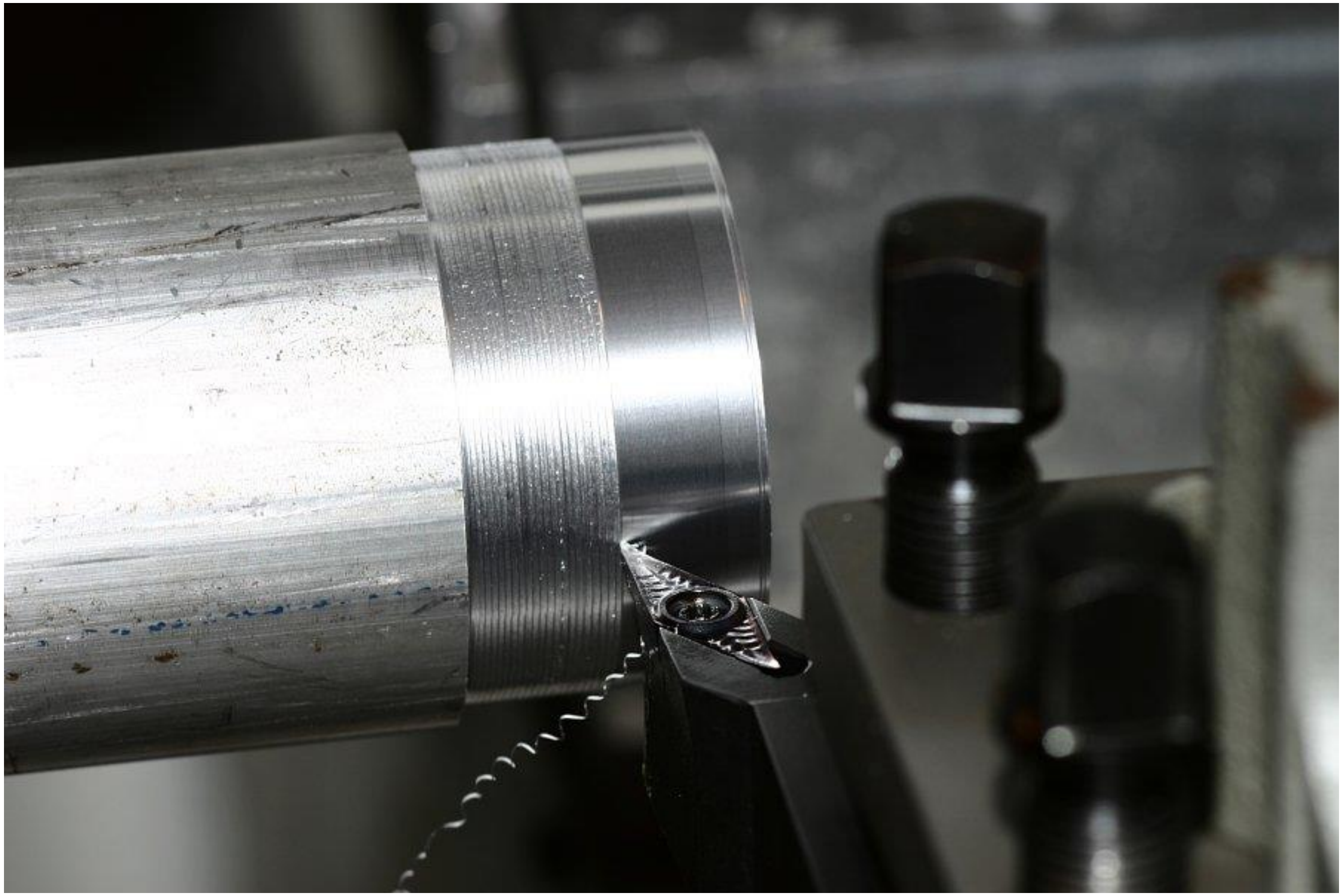
ME361 – Manufacturing Science Technology

