Manufacturing Processes (2), IE-352
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Manufacturing Engineering Technology in SI Units, 6th Edition

Chapter 25:
Machining Centers, Machine Tool Structures and Machining Economics

Chapter Outline

- *Introduction*
- *Machining Centers*
- *Machine-tool Structures*
- *Vibration and Chatter in Machining Operations*
- *High-speed Machining*
- *Hard Machining*
- *Ultraprecision Machining*
- **Machining Economics**

Machining Economics

- Limitations of machining/material removal operations:

1. Wasted material (although may be small)
2. Longer time (vs. forming/shaping): cutting/non-cutting
3. Require more energy (vs. forming/shaping)
4. Adverse effects on surface quality / properties of product

- Importance of machining (despite above):

1. Producing complex workpiece shapes (e.g. internal features)
2. High dimensional accuracy / surface finish

Machining Economics

- Costs/factors involved with machining:

1. Machine tools, work-holding devices, fixtures and cutting tools
2. Labor and overhead
3. Setting up time (machine for operation)
4. Material handling and movement (e.g. loading blank, unloading machine part)
5. Gaging for dimensional accuracy and surface finish
6. Cutting times and non-cutting time

Machining Economics

Minimizing Machining Cost per Piece

- Important in all manufacturing processes to minimize:
  - Machining *cost* per piece, C_p
  - Machining *time* per piece, T_p
- Various approaches exist (using software)
- Important: input data must be accurate and up to date to be reliable
- We show here simple/popular method of analyzing machining cost in turning operation

Machining Economics

Cont. Minimizing Machining Cost per Piece

- Total machining cost per piece, C_p, in turning is

$$C_p = C_m + C_s + C_l + C_t$$

C_m = Machining cost
C_s = Cost of setting up for machining—including mounting the cutter, setting up fixtures, and preparing the machine tool for the operation
C_l = Cost of loading, unloading, and machine handling
C_t = Tooling cost, often only about 5% of the total cutting operation. Consequently, using the least expensive tool is not always an effective way of reducing machining costs

- Following slides: discuss each of these costs in more detail

Machining Economics

Cont. Minimizing Machining Cost per Piece

$$C_p = C_m + C_s + C_l + C_t$$

- **Machining cost** per piece, C_m, is given by:

$$C_m = T_m \left(L_m + B_m \right)$$

  - T_m: machining time per piece
  - L_m: labor cost of production personnel per hour
  - B_m: burden rate (aka overhead charge), including:
    - Depreciation
    - Maintenance
    - Indirect labor, etc.

- The **setup cost**, C_s,is fixed amount (in $) per piece

Machining Economics

Cont. Minimizing Machining Cost per Piece

$$C_p = C_m + C_s + C_l + C_t$$

- **Loading**/unloading, machine-handling **cost**, C_l, per piece:

$$C_l = T_l\left(L_m + B_m\right)$$

  - T_l: time required to,
    - load/unload part
    - change speeds
    - change feed rates, etc.
  - L_m and B_m: see last slide

Machining Economics

Cont. Minimizing Machining Cost per Piece

$$C_p = C_m + C_s + C_l + C_t$$

- The **tooling cost**, C_t, per piece:

$$C_t = \frac{1}{N_i}[T_c(L_m + B_m) + D_i] + \frac{1}{N_f}[T_i(L_m + B_m)]$$

  - N_i: numbered of parts machined per insert
  - N_f: numbered of parts that can produced per insert face
  - T_c: time required to change the insert
  - T_i: time required to index the insert
  - D_i: depreciation of insert (in $)

Machining Economics

Cont. Minimizing Machining Cost per Piece

- The time required to produce one part is

$$T_p = T_l + T_m + \frac{T_c}{N_i} + \frac{T_i}{N_f}$$

  - T_m: calculated for each particular operation
- Example: for turning:

$$T_m = \frac{L}{fN} = \frac{\pi LD}{fV}$$

  - L: length of cut
  - f: feed
  - N: angular speed (rpm) of the workpiece
  - D: workpiece diameter
  - V: cutting speed (note, appropriate units must be used)

Machining Economics

Cont. Minimizing Machining Cost per Piece

- From the Taylor tool-life equation, $$T = \left(\frac{C}{V}\right)^{1/n}$$
  - T: time (min) to reach a certain flank wear (before regrinding/changing insert)
- The number of pieces per insert face: $$N_f = \frac{T}{T_m}$$
- Number of pieces per insert: $$N_i = mN_f = \frac{mT}{T_m}$$
  - m: number of faces actually used
    - Note, m: not necessarily number of faces per insert
    - Reason: not all faces are used before insert is discarded
- Combining T and T_m in N_i: $$N_i = \frac{mfC^{1/n}}{\pi LDV^{(1/n)-1}}$$

