

Basics of Mechanical Engineering-2

Prof. J. Ramkumar

Prof. Amandeep Singh Oberoi

Department of Mechanical Engineering

Indian Institute of Technology, Kanpur

Week 10

Lecture 40

Tutorial-5 (Part 1 of 2)

Welcome back to the course Basics of Mechanical Engineering II, where we were discussing manufacturing processes. In the last week and in this week, we have discussed machining. In the machining, we have discussed about single point cutting tool, then lathe machining operations, then some of the milling operations because milling is a versatile process, versatile machining system, in which we do end-mill, we do a lot of kind of the operations that happens on the face, happens inside cutting slots, etc. Then, we also discussed about grinding operations. I will now try to take some problem statements, that is the tutorial session is on the machining, the points that we have discussed in the last week and in this week. So, this is tutorial session on machining. I am Dr. Amandeep Singh Oberoi.

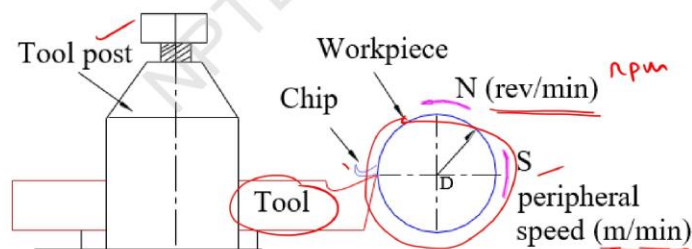
Metal Cutting Problems and Solutions



Operating/Cutting Conditions in Metal Cutting:

1. ✓ Cutting Speed v
2. ✓ Feed f
3. ✓ Depth of Cut d

Relative feed forward in 1 rotation
 $= \pi D$
Peripheral speed = πDN



Just to recall the concepts that we have discussed in the last week about the cutting speed feed and depth of cut. Because generally when we have a specific dimensions of the material, we have a specific machine in which the machining speed is specifically defined. There are variable speeds in the CNC systems when we talk about there are machines for example, if the speed variations between 0 to 10,000 rotations per minute.

We can set even 9992. We can set even 8884 something. The operations even up to the variation of 1 meter per minute speed could be put as an input there. But in the conventional machining setups, the machining speed is sometimes generally fixed. For example, first variation is 100 meters per minute, second could be 120, third could be 140, then it could be 200.

So, based upon those only, we can have the cutting speed. And feed and depth of cutter are also generally fixed accordingly so that the surface roughness and the overall machining time are minimized, and the quality that you need is appropriate. So, in a lathe machining setup, you can see this is a tool post that is holding the tool, and the tool is cutting.

This is how the chip is coming out, and this is revolutions per minute, that is, rotations (RPM), and s is the peripheral speed, which is in meters per minute. So, this is RPM, and this is meters per minute, as given here. Relative tool travel in one rotation could also be expressed as πD , which is the whole periphery of the workpiece taken in one rotation (πD). Then, peripheral speed could also be expressed as πDN .

Metal Cutting Problems and Solutions



D – Diameter (mm)

N – Revolutions per Minute (rpm)

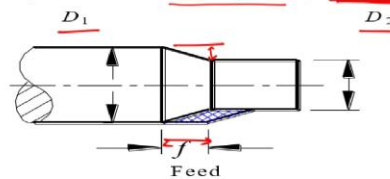
$$v = \frac{\pi D N}{1000} \quad (\text{m/min})$$

The **Peripheral Speed** of Workpiece past the Cutting Tool = **Cutting Speed**

Feed (f) – the distance the tool advances for every rotation of workpiece (mm/rev)

Feed rate (f_r) – linear travel rate (mm/min)

$$f_r = f N$$



M.P. Groover, Fundamental of modern manufacturing Materials, Processes and systems, 4ed

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Now, if we are given the diameter and the RPM (rotational speed), we can calculate the cutting speed or the peripheral speed using $v = \frac{\pi D N}{1000}$. The factor of 1000 comes into play because we are converting the diameter into meters, as meters per minute is squared, and the diameter is generally given in millimeters.

So, N is your rotational speed, that is, revolutions per minute. This is how we get the peripheral speed of the workpiece past the cutting tool, which is equal to the cutting speed. Feed: the distance the tool advances for every rotation of the workpiece.

