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Estimating Hobbing Times

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Courtesy of Mikron/Starcut Sales, Inc.

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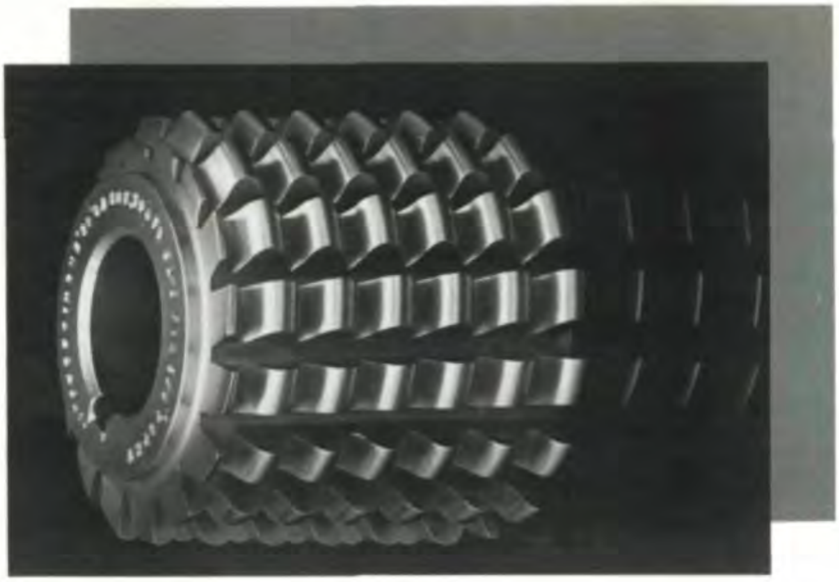
Hobbing is a continuous gear generation process widely used in the industry for high or low volume production of external cylindrical gears. Depending on the tooth size, gears and splines are hobbed in a single pass or in a two-pass cycle consisting of a roughing cut followed by a finishing cut. State-of-the-art hobbing machines have the capability to vary cutting parameters between first and second cut so that a different formula is used to calculate cycle times for single-cut and double-cut hobbing.



Single-Cut Hobbing Cycle

The cycle time is given by the equation,

$$T = \frac{Z \times L}{N \times K \times F} \qquad (1)$$

where

- T = cycle time in minutes
- Z = number of gear teeth
- L = length of cut in inches
- N = hob revolutions per minute
- K = number of hob starts
- F = feed rate in inches per revolution of work

Double-Cut Hobbing Cycle

The cycle time is given by the equation,

$$T = \frac{Z \times L1}{N1 \times K \times F1} + \frac{Z \times L2}{N2 \times K \times F2} \qquad (2)$$

where

- T = hobbing time in minutes
- Z = number of gear teeth
- L1 = hob travel in inches, first cut
- L2 = hob travel in inches, second cut
- N1 = hob revolutions per minute, first cut
- N2 = hob revolutions per minute, second cut
- K = number of hob starts
- F1 = feed rate in inches per revolution of work gear, first cut
- F2 = feed rate in inches per revolution of work gear, second cut

Some of the parameters of the cycle time formulae, such as the number of gear teeth, can be found directly on the part print. Others require additional calculations before they can be entered in the equation.

It is important to know that diametral pitch and pitch diameter of the work gear determine the size of the hobbing machine required for the job. The size of the gear tooth will also influence the feed rate that will be used to cut the gear, and whether the gear must be hobbed in a single- or double-cut cycle.

Calculation of Hob Travel (L)

The hob travel length consists of four elements: gear face width, spacer width, hob approach and hob overrun.

Gear Face Width. The gear face width is also indicated on the part print as the width of the gear blank. When more than one part is loaded per cycle, the total gear width must be taken into account. (Fig. 1)

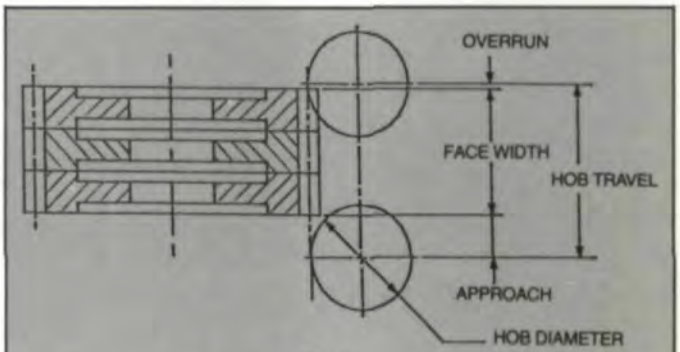


Fig. 1

Spacer Width. Gear configuration may be such that a spacer is required between gears in order to load more than one part per cycle. In this case the width of the spacer must be added to the total face width. (Fig. 2)

Approach. Hob approach is the distance from the point of initial contact between hob and gear blank to the point where the hob reaches full depth of cut. The approach length is a function of hob diameter, gear outside diameter, depth of cut and gear helix angle.

