Production Technology

Economics of Metal Cutting Operations

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INTRODUCTION

- In practice a high production rate would probably mean low production costs, it should be pointed out that these two factors must be considered separately
- The production time is defined as the average time taken to produce one component
- The production cost is defined as the total average cost of performing the machining operation on a component using one machine tool.
- The production of a component will involve several machining operations using a variety of machine tools. Hence, the total manufacturing costs, apart from the cost of the material, involve many items

- For example, the raw material must be brought to the first machine and placed in the machine, and then when the first machining process is completed, the component must be removed, stacked, or stored temporarily, transported eventually to the second machine tool, and so on
- Assuming the appropriate tool and cutting fluid were chosen for the machining of a batch of components, the only cutting conditions to be determined are the cutting speed and feed
- Feed is the distance moved by the tool relative to the work piece in the feed direction for each revolution of the tool or work piece

- If the feed speed in a milling operation is v_f and the rotational frequency of the tool is n_f the work piece feed during each revolution of the cutter is given by v_f / n_f & the maximum cutting speed v in a milling operation is given by $\Pi.d.n_f$ where d is the tool diameter. It now follows that if it is required to double the cutting speed in a milling operation while keeping the feed constant will be necessary to double both the rotational frequency of the cutter and the feed speed
- Either the cutting speed or feed arc increased while the other condition is held constant the actual machining time will be reduced, and the tool-wear rate will increase

- Very low speeds and feeds will result in a high production time because of the long machining time. Alternatively, very high speeds and feeds will result in a high production time because of the frequent need to change cutting tools. Clearly, an optimum condition will exist giving minimum production time.
- Similarly, an optimum condition will arise for minimum production cost At low speeds and feeds costs will be high because of the cost of using the machine and operator for the long machining times. At high speeds and feeds costs will be high because of the cost of frequent tool replacement

CHOICE OF FEED

- When a finishing cut is to be taken, the appropriate feed will be that which gives an acceptable surface finish
- An increase in feed will not affect the relative speed of sliding at the wearing surface of the tool, whereas the speed of sliding will change in proportion to the cutting speed. Since tool wear is a function of both temperature and relative speed of sliding. it can be appreciated that increases in cutting speed will result in a greater reduction in tool life than similar increases in feed
- If an increased production rate is required in rough machining. it will always be preferable to increase the feed rather than increase the speed

- This procedure will not always be practical since, in general, an increase in feed will increase the tool forces, whereas an increase in cutting speed will not. A limit on feed increase will therefore exist and will depend on the maximum tool force the machine tool is able to withstand. The guiding principle in choosing optimum cutting conditions in a roughing operation is that the feed should always be set at the maximum possible

CHOICE OF CUTTING SPEED

- In this case the time spent by the operator and his machine in producing a batch of components N_b can be separated into three items

1. Total non-productive time = $N_b \cdot t_1$

   where,

   t_1 = time to (load the stock + position the tool + unload the part)

   N_b = the total number of parts in the batch.

2. Total machining time = $N_b \cdot t_m$

where,

t_m = time to machine the part

3. Total tool change time = $N_t \cdot t_c$

where,

t_c = time to replace the worn tool with a new

N_t = total number tools used to machine the entire batch.

- Cost of each tool = C_t
- Cost per unit time for machine and operator = M
- if M is the total machine and operator rate, the total machine and operator costs will be

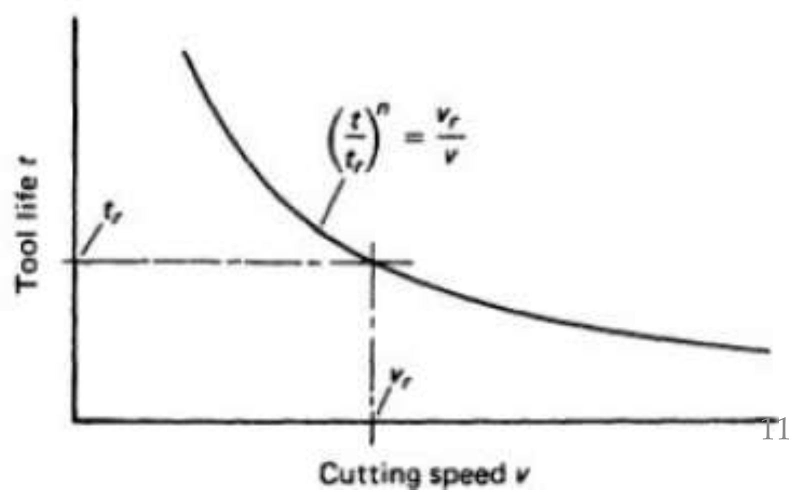
$$M\left(N_b \cdot t_1 + N_b \cdot t_m + N_t \cdot t_c\right)$$

