max | 2.3–3.2 (0.090–0.125) | max | 2.3–2.5 (0.090–0.100) | max | 1.5–2.3 (0.060–0.090) | max |
| Bronze | Soft | max | 2.3–3.8 (0.090–0.150) | max | 2.3–3.2 (0.090–0.125) | max | 2.3–3.2 (0.090–0.125) | max | 2.3–2.5 (0.090–0.100) | max |

(a) For a depth of cut ranging from 0.08–0.38 mm (0.003–0.015 in.). Finishing feeds at these speeds depend on the type of tool used. Flat-nose tools are used for cast iron and bronze at feeds of 13–25 mm (½–1 in.) per stroke; variations of flat-nose tools are used for steel at feeds of 3.2–13 mm (⅛–½ in.) per stroke. Round-nose tools are sometimes used at feeds of 1.1–1.5 mm (0.045–0.060 in.), depending on the nose radius and on the finish desired.

**ASM Metals HandBook Volume 16 - Machining Processes**

# Pressão Específica de Corte

*Tabela 4.1 - Valores dos parâmetros 1-z e $K_{s1}$ para diversos materiais*

| MATERIAL | $\sigma_t$ (N/mm²) | 1-z | $K_{s1}$ |
|---|---|---|---|
| Aço ABNT 1030 | 520 | 0,74 | 1990 |
| 1040 | 620 | 0,83 | 2110 |
| 1050 | 720 | 0,70 | 2260 |
| 1045 | 670 | 0,86 | 2220 |
| 1060 | 770 | 0,82 | 2130 |
| 8620 | 770 | 0,74 | 2100 |
| 4320 | 630 | 0,70 | 2260 |
| 4140 | 730 | 0,74 | 2500 |
| 4137 | 600 | 0,79 | 2240 |
| 6150 | 600 | 0,74 | 2220 |
| Ferro Fundido | HRc = 46 | 0,81 | 2060 |
| Ferro Fundido GG26 | HB = 200 | 0,74 | 1160 |

**Diniz, 1999**

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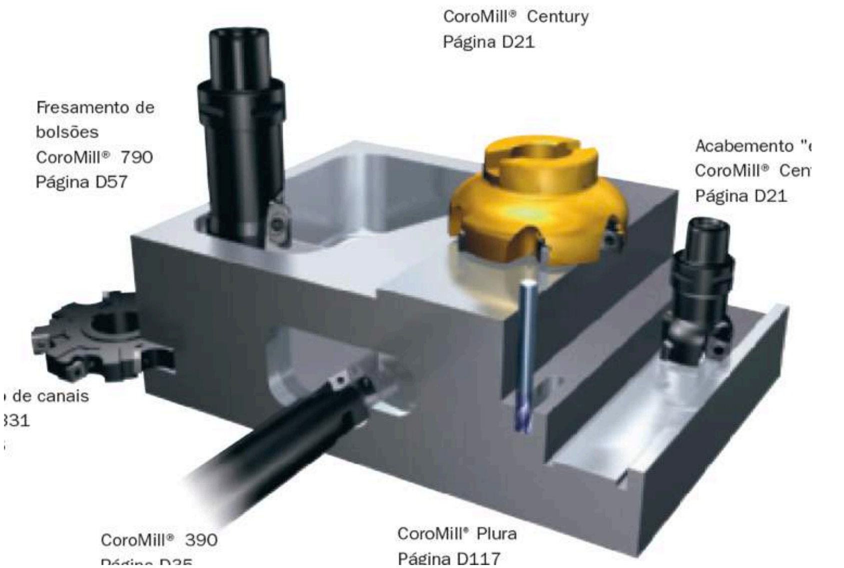
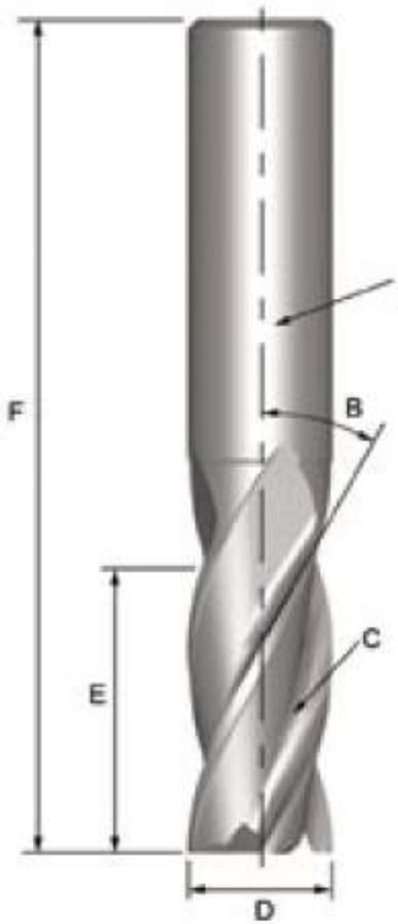
# Ferramentas Multicortantes:

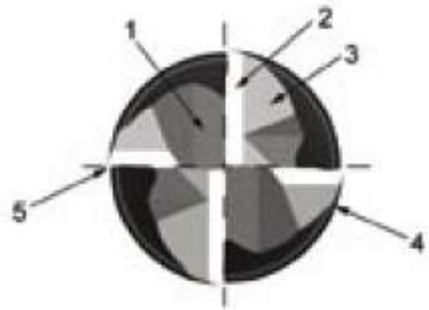


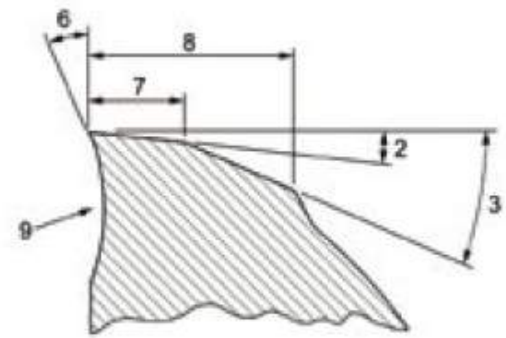
- **Fresamento**
- **Furação**
- **Alargamento**
- **Rosqueamento**



# Fresa

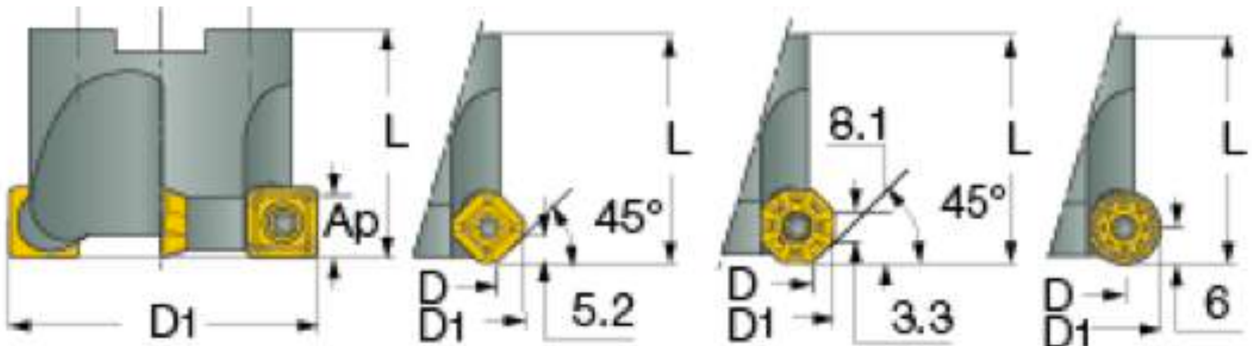



**Ângulo de Saída**
**Ângulo de Folga**

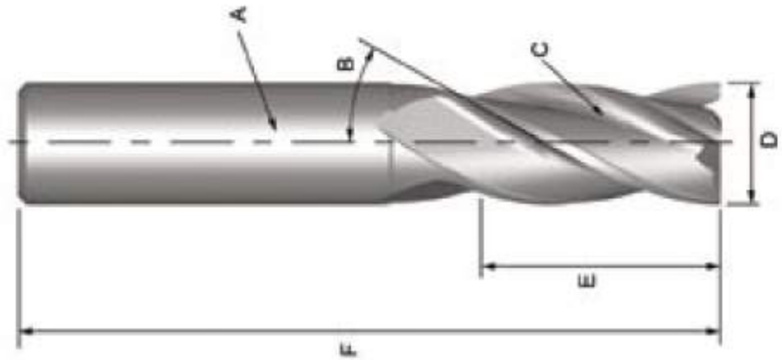
## Pastilhas Intercambiáveis



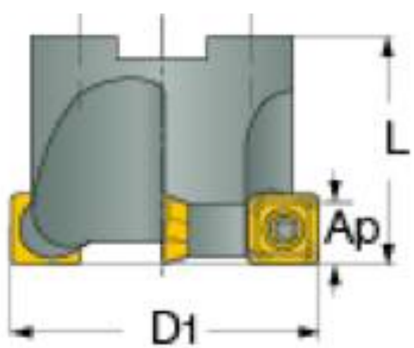

**Ângulo de Posição**

# Materiais das Ferramentas

## HSS (Aço Rápido)



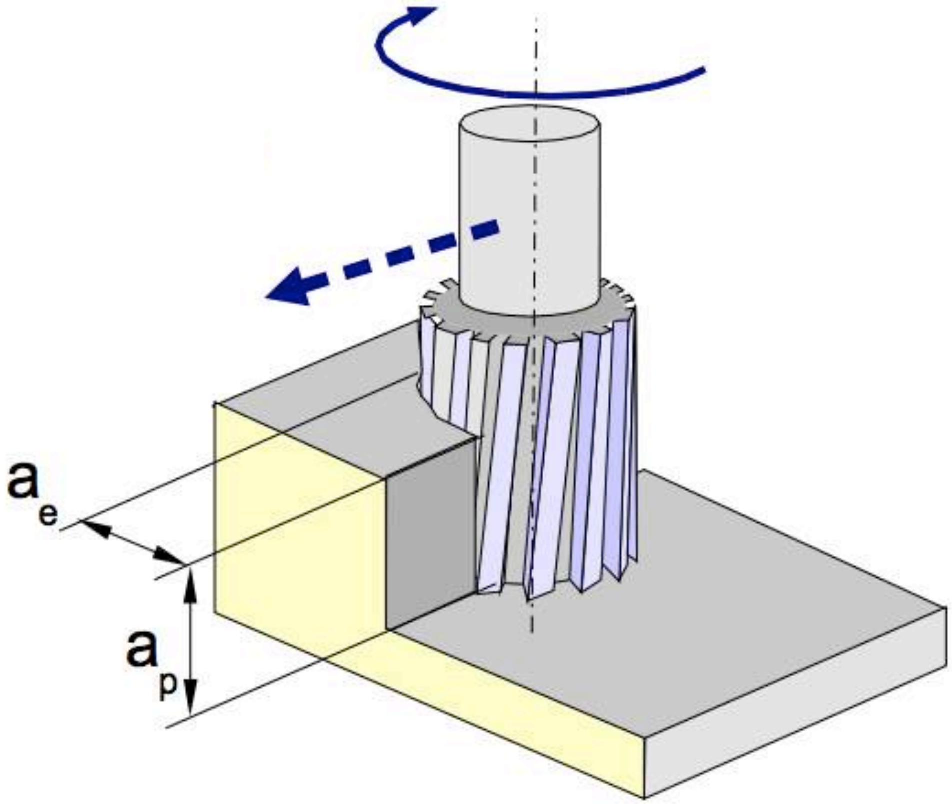

## Metal Duro



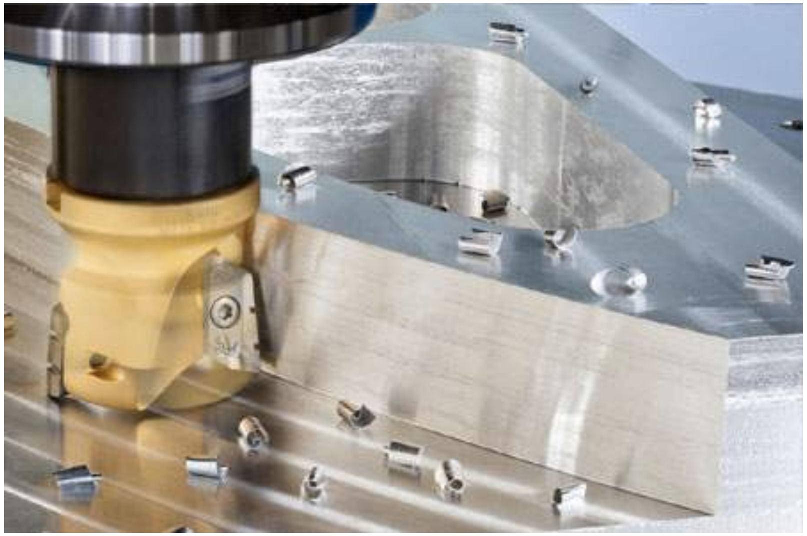

| ISO/ANSI | |
|---|---|
| Aços | P |
| Aços inoxidáveis | M |
| Ferros fundidos | K |
| Materiais não-ferrosos | N |
| Ligas de titânio | S |
| Material endurecido | H |

# Fresamento

- Velocidade de Corte
- Diâmetro da Fresa
- Velocidade de Rotação
- Número de dentes
- Avanço por dente
- Profundidade de Corte
- Largura de corte



# Processos de Usinagem



Vc – Velocidade de Corte:
Definida para o material usinado
Com a ferramenta escolhida.

