Modification of Cost Equation for Optimization of Cutting Parameters in Turning in view of Energy Conservation

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***Abstract---* With depleting pace of natural energy resources and pollution in the environment it is necessary to reduce the amount of energy consumption. On the other hand price of energy is increasing due to likely increase in oil prices. So it is necessary to see the effect of energy cost in total machining cost. In the present work conventional cost equation is modified to consider the energy cost as variable of v, f and d instead of energy cost as constant in conventional cost equation. Different costs are compared by taking the particular value of parameters v, f and d. It was found that energy as a variable cost have considerable portion in total machining cost.**

***Keywords*—Pollution, environment, energy consumption, cost equation, modified cost equation.**

I. INTRODUCTION

Machining is one of the important widely used manufacturing process in industries like automobile, aerospace and other engineering purposes. In machining process energy consumption in the form of electricity is having the major environmental impact [1]. Although the world energy production is continuously increasing, but most of the energy is produced by nonrenewable energy resources (Fig 1).

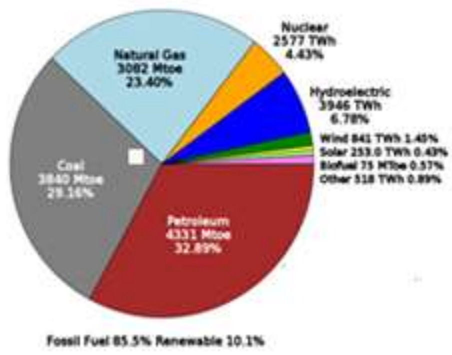

Fig1: World energy consumption by fuel (2015)[2]

Major carbon emission in the world is due to electricity and heat i. e. 45.9% (Fig 2).As the electricity is produced by burning fossil fuels and other means which create carbon emission in the environment due to this various environmental issues like green house gas effect,ozon layer depletion and global warming etc create.

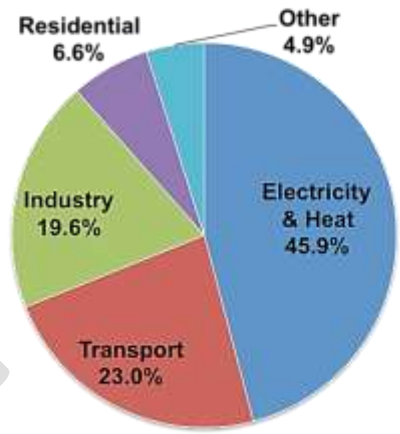

Fig2: World CO_2 carbon emission [3]

This ultimately causes increasing pace of exploitation of natural resources and pollution in the environment so it is necessary to minimize the consumption of energy. The critical link between energy and economy has exposed the vulnerability/position of nations to the volatile energy situation. Energy today has become a key factor in deciding the product cost at micro level as well as indicating the inflation and debt burden at the macro level. Energy price is continuously increasing and it is likely to increase in future also due to increase in oil prices. Manufacturing industries require the major amount of energy in terms of electricity. So energy cost is a significant factor in machining activity with factors of production like capital,l and and labour etc. As a result energy shortage situation calls for energy conservation measures which mean using less energy for same level of activity.

On one hand demand for energy is increasing on the other hand energy sources are becoming scarce and costlier. There is steady increase in gap. Also in industry there is 20-40% of wastage of energy [4] By applying energy efficiency measures energy consumption can be reduced [5]-[7]. The progress of the country depends upon the manufacturing activity so it cannot be stopped. So a concept of sustainable development of using the resources economically come into play so that the resources should be available and environment should be living worth for future generations also. This has not only compelled the technocrats and decision makers in the industry to develop new measures of energy conservation but also to have systematic approach towards present trend of energy consumption through energy auditing and application of modern techniques and methods for minimizing energy wastage.

One method of minimizing energy waste is conserving the energy. Ways to reduce energy consumption in machining are:

- To improve the design of product or machine tool,
- Proper selection of process operating environment
- Process parameters and proper process planning and
- On line monitoring of energy.

Out of these selection of process parameters is the important one.

