Today:

- Machining: An Introduction
- Orthogonal Cutting Model
- Cutting Physics
  - Geometry
  - Forces
  - Energy

Material removal processes (the oldest process):

- Mechanical
  - Milling, Turning, Shaping, Grinding, Broaching, Polishing,
- Thermal
- Electrochemical
- Chemical

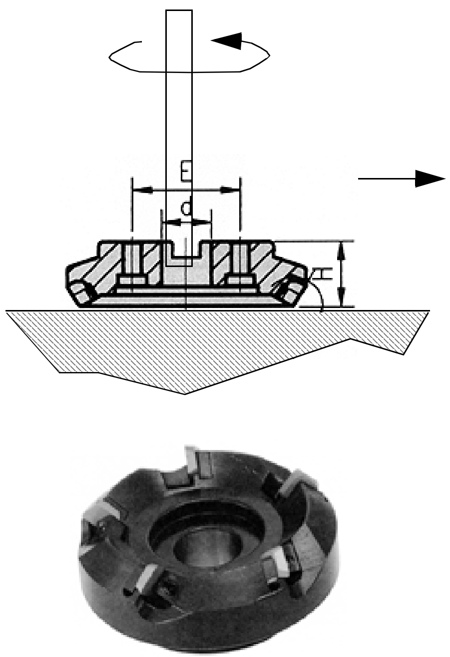
Cost: 👎
Expensive $100.00 — $10,000.00

Flexibility: 👍
Any shape under the sun!

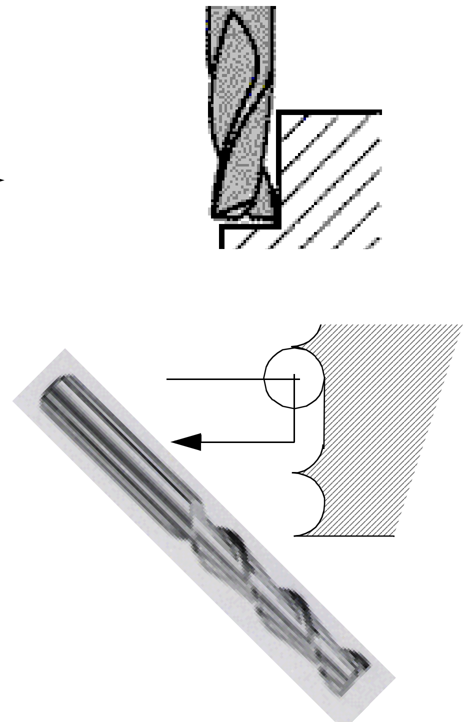
Quality: 👍
Very high quality.

Rate: 👎
Slow compared to other production techniques.

Roughness of machining



A face milling operation
will render a smooth finish



Side milling with an end-mill
will give you some surface
roughness.

Most machining processes will give you some finite surface roughness, which depends on the mass of material removed - tooth size, cutter

Process modeling

- Understand the process: optimization & control
- Analytical, Numerical and Experimental

Key issues:

- How does cutting work?
- What are the cutting forces?
- How do material propertiers affect cutting?
- What are the power requirements?

