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FORCE DETECTION IN REAL TIME MACHINING PROCESS USING MACHINE CONDITION MONITORING SYSTEM

Engineering

KEYWORDS: Machining; LabVIEW software; data acquisition system; strain gauges; cutting forces

Harichand Singh	Central Scientific Instruments Organisation, Sector-30, Chandigarh-160030, India
Sanjeev Verma	National Institute of Technical Teachers Training and Research, Sector-26, Chandigarh-160019, India
Kashidas Chattopadhyay	Chitkara University, Rajpura campus, Punjab-140401, India
Narinder Singh Jassal	Central Scientific Instruments Organisation, Sector-30, Chandigarh-160030, India

ABSTRACT

Cutting is a process of extensive stresses and plastic deformations. The high compressive and frictional contact stresses on the tool face result in a substantial cutting forces. Cutting forces are background for evaluation of necessary power required for machining and for dimensioning of machine tool components. They influence the deformation of the work piece, its dimensional accuracy, chips formation and machining system stability. The direct approach to study cutting forces in machining is very expensive and time consuming, especially when a wide range of parameters like tool geometry, material, cutting conditions, etc are included. The study presents an attempt to estimate the cutting forces during turning and facing in real time constraints using condition monitoring system for machine tool. The system is based on LabVIEW software, data acquisition system and strain gauges fixed on the cutting tool for measuring the cutting forces. Three levels of cutting parameters i.e. depth of cut, cutting speed and feed rate are chosen. The strain gauges measures the strain produced during machining and values are stored in the computer using data acquisition system. The system measures the experimental cutting forces by means of strain gauges fixed on cutting tool and developed calibration curve. The data obtained from the acquisition system was then compared with the calculated cutting forces values.

I. INTRODUCTION

Cutting forces developed during machining influences the machining performance and part costs directly. Cutting forces generates extensive stresses and plastic deformations on the tool and work material. The high compressive and frictional contact stresses on the tool face results in a substantial cutting force. Cutting forces influences the cutting parameters such as cutting speed, feed rate, depth of cut, rake angle and tool life. Therefore, various force measurement methods have been developed to establish the relationship between these cutting variables and the cutting forces. With the use of computers in machining, many problems encountered in conventional machining have been eliminated. It is known that piezoelectric, thermo-electric, photoelectric, load cell and transducer type dynamometers developed for cutting force measurements are known to convert the mechanical energy to electrical signals. Significant improvements in machining have been achieved by using simulation software to estimate cutting forces and stress values before machining. Increasing use of tool and process monitoring system is one of the most significant developments in manufacturing environment. Strain gauges most commonly used in such systems measure cutting force component. In the present work, the cutting parameters affecting the cutting forces were studied during orthogonal machining.

Understanding about the cutting forces results in:

- Proper design of the cutting tools
- Proper design of the fixtures used to hold the workpiece and cutting tool
- Calculation of the machine tool power
- Selection of the cutting conditions to avoid excessive distortion of the workpiece

For machining process, where the geometry of the metal removal process is constantly changing, setting optimum cutting parameters has not only great economic benefits, but is also very challenging. Proper selection of cutting tools, machining parameters for optimal surface quality and tool life requires a methodical approach by using experimental methods and statistical models. Aggarwal et al. [1] obtained the optimum CNC turning conditions for surface roughness, tool life, power consumption and cutting force while turning AISI P20 tool steel. The single response optimization was conducted by Taguchi method and Analysis of Variance (ANOVA) was used to find out the most influential parametric combination for multi-response problems. Ghosh et al. [2] used L18 orthogonal array to study surface finish and tool life for machining hardened steel. Chipping and adhesion were reported to be the main cause of the wear. Multiple regression equations were formulated for estimating the optimal values of surface roughness and tool wear. Ozel at el [3] studied the effects of cutting edge geometry, work piece hardness, feed rate and cutting speed on surface roughness and cutting forces while finish turning hardened AISI H13 steel. Results show that the effect of spindle speed on the surface roughness is the most significant while cutting tool material is less significant. Lalwani et al. [4] investigated the effect of cutting speed, feed rate and depth of cut on feed force, thrust force, cutting force and surface roughness while finish turning of MDN250 steel using coated ceramic tool using response surface methodology (RSM). The results show that cutting forces and surface roughness do not vary much with cutting speed in the range 55–93 m/min. Depth of cut is the dominant contributor to the feed force accounting for 89.05% of the feed force. In the thrust force, feed rate and depth of cut contribute 46.71% and 49.59%, respectively. In the cutting force, feed rate and depth of cut contribute 52.60% and 41.63% respectively. Kosaraju et al [5] studied the effect of rake angle and feed rate on the cutting forces during orthogonal turning of EN8. The forces were measured using 4-component piezoelectric dynamometer. The experimental results show that the feed force is greater than the tangential force and the longitudinal force is least in magnitude irrespective of the tool rake angle. Gunay et al [6] presented a comparison of empirical and experimental results for main cutting force during machining of AISI 1040. A dynamometer was designed for measuring the forces using two strain gauges. Main cutting force was observed to have a decreasing trend as the rake angle increased from negative to positive values. The deviation between empirical approach and experiments was of the order of 10–15%. Prashanth et al [7] presented the experimental investigations on the HSS cutting tool with varied side rake angles while machining EN8 material under dry conditions. The cutting force, feed force and thrust force was measured using turning tool dynamometer. The results indicated that the 12° positive side rake angle tool results in least cutting force while 12° negative side rake angle tool results in highest cutting force. Saini et al. [8] designed data acquisition system for strain gauge based dynamometer for measuring cutting force component during machining on lathe. Cus at al. presented an approach for design of condition monitoring system for online optimization of cutting parameters using Labview and dynamometer [9]. The literature review reflects that in turning operation, the parameters such as cutting speed, feed rate, depth of cut and tool properties affect the performance characteristics i.e. cutting force, feed force, radial force and surface finish to a significant extent. Very few experimental studies have been undertaken for obtaining the cutting forces in real time constraints using machine condition monitoring system using lab view software.