To perform effectively in terms of quality and economy the machining process should be optimized. The most commonly used criteria are minimising cost or time. But these days environmental aspects are also important and also mandatory to consider due to environmental laws as well as to achieve cleaner production along with productivity. For this minimum energy consumption is being used as criteria for optimisation.

II. MODIFIED COST EQUATION

Parameters are being selected on the basis of minimum total machining cost, maximum production rate and maximum profit rate etc. Minimum machining cost is the most commonly used criteria. In conventional cost equation the energy cost used as a constant inover head cost. In modified cost equation the energy cost is taken as variable of parameters v, f and d like other cost i.e. machining cost, tool cost etc. in total machining cost equation. By using it effect of variation of v, f and d can also be seen and energy efficiency may be increased by proper optimization of parameters.

The values of total machining cost C(X), can be analytically determined as given below for turning of work piece of diameter D and per pass length L (Fig3).

Where $X=\begin{Bmatrix} v \\ f \\ d \end{Bmatrix}$,

X is design vector collectively represented the variables v, f and d

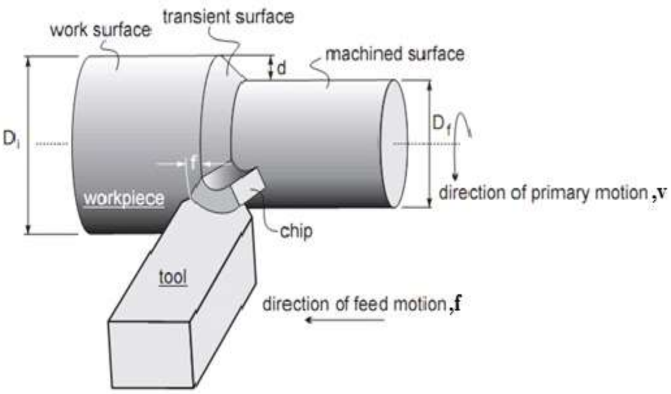

Fig3: Details of turning operation

Total machining cost per pass can be represented as[8]:

Total machining cost per pass (C_c)= set up cost + loading and unloading of work piece + cutting tool advance and withdrawal time+ machining cost + tool change cost + tool cost

In C_c, energy cost has not been considered as a separate cost but it (as per maximum power rating of motor) is included in the overall overhead cost C_o (Rs/hr).Overall overhead cost includes manpower cost and machine tool operating cost. Machine tool operating cost includes machine depreciation and other cost associated with the running of the machine tool such as power consumed, maintenance overhead consumables such as oil etc. This may also include the other overhead costs which take care of all the fixed overheads such as buildings, land and administrative overhead. So cost per pass for turning of workpiece with diameter D and per pass length L, with energy cost included in overall overhead cost can be represented as:

$$C_c = \frac{\pi D L C_o}{1000 v f} + \left[\frac{L\pi D v^{p-1} f^{q-1} d^r C_o (t_c)}{1000 C_1} + \frac{L\pi D v^{p-1} f^{q-1} d^r C_e}{1000 C_1}\right] \quad (1)$$

In the above equation setup cost, loading and unloading cost are not functions of v, f, d and therefore ignored while optimizing. The values of work piece diameter (D), length per pass (L), tool change time (t_c) and tool cost (Ce) are already known. The values of constants p, q, r and C_1 in Taylors extended tool life equation (2) are to be taken from manufacturer standard tables.

$$t = \frac{C_1}{v^p f^q d^r} \quad (2)$$

Due to increasing carbon foot print due to power generation and increase in cost of power it is the demand of today to consider cost of energy separately as a variable and as a function of v, f, d. So total cost per pass can be represented with energy cost as a variable of v, f, d. The power during machining as per Gutoswki T [9] can be taken as

$$P = P_0 + k\dot{v} \qquad (3)$$

Where P is the total power consumed by machining process. P_0 is the idle power at zero load (power when machine is not cutting) and it is consumed by all machine modules required for start up the computer, fan, motor, coolant pump etc. $k\dot{v}$ is the machining power where k is the specific cutting energy (Ws/mm^3) and $\dot{v}$ is the material removal rate (mm^3/s). The energy required per pass for machining process E in Joule can be obtained from equation (3).