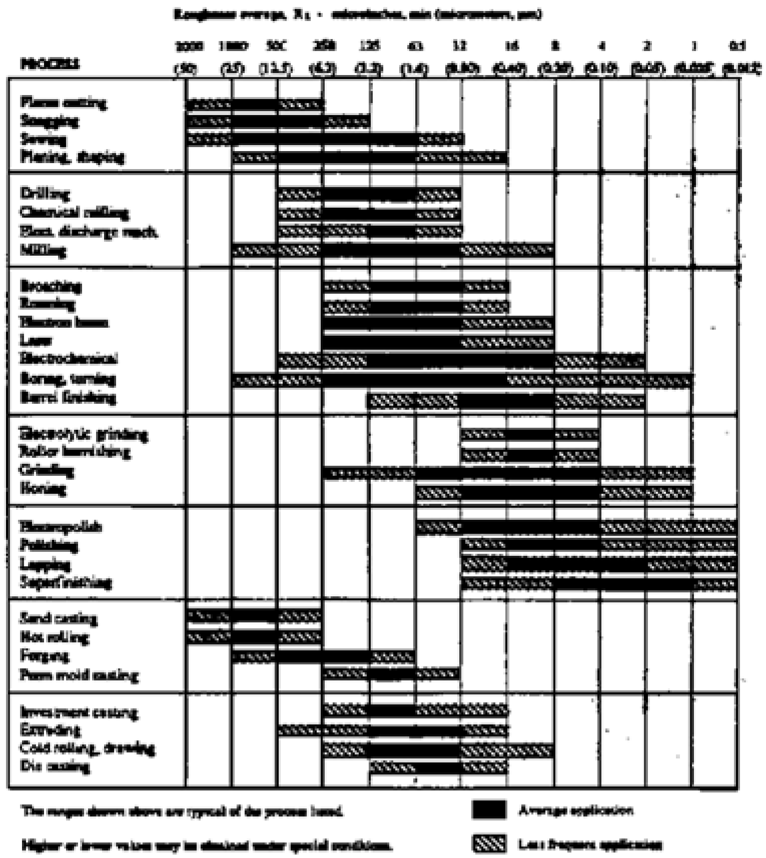


TABLE 2.4 Surface Quality for Different Machining Processes

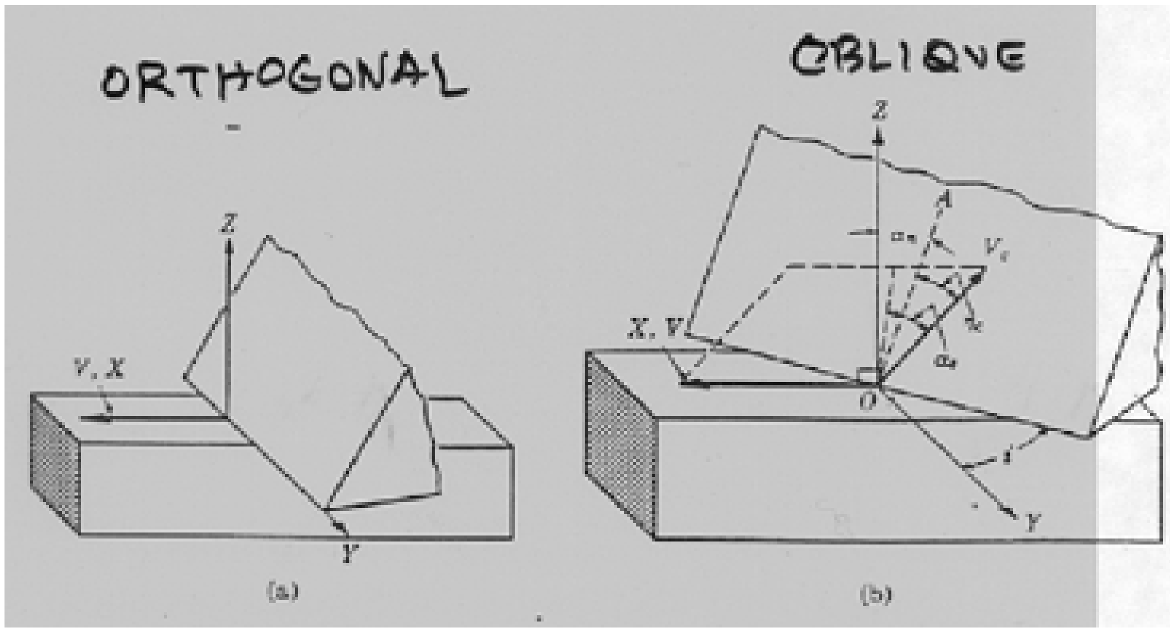
	Cost	Production Rate	Quality	Flexibility
Removing Processes	Medium Tooling/ High Labor Cost	Medium (Milling) to Low (Grinding)	High	High

