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Numerical Optimization of Turning Operation By Variant Machining Environments

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ABSTRACT

Here in this paper we try to optimize the turning operation by varying some variables by some positive constraint involving numerical solution of maximizing problem as a objective function. For turning operation we Consider unit cost of production as an objective function. The optimality conditions for single point cutting operation are determined based on objective function. By considering tool life equation and minimum cost involve with minimum tool wear to optimize the turning operation.

KEYWORDS: cost, tool life, feed rate, depth of cut, cutting speed.

1.INTRODUCTION

In today's global setting, advance-manufacturing process demands high quality of product with minimum cost. Machining operation is one of the major cost centers for manufacturing of a product. The production cost can also be minimized by reduction of machining cost through optimization of machining condition and proper setting of various parameters during machining. The production cost may be enhanced due to rapid tool wear and frequent changes of cutting tool. The production cost can also be reduced by reducing the lead time and proper selection of machine tools, cutting tool material, tool geometry, cutting parameters, e.g. velocity, feed rate, depth of cut and as well as through proper selection of work-piece geometry. This variable governs the economics of machining operations.

Cakir and Gurada, 2000.There is a vital need to correlate the technological factors Involve in the machining process to reach economy of the process and product in practice.Considering minimum production

NOMENCLATURE

C = total cost of making one component (excluding material cost)
C_1 = non-productive cost per component (cost of loading and unloading the component, idle time costs and other non-cutting time costs)
C_2 = cost of machining time,
C_3 = tool changing time cost,
C_4 = tool cost per component,
D = *work* diameter
d = depth of cut in m, and
f = feed in m/rev,
l = distance traveled by the tool in making one turning pass (m),
N = spindle speed (revolutions per second),
T = tool life,
T_{ac} = actual cutting time;
$\left(\frac{T_{ac}}{T}\right)$ =Number of tool (or cutting edge) changes per component,
T_c = changing time,
T_d = time required to change a cutting edge,
T_{fm} = tool life for minimum cost per component (while optimizing feed rate)

T_l = sum of all non-productive times,
T_{vm} = tool life for minimum cost per component (while optimizing cutting speed).
V = cutting speed in m/min,
x = cost rate including labor and overhead cost rates, and
y = tool cost per cutting edge.
K, A, B = constants.
$1/n$, $1/n_1$, $1/n_2$ are exponents of speed, feed and depth of cut

cost as the objective function described a procedure for evaluating the machining conditions during milling operation.

Juan et al., 2003Forminimizing production cost during rough milling, an optimization algorithm using a simulated annealing method was developed.

Shunmugam et al., 2000To yield the minimum total production cost during face milling operation the machining parameters such as depth of cut in each pass, speed and feed were optimized using genetic algorithm.

2. ECONOMIC OPTIMIZATION OF MACHINING CONDITIONS

In general, the lowest cost per component consideration leads to lower production rate. Sometimes, optimization process may give the machining conditions which may be beyond the capabilities of the available machine tool. Hence, in selecting the economic operating conditions, machine tool capacities must be taken into account. If the selected conditions are not available on the machine tool proposed for a particular operation, it is necessary to either change the operating conditions or review the machine tool selection by cost comparison. One should not select the machine tool of the capacity higher than the desired one. The capacity limits of a machine tool include feed, speed, power and maximum allowable cutting force (or thrust force). Further, there may be feed and speed constraints to achieve the desired surface finish on the component. A component usually requires more than one pass of cutting for completion. For simplicity of analysis, we have analyzed only a simple case of single pass turning operation.

2.1 Unit Cost per Component

The machining cost per component is made up of a number of different costs. The total cost (C) of making one component (excluding material cost) is given by

$$C = xT_l + xT_c + xT_d\left(\frac{T_{ac}}{T}\right) + y\left(\frac{T_{ac}}{T}\right) \quad (1)$$

$$\text{or,} \quad C = C_1 + C_2 + C_3 + C_4 \quad (2)$$

(Fixed charges are not taken into account because they will not affect optimization.)

