VOL. 5, NO. 3, MARCH 2010 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

PROCESS MONITORING AND CONTROL OF MACHINING OPERATIONS

Uche R.[1] and Ebieto C. E.[2]
[1]Department of Mechanical Engineering, Federal University of Technology, Owerri, Nigeria
[2]Department of Mechanical Engineering, University of Port Harcourt East-West Road, Choba, Port Harcourt, Nigeria
E-Mail: ucheremy@yahoo.com

ABSTRACT

This paper presents process monitoring and control of machining operations. In this work, a cutting dynamometer mounted on the machine was used to measure the cutting force, cutting speed and the power consumed in the operation. The tool life was also calculated using the Taylor's equation. It was shown that when the cutting tool lifetime elapse, the tool no long give a good cut which imperatively indicates a deteriorating condition of tool life and possible failure.

Keywords: machining operations, process control, process monitoring, tool wear, tool life, cutting speed, cutting force.

INTRODUCTION

Machining operations are shape transformation processes in which metal is removed from a work-piece to produce a part. This operation is aimed at producing parts with specific quality. Process monitoring is the manipulation of sensor measurements (e.g. force, temperature) to determine the state of the processes. The machine tool operator routinely performs monitoring tasks, like visually detecting missing and broken tools and detecting chatter from the characteristic sound it generates. The state of complex process is monitored by sophisticated signal processing of sensor measurements that typically involve thresholding or artificial intelligence (AI) techniques [1]. Process control is the manipulation of process variables (e.g. feed, speed, depth of cut) to regulate the processes. Machine tool operators perform on-line and off-line process control by adjusting feeds and speeds to suppress chatter, initiate an emergency stop in response to a tool breakage event, and rewrite a part program to increase the depth of cut to minimize burr formation.

Figure-1 clearly illustrates the benefits of process monitoring and control. A trend toward more frequent product changes has driven research in the area of reconfigurable machining systems [2]. Process monitoring technology will be critical to the cost-effective ramp-up of these systems, while process control will provide options to the designer who reconfigures the machining system. Process monitoring and control technology will have a greater impact in future machining systems based on open-architecture systems that provide the software platform necessary for the cost effective integration of this technology [3].

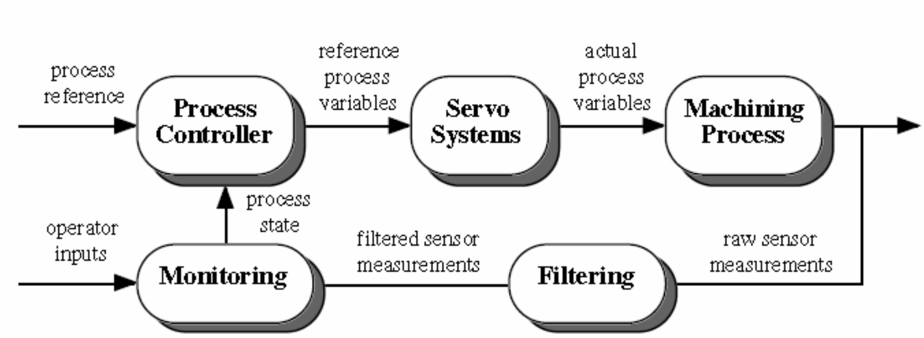

Figure-1. Process feedback control system.

The trend toward making products with greater quality, faster, cheaper and to avoid failure in the machine has lead to this investigation of the process monitoring and control of machining operation.

Most common monitoring techniques are based on tool condition monitoring where vision sensors and probes are used to detect missing cutting tools in a tool magazine and to ensure the correct tool in being used. Vision and force sensors are also used to detect tool-work-piece collisions or tool-tool collisions in parallel machining operations. If a collision is detected, an emergency stop is initiated and the part program is rewritten. A tool fails when it can no longer perform its designated functions. Failed tools drastically decrease productivity by increasing unnecessary tool changes, wasting tools, and creating scrap parts, and possibly injuring operators. Many sensors have been used to indirectly detect tool failure, including acoustic emission, force, sound, vibration etc. In these indirect methods, the signal magnitude, root mean square value, or the magnitude of the power spectrum, among others is inspected, typically via thresholding. One example is

VOL. 5, NO. 3, MARCH 2010 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

where the residual of a first-order adaptive auto-regressive time series filter of the average drive current was monitored to detect insert chippage [4].

The present work applies the Taylor's tool equation [5] to calculate the cutting tool life at specified cutting speed. If cutting continues in machine if the calculated tool life is reached, the tool is replaced with a new tool to avoid failure.