Turning

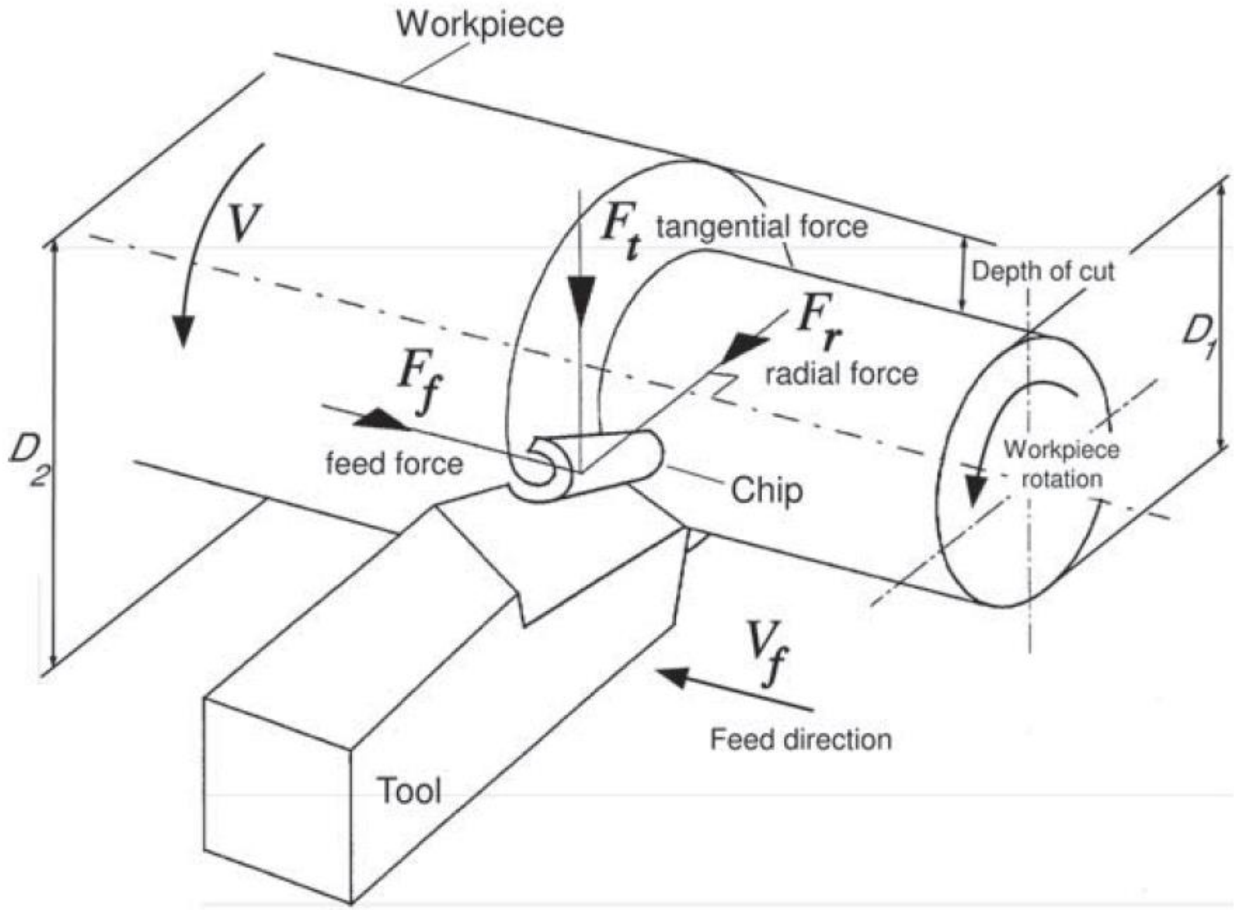
Dr. Mohit Law

mlaw@iitk.ac.in

Turning



Geometry of turning process



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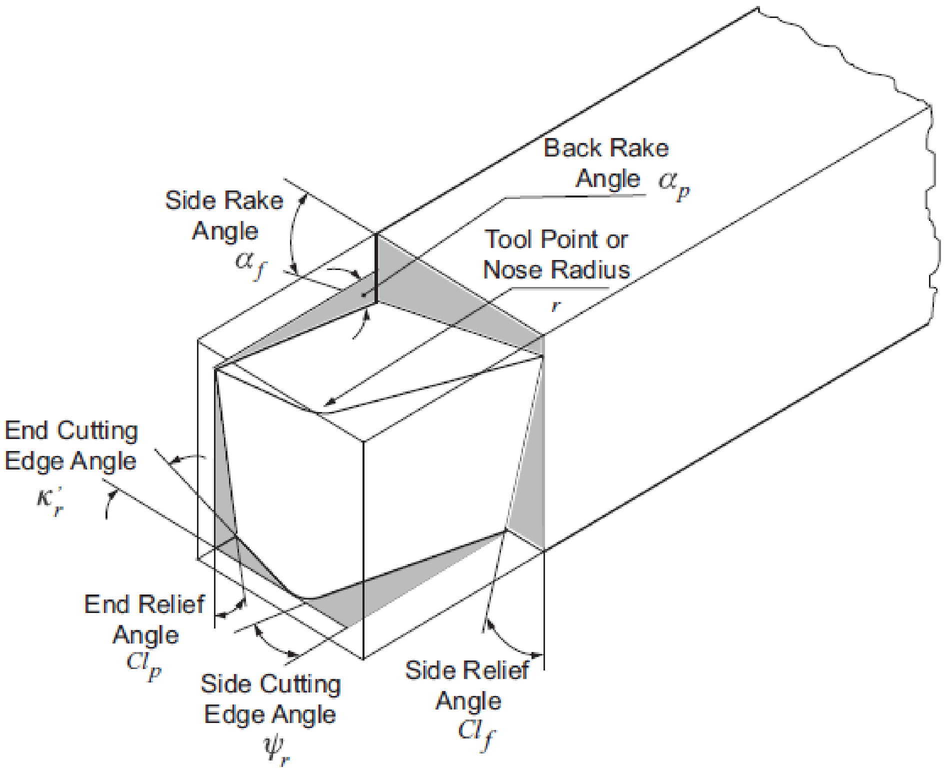
Geometry of turning tool



- Cutting occurs along major as well as minor edge
- Tool has a finite nose radius
- Angles of interest are:
    - Equivalent oblique angle, i $(i = f(\alpha_p, \alpha_f, \psi_r))$
    - Side cutting edge angle, ψ_r
    - Orthogonal rake angle, α_o $(\alpha_o = f(\alpha_f, \psi_r))$
    - Normal rake angle, α_n $(\alpha_n = f(\alpha_o, i))$

