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Research Paper

CONDITION-BASED MAINTENANCE OF CNC TURNING MACHINE

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In this paper, condition-based Preventive Maintenance (PM) approach is used for a Computer Numerical Control (CNC) turning machine .Wearing of CNC machine is based on the various machining conditions (such as cutting speed, feed and depth of cut) and the time for which it is being used. Larger value of machine power and production rates usually results in more wear and failure of CNC machine. The various machining conditions of CNC machine usually affects the PM requirement. Higher production rate usually results in greater deterioration of the machine, and hence there is a need of frequent preventive maintenance of the machine. In this paper, we adopted the methodology of PM approach to determine the preventive maintenance index function, using the values taken from a CNC machine, to determine the exact time needed between the 2 PM visits, which in turn can help in reducing the frequent breakdowns occurring in the CNC machine.

Keywords: Preventive Maintenance, CNC machines, Machining Conditions, PM Index, Tool-Life

INTRODUCTION

Preventive Maintenance (PM) can be described as maintenance of equipment or systems before fault occurs. While PM is generally considered to be worthwhile, there are risks such as equipment failure or human error involved when performing preventive maintenance, just as in any maintenance operation. In other words, PM is the planned maintenance of an equipment with the goal of improving equipment life by preventing excess depreciation and deterioration. This maintenance includes, but is not limited to, adjustments, cleaning, lubrication, repairs, replacements, and the extension of equipment life.

We usually observe in our day-to-day life, that if the machine works continuously under

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certain conditions, then there will be frequent need for the inspection and repair of the machine. Thus, in our study, we tries to determine the exact time needed to do the preventive maintenance of the CNC machine, from the data gathered by working on the CNC turning machine type AUTOCOMP-55. On this machine, a particular type of design or product is made and the values concerning to that product is taken into analysis, to determine the various parameters like optimum values of cutting speed and the corresponding feed rate, processing time of an operation using a particular tool type under some constraints, which are due to some technical limitations of machine and tool and design requirement for the part.

LITERATURE REVIEW

The literature review has been carried-out in the areas of maintenance of CNC machines. Techniques of preventive maintenance index function and geometric programming model have been reviewed to assess the various parameters of CNC machines.

Nolden (1987) used the devices like vibration monitoring, wear particle analyzers, etc. to predict failures which helps in determining the predictive maintenance of a CNC machine.

For optimization of the condition-based maintenance Banjevic *et al.* (2001) presented a control-limit policy and software respectively.

To minimize the total weighted tardiness (lateness) of jobs in a CNC machine Cassady and Kutanoglu (2003) considered the PM planning and Production Scheduling (PS) decisions simultaneously.

Various Mathematical models and their solution procedures for various machining conditions selection problems specially for the turning operation are done by Hitomi (1996).

Formulating the machining conditions selection problem as a multi-objective decision-making problem is done by the Malakooti and Deviprasad (1989).

According to the Gray *et al.* (1993), the decisions like preventive maintenance and tool replacement are solved at different levels of the decision-making hierarchy keeping in view that the preventive maintenance (PM) decisions are always handled at a higher level than the tool replacement decisions.

For tool life distributions, some models are proposed by the Lakovou *et al.* (1996) to determine the selection of optimal cutting speed and policies for tool replacement in machining problems.

Koomsap *et al.* (2005) studies that integrates both the process planning and Condition-Based Maintenance (CBM) scheduling decisions. They proposed a system that usually collects information on the current condition of a machine in order to determine its working lifetime.

Figure 1: AUTOCOMP 55 CNC Turning Machine

Cassady and Kutanoglu (2003 and 2005) also considered the preventive maintenance planning and production scheduling decisions simultaneously to minimize the total weighted tardiness (lateness) and total expected weighted completion time, respectively.

PRESENT WORK

Condition Based Maintenance (CBM) is a maintenance which is usually performed whenever its need arises. This type of maintenance is performed when we get the kind of indications showing that the equipment or machine's performance is deteriorating or is going to fail.

In this present work, I usually put emphasis on finding the time between the two PM visits, using the data collected from the CNC turning machine (AUTOCOMP-55, which is making certain specific types of products).

METHODOLOGY

Proposed PM Index Methodology

The notation used throughout the paper is as follows.