Hob approach is calculated with the formula

$$A = \sqrt{W \times \left[\frac{D + G - W}{\cos^2 (H)} - G\right]} \qquad (3)$$

where

A = hob approach in inches
W = depth of cut in inches
D = hob outside diameter in inches
G = gear outside diameter in inches
H = gear helix angle

For spur gears, $H = 0$ and $\cos H = 1$, so that the approach formula is simplified to

$$A = \sqrt{W \times (D - W)} \qquad (4)$$

Fig. 3 illustrates this relationship.

In a single-cut cycle the depth of cut is

$$W = \frac{\text{Gear outside dia.} - \text{Gear root dia.}}{2}$$

In a double-cut cycle the approach travel for roughing is longer than for finishing because of the difference in cutting depth. (Fig. 4)

Overrun. Hob overrun is the linear hob travel beyond full cutting depth required to complete generation of the gear teeth.

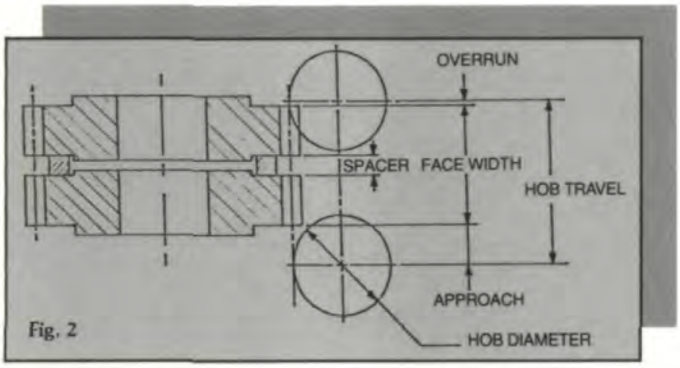


Fig. 2

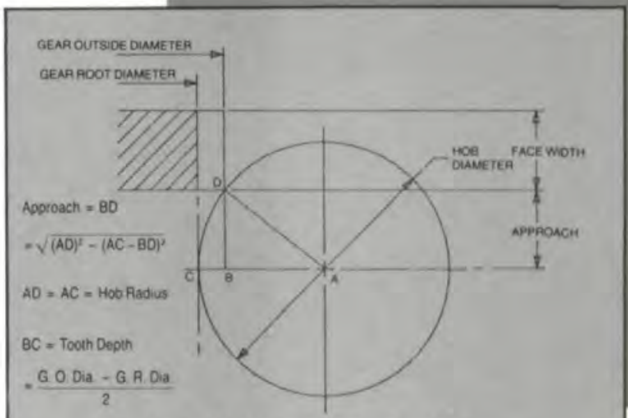


Fig. 3 – Hob Approach For Spur Gears

Hob overrun is calculated with the formula

$$R = \frac{S \times \cos (H) \times \tan (SA)}{\tan(PA)} \qquad (5)$$

where

R = hob overrun in inches
S = addendum of gear in inches
H = Gear helix angle
SA = hob head swivel angle
PA = gear pressure angle

The hob head swivel angle is a function of helix angle and hand of both work gear and hob.

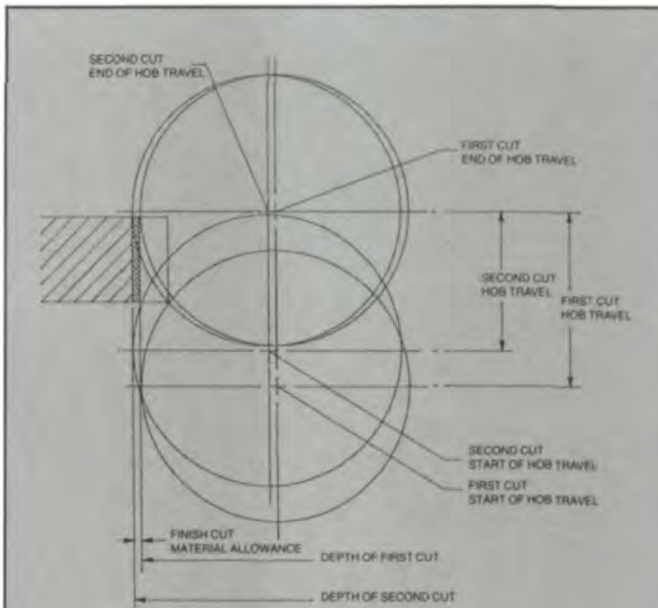


Fig. 4 – Hob Approach In A Two-Cut Hobbing Cycle

Table 1		
gear helix hand	hob helix hand	hob head swivel angle
left	left	H − HB
left	right	H + HB
right	left	H + HB
right	right	H − HB