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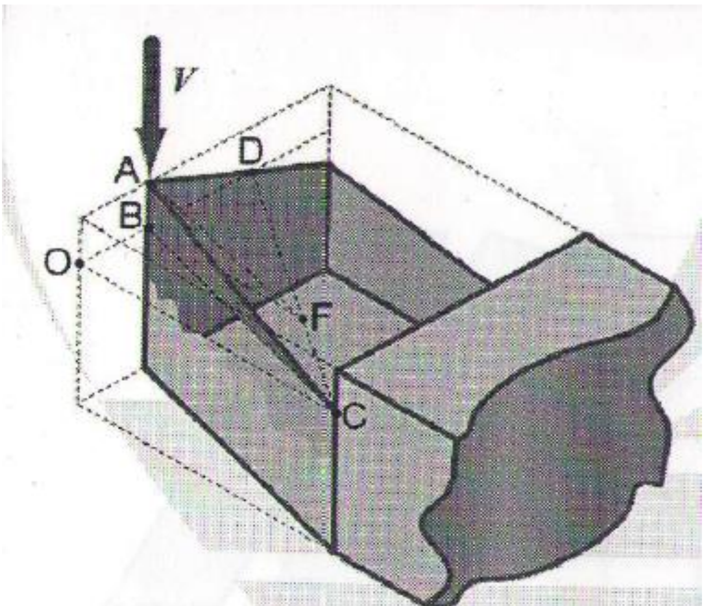
Equivalent oblique angle, i



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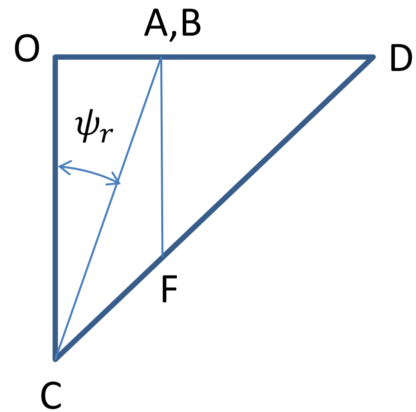
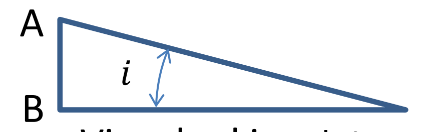
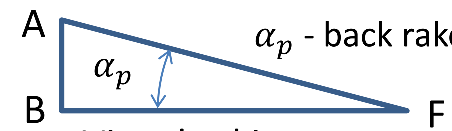


