Influence of electromagnetic field on metal cutting in turning operation of AISI 1018 low carbon steel

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Abstract. The effects of magnetic field on the machining force and tool wear in turning operation has been investigated. AISI 1018 low carbon steel used during machining as it is generally used in industry. The present and absent of the magnetic field during machining in dry condition was studied, and has been analysed. Taguchi approach has been used when designing the experiment. The results shown in this study related to the machining force and tool wear. The experimental results shown that when magnetic field has been applied, the machining force in turning operation such as radial force ($F_r$), feed force ($F_f$), and cutting force ($F_c$) gave higher results as compared to the absent of magnetic field. As for the tool wear, the results shown that the tool life is getting longer when the magnetic field has been applied which has been proven by the previous studies done before.

1. Introduction

In the present years, manufacturing industry has demand an efficient strategy in order to satisfy market requirements. The researchers are trying to find solutions to reduce the machining costs by having the reduction in force experienced and improvements in tool life when the steel was being cut since earlier time. The machining force is closely related to the tool wear and it can also act as the main feedback of wear level during machining process [1]. Therefore, the application of external electromotive sources such as magnetic field in the machining process has been studied previously.

The investigation has been made on the effects of a magnetic field on the frictional behaviour of steel XC48/graphite couple [2]. The application of the magnetic field has led to a decrease of a mean value of friction coefficient of the sliding contact but the wear rate has not been discussed. The similar studies has been made regarding the wear and friction behaviour of a nickel/XC 48 steel couple which gave the increased value of friction coefficient and has shown the decreased wear rate [3]. This results has agreed to the studies made on the ferromagnetic steel surface in sliding contact under the influence of magnetic field [4].

As for the machining in turning operation, the effects of heat treatment and magnetic field of turning the mild steel by considering the tool life, surface roughness and chip morphology has been done [5]. The application of magnetic field has later been introduced as one of the external source to provide reduction in tool wear and improving machinability of materials [6-7]. For surface plastic deformation (SPD), the investigation has been done in dry cut of magnetized ferromagnetic AISI 1045 steel which resulted in the strengthens of the cut surface of the chip segmentation in high cutting speed [8].
In this study, the application of magnetic field has been analysed on the turning process of AISI 1018 low carbon steel. The corresponding effect of this application has been obtained to the cutting force and tool life during the machining. The experimental results has been analysed and discussed.

2. Experimental Designs and Procedure
The experimental designs and procedure have been explained below which divided to three subsections which are designation of experiment which explains the tool, material, and parameter used in this experiment. Next subsection would explain regarding the measured tool life and final subsection is the measured machining force during the present and the absence of the magnet.

2.1 Designation of Experiment
In this study, all experiments have been carried out in dry machining condition on the OKUMA LB15 CNC lathe. The range of spindle speed that can be used for this machine is between 75- 4200 RPM. The workpiece material used is AISI 1018 low carbon steel because it has been widely used in industry. The diameter of the workpiece is 100 mm and the length of cut is 180 mm. TNMG 160408N-GU made by Sandvik is used in this experimental work is in the form of triangular insert which is made of coated carbide of grade AC820P. Cutting speed (v), feed rate (f), and depth of cut (d) were selected as the machining parameters to analyze the influence of electromagnetic field on metal cutting which has been shown in The applications of the electromagnets when attached to dynamometer

Table 1. The experiment has used Taguchi method in this study. L9 (2^4) Orthogonal Array has been selected as the chosen parameters has been shown in the Table 2. Figure 1 has shown the sample workpiece of AISI 1018 low carbon steel and Figure 2 shown the DC electromagnet which attached to tool holder.

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Figure 1. Sample workpiece of AISI 1018 low carbon steel
Figure 2. The applications of the electromagnets when attached to dynamometer

Table 1. The machining parameters and levels.

| Symbol | Machining Parameters     | Levels          |
|--------|--------------------------|-----------------|
|        |                          | Level 1 | Level 2 | Level 3 |
| v      | Cutting speed (m/min)    | 190     | 220     | 250     |
| f      | Feed rate (mm/rev)       | 0.20    | 0.30    | 0.40    |
| d      | Depth of cut (mm)        | 0.75    | 1.00    | 1.50    |

Table 2. Machining parameters assigned in a L9 (2⁴) orthogonal array.

| Experiment No. | Cutting speed, v (m/min) | Feed rate, f (mm/rev) | Depth of cut, d (mm) |
|----------------|--------------------------|-----------------------|----------------------|
| 1              | 190                      | 0.20                  | 0.75                 |
| 2              | 220                      | 0.30                  | 0.75                 |
| 3              | 250                      | 0.40                  | 0.75                 |
| 4              | 190                      | 0.30                  | 1.00                 |
| 5              | 220                      | 0.40                  | 1.00                 |
| 6              | 250                      | 0.20                  | 1.00                 |
| 7              | 190                      | 0.40                  | 1.50                 |
| 8              | 220                      | 0.20                  | 1.50                 |
| 9              | 250                      | 0.30                  | 1.50                 |

2.2 Tool Life
Tool wear measured up to tool failure to analyse the effect of cutting operation under electromagnetic field on tool life. In this study, the tool life measured is in terms of time in minutes. According to International Standard Organization, ISO 3685 (1993), tool wear is achieved when the average flank...
wear, $V_B$ of the insert has reached 0.30 mm or the maximum flank wear, $V_{B_{\text{max}}}$ has reached twice of the average which is 0.60 mm.