After each rotation, it advances. In the second rotation, it advances. So, after each rotation, it is millimeters per revolution. So, millimeters per revolution is also the unit of feed. Feed rate: it is linear travel.

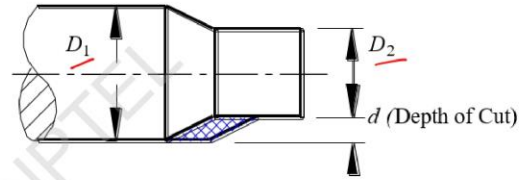
It is mm/min. This is equal to feed into the RPM. So, this is the feed that is getting into the workpiece. And this is my the initial diameter and final diameter, this becomes my depth of cut.

Metal Cutting Problems and Solutions



Depth of cut (d) perpendicular distance between machined surface and uncut surface of the Workpiece

$$d = \frac{(D_1 - D_2)}{2} \quad (\text{mm})$$



Now, depth of cut that I have given in the next slide, depth of cut is $d = \frac{(D_1 - D_2)}{2}$ this is the depth of cut which is also given in general in millimeters.

Metal Cutting Problems and Solutions



Machining Feed (f_m) = Cutting speed (N) × feed per tooth (f_t) × number of teeth (n)

Total distance travelled by the tool in single pass (L_s) =

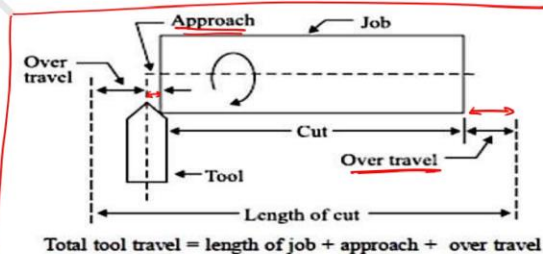
Length of the workpiece (L) + Length of the tool approach (X) + Length of tool over travelled (Y)

Length travelled by the tool in n₁ pass =

Total distance travelled by the tool in single pass (L_s) × number of pass (n₁)

If in question, Length of the tool approach and Length of tool over travelled not mentioned then neglect the length X and Y

$$\Rightarrow L_s = L$$



Total tool travel = length of job + approach + over travel



Before embarking upon the problem statements, let us try to see some more relations because these are important. In this figure that you are looking at, we have the tool when

it approaches the workpiece. So, there is a reach of the tool towards the workpiece. When the tool comes very close to the workpiece, the tip has just reached close to the workpiece face here. This distance is known as approach.

And after the cutting, the tool also goes over and beyond the workpiece's contact. This is known as over travel. Then, the total distance travelled by tool that is length of single pass in a single pass when the tool has to come there is work piece tool has to approach it this approach length plus work piece length plus over travel length.

So, this becomes my total length of pass, this is Length of the workpiece (L) + Length of the tool approach (X) + Length of tool over travelled (Y). Now, Machining Feed(f_m) = Cutting speed (N) × feed per tooth (f_t) × number of teeth (n)

So, if in question the length of the tool approach and the length of the tool overtravels are not mentioned, then neglect X and Y, and the length of the single pass = length of the workpiece.

Metal Cutting Problems and Solutions



Machining Time or Cutting Time (T_m): required time to machine one pass.

Job length or length of workpiece (L) in mm,

Feed (f) in mm/rev,

Feed per tooth(f_t) in mm/ tooth,

feed rate (f_r) in mm/min

speed (N) in rpm,

outer diameter (D_0) in mm,

cutting speed (v) in mm/min,

$$T_m = \frac{L}{f N} = \frac{L}{f_r} = \frac{L \pi D_0}{f v} \text{ min}$$

Manufacturing Time: the overall time to produce the product.

Manufacturing time = Machining Time + Setup Time + Moving Time + Waiting Time



Then, machining time would also have to be calculated sometimes. Machining time or cutting time is the time required to machine one pass of the job or the length of the workpiece in millimeters. That is,

$$T_m = \frac{L}{f N} = \frac{L}{f_r} = \frac{L \pi D_0}{f v} \text{ min}$$

Manufacturing time is the overall time to produce the product, which is machining time plus setup time plus moving time plus fitting time. That is a different scenario. We are only trying to talk about the machining time majorly here.