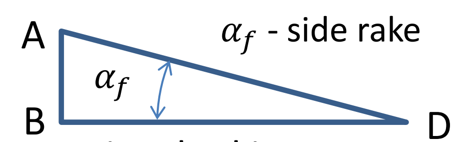
View looking in the direction of V



View looking ⊥ to plane ABC



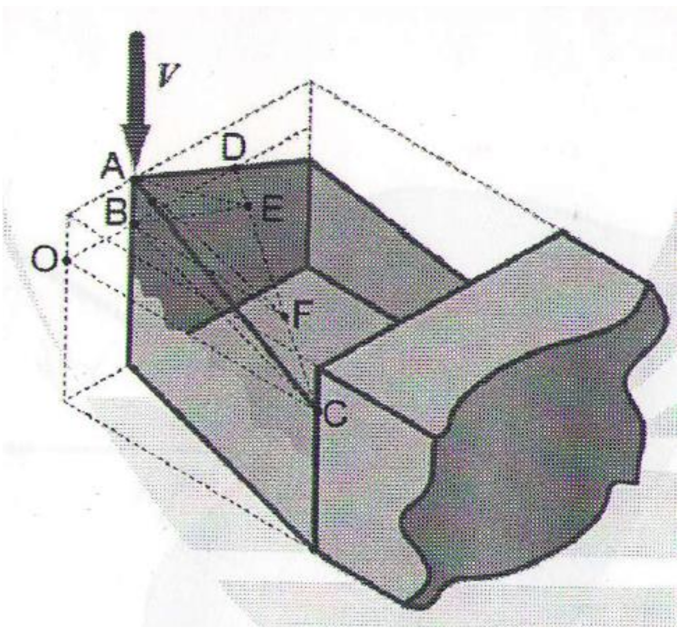
View looking ⊥ to plane ABF



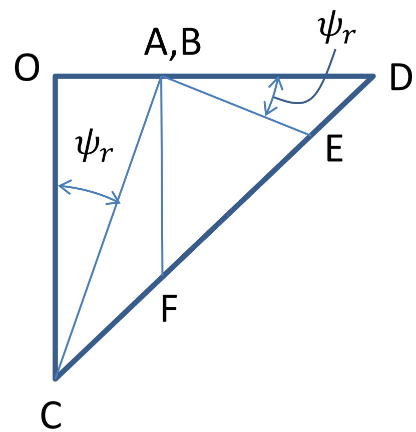
View looking ⊥ to plane ABD

$$\boxed{\tan i = \tan \alpha_p \cos \psi_r - \tan \alpha_f \sin \psi_r}$$

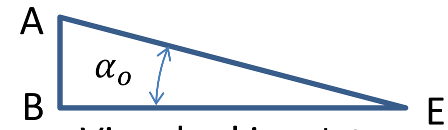
Orthogonal rake angle, α_o



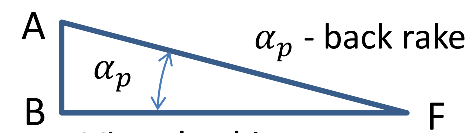
Endres, Adv. Mcing. Processes



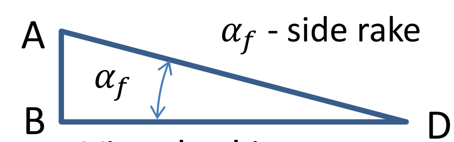
View looking in the direction of V



View looking ⊥ to plane ABE



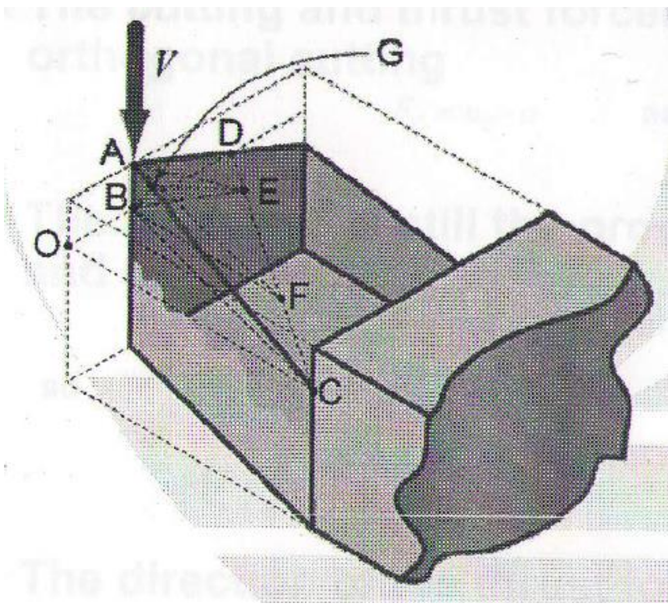
View looking ⊥ to plane ABF



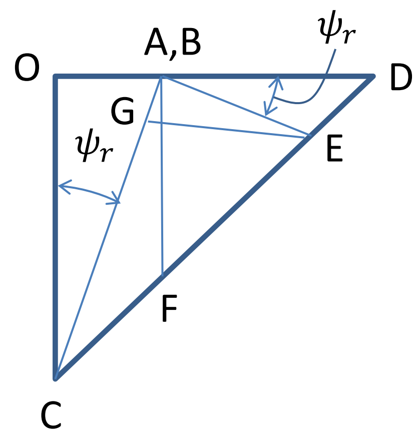
View looking ⊥ to plane ABD

$$\boxed{\tan \alpha_o = \tan \alpha_f \cos \psi_r + \tan \alpha_p \sin \psi_r}$$

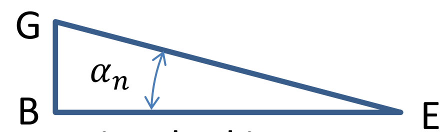
Normal rake angle, α_n



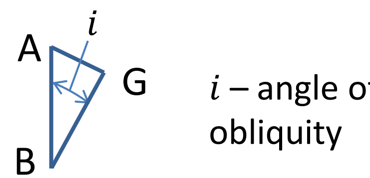
Endres, Adv. Mcing. Processes



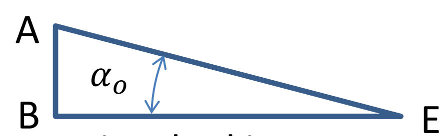
View looking in the direction of V



View looking ⊥ to plane BEG



View looking ⊥ to plane ABG

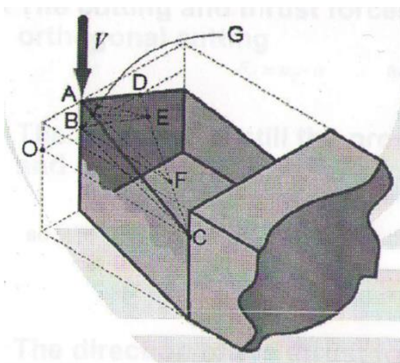


View looking ⊥ to plane ABE

$$\tan \alpha_n = \left(\tan \alpha_f \cos \psi_r + \tan \alpha_p \sin \psi_r\right) \cos i = \tan \alpha_o \cos i$$

Force prediction in turning

Transform orthogonal cutting parameters to an oblique turning geometry using



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Equivalent oblique angle $\boxed{\tan i = \tan \alpha_p \cos \psi_r - \tan \alpha_f \sin \psi_r}$

Orthogonal rake angle $\boxed{\tan \alpha_o = \tan \alpha_f \cos \psi_r + \tan \alpha_p \sin \psi_r}$

Normal rake angle $\boxed{\tan \alpha_n = \tan \alpha_o \cos i}$

Evaluate cutting force coefficients

$$K_{fc} = \left[\frac{\tau_s}{\sin \phi_n \cos i} \frac{\sin(\beta_n - \alpha_n)}{\sqrt{cos^2(\phi_n + \beta_n - \alpha_n) + tan^2\eta sin^2\beta_n}}\right]$$

