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Performance investigation of micro hole textured cutting inserts on power consumption and its measuring methodology in turning process

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Abstract Modern manufacturing industries are facing challenges in saving energy with less environmental impacts. The Textured cutting tool insert with solid lubrication is attempted by researchers for tribological enhancement and enhance the sustainability in machining. In this work, turning process is performed on Inconel 718 using micro hole textured insert filled with tungsten disulfide (WS_2) solid lubricant. The main aim of this investigation is to minimize the power consumption using textured cutting inserts and select appropriate device for measuring power consumption during machining. Three different devices are used to measure the power consumption and the results are analyzed. The results of the investigation revealed that tribological properties are enhanced using micro hole textured cutting inserts with solid lubricant. It is leads to near dry machining and sustainability in manufacturing. The result also pointed out direct measurement of power consumption is accurate and free from errors.

1. Introduction

Machine tool needs power to give the relative motion to the cutting tool with respect to the work piece and rotation of spindle. Sustainability performance is achieved by reducing the power consumption. This reduction of power consumption influences the environmental impact of power production. In the year 2010 to 2040, prediction of energy consumption for the world to achieve an increase of 56% from existing one and also this world energy consumption related to carbon

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dioxide emission estimation [1,2]. In manufacturing industries, machining process is one of the important one and the energy required for the machining process is drawn from the electrical grid [3]. In manufacturing environment, energy reduction is an important concern [4]. Energy consumption leads too energy generation which is a key contributor to emissions and climate changes. Concentration of reduction in energy utilization is an essential consideration for enhancement of sustainability in manufacturing process [5].

2. Measurement of power consumption

2.1. Power measurement using mathematical expression

The main cutting force is measured using piezoelectric dynamometer (Eg: model is 9257B, Kistler, Fig. 1). During the measurement of cutting force, computer and charge amplifier are used to collect data with appropriate software. Generally, the machining power is estimated using the mathematical expression by considering main cutting force and cutting speed.

Power required to machining can be calculated by following expression [6–9]

$$\text{Machining power}, \mathrm{P} = \mathrm{F} \times \mathrm{V} \quad (1)$$

where F represents main cutting force in Newton and V represents cutting speed in m/min.

2.2. Power measurement using Wattmeter

Power consumption during machining process in lathe machine can be measured using wattmeter. Fig. 2 shows the Wattmeter setup which is preferable for three different loads, fundamental electric power factor instantaneous value and demand. In this method, three voltage wires are connected to voltage input terminals as well as clamped with proper direction of clamp sensor to electric wires based on the wiring number. Proper connection is made and ensures safety; the instrument is ready to measure value during machining process [10–13].

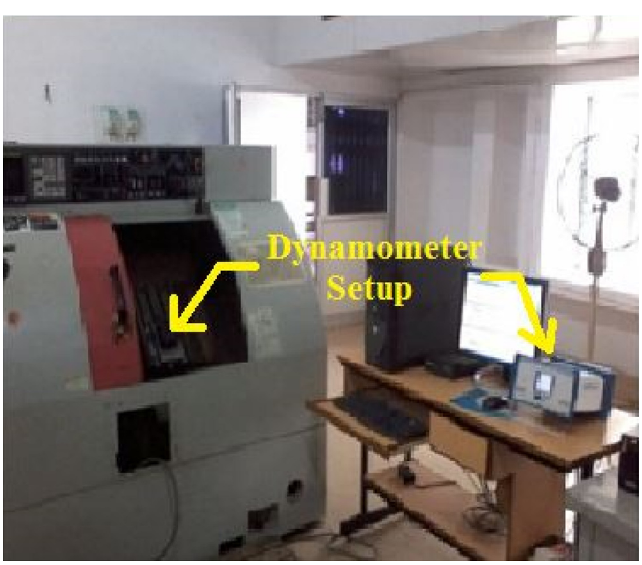


Fig. 1 CNC Machine with dnamometer setup.

Fig. 2 Wattmeter setup.

