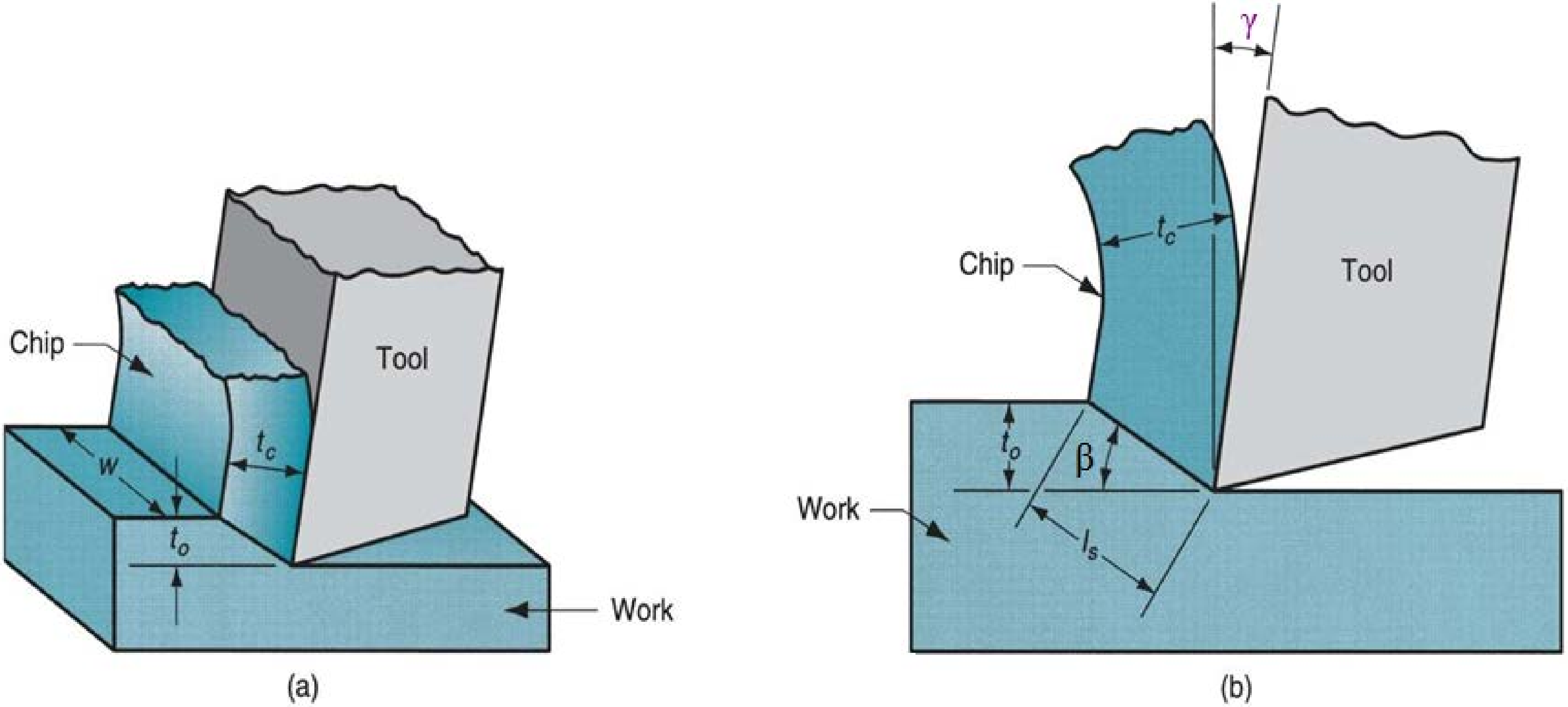
Single Point Cutting Tool



$t_0 = Uncut\ chip\ thickness$
$t_1 or\ t_c = Chip\ thickness$

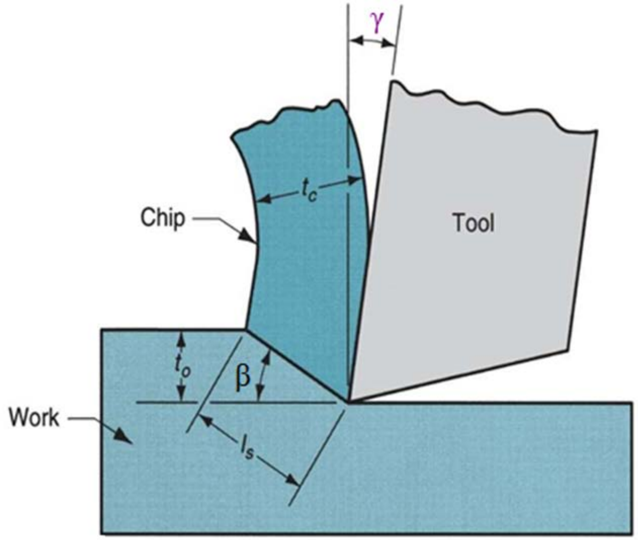
β = Shear Angle, γ = Rake Angle

Chip Thickness Ratio

- During cutting, the cutting edge of the tool is positioned a certain distance below the original work surface. This corresponds to the thickness of the chip prior to chip formation, t_o.