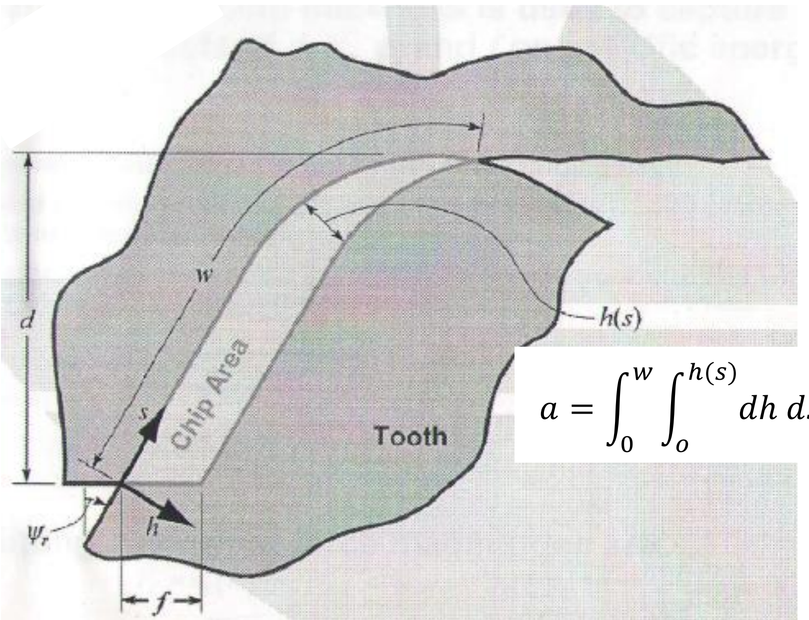
$$K_{tc} = \left[\frac{\tau_s}{\sin \phi_n} \frac{\cos(\beta_n - \alpha_n) + \tan i \tan \eta \sin \beta_n}{\sqrt{cos^2(\phi_n + \beta_n - \alpha_n) + tan^2\eta sin^2\beta_n}}\right]$$

$$K_{rc} = \left[\frac{\tau_s}{\sin \phi_n} \frac{\cos(\beta_n - \alpha_n) \cos(\beta_n - \alpha_n) \tan i - \tan \eta \sin \beta_n}{\sqrt{cos^2(\phi_n + \beta_n - \alpha_n) + tan^2\eta sin^2\beta_n}}\right]$$

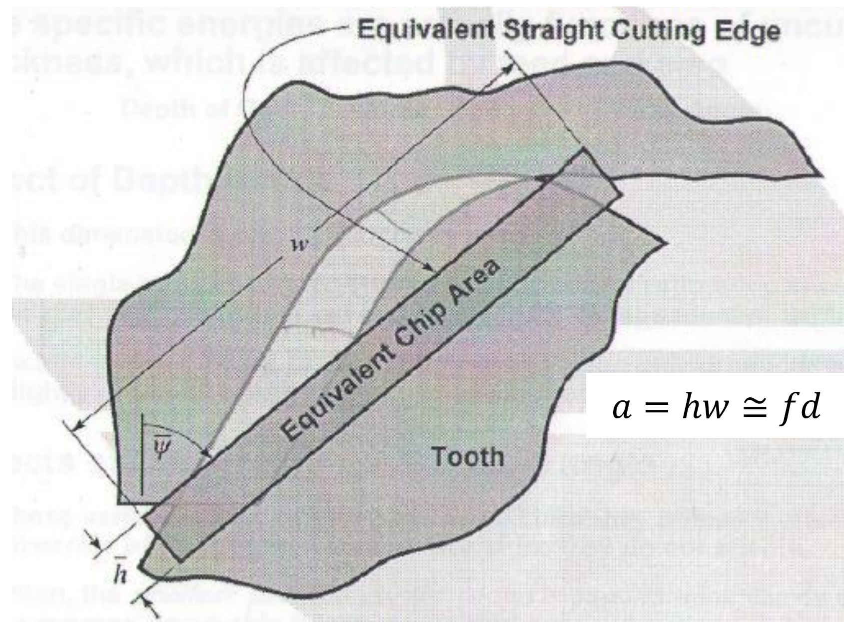
Predict cutting forces

$$\begin{aligned} F_t &= K_{tc}bh + K_{te}b; \\ F_f &= K_{fc}bh + K_{fe}b; \\ F_r &= K_{rc}bh + K_{re}b; \end{aligned}$$