Metal Cutting Problems and Solutions



Material Removal Rate (MRR):

- Volume of material removed in one revolution

$$\text{MRR} = \pi D d f \quad \text{mm}^3/\text{rev}$$

(mm)(mm)(mm/rev)

- Job makes N revolutions/min

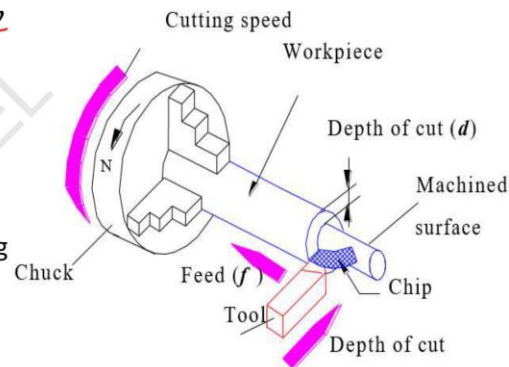
$$\text{MRR} = D d f N \quad \text{mm}^3/\text{min}$$

(mm)(mm)(mm/rev)(rev/min)

- If width of tool (w), depth of cut (d), machining feed in mm/min (f_m) are given,

$$\text{MRR} = w d f_m \quad \text{mm}^3/\text{min}$$

(mm)(mm)(mm/min)



Then, we sometimes have to calculate the material removal rate. Material removal rate is in three forms. That is, material removed in one revolution, Then, N rev/min, then depending upon the width of the tool and the depth of cut, this is also calculated.

First is the material removal rate per revolution, which is $\text{MRR} = \pi D d f$. This is the diameter of the workpiece, this is the depth of cut, and this is the feed per revolution. So, this becomes mm^3/rev . That is the volume removed per revolution. The job makes N revolutions per minute.

Then, $\text{MRR} = D d f N$. The depth of cut is also in millimeters. This feed is in millimeters per revolution. And N is revolutions per minute. So, this becomes the volume removed per minute.

If the width of the tool, depth of cut, machining feed in millimeter per minute are given, then it becomes $MRR = w d f_m$ which is w in millimeters, d in millimeters, and f_m is millimeters per minute. For this, it turns to be millimeter cube per minute.

Metal Cutting Problems and Solutions



Problem Statement: The feed rate of single point cutting tool is 3 mm/revolution and the workpiece is rotating at 600 rpm. Determine the total machining time to turn the cylindrical surface of length 300 mm of the workpiece.

$$f = 3 \text{ mm/rev.}$$

$$N = 600 \text{ rpm}$$

$$L = 300 \text{ mm}$$

$$T = \frac{L}{f \cdot N}$$

$$= \frac{300}{3 \times 600}$$

$$= 0.1666 \text{ min}$$

$$0.1666 \text{ min} = 0.1666 \times 60 \text{ sec}$$

$$= 10 \text{ sec}$$



Let me now come to a problem statement, a very simple problem statement. The feed rate of single point cutting tool is 3 mm/revolution and the workpiece is rotating at 600 rpm. Determine the total machining time to turn the cylindrical surface of length 300 mm of the workpiece.

Given:

$$F = 3 \text{ mm/rev}$$

$$N = 600 \text{ rpm}$$

$$L = 300 \text{ mm}$$

Solution:

$$T = L/fN = \frac{300}{3 \times 600} = 0.1666 \text{ min}$$

$$0.1666 \text{ min} = 0.1666 \times 60 \text{ sec} = 10 \text{ sec (ans.)}$$

Metal Cutting Problems and Solutions

Problem Statement: A 150 mm long, 12.5 mm diameter stainless steel rod is being reduced to a diameter of 12 mm by turning operation. The lathe spindle rotates at 400 rpm. Calculate the cutting speed.

$$N = 400 \text{ rpm}$$

$$D_1 = 12.5 \text{ mm}$$

$$D_2 = 12 \text{ mm}$$

$$L = 150 \text{ mm}$$



$$\begin{aligned}
 v &= \pi DN / 1000 \\
 &= \frac{\pi \times 12.5 \times 400}{1000} \\
 &= 15.7 \text{ m/min}
 \end{aligned}$$

A 150 mm long, 12.5 mm diameter stainless steel rod is being reduced to a diameter of 12 mm by turning operation. The lathe spindle rotates at 400 rpm. Calculate the cutting speed.