TABLE 2.5 Characteristics of Material Removal Processes

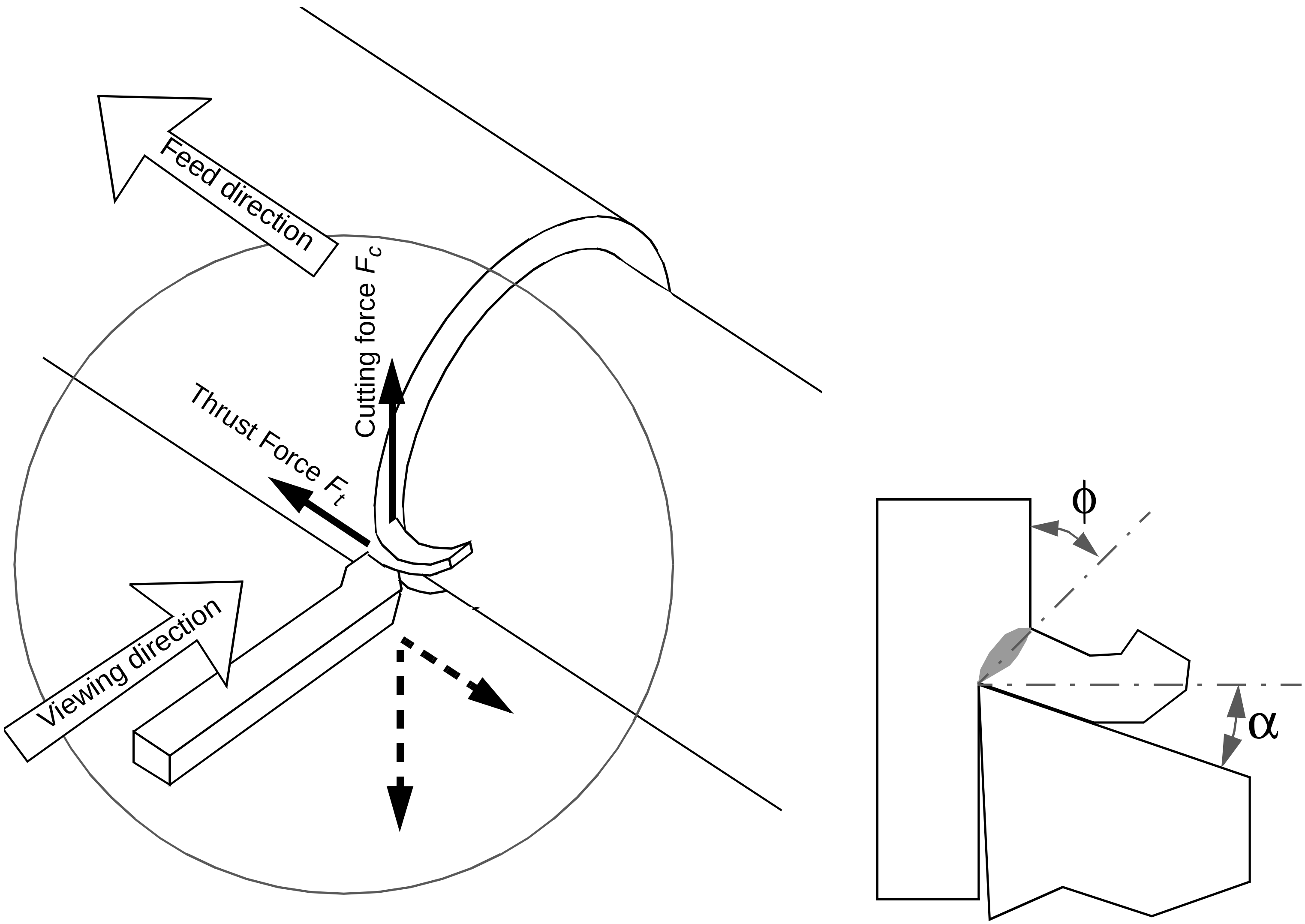
Basic cutting geometry

2 Dimensional

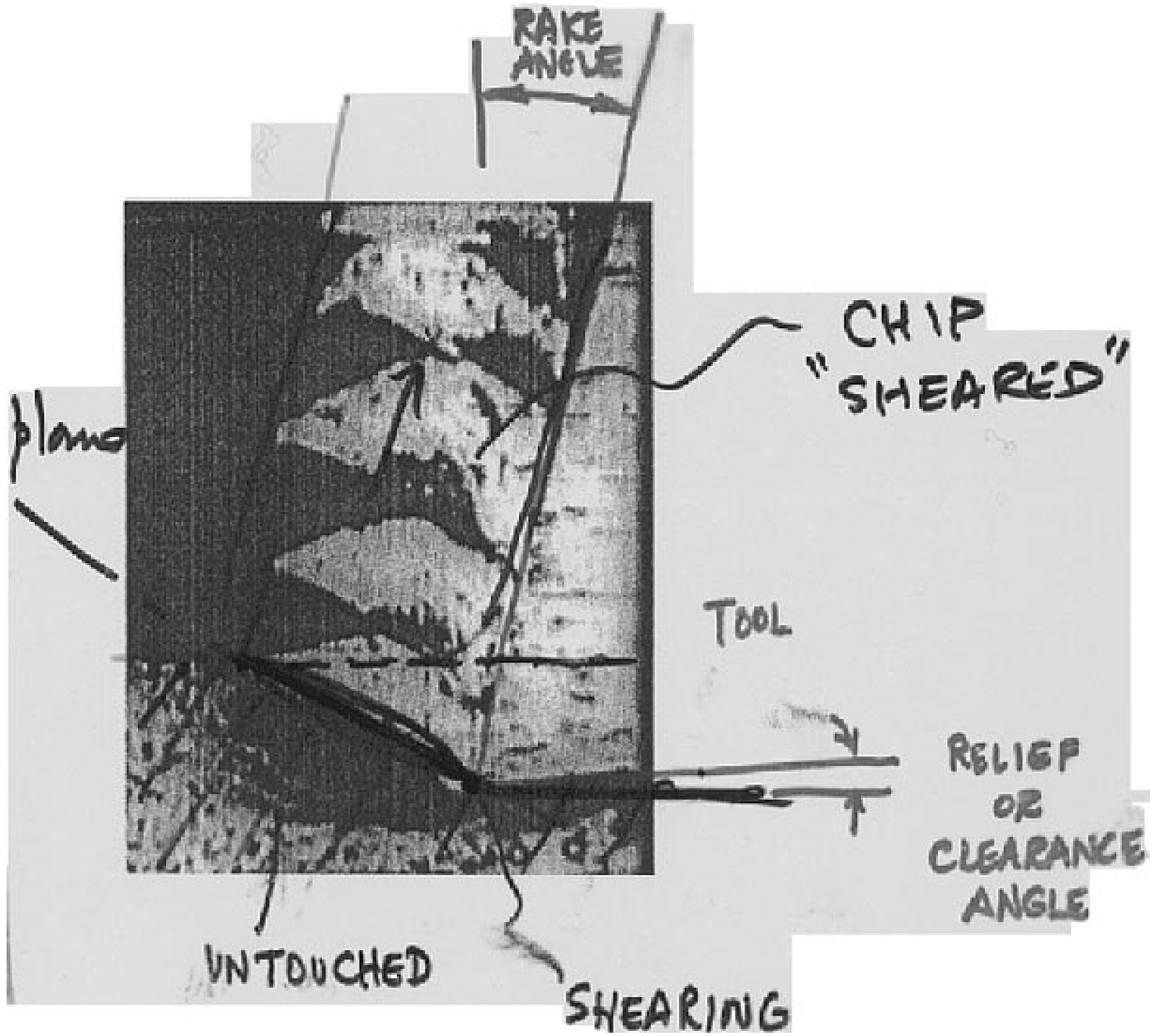
3 Dimensional