**Velocidade de rotação**

$$n[rpm] = \frac{1000.V_c[m/min]}{\pi d[mm]}$$

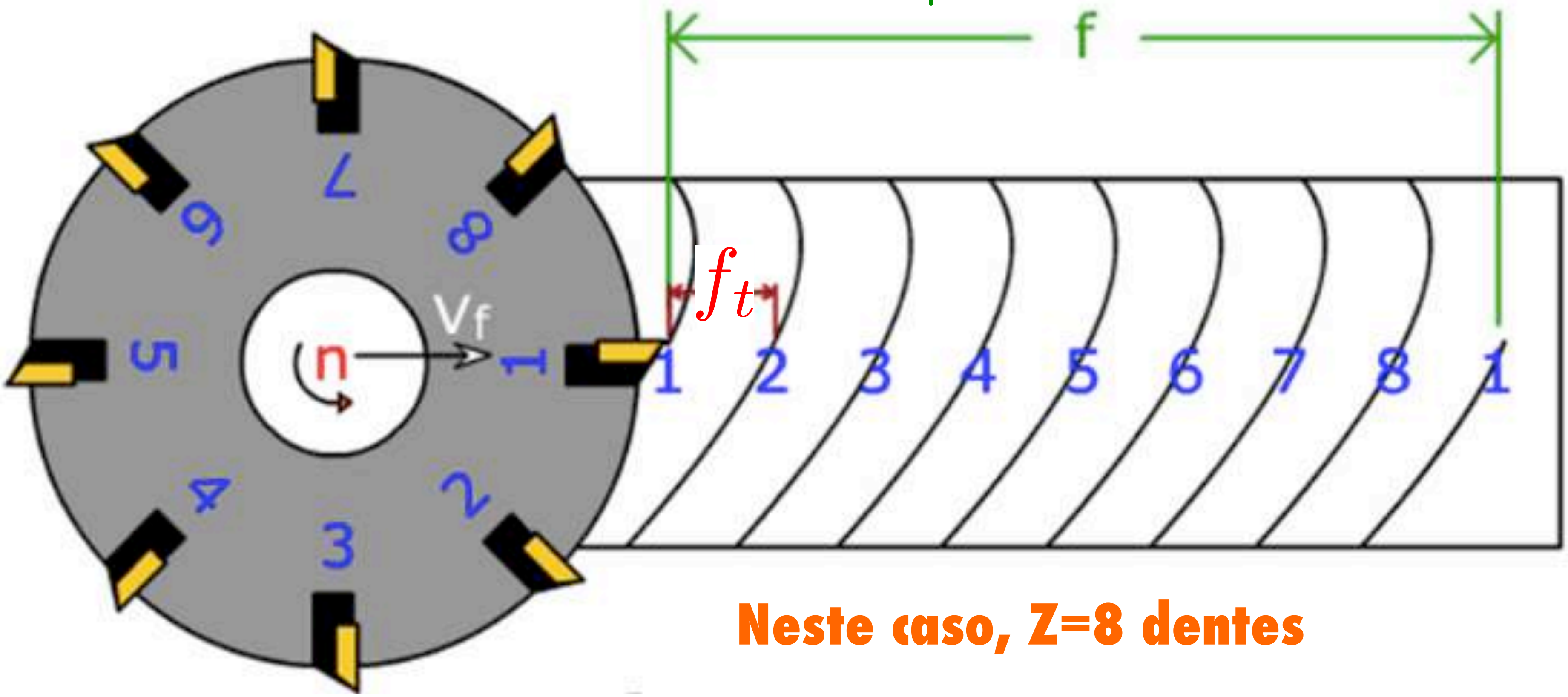
**Velocidade de avanço (Vf)**

Avanço por aresta (ft)
Por rotação: torneamento (Z=1)
Por dente: Fresamento (Z dentes)

$$V_f[mm/min] = f_t[mm/dente].Z[dentes/rot].n[rpm]$$

# Fresamento – Avanço por dente

$$V_f[mm/min] = \underbrace{f_t[mm/dente].Z[dentes/rot]}.n[rpm]$$




**Neste caso, Z=8 dentes**

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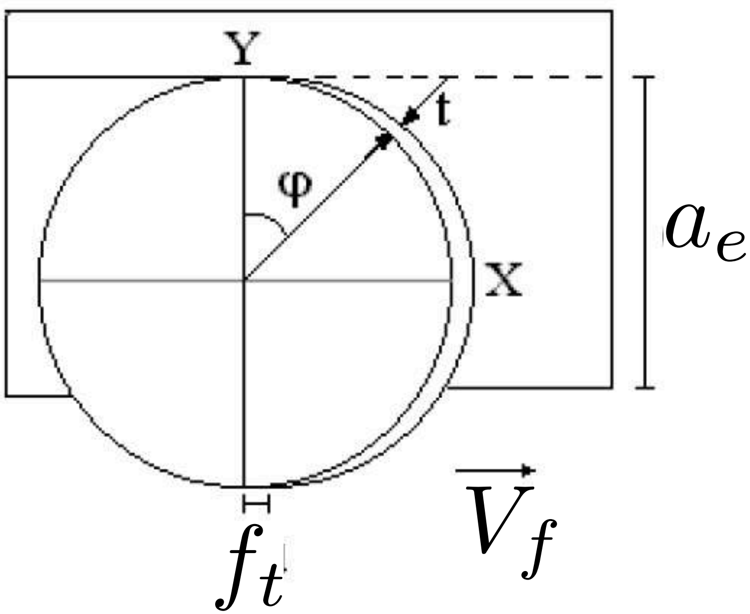
# Fresamento – Área de Corte




$$t_c = f_t \sin\varphi$$

$$A_c \simeq a_p f_t \sin\varphi$$

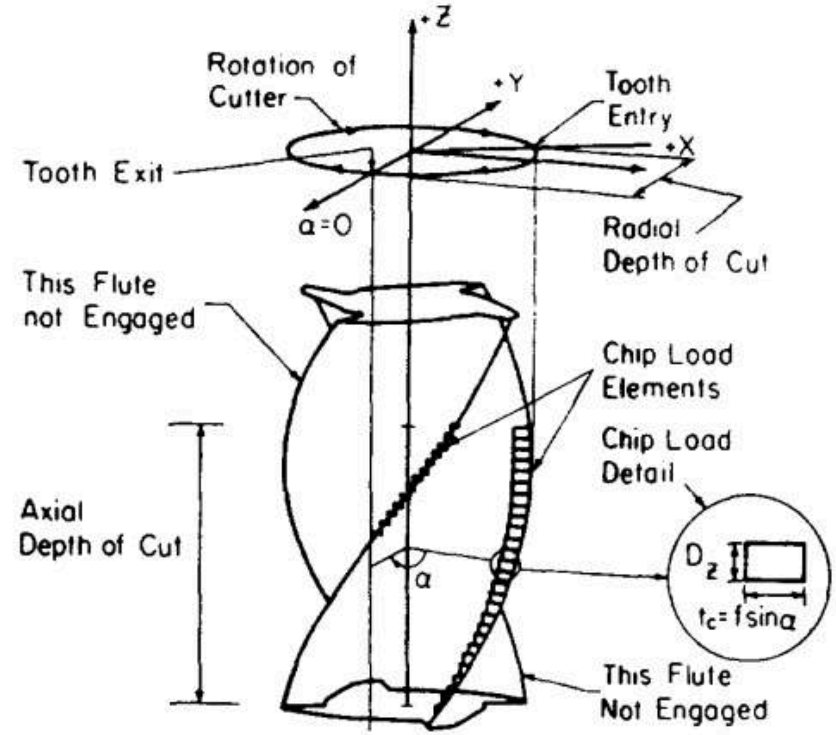
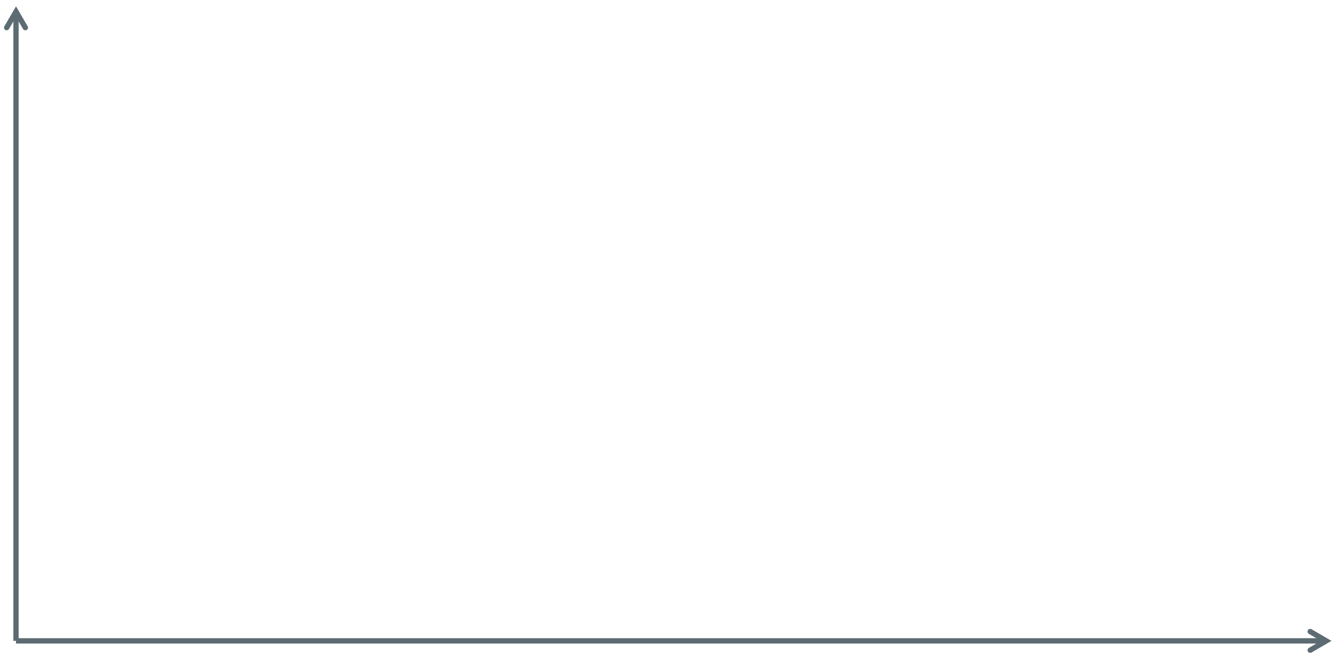



FIG. 2. End mill with chip load elements.