2.3. Power measurement using powerqulity analyzer

Power quality analyzer (Eg: KRYKARD, Fig. 3) to measure the power consumption in Watts of cutting process is connected to the power supply of CNC turning center. Generally, the machining power is estimated using the mathematical expression by considering main cutting force and spindle speed. In some situations, the estimation of main cutting force may or may not be an optimal one. To avoid this difficulty, machining power is measured directly during machining [14–15].

2.4. Literature review

The literature review regarding has been made in different areas, namely power consumption using mathematical expression, Wattmeter and Power Quality Analyzer (PQA).

2.5. Review on power consumption using mathematical expression

Suresh et al. [6] experimentally investigated that turning of AISI 4340 steel with multi layer coated tools. In their work,

Fig. 3 Power quality analyzer.

they were investigated that effect of machining parameters on power consumption in turning process. The result indicated that lower cutting parameters were offered lower friction, hence low cutting fore and power consumption. Kant and Sangwan [7] optimized process parameters for minimization of power consumption using grey relational analysis and ANOVA. The result showed that feed rate was the significant factor to control the power consumption. Zhang et al. [8] optimized process parameters for improving environmental machining in turning process of stainless steel. In their work, dry environment, wet environment and minimum quantity lubrication effect on specific energy consumption for machining of austenitic stainless steel. The optimized process parameters were used to enhance the environmental machining. Zerti et al. [9] analyzed and optimized the effect of process parameters on power demand in turning of AISI 420. Power demand was calculated by mathematical expression. Neural network and Response surface method were used. The result of this study indicated that minimum power demand was obtained by machining parameters effect.

2.6. Review on power consumption using Wattmeter

Aggarwal et al. [10] used RSM and Taguchi technique for optimization of power consumption in turning of AISI-P20 tool steel. The result revealed that both RSM and Taguchi method predicted similar results to control the power consumption in turning operation. Ravi et al. [11] experimentally investigated the machining power in turning of high chromium white cast iron. In their investigation, Taguchi technique, regression analysis and Artificial Neural Network (ANN) methods were used. The results concluded that Taguchi method was used to enhance the machining performance and better machining power was predicted using regression and ANN methods. Velchev et al. [12] developed a mathematical model for SEC by considering rate of material removal in turning of steel 40 X (GOST 4543). The developed mathematical model was used for better precision of prediction of energy consumed during turning process. Bagaber and Yusoff [13] optimized the machining parameters for minimum power consumption in dry turning of SS 316. Response surface methodology was employed to optimize machining parameters and the result revealed that effectively reduction in the effects and costs of the machining process.

2.7. Review on power consumption using power quality analyzer

Ahilan et al. [14] developed a mathematical model to create relationship between machining parameters and machining power using ANN. The developed model was used to predict the best combination of machining parameters for minimum power consumption and maximum productivity. Balogun at al. [15] the evaluated the energy modeling of the effect of chip thickness, tool wear, nose radius and cutting environment. They suggested that, results were an essential guide for the application of models to estimate energy demand in practical machining processes. Result indicated that developed energy modeling was used to improve accuracy of power consumption of machining processes.

From the literature review, it is understood that mathematical expression procedure, power estimation with the help of cutting force determination and cutting velocity employed are considered. Hence, it has been found that no studies are reported on comparison of power measurement using different devices and their result analysis in turning process. Hence, an effort has been made to estimate the effect of textured cutting inserts and process parameters on power consumption during turning process of Inconel 718.

3. Experimental setup

Inconel 718 is used as work piece material which is widely used high temperature and corrosion resistance applications. The work piece is round cross-section with 25 mm diameter and 45 mm length. Tables 1 and 2 show the mechanical properties and chemical compositions of Inconel 718. The cutting tool material used in this work is uncoated tungsten carbide (make WEDIA) with grade of CNMA 120408. Textures are produced on the rake surface using LASER source. Micro holes on rake face using LASER source is carried out at Meer Laser Solutions, Chennai.MLS-F20 model machine is used with power of 20 W, frequency of 20 kHz and marking speed of 100 mm/sec. Micro hole dimensions are diameter 150 μm, depth 200 μm and edge distance 150 μm. Fig. 4a-cshows the image of micro hole texture cutting inserts and machined samples. Tungsten disulfide (WS_2) is selected as solid lubricant in this work. SAE 40 oil is mixed with solid lubricant in the ratio of 80 to 20 by weight. Taguchi L_9 orthogonal array is used to perform experiments. Input parameters considered are cutting speed, feed rate and depth of cut. Output parameters include machining power consumption. Power consumption during cutting process is measured by cutting force dynamometer, watt meter and PQA. Table 3 shows the experimental results.