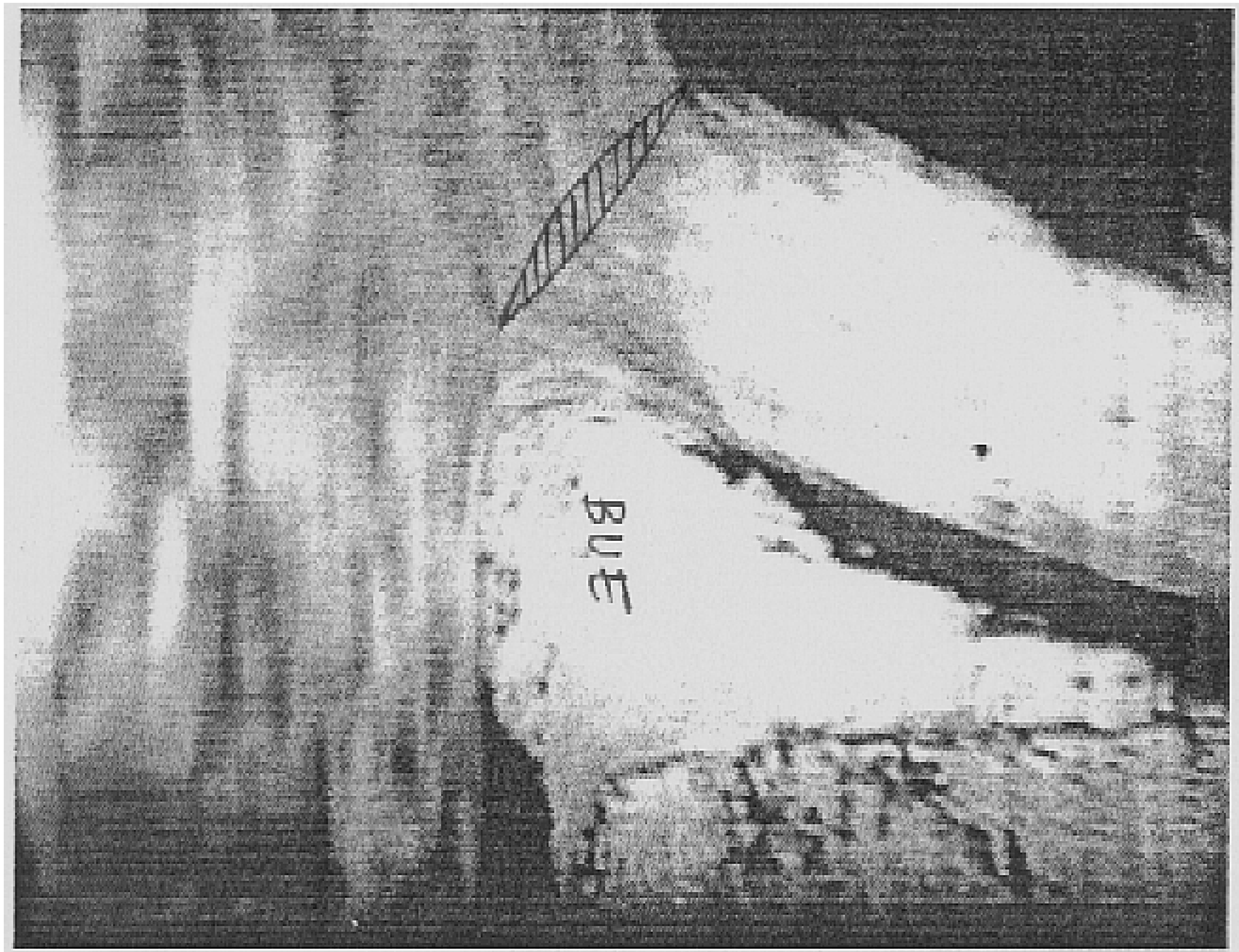
Orthogonal machining in a lathe



from video . . .


RAKE
ANGLE
plane
CHIP
"SHEARED"
TOOL
RELIEF
OR
CLEARANCE
ANGLE
UNTOUCHED
SHEARING

from video . . .



