Optimization of Machining Processes

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Outline

- Product-Process Optimization criteria
- Machining Process Optimization Objective
  - To *Maximize* Productivity
  - To *Minimize* Cost
  - To *Maximize* Profit rate
- Selection of Optimum Process Parameters

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Product-Process Optimization Perspective

Product Design Optimization

- Material Selection – Function related
- Shape design Constraints : Size, Stress, Thermal
- Product Quality - Dimensions, Tolerances

Production Process Optimization

- Optimum Plant Layout
  - Product Flow in shop
- Supply Chain ; Inventory management
- Production Unit Operation
  - Selection of Optimum Process Parameters (Local optimization)

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Criteria for Process Optimization

Aim

To select Optimum Process Parameters

Criteria

- *Maximize* Productivity
  - Minimum Production time / job
- *Minimize* Cost per piece
- *Maximize* Profit rate

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Formulating Objective Function

Nomenclature

N_b = No of parts produced in the batch
N_t = No of Tools used for N_b
t_s = Setup time per job
t_m = Machining time per job
t_{ct} = Tool changing time per tool
N = Spindle speed
V = cutting Speed (m/min)
f = feed rate (mm/rev)

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Calculation of Production Time

Production time for batch of N_b parts

$T = N_b.t_s + N_b.t_m + N_t.t_{ct}$

Production Time per piece t_p

$$t_p = \frac{T}{N_b} = t_s + t_m + \frac{N_t}{N_b}.t_{ct}$$

Where,
t_s = Setup time per job
t_m = Machining time per job
t_{ct} = Tool changing time per tool

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Calculating Setup Time t_s

Set up time is the *Non Cutting* (Idle) time.

It comprises of

- Set up of machine / Tool / Fixtures
- Loading/ Unloading of job
- Approach of tool to job at start
- Tool return to the start of cut

Optimization of Turning Process

Single Pass, Single Tool, Constant feed Operation

Cutting Speed $V = \frac{\pi DN}{1000}$ (m/min)
Job dimensions D,L in mm
Spindle speed N in RPM
Feed f in mm/rev

Machining time per job

$t_m = \frac{L}{N.f}$ min

$= \frac{\pi DL}{1000Vf}$

$t_m = \frac{K}{V}$ K is the Constant

Calculating Tools used

Taylor's Tool Life Equation

$VT^n = C$

Tool Life T = $\frac{C^{Vn}}{V^{Vn}}$

Cutting Speed V in m/min; Tool Life T in min

N_t tools are used for producing N_b jobs

$N_t .T = N_b .t_m$

Substituting

$\frac{N_t}{N_b} = \frac{t_m}{T} = \frac{KV^{n-1}}{C^{Vn}}$

Formulating Objective Function - t_p

Time per piece t_p

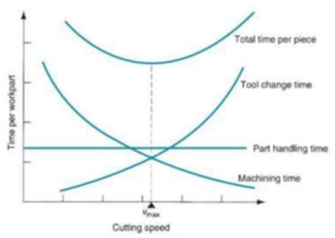
$$t_p = t_s + \frac{K}{V} + \frac{KV^{\frac{1}{n}-1}}{C^{1/n}}.t_{ct}$$

To maximise Productivity
Minimize t_p

$\frac{dt_p}{dv} = 0$

t_p varies as a function of V

Production time t_p vs V



Optimum Parameters for minimum t_p

For minimum t_p

Tool Life t_p is

t_p = $(\frac{1}{n} - 1)\, t_{ct}$

Ccutting Speed V_p

V_p = $\frac{C}{{T_p}^n}$

Optimizing Cost per piece C_p

C_p includes M and C_t

M = Machine Hour Rate (Rs/min)
M includes
- Price of the machine
- Amortization period
- Labor Rate
- Cost of land, power
- Overheads

C_t = Cost of one tool / insert edge

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Objective Function C_p

Cost of producing N_b parts in the batch

C_b = Setup + Machining + Tool cost

$= M.\ N_b\ .\ t_s + M.\ N_b\ .\ t_m + N_t\ .C_t + N_t\ .t_{ct}\ .M$

Cost per piece $C_p = \frac{C_b}{N_b}$

$C_p = M.\ t_s + M.\ t_m + \frac{N_t}{N_b}.C_t + \frac{N_t}{N_b}.t_{ct}\ .M$

$C_p = M.\ t_s + M.\ t_m + M\frac{N_t}{N_b}[t_{ct} + \frac{C_t}{M}]$

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Formulating Objective Function C_p

Substituting

$t_m = \frac{K}{V}\ ;\ \frac{N_t}{N_b} = \frac{KV^{\frac{1}{n}-1}}{C^{V_n}}$

Objective Function C_p

$C_p = M.\ t_s + M.\frac{K}{V} + M\frac{KV^{\frac{1}{n}-1}}{C^{V_n}}[t_{ct} + \frac{C_t}{M}]$

To minimize Cost C_p

$$\frac{dC_p}{dv} = 0$$

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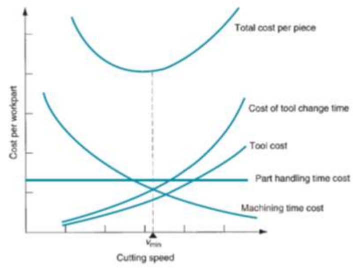
Cost per piece C_p vs V



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Optimum Parameter for minimum C_p

For minimum C_p,

Optimum Tool Life T_c

$T_c = (\frac{1}{n} - 1)[t_{ct} + \frac{C_t}{M}]$

Optimum Cutting Speed V_c

$V_c = \frac{C}{T_c^{\ n}}$

It is seen that

$T_c > T_p$

So $V_c < V_p$

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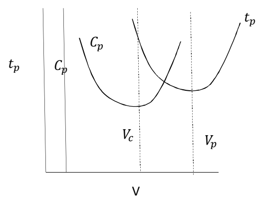
Hi – Efficiency Range



V_c - V_p – high E Range

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Calculation of Tool Cost C_t

<u>Regrindale tools</u>

N_g = No of grinds

C_g = Cost of grinding per regrind

$$C_t = \frac{N_g \times C_{g\ +\ Tool\ Cost}}{N_g + 1}$$

<u>Throw away Carbide insert</u>

C_i = cost of insert

N_e = No of cutting edges provided

$$C_t = \frac{C_i}{N_e}$$

For a square insert;

N_e = 4 (positive rake on insert)

= 8 (Zero rake on insert)

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Constraints in Optimization

On the *Unconstrained* Optimization , the following constraints apply

- Maximum Speed, Feed provided on machine
- Steps in Speed, Feed (or Stepless speed drve)
- Permissible Surface Finish
- Maximum Cutting Force, Power
- Shop Practices

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Two Factor Optimization

<u>Objective Function</u>

t_p or C_p = f(V, f)

<u>Extended Taylor's Tool Life equation</u>

T $V^{n_1}\ f^{n_2}\ = C^1$

<u>Optimization Technique</u>

- Unconstrained
- Cconstrained

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