Given:

$$N = 400 \text{ rpm}$$

$$D_1 = 12.5 \text{ mm}$$

$$D_2 = 12 \text{ mm}$$

$$L = 150 \text{ mm}$$

Solution:

$$v = \pi DN / 1000$$

$$= \frac{\pi \times 12.5 \times 400}{1000} = 15.7 \text{ m/min (ans.)}$$

Metal Cutting Problems and Solutions

Problem Statement: On a lathe, a cylindrical work piece of 100 mm diameter is being turned. The RPM is 100. Find the cutting speed (in m/min).

$$V = \frac{\pi D N}{1000}$$

$$V = 31.41 \text{ m/min}$$

On a lathe, a cylindrical work piece of 100 mm diameter is being turned. The RPM is 100. Find the cutting speed (in m/min).

You can calculate it by yourself. I will just give you the solution. The solution will give $v = 31.41$ m/min.

Metal Cutting Problems and Solutions

Problem Statement: A hollow workpiece of 250 mm long and 40 mm diameter is to be turned in 4 passes. Calculate the machining time if the approach length = 15 mm, over travel = 10 mm, feed = 0.7 mm/rev and cutting speed = 32 m/min.

$$\begin{aligned} \text{Total distance} &= L + X + Y \\ L &= 250 \text{ mm} \\ X &= 15 \text{ mm} \\ Y &= 10 \text{ mm} \\ D &= 40 \text{ mm} \\ f &= 0.7 \text{ mm/rev} \\ v &= 32 \text{ m/min} \\ n &= 4 \text{ passes} \end{aligned}$$

$$\begin{aligned} L_s &= 250 + 15 + 10 \\ L_s &= 275 \text{ mm} \\ \text{Total length travelled in 4 passes} &= 275 \times 4 = 1100 \text{ mm} \\ v &= \frac{\pi D N}{1000} \\ N &= \frac{1000 \times 32}{\pi \times 40} \\ N &= 255 \text{ rpm} \end{aligned}$$

$$T_m = \frac{L}{f N} = \frac{1100}{0.7 \times 255}$$

$$T_m = 6.16 \text{ min}$$



A hollow workpiece of 250 mm long and 40 mm diameter is to be turned in 4 passes. Calculate the machining time if the approach length = 15 mm, over travel = 10 mm, feed = 0.7 mm/rev and cutting speed = 32 m/min.

Given:

$$L = 250 \text{ mm}$$

$$X = 15 \text{ mm}$$

$$Y = 10 \text{ mm}$$

$$D = 40 \text{ mm}$$

$$f = 0.7 \text{ mm/rev}$$

$$v = 32 \text{ m/min}$$

$$n = 4 \text{ passes}$$

Solution:

$$\text{Total distance} = L + X + Y$$

$$L_s = 250 + 15 + 10 = 275 \text{ mm}$$

Total length travelled in 4 passes = $275 \times 4 = 1100$ mm

$$v = \pi DN/1000$$

$$N = \frac{1000 \times 32}{\pi \times 40} = 255 \text{ rpm}$$

$$T_m = L/fN = \frac{1100}{0.7 \times 255} = 6.16 \text{ min (ans.)}$$

Metal Cutting Problems and Solutions



Milling Operation **Problem Statement:** Estimate the machining time that will be required to finish a vertical flat surface of length 120 mm and depth 15 mm by an 8 teeth HSS end mill cutter of 32 mm diameter in a milling machine.

Assume, cutting velocity: 30 m/min, feed=0.15 mm/tooth.

$$L = 120 \text{ mm}$$

$$d = 15 \text{ mm}$$

$$n = 8$$

$$D = 32 \text{ mm}$$

$$V = 30 \text{ m/min}$$

$$f_t = 0.15 \text{ mm/tooth}$$

$$N = ? \quad V = \frac{\pi DN}{1000}$$

$$\text{Machine feed: } f_m = f_t \times N \times n$$

$$\text{Cutting time: } T = \frac{L}{f_m}$$

$$T_m = 20.1 \text{ sec}$$



Estimate the machining time that will be required to finish a vertical flat surface of length 120 mm and depth 15 mm by an 8 teeth HSS end mill cutter of 32 mm diameter in a milling machine.

