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STATISTICAL ANALYSIS OF EFFECT OF CUTTING PARAMETERS ON ENERGY CONSUMPTION IN TURNING PROCESS

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Abstract

Effect of cutting parameters on energy consumption in turning AISI 304 alloy steel under dry and wet cutting conditions were analyzed statistically. The experiment involved the use of AISI 304 alloy steel as workpiece material and tungsten cutting tool. Design of experiment via Response Surface methodology was used to design the experiment, while Minitab software 17 was employed to analysis the data obtained from the experimental runs. It was observed that for both dry cutting and wet cutting conditions, depth of cut has the most significant effect on the energy consumption with 81.96% and 42.64% respectively.

1.0 Introduction

The manufacturing sector is a key industry that relies on the use of energy in driving value addition through manufacturing processes. Machining process is usually necessary where light tolerances on dimension and fine surface finish is required. Turning is a machining operation where the workpiece is primarily rotated and then moved against the cutting tool to facilitate cutting. Recently, rising cost for energy heavily burdens on large number of manufacturing companies all over the world. Hence, from both environmental and economic perspectives, improved energy efficient manufacturing is urgently required. Energy reduction in industry is very paramount towards achieving environmentally friendly manufacturing. According to IEA (2007), intensive consumption of energy in industry has drawn increasing attention due to its adverse environmental impact and the exhaustion of natural resources. The energy consumed by manufacturing industries accounts for 30% of the total world energy and 36% of the global CO_2 emission. Machining processes such as turning and milling, extensively applied in many manufacturing companies, are considered to be essential for energy consumption. Thus, reducing the energy foot print of machine tools can effectively help companies to accomplish green production (Yansong *et al,* 2012).

The energies consumed globally are obtained from various primary sources which include renewable, e.g, fossil fuels and mineral fuels, and non- renewable, e.g, hydroelectric and biomass. Composition of Total Primary Energy Demand (TPED) between 1820 and 2010 is given in Figure 1.

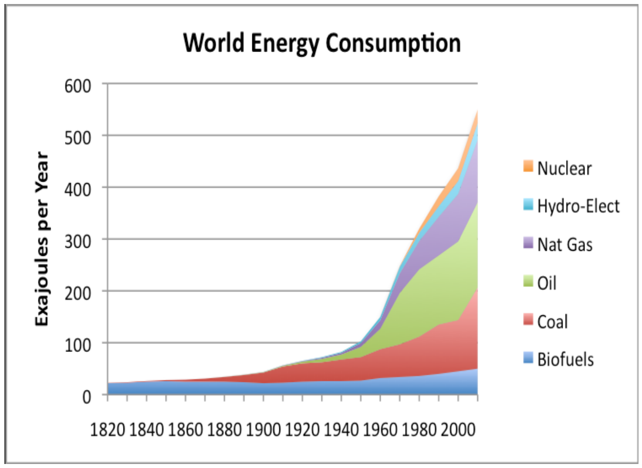

Figure 1: Composition of TPED between 1820 and 2010 (Source: Reza, 2013)

The future of human energy consumption is a matter of serious concern, visualizing from both environmental and economic perspectives. If the future of human energy consumption is effectively managed, environmental disasters and economic catastrophes can be avoided. Humans consume energy through energy consuming systems or device to perform task, e.g. burning fuel in a car engine to move from point A to point B, consuming electricity in a refrigerator to keep foods and drinks cool and preserved, consuming electricity on a lathe to turn a cylindrical workpiece from the initial dimension to the designed finished dimension of the needed component, etc. The global energy consumption is the sum of energy consumption in these and similar systems. In order to reduce the energy consumption globally, the energy required in performing the tasks mentioned and other similar ones, either domestically or industrially must be reduced. Since, the objective of any business organization is to minimize cost and maximize profit. In orthogonal turning, the use of lathe for turning of cylindrical components involves huge energy consumption which increases manufacturing cost and decreases profitability. The demand for huge energy is accomplished with emission of carbon dioxide (CO_2) into the atmosphere and enhances the unwanted global climate change. Shailesh *et al* (2015) revealed that understanding and estimating the energy consumption in machining are essential as it is responsible for a substantial part of environmental burdens in manufacturing industries. The energy consumption of CNC machining greatly depends on the operation states of energy consuming components by CNC codes. The correlation between energy consuming components of machine tools and CNC codes is analyzed to identify the corresponding operation behaviours of energy consuming components. According to Taha *et al* (2010) every machining parameter has impact on power consumption in machining process. Hence, combinations of machining parameters need to be optimized in order to get minimum power consumption. Guo et al (2012) reported that an approach which incorporates both energy consumption and surface roughness is presented for optimizing the cutting parameters in finish turning. Based on a new energy model and a surface roughness model, derived for a machine tool, cutting parameters are optimized to accomplish a precise surface finish with minimum energy consumption. This research work, minimization of energy consumption in orthogonal turning of AISI 304 alloy steel which takes cognizance of all input independent cutting variables such as cutting speed, feed rate and depth of cut as well as output dependent variables which include surface roughness and energy consumption using different cutting fluids is being investigated.