- The average production cost for each component can now be written

$$\boxed{C_{pr} = Mt_l + Mt_m + M\frac{N_t}{N_b}t_c + \frac{N_t}{N_b}C_t}$$

where, $N_t \cdot C_t$ = total number tools used to machine the entire batch

- To calculate the number of tools used in producing the batch of components ii is necessary to know the relationship between cutting speed and tool life. Taylor showed that an empirical relationship exists between these variables as shown



- Now, $\boxed{\dfrac{v}{v_r} = \left(\dfrac{t_r}{t}\right)^n}$

  where,

  v = cutting speed

  t = tool life

  n = constant

  t_r = measured tool life for a given cutting speed v_r

- The value t_r of may be found for a particular work piece and tool material and a particular feed either by experiment or from published empirical data. The index n depends mainly on the tool material; for high-speed steel n~0.125,for carbide $0.25 < n < 0.3$, and for ceramics $0.5 < n < 0.7$

- Traditionally, the Taylor tool-life equation is,

$$\boxed{v.t^n = C}$$

- The number of tools N_t used in machining the batch of components is given by $N_b . t_m / t$ assuming that the tool is engaged with the work piece during the entire machining lime. Thus,

$$\frac{N_t}{N_b} = \frac{t_m}{t} = \frac{t_m}{t_r} . \left(\frac{v}{v_r} \right)^{1/n}$$

- Finally, the machining time for one component is given by

$$t_m = \frac{L}{v}$$

where v is the cutting speed and L is a constant for the particular operation

- The relationship between the production cost and the cutting speed can now be obtained by

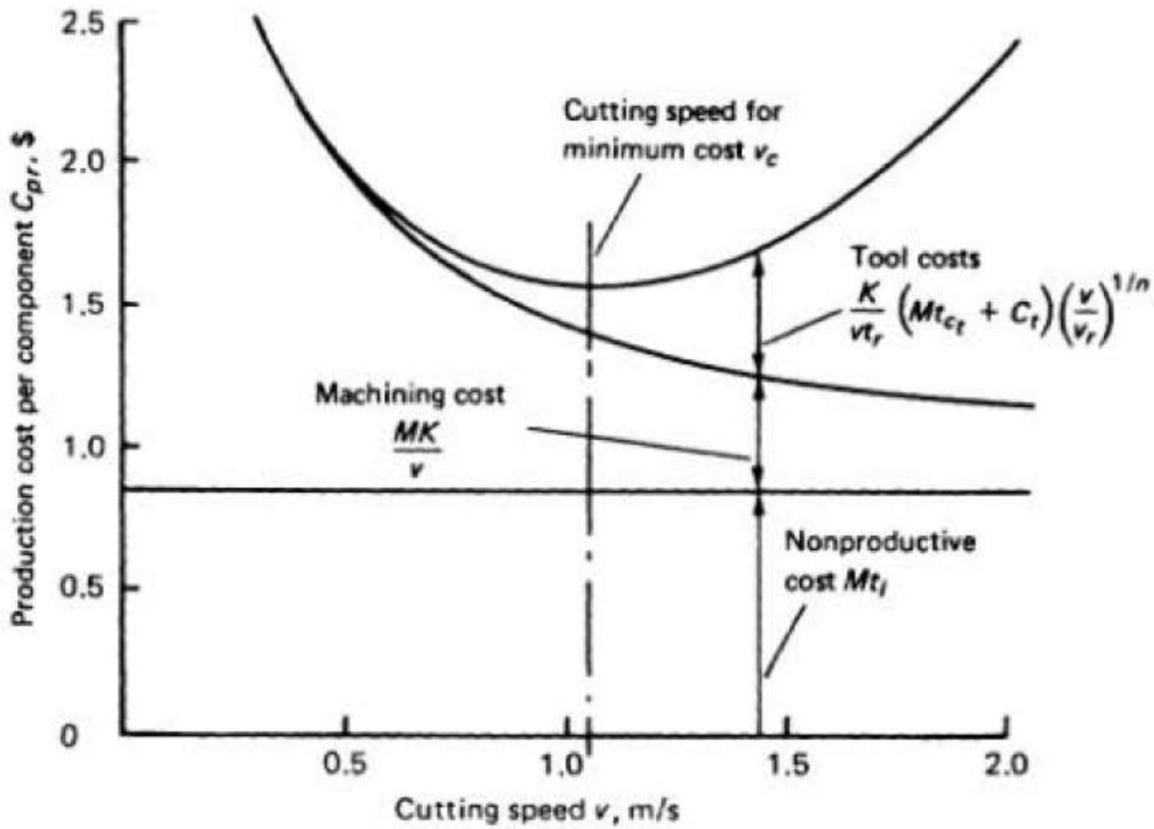
$$C_{pr} = Mt_1 + MLv^{-1} + \frac{L}{v_r^{1/n} \cdot t_r}(M\,t_c + C_t)V^{(1-n)/n}$$

