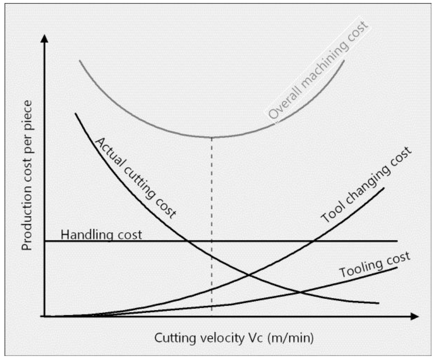
ME338 – Manufacturing Process II
Lecture 8 : Machining Economics



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Selection of process parameters

- Process Parameters : Cutting speed, feed, depth of cut
- First select depth of cut:
  - Based on the dimensions required and operation sequence
- Then, select feed rate
  - Rough cut or finish cut
  - Upper limit of feed based on machine tool, fixturing for roughing
- Optimize the cutting speed
  - Cutting speed should provide a high metal removal rate yet suitably long tool life
- Selection of cutting speed, or cutting speed and feed can be made using unconstrained or constrained mathematical optimization methods.
  - Optimization is based on time, cost, or profit rate criteria.

Optimization Criteria

- Commonly employed optimization criteria (objectives) are:
- Max. production rate or min. production time :
  - aims to maximize number of parts produced in a unit time interval or minimizes the time per unit part.
  - <u>Neglects cost and/or profit.</u>
- Min. production cost :
  - aims to determine the least production cost. Coincides with max. profit rate criterion for constant unit revenue.
  - <u>Ignores time constraints.</u>
- Usually one of the two criteria is used. Sometimes both criteria are used simultaneously.
- Decision Variables : Depth of cut (d), Feed (f), Cutting speed (V)

Processing time

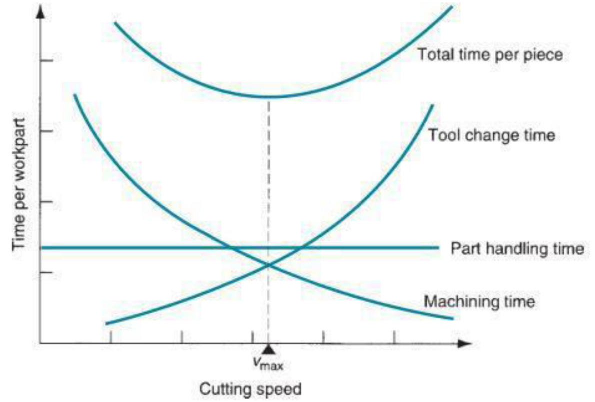
- Production time in machining
  - Part handling time, Machining time & Tool changing time
- Part handling time (t_h)
  - Time required for loading and unloading of the part
  - Also includes additional time required to reposition the tool for the next operation
- Machining time (t_m)
  - The actual time required for the machining of the part will depend on the feed rate a
  - Rotation speed $N = \frac{V}{\pi D}$
  - Machining time for turning operation:
  - $t_m = \frac{L}{f_r} = \frac{L}{fN} = \frac{\pi DL}{Vf}$

Processing time

- Tool change time, (t_t)
  - Tool is changed, at the end of its tool life
  - If n_p= The number of pieces cut in a single tool life (T)
  - Then the tool change time per part = $\frac{t_t}{n_p}$
  - Number of components produced in given tool life (T) will be = $n_p = \frac{T}{t_m}$
- Using Taylor's tool life equation $VT^n = C$, OR $T = \left(\frac{C}{V}\right)^{\frac{1}{n}}$
- Now, $n_p = \frac{T}{t_m} = \frac{\left(\frac{C}{V}\right)^{\frac{1}{n}}}{\frac{\pi DL}{Vf}}$; $n_p = \frac{fC^{\frac{1}{n}}}{\pi DLV^{\frac{1}{n}-1}}$;
- If n_p components are made in given tool life, then total production time per component $t_C = t_h + t_m + \frac{t_t}{n_p}$
- $t_C = t_h + \frac{\pi DL}{Vf} + t_t \frac{\pi DLV^{\frac{1}{n}-1}}{fC^{\frac{1}{n}}}$

Processing time

- If n_p components are made in given tool life, then total production time per component
- $t_C = t_h + t_m + \frac{t_t}{n_p}$
- Note that only tool life T and the machining time t m are functions of V



Processing Cost

- Cost components that determine total cost of producing one part during a turning operation
- Machine and operator rate (C_0):
  - It includes the operator's labor rate, operator overheads (OH), Machine tools depreciation rate and machine tool overheads (OH), etc
- C_0 = Labor rate (salary/hour) + (%operator OH) × labor rate + Machine tool depreciation rate + (% machine tool OH) × Machine tool depreciation rate
- Labor rate can be find assuming 8 hour per day, 5/6 days per week
- Overhead (OH): Indirect costs
  - To calculate the overhead costs of a business, add all the ongoing business expenses that keep business running but do not contribute to the revenue generation process.
  - Indirect costs: Administrative expenses, Selling and marketing costs and production expenses.
  - Often exceed more than the direct costs, i.e., OH>100%

Processing cost

- Cost of part handling:
  - Cost of the time the operator spends loading and unloading the part
  - If C_0 is the machine and labor rate, the cost for handing is $C_0 t_h$
- Cost of machining:
  - Cost of the time the tool is engaged in machining
  - It is given by, $C_0 t_m$
- Cost of tool change:
  - Cost of changing the tool $C_0 \frac{t_t}{n_p}$
  - Where t_t is tool changing time and n_p is number of pieces machined with cutting edge
- Tooling cost:
  - In addition to the cost associated with tool change time, the tool itself has a cost that must be added to the total operation cost