**Se for ignorado o ângulo de hélice**

# Fresamento – Área de Corte

- Como varia a área de corte com o tempo?

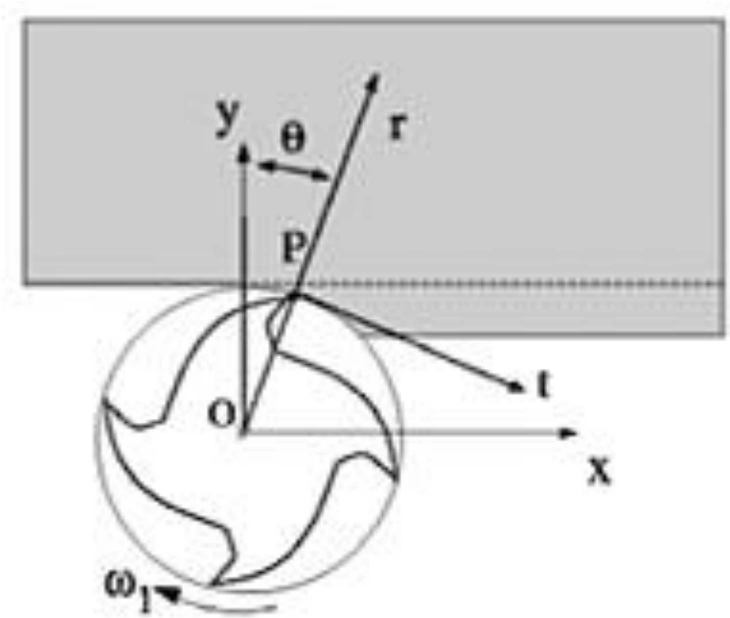


# Força de Corte no Fresamento

**Força = Pressão Esp. x Area de corte**

$$F_c \simeq K_c a_p f_t \sin\varphi$$
$$F_r \simeq K_r a_p f_t \sin\varphi$$

**Força por unidade de área em cada direção**



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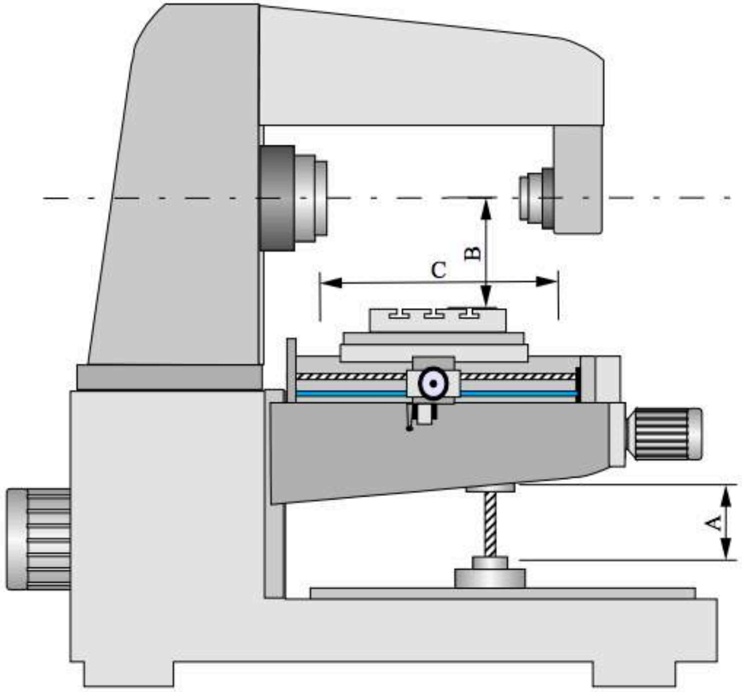
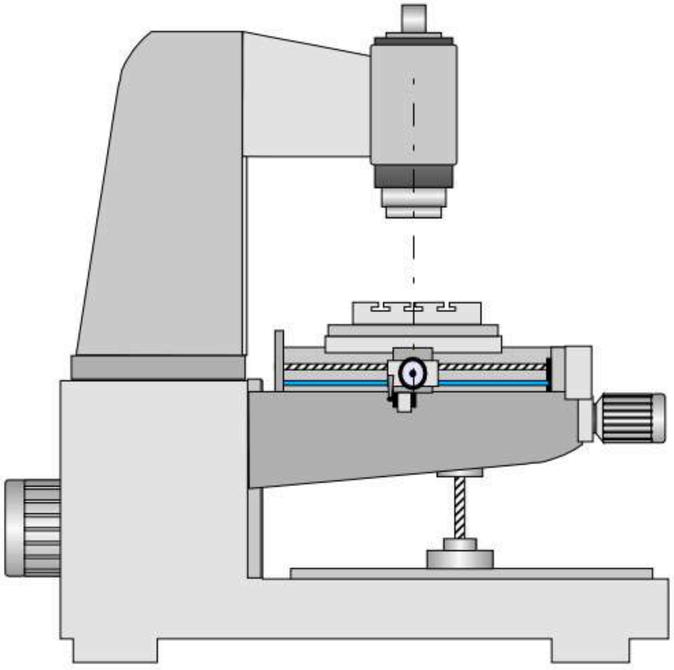
# Máquina-Ferramenta



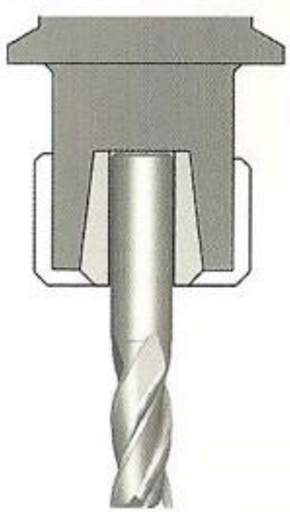
# Sistemas de Fixação da Fresa

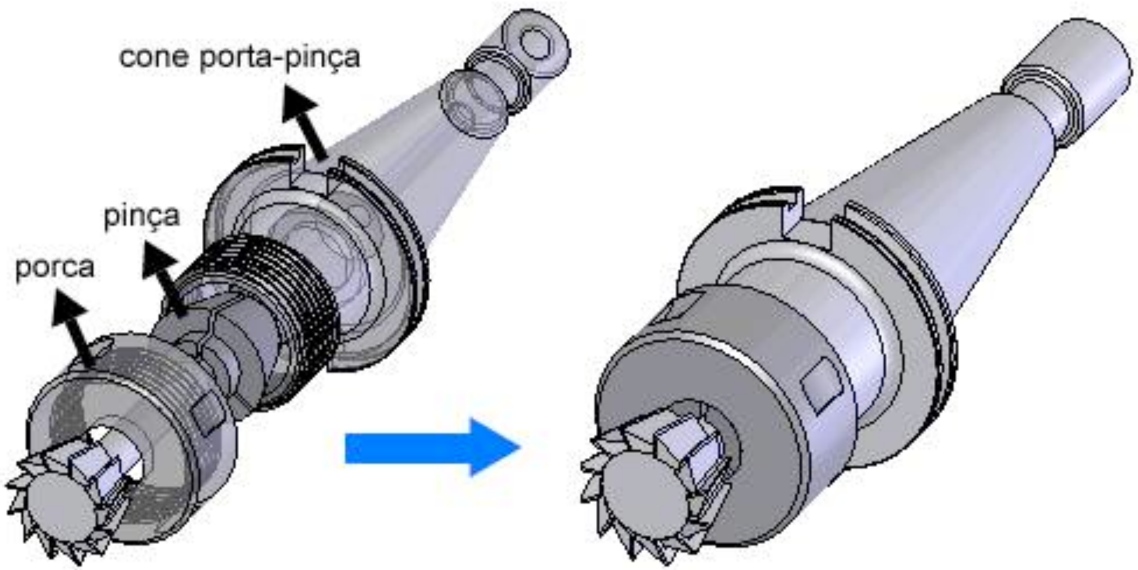
*SISTEMAS DE FIXAÇÃO*

Existem quatro tipos diferentes de sistemas de fixação para as ferramentas:

1. Mandril DIN 6388 e DIN 6499
2. Mandril Hidráulico
3. Encaixe por contração
4. Weldon e Whistle Notch (Lingüeta de arraste)