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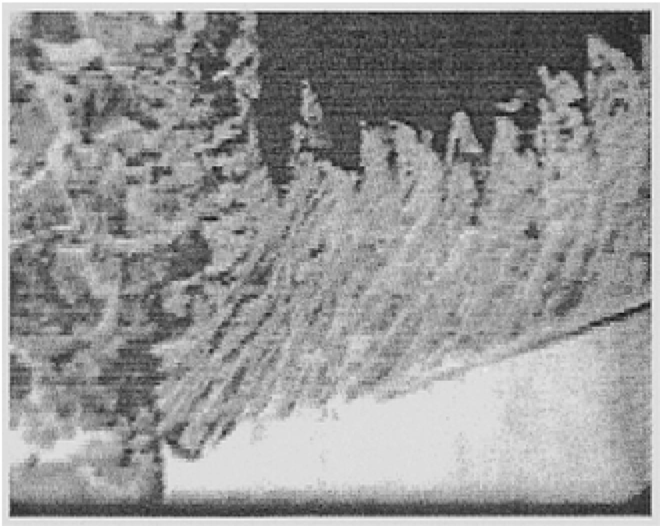
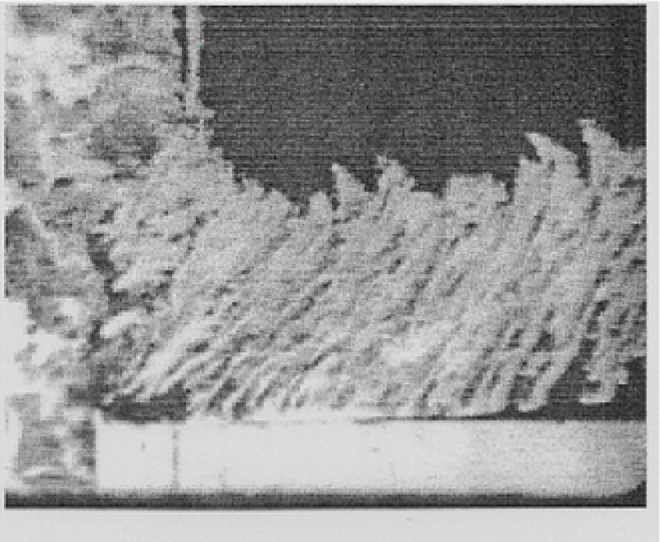
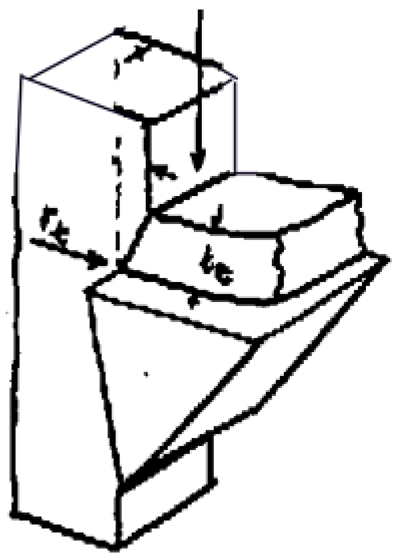
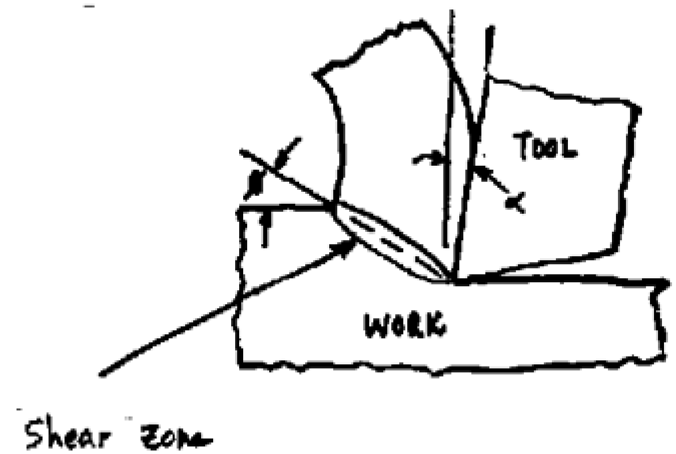