In Table 1, HB represents the hob helix angle. The minimum hob head swivel angle is obtained when the helix of gear and hob have the same hand.

All formulae are based on the theoretical points of contact between hob and workpiece. In practice, clearance between hob and work gear is needed in order to assure safe cutting conditions. Therefore, a clearance amount of .040 to .100 inch must be added to the theoretical values of approach and overrun.

For spur gears, $H = 0°$; $\cos(H) = 1$; and $SA = HB$. For a 7 diametral pitch gear, with 20° pressure angle, and hobbed with a 3° helix hob, the overrun is

$$R = \frac{.1429 \times 0.05241}{0.36397} = 0.020$$

Obviously, for practical purposes the theoretical calculation of hob overrun for spur gears can be replaced by a fixed value which includes clearance, for instance, .100".

Hob Revolutions Per Minute (N)

Cutting speed in a hobbing operation is defined as the peripheral velocity of the hob.

$$V = \frac{\pi \times D \times N}{12} \tag{6}$$

where

V = Cutting speed in surface feet per minute (SFPM)
D = Hob diameter in inches
N = Revolutions per minute of the hob
π = 3.14159 . . .

In terms of machine set up, it is more significant to know the number of revolutions of the hob.

$$N = \frac{12 \times V}{\pi \times D} \tag{7}$$

As in most metal cutting processes, there are no specific values of speeds and feeds that must be used. Cutting parameters are, in fact, dependent on many variables, and starting values are often determined by past experience.

Speeds and feeds in an hobbing operation are affected by

- physical properties of tool material
- machinability of work material
- quality specifications
- ridigity of machine and fixture
- desired tool life
- cutting fluids, lubricants and coolants

Number of Hob Starts (K)

Number of hob starts and cycle time are inversely related to each other. Cycle time decreases when the number of hob starts is increased.

A single-start hob rotates the work one tooth for each revolution of the hob. With a 2, 3 or 4-start hob, the work is rotated over 2, 3 and 4 teeth for each revolution of the hob. Assuming the same feed rate for multistart as for single-start hobbing, the cycle will be completed 2, 3 or 4 times faster.

Quality considerations, however, limit the application of multistart hobs. In this process, fewer hob teeth participate in the generation of the tooth profile; therefore, it is less accurate. Multistart hobs also have an inherent thread spacing error which is repeated in the workpiece under certain conditions.

The following guidelines should be followed when estimating times with multistart hobs.

- The number of teeth in the gear must not be divisible by the number of hob starts.
- Only gears with a large number of teeth ($Z > 25$) are suitable for cutting with multistart hobs.

When working with multistart hobs the feed rate must be reduced to compensate for the increased tooth loading of the hob. The following reduction factors are recommended.

Table 2

Number of hob starts	Reduction factor
1	1
2	0.67
3	0.55
4	0.50

Example: Normal feed rate with single-start hob is .160″ per revolution of workpiece.
When using a 2-start hob for the same job, the feed rate should be reduced to
$.67 \times .160 = .107$ inch/revolution.

Field of Application

Although hobbing is the most widely used method of gear manufacturing, its field of application is restricted by the part geometry. The major limitation is that hobbing is not applicable to internal gears. Other methods of gear manufacturing like shaping, broaching or skiving must be used for production of internal gears.

Another important limitation is that hobbing is not applicable to shoulder gears. This restriction is a direct result of the approach length, which is a function of the hob diameter. The distance between gear face and an adjacent shoulder must be greater than the minimum value of hob approach length in order to allow hobbing. In some cases it is possible to reduce the approach length by specifying hobs with reduced outside diameter. However, hob design considerations limit the variation in outside diameter.

Hobbing is without a doubt the most productive gear cutting method for external gears. It can be used as a semi-finishing or finishing gear process. Hobbing as a finishing process is accomplished by rough and finish cutting the gears on the hobbing machine without a subsequent tooth finishing operation. Most often hobbing is used in combination with a gear finishing operation like shaving or grinding.