$$E = (P_0 + k\dot{v})T \qquad (4)$$

whereT is the time taken for machining per pass. Energy in terms of v, f, d can be represented as

$$E = (P_0 + kvfdx1000)T \qquad (5)$$

$$T = \frac{\pi(D_i - d)L}{1000vf} \qquad (6)$$

In case of energy cost as a variable of v, f, d overall overhead cost is considered without the cost of energy (as per maximum power rating of motor) and can be represented as C_{01} and is given by

$$C_{01} = C_0 \text{ -Constantenergy cost} \qquad (7)$$

Putting the value of C_{01} in place of C_0 in equation (1) along with the energy cost as a variable of v, f, d the following cost equation for this case has been obtained.

$$C_v = \left[\frac{L\pi D v^{p-1} f^{q-1} d^r C_{01}(t_c)}{1000 C_1} + \frac{\pi D L C_{01}}{1000vf} + \frac{L\pi D v^{p-1} f^{q-1} d^r C_e}{1000 C_1}\right]$$

$$+ \frac{1}{3600}[60P_0 + kdfv \times 1000]\frac{\pi DL}{1000vf} \times \text{electricity rate} \qquad (8)$$

No load power (P_0) and specific cutting energy (k) are to be obtained from experimental data usingequation (3) and C_0 is determined as per the details given in the paper [10]. The modified cost equation can be used to minimize the total machining cost for selection of parameters. It can also be used while minimizing total machining cost, quantity of energy and time etc. using multi objective optimization. Both conventional and nonconventional techniques can be used for optimization.

III CASE STUDY

Experiments were conducted on the lathe powered by a 10.3 kW motor which provides step wise speed control throughout the range 40 to 2000 rpm. The machining of EN8steel (48mmx110mm) was conducted by SNUN120412 carbide cutting tool inserts under dry conditions. During dry runs, time for each pass was recorded using stop watch. For the value of energy consumption voltage, current and power factor have been measured for all the 17 groups of experiments obtained by design of experiments. For comparing the different cost of the conventional cost equation and modified cost equation the data from above case study is being used.

IV. RESULTS AND DISCUSSIONS

Table 1 is showing the different costs of conventional (1a,2a) and modified cost equation(1b,2b) at different values of parameters v, f and d. From the table it can be seen that for the present case total value of cost from conventional cost equation is more in comparison to modified cost equation. The major cost contribution is due to machining cost. From the table it can also be seen that the difference in the total values of the machining cost for conventional and modified equation is more at lower value of cutting speed and less at higher values of cutting speed due to decrease in value of machining cost.

TABLE 1: COST DISTRIBUTION IN CONVENTIONAL AND MODIFIED COST EQUATION

S.No	Different costs	Cost (Rs)	Percentage value (%)
For v=90m/min,f=0.13mm/rev,d=2mm			
1a	Machining cost	5.52	97.56
	Tool cost	0.138	2.44
	Total cost	5.658	
b	Machining cost	3.87	82.20
	Tool cost	0.13	2.76
	Energy cost	0.71	15.04
	Total cost	4.71	
For v=150m/min, f=0.13mm/rev, d= 2mm			
2a	Machining cost	3.31	79.66
	Tool cost	0.845	20.34
	Total cost	4.155	
b	Machining cost	2.33	64.15
	Tool cost	0.797	21.94
	Energy cost	0.505	13.90
	Total cost	3.632	

At constant value of f and d the total value of conventional cost and modified cost both decrease when value of v increases. The individual costs in conventional cost equation the with increasing v tool cost is more and machining cost is less. While in modified cost equation tool cost is more and machining and energy cost is less at increasing speed and constant f and d. In the figure 4a, 4b and 5a,5b the percentage distribution of different costs of conventional and modified cost equation are shown.