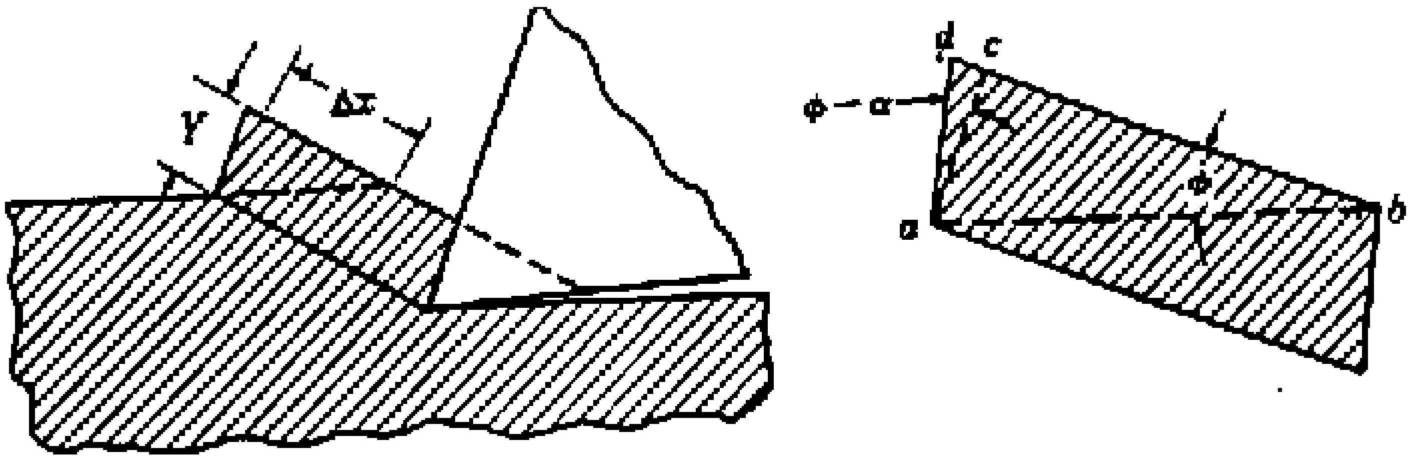


t_c



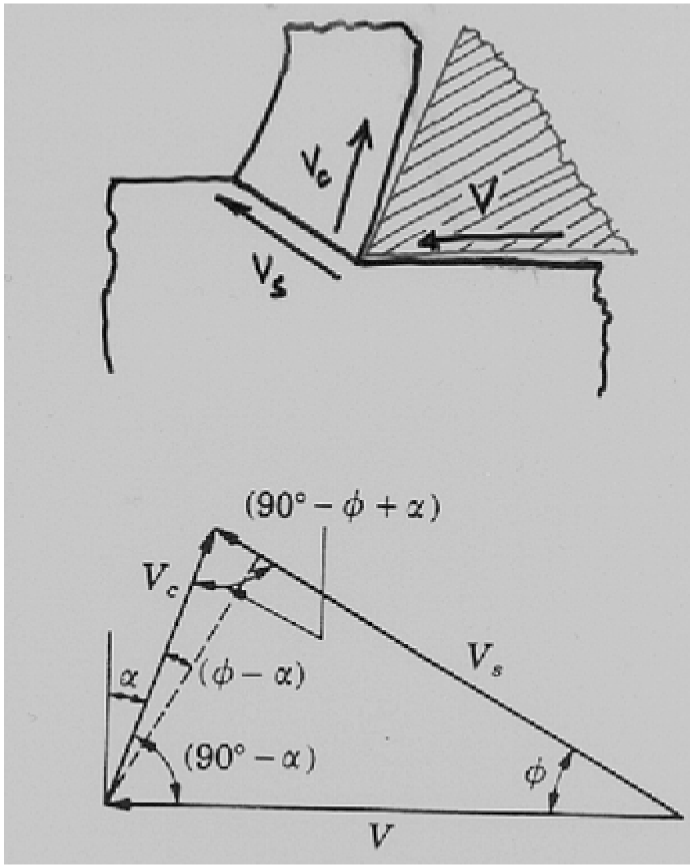
TOOL
WORK
Shear Zone

Analysis of geometrical shear strain



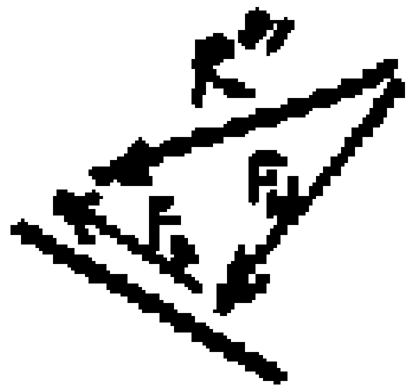
$$\gamma = \frac{\Delta x}{Y} = \frac{bc + cd}{ac} = \cot\phi + \tan(\phi - \alpha)$$

velocity diagram in the cutting zone



$$\frac{V}{\cos(\phi - \alpha)} = \frac{V_s}{\cos\alpha} = \frac{V_c}{\sin\phi}$$

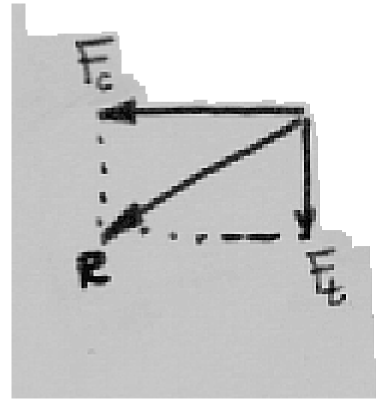
Shear forces



R = R”   :   Fs = Fc cos[phi] - Ft sin[phi]

Fn = Fc sin[phi] - Ft cos[phi]