**Mandril DIN 6388, DIN 6499**

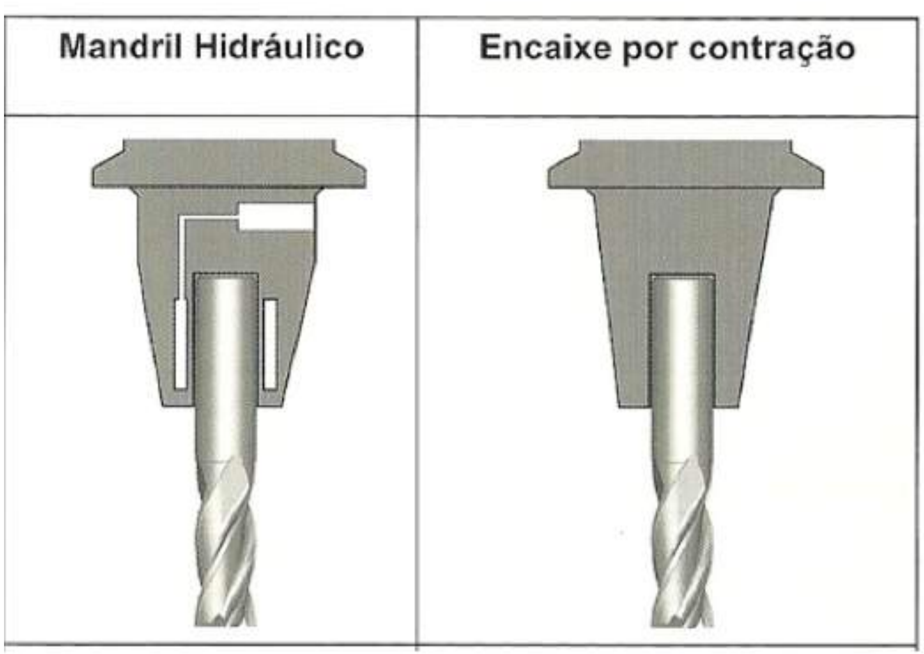


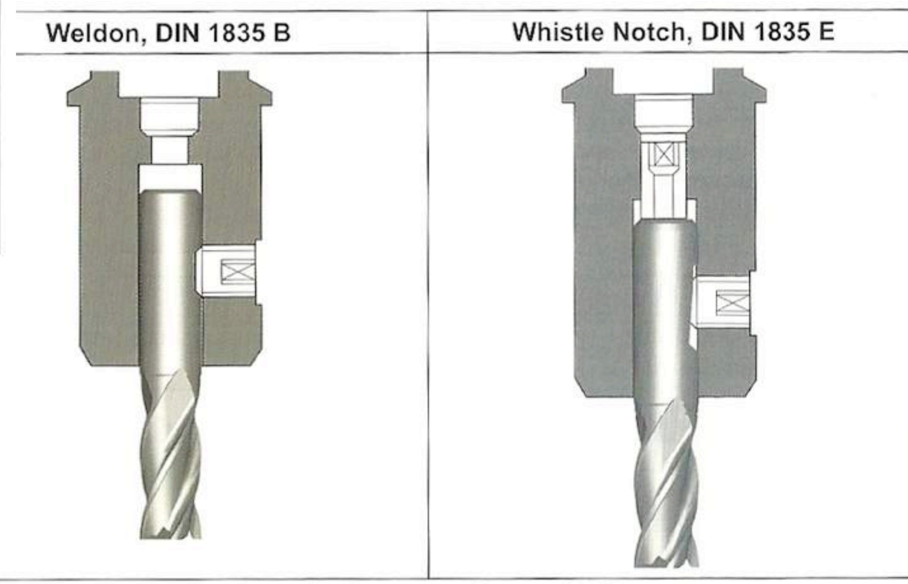



Fresa antes da montagem

Fresa após montagem

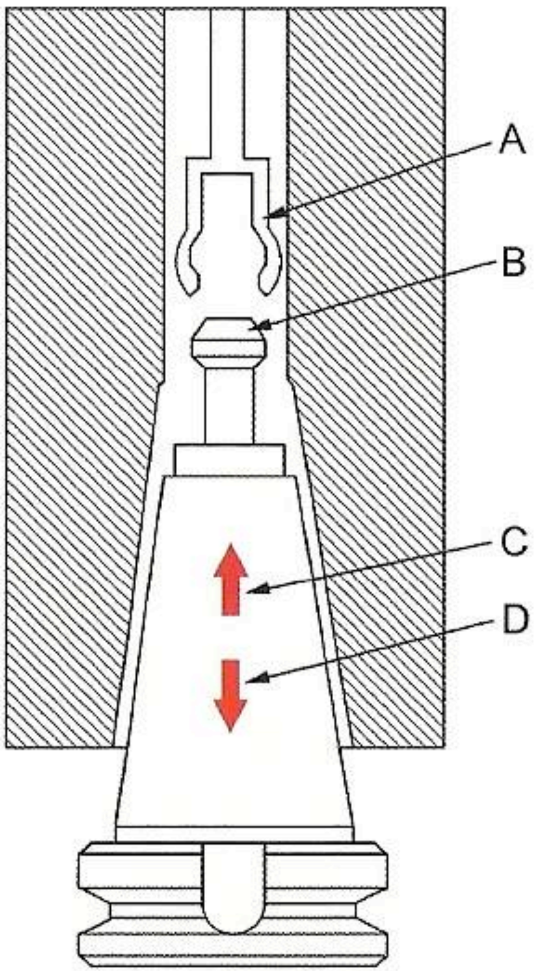
# Sistemas de Fixação da Fresa




Para mandris Weldon e Whistle Notch, um parafuso radial fica em contato com a ferramenta e a mantém no seu lugar. A ferramenta necessita ter uma área plana retificada na haste.

# Porta-Ferramenta




A Barra de tração com trava
B Pino de tração
C Fixação
D Liberação

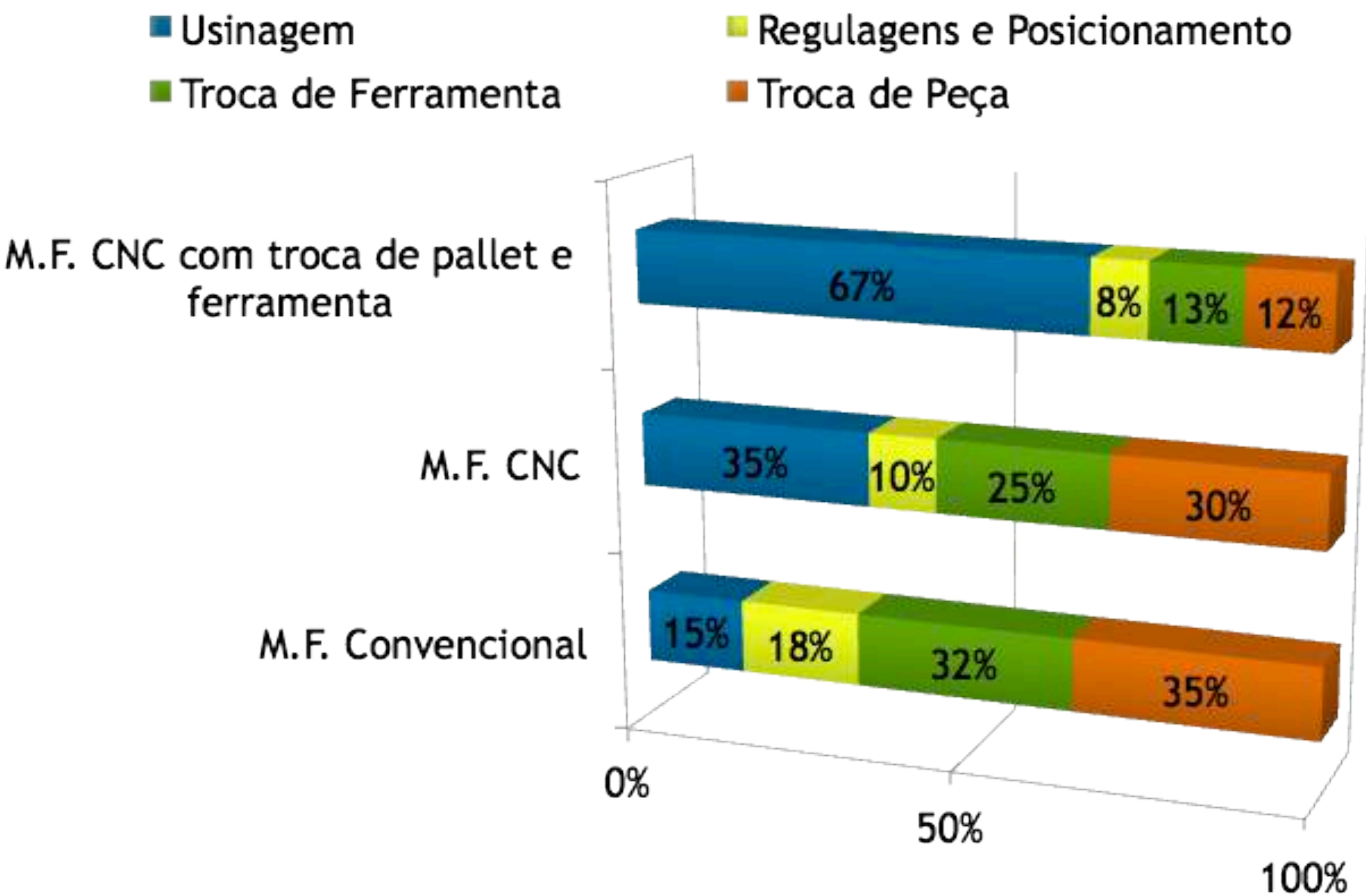
# Fluidos de Corte

# Comando Numérico

- Máquinas Convencionais
- Máquinas Automáticas
- Máquinas de Comando Numérico
  - 3 eixos
  - 4 eixos
  - 5 eixos


(Haas Automation)

# Comando Numérico



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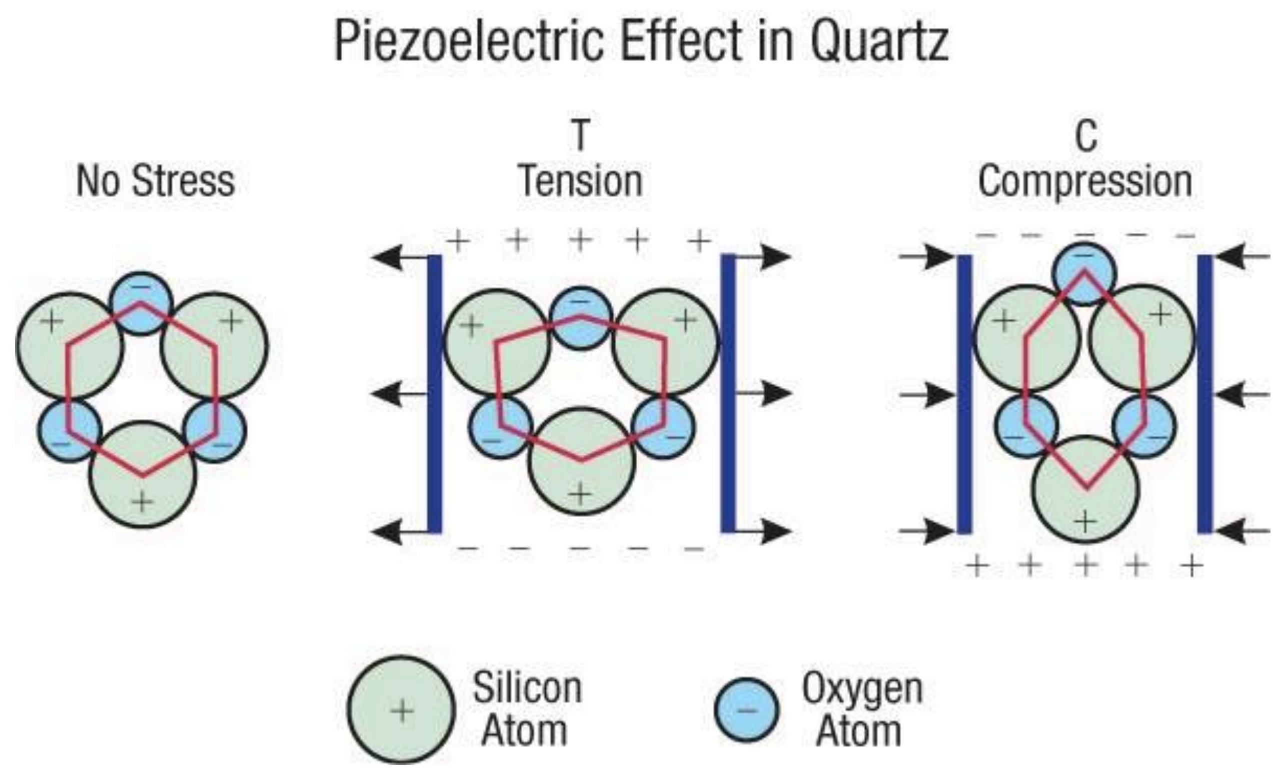
# Piezoeletricidade