4. Results and discussions

Power consumed during machining process can be measured by various methodologies. Generally, improvement of energy efficiency of machining process requires knowledge about machine tool and cutting process [16]. Also, analyzing the measuring devices based on procedure and principle has not received significant attention. The power consumption studies in turning operations are attempted by mathematical expression, Wattmeter and power quality analyzer. Table 3 shows the experimental results obtained using L_9 orthogonal array. Main effect plot is used to identify the level of each factor that provides the minimum response value.

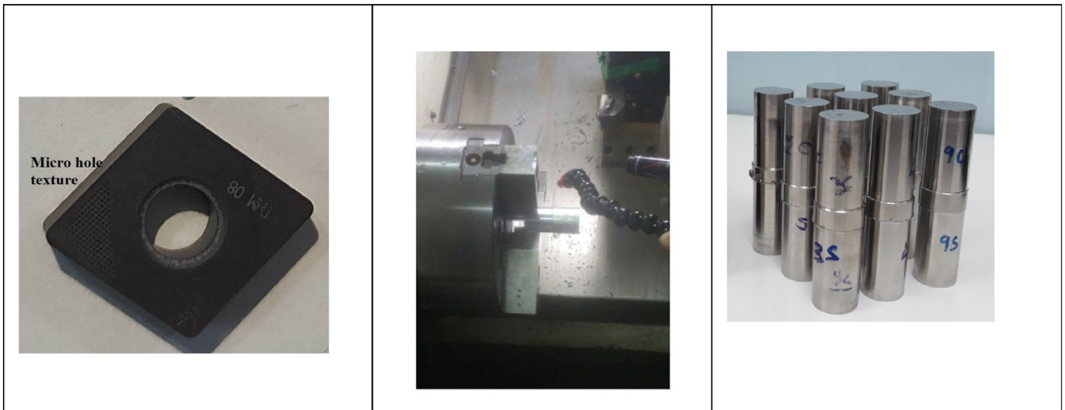
Fig. 5a-c shows that minimum power consumption is obtained in the combination of lower level of cutting speed, feed rate and depth of cut. It is observed that, work material produces less resistance to cutting tool at lower level of cutting parameters. The difference of friction between the work piece material and cutting tool offers variation in the cutting forces which leads the power consumption. The increment of these

Table 1 Mechanical Properties of Inconel 718.

Tensile strength in MPa	Yield strength in Mpa	Elongation	Hardness in HRC
1170–1240	1030–1375	23%	35–40

Table 2 Chemical compositions of Inconel 718.

Ni	Cr	C	Mn	Si	Co	Mo	Nb	Ti	Al	Fe
53	18	0.04	0.06	0.14	0.22	2.9	5.3	0.94	0.48	18



a. Cutting Inserts | b. Machining zone | c. Machined sample

Fig. 4 a-c Cutting insert, machining zone and samples.