- As the chip is formed along the shear plane, its thickness increases to t_c.

- The ratio of t_o to t_c is called the chip thickness ratio (or simply the chip ratio) **r**

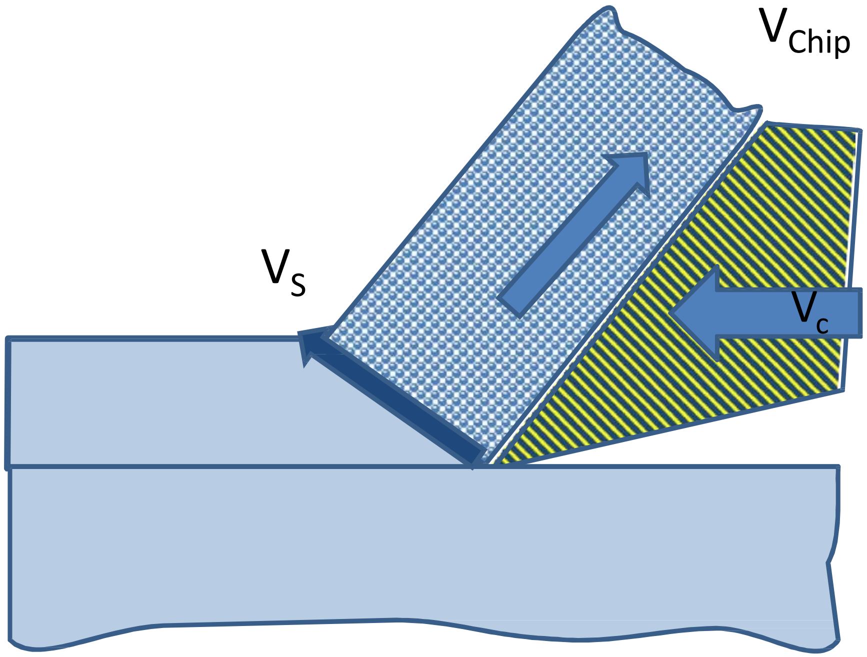


$$r = \frac{t_0}{t_c} \qquad \text{and } \xi = \frac{t_c}{t_0} = \frac{1}{r}$$

ξ = Chip Reduction Coefficient

Chip thickness after cut is always greater than before, so r is always less than 1.0

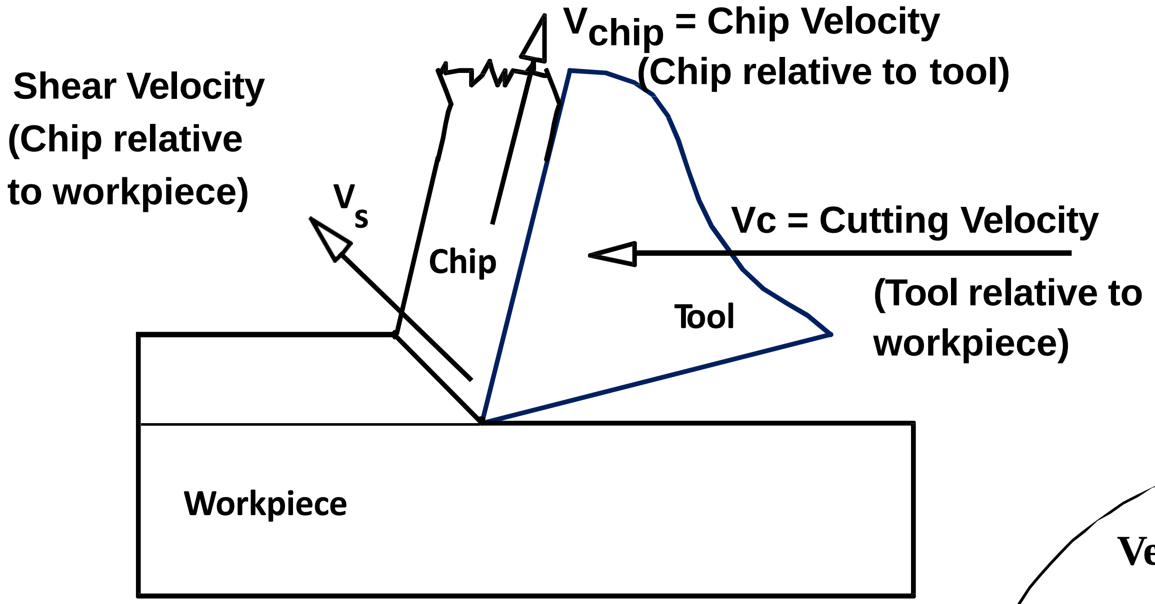
Relation between three velocities in orthogonal cutting