- Optimum speed for minimum cost can be given by

$$\frac{dC_{pr}}{dV} = 0$$

$$\boxed{\therefore v_c = v_r\left(\frac{M\,t_r}{(M\,t_c + C_t)}\frac{n}{(1-n)}\right)^n}$$

- The effect of cutting speed on the cost of production can more clearly be shown in the form of a graph. In the figure the three individual cost items represented, the nonproductive cost, the machining cost, and the tool costs, are plotted separately and show how an optimum cutting speed arises for a given set of conditions



- To find the cutting speed giving maximum production rate (or minimum production time) it is necessary to follow a similar procedure
- Average production time for one component is given by

$$t_{pr} = t_1 + t_m + \frac{N_t}{N_b} t_c$$

- And cutting speed for minimum production time is,

$$\boxed{v_p = v_r \left(\frac{t_r}{t_c} \frac{n}{(1-n)} \right)^n}$$

- Comparison shows that application of the criteria for minimum cost and minimum production time yield different conditions

TOOL LIFE FOR MINIMUM COST AND MINIMUM PRODUCTION TIME

- The optimum tool life for minimum cost t_c and t_p the optimum tool life for minimum production time.

$$t_c = \frac{1-n}{n}\left(t_{c_t} + \frac{C_t}{M}\right)$$

and $$t_p = \left(\frac{1-n}{n}\right)t_{c_t}$$

For practical use the factor $\frac{(1-n)}{n}$ in upper equation given the valve 7 for high speed steel, 3 for carbide, and 1 for oxide or ceramic.

- these values the approximate expressions for the optimum tool life for various tool materials becomes for
- High-speed steel:

$$t_c = 7\left(t_{c_t} + \frac{c_t}{M}\right)$$

$$t_p = 7t_{c_t}$$

- carbide:

$$t_c = 3\left(t_{c_t} + \frac{C_t}{M}\right)$$

$$t_p = 3t_{c_t}$$

- oxide or ceramic:

$$t_c = t_{c_t} + \frac{C_t}{M}$$

$$t_p = t_{c_t}$$

- Finally, the corresponding optimum cutting speeds can be found from

And $$v_c = v_r\left(\frac{t_r}{t_c}\right)^n$$

$$v_p = v_r\left(\frac{t_r}{t_p}\right)^n$$

ESTIMATION Of FACTORS NEEDED TO DETERMINE OPTIMUM CONDITIONS

- The method of calculating these costs varies from factory to factory, but the following expression would be applicable in most cases:

$$M = W_0 + \left(\frac{operator}{100}\right) W_0 + M_t \left(\frac{machine}{100}\right) M_t$$

w_0= operator's wage rate

M_t = depreciation rate of machine tool

- Operator overhead can vary from 100 to 300 percent and in· eludes the worker's benefits provided by the company,

- the cost of providing the working facilities, and the cost of the administrators necessary to employ the worker.
- Machine overhead includes the cost of the power consumed by the machine,
- the cost of servicing the machine, and possibly the cost of providing the location for the machine.