Parameters

A, B, k, T	Coefficients for the proposed PM index function
α, β, γ	Speed, feed, depth of cut exponents for tool
K_j	Taylor's tool life constant for tool j
C_m, b, c, e	Specific coefficients of the machine power constraint
C_s, g, h, l	Specific coefficients and exponents of the surface roughness constraint
C_o	Operating cost of the CNC machine (Rs/min)
C_{tj}	Cost of tool j (Rs./tool)
D_i	Diameter of the generated surface for operation i (in.)
d_i	Depth of cut for operation i (in.)
H	Maximum available machine power (hp)
L_i	Length of the generated surface for operation i (in.)
S_i	Maximum allowable surface roughness for operation i (min.)
C_{PM}	Cost of a PM visit (Rs./visit)
τ_{PM}	Duration of a PM visit (min)
t_r	Tool replacement time (min)

Decision Variables

v_{ij}	Cutting speed for operation i using tool j (fpm)
f_{ij}	Feed rate for operation i using tool j (ipr)

Dependent Variables

$t_{m_{ij}}$	Processing time of operation i using tool j (min)
r_i	Production rate of the machine for operation i (part/min)
Z_{ij}	Expected tool life of tool j for operation i (min)
U_{ij}	Expected usage rate of tool j for operation i
P_{ij}	PM index for operation i used

Data Collection and Calculations

The values of some of the constraints taken from the previous research papers are

Table 1: Values of Constraints Used	
Tool Used : Single Tool Type	
Taylor's Tool Constant, C_j: 125321000	
Tool-Life Constraints	α = 4.3 β = 1.6 γ = 1.2
Machine Power Constraints	b = 0.96 c = 0.70 e = 0.71 C_m=1.637
Surface Roughness Constraints	g = -1.60 h = 1.005 l = 0.30 C_s=259500000
PM cost of m/c when it is idle	A = 10 (Assume)
B,k (Dependent on T and on cost of PM visit)	B = 30 (Assume) k = 2.5 (Assume)

Data collected from CNC turning machine are as follows:

Table 2: Data Collected from CNC Turning Machine

S.No.	Machining Parameters & their values
1.	Depth of Cut (d_i) = 3mm = 0.118 in
2.	Max. Allowable Surface Roughness (S_i) = 300 in
3.	Dia. of generated surface (D_i) = 543mm = 21.378 in
4.	Length of generated surface (L_i) = 500mm = 19.685 in
5.	Operating Cost of CNC machine (C_o) = Rs.350 per 8 h = 0.72916 Rs/min
6.	Cost of a PM visit (C_{PM}) = Rs.526 Rs/visit
7.	Tool Replacement time (t_r) = 3 min
8.	Cost of tool j = Rs.1000 (Assume Avg)
9.	Operating time period (T) = 1680 min Cycle Time = 25 min Clamping / Declamping Time = 5 min

The various relations that are using for finding the PM index are as given below:

- $t_{mij} = \dfrac{\pi D_i L_i}{12 v_{ij} f_{ij}}$

- $U_{ij} = \dfrac{t_{mij}}{Z_{ij}} = \dfrac{(\pi D_i L_i)/(12 v_{ij} f_{ij})}{K_j / \left(v_{ij}^{\alpha} . f_{ij}^{\beta} . d_i^{\gamma}\right)}$

- $PM\ Cost = A + B.r^k$

- $n = T/(t_m + t_r . U)$

- PM Cost per Operation

$$= \frac{1}{T}\left(A.t_m + A.t_r.U + \frac{B}{t_m^{k-1}} + \frac{B.t_r.U}{t_m^{k}}\right)$$

- PM Index =

$$\frac{1}{T.C_{PM}}\left(A.t_m + A.t_r.U\ \frac{B}{t_m^{k-1}} + \frac{B.t_r.U}{t_m^{k}}\right)$$

In terms of v_{ij} and f_{ij}, it can be expressed as

- $P_{ij} = P_1 v_{ij}^{-1} f_{ij}^{-1} + P_2 v_{ij}^{\alpha-1} f_{ij}^{\beta-1} + P_3 v_{ij}^{k-1} f_{ij}^{k-1} + P_4 v_{ij}^{\alpha+k-1} f_{ij}^{\beta+k-1}$