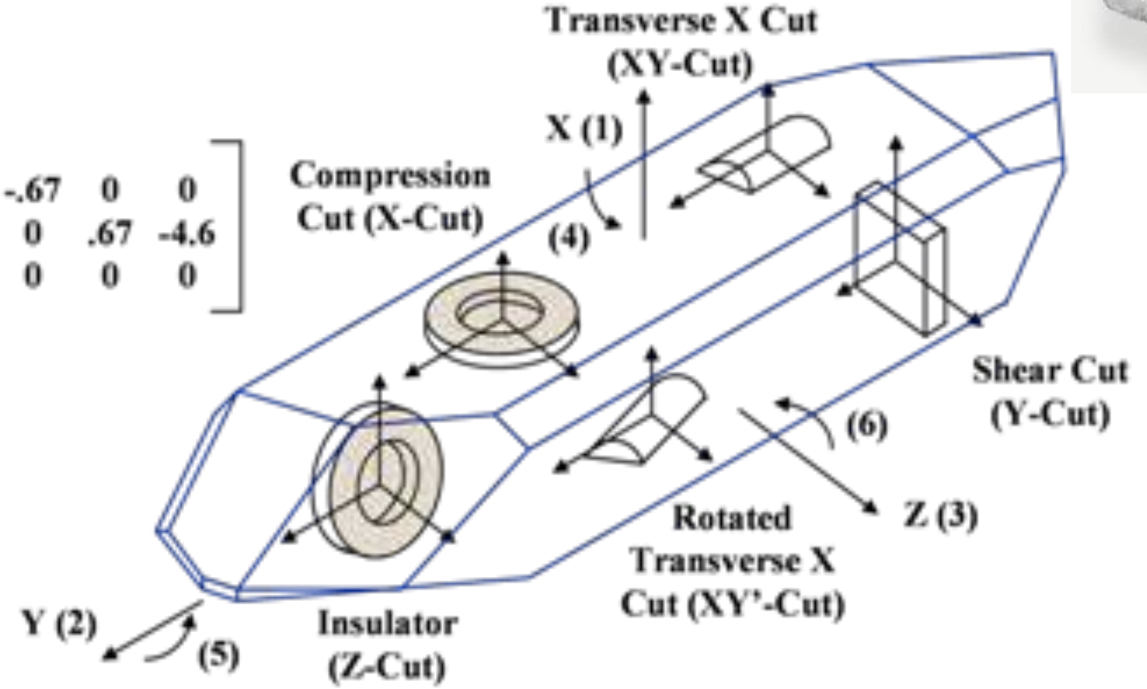




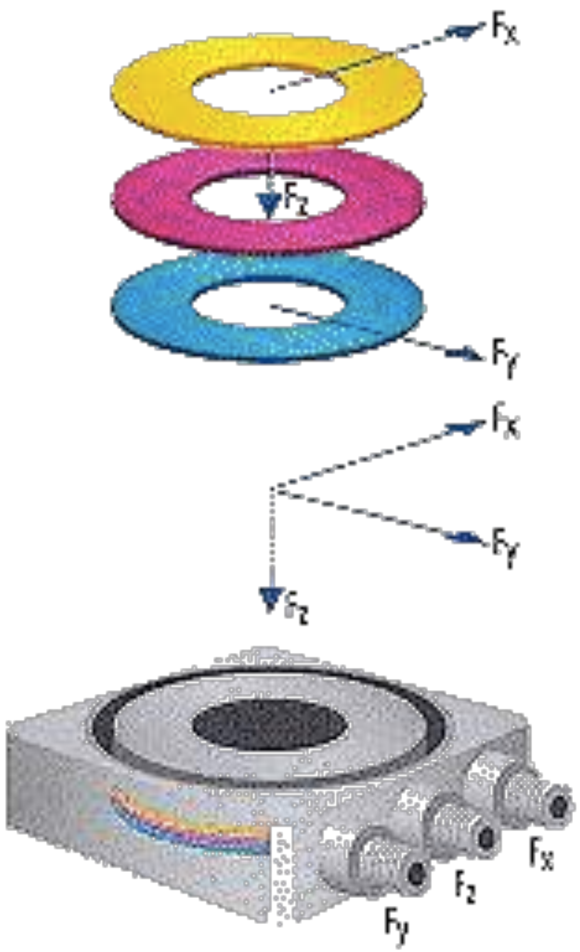
# Dinamometria (Sensor Piezoelétrico)

## Cristal de Quartzo

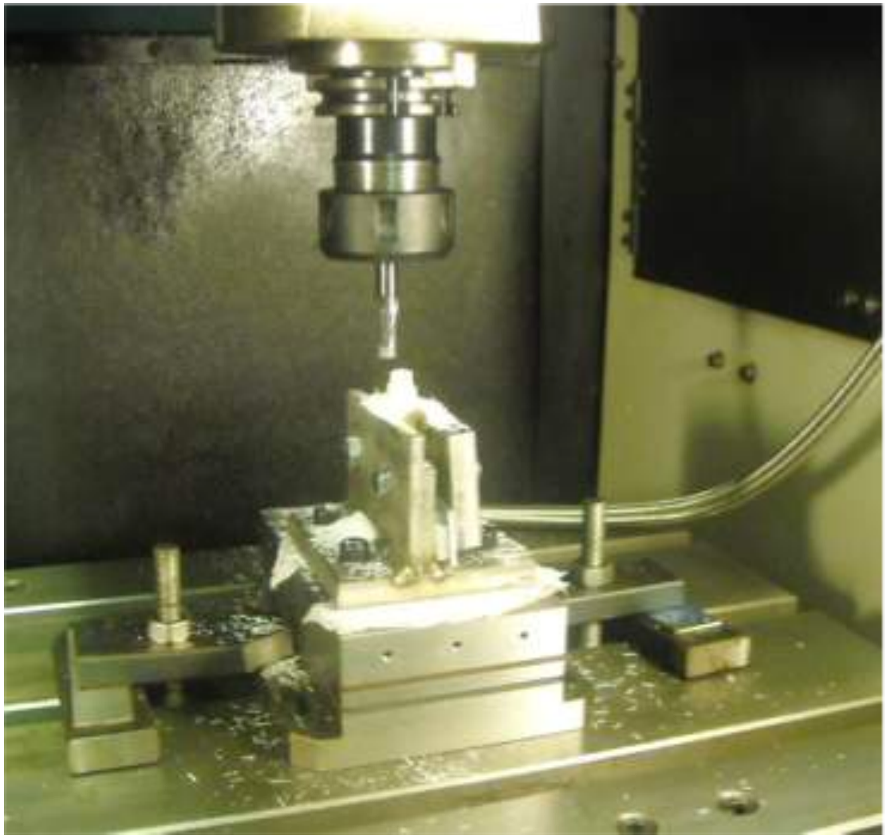
$$d = \begin{bmatrix} 2.3 & -2.3 & 0 & -.67 & 0 & 0 \\ 0 & 0 & 0 & 0 & .67 & -4.6 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