Processing cost : Tooling cost

- Tooling cost (C_t):
  - In addition to the cost associated with tool change time, the tool itself has a cost that must be added to the total operation cost
- Tooling cost for disposable insert (ceramic):
  - Tooling cost (C_t) $C_t = \frac{P_t}{n_e}$
  - Where P_t price of the insert and n_e number of cutting edges per insert
- Tooling cost for re-grindable insert (like HSS):
  - Tooling cost (C_t) $C_t = \frac{P_t}{n_g} + t_g C_g$
  - n_g = the number of times the tool can be ground before it can no longer be used,
  - t_g = time to grind or regrind the tool, min/tool life;
  - C_g = grinding machine and labor rate

Processing cost

- Total cost per unit product for the machining cycle (C_c):

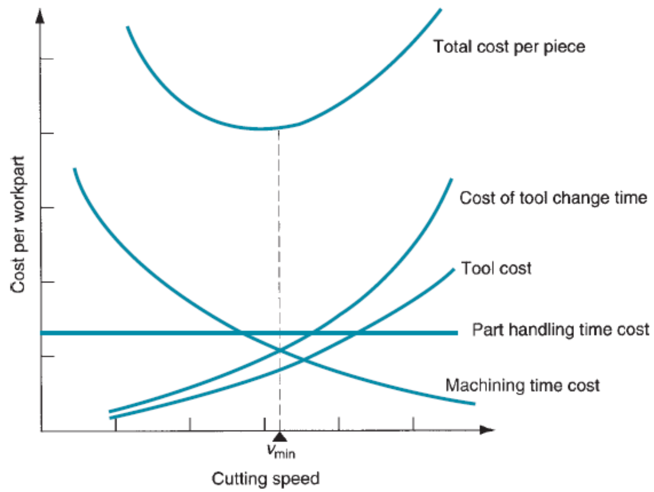
$$C_c = C_0 t_h + C_0 t_m + \underbrace{\frac{C_0 t_t}{n_p} + \frac{C_t}{n_p}}_{\text{Costs associated with tooling}}$$

- Substituting the processing times in the above equation:

$$C_c = C_0 t_h + C_0 \frac{\pi D L}{f V} + (C_0 t_t + C_t) \frac{\pi D L V^{\frac{1}{n}-1}}{f C^{\frac{1}{n}}}$$

- Thus, C_c is a function of cutting speed (V)

Processing Cost



Maximizing Production Rate

- Minimizing actual cutting time per component will realize maximum production rate.
- $t_C = t_h + t_m + \frac{t_t}{n_p}$ or $t_C = t_h + \frac{\pi D L}{V f} + t_t \frac{\pi D L V^{\frac{1}{n}-1}}{f C^{\frac{1}{n}}}$
- As cycle time, t_c is function of cutting speed V :

$$\frac{dt_c}{dV} = 0 \Rightarrow \quad V_{opt} = \frac{C}{\left\{\left(\frac{1}{n} - 1\right) t_t\right\}^n}$$

- The corresponding tool life (T_{opt})for max production rate:

$$T_{opt} = \left(\frac{1}{n} - 1\right) t_t$$

- For practical use the factor $(\frac{1}{n} - 1)$ = 7 for HSS tool, = 3 for carbide, and = 1 for ceramic tool

Minimizing Cost per Unit

- For minimum cost per unit, the speed that minimizes production cost per piece for the operation is determined
- As the cost C_c is function of cutting speed V :

$$C_c = C_0 t_h + C_0 \frac{\pi DL}{fV} + (C_0 t_t + C_t) \frac{\pi DLV^{\frac{1}{n}-1}}{fC^{\frac{1}{n}}}$$

$$\frac{dC_c}{dV} = 0 \Rightarrow \quad V_{opt} = C\left\{\left(\frac{n}{1-n}\right)\frac{C_0}{C_t + C_0 t_t}\right\}^n$$

- The corresponding tool life for min cost per unit:

$$T_{opt} = \left(\frac{1}{n} - 1\right)\left(\frac{C_0 t_t + C_t}{C_0}\right)$$

Example

A cylindrical bar is to be turned. The maximum allowable feed is 0.2 mm/revolution and at this feed rate Taylor's tool life equation for a tool-work combination is found to be $vT^{0.25} = 75$, where v is the cutting speed in m/min and T is the corresponding tool life in minutes. The labour cost and overheads is \$0.15 per minute and the total cost involved in each regrinding of the tool is \$2.50. On the average, it takes about 2 minutes to change the tool. Estimate the cutting speed that will lead to the minimum cost.

Example

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.

Solution

- 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

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

Solution

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.

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

$$= 3.07ks(51.2\,\text{min})$$

Solution

- 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 :

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

and the corresponding cutting speed

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

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

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

Solution

- minimum cost the time taken to machine one component t_m,

$$t_m = \frac{\pi d_w l_w}{vf} = \frac{\pi\times76\times10^{-3}\times300\times10^{-3}}{1.52\times0.25\times10^{-3}} = 189s(3.15\,\text{min}$$

- 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 x 10^{-3} x 120
= \$0.432

Solution

- Machining cost = Mt_m = 3.6 x 10^{-3} x 189
= \$0.68

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

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

$$= \$0.23$$

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_r. is 328 s (5.5 min~

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

$$= 18.75s$$