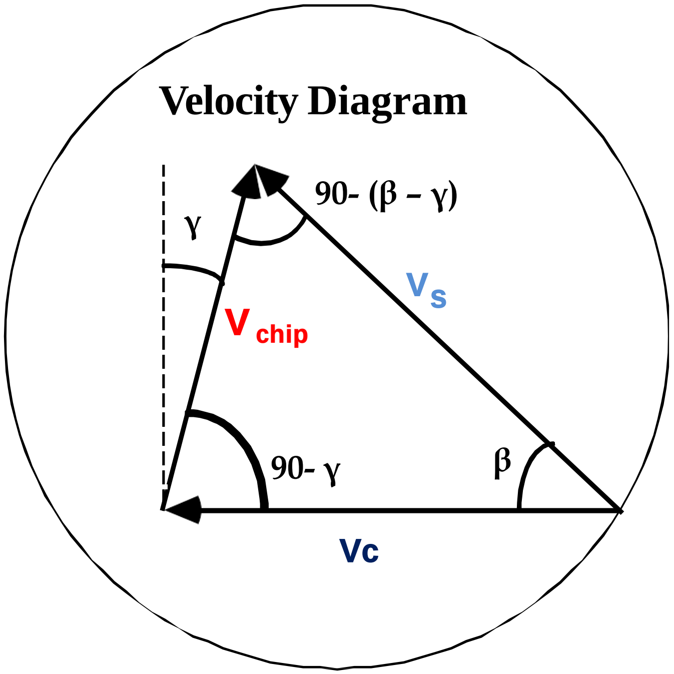


- The workpiece passes the tool with velocity **Vc**, the cutting speed.
- The chip has velocity **Vchip**.
- The shear process has velocity **Vs** and occurs at the onset of shear angle β

Velocities

(2D Orthogonal Model)





Using Sin rules

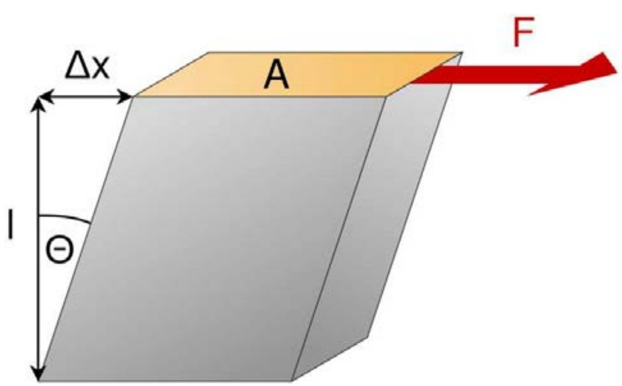
$$\frac{V_s}{\sin(90-\gamma)} = \frac{V_c}{\sin 90-(\beta-\gamma)} = \frac{V_{chip}}{\sin\beta}$$

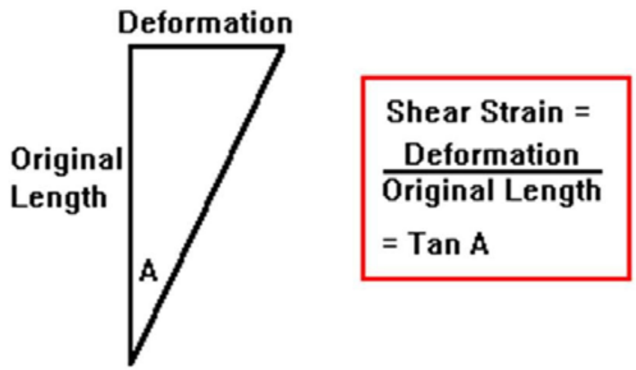
$$\frac{V_s}{\sin(90-\gamma)} = \frac{V_c}{\cos(\beta-\gamma)} = \frac{V_{chip}}{\sin\beta}$$

Shear Strain in Chip Formation

Shear Strain is

- Deformation of a solid body
- Displacement of any plane relative to a second plane divided by the perpendicular distance between the planes.
- Expressed by ϒ
- In most engineering cases it is expressed as the % of the original length.





Shear Strain

Shear strain in machining can be computed from the following equation, based on the preceding parallel plate model