where

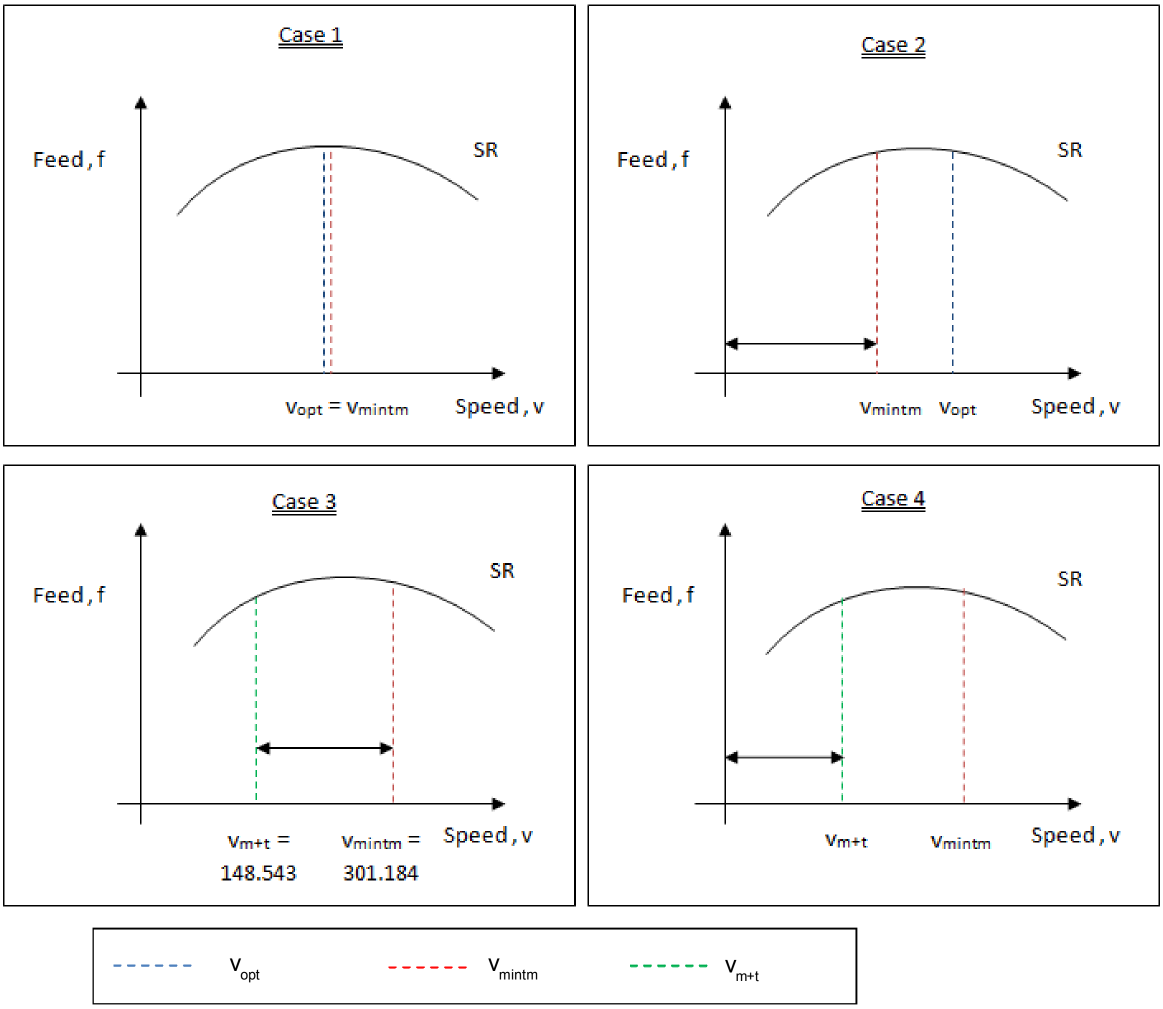
$$P_1 = \frac{A\pi D_i L_i}{12TC_{PM}},\ P_2 = \frac{At_r \pi D_i L_i d_i^{\gamma}}{12K_j TC_{PM}},$$

$$P_3 = \frac{B}{TC_{PM}}\left[\frac{12}{\pi D_i L_i}\right]^{(k-1)},$$

$$P_4 = \frac{Bt_r d_i^{\gamma}}{K_j TC_{PM}}\left[\frac{12}{\pi D_i L_i}\right]^{(k-1)}$$