Friction forces

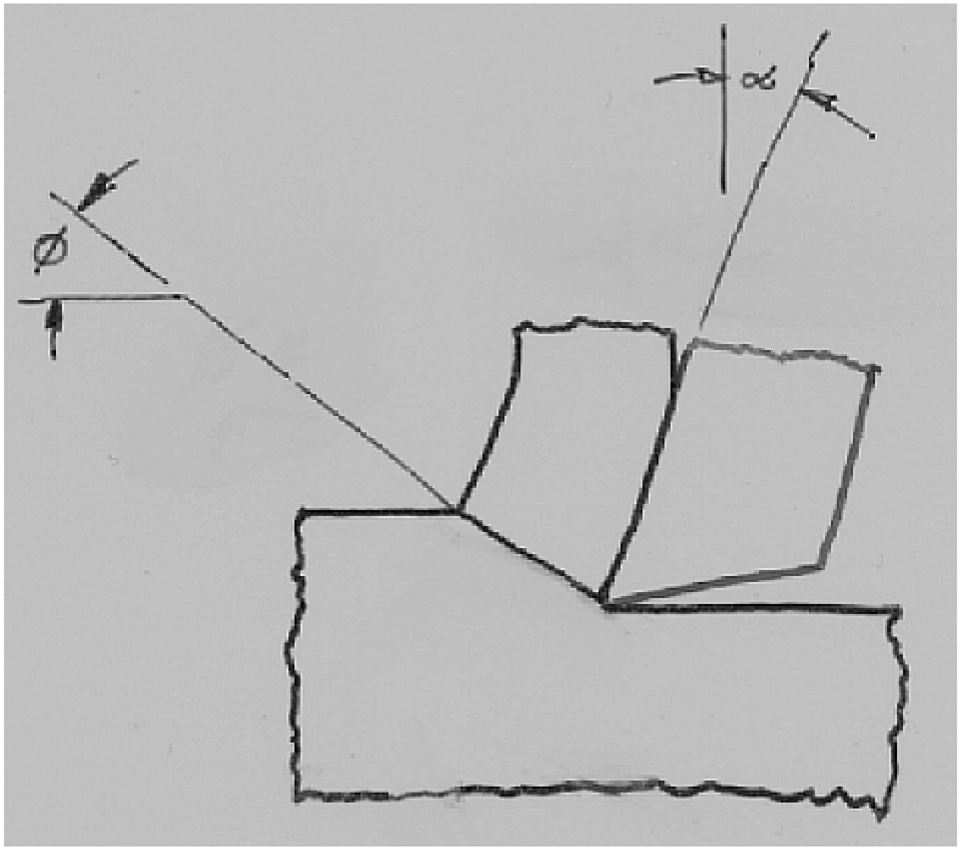


$R = R''$:

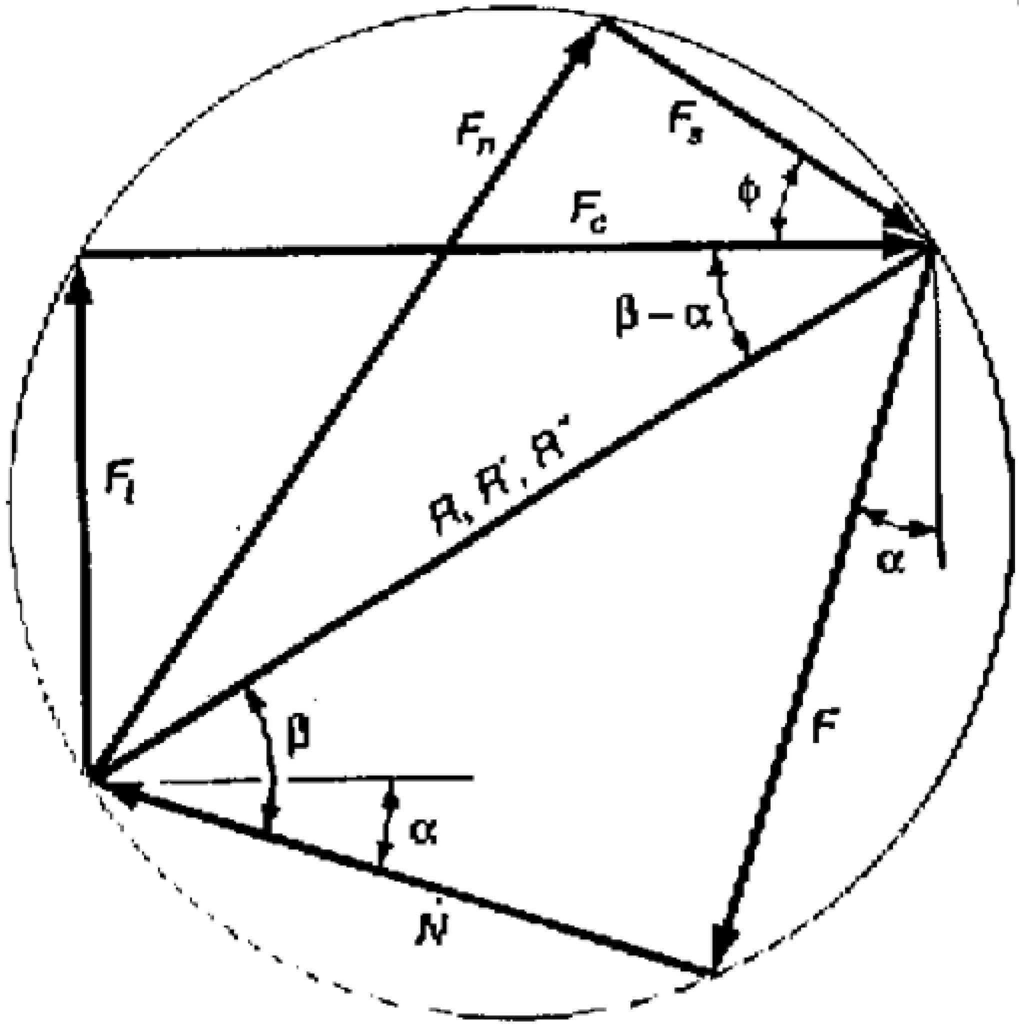
$$F = F_c \sin\alpha + F_t \cos\alpha$$
$$N = F_c \cos\alpha - F_t \sin\alpha$$