$$\epsilon_s = \tan(\beta - \gamma) + \cot\beta$$

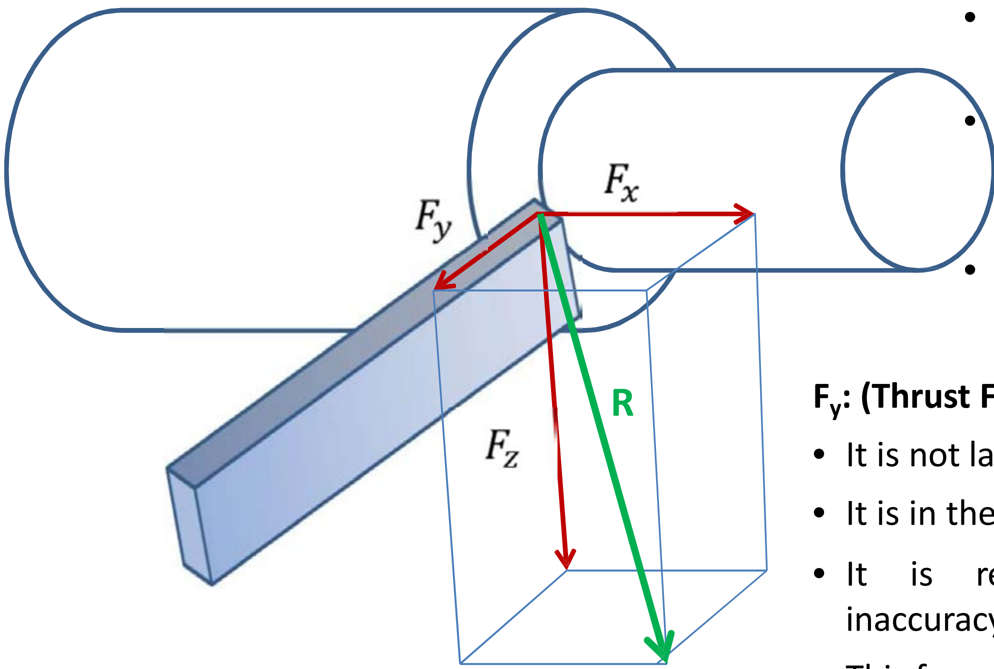
Where,

ϵ_s = shear strain,

β = shear plane angle, and

γ = rake angle of cutting tool

Force System During Turning



F_z (Cutting force)

- It is called the main or major component as it is the largest in magnitude.
- It is also called power component as it being multiplied by cutting velocity **'V'** decides cutting power (F_z.V) consumption.
- This force accounts for **99% of the power required by the process**.

F_y: (Thrust Force)

- It is not large in magnitude
- It is in the direction of cutting tool axis.
- It is responsible for causing dimensional inaccuracy and vibration.
- This force is typically about 50% of $F_{x.}$
- It contributes very little to power requirements because velocity in the radial direction is negligible.

F_x (feed force)

- It, even if larger than F_y is least harmful and hence least significant.
- This force **accounts for only a small percentage of the power required because feed rates are usually small compared to cutting speeds.**

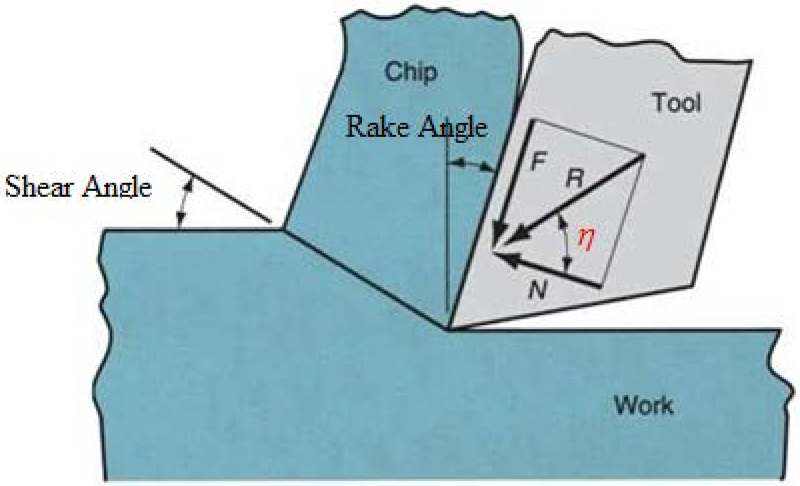
Forces in Metal Cutting

i. Forces acting on the chip by tool

The forces acting on the chip by tool during orthogonal cutting can be separated in two mutually perpendicular components:

(1) The *friction force* **F** is the force resisting the flow of the chip along the rake face of the tool.

(2) N is *normal force* perpendicular to the friction force.



Coefficient of friction (μ) between the tool and the chip:

$$\mu = F/N$$

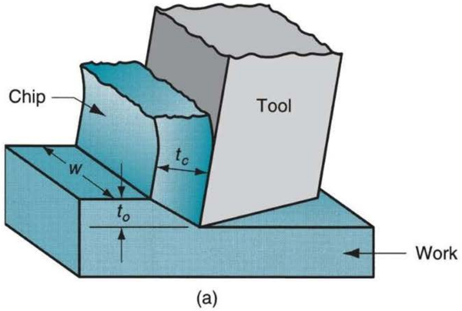
The friction force and its normal force can be added vectorially to form a resultant force **R**, which is oriented at an angle **η,** called the friction angle.