Assume, cutting velocity: 30 m/min, feed=0.15 mm/tooth.

Given:

$$L = 120 \text{ mm}$$

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$$n = 8$$

$$D = 32 \text{ mm}$$

$$V = 30 \text{ m/min}$$

$$f_t = 0.15 \text{ mm/tooth}$$

$$N = ?$$


Solution:

$$v = \pi DN/1000$$

$$\text{Machine feed: } f_m = f_t \times N \times n$$

$$\text{Cutting time: } T = L/f_m$$

$$T_m = 20.1 \text{ sec (ans.)}$$



Metal Cutting Problems and Solutions


Milling Operator **Problem Statement:** A slab milling operation is being carried out on a 50 mm long and 10 mm wide high strength block at a feed of 0.01 mm/tooth and depth of cut of 0.15 mm. The cutter has a diameter of 3 mm has 10 straight cutting and rotates at 150 rpm. Calculate the material removal rate and cutting time. *teeth*

$L = 50 \text{ mm}$
 $w = 10 \text{ mm}$
 $f_t = 0.01 \text{ mm/tooth}$
 $d = 0.15 \text{ mm}$
 $D = 3 \text{ mm}$
 $n = 10$
 $N = 150 \text{ rpm}$

Machine feed: $f_m = f_t \times N \times n$
 $= 0.01 \times 150 \times 10$
 $= 15 \text{ mm/min}$

MRR = $w \times d \times f_m$
 $= 10 \times 0.15 \times 15$
 $= 22.5 \text{ mm}^3/\text{min}$

Cutting time: $T = \frac{L}{f_m} = \frac{50}{15} \times 60 = 200 \text{ sec}$



A slab milling operation is being carried out on a 50 mm long and 10 mm wide high strength block at a feed of 0.01 mm/tooth and depth of cut of 0.15 mm. The cutter has a diameter of 3 mm has 10 straight cutting and rotates at 150 rpm. Calculate the material removal rate and cutting time.

Given:

$$L = 50 \text{ mm}$$

$$W = 10 \text{ mm}$$

$$f_t = 0.01 \text{ mm/tooth}$$

$$d = 0.15 \text{ mm}$$

$$D = 3 \text{ mm}$$

$$n = 10$$

$$N = 150 \text{ rpm}$$

Solution:

$$\text{Machine feed: } f_m = f_t \times N \times n = 0.01 \times 150 \times 10$$

$$= 15 \text{ mm/min}$$

$$\text{MRR} = w \times d \times f_m$$

$$= 10 \times 0.15 \times 15 = 22.5 \text{ mm}^3/\text{min (ans.)}$$

$$\text{Cutting time: } T = L/f_m = \frac{50}{15} \times 60 = 200 \text{ sec (ans.)}$$

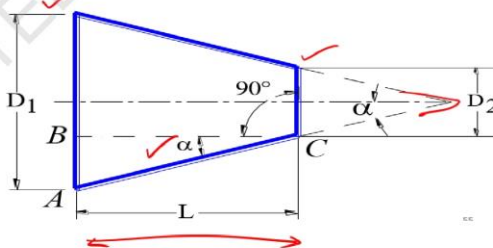
Metal Cutting Problems and Solutions



Taper Turning:

Taper turning is a machining process used to gradually reduce the diameter of a cylindrical workpiece over a specific length. The taper is defined by the difference in diameters along the length of the taper.

Two important parameters in taper turning are **Conicity (K)** and **Taper Angle (α)**.



Next is the concept of taper turning. Taper turning means on one side diameter is larger, other side the diameter is smaller. The D1 is a larger diameter, D2 is a smaller diameter and there is a length that has been turned from the larger to the smaller diameter. And

here we have multiple parameters here, we have taper angle alpha here, we have conicity K, By the definition, taper turning is a machining process used to gradually reduce the diameter of a cylindrical workpiece over a specific length. A taper is defined by the difference in the diameters along the length of the taper. So, here this alpha is half of this angle, total angle. And conicity is also calculated. How is K calculated?