Machining Economics

Cont. Minimizing Machining Cost per Piece

- We now seek to determine optimum V (V_o) and T (T_o)
- First we find V_o and T_o for **min. cost**, C_p
- We differentiate C_p with respect to V and set it to zero,

$$\frac{\partial C_p}{\partial V} = 0$$

$$\Rightarrow \qquad V_0 = \frac{C\left(L_m + B_m\right)^n}{\left(\frac{1}{n} - 1\right)^n \left\{\frac{1}{m}\left[T_c\left(L_m + B_m\right) + D_i\right] + T_i\left(L_m + B_m\right)\right\}^n}$$

$$T_0 = \left(\frac{1}{n} - 1\right) \frac{\frac{1}{m}\left[T_c\left(L_m + B_m\right) + D_i\right] + T_i\left(L_m + B_m\right)}{L_m + B_m}$$

Machining Economics

Cont. Minimizing Machining Cost per Piece

- Again we seek to determine optimum V (V_o) and T (T_o)
- Now we find V_o and T_o for **max. prod^{on},** i.e. min. T_p
- We differentiate T_p with respect to V and set it to zero,

$$\frac{\partial T_p}{\partial V} = 0$$

$$\Rightarrow \qquad V_0 = \frac{C}{\left[\left(\frac{1}{n} - 1\right)\left(\frac{T_c}{m} + T_i\right)\right]^n}$$

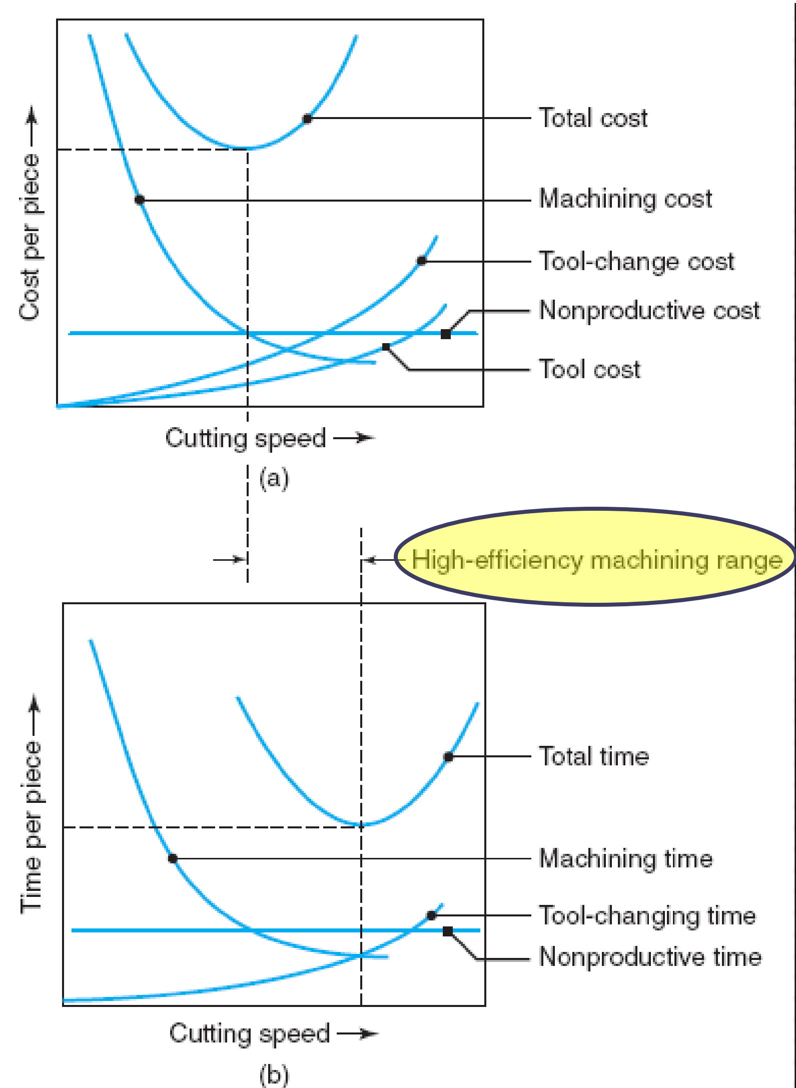
$$T_0 = \left(\frac{1}{n} - 1\right)\left(\frac{T_c}{m} + T_i\right)$$

Machining Economics

Cont. Minimizing C_p per Piece

- Qualitative plot of C_p/piece
  - Note, C_p also depends on req. surface finish:
    better S.F. $\Rightarrow$ higher C_p
  - Note, $\boldsymbol{V_o = V\ @C_{p,min}}$

- Qualitative plot of T_p/piece (i.e. production rate)
  - Note, $\boldsymbol{V_o = V\ @T_{p,min}}$
  - Range bet. Two V_o's is: "high-efficiency machining range"



Machining Economics

Cont. Minimizing Machining Cost per Piece

- Final notes
  - Important to have accurate data, since small changes in V greatly affect $C_{p,min}$ and $T_{p,min}$ (see last slide)
  - Previous analysis can be done for all manufacturing processes:
    - E.g. Cost/part in sand casting uses
    - E.g. Cost/part in powder metallurgy, etc.