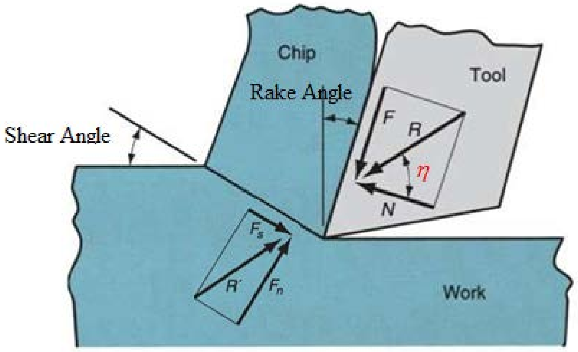
The friction angle is related to the coefficient of friction as $\mu = \tan \eta$

Forces in Metal Cutting

ii. Forces applied by the work piece on the chip

There are two force components applied by the work piece on the chip:





(3) The *shear force* **F_s** is the force that causes shear deformation to occur in the shear plane,

(4) The *normal force to shear* **F_n** is perpendicular to the shear force.

Based on the shear force, we can define the **shear stress** that acts along the shear plane between the work and the chip:

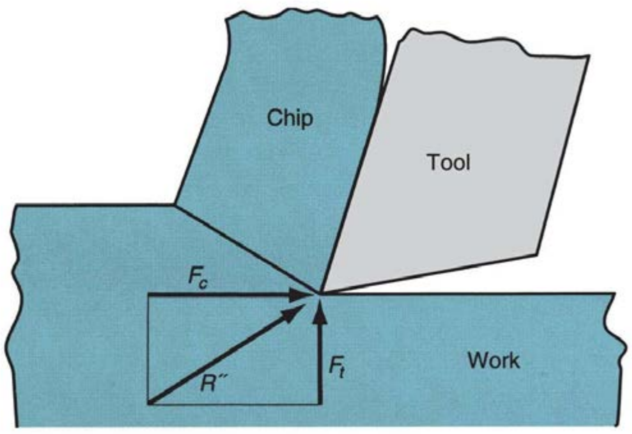
$$\tau_s = \frac{F_s}{A_s}$$

where **A_s** = *area of the shear plane*. This shear plane area can be calculated as

$$A_s = \frac{t_o w}{\sin\beta}$$

Forces acting on the tool (Cutting Force and Thrust Force)

- *F*, *N*, F_s, and F_n cannot be directly measured in a machining operation.
- Two force components that act against the tool can be directly measured. The two forces are:



(b)

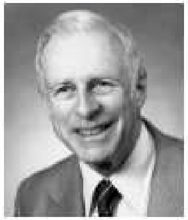
(5) Cutting force F_c. The cutting force **Fc** is in the direction of cutting, the same direction as the cutting speed *v.*

(6) Thrust force F_t. This force is perpendicular to the cutting force and is in the direction of $\mathbf{t_o}$.

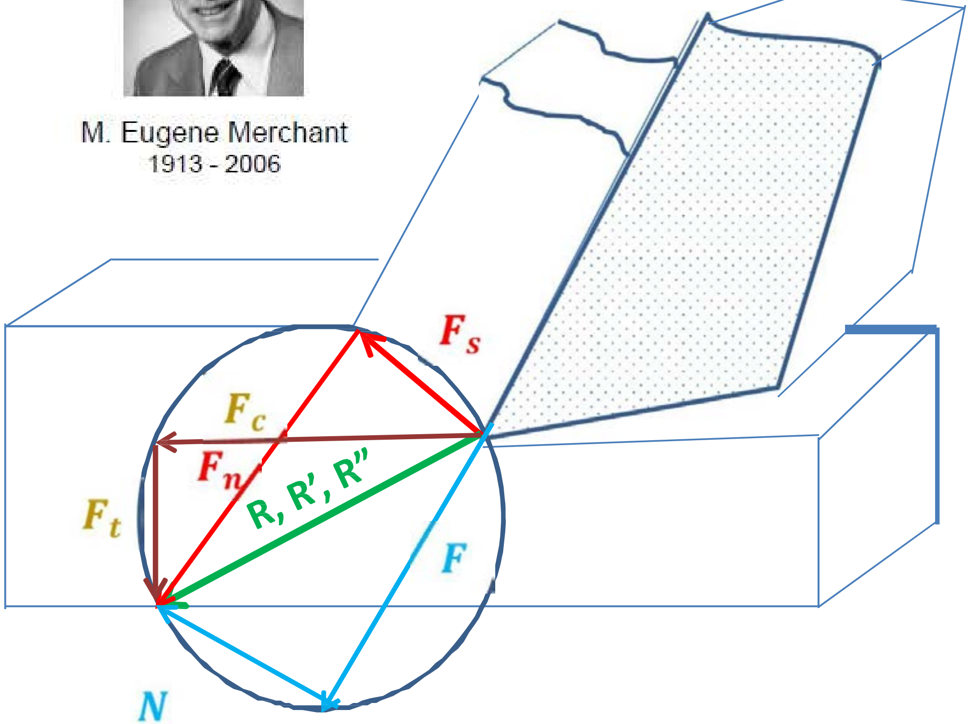
Once F_c & F_t have been experimentally found (using dynamometer) *F*, *N*, F_s, and F_n can be easily determined with the help of equations.