MATERIALS AND METHODS

The contact between the cutting tool and work-piece generates significant force. These forces create torque on the spindle and drive motors and the torque generate power that is drawn from the motors. Excessive forces and torques causes tool failure, spindle stall (an event which typically detected by monitoring the spindle speed), undesired structural deflections etc. [6]. The cutting forces torques and power directly affect the other process phenomena; therefore these quantities need to be monitored as an indirect measurement of other processes phenomena and are regulated so that productivity is maximized while meeting machine tool and product quality constraints. In this work, cutting tool dynamometer in attached to the machine tool, was used measure the cutting and the tangential force in the process**.** The torque is monitored in the spindle unit(s) with strain gauge device and the feed is selected as the variable to adjust for regulation. The depth-of-cut is fixed from the part geometry. The cutting force speed was calculated using Equation 1

$$V_c = \frac{\pi D N}{60} \quad (1)$$

Where V_c is the cutting force speed, D is the diameter of work-piece and is the spindle speed. The power can be calculated from Equation 2.

$$P = F_c V_c \quad (2)$$

P is the power; F_c is the cutting force and V_c cutting speed. Figure-2 shows a typical cutting mechanism and the various forces involved.

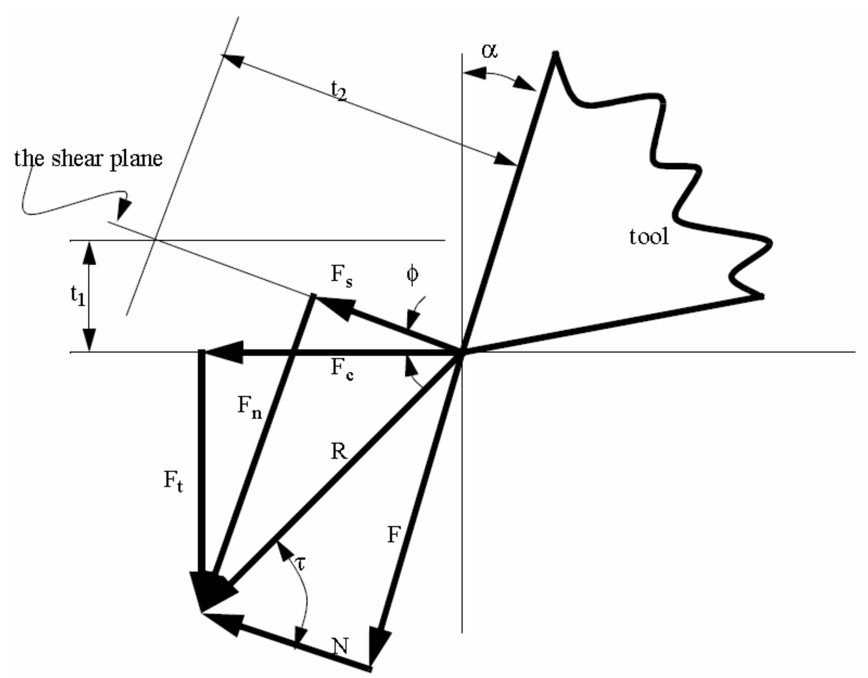

Figure-2. Cutting mechanism showing forces.

Where

F_s = Shear Force
F_N = Force normal to shear plane
α = Tool rake angle (positive as shown)
Φ = Shear angle
τ = Friction angle
F = Friction force between tool and chip
N = Normal force between tool and chip
R = Resultant of F_c and F_t

From the diagram above,

$$\frac{F}{N} = \tan\tau = \mu \quad (3)$$

Where μ = Coefficient of friction

Also, $r_c = \frac{t_1}{t_2}$ and r_c = the cutting ratio

VOL. 5, NO. 3, MARCH 2010 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

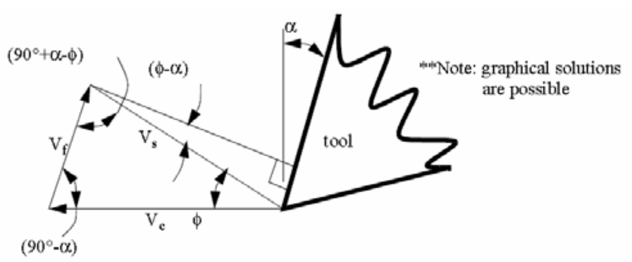

Figure-3. Velocity diagram.