$$\mu = \frac{F}{N} = \tan\beta$$

Cutting Forces



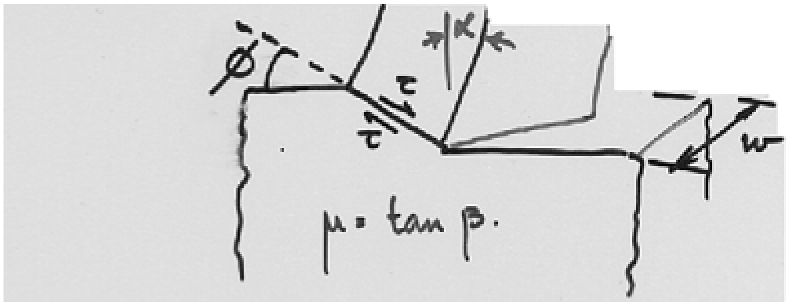
Force diagram



showing geometric relationships amongst all the forces.

where are we heading?

a relationship !



$$\tau = \frac{[F_c \cos\phi - F_t \sin\phi]}{(t_o w / \sin\phi)}. \quad \text{— I}$$

From force balance:

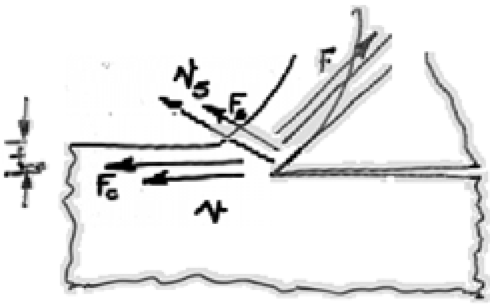
$$\frac{F_t}{F_c} = \tan(\beta - \alpha) \quad \text{— II}$$

substitute II into I, set $\frac{\partial \tau}{\partial \phi} = 0$.

$$\Rightarrow \boxed{\phi = 45 + \frac{\alpha}{2} - \frac{\beta}{2}}$$

Merchant's relationship

Energy Considerations

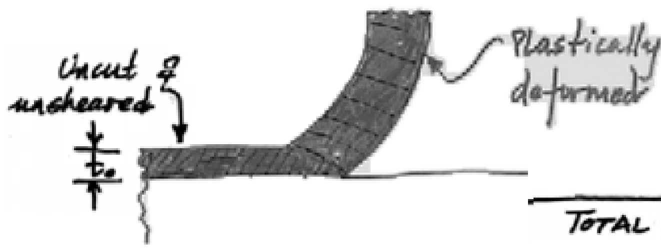


WD OF SLAB 'b'. (same as 'w')

MATERIAL REMOVAL RATE is

$$b \cdot t_o \cdot v$$

(MRR)



SPECIFIC ENERGIES

TOTAL ENERGY	SHEAR ENERGY	FRICTION ENERGY
$u = \frac{F_c v}{b t_o v} = \frac{F_c}{b t_o}$	$u_s = \frac{F_s V_s}{b t_o V} = \frac{\tau_s}{\sin\phi} \times \frac{V_s}{V} = \tau_s \cdot \gamma$	$u_f = \frac{F V_c}{b t_o V}$

$$u = u_s + u_f + \text{other negligible terms}$$

u_s: 75%, u_f: 20%, other negligible terms: 5%

TABLE 20.1

APPROXIMATE ENERGY REQUIREMENTS IN VARIOUS CUTTING OPERATIONS (at drive motor, corrected for 80% efficiency)

MATERIAL	SPECIFIC ENERGY ($W \cdot s/mm^3$)*
Aluminum alloys	0.4–1.1
Cast irons	1.6–5.5
Copper alloys	1.4–3.3
High-temperature alloys	3.3–8.5
Magnesium alloys	0.4–0.6
Nickel alloys	4.9–6.8
Refractory alloys	3.8–9.6
Stainless steels	3.0–5.2
Steels	2.7–9.3
Titanium alloys	3.0–4.1

* Divide by 2.73 to obtain $hp \cdot min/in^3$.

Works best for $t_o = 0.01''$
$\alpha = 10°$.

Thumb rule: $u \sim (1 \text{ to } 0.5)\, H_B$

The utility of energy analysis

The specific energy is an “approximate” but quick way to estimate the power requirements of machining a given material. A terrific tool for a designer!

Say you wanted to machine Titanium at

T_o = 0.01”, b = 1”, V = 20 inch/minute

1. What horsepower spindle do you need?
2. What forces do you expect on the tool?
3. How hot can the tool become?

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