R” is resultant of F_c & F_t

Single shear plane model- (Ernst and merchant)



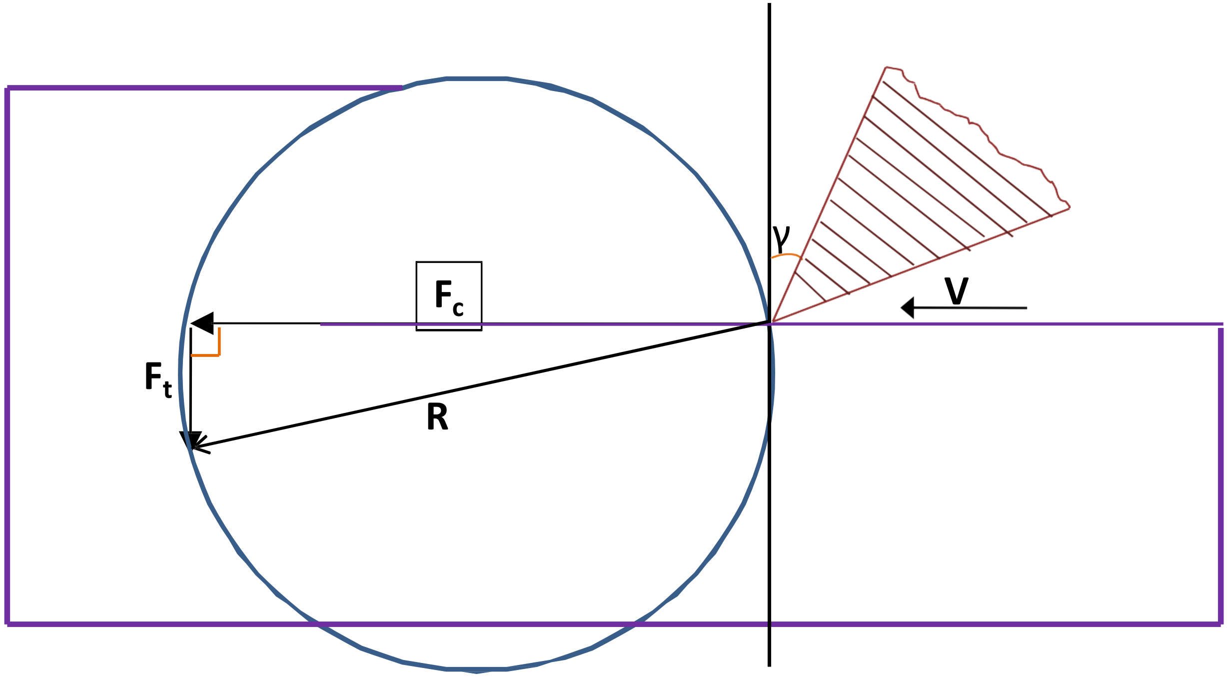
M. Eugene Merchant
1913 - 2006



- For establishing the relationship between measurable and actual forces in metal cutting Merchant's circle diagram is used.
- It is analysis of three forces system, which balance each other for cutting to occur. Each system is a triangle of forces