For a brazed tool tip, the cost / cutting edge

$$y = \frac{\text{Cost of tool}}{\text{No. of resarpening} + 1} \quad (3)$$

For the throw away tips,

$$y = \frac{\text{Cost of tool}}{\text{No. of cutting edges}} + \frac{\text{Cost of tool holder} + \text{Accessories}}{\text{No. of cutting edges over the life of the tool holder}} \quad (4)$$

From Eq. (1), it is evident that cost per component can be reduced by decreasing the loading time, unloading time, idle time and tool changing time (by employing improved fixtures, jigs, inspection gauges, tool holder, etc). Improved tool materials and tool geometry which give longer tool life values and hence would reduce the number of tool replacements and grinding costs. Increasing the cutting speed has opposing effects on the cost per component because C_2 decreases while the total tool costs ($C_3 + C_4$) increase. The production rate is inversely proportional to the production time per component. The total production time per component (T_t) is given by

$$T_t = T_l + T_c + T_d\left(\frac{T_{ac}}{T}\right) + y\left(\frac{T_{ac}}{T}\right) \quad (5)$$

As for minimum cost, decrease in T_l and T_d will increase the production rate. Increase in cutting speed will reduce T_c but it will increase the tool changing time per component (tool life decreases at higher cutting speed).

The generalized tool life equation for a turning operation is given by

$$T = \frac{K}{V^{1/n} f^{1/n_1} f^{1/n_2}} = \frac{A}{V^{1/n} f^{1/n_1}} = \frac{B}{V^{1/n}} \tag{6}$$

2.3 MINIMUM COST PER COMPONENT CRITERION

Procedure to achieve optimum cutting speed and optimum feed rate for minimum cost per component involves the following steps :

(i) Write the total cost equation (Eq. (1)) in terms of the two variables (f and V) only (depth of

cut is assumed to remain constant for a single pass case).

(ii) Differentiate the total cost equation with respect to cutting speed V and feed f separately, and solve them.

(iii) From the equations obtained in Step (ii), derive an equation for tool life for minimum cost per component.

(iv) Consider various necessary constraints and modify the selected optimum machining conditions.

The values x, T_l, T_d and y in Eq. (1) are found from the cost data and standard times hand book. Since the depth of cut is usually fixed, the speed and feed must be chosen to minimize the cost per component. Machining time (for single pass) T_c is, generally, approximately equal to the actual cutting time T_{ac}, and is found from

$$T_c = \frac{l}{fN} = \frac{l}{\lambda V f} \cong T_{ac} \tag{7}$$

Step 1

Substituting Eqs. (6) and (7) in (1), cost per component in terms of speed and feed is given by.

$$C = xT_l + x\frac{l}{\lambda V f} + xT_d\frac{l}{\lambda A}V^{(1/n-1)}f^{(1/n_1-1)} + \frac{yl}{\lambda A}V^{(1/n-1)}f^{(1/n_1-1)} \tag{8}$$

Step 2

Following two cutting conditions should be satisfied to get minimum cost per component (i.e., to get optimum cutting speed and optimum feed).

$$\frac{\partial C}{\partial V} = 0 \tag{9}$$

$$\frac{\partial C}{\partial f} = 0 \tag{9.1}$$

Partially differentiating Eq. (8) with respect to cutting speed V, we get,

$$\frac{\partial C}{\partial V} = 0 + x\frac{l}{\lambda f}(-1)V^{-1-1} + xT_d\frac{l}{\lambda A}f^{1/n_1-1}\left(\frac{1}{n}-1\right)V^{1/n-1-1} + \frac{yl}{\lambda A}f^{1/n_1-1}\left(\frac{1}{n}-1\right)V^{1/n-1-1}$$

or, $$\frac{\partial C}{\partial V} = -x\frac{l}{\lambda f}V^{-2}\frac{l}{\lambda A}f^{1/n_1-1}\left(\frac{1}{n}-1\right)V^{1/n-2}(xT_d + y) \tag{9.2}$$

Using Eq. (9.1), Eq. (9.2) become as :

$$\frac{xl}{\lambda f V^2} = \frac{l}{\lambda A}f^{1/n_1-1}\left(\frac{1}{n}-1\right)V^{1/n-2}(xT_d + y)$$

or, $$1 = \left(\frac{1}{n}-1\right)\frac{f^{1/n_1}V^{1/n}}{A}\left(\frac{xT_d + y}{x}\right) \tag{10}$$

$$1 = \left(\frac{1}{n}-1\right)\frac{V^{1/n}}{B}\left(\frac{xTd + y}{x}\right) \tag{10.1}$$

Eq. (10) gives the condition to determine optimum cutting speed.