Figure-3 above is the velocity diagram showing all the different velocities involved in cutting. The shear angle can be calculated from Figure-3 using Equation 4:

$$\tan\phi = \frac{r_c \cos\alpha}{1 \quad r_c \sin\alpha} \tag{4}$$

Applying trigonometry to Figure-2, the forces involved in the cutting process can be calculated in terms of the cutting force, tangential force and the rake angle with the formulas below (Equation 5).

$$F = F_t \cos\alpha + F_c \sin\alpha$$
$$N = F_c \cos\alpha - F_t \sin\alpha \tag{5}$$
$$F_s = F_c \cos\phi - F_t \sin\phi$$
$$F_n = F_c \sin\phi + F_t \cos\phi$$

RESULTS AND DISCUSSIONS

The contact between the cutting tool and the chips causes the shape of the tool to change (Figure-4). This is known as tool wear and it has a major influence in machining economics, affects the final work peace dimensions, and will lead to eventual tool failure. A typical tool-wear curve is shown in Figure-5 from an economic point of view; the designer or user would like to use the tool until just before it enters the accelerated wear phase during which the tool will eventually fail.

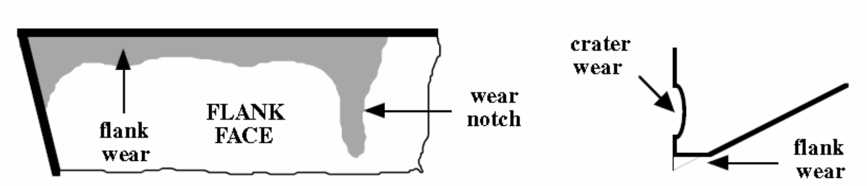

Figure-4. Illustration of different types of tool wear.

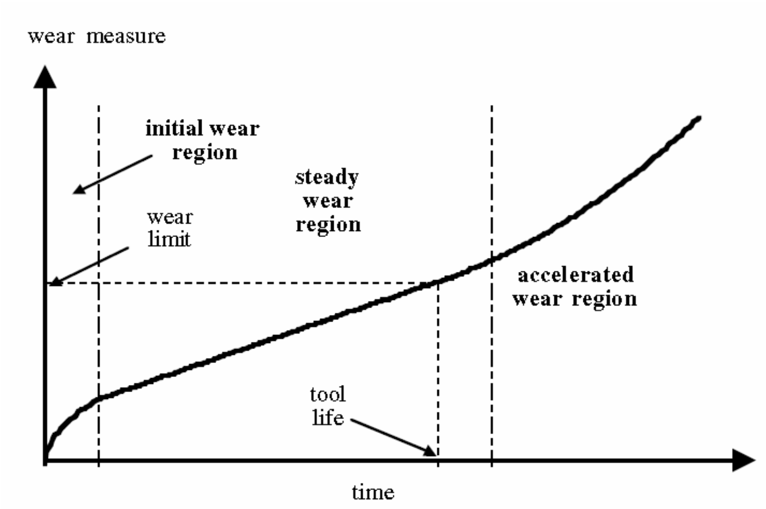

Figure-5. Tool wear history.

The three main tool-wear mechanisms include abrasion between the cutting tool and work-piece, which is always present; adhesion of the chips or work-piece to the cutting tool, which removes cutting tool material and is more active as the cutting temperature increases; and diffusion of the cutting tool atoms to the chips or work-piece, which is typically active during the accelerated tool-wear phase [7].

With the measured cutting velocity, the shear velocity can be calculated and Figure-6 below shows a graph of estimate shear velocity against cutting time. The graph shows that as the cutting time increases, the shear velocity increases which in turn increases the wear of the tool.

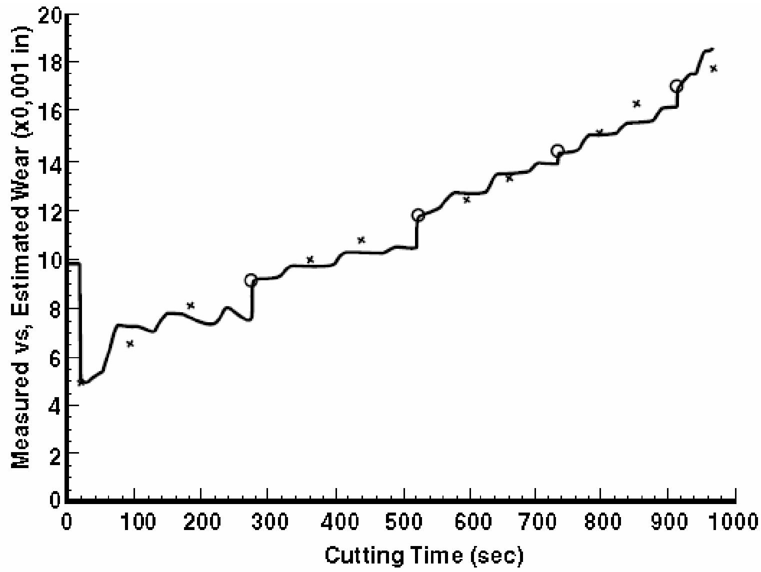

Figure-6. Estimated wear.