For every experiment after each pass of length of cut, the insert is taken out and will be observed under microscope to collect the measurement of the flank wear. The average value of the flank wear will be measured after several experiments until the flank wear has reached 0.30mm.

2.3 Machining Forces
The measured machining forces were determined to identify whether the presence of magnets will reduce the machining force from the workpiece. Machining forces were also measured to determine the effects of each machining parameters. The forces of machining were determined using a dynamometer which is based on piezoelectric effect. Then it is connected to a multichannel amplifier to convert those charges into voltages. These voltages are in the form of analogue mode and it will be converted by using a digital storage oscilloscope. These digitized waveforms then will be sent to a computer where the force values are then computed.

Based on the setup specification of the amplifier, three components of forces would be calculated according to the voltage obtained from the oscilloscope. These forces will be compared against forces obtained during different set of parameters and with or without the presence of magnet. The three components of forces which have been obtained are radial force ($F_r$), feed force ($F_f$), and cutting force ($F_c$).

3 Results and Discussion

3.1 Tool life and machining force in Normal Experiments
The measured tool life in normal experiments has been determined as shown in Table 3. The mean values of machining forces also have been tabulated shown in Table 4. The longest and shortest time of cut is stated as experiment 1 (83.50 minutes) and experiment 5 (3.08) respectively. Thus, both of these experiments are conducted under electromagnetic field for comparison and further discussion.

| Experiment No. | Tool Life (min) |
|----------------|-----------------|
| 1              | 83.50           |
| 2              | 19.40           |
| 3              | 5.85            |
| 4              | 22.70           |
| 5              | 3.08            |
| 6              | 41.80           |
| 7              | 4.35            |
| 8              | 15.00           |
| 9              | 4.18            |
Table 4. Machining of forces in Normal Experiments

| Experiment No. | Radial Force, $F_r$ (N) | Feed Force, $F_f$ (N) | Cutting Force, $F_c$ (N) |
|---------------|------------------------|----------------------|------------------------|
| 1             | 137.82                 | 156.22               | 391.83                 |
| 2             | 113.07                 | 156.22               | 416.78                 |
| 3             | 210.89                 | 260.37               | 827.52                 |
| 4             | 270.30                 | 327.71               | 582.52                 |
| 5             | 266.34                 | 360.60               | 894.30                 |
| 6             | 84.95                  | 283.07               | 416.78                 |
| 7             | 424.36                 | 555.58               | 951.42                 |
| 8             | 253.66                 | 368.04               | 477.11                 |
| 9             | 345.15                 | 480.01               | 680.28                 |

3.2 Machining forces between Normal Experiments and Electromagnetic Experiments

Based on Figure 3 below have shown the graph of three component of forces which are radial force ($F_r$), feed force ($F_f$), and cutting force ($F_c$). As shown in Figure 3(b) and Figure 3(d), Experiment 5 has shown both higher values for normal and electromagnet experiment compared to Experiment 1. From these graphs, it has shown that the higher the feed rate, cutting speed, and depth of cut which has been applied, the higher the value of machining force.

As for Figure 3(c), the graph of the feed force versus time has been quite difficult to be compared graphically, as their value often fluctuated and overlapped between each other. Therefore, it has shown in Figure 3(d), the average values of feed forces for Experiments 5 both in normal and electromagnetic experiments have higher feed forces.

Figure 3(e) has been shown that, the cutting force versus time is not easily to be analysed for a comparison of normal and electromagnetic experiment. Based on Figure 3(f) which has shown mean of feed force, there is a little difference which can be seen here. Unlike for other previous two forces which are mean of radial force and feed force have the same pattern value which normal experiment 5 has lower value of force compare to its electromagnetic experiment, the cutting force for normal experiment 5 is a lot higher compared to electromagnetic experiment.
Figure 3. Graph component of forces versus Time and Mean of Component of Forces.