$\frac{\partial C}{\partial f} = 0$ we get

$$\frac{\partial C}{\partial f} = 0 + x\frac{l}{\lambda V}(-1)f^{-1-1} + xT_d\frac{l}{\lambda A}V^{1/n-1}\left(\frac{1}{n_1}-1\right)f^{1/n-1-1} + \frac{yl}{\lambda A}V^{1/n_1-1}\left(\frac{1}{n}-1\right)f^{1/n-1-1}$$

or, $$\frac{xl}{\lambda f V^2} = \frac{l}{\lambda A}\left(\frac{1}{n}-1\right)V^{1/n-1}f^{1/n_1-1}(xT_d + y) \tag{11}$$

Eq. (11) gives the condition to determine optimum feed rate.

Eqs. (10) and (11) cannot be satisfied simultaneously and unique minimum does not occur.

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Step 3

Eq. (10) is represented in the form

$$\frac{A}{V^{1/n} f^{1/n_1}} = \left(\frac{1}{n} - 1\right)\left[\frac{xT_d + y}{x}\right] = T_{vm} \quad (12)$$

$$V = \frac{A^n}{T_{vm}^n f^{n/n_1}} \quad (13)$$

Problem Description

In a certain manufacturing company, a turning operation is performed under the following conditions:

Depth of cut = 0.00127 m
feed rate = 3.81 × 10^{-4} m / rev
work dia. = 76.2 × 10^{-3} m
axial length of cut = 0.1524 m
time required to load and unload components = 15 s/component
time required to change a tool = 4 min / tool.
Average cost of reconditioning a worn tool is Rs. 2/- per cutting edge
Machine operating cost is Rs. 10/hr
Number of components required per year is 30,000. The average numbers of components produced are 620 at 330 RPM and 15 at 535 RPM during the life of tools for each speed.

Solution towards optimization

To solve the problem, the steps to be followed are as given below:

(a) Convert all the data in the same units as shown in step 1

(b) Two spindle speeds are given in the problem and the third speed (optimum speed) can be calculated. Using the cost per component at these three speeds, the minimum cost per unit calculated using Eq. (1).

$$C = xT_l + xT_c + xT_d\left(\frac{T_{ac}}{T}\right) + y\left(\frac{T_{ac}}{T}\right)$$

(c) Calculate T_{ac} and T for both the given speeds using Eq. (7).

$$T_{ac} \approx \frac{l}{fN}$$

Tool life, T = time per component (T_{ac}) × total number of components that can be produced.

(d) Now, optimum speed should be determined using the following equation

$$1 = \left(\frac{1}{n} - 1\right)\frac{V^{1/n}}{B}\left(\frac{xTd + y}{x}\right)$$

Here, $1/n$ and B are unknown. They should be determined using the following relationship.

$$T = \frac{B}{V^{1/n}}$$

T has been calculated (step (c)) for two speeds. Make two equations for T_1 and T_2 and then solve them to evaluate B and $1/n$. Now, substitute the values of B and $1/n$ to determine optimum speed (or optimum spindle speed) from Eq. (10).

(e Calculate cost per component for three cases (C_1, C_2 and C_3) from Eq. (1)

Stestep 1

Given :d = 1.27 × 10^{-3} m, f = 3.81 × 10^{-4} m / rev, D = 76.2 × 10^{-3} m, l = 0.1524 m, T_l = ¼ min /comp, T_d = 4 min per tool, y = Rs. 2/- per cutting edge = 200.0 paise per cutting edge, x = Rs 10/- per hour = 16.67 paise / min, N_1 = 330 RPM, N_2 = 535 RPM.

Stestep 2

The equation that gives the optimum speed for minimum cost per component is given by

$$1 = \left(\frac{1}{n} - 1\right)\frac{V^{1/n}}{B}\left(\frac{xTd + y}{x}\right)$$

To know optimum V, $1/n$ and B should be known. These two unknowns can be determined from the following relationship.

$$T = \frac{B}{V^{1/n}}$$

where, T = tool life in min, and V = velocity in m/min.

Let V_1 be the cutting speed at N_1 and V_2 be the cutting speed at N_2. Then,

$V_1 = \pi D N_1 = \pi \times 76.2 \times 10^{-3} \times 330$

or, $V_1 = 78.998$ m/min.