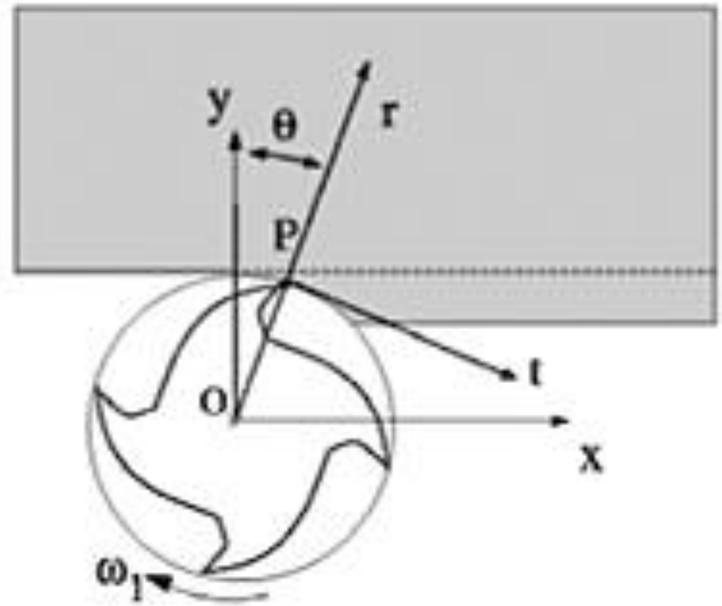


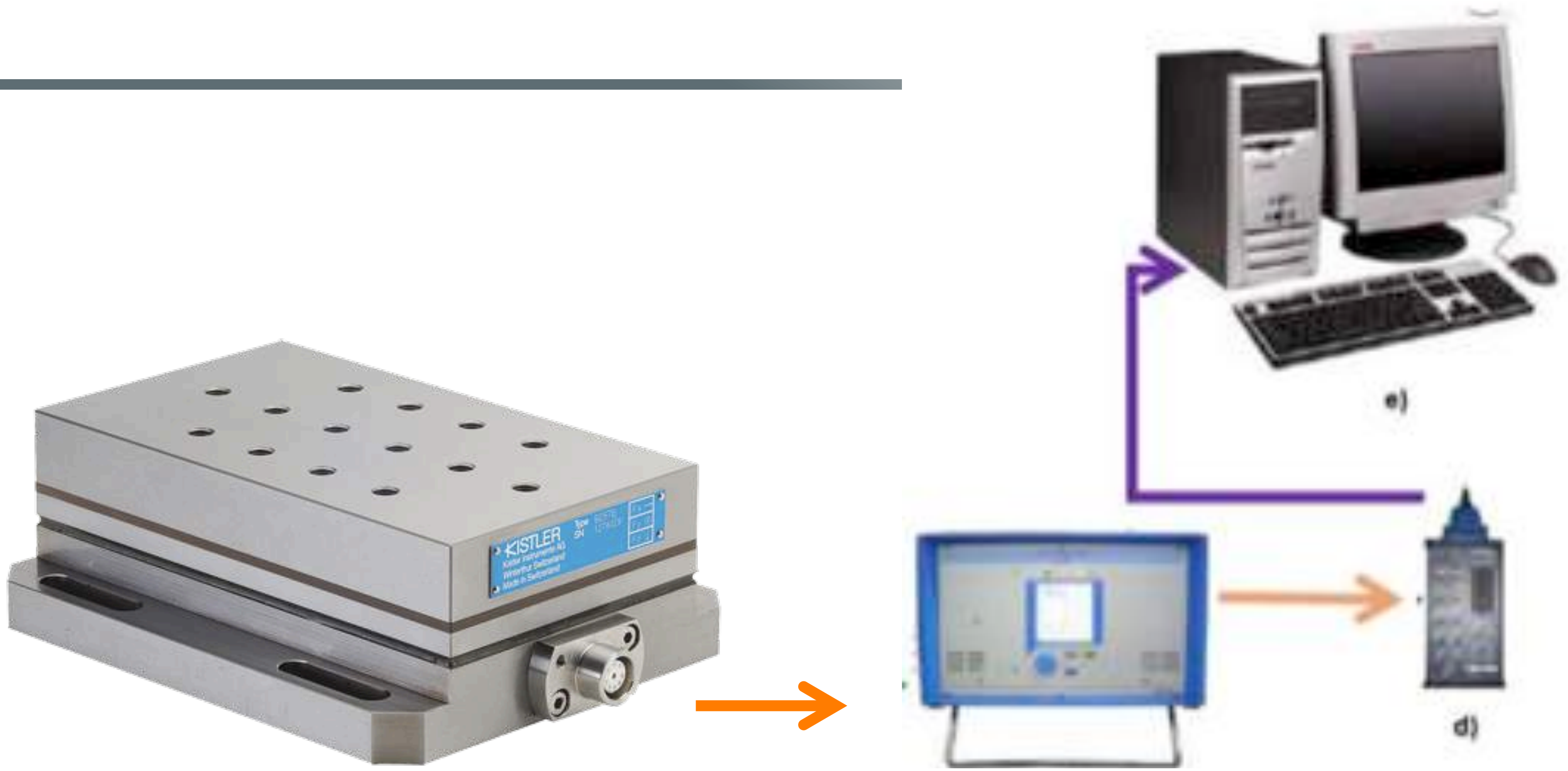
# Dinamômetro Piezelétrico




# Quais as forças mede o dinamômetro?

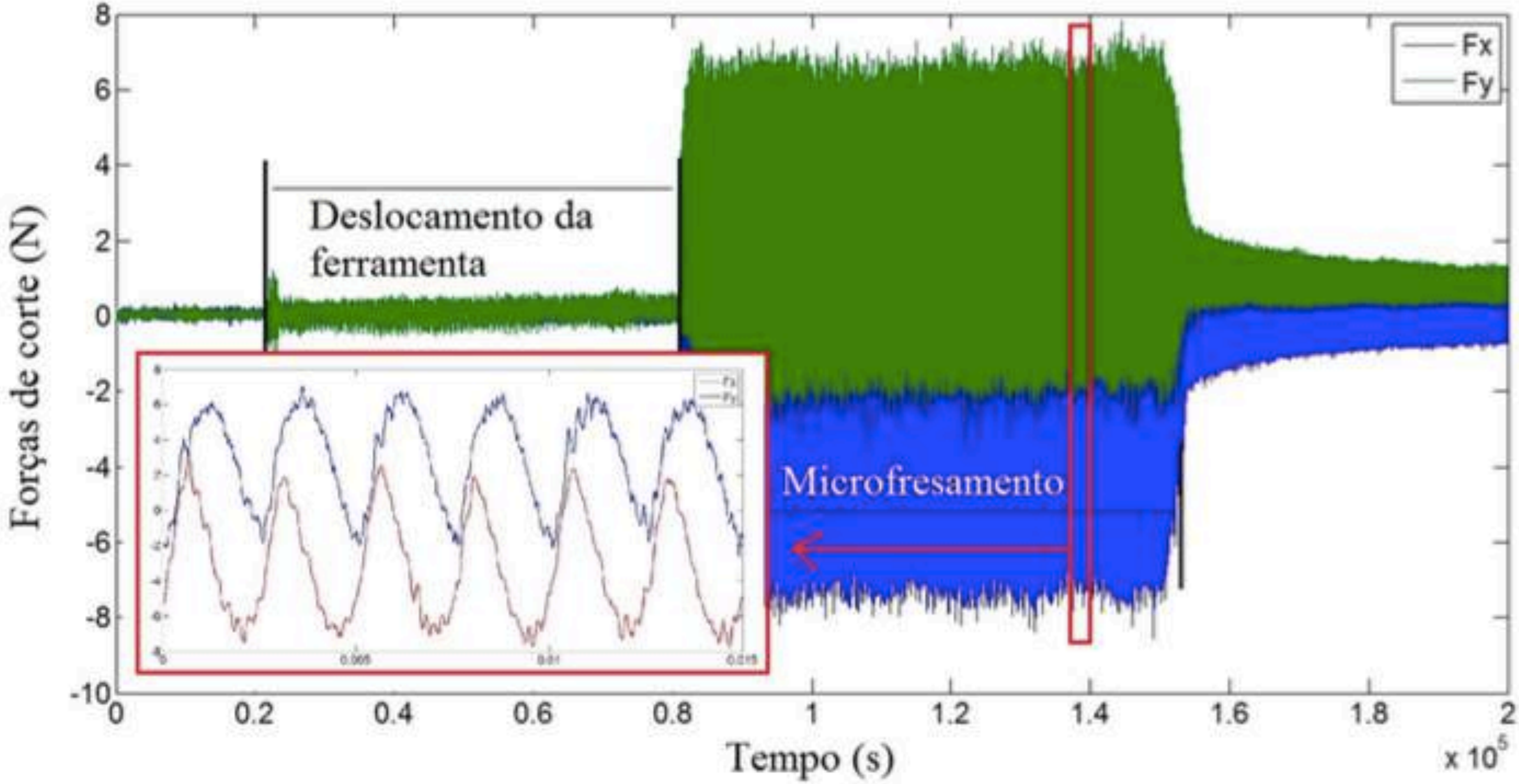







Dinamômetro → Condicionador de Sinais → Placa de Conversão Analógica-Digital → Computador (Matlab, Origin, etc)

# Forças em Microusinagem



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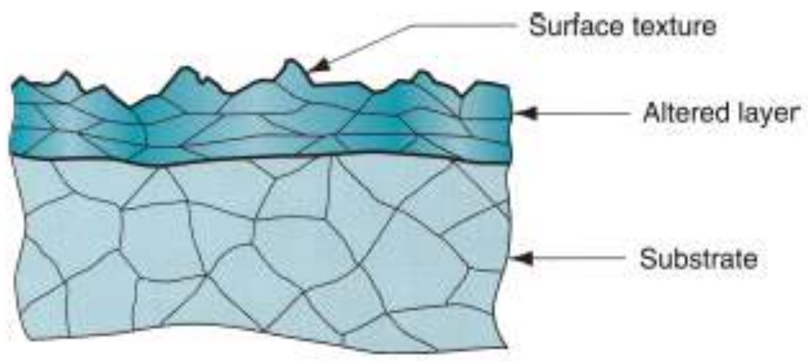
# Rugosidade de Superfície



**FIGURE 4.2** A magnified cross section of a typical metallic part surface. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



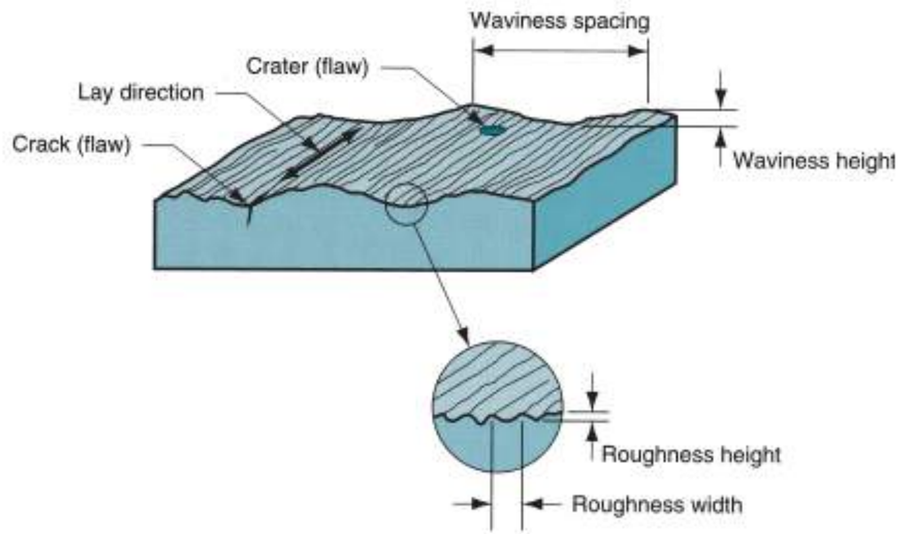
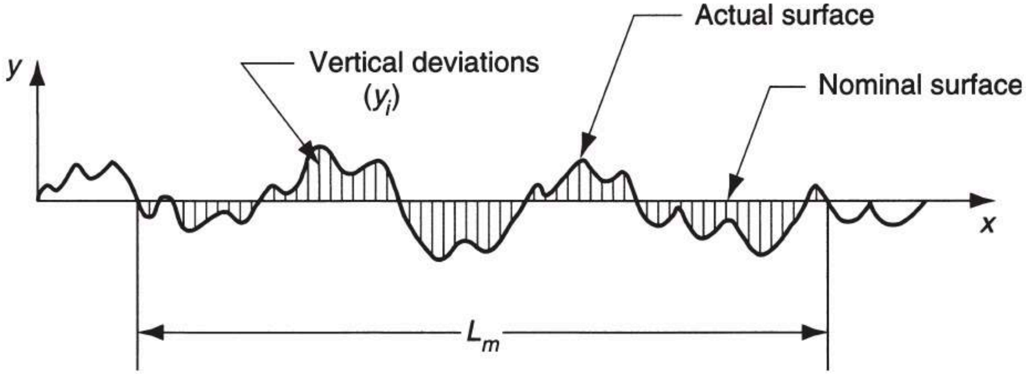