- $M_{ij}(v) = C_1 (C_s')^{(1/h)} v_{ij}^{(g-h)/h} + C_2 (C_s')^{-(\beta-1)/h} v_{ij}^{[h(\alpha-1)-g(\beta-1)]/h} + C_3 (C_s')^{-(k-1)/h} v_{ij}^{[(h-g)(k-1)]/h} + C_4 (C_s')^{-(\beta+k-1)/h} v_{ij}^{[h(\alpha+k-1)-g(\beta+k-1)]/h}$

Figure 2: Possible Intervals or Range to Determine Optimum Value



where

$$C_1 = \frac{\pi D_i L_i C_0}{12} + C_{PM} P_1,$$

$$C_2 = \frac{\pi D_i L_i d_i^{\gamma} C_{tj}}{12 K_j} + C_{PM} P_2,$$

$$C_3 = C_{PM} P_3, \; C_4 = C_{PM} P_4,$$

$$C_t' = \frac{\pi D_i L_i d_i^{\gamma}}{12 K_j}, \quad C_m' = \frac{C_m d_i^{e}}{H},$$

$$C_S' = \frac{C_S d_i^{l}}{S_i}$$

- $f_{ij} = (1/(C_S' v_{ij}^{g}))^{1/h}$

The algorithm used for the single machining operation problem is as follows:

Step 1: Finding (v,f) pair subjected to surface roughness and machine power constraints.

$$V_B = \left(\frac{1}{C_S' f_B^{h}}\right)^{1/g}, \quad f_B = \left[(C_m')^{g} (C_s')^{-b}\right]^{1/(bh-gc)}$$

Thus, $f_B = 0.0435$, $v_B = 480.2$

Step 2: Finding (v, f) pair subjected to surface roughness and tool life constraints.

$$v_A = \left(\frac{1}{C'_S, f_A^h} \right)^{1/g},$$

$$f_A = \left[(C'_s)^{\alpha-1} (C'_t)^{-g} \right]^{1/[g(\beta-1)-h(\alpha-1)]}$$

Thus, $f_A = 0.0207$, $v_A = 301.184$

Step 3: $v_{mintm} = min\,[v_A, v_B]$

i.e., $v_{mintm} = v_A = 301.184$

Step 4: Find the derivative of M(v) w.r.t. v, 2 conditions arises:

(i) $M'(v) \leq 0$, then $v_{opt} = v_{mintm}$ (Case 1 in Figure 2).

(ii) $M'(\text{v}) > 0$, then $v_{opt} = v_{m+t}$

Step 5: Find the cutting speed minimizing the machining plus tooling cost on the surface roughness constraint.

$$v_{m+t} = \left[\frac{C_1}{C_2} (C'_S)^{(\beta/h)} \frac{h-g}{h(\alpha-1)-g(\beta-1)} \right]^{h/(h\alpha-g\beta)}$$

or, $v_{m+t} = 148.543$

Step 6: Determine the upper and lower bounds of the interval.

- If $v_{mintm} < v_{m+t}$, then $v_1 = 0$ and $v_2 = v_{mintm}$ (Case 2 in Figure 2)
- If $M'(v_{m+t}) < 0$, then $v_{m+t} = v_1$ and $v_{mintm} = v_2$ (Case 3 in Figure 2)
- If $M'(v_{m+t}) < M'(v_{mintm})$, then $v_1 = 0$ and $v_2 = v_{m+t}$ (Case 4 in Figure 2)

Thus,

$v_{m+t} < v_{opt} < v_{mintm}$

or, $148.543 < v_{opt} < 301.184$

Step 7: Optimal value of speed and feed can be obtained by employing the one-dimensional optimization method like Newton-Raphson method, Bisection method, etc.

Thus, after performing various iterations, the optimal value of cutting speed is

$v_{opt} = 148.6175$ rpm

Similarly, the optimal value of feed rate is

$f_{opt} = 0.0006723$ ipr

Step 8: Now, Processing time of an operation, $t_m = 110.265$ min

Expected Tool Usage, $U_{ij} = 0.0495$

PM/Operation = 0.65724

PM Index = $1.2495 \text{ X } 10^{-3}$

= 0.0012495

Time b/w 2 PM visits

= t_m/PM Index

= 88247.077 min

= 183.85 ≈ 184 days

≈ 6 months

RESULT/CONCLUSION

In this study concerning to the CNC machine, we proposed a PM approach, which is used to find out the time between two PM visits on the CNC turning machine. The proposed PM methodology finally results that the preventive maintenance concerning to the operation of CNC turning machine should be carried out every 6 months, thus making the life of the tool as well as machine to increase without any failure or breakdown.

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