II. METHODOLOGY

The three levels of cutting parameters selected for experimentation using single point side cutting tool HSS tool are given Table 1. The machining process on lathe was studied for EN1A mild steel with composition as given in Table 1. HSS tool used has side rake 18°, back rake 0°, front clearance 6°, and side clearance 6°.

Strain gauge detects and converts variety of physical variables into electric signals. These have widespread use in sensors of force, pressure, displacement, acceleration and torque. For selecting the most suitable strain gauge for each application, consideration must be given to the variation in pattern design, grid alloy, self temperature, compensation backing material, and optional features. Self temperature compensation, surface preparation, adhesive selection and soldering of wires are important factors to be considered to get the better results during experimentation. The specifications of strain gauge used in our application are given in Table 2.

Table 1: Specification of Material Chosen and Process Variables

Parameter	Detail		
Work piece			
Workpiece Material	Mild steel - EN1A		
Chemical composition	C-0.16%, Mn-0.55%, Si-0.25%, P-0.02%, S-0.29%,		
Diameter	30 mm		
Cutting variables			
Cutting speed (rpm)	180	270	450
Feed (mm/rev)	0.125	0.25	0.4
Depth of cut (mm)	0.04	0.08	0.12
Environment	Dry		
Tool overhang	30 mm		
Process	Fine turning and facing		

Advantageous features of strain gauges are:

- Precision measurement of strain occurring at a specific point on surface of a measuring object
- Quick response to high speed phenomena
- Superior linearity within a wide range of strains sensed
- Measuring service in a broad range of temperature and in adverse environments

To perform the experiments, work piece were cut from the 30 mm diameter cylindrical bars of EN-1A material. The pieces were turned and faced before the actual experimentation. The finished facing operation was carried out on these work pieces using the different combination of input cutting parameters as designed by the design of experiment. The GeDee-Weiler lathe machine was used for experimentation. The cutting tool was clamped on the tool holder with overhang of 30 mm. The work piece was clamped in the 3-jaw chuck. Determination of cutting force using strain gauges Wheatstone bridge has been done through the plan of experiment as shown in flowchart in figure 1.

Table 2: Strain Gauge Specifications

Parameter	Details
Resistance in ohms	350
Gage factor	2.12
Length and breadth	10.3x 4.8 mm
Bonding adhesive	Cino-Acrylic
Grid and tab geometry	Zig zag
Carrier Matrix Material	Polyamide
Resistance element material	Cu-Ni alloy