Mechanics of turning – effects of nose radius



$$a = \int_0^w \int_o^{h(s)} dh\, ds$$



$$a = hw \cong fd$$

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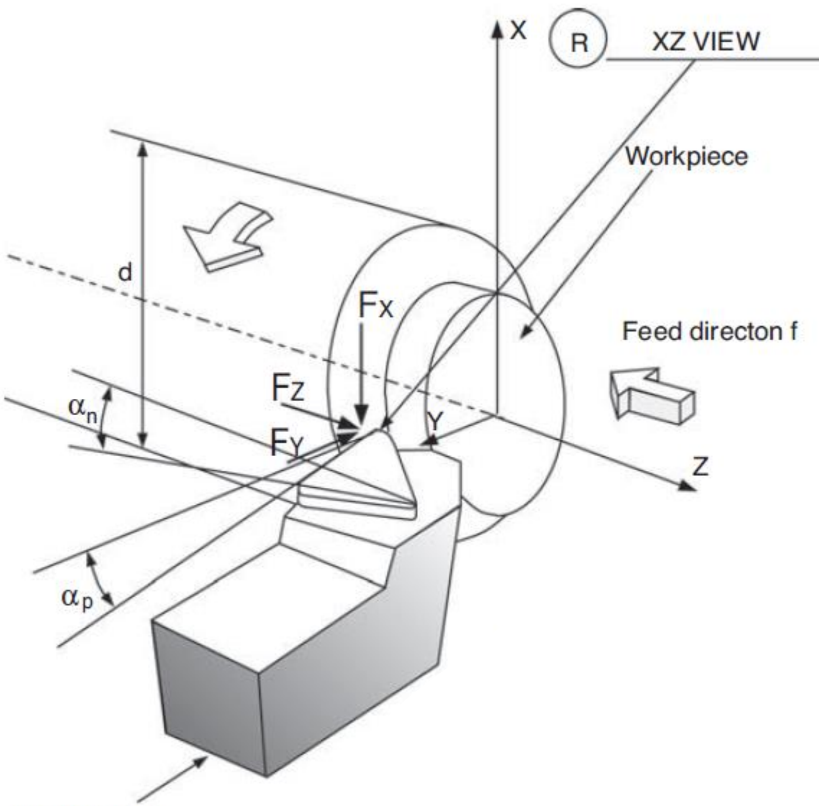
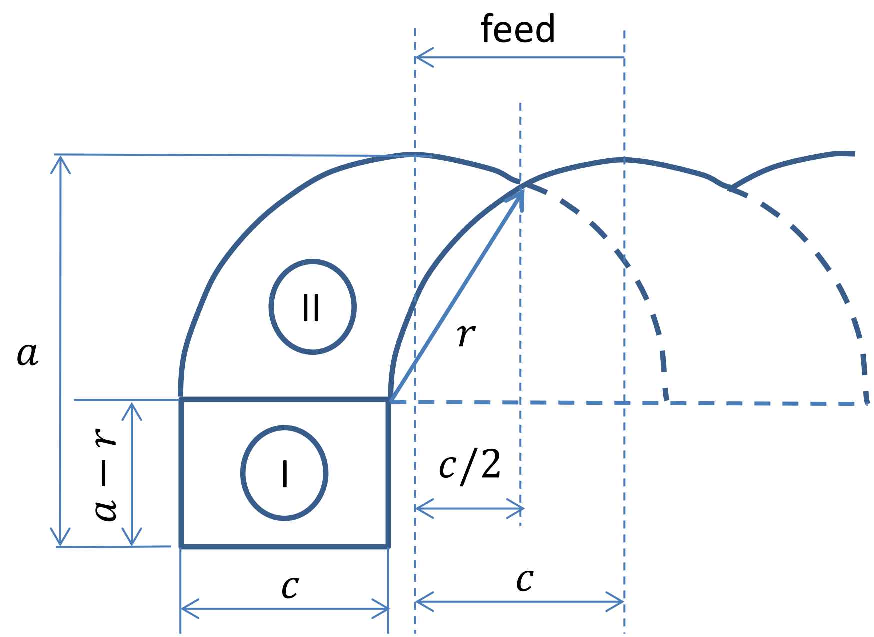
Mechanics of turning





Region I: chip thickness is constant
Region II: chip thickness reduces continuously

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Mechanics of turning – Region I

- chip thickness is constant and equal to feed rate, i.e. $h = c$
- radial depth is less than corner radius, i.e. $0 < y < r$
- Side cutting angle is zero, i.e. $\psi_r = 0$

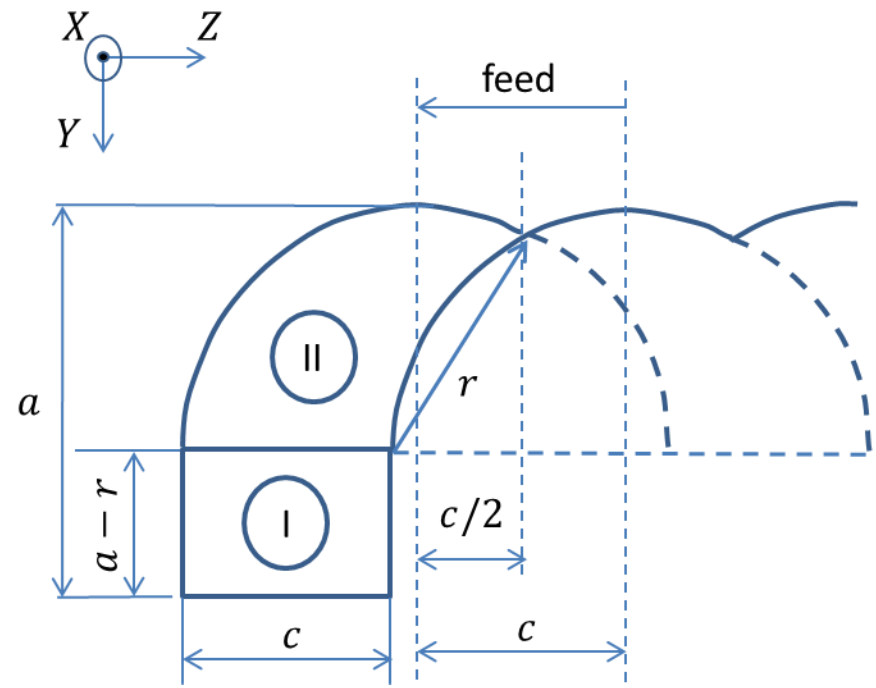
↓

Cutting forces in x, y, z coordinates are parallel to the oblique cutting forces

$$F_{x_I} = F_{t_I} = K_{tc}c(a-r) + K_{te}(a-r);$$
$$F_{y_I} = F_{r_I} = K_{rc}c(a-r) + K_{re}(a-r);$$
$$F_{z_I} = F_{f_I} = K_{fc}c(a-r) + K_{fe}(a-r);$$