Metal Cutting Problems and Solutions



Conicity (K): It is the ratio of the difference in diameters to the taper length and is given by the formula:

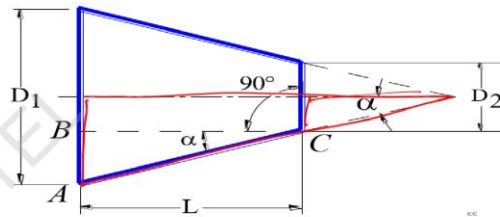
$$K = \frac{D_1 - D_2}{L}$$

where,

D_1 = Larger diameter (mm)

D_2 = Smaller diameter (mm)

L = Length of the taper (mm)



Taper Angle (α): It is the angle between the tapered surface and the axis of the workpiece. It is calculated using

$$\tan \alpha = \frac{D_1 - D_2}{2L} = \frac{K}{2}$$

This concept is widely used in manufacturing to produce machine components such as shafts, spindles, and tool holders.



Let us see here $K = \frac{D_1 - D_2}{L}$, that is conicity D_1 is a larger diameter, D_2 is a smaller diameter and L is the length of the taper. We can also calculate the taper angle that is $\tan \alpha = \frac{D_1 - D_2}{2L} = \frac{K}{2}$

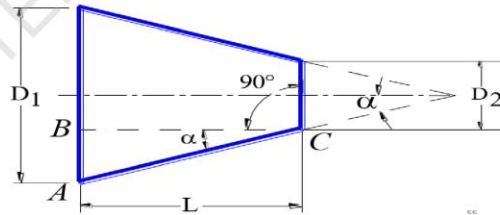
So, here we can develop a triangle here. This is one triangle, and that triangle, using the triangle relationship, $\tan \alpha = \frac{D_1 - D_2}{2L}$, which is conicity by 2. This concept is widely used in manufacturing to produce machine components such as shafts, spindles, tool holders, etc.

Metal Cutting Problems and Solutions



Problem Statement: A cylindrical workpiece is being taper-turned over a length of 400 mm, with a larger diameter (D_1) of 100 mm and a smaller diameter (D_2) of 60 mm. Determine the Taper Angle (α) and Conicity (K).

$$\begin{aligned}L &= 400 \text{ mm} \\D_1 &= 100 \text{ mm} \\D_2 &= 60 \text{ mm} \\ \alpha &=? \\K &=?\end{aligned}$$



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Metal Cutting Problems and Solutions



Solution:

$$\begin{aligned}\text{Conicity (K)} &= \frac{D_1 - D_2}{L} = \frac{100 - 60}{400} \\ &= 0.1 \quad (\text{Dimensionless quantity}) \\ \tan \alpha &= \frac{D_1 - D_2}{2L} \\ \alpha &= \tan^{-1} \left(\frac{0.1}{2} \right) \\ &= \tan^{-1} (0.05) \\ \alpha &= 2.86^\circ\end{aligned}$$



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A cylindrical workpiece is being taper-turned over a length of 400 mm, with a larger diameter (D_1) of 100 mm and a smaller diameter (D_2) of 60 mm. Determine the Taper Angle (α) and Conicity (K).

Given:

$$L = 400 \text{ mm}$$

$$D_1 = 100 \text{ mm}$$

$$D2 = 60 \text{ mm}$$

$$\alpha = ?$$

$$K = ?$$

Solution:

$$K = \frac{D1 - D2}{L} = \frac{100 - 60}{400} = 0.1 \text{ (Dimensionless quantity)}$$

$$\tan \alpha = \frac{D1 - D2}{2L}$$

$$\alpha = \tan^{-1} (0.1/2)$$

$$= \tan^{-1} (0.05)$$

$$\alpha = 2.86 \text{ degree (ans.)}$$

With this, I am taking a break here. And the second part of the tutorial will cover the other problems. This was just a simple machining system. Now, we will also try to see the tool, the shear angle, and the nose radius of the tool. How do we calculate those? Also, the tool life equation that you saw in the 3D lectures will also be covered in the next part of the tutorial.

Thank you.