Lateness Policies

**Part submissions**
1 – 7 days late: 30% deduction
7 – 14 days late: 60% deduction
>14 days: 0%

**Lecture assignment submissions**
Up to 24 hours late: 25% deduction
24 – 48 hours late: 50% deduction
>48 hours late: 75% deduction

**Lab quizzes**
50% deduction for submission after your lab
The Stirling Engine
History

- Patented in 1816
- Closed-cycle regenerative hot air engine
- Theoretical full Carnot efficiency
- Any heat source
- Semi-reversible

Dr. Robert L. Stirling
Operating Principles

Beta-type Stirling Engine

Heating the air chamber leads to an expansion of the working fluid

\[ PV = nRT \]

An increase in system pressure drives the piston forward

Energy is stored in the flywheel to ensure full return of piston and smooth operation

Operating Principles

- Isothermal compression (heat rejection)
- Isochoric heating
- Isothermal expansion (heat adsorption)
- Isochoric cooling

Graph showing the relationship between pressure ($p$) and volume ($V$) with ideal and reality paths.
Anatomy of a Vertical Mill
Types of Milling

- Slab, peripheral, plane milling
- Face milling
- End milling
End Mills

Square end
(pocket machining, end milling, profile milling)

Roughing
(large volume material removal)

Ball end
(shaping)

Corner rounding
(shaping – radii)
Types of Milling

Conventional (chip)

Climb
Face Milling Tools

**Fly Cutter**
(single cutting edge, low throughput, cheaper)

**Face Mill**
(multiple edges / carbide inserts, higher throughput / feed rate, more expensive)
Milling Techniques

Face milling with a square end mill

End milling
Work Holding (Vise)
Work Holding (Parallels)
Work Holding (Vise Stop)

Accurate placement along the lateral axis of the mill
Feeds and Speeds

Feeds and speeds determine the efficacy of the cutting operation and are heavily influenced by the type of cutting operation, materials being cut, and the cutting bit.

**Speed Equation**

\[
\text{Spindle Speed [RPM]} = \frac{4 \times \text{Cutting Speed [SFPM]}}{\text{Tool Diameter [in.]}},
\]

You set this

Empirically determined parameter

Provided or selected
Feeds and Speeds (Speed Derivation)

\[ v = r \omega_r \]

Relationship between velocity and angular speed

\[ \omega_r \text{[rad/min]} = 2\pi \omega_c \text{[rev/min]} \]

Relationship between angular and rotational speed

\[ r = \frac{1}{2} d \]

Relationship between radius and diameter
Feeds and Speeds (Speed Derivation)

\[ \omega_c \text{[rev/min]} = \frac{v \text{[ft/min]}}{\pi d \text{[ft]}} \]

Substituting values

\[ d \text{[ft]} = \frac{1}{12} d \text{[in]} \]

Relationship between tool diameter in feet and inches

\[ \omega_c \text{[rev/min]} = \frac{4v \text{[ft/min]}}{d \text{[in]}} \]

Final result – look familiar!
# Feeds and Speeds

<table>
<thead>
<tr>
<th>Material Identity</th>
<th>High-speed Steel Cutting Tool</th>
<th>Carbide Cutting Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastics</td>
<td>500</td>
<td>800</td>
</tr>
<tr>
<td>Aluminum</td>
<td>300</td>
<td>600</td>
</tr>
<tr>
<td>Brass</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>Mild Steel</td>
<td>75</td>
<td>250</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

Cutting Speed
(SFPM = surface feet per minute)
Feeds and Speeds

**Feed Equation**

You set this

Feed Rate \( \left[ \frac{\text{in}}{\text{min}} \right] \) = Chip Load [in.] \( \times \) Number of Teeth \( \times \) Spindle Speed [RPM]

Determined by the speed equation

Roughing = 0.005”
Finishing = 0.001 – 0.002”
Feeds and Speeds

Speeds and feeds for Al and a 2-fluted mill

For most milling operations 1000 RPM and 10 in/min. are sufficient.
Part Indication – Edge Finding

- Shank
- Slide Tip Off Center
- Spinning
- Workpiece
- Spindle Axis
- Edge of Workpiece 0.100”