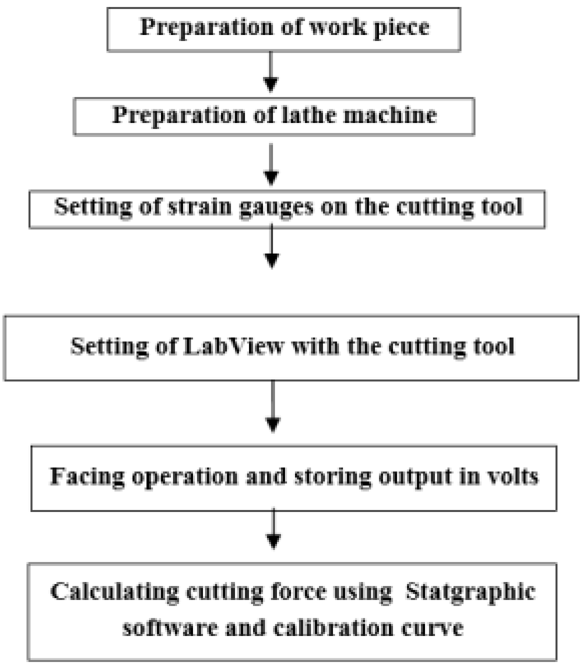

Figure 1: Flowchart of Experimentation

A. Setting of strain gauges on cutting tool

The HSS tool bit was prepared for its cutting angles and two strain gauges were fixed on it using a special adhesive, as shown in figure 2.The direction of fixing the strain gauges on the cutting tool is very critical. One strain gauge was fixed in such a direction so that it can record the cutting forces, while the other strain gauge was used to give temperature compensation. The wires were soldered to the strain gauge and other end of the wire was connected to the NI DAQ card as shown in figure 3.

B. Design of experiments

Statistical design of experiments is the process of planning the experiments so that the appropriate data could be collected, which may be analyzed by statistical methods resulting in valid and objective conclusions. Full factorial design is the most widely used design. If there are three factors (say A, B and C) under study and each factor has three levels, then this constitutes a 33 factorial design i.e. 27 combinations. To minimize the errors, each experiment was carried out three times.

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Figure 2: Cutting Tool with Strain Gauge

Figure 3: Attaching the Strain Gauges with DAQ Card and LabView

C. Labview for data collection

One of the most significant developments in the manufacturing environment is the increasing use of tool and process monitoring systems. Many different sensors coupled with signal processing technologies are now available and many sophisticated signal and information processing technologies have been invented. The system is based on Labview software, data acquisition system and the cutting force measuring devices (strain gauges). This system is mounted on the lathe machine for experimentation. The system collects the deflections of the tool during the cutting process by means of strain gauges. The output response was obtained in the form of volts. These values in volts were converted into cutting force in Newtons, using a calibration chart. Calibration chart was prepared by doing experiments using force gauge and strain gauges.

The NIcDAQ-9178 is an eight-slot NI Compact DAQ chassis designed for small, portable, mixed-measurement test systems. The cDAQ-9178 can be combined with up to eight NI compact series I/O modules for a custom analog input, analog output, digital I/O and counter/timer measurement system. The cDAQ-9178 has four 32-bit general purpose counter/timers built in. It can access counters through an installed hardware-timed digital module such as the NI 9401 or NI 9402 for applications that involve quadrature encoders, PWM, event counting, pulse train generation and period or frequency measurement. Parts of USB data acquisition system are shown in figure 4. NI-9237 module is a 4-Channel, 24-Bit, Half Bridge, Analog Input 60 VDC system. For the experimentation half bridge is used. VI program for data acquisition and its front panel is shown in figure 5 and figure 6.

Figure 4: USB data acquisition system, NI-9237 and NI cDAQ-9178

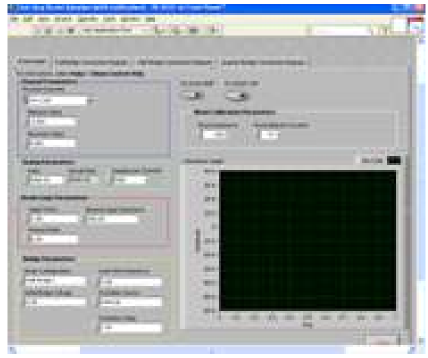

Figure 5: VI Front Panel

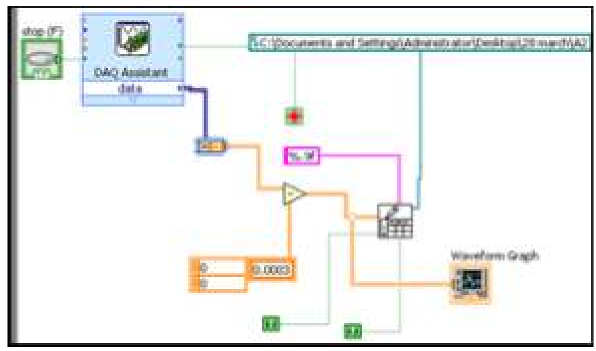

Figure 6: VI program for data Acquisition

The parameters were varied and experiments were performed with design of experiments approach. During the experimentation, the strain gauges were fixed on HSS cutting tool using adhesive. Extension wires were soldered to the strain gauge. Further these wires were connected to the NI DAQ card 9178 and suitable resistance to make half wheat-stone bridge circuit. The signals corresponding to the strain produced on the cutting tool during cutting operation were obtained in volts through Labview. These values are shown in the Table 3.