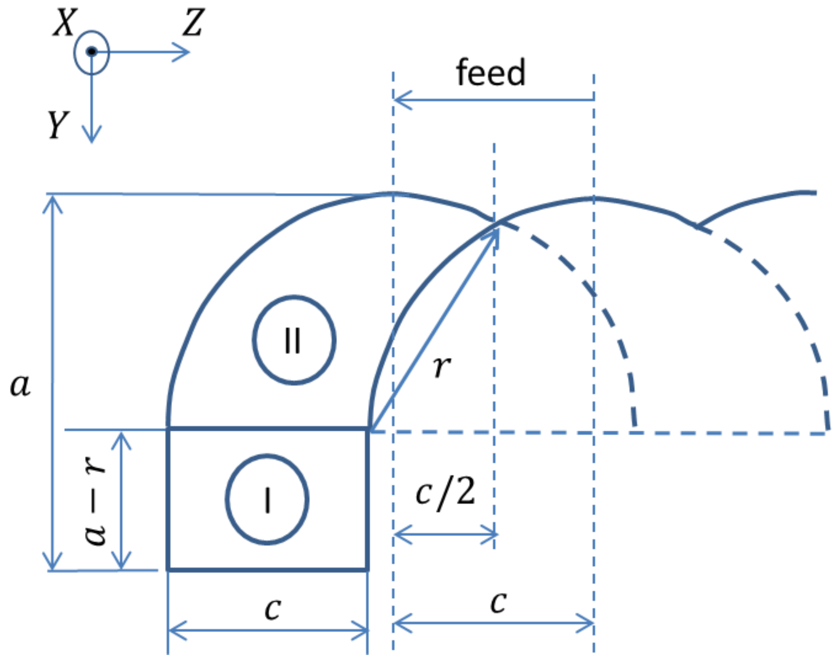
↓

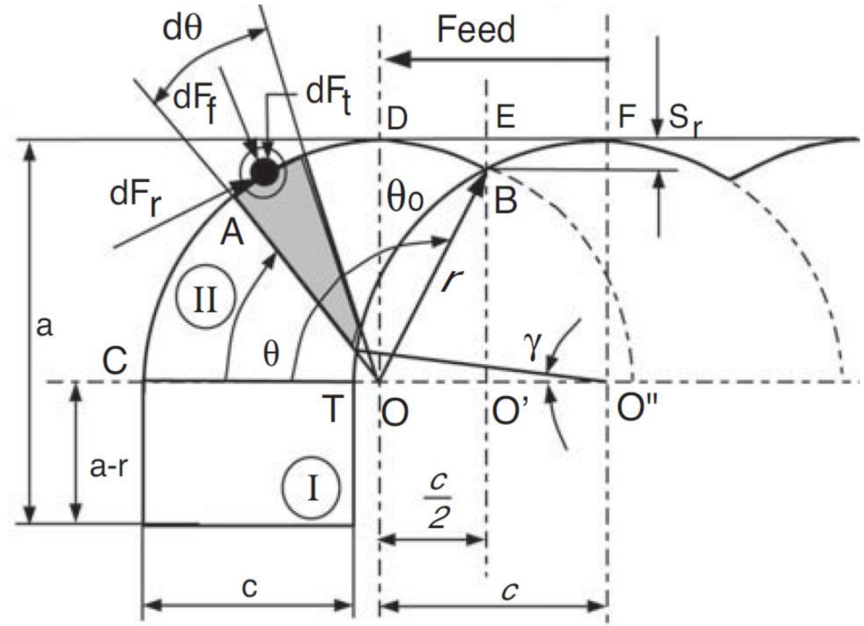
Cutting constants (K_{tc}, K_{rc}, K_{fc}) are evaluated using orthogonal cutting parameters $(\phi_n, \tau_s, \beta_a)$. →



However, because tool has of side rake and back rake angles (α_p, α_f), oblique (i) and normal rake angles (α_n) are evaluated as discussed

Mechanics of turning – Region II





- Divide chip into differential elements with an angular increment of $d\theta$
- Center of chip's outer surface curvature is O, and center of its inner curvature is O''
- Total angular contact is $\angle COB = \theta_0$