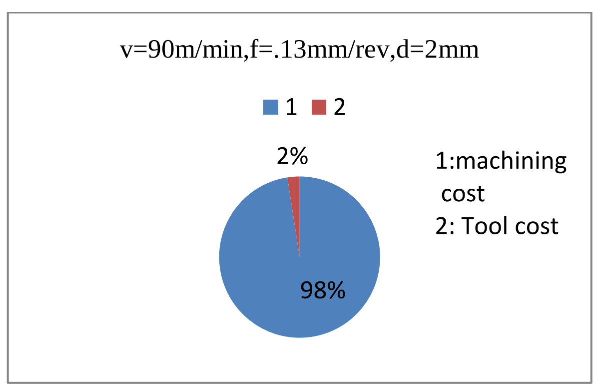

Fig 4a: Cost distribution for conventional cost equation at v = 90m/min, f=0.13mm/rev, d= 2mm

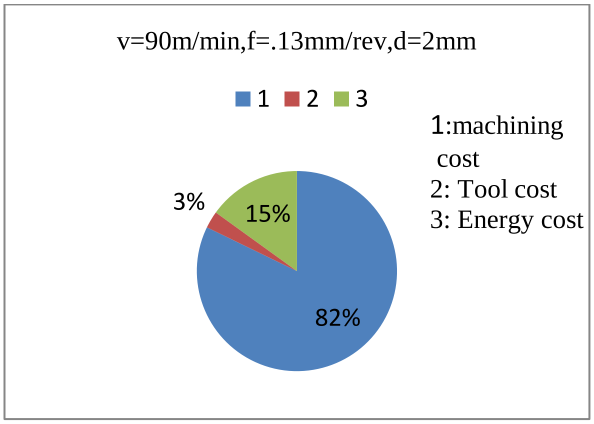

Fig 4b:Cost distribution for modified cost equation at v =90m/min, f=0.13mm/rev, d= 2mm

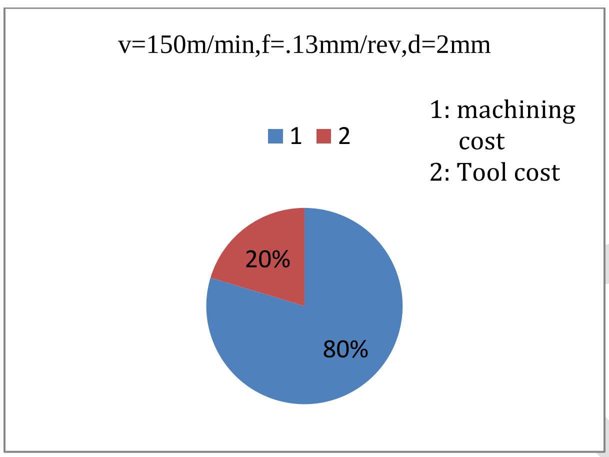

Fig 5a: Cost distribution for conventional cost equation at v=150m/min,f=0.13mm/rev,d= 2mm

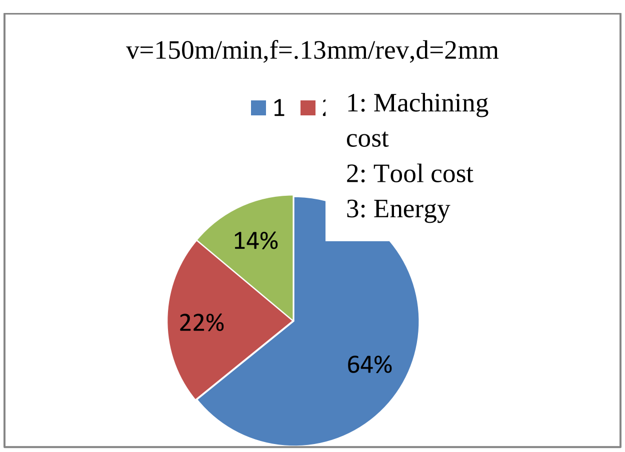

Fig 5b:Cost distribution for modified cost equation at v =150m/min, f=0.13mm/rev, d= 2mm

V. CONCLUSIONS

There is a need to modify conventional cost equation to consider energy cost as a separate factor rather than fixed proportion in overhead cost. In this paper modified cost equation has been developed which can be used for single optimization of v, f and d to minimize total cost and multi objective optimization when total machining cost, energy consumption and total time etc. are to be considered simultaneously.

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