Table 5. Percentage differences of Mean Forces in Normal Experiments and Electromagnetic Experiments

| Experiment No. | Condition      | Radial Force, $F_r$ (N) | Feed Force, $F_f$ (N) | Cutting Force, $F_c$ (N) |
|----------------|----------------|-------------------------|-----------------------|-------------------------|
| 1              | Normal         | 137.82                  | 156.22                | 391.83                  |
|                | Electromagnet  | 179.01                  | 181.28                | 401.49                  |
|                | **Percentage of Difference (%)** | +29.89                  | +16.04                | +2.47                   |
| 5              | Normal         | 266.34                  | 360.60                | 894.30                  |
|                | Electromagnet  | 380.20                  | 379.39                | 272.85                  |
|                | **Percentage of Difference (%)** | +42.75                  | +5.21                 | -6.95                   |
There are three basic component forces which have been recorded the mean value of forces in both condition which are in electromagnet and normal experiments as shown in Table 5. These forces in electromagnet condition are expected to be lower than the normal experiments. However, based on analyses which have been done apparently shows different result that most of the forces are actually get higher values when machined under electromagnetic field.

As been stated by [1], the forces measured under electromagnetic field in turning operation were lower compared to corresponding normal experiments. He justified that the presence of electromagnetic field in the form of eddy current during machining is needed to lower the value of forces.

Justification that can be made from this analysis is due to larger part of the tool overhang when machined in electromagnetic condition. Initially, when the experiments have been carried out, normal experiments have been first completed before determining which experiments that would need to be conducted under electromagnetic field. Then, the tool overhang was kept constant throughout the normal experiments. Unfortunately, during setup of electromagnetic experiments, the electromagnets were not able to fit in the space between the tool holder’s clamp and the dynamometer. In order to resolve this problem, the position of the tool holder has been shifted for 2 to 3 mm in distance to make sure the electromagnets would attach on the tool holder firmly. Therefore, the tool holder has been shifted outwards. Probably with larger tool overhang and movement during placing of electromagnet, there is higher vibration will occur and these will lead to higher machining forces.

3.3 Tool Life between Normal Experiments and Electromagnetic Experiments

The flank wear plotted against cutting time as shown in Figure 4 and Figure 5 which have shown both Experiment 1 and Experiment 5 respectively. The total cutting time of Experiment 5 has shorter duration compared to Experiment 1. This is due to the increase in the cutting speed, feed rate and depth of cut. In Figure 4, the graph of electromagnet shown longer tool life compared to corresponding normal experiments. This is same as compared to Figure 5 where there has shown longer time of tool life for electromagnet than the normal experiments.

As for further discussion of the analysis, Table 6 has shown the percentage of difference of tool life in normal experiments and electromagnetic experiments. It has shown that for both experiments, the tool life for electromagnetic experiments is higher than corresponding normal experiments. The percentage difference for both experiments has achieved significant improvements since the value is more than 20%. Results obtained were similar to other previous studies. The study has been made of an application on external electromotive force (EMF) such as magnetic field during cutting process [3]. The result has significantly improved the cutting tool life. The previous study have been done for the contribution of better understanding on the influence of magnetic field on the wearing of tools in dry cutting process [4]. The presented result obtained of magnetized ferromagnetic AISI 1045 steel has shown that there was a reduction of wear due to the magnetic applied.
Figure 4. Flank Wear versus Time (Experiment 1)

Figure 5. Flank Wear versus Time (Experiment 5)

Table 6. Tool life in Normal Experiments and Electromagnetic Experiments

| Exp. No | Tool Life (minutes) | Percentage of Difference (%) |
|---------|---------------------|-----------------------------|
|         | Normal   | Electromagnet |                     |
| 1       | 83.50    | 103.00        | +23.25              |
| 5       | 3.08     | 3.92          | +27.27              |
4. Conclusions
In this study, when direct current (d.c) magnetic field has been applied during machining in turning operation, the analysed results obtained high machining forces and longer tool life. For the tool life it has been proven that when magnetic field is applied, the tool life has achieved significant improvement since the percentage of difference obtained in normal experiments and electromagnet experiments shown more than 20%. The value obtained as for Experiment 1 is +23.25% and Experiment 5 is +27.27%. As for the machining forces, justification has been made due to the larger tool overhang when placing the electromagnetic fields which cause the vibrations to occur frequently. This lead to higher machining forces when machined in electromagnetic condition compared to the corresponding normal experiments. The percentage of difference of experiments for each component of force has shown mostly higher machining forces.

For both experiment when electromagnetic field is absent and present condition, the results obtained will be shown below.

- The percentage of difference obtained in Experiment 1 for mean of component forces for radial force ($F_r$), feed force ($F_f$), and cutting force ($F_c$) were +29.89%, +16.04%, and +2.47%.
- The percentage of difference obtained in Experiment 5 for mean of component forces for radial force ($F_r$), feed force ($F_f$), and cutting force ($F_c$) were +42.75%, +5.21%, and -6.95%.

In future, the further for more number of experiments should have been made and other type of material should have been considered to determine the significant results when the magnetic field been applied. In addition, more research needs to be done in order to determine the extent and limitation of influence of magnetic field on metal cutting.

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