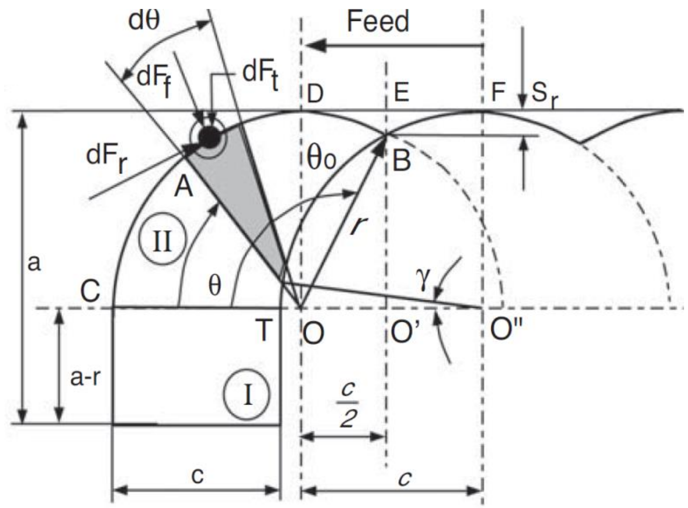
Mechanics of turning – Region II

Differential chip area $\boxed{dA \approx \overline{AT}\,dS}$

$$\boxed{dS = r d\theta}$$

$$\boxed{\begin{array}{c}\overline{AT} = \overline{AO} - \overline{TO}, \\ \overline{AO} = r, \overline{OO''} = c,\end{array}}$$

$$\boxed{\overline{TO} = \sqrt{c^2 + r^2 - 2cr\cos\gamma}}$$



Sine rule

$$\boxed{\frac{\overline{OO''}}{\sin[\pi - (\pi - \theta + \gamma)]} = \frac{\overline{TO''}}{\sin(\pi - \theta)}}$$

$$\boxed{\gamma = \theta - \sin^{-1}\left[\frac{c}{r}\sin(\pi - \theta)\right]}$$

Instantaneous chip thickness at θ

$$\boxed{\overline{AT} = h(\theta) = r - \sqrt{c^2 + r^2 - 2cr\cos\gamma}}$$

Corresponding differential chip area

$$\boxed{dA_i = h(\theta) r d\theta}$$

Mechanics of turning – Region II

Tangential ($dF_{t_{II}}$), radial ($dF_{r_{II}}$), and feed forces ($dF_{f_{II}}$) acting on a differential element are:

$$dF_{t_{II}} = K_{tc}(\theta)dA + K_{te}dS = [K_{tc}(\theta)h(\theta) + K_{te}]rd\theta$$
$$dF_{r_{II}} = K_{rc}(\theta)dA + K_{re}dS = [K_{rc}(\theta)h(\theta) + K_{re}]rd\theta$$
$$dF_{f_{II}} = K_{fc}(\theta)dA + K_{fe}dS = [K_{fc}(\theta)h(\theta) + K_{fe}]rd\theta$$

Since oblique geometry varies as a function of θ, evaluate cutting coefficients for each differential element separately. Take $\psi_r = \theta$

Equivalent oblique angle

$$\tan i = \tan\alpha_p \cos\psi_r - \tan\alpha_f \sin\psi_r$$

Orthogonal rake angle

$$\tan\alpha_o = \tan\alpha_f \cos\psi_r + \tan\alpha_p \sin\psi_r$$

Normal rake angle

$$\tan\alpha_n = \tan\alpha_o \cos i$$

$$K_{fc} = \left[\frac{\tau_s}{\sin\phi_n \cos i}\frac{\sin(\beta_n - \alpha_n)}{\sqrt{cos^2(\phi_n + \beta_n - \alpha_n) + tan^2\eta sin^2\beta_n}}\right]$$

$$K_{tc} = \left[\frac{\tau_s}{\sin\phi_n}\frac{\cos(\beta_n - \alpha_n) + \tan i \tan\eta \sin\beta_n}{\sqrt{cos^2(\phi_n + \beta_n - \alpha_n) + tan^2\eta sin^2\beta_n}}\right]$$

$$K_{rc} = \left[\frac{\tau_s}{\sin\phi_n}\frac{\cos(\beta_n - \alpha_n)\cos(\beta_n - \alpha_n)\tan i - \tan\eta \sin\beta_n}{\sqrt{cos^2(\phi_n + \beta_n - \alpha_n) + tan^2\eta sin^2\beta_n}}\right]$$

Force prediction – turning

Resolving the differential oblique cutting forces in in x, y, z directions:

$$dF_{x_{II}} = dF_{t_{II}}$$
$$dF_{y_{II}} = -dF_{f_{II}} \sin\theta + dF_{r_{II}} \cos\theta$$
$$dF_{z_{II}} = dF_{f_{II}} \cos\theta + dF_{r_{II}} \sin\theta$$

Integrating along curved chip segment

$$F_{q_{II}} = \int_0^{\theta_0} dF_{q_{II}}, \qquad q = x, y, z$$

Limit of the approach angle (side cutting edge angle)

$$\theta_0 = \pi - \cos^{-1}\left[\frac{c}{2r}\right]$$

More convenient to digitally integrate forces. Assume chip is divided into $K = \theta_0/\Delta\theta$ segments

$$F_{q_{II}} = \sum_{k=0}^{K} dF_{q_{II}}, \qquad q = x, y, z$$

Total force acting on tool

$$F_q = F_{q_I} + F_{q_{II}}, \qquad q = x, y, z$$

Torque

$$T = F_x\left(\frac{d-a}{2}\right)$$

Power

$$P = F_x V$$