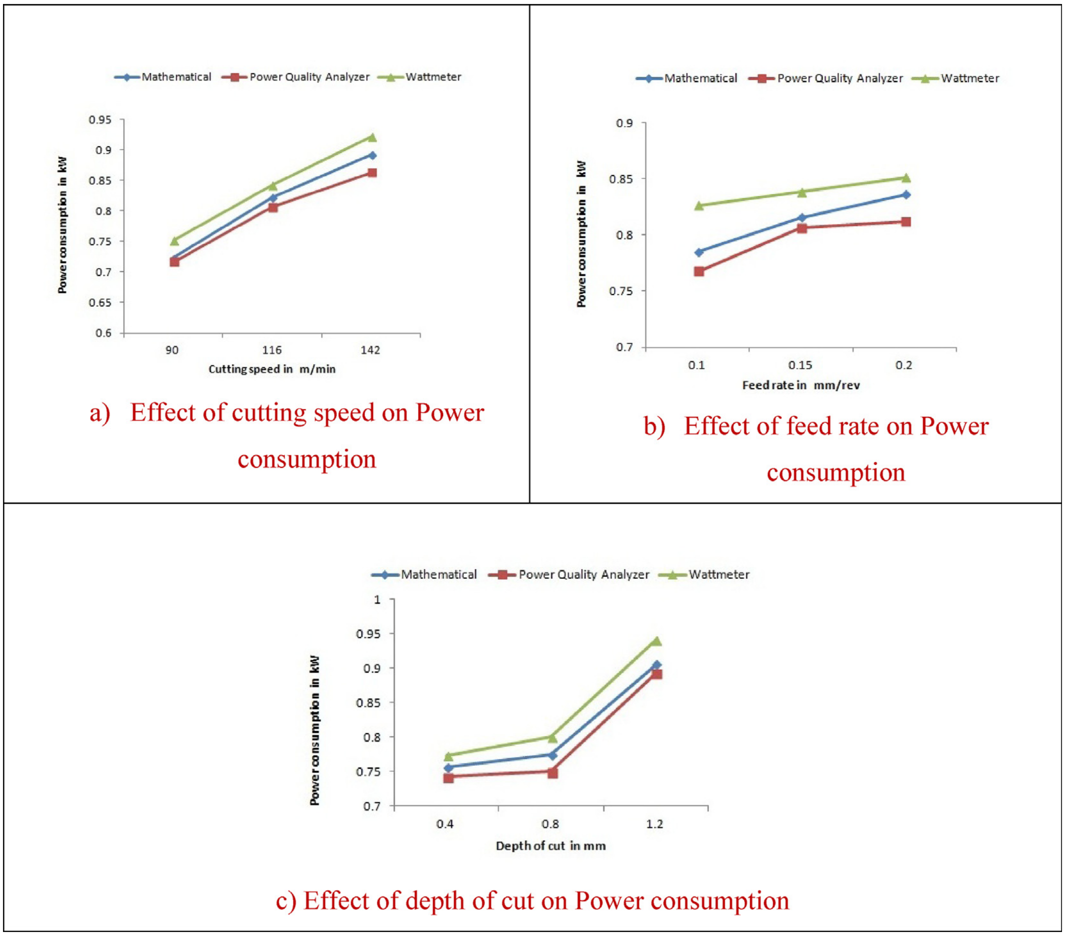
Table 3 Experimental Results.

Sl. No	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Power consumption during machining in kW		
				Dynamometer	Watt meter	PQA
1	90	0.10	0.4	0.648	0.672	0.638
2	90	0.15	0.8	0.741	0.782	0.734
3	90	0.20	1.2	0.781	0.801	0.778
4	116	0.10	0.8	0.697	0.727	0.681
5	116	0.15	1.2	0.926	0.942	0.916
6	116	0.20	0.4	0.842	0.859	0.822
7	141	0.10	1.2	1.010	1.080	0.984
8	141	0.15	0.4	0.780	0.791	0.768
9	141	0.20	0.8	0.885	0.893	0.836

factor influences rate of material removal hence the machine tool need to consume more power. When the feed rate is increased form lower level to higher level, axis motors want to travel quicker and utilized more amount of power. The same one happens in the case of higher level of cutting speed, due to the spindle movement. The similar trend can be observed from Bushan [3]; Suresh et al. [6] and Abbas et al. [17].