The relationship between the cutting velocity and the tool life for a ceramic tool is given in Table-1.

Table-1. Measured cutting velocity and tool life.

S. No.	**Cutting speed** (m/s)	**Tool life** (s)
1	16.44	54.60
2	19.11	33.12
3	22.20	20.09
4	25.79	12.18
5	29.96	7.39
6	34.81	4.48

These values are plotted in Figure-7.

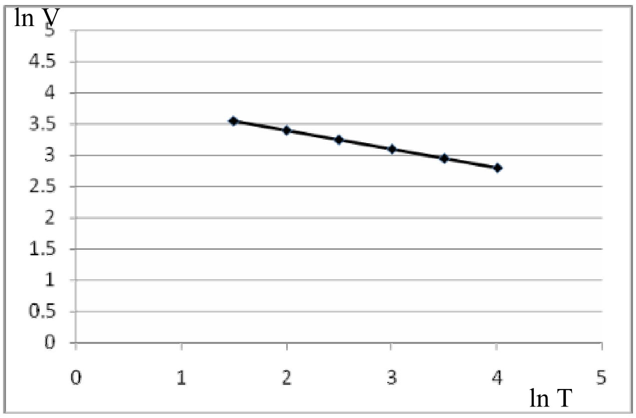

Figure-7. Measured cutting velocity versus tool life.

For that of the power, the total calculated power must not exceed the power of the motor to avoid failure in the system. For this work, Table-2 shows range of calculated power consumed by a machine and its motor power.

Table-2. Calculated power and motor power.

Cutting force (N)	**Cutting velocity** (m/s)	**Power consumed** (kW)	**Motor power** (kW)
1360	1.59	2.1625	4.5
1700	1.2	2.04	4.5
500	2.0	1.0	4.5

CONCLUSIONS

This paper presents the process monitoring and control of machining operations. Work is being conducted on monitoring and controlling of the cutting of the cutter's force and the tool life and order to maintain product quality, cutting tool wear and the machine failure. In this work, a cutting dynamometer mounted on the machine was used to measure the cutting force and the cutting speed calculated from the spindle speed and work-piece diameter. These data are further used to calculate the power consumed for cutting. To avoid the failure of the machine, the consumed for cutting must not exceed the motor power.

The tool life was also calculated using the Taylor's equation, where t1 is the total life time and C and n are empirically determined constants for different cutting tool .In cutting, the calculated tool lifetime must not be exceed when using a particular tool to cut.

It was shown that when the cutting tool lifetime elapse, the tool no long give a good cut and a visual inspection that the tool has wear out. This system is capable of detecting when a particular tool will fail instead of allowing the tool to fail before detecting it. It also helps us to detect if the machine will fail at a particular applied force, and a spindle speed.

VOL. 5, NO. 3, MARCH 2010 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

REFERENCES

[1] Du R. Elbestawi M. A. and Wu S. M. 1995. Automated monitoring of manufacturing processes, Part1: Monitoring methods. ASME Journal of Engineering for Industry. pp. 117, 121.

[2] Koren Y. and Ulsoy A. G. 1998. Reconfigurable manufacturing systems, Technical Report #1. NSF Engineering Research Center for Reconfigurable Machining Systems, University of Michigan, Ann Arbor.

[3] Pritschow G., Daniei C. H., Jurghans G. and Sperling W. 1993. Open systems controllers - a challenge for the future of the machine tool industry. Annals of the CIRP. 42: 449.

[4] Altintas Y. 1992. Prediction of cutting forces and tool breakage in milling from feed drive current measurements. ASME Journal of Engineering for Industry. 114: 386.

[5] Sharma P.C. 2004. A Textbook of Production Technology. S. Chand and Company Ltd., Ram Nagar, New Delhi-110 055.

[6] Ullman D.G. 1997. The Mechanical Design Process. McGraw-Hill.

[7] Lemaster R. L., Daniel S. and Supasit R. 2001. Update of Process Monitoring and Control Research at NC State University. 15th International Wood Machining Seminar. July 30 - August 01. pp. 511-522.