**FIGURE 4.3** Surface texture features. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

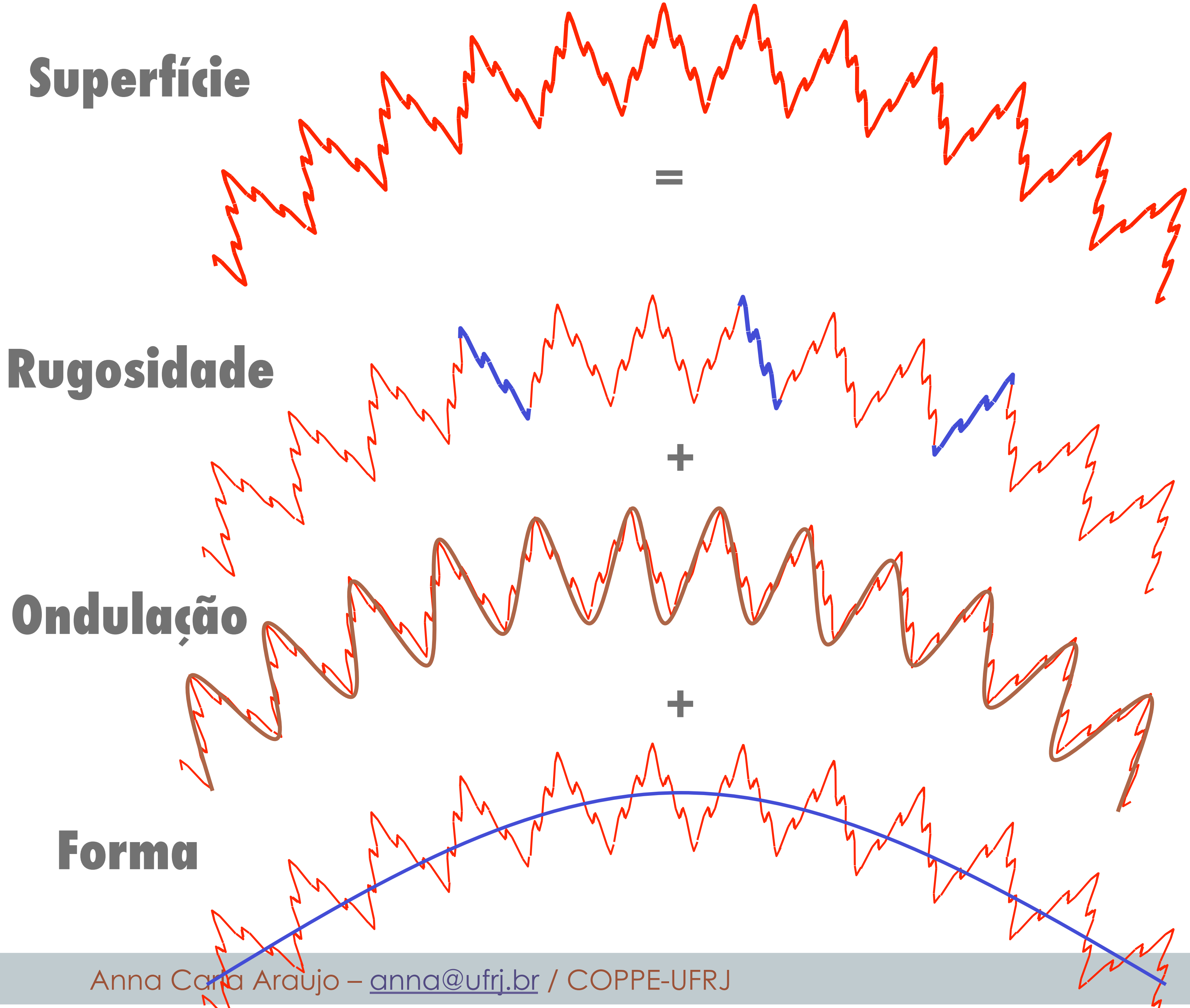
# Rugosidade de Superfície



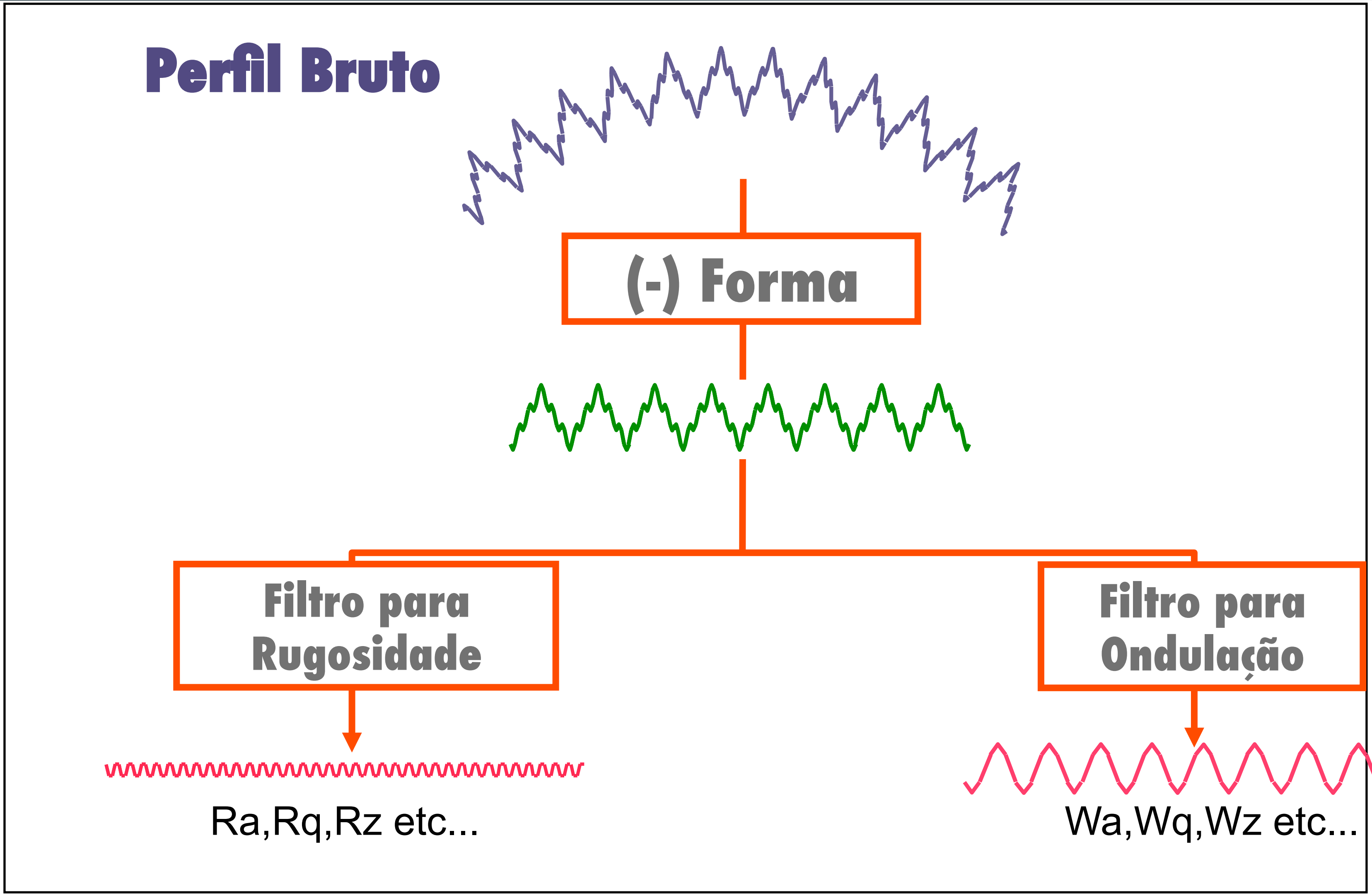

$$R_a = \int_0^{L_m} \frac{|y|}{L_m} dx$$

$$R_a = \sum_{i=1}^{n} \frac{|y_i|}{n}$$

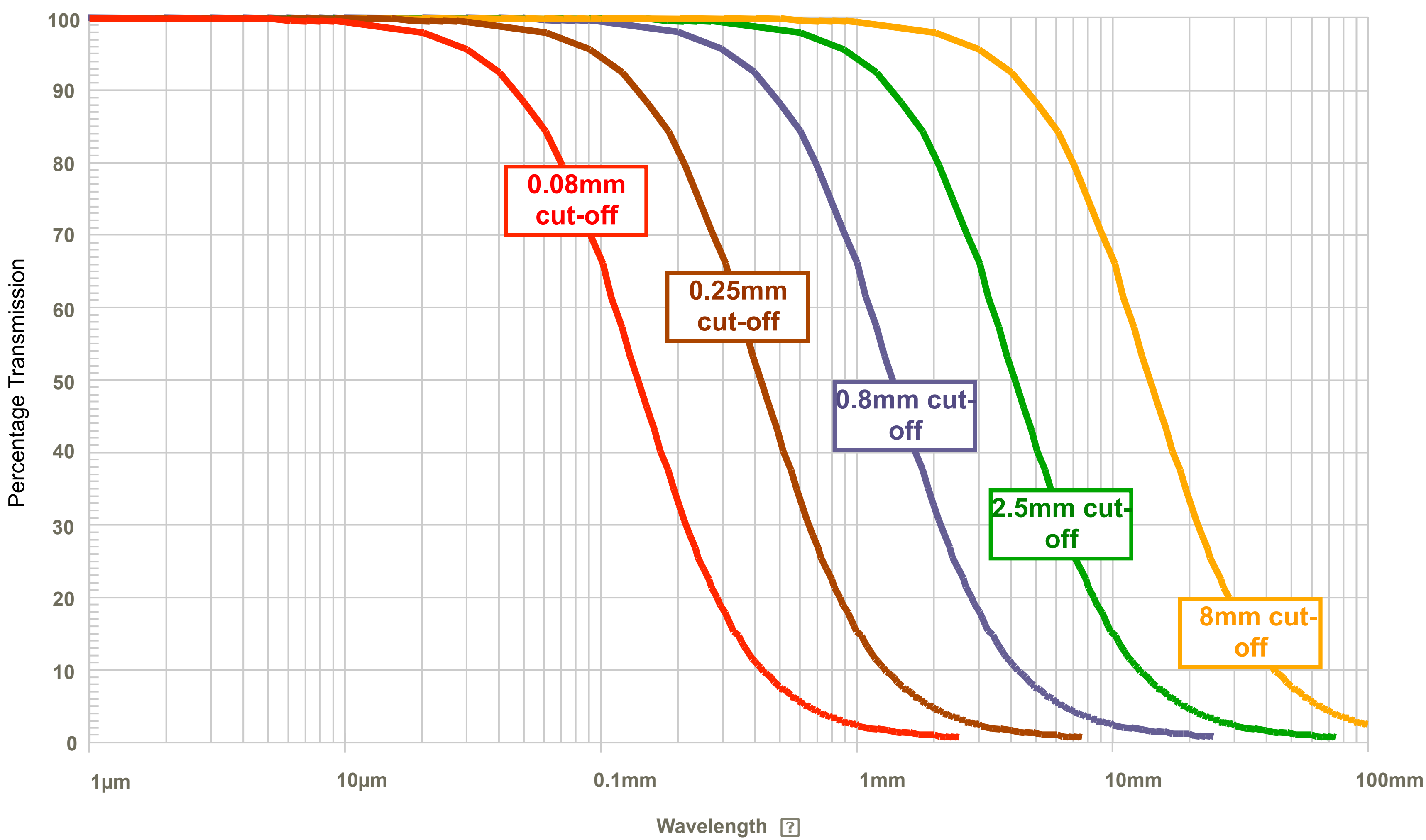
| Lay symbol | Surface pattern | Description | Lay symbol | Surface pattern | Description |
|---|---|---|---|---|---|
| = |  | Lay is parallel to line representing surface to which symbol is applied. | C |  | Lay is circular relative to center of surface to which symbol is applied. |
| ⊥ |  | Lay is perpendicular to line representing surface to which symbol is applied. | R |  | Lay is approximately radial relative to the center of the surface to which symbol is applied. |
| X |  | Lay is angular in both directions to line representing surface to which symbol is applied. | P |  | Lay is particulate, nondirectional, or protuberant. |


Superfície
=
Rugosidade
+
Ondulação
+
Forma

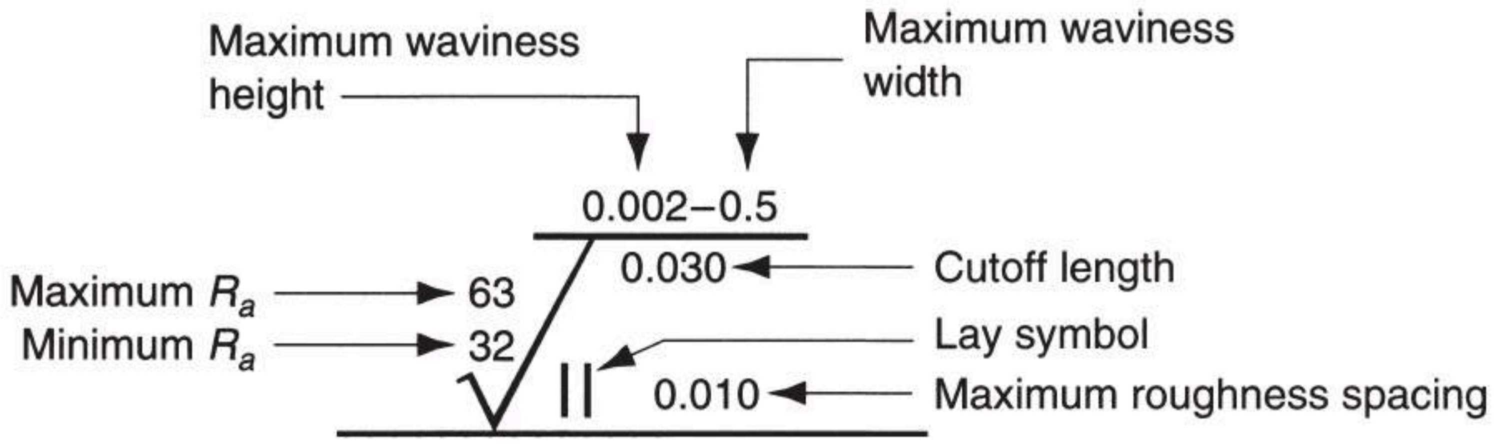
# Rugosidade de Superfície

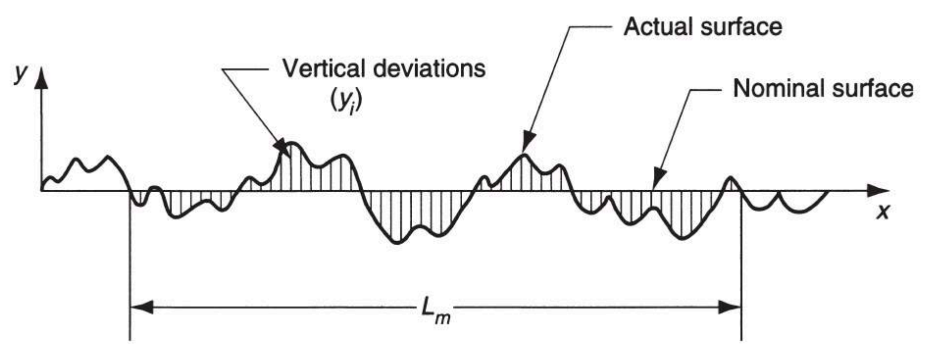


# Cut-off e Filtros para Rugosidade



# Rugosidade de Superfície




**>3.Cutoff**

# Rugosidade de Superfície

**TABLE 4.3 Surface roughness values produced by the various manufacturing processes.[a]**

| Process | Typical Finish | Roughness Range[b] | Process | Typical Finish | Roughness Range[b] |
|---|---|---|---|---|---|
| Casting: | | | Abrasive: | | |
| Die casting | Good | 1–2 (30–65) | Grinding | Very good | 0.1–2 (5–75) |
| Investment | Good | 1.5–3 (50–100) | Honing | Very good | 0.1–1 (4–30) |
| Sand casting | Poor | 12–25 (500–1000) | Lapping | Excellent | 0.05–0.5 (2–15) |
| Metal forming: | | | Polishing | Excellent | 0.1–0.5 (5–15) |
| Cold rolling | Good | 1–3 (25–125) | Superfinish | Excellent | 0.02–0.3 (1–10) |
| Sheet metal draw | Good | 1–3 (25–125) | Nontraditional: | | |
| Cold extrusion | Good | 1–4 (30–150) | Chemical milling | Medium | 1.5–5 (50–200) |
| Hot rolling | Poor | 12–25 (500–1000) | Electrochemical | Good | 0.2–2 (10–100) |
| Machining: | | | Electric discharge | Medium | 1.5–15 (50–500) |
| Boring | Good | 0.5–6 (15–250) | Electron beam | Medium | 1.5–15 (50–500) |
| Drilling | Medium | 1.5–6 (60–250) | Laser beam | Medium | 1.5–15 (50–500) |
| Milling | Good | 1–6 (30–250) | Thermal: | | |
| Reaming | Good | 1–3 (30–125) | Arc welding | Poor | 5–25 (250–1000) |
| Shaping and planing | Medium | 1.5–12 (60–500) | Flame cutting | Poor | 12–25 (500–1000) |
| Sawing | Poor | 3–25 (100–1000) | Plasma arc cutting | Poor | 12–25 (500–1000) |
| Turning | Good | 0.5–6 (15–250) | | | |

[a]Compiled from [1], [2], and other sources.
[b]Roughness range values are given, μm (μ-in). Roughness can vary significantly for a given process, depending on process parameters.