Solid lubricants are lubricant materials which are basically solid but soft from frictional heat at the point of contact. Thin lubricated layer has been formed at the tool-chip interface due to temperature raise and followed by thermal expansion of solid lubricant. The result of the lubricated layer was observed that less frictional force and tool wear were compared to plain tool [18]. This micro grooved cutting inserts were provided aerodynamic lubrication effect due to creation of air pockets between tool rake face and chip back surface [19,20]. This thin layer may reduce friction, cutting force and temperature in the machining zone. Tungsten disulfide provides less coefficient of friction. Micro hole textured cutting inserts are used to reduce friction and tool-chip contact length. Solid lubricant filled in micro grooves are termed as self-lubricating textured inserts. Texture on micro hole acts as lubricant storage while performing machining. It is used to provide lubricity and anti-adhesion effect in between the tool-workpiece interface. Also, there is a chance to high localized pressure in the direction of chip flow. This might lead to, less co-efficient of friction and followed by reduction in surface roughness, force and temperature. This is the reason minimum power consumption is obtained with micro hole textured cutting inserts.

In mathematical expression procedure, power estimation with the help of cutting force determination and cutting velocity employed were considered. In experiment measuring cutting force value measured may be accurate or inaccurate due to errors in instrument or may be from other sources of error. Researchers were suggested; to avoid this difficulty, power must be measured directly during machining. In Wattmeter measurement, multiplication factor is used to calculate the



a) Effect of cutting speed on Power consumption

b) Effect of feed rate on Power consumption

c) Effect of depth of cut on Power consumption

Fig. 5 a-c Main effect plots on power consumption.

power consumption during machining. It is based on types of devices and also some basic knowledge is required to connect terminals to the machine with Wattmeter during measurement of power consumption. Power quality is the quality of current of voltage or current wave form. Any deviation of voltage or current waveform from standard value is known as power quality problem. The presence of harmonic creates torque pulsation which results errors in any measurement. Using power quality analyzer current harmonics and voltage harmonic can be measured. Hence, direct measurement of power during turning process, power quality analyzer is an accurate solution.

In manufacturing industry, to increase sustainability and environmental consciousness, various models with relationship between cutting parameters and energy consumption for material removal processes are available. But, those models are without considering the effects of cutting parameter combinations at a certain material removal rate. Hence, some studies are required in this area. Few works were carried out energy modeling to estimate the energy demand in practical machining process [2]. In this paper, various author's attempted devices or methodologies are reported for measuring power consumption in turning operation. At the same time, researchers are excluded their studies between devices. As per author's knowledge voltage and current meter, LAB View, Picolog current data logger and clamp on power logger are also recent consideration for power measuring in turning process [2,17,21–24].

5. Conclusions

This investigation is used to analyze the effect of process parameters on power consumption using textured inserts with solid lubrication in turning operation. The following conclusions are derived from this analysis:

- Micro hole textured insert is not direction dependent, less co-efficient of friction and better lubricious in nature and filled with solid lubricant acts as an alternative to hydrocarbon based cutting fluid. Deformation or fracture of solid lubricant is an important reason to achieve better lubricity and frictional coefficient.
- WS_2 solid lubricant has hexagonal structure, texture II, lower shear value and better lubricious due to its ultra-low coefficient of friction. Hence, it is easily smearing and forms a thin lubricant layer. The advantage of both textured cutting inserts and solid lubrication leads to thin lubricant layer and less co-efficient of friction. It is useful to give minimum cutting force followed by lower power consumption.
- Machine tool needs power to give the relative motion to the cutting tool with respect to the work piece and rotation of spindle. Measurement of power consumption during machining is an important one which leads to energy saving plan, energy efficiency and environmental impacts.

- Power consumption during the machining process is measured by three methods namely mathematical expression by product of cutting force and cutting velocity, watt meter and PQA. The result revealed that direct measurement of power consumption (PQA) is the most accurate, avoiding assumption, calculation and free from errors.
- This experimental investigation is observed that first level of cutting speed (90 m/min), feed rate (0.10 mm/rev) and depth of cut (0.4 mm) lead to minimum power consumption in turning of Inconel 718. Machining power influenced by lower level of cutting parameters which offer low resistance between cutting tool and work piece material. This is produced cutting force variation, which is an important factor for minimization of power consumption during machining.
- Energy utilization in manufacturing sector is a significant contributor for analyzing global warming potential and environmental burden of manufacturing industries. This work highlights the sustainability, ISO14000 responsibility, importance in machining.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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