Productivity can be increased by stacking several gears on the hobbing fixture. Stacks of more than two gears require good quality gear blanks with the gear rim faces parallel to each other and square to the bore.

One remarkable feature of the hobbing machine is the ability to make crowned or tapered gears. Crowning is often used in gear design practice to avoid end loading of the gear teeth. Taper hobbing can be used to compensate for uneven shrinkage in heat treatment.

Heat treated helical gears are typically affected by lead unwind, which is a change in helix angle after hardening. Lead angle variations are very easily compensated for on a gear hobbing machine by installing sets of differential change gears, or by programming of corrected helix angles on CNC controls.

EXAMPLES OF CYCLE CALCULATIONS

Example 1

Transmission gear hobbed on arbor fixture (Fig. 5)

Part print data

Number of teeth	61
Diametral pitch	7
Pitch diameter	8.714
Outside diameter max	8.990
Outside diameter min	8.985
Root diameter max	8.346
Root diameter min	8.336
Pressure angle	20°
Helix angle	0°
Face width	1.215
Material	SAE 8620

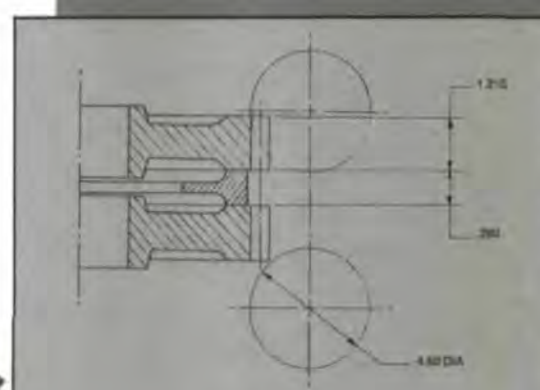


Fig. 5

Machine setting data

Double cut cycle	
Cutting speed rough	230 sfpm
Cutting speed finish	290 sfpm
Feed rate rough	.177 ipr
Feed rate finish	.236 ipr
Number of parts per cycle	2
Spacer width	.260
Finish cut material allowance	.060

Hob data

Outside diameter	4.60
Number of starts	1
Spiral angle	4.25°
Material	HSS

Cycle time calculation

$$\text{Hob rpm rough} = \frac{12 \times 230}{3.14159 \times 4.6} = 190 \text{ rpm}$$

$$\text{Hob rpm finish} = \frac{12 \times 290}{3.14159 \times 4.6} = 240 \text{ rpm}$$

$$\text{Gear addendum} = \frac{8.9875 - 8.7142}{2} = .137$$

$$\text{Whole tooth depth} = \frac{8.9875 - 8.341}{2} = .323$$

Depth of cut, roughing cut $= .323 - .060 = .263$

Depth of cut, finishing cut $= .060$

Hob approach, roughing cut $= \sqrt{.263 \times (4.60 - .263)} = 1.068$

Add .040 clearance $= .040 + 1.068 = 1.108$

Hob approach, finishing cut $= \sqrt{.060 \times (4.60 - .060)} = .522$

Add .040 clearance $= .040 + .522 = .562$

$$\text{Hob overrun, rough and finish} = \frac{.137 \times \cos 0 \times \tan 3.25}{\tan 20}$$

$$= \frac{.137 \times .05678}{.36397} = .021$$

Add .040 clearance $= .040 + .021 = .061$

Total hob travel, roughing $= 1.068 + .061 + 2.430 + .260 = 3.819$

Total hob travel, finishing $= .562 + .061 + 2.430 + .260 = 3.313$

$$\text{Cycle time} = \frac{61 \times 3.819}{190 \times .177} + \frac{61 \times 3.313}{240 \times .236}$$

$= 10.495$ min for 2 pieces

$= 5.297$ min for 1 piece

Example 2

The procedure is the same as in Example 1, however, the gear is now hobbed with a 2-start hob. We will assume that the 2-start hob has the same outside diameter as the single-start hob so that approach and overrun values are same as in previous example.

Feed rate for roughing $= .67 \times .177 = .118$

Feed rate for finishing $= .67 \times .236 = .158$

$$\text{Cycle time} = \frac{61 \times 3.819}{190 \times 2 \times .118} + \frac{61 \times 3.313}{240 \times 2 \times .158}$$

$= 7.859$ min for 2 pieces

$= 3.929$ min for 1 piece

The savings in cycle time is $10.495 - 7.859 = 2.636$ min or 25%.

This example illustrates clearly the increased productivity which results from the use of multistart hobs. ■