2. Materials and Methods

2.1 Materials

2.1.1 Workpiece

The workpiece material for this research is a round bar of AISI 304 alloy steel with diameter of 25 mm and length of 500 mm. The choice of this material is bore out of its high corrosion resistance property which makes it suitable for use in some vital engineering applications. Such applications include pumps, valves, marine fittings, fasteners, paper and pulp machineries and petrol chemical equipment.

2.1.2 Cutting tool

The cutting tool used is tungsten coated tool insert (WIDIA, model CNMG) with the specification of clearance angle 6^0, rake angle of 7^0 and nose radius of 0.4 .

2.2 Method

2.2.1 Design of Experiment

Response Surface Methodology (RSM) using central composite design (CCD) was selected for the three variables to design the experiment as shown in Table 1. A total of 20 experiments each were conducted under dry and wet conditions.

Table 1: Variables and their levels

Factor	Unit	L1	L 2
Cutting speed	rev/min	600	1200
Feed rate	mm/rev	0.5	1.0
Depth of cut	mm	0.25	0.25

2.2.2 Experimental Procedure

The turning process experiment was conducted at Prototype Engineering Development Institute (PEDI), Ilesha. Nigeria using AISI 304 workpiece of diameter 25 mm and length

600 mm. The workpiece was fixed on CNC lathe (PRODIS CORP, model 2060ENC) chuck and then centre drilled. The workpiece was supported and firmly held by tightening the 3-

jaw dependent chuck firmly after ascertaining the concentricity of the mounted workpiece. The needs to support the workpiece arise from the fact that, the ratio $\frac{l}{d} = \frac{550}{25} = 22 > 4.$ When the ratio $\frac{l}{d} > 4,$ the workpiece must be supported (Lawal et al, 2013). Where *l* is the overhang length of the workpiece and *d* is the diameter. The cutting tool holder with the insert fixed was then mounted on the CNC lathe's tool post to facilitate orthogonal turning. A clamp meter specified as DT -266 digital clamp meter was used to measure current and voltage to facilitate evaluation of cutting power and specific energy consumption. The current and voltage on no load were measured and recorded. This is to facilitate calculation of no load power and energy consumption. In line with the submission of Lawal et al (2013), water to oil ratio of 9:1 was used for the formulation of cutting fluid and flood technique was used in the application of the cutting fluid.

(a) Determination of current:- For each experimental run, the clamp meter was used in measuring the current flowing through each of the 3-phase mains wire i.e. red, yellow and blue phase wires. The measurements were accomplished by setting the knob of the instrument to current measurement mode and then clamp the jaws of the clamp meter around the phase wire. The current flowing through the wire is then displayed on the instrument and was noted and recorded. The current for red, yellow and blue phase wires were recorded as I_R, I_Y and I_B respectively.

(b) Determination of voltage:- This was accomplished by setting the knob of the instrument to voltage measurement mode and then connected to the mains supply wire of the machine. The voltage drop across each phase which was then displayed on the instrument was noted and recorded. The voltages for red, yellow and blue phases were recorded as V_R, V_Y and V_B respectively**.**

(c) Evaluation of Power Consumption:- In CNC, machine tool processes, the machine tool energy consumption, MTEC comprises of energy used in driving the spindle in order to machine the component from the initial to the final dimensions, energy consumed in axis feed, energy consumed by coolant pump, energy consumed by tool change system and other components that consumed a fixed amount of energy.

$$E_T = E_S + E_f + E_t + E_C + E_{fx} \qquad (1)$$

Where E_T = total energy consumed (J); E_S = energy consumed running the spindle (J); E_f = energy consumed in axis feed (J); E_t = energy consumed in changing tool (J); E_C = energy consumed by coolant pump (J); E_{fx} = energy consumed by other component (J).