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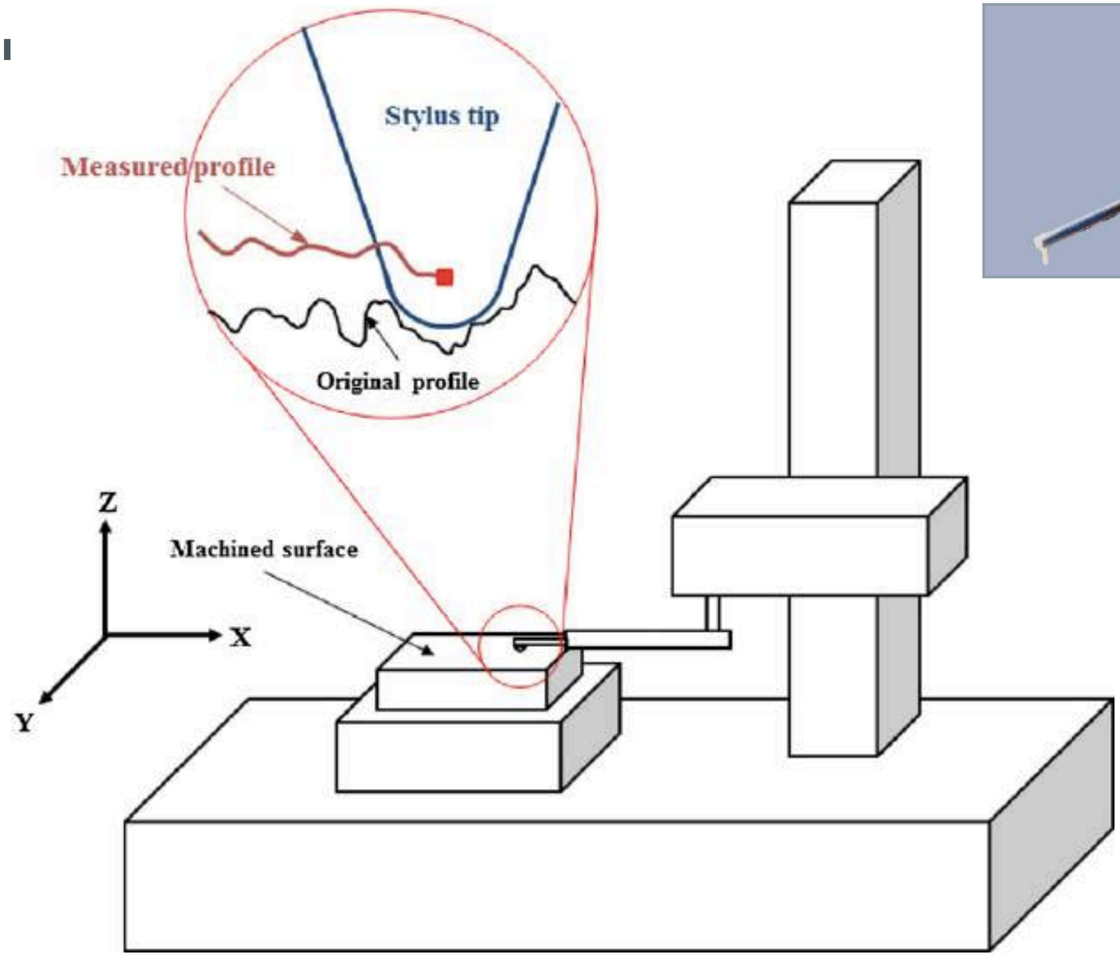
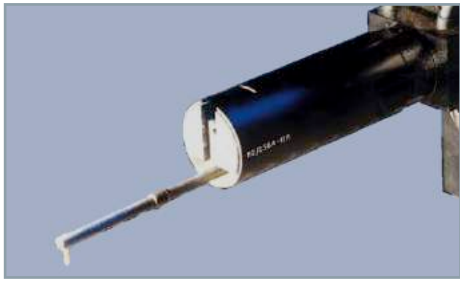
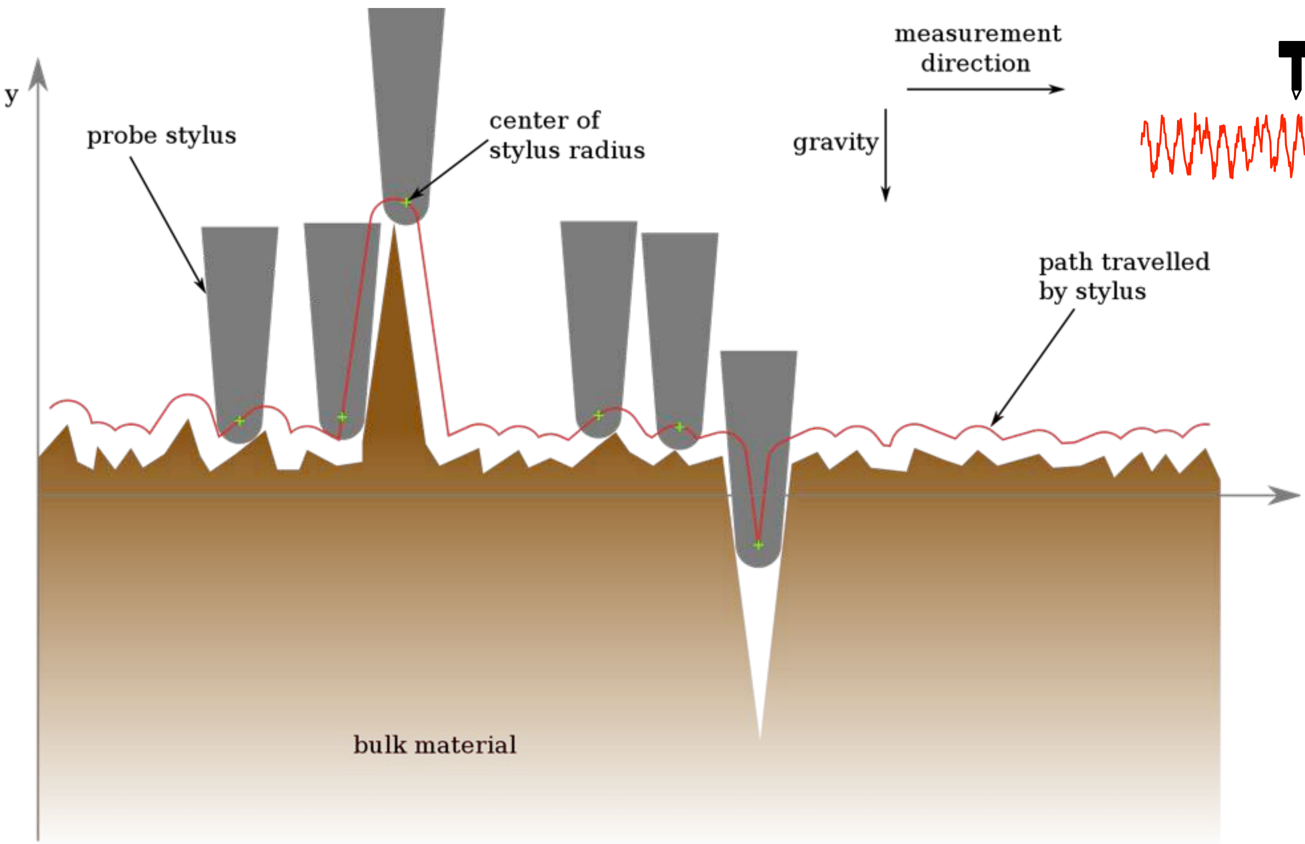
# Medida de Rugosidade

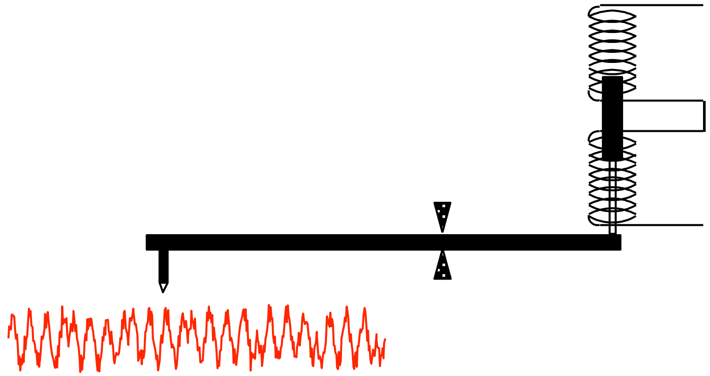




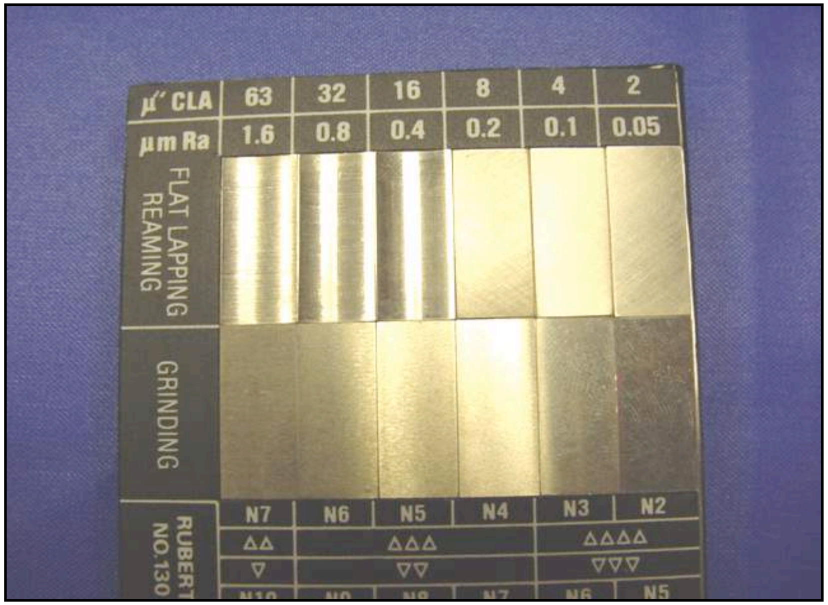



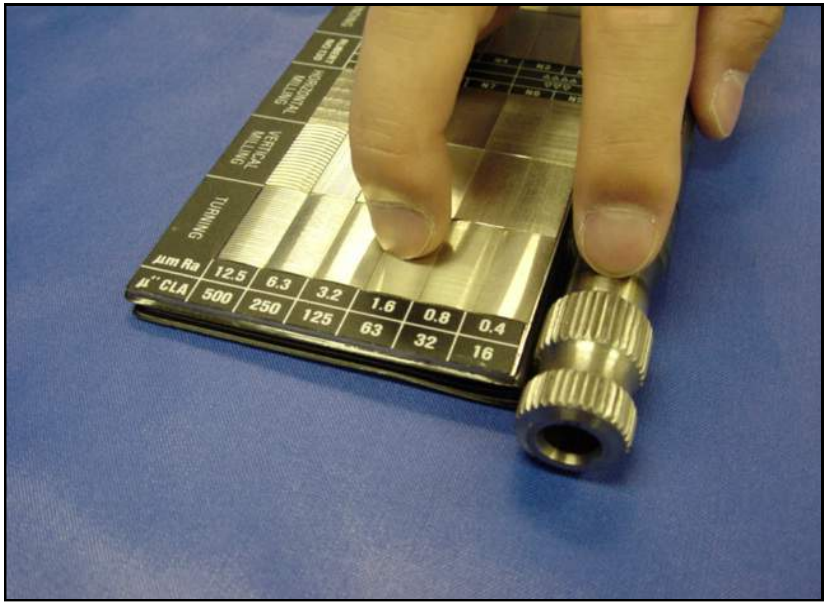
# Apalpador – Geometria x Medida



# Rugosidade - Visual



# Vamos ao CEFCON - I-142