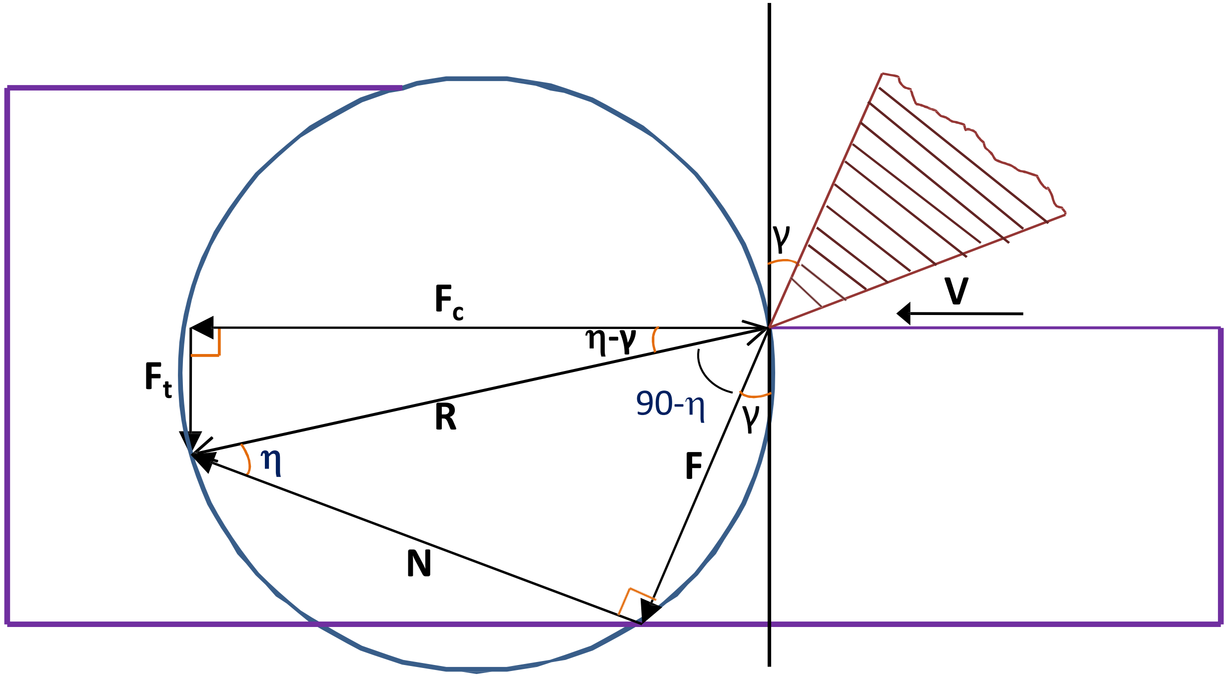
Construction of merchant's circle

- Set up x-y axis labeled with forces, and the origin in the centre of the page.
- The cutting force (F_c) is drawn horizontally, and the tangential force (F_t) is drawn vertically.
- Draw in the resultant (R) of F_c and F_t.
- Locate the centre of R, and draw a circle that encloses vector R. If done correctly, the heads and tails of all 3 vectors will lie on this circle.
- Draw in the cutting tool in the upper right hand quadrant, taking care to draw the correct rake angle (γ) from the vertical axis.



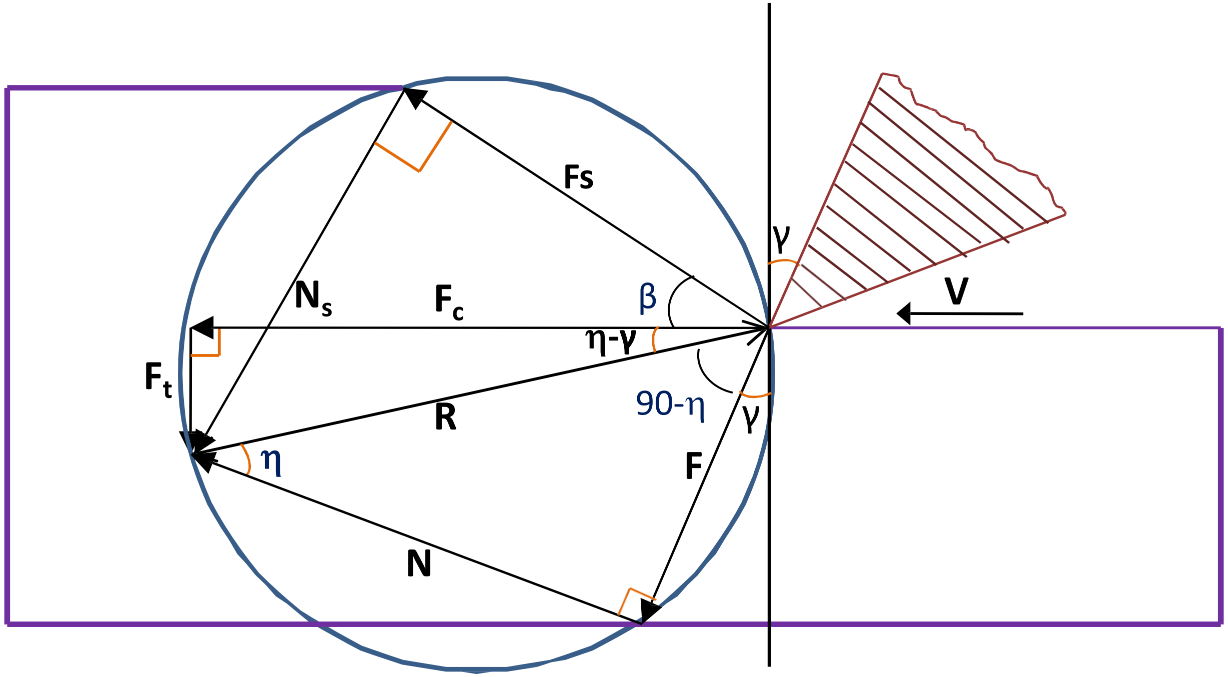
Construction of merchant's circle

- Extend the line that is the cutting face of the tool (at the same rake angle) through the circle. This now gives the friction vector (F).
- A line can now be drawn from the head of the friction vector, to the head of the resultant vector (R). This gives the normal vector (N).
- Also add a friction angle (η) **between vectors R and** N. Therefore, mathematically, $R = F_c + F_t = F + N$.