$V_2 = \pi D N_2 = \pi \times 76.2 \times 10^{-3} \times 535$

or, $V_2 = 128.07$ m/min.

$$T_{c1} \approx T_{ac} = \frac{l}{fN_1} = \frac{0.1524}{3.81 \times 10^{-4} \times 330}$$

$T_{c1} = 1.21$ min

Therefore, T_1 = time per component x total no. of components

$= 1.21 \times 620$

or, $T_1 = 750$ min

$$T_{c2} = \frac{l}{fN_2}$$

$$= \frac{0.1524}{3.81 \times 10^{-4} \times 535}$$

$T_{c2} = 0.748$ min

$T_2 = 15 \times 0.748$

$or,\ T_2 = 11.22$ min

Step 3

On putting the values of T_1 and T_2 in Eq. (6), we get

$$750 = \frac{B}{(78.889)^{1/n}}$$

$$11.2 = \frac{B}{(128.07)^{1/n}}$$

$$\therefore \frac{1}{n} = 8.71$$

$$\therefore\ 750 = \frac{B}{(79)^{8.71}}$$

$B = 2.53 \times 10^{19}$

Putting these values in Eq. (10.1), we get,

$$1 = (8.71 - 1)\frac{V^{8.71}}{2.53 \times 10^{19}}\left[\frac{16.67 \times 4 + 200}{16.67}\right]$$

$$V^{8.71} = \frac{2.05 \times 10^{19}}{7.71} \times \frac{1}{15.9976} = 2.05 \times 10^{17}$$

$V_{opt} = 97.18$ m/min

After having obtained the optimum cutting speed, the corresponding spindle speed (N_3) can be obtained as follows :

$$N_3 = \frac{V_{opt}}{\pi D} = \frac{97.18}{\pi \times 0.0762}$$

$N_3 = 405.95$

$\therefore\ N_3 = 406$

Step 4

Now, let us calculate C_1, C_2 and C_3 to compute minimum cost.

Let, C_1=cost/component at speed 330 RPM.

$$C_1 = xT_l + xT_{c1} + xT_d\left(\frac{T_{ac1}}{T_1}\right) + y\left(\frac{T_{ac1}}{T_1}\right)$$

$T_{c1} \approx T_{ac} = 1.21$ min (from step 2)

$T_1 = 750$ min (from step 2)

$$C_1 = 16.67 \times \frac{1}{4} + 16.67 \times 1.21 + 16.67 \times 4 \times \left(\frac{1.21}{750}\right) + 200\left(\frac{1.21}{750}\right)$$

C_1 =24.68 paise/component

Similarly, cost per component at spindle speed 535 is C_2. Then,

$$C_2 = xT_l + xT_{c2} + xT_d\left(\frac{T_{ac2}}{T_2}\right) + y\left(\frac{T_{ac2}}{T_2}\right)$$

$T_{c2} = 0.748$ min (from step 2)

$T_2 = 11.2$ min. (from step 2)

Therefore,

$$C_2 = 16.67 \times \frac{1}{4} + 16.67 \times 0.748 + 16.67 \times 4 \times \left(\frac{0.748}{750}\right) + 200\left(\frac{0.748}{750}\right)$$

C_2 =34.34 paise/component

Let the cost per component at speed V_{opt} be C_3. Then,

$$C_3 = xT_l + xT_{c3} + xT_d\left(\frac{T_{ac3}}{T_3}\right) + y\left(\frac{T_{ac3}}{T_3}\right)$$

$$T_{c3} \approx T_{ac3} = \frac{l}{fN_3} = \frac{0.1524}{3.81 \times 10^{-4} \times 460}$$

$T_{c3} = 0.985$ min

$$T_3 = \frac{B}{(V_{opt})^{1/n}}$$

$$= \frac{2.53 \times 10^{-4}}{(97.18)^{8.71}}$$

$T_3 = 123.4$ min

$$C_3 = 16.67 \times \frac{1}{4} + 16.67 \times 0.985 + 16.67 \times 4 \times \left(\frac{0.985}{123.4}\right) + 200\left(\frac{0.985}{123.4}\right)$$

C_3 = 22.72 paise / component

So Minimum unit cost obtained at $V_{opt} =$ 97.18 m/minis *22.72*paise / component

CONCLUSIONS

By numerical optimization we conclude that, The technologically advanced optimal conditions for minimum cost of unit construction are successfully proposed for single point turning operation. These developed models can help directly for evolution of minimum unit cost of production under various machining conditions.And Cutting speed the machining time, tool reuse time, tool-changing time, setup time, tool life, etc. are the influential parameters on the objective function. The minimum unit cost of production is associated with the machining time0.985 min, tool life 123.4 min, optimum Cutting speed = 97.18 m/min,

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