In order to reduce the total energy consumption E_T, energy consumption in various components shown in equation (1) must be reduced. This can be achieved by optimal election of the cutting environment and cutting variables. According to Theraja (2004) the following relationships are established,

Apparent Power = $V \times I$ (2)

True power $= V \times I \times p.f$ (3)

Where $p.f$ = power factor

The true power on each phase is thus calculated as follows:

For red phase, Power $P_R = V_R \times I_R \times p.f$ (4)

For yellow phase, Power $P_Y = V_Y \times I_Y \times p.f$ (5)

For blue phase,

Power $P_B = V_B \times I_B \times p.f$ (6)

Hence, Power consumption for each experimental run is given by

$$P_i = P_R + P_Y + P_B \quad (7)$$

Where i= run order number = 1, 2,3,4,5 ---------------20.

Energy Consumption

Energy consumption, E = Power consumption (watts) x time taken (minutes)

Therefore, $E_i = P_i \times t$ (8)

Where i= run order number =1, 2,3,4,5 ---------------20.

According to Ithipri et al., (2015),

Specific Energy consumption, $E_s = \dfrac{P_i}{V_c \times f \times d}$ (9)

Where V_c = cutting speed (mm/min), f = feed rate (mm/rev), and d = depth of cut (mm).

Since Spindle speed $N = \frac{1000V_c}{\pi D}$ rpm (10)

Where D = diameter of workpiece (mm)

Hence, $V_c = \frac{\pi DN}{1000}$ (11)

Since diameter of workpiece used is 25mm, hence $V_C = 0.07854N$

3. Results and Discussion

The calculated values of the specific energy consumption for each of the 20 experimental runs for all the two cutting conditions which include dry and wet are presented in Tables 2.

Table 2: Specific Energy Consumption in dry and wet cutting conditions

Run order	Cutting speed (rev/min)	Feed rate (mm/rev)	Depth of cut (mm)	Specific Energy consumption (J/mm^3) (dry)	Specific Energy consumption (J/mm^3) (wet)
1.	900	1.17045	0.50	85.786	28.987
2.	1200	0.50	0.75	100.100	39.908
3.	1200	1.00	0.25	124.748	140.521
4.	900	0.75	0.50	120.399	134.973
5.	1200	0.50	0.25	247.802	272.384
6.	900	0.75	0.92	68.385	58.074
7.	600	1.00	0.75	60.038	53.523
8.	395.46	0.75	0.50	195.166	252.588
9.	900	0.75	0.50	125.964	124.214
10.	900	0.75	0.50	136.032	87.964
11.	900	0.32955	0.50	293.122	180.877
12.	600	0.50	0.25	318.031	354.035
13.	1404.54	0.75	0.50	88.941	27.152
14.	600	0.50	0.25	118.012	233.195
15.	900	0.75	0.50	128.300	122.672
16.	900	0.75	0.50	132.178	104.907
17.	1200	1.00	0.75	49.257	47.153
18.	900	0.75	0.50	131.010	124.920

19.	900	0.75	0.079552	864.208	75.242
20.	600	1.00	0.25	270.897	245.080

The significant effect of cutting parameters on the energy consumption during dry cutting is shown in Table 3. It is observed that depth of cut has the highest significant effect with 81.96%, follow by feed rate with 6.15% and cutting speed has the least effect with 4.75%.

Table 3: Analysis of variance for energy consumption in dry cutting condition

Factor	DOF	SS	MS	F	P
Cutting speed	4	36858	9214.5	1.162412	4.746339
Feed rate	4	47720	11930	1.504973	6.145079
Depth of cut	4	636489	159122.3	20.07331	81.96301
Error	7	55489.382	7927.055		7.14557
Total	19	776556.38	40871.39		100

The significance effect of the input parameters on the energy consumption in wet cutting condition are as follows: 29.04% of cutting speed, 23.95% of feed rate and 42.64% of depth of cut as shown in Table 4. These results revealed that depth of cut has the most significant effect on energy consumption, followed by cutting speed and feed rate having the least effect.

Table 4: Analysis of variance for energy consumption in wet cutting condition

Factor	DOF	SS	MS	F	P
Cutting speed	4	**75191**	18797.75	11.64414	29.04243
Feed rate	4	62006	15501.5	9.602298	23.94974
Depth of cut	4	110403	27600.75	17.09709	42.64303
Error	7	11300.473	1614.353		4.364794
Total	19	258900.47	13626.34		100

4. Conclusion

It has been observed that for both dry cutting and wet cutting conditions, the parameter that has the most significant effect is depth of cut. The significant effect of depth of cut in dry cutting condition is 81.96% while that of wet cutting condition is 42.64%.

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