Table 3 Input Parameters and Strain response

Experment No.	Cutting Speed (rpm)	Feed Rate (mm/rev)	Depth of cut (mm)	Strain gauge output in Volts
1	180	0.125	0.04	0.005802
2	180	0.125	0.08	0.005806
3	180	0.125	0.12	0.005812
4	180	0.25	0.04	0.005831
5	180	0.25	0.08	0.005833
6	180	0.25	0.12	0.005835
7	180	0.4	0.04	0.00586
8	180	0.4	0.08	0.005869
9	180	0.4	0.12	0.005898
10	270	0.125	0.04	0.005804
11	270	0.125	0.08	0.005808
12	270	0.125	0.12	0.00587
13	270	0.25	0.04	0.005818
14	270	0.25	0.08	0.005832
15	270	0.25	0.12	0.005912
16	270	0.4	0.04	0.005826
17	270	0.4	0.08	0.005837
18	270	0.4	0.12	0.00592
19	450	0.125	0.04	0.00582
20	450	0.125	0.08	0.005828
21	450	0.125	0.12	0.005836

22	450	0.25	0.04	0.005842
23	450	0.25	0.08	0.005843
24	450	0.25	0.12	0.00594
25	450	0.4	0.04	0.005845
26	450	0.4	0.08	0.005847
27	450	0.4	0.12	0.00596

A. Calibration equation

After experimentation, there was a need of calibration chart or equation, from which the cutting forces could be measured from strain volts data. The cutting tool fixed with strain gauges was clamped on the table and the wires from the strain gauges were connected to the DAQ card and Labview software. A force gauge was used to deflect the cutting tool from the cutting point. Using force gauge, known value of force was applied at the tool cutting point. This force produced the strain in the cutting tool, which was further recorded by the Labview software. Table 4 shows the values recorded for preparing the calibration equation.

The following quadratic equation model was assumed.

$$x=a+by+cy^2 \quad .....(1)$$

where x, y are variables and a,b,c are constants.

The calibration equation, developed using stat-graphics software, for cutting force is:

Cutting Force= -16979.6 + 5.27525E6*Strain - 4.0466E8* Strain*Strain .....(2)

Table 4 Values Recorded for Preparing the Calibration Equation

S. No.	Cutting Force from force gauge (N)	Strain gauge output in Volts
1	5.2	0.005802
2	8.2	0.005807
3	19.1	0.005824
4	23.6	0.005838
5	34.5	0.005854
6	53.2	0.005889
7	62.7	0.005908
8	76.2	0.005938

The strain values in Table 3 were converted into the cutting force values using this calibration equation and are shown in Table 5. The output shows the results of fitting a multiple linear regression model to describe the relationship between cutting force and the strain gauge output.

Table 5 Conversion of Strain Gauge Voltage to Cutting force

Experiment No.	Strain gauge output in Volts	Cutting Force (N)
1	0.005802	4.97
2	0.005806	7.29
3	0.005812	10.73
4	0.005831	21.44
5	0.005833	22.55
6	0.005835	23.66
7	0.00586	37.22
8	0.005869	41.98
9	0.005898	56.88
10	0.005804	6.13
11	0.005808	8.44
12	0.00587	42.51
13	0.005818	14.14
14	0.005832	21.99
15	0.005912	63.82
16	0.005826	18.65
17	0.005837	24.76
18	0.00592	67.72
19	0.00582	15.27
20	0.005828	19.77
21	0.005836	24.04
22	0.005842	27.51
23	0.005843	28.05
24	0.00594	77.24
25	0.005845	29.14
26	0.005847	30.23
27	0.00596	86.43

Using the mechant theory relations, cutting force was calculated at some values of input variables. It was found that the experimental cutting forces are always higher by 4% to 25% as compared to the calculated cutting forces.

IV. Conclusions

Based on the experimental work carried out, following conclusions were made:

1. It was found that the values of experimental cutting forces are always higher than that of calculated cutting forces. Experimental cutting forces are more reliable than calculated cutting forces for designing the machine tool.
2. To obtain the accurate value of cutting force, rigidity of machine, proper conductivity between strain gauge, DAQ card and Labview software, orientation of strain gauge, rigidity of the cutting tool should be maintained.
3. Cutting force increases with the increase in the feed rate and depth of cut.
4. Cutting force decreases slightly with the increase in the cutting speed.

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