- The following expression would generally be used to estimate the machine depreciation rate:

  M_t = initial cost of machine /(num of working hours per year)*(amortization period)

- The method used to estimate tool costs depends on the type of tool used. For regrindable tools the following expression can be used to estimate the cost of providing a sharp tool
- C_t= cost of grinding + cost of tool /(avg num of regrinds possible)
- For disposable-insert tools, the cost of providing a sharp tool can be estimated from the following equation:

  C_t = cost of insert / (avg num of cutting edge use per insert)

  \+ cost of holder / (num of cutting edges used during life of holder)

- To illustrate the application of the expressions developed thus far it will be assumed that a large batch of steel shafts are to be rough-turned to a 76mm diameter for 300mm of their length at a feed of 0.25 mm . A brazed type carbide tool is to be used, and the appropriate constants in Taylor's tool-life equation for the conditions employed arc as follows: n=0.25, and v_r=4.064 m/s when t_r =60s (C =800 ft/min). The initial cost of the machine was $10,800 and is to be amortized over 5 years. The operator's wage will be assumed to be $0.0015/s ($5.40/hr), and the operator and machine overheads arc 100 percent Tool-changing and resetting time on the machine is 300s and the cost of regrinding the tool is $2.00. The initial cost of a tool is $6.00, and, on the average, it can be reground 10 times. Finally, the nonproductive time for each component is 120 s.

- The first step in these calculations is to estimate the magnitudes of the relevant factors:

1. The machine and Operator rote M: If the machine is to be used on an 8·hr shift per day, 5 days per week, and 50 weeks per year , each year will contain 7.2 Ms (7 X 10^6 s) of working time. The machine depreciation rate (Eq M_t)therefore

$$M_t = \frac{10800}{7.2\times10^6\times5} = \$0.0003/s$$

thus the machine and operator rate

$$M = 0.0003 + 0.0003 + 0.0015 = \$0.0036/s$$

2. The cost of providing a sharp tool C_t: This cost can be found from

$$C_t = \$2.60$$

3. The tool-changing time t_{c_t}: This value is given as

$$t_{c_t} = 300s$$

It is now possible to estimate the tool life t_c, and cutting speed v_c, for minimum cost and the tool life t_p, and cutting speed v_p, for minimum production time.

$$t_c = 3\left(t_{c_t} + \frac{c_t}{M}\right) = 3\left(300 + \frac{2.6\times10^3}{3.6}\right)$$

$$= 3.07ks(51.2\min)$$

- and the corresponding cutting speed

$$v_c = v_r \left(\frac{t_r}{t_c} \right)^n = 4.064 \left(\frac{60}{3070} \right)^{0.25}$$

for min production time :

$$= 1.52 m/s (407 ft/\min)$$

and the corresponding cutting speed

$$t_p = 3 t_{c_t} = 900 \, s$$

$$v_p = v_r \left(\frac{t_r}{t_p} \right)^n = 4.064 \left(\frac{60}{900} \right)^{0.25}$$

$$= 2.065 m/s (407 ft/\min)$$

- minimum cost the time taken to machine one component $t_{m,}$

$$t_m = \frac{\pi d_w l_w}{vf} = \frac{\pi \times 76 \times 10^{-3} \times 300 \times 10^{-3}}{1.52 \times 0.25 \times 10^{-3}} = 189s(3.15\,\text{min}$$

- Since the tool life is 3070s, each tool will produce 16 components, and the ratio N_t/N_b. in the cost equation will be equal to 0.0625.
- Nonproductive cost= $Mt_m = 3.6 \times 10^{-3} \times 120$

  $= \$0.432$

- Machining cost = Mt_m = 3.6 x 10^{-3} x 189

= \$0.68

$$tool\,\text{cost} = \left(\frac{N_t}{N_b}\right)\left(Mt_{c_t} + c_t\right)$$

$$= 0.625\left[\left(3.6\times10^{-3}\times300\right)+2.6\right]$$

$$= \$0.23$$

Finally the total cost C_{pr} is \$1.34.

Nonproductive time = t_l = 120 s

Machining time = t_m = 189 s

Tool changing time =

the total production time t,. is 328 s (5.5 min~

$$\left(\frac{N_t}{N_b}\right)t_{c_t} = 0.0625\times300$$

$$= 18.75s$$

Reference

- Fundamentals of Machining & Machine Tools 2Ed - Geoffrey Boothroyd