Contraction of Merchant Circle

β = Shear Angle
γ = Rake Angle
η = Friction Angle
F_c = Cutting Force, FT = Thrust Force or Feed Force
Fs = Shear Force, Ns = Normal Shear Force
F = Friction Force (Resistance) , N = Normal friction force



Formula used in Merchant circle

- Equations to relate the forces

$$F = F_c \sin\gamma + F_T \cos\gamma \qquad \tan\beta = \frac{r\cos\gamma}{1 - r\sin\gamma}$$

$$N = F_c \cos\gamma - F_T \sin\gamma$$

$$F_s = F_c \cos\beta - F_T \sin\beta \qquad r = \frac{t_0}{t_1}$$

$$N_s = F_c \sin\beta + F_T \cos\beta \qquad \epsilon_s = \tan(\beta - \gamma) + \cot\beta$$

$$\frac{F_T}{F_c} = \tan(\eta - \gamma) \qquad \frac{F}{N} = \tan\eta = \mu$$

$$\zeta_s = \frac{F_s \sin\beta}{t_0 w} \qquad Fs = \zeta_s\, A_s \qquad \zeta_s = \text{Shear Force}$$

A_s = Shear Area

The Merchant Equation

- Of all the possible angles at which shear deformation can occur, the work material will select a shear plane angle β that minimizes energy

$$\boxed{2\beta + \eta - \gamma = 90°}$$

$\beta =$ Shear Angle
$\eta =$ Friction Angle
$\gamma =$ Rake Angle

- **To increase shear plane angle**
  - ✓ Increase the rake angle
  - ✓ Reduce the friction angle (or coefficient of friction)
  - ✓ Higher shear plane angle means smaller shear plane which means lower shear force
  - ✓ Result: lower cutting forces, power, temperature, all of which mean easier machining

Lee and Shaper Theory

$$\beta + \eta - \gamma = 45°$$

Stabber Theory

$$\beta + \eta - \frac{\gamma}{2} = 45°$$

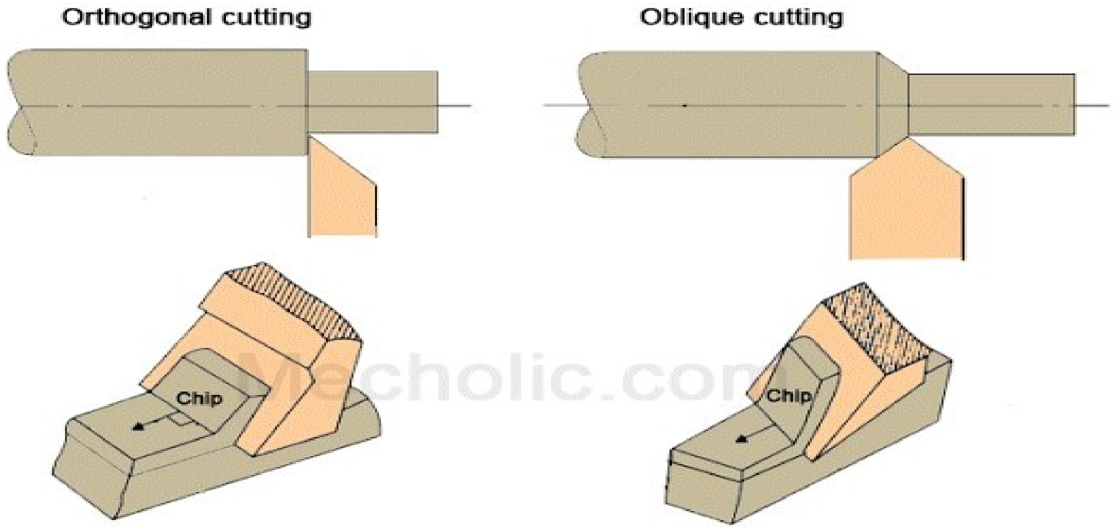
Orthogonal Cutting

Orthogonal Cutting

- In orthogonal cutting, the tool approaches the work piece with its **cutting edge at right angles to the direction of cutting** and parallel to the uncut surface.
- Thus tool approach angle and cutting edge inclination are Zero. This type of cutting is also known as **Two-dimensional Cutting.**

Oblique Cutting

- In oblique cutting , the cutting edge of the tool is inclined at an acute angle with the direction of tool feed or work feed, the chip begin disposed of at a certain angle.
- This type of cutting is also called Three-dimensional cutting.



Comparison between the orthogonal and oblique cutting

Orthogonal cutting	**Oblique Cutting**
The cutting edge of the tool is perpendicular to the direction of feed motion.	The cutting edge of the tool is inclined to the direction of feed motion.
Chip flow is expected to in a direction perpendicular to the cutting edge.	The chip flow angle is more than zero.
There are only two components of force; these components are mutually perpendicular.	There are three mutually perpendicular forces acting while cutting process.
The cutting edge is larger than cutting width.	The cutting edge may or may not be larger than cutting width.
Chips are in the form of a spiral coil.	Chip flow is in a sideways direction.
High heat concentration at cutting region.	Less concentration of heat at cutting region compared to orthogonal cutting.
For a given feed and depth of cutting, the force acts on a small area as compared with oblique cutting, so tool life is less.	Force is acting on a large area, results in more tool life.
Surface finish is poor.	Good surface finish obtained.
Used in grooving, parting, slotting, pipe cutting.	Used almost all industrial cutting, used in drilling, grinding, milling.