Impact Factors of Back Rake Angle on the Oblique Cutting Force in AISI 4140 Low Alloy Steels Standard

Chumphon Chaipradermsak
Suthep Yiemchaiyaphum
Department of Production Engineering, Faculty of Engineering
Rajamangkala University of Technology Krungthep, Sathorn Bangkok, Thailand
Email: y_suthep@hotmail.com

Abstract

Currently manufacturing a large number of machine parts using CNC turning machine requires efficient planning in choosing components of the turning process. Oblique cutting with tool inserts is a factor affecting such efficiency in using back rake angle appropriately. This research aimed to study factors affecting oblique cutting. The study used back rake angle – 30, -15, 0, 15, and 30 degrees to see how they have an impact on radius force (F_R), tangential force (F_P) and feed force (F_Q). The findings from the study showed that when *the higher negative bake rake angle value* was given, the *more cutting force* was required; and the cutting force decreased when *the lower negative bake rake* angle was used. When *the higher positive bake rake angle value* was given, *the more cutting force* was required as well. Similarly, considered contributing factors like feed and depth of cut, the cutting force would increase and decrease depending on the value of bake rake angle significantly, both positive and negative. *All cutting forces are equal both positive and negative* from the experimental results, ranging from radius force (F_R), tangential force (F_P), and feed force (F_Q), respectively. The study results can be adopted to design back rake angles for greater efficiency.

Keywords: Oblique cutting, CNC Turning Machine, tool inserts

1. Introduction

Manufacturing a machine part requires various manufacturing processes. A large number of manufactured machine parts are obtained from a turning process using a CNC turning machine. CNC turning machines play a high important role and the number seems to be higher every year. Based on the speedy flow of such technology, operators are not able to choose types and kinds of CNC tool inserts to be consistent with work pieces efficiently. Different materials require different tool inserts, including components of a turning process. Most CNC turning machines provide *oblique cutting* and a component affecting the oblique cutting is an angle of lathe cutting tool called back rake angle (Arshinov & Alexseev, 1976; Bhattcharyya & Ham, 1969; Fryderyk & Gorcyzyca, 1987; Wiriyakosol, 1999) so that it will be appropriate to and efficient for designing a turning process with CNC turning machines. An effect on the different sizes of back rake angles has to be used for taking into consideration and it is necessary to make an experiment to have useful information (Arshinov & Alexseev, 1976; Wiriyakosol, 1999; Nalbanta et al., 2009; Bharily et al., 2015).

Thus, this research studied forces during a turning process, i.e., tangential force (F_P), radius force (F_R), and feed force (F_Q) of oblique cutting from back rake angle as a factor having a direct effect on cutting force. The back rake angles to be studied are -30, -15, 0, 15, and 30 degrees. Work pieces were *AISI4140 low alloy steels* with a diameter of 50 mm. and 300 mm. length that were shaped with a lathe. The condition of the turning process is a constant cutting speed set at 150 m./minute. In order to have clarified change and difference of the result, contributing factors included a feed of 0.15, 0.20 and 0.25 mm./revolution with 1.5, 2.5, and 3.5 mm. depth of cut. An experiment was performed to measure cutting force during a turning process in x,y,z axes. The obtained value was measured by tangential force (F_P), radius force (F_R), and feed force (F_Q) acting on cutting tools to get different results of each factor affecting directly an increase or a decrease of such forces (Lin & Lin, 1999; Trent & Wright, 2000; Nalbanta et al., 2009).

Figure 1: Characteristics of Oblique Cutting
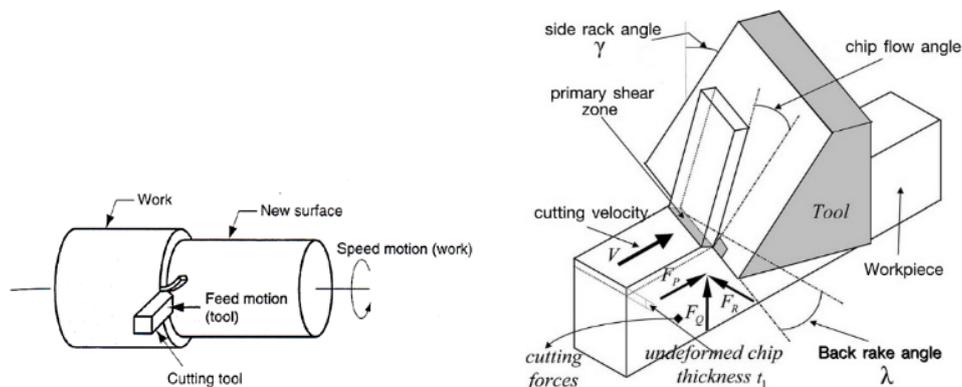
2. Research Objective

The research was to study impact factors of back rake angle on the oblique cutting force in AISI4140 low alloy steels.

3. Research Methodology

Oblique cutting was performed using CNC machines without coolant on AIS4140 low alloy steels with a diameter of 50 mm. and 300 mm. length. TNMG160404R-S T9125 triangle tool inserts were used to shape work pieces in a turning operation in accordance with the main factors, which are back rake angle of -30, -15, 0, 15 and 30 degrees. Contributing factors consisted of a feed of 0.15mm., 0.20mm., and 0.25mm./ revolution, a depth of cut of 1.5mm., 2.5mm., and 3.5mm. The cutting speed was set at 150 m./minute. During a turning process being performed, the values of cutting force acting in the X, Y, and Z axes were measured by a dynamometer. The obtained cutting force values according to the experimental design process were based on the aforementioned contributing factors. A graph was made using the equation determining tangential force (F_P), radius force (F_R) , and feed force (F_Q) (Nalbanta et al., 2009; Zou et al., 2009; Grzesik et al., 2013; Bharily et al., 2015; Mikolajczyk et al., 2018; Nutnang & Yiemchaiyaphum, 2018; Lofti et al., 2019; Pritcharda et al., 2019). In this research, components in the experiment were specified as follows:

Table 1: Machining Conditions

Workpiece material	AISI 4140, $\varnothing$ 50 mm	
Machining tool	Geometry	TNMG160404R-S T9125
		Side Rake angle 15°
		Side Relief angle 8°
		After fixing in the tool holder:
		Back Rack angle-30°, -15°,0°,
		15° and 30°
	Substrate	Cemented carbide (P10 grade)
	Coating composition	TiN-coated
	Coating thickness	16 µm.
Machining conditions	Cutting speed	150 m./min
	Feed	0.15 , 0.20 , 0.25 mm./rev.
	Depth of cut	1.5 , 2.5 , 3.5 mm.
	Cooling	Dry

Figure 2: Oblique Cutting in a Turning Operation


4. Results and Discussion

4.1 Impact of contributing factors of back rake angle, feed, and depth of cut on oblique cutting in tangential force (F_P)

Experimental conditions in this research were composed of back rake angle of -30, -15, 0, 15 and 30 degrees and contributing factors included a feed of 0.15, 0.20, and 0.25 mm./revolution, a depth of cut of 1.5, 2.5, and 3.5 mm. The cutting speed was set at 150m./minute. The result showed that when a low negative back rake angle value was given, cutting force acting in tangential force (F_P) decreased, when a high negative back rