

Module 4 General Purpose Machine Tools

Lesson

25

Estimation of machining time

Instructional objectives

At the end of this lesson, the students will be able to

- (i) Realize the necessity of evaluating the machining time requirement
- (ii) Identify the factors that govern the machining time.
- (iii) Estimate or evaluate the time required for specific;
 - (a) turning operation
 - (b) drilling and boring operations
 - (c) shaping and planing operations
 - (d) milling operation.

(i) Necessity Of Estimation Or Determination Of Machining Time Requirement For Particular Operations.

The major aim and objectives in machining industries generally are;

- reduction of total manufacturing time, T
- increase in MRR, i.e., productivity
- reduction in machining cost without sacrificing product quality
- increase in profit or profit rate, i.e., profitability.

All those objectives are commonly and substantially governed by the total machining time per piece, T_p , where again,

$$T_p = T_i + T_C + \frac{T_C}{T_L} TCT \quad (4.9.1)$$

where, T_i = idle time per piece, min

T_C = actual cutting time per piece

T_L = Tool life

TCT = average tool change time per piece.

T_i and TCT could have been spectacularly reduced by development and application of modern mechanisation or automation.

The tool life, T_L has been substantially enhanced by remarkable developments in the cutting tool materials.

Therefore, the actual cutting or machining time T_C remains to be controlled as far as possible for achieving the objectives and meeting the growing demands.

Hence, it becomes extremely necessary to determine the actual machining time, T_C required to produce a job mainly for,

- assessment of productivity
- evaluation of machining cost
- measurement of labour cost component
- assessment of relative performance or capability of any machine tool, cutting tool, cutting fluid or any special or new techniques in terms of saving in machining time.

The machining time, T_C required for a particular operation can be determined

- o roughly by calculation i.e., estimation
- o precisely, if required, by measurement.

Measurement definitely gives more accurate result and in detail but is tedious and expensive. Whereas, estimation by simple calculations, though may not be that accurate, is simple, quick and inexpensive.

Hence, determination of machining time, specially by simple calculations using suitable equations is essentially done regularly for various purposes.

(ii) Major Factors That Govern Machining Time

The factors that govern machining time will be understood from a simple case of machining. A steel rod has to be reduced in diameter from D_1 to D_2 over a length L by straight turning in a centre lathe as indicated in Fig. 4.9.1.

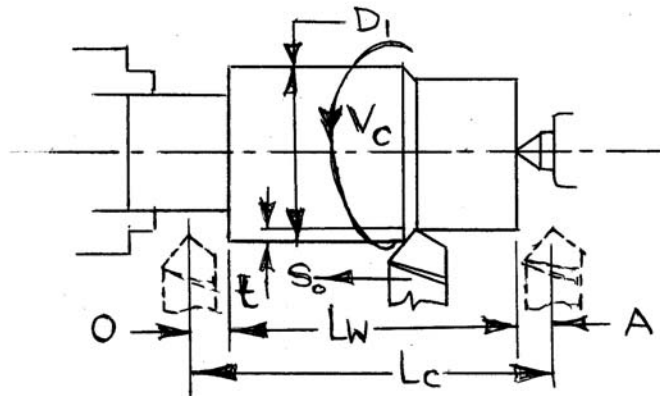


Fig. 4.9.1 Estimation of machining time in turning.

Here,
$$T_C = \frac{L_C}{Ns_o} x n_p \quad (4.9.2)$$

where, L_C = actual length of cut
 $= L + A + O$

A, O = approach and over run as shown

N = spindle speed, rpm

s_o = feed (tool), mm/rev

n_p = number of passes required

Speed, N, is determined from cutting velocity, V_C

$$V_C = \frac{\pi DN}{1000} \text{ m/min} \quad (4.9.3)$$

where, D = diameter of the job before cut

Therefore,
$$N = \frac{1000V_C}{\pi D} \quad (4.9.4)$$

The number of passes, n_p is mathematically determined from,

$$n_p = \frac{D_1 - D_2}{2t} \quad (4.9.5)$$

where, t = depth of cut in one pass, mm.

But practically the value of t and hence n_p is decided by the machining allowance kept or left in the preformed blanks. Usually, for saving time and material, very less machining allowance is left, if not almost eliminated by near – net – shape principle.

Hence, number of passes used is generally one or maximum two : one for roughing and one for finishing.

However, combining equations 4.9.2, 4.9.4 and 4.9.5, one gets,

$$T_C = \frac{\pi D L_C (D_1 - D_2)}{2000 V_C s_o t} \quad (4.9.6)$$

or
$$T_C = \frac{\pi D L_C}{1000 V_C s_o} \quad \text{for single pass turning} \quad (4.9.7)$$

Equation 4.9.7 clearly indicates that in turning to a given diameter and length, the cutting time, T_C is governed mainly by the selection of the values of cutting velocity, V_C and feed, s_o . This is true more or less in all machining operations being done in different machine tools.

A number of factors are essentially considered while selecting or deciding the values of V_C and s_o for any machining work.

The major factors considered for selecting V_C are :

- **Nature of the cut;**
 - Continuous cut like turning, boring, drilling etc. are done at higher V_C
 - Shock initiated cuts in shaping machine, planing machine, slotting machine etc. are conducted at lower V_C
 - Intermittent cuts, as in milling, hobbing etc. are done at quite lower speed for dynamic loading
- **Work material** (type, strength, hardness, heat resistance, toughness, chemical reactivity etc.) For instance;
 - Harder, stronger, heat resistant and work hardenable materials are machined at lower V_C
 - Soft, non-sticky and thermally conductive materials can be machined at relatively higher cutting velocity
- **Cutting tool material** (type, strength, hardness, heat and wear resistance, toughness, chemical stability, thermal conductivity etc.); For instance;
 - HSS tools are used at within 40 m/min only in turning mild steel whereas for the same work cemented carbide tools can be used at V_C , 80 to 300 m/min
 - High performance ceramic tools and cBN tools are used at very high speed in machining steels of different strength and hardness.
 - Diamond tools can be used in machining various materials (excepting Fe-base) at V_C beyond 500 m/min
- **Cutting fluid application;** for instance,
 - Proper selection and application of cutting fluid may allow increase in V_C by 20 to 50%
- **Purpose of machining;** for instance,

- Rough machining with large MRR is usually done at relatively low or moderate velocity
- Finish machining with small feed and depth of cut is usually done at high V_C
- **Kind of machining operation;**
 - Unlike turning, boring etc. the operation like threading, reaming etc. are carried out at much lower (20 to 50%) cutting velocity for achieving quality finish
- **Capacity of the machine tool**
 - powerful, strong, rigid and stable machine tools allow much higher V_C , if required and permissible
- **Condition of the machine tool**
 - Cutting velocity is kept lower than its normal value stipulated for a given tool – work material pair, if the machine tool is pretty old and / or having limitations due to wear and tear, backlash, misalignment, instability etc.

The factors that are considered during selecting the value of feed, s_o are,

- Work material (type, strength, hardness etc.)
- Capacity of the machine tool (power, rigidity etc.)
- Cutting tool; material, geometry and configuration
- Cutting fluid application
- Surface finish desired
- Type of operation, for instance threading operation needs large feed according to the lead of the thread.
- Nature of cut; continuous, shock initiated type, and intermittent
Feed, which raises cutting forces proportionally, is kept low in shock and intermittent type cuts

Apart from the total volume of material to be removed, permissible values of cutting velocity, feed and depth of cut and cutting fluid application, there are few more factors which also play role on machining time.

Those additional factors include :

- Quick return ratio in operations like shaping, planing, slotting, gear shaping etc.
- Jobs of odd size and shape and irregular and harder surfaces like large castings are essentially machined much slowly with lower cutting velocity
- Some special techniques like hot machining and cryomachining enables faster machining of some exotic materials and even some common metals like steels at higher V_C and s_o .

(iii) Estimation Of Machining Time By Calculations

(a) In case of turning in lathes

Fig. 4.9.1 and equations like Equation 4.9.7 enable determination of the amount of time required for straight turning in lathes following the given procedural steps :

- Determine the length of cut by proper selection of amount of approach, A (2 ~ 5 mm) and over run, O (1 to 3 mm), if required
- Select the approximate values of V_C and s_o based on the tool – work materials and other factors previously mentioned [depth of cut is decided based on the machining allowance available and the final diameter desired]
- Determine the spindle speed, N using equation 4.9.4 and then fix N as well as s_o from the chart giving the lists of N and s_o available in that lathe
- Finally determine T_C using equation 4.9.7.

$$T_C = \frac{\pi D(L_w + A + O)}{1000V_C s_o}$$

Example

For, $D = 100$ mm, $L_w = 200$ mm, $A = O = 5$ mm, $V_C = 120$ m/min and $s_o = 0.2$ mm/rev,

$$\begin{aligned} T_C &= \frac{\pi \times 100 \times (200 + 5 + 5)}{1000 \times 120 \times 0.2} \text{ min} \\ &= 2.75 \text{ min} \end{aligned}$$

The machining time for facing, grooving, taper turning, threading, parting etc. in lathes can also be determined or estimated following the same principle and method.

(b) In case of drilling and boring

The basic principle and procedure of estimation of machining time in drilling and boring are almost same as that of turning operations. Fig. 4.9.2 shows making through hole by drilling and boring.

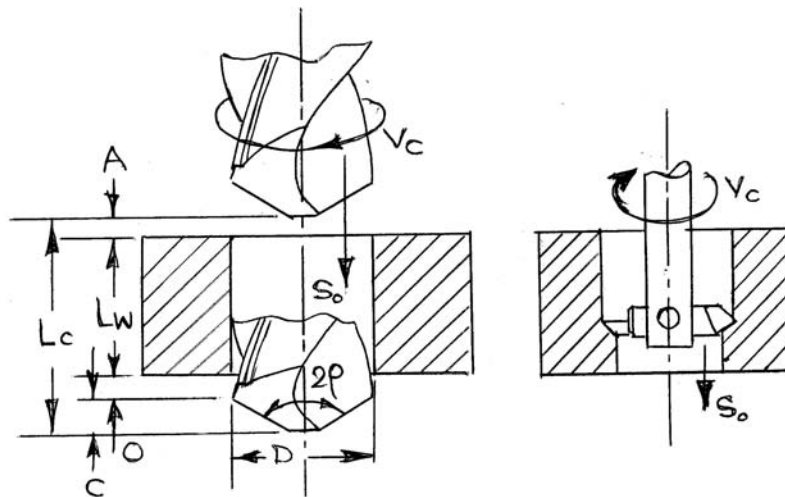


Fig. 4.9.2 Drilling and boring operations.

For drilling a through hole (Fig. 4.9.2),

The machining time, T_C is estimated from,

$$T_C = \frac{L'_C}{N s_o} \quad (4.9.8)$$

where, $L'_C = L_h + A + O + C$
 $A, O =$ approach and over run

$$\text{and } C = \frac{D}{2} \cot \rho$$

$D =$ diameter of the hole, i.e., drill

$\rho =$ half of the drill point angle.

Speed, N and feed s_o are selected in the same way as it is done in case of turning.

Therefore, the drilling time can be determined from,

$$T_C = \frac{\pi D (L_h + A + O + C)}{1000 V_C s_o} \quad (4.9.9)$$

In the same way T_C is determined or estimated in boring also. Only the portion 'C' is not included.

For blind hole, only over run, 'O' is excluded.

Example

For $D = 25 \text{ mm}, \rho = 60^\circ, V_C = 44 \text{ m/min}$

$L = 60 \text{ mm}, s_o = 0.25 \text{ mm/rev}$

$A = O = 2 \text{ mm}$

$$T_C = \frac{\pi \times 25 \{60 + 2 + 2 + (25/2) \cot 60^\circ\}}{1000 \times 44 \times 0.25} \\ = 0.5 \text{ min.}$$

(c) Machining time in shaping and planing

Machining time in shaping can be estimated using the scheme given in Fig. 4.9.3 which shows the length of tool – work travels required to remove a layer of material from the top flat surface of a block in a shaping machine.

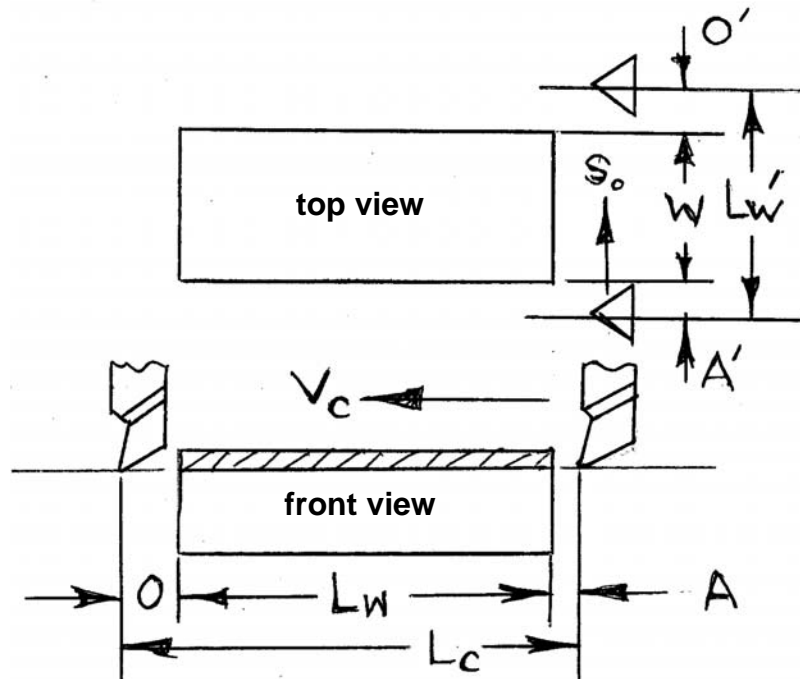


Fig. 4.9.3 Surfacing in shaping machine.

Using Fig. 4.9.3, the total machining time, T_C can be determined from the expression,

$$T_C = \frac{L_w}{N_s s_0} \text{ min} \quad (4.9.10)$$

where, L_w = total length of travel of the job
 $= W + A' + O'$

w = width of the job

A', O' = approach and over run

N_s = number of strokes per min

s_0 = feed of the job, mm/stroke

N_s has to be determined from,

$$V_C = \frac{N_s}{1000} [L_C (1 + Q)] \text{ m/min} \quad (4.9.11)$$

where, V_C = cutting velocity, m/min

L_C = stroke length, mm

$= L_w + A' + O'$

L_w = length of the workpiece

A', O' = approach and over run

and Q = quick return ratio

$= \text{time of return stroke} \div \text{time of cutting stroke}$

$$\text{Therefore, } N_s = (1000V_C) / [L_C(1+Q)] \quad (4.9.12)$$

Practically the speed that is available nearest to this calculated value is to be taken taken up.

The values of V_C and s_o are to be selected or decided considering the relevant factors already mentioned in case of turning.

Example

For $L_w = 100 \text{ mm}$, $A = 5$, $O = 5$, $W = 60$, $A' = O' = 2$
 $Q = 2/3$, $V_C = 40 \text{ m/min}$ and $s_o = 0.2 \text{ mm/stroke}$
 $N_s = (1000 \times 40) / [(100 + 5 + 5)(1 + 2/3)] = 200$
 Then, $T_C = (60 + 2 + 2) / (0.2 \times 200) = 1.6 \text{ min}$

Machining times of planing operations in planing machine are also determined in the same way, because the only difference is that in planing machine, cutting strokes and feed travels are imparted to the job and the tool respectively, just opposite to that of shaping machine. Besides that, though both shaping and planing are reciprocating type, planing machine may allow higher V_C .

(d) Machining time in Milling operations

There are different types of milling operations done by different types of milling cutters;

- o Plain milling by slab milling cutter mounted on arbour
- o End milling by solid but small end mill cutters being mounted in the spindle through collet
- o Face milling by large face milling cutters being directly fitted in the spindle.

Fig. 4.9.4 shows the scheme of plain milling by a plain or slab milling cutter and indicates how the machining time is to be calculated.

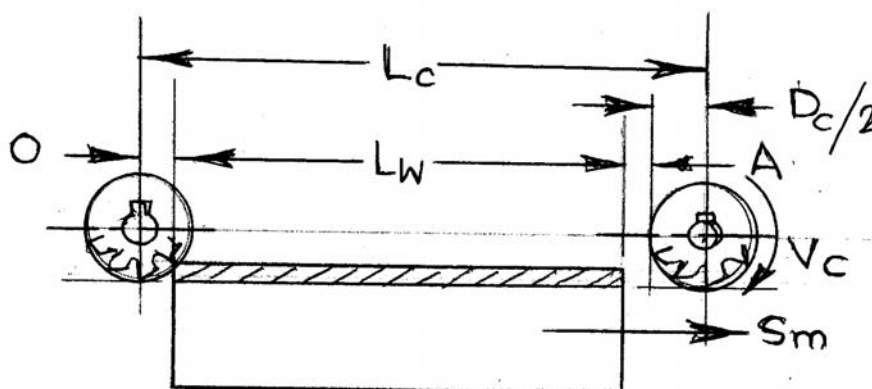


Fig. 4.9.4 Plain milling operation.

Following the Fig. 4.9.4, the machining time, T_C for plain milling a flat surface can be determined as,

$$T_C = L_C / s_m \quad (\text{for job width} < \text{cutter length}) \quad (4.9.13)$$

Where, L_C = total length of travel of the job
 $= L_w + A + O + D_C/2$

L_w = length of the workpiece

A, O = approach and over run (5 to 10 mm)

D_C = diameter of the cutter, mm

S_m = table feed, mm/min

$$= s_o Z_C N$$

where, s_o = feed per tooth, mm/tooth

Z_C = number of teeth of the cutter

N = cutter speed, rpm.

Again, N has to be determined from V_C as

$$V_C = \frac{\pi D_C N}{1000} \quad \text{m/min}$$

V_C and s_o have to be selected in the usual way considering the factors stated previously. Since milling is an intermittent cutting process, V_C should be taken lower (20 ~ 40%) of that recommended for continuous machining like turning. S_o should be taken reasonably low (within 0.10 to 0.5 mm) depending upon the tooth – size, work material and surface finish desired.

Example :

Determine T_C for plain milling a rectangular surface of length 100 mm and width 50 mm by a helical fluted plain HSS milling cutter of diameter 60 mm, length 75 mm and 6 teeth. Assume $A = O = 5$ mm, $V_C = 40$ m/min and $s_o = 0.1$ mm/tooth

Solution:

$$T_C = \frac{L_C}{s_m} \text{ min}$$

$$L_C = L_w + A + O + \frac{D_C}{2} = 100 + 5 + 5 + 30 = 140 \text{ mm}$$

$$s_m = s_o Z_C N = 0.1 \times 6 \times N$$

where,
$$N = \frac{1000 V_C}{\pi D_C} = \frac{1000 \times 40}{\pi \times 60} \cong 200 \text{ rpm}$$

$$s_m = 0.1 \times 6 \times 200 = 120 \text{ mm/min}$$

So,
$$T_C = \frac{L_C}{s_m} = \frac{140}{120} = 1.17 \text{ min.}$$

In the same method, T_C can be determined for end milling and face milling by proper selection of speed and feed depending upon the tool – work materials and other relevant factors.

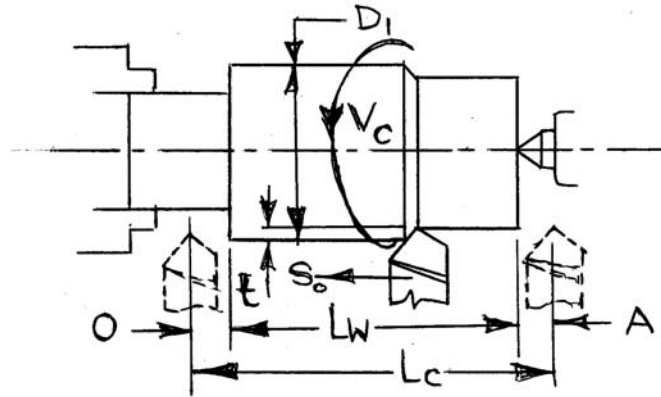
Exercise – 4.9

1. How much machining time will be required to reduce the diameter of a cast iron rod from 120 mm to 116 mm over a length of 100 mm by turning using a carbide insert. Reasonably select values of V_C and s_o .
2. Determine the time that will be required to drill a blind hole of diameter 25 mm and depth 40 mm in a mild steel solid block by a HSS drill of 118° cone angle. Assume suitable values of V_C and s_o .
3. In a mild steel block, a flat surface of length 100 mm and width 60 mm has to be finished in a shaping machine in a single pass. How much machining time will be required if $N_s = 80$, $s_o = 0.2$ mm/stroke, $A = O = 5$ mm, $QRR = 0.5$.
4. Estimate the machining time that will be required to finish a vertical flat surface of length 100 mm and depth 20 mm by an 8 teeth HSS end mill cutter of 32 mm diameter and 60 mm length in a milling machine. Assume, $V_C = 30$ m/min, $s_o = 0.12$ mm/tooth.

Solution of the Problems in Exercise – 4.9

Problem – 1

Solution :



$$T_C = \frac{L_C}{N s_0} \text{ for single pass}$$

$$L_C = 100 + 5 + 5 = 110 \text{ mm}$$

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

For turning C.I. by carbide insert, V_C is taken as 100 m/min and $s_0 = 0.2$ mm/rev

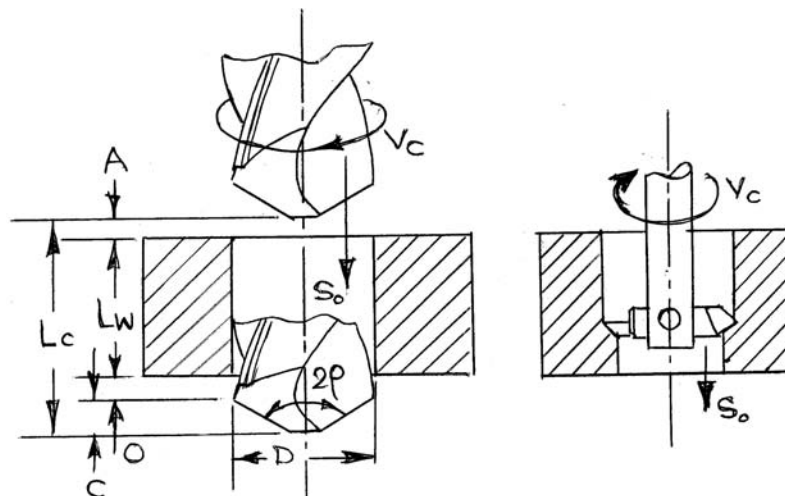
$$\therefore N = \frac{1000 \times 100}{\pi \cdot 120} \cong 250 \text{ rpm}$$

Nearest standard speed, $N = 225$

$$\therefore T_C = \frac{110}{225 \times 0.2} = 2.5 \text{ min} \quad \text{Ans.}$$

Problem – 2

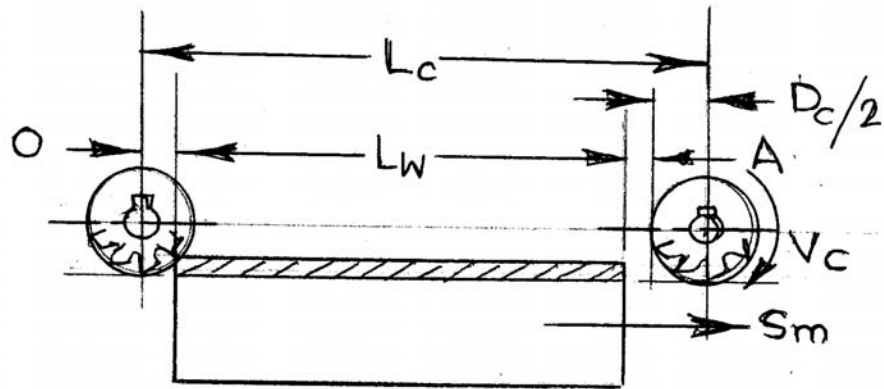
Solution :



Assumed for the given condition, $V_C = 25$ m/min and $s_0 = 0.16$ mm/rev

Problem – 4

Solution :



$$T_C = L_C / s_m ; L_C = 100 + 2 + 2 + 16 = 120 \text{ mm}$$

$$s_m = s_o Z_C N = 0.12 \times 8 \times N$$

$$N = \frac{1000 V_C}{\pi D_C} = \frac{1000 \times 30}{\pi \times 32} \cong 300 \text{ rpm}$$

Then $s_m = 0.12 \times 8 \times 320 = 320 \text{ mm/min}$

$$\therefore T_C = \frac{120}{300} \cong 0.40 \text{ min} \quad \text{Ans.}$$