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OPTIMIZATION OF STEPPED PART TURNING

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ABSTRACT

The determination of the optimal cutting conditions for a stepped part is still one of the most difficult problems facing the production engineer. A computer program has been constructed to find the optimal cutting variables to minimize the production cost and to increase the rate of production and consequently the profit. The computer program is used to determine the optimum cutting variables for any number of steps and dimentions. These determined cutting variables can be applied for each step without changing the setting of the machine tool used.

KEYWORDS

Optimization. turning operation, stepped part, minimum cost, maximum production rate, objective function.

INTRODUCTION

The optimization of the production process aims to produce any part with minimum manufacturing cost and maximum production rate to gain maximum profit. This optimization means the selection of the optimum cutting variables (cutting speed, cutting feed and cutting depth) taking into consideration such constraints as tool life, maximum power of machine tool, maximum cutting speed, maximum and minimum feed.

The determination of optimal cutting conditions for a single stage cylindrical part has been investigated [1-6] . However, in practice mechanical parts consist of different steps with differing lengths and diameters.

For parts with large diameter ratios, the spindle speed should be changed at each step to achieve the optimal conditions [7], and for parts with relatively small diameter ratios R (R =2) a computer program must be constructed to find a single spindle rotational speed which incorporates all the steps without interrupting the machine setting.

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PROBLEM FORMULATION

The workpiece shown in Fig.1 is to be turned from a bar stock its diameter d_1. The number of steps is n, the diameter of the ith step is d_1, the length of the ith step is k_i. The dimensions of the workpiece can be expressed as follows:

Raw material diameter : d_1
First step diameter : d_2
Second step diameter : d_3
ith step diameter : d_{i+1}
nth step diameter : d_{n+1}

If the total length of the workpiece is L_1 and the length of the first step K_1 referring to Fig.1, the following relations can be written:

$$L_1 = \sum_1^n K_i$$

$$L_2 = L_1 - K_1$$

$$L_3 = L_2 - K_2$$

$$L_i = L_{i-1} - K_{i-1}$$

$$L_n = L_{n-1} - K_{n-1}$$

$$\Delta 1 = (d_1 - d_2)/2$$

$$\Delta 2 = (d_2 - d_3)/2$$

$$\Delta i = (d_i - d_{i+1})/2$$

$$\Delta n = (d_n - d_{n+1})/2$$

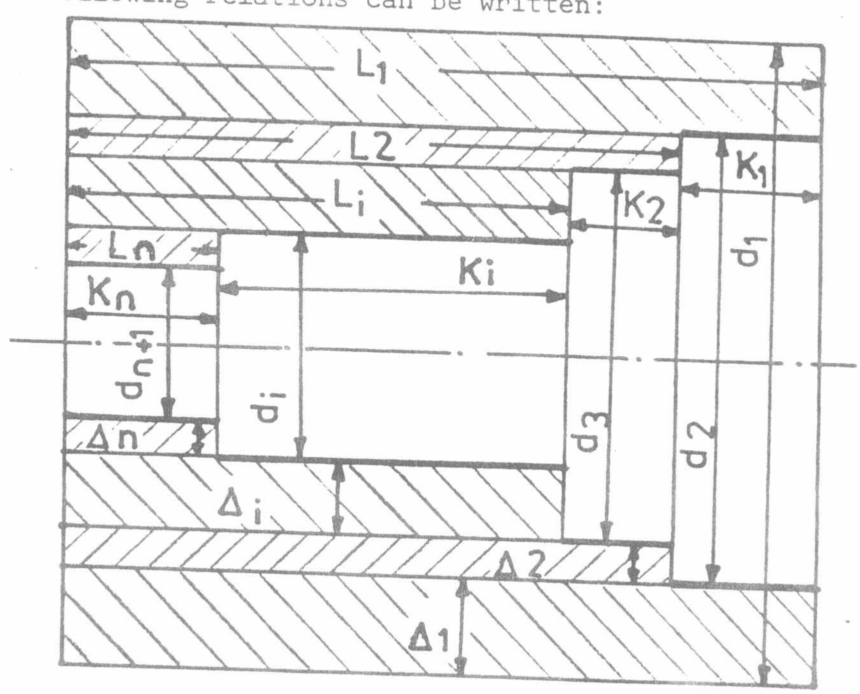

Fig.1 Workpiece

Objective Functions

The production time (t_p) can be calculated from the following statement:

$$t_p = t_h + t_m + t_c \cdot \frac{t_m}{T} \tag{1}$$

where,

t_h : handling time in min., t_m : machining time in min.and T : tool lift in min.

The tool life can be calculated by applying Taylor's equation

$$T = C_1 . V^{C_2} . f^{C_3} . A^{C_4} \tag{2}$$

where, T : tool life in min., V : cutting speed in m/min., f : feed rate in mm/rev., A : cutting depth in mm, C_1, C_2, C_3 & C_4 are constants depending upon cutting tool and workpiece materials.

$/C_2/ > 1$, $/C_3/ \lesseqgtr 1$ & $/C_4/ < 1$ [2]

The machining time for a single pass for one stage can be calculated from the following equation:

$$t_m = \frac{L}{f \times N} \tag{3}$$

where, t_m : machining time in min., L : cutting tool travel which includes the length to be turned, tool approach and tool overtravel, f : feed rate in mm/rev. & N : rotational speed of the main spindle in rpm.

In the present case only the length of the step itself is taken into account and the others are neglected. For a stepped part as previously mentioned, the total machining time for n steps can be calculated as follows:

$$t_{m\ total} = \frac{L_1}{f.N} \cdot \frac{\Delta_1}{A_1} + \frac{L_2}{f.N} \cdot \frac{\Delta_2}{A_2} + \frac{L_3}{f.N} \cdot \frac{\Delta_3}{A_3} + \ldots$$

$$+ \frac{L_i}{f.N} \cdot \frac{\Delta_i}{A_i} + \ldots + \frac{L_n}{f.N} \cdot \frac{\Delta_n}{A_n}$$

$$= \frac{1}{f.N} \sum_{i=1}^{n} \frac{L_i.\Delta_i}{A_i} \tag{4}$$

where, A : cutting depth in mm

The cutting speed can be calculated from the following equation:

$$V = \frac{\pi \times d \times N}{1000} \quad \text{m/min} \tag{5}$$

Substituting the values of V, T and t_m in the production time equation we get:

$$t_p = t_h + \frac{1}{f.N} \sum_{i=1}^{n} \frac{L_i.\Delta_i}{A_i} + t_c \frac{1}{f.N} \cdot \frac{\sum_{i=1}^{n}(L_i.\Delta_i/A_i)}{C_1\left(\frac{\pi.dm.N}{1000}\right)^{C_2} . f^{C_3} A_m^{C_4}} \tag{6}$$

where, mean cutting depth.

$$A_m = \frac{\sum_{i=1}^{n} A_i}{n}$$

mean diameter

$$d_m = \frac{\sum_{i=1}^{n} d_i}{n}$$

The total manufacturing cost per piece is calculated from the following equation:

$$C_t = C_o \cdot t_h + C_o \cdot t_m + (C_o \cdot t_c + C_{th} / e) \cdot \frac{t_m}{T} \qquad (7)$$

where, C_o : labour cost rate L.E./hr, C_{th} : cost of throwaway tip L.E., e : number of cutting edges and t_c : tool change time in min.

Referring to Fig.1, the total manufacturing cost is written as follows:

$$C_t = C_o \cdot t_h + C_o \cdot \frac{1}{f \cdot N} \sum_{i=1}^{n} (L_i \cdot \Delta_i / A_i) + (C_o \cdot t_c + C_{th}/e) \cdot \frac{\sum_{1}^{n} (L_i \cdot \Delta_i / A_i)}{f \cdot N \cdot C_1 \left(\frac{\pi \cdot d_m \cdot N}{1000}\right)^{C_2} \cdot f^{C_3} \cdot A_m^{C_4}} \qquad (8)$$

The constraints are:

$N_{min} \leqslant N \leqslant N_{max}$

$f_{min} \leqslant f \leqslant f_{max}$

$A_{min} \leqslant A \leqslant A_{max}$

The lower and upper limits of the above mentioned constraints can be determined from the machine tool specification and surface finish requied,the range of spindle speed will be:

$$N_{min} = \frac{1000 \times V_{min}}{\pi \times d_{max}}$$

$$N_{max} = \frac{1000 \times V_{max}}{\pi \times d_{min}}$$

where, d_{min}&d_{max} are the minimum and maximum diameters to be turned.

Equations 1&7 are the objective functions. In the present work a computer program has been constructed to determine the optimum rotational speed giving minimum production time and minimum cost per piece for all steps, without changing the setting of the machine tool used. This program has been written in BASIC.

PESULTS AND DISCUSSIONS

The obtained results from the computer program show that the feed rate has a very small effect on the objective functions and the larger value of the rate is recommended. The rotational spindle speed leading to minimum cost is usually smaller than that required for minimum production time. The optimum rotational speed varies from machine tool to another according to the machine tool specification for machining the same workpiece. The spindle speed is the most important decision factor for minimizing the objective function. The machine tools having smaller values of the common vatio of its gearbox-steps, are preferred in case of minimum cost . On other hand larger values of the common vatio of gearbox-steps are recommended in case of minimum manufacturing time.

The coputer program can be used to determine the machine tool which gives minimum cost or minimum time when there are different types of machine tools capable to machine the same workpiece.

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A computer program for determining the optimum rotational speed in case of stepped part turning.

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10 REM OPTIMIZATION OF CUTTING CONDS
20 REM ENTER DATA
50 INPUT"NUMBER OF SPEEDS";NN
55 INPUT"NUMBER OF STAGES";ND
60 INPUT"AVG DIAMETER";DM
65 INPUT"LABOR&M/C COST";CO
70 INPUT"HANDLING&SETTING TIME";TH
75 INPUT"TIP COST";CTH
80 INPUT"NUMBER OF EDGES";E
90 INPUT"CHANGE TIME";TC
95 INPUT"TAYLOR CONST 1";C1
100 INPUT"TAYLOR CONST 2";C2
105 INPUT"TAYLOR CONST 3";C3
110 INPUT"TAYLOR CONST 4";C4
115 INPUT"FEED";F
120 FORI=1TOND:PRINT"DEPTH OF CUT IN STAGE"I;:INPUTA(I):AM=AM+A(I)
125 PRINT"REDUCTION IN RADIUS STAGE"I;:INPUTD(I)
130 PRINT"LENGTH TO BE TURNED STAGE"I;:INPUTL(I):NEXTI
140 AM=AM/ND
150 FORI=1TOND:S=S+D(I)*L(I)/A(I):NEXTI
155 S=S/F
160 VV=π*DM/1000
170 PRINT:PRINT"      N    ","    TP    ","     TC":PRINT
200 FORI=1TONN:PRINT"SPEED"I:INPUTN
205 PRINTN,:
210 TP=TH+S/N+TC*S/N/(C1*(VV*N)↑C2*F↑C3*AM↑C4)
214 IF I=1THEN MTP=TP:N1=N
215 IFTP<MTP THEN MTP=TP:N1=N
220 PRINTTP,
225 CT=CO*TH+CO*S/N+(CO*TC+CTH/E)*S/N/(C1*(VV*N)↑C2*F↑C3*AM↑C4)
230 IF I=1THEN MCT=CT:N2=N
235 IFCT<MCT THEN MCT=CT:N2=N
240 PRINTCT
275 NEXTI:PRINT:PRINT
280 PRINT"MINIMUM TIME IS ";MTP;"      AT SPEED";N1
290 PRINT"MINIMUM COST IS ";MCT;"      AT SPEED";N2
300 END

READY.
```

```
# SPEEDS 12
# DIAMETERS 5
AVG DIAMETER 60
CO =  .1
TH =  5
CTH=  3
E  =  4
TC =  1
C1 =  300000
C2 = -2.9
C3 = -1
C4 = -.5
Am =  .5
F  =  1
```

The results which are obtained by using the computer program in case of turning the work-piece on two machines having different spindle speeds.

N	TP	TC
180	15.3514282	2.00704727
250	13.1745218	1.90678236
355	12.2162761	2.31168674
500	12.8834702	3.82164953
710	15.9990497	9.75364354
1000	23.1096894	42.2026137
1400	37.2540424	330.83831
1800	55.9518266	4139.38714
2500	98.9955803	96556.5309
3555	187.617574	4396365.79
5000	353.541418	382694244
7100	683.146921	6.48571494E+10

MINIMUM TIME IS 12.2162761 AT SPEED 355
MINIMUM COST IS 1.90678236 AT SPEED 250

N	TP	TC
100	22.7059563	2.42506284
125	19.3147053	2.12226557
160	16.4405406	1.91095049
200	14.518656	1.81908151
250	13.1745218	1.85158989
315	12.3776258	2.08119427
400	12.2437258	2.7169665
500	12.8834702	4.26578247
630	14.5779842	8.70984879
800	17.8939632	25.1023153
1000	23.1096894	104.977489
1250	31.3979318	659.194823

MINIMUM TIME IS 12.2437258 AT SPEED 400
MINIMUM COST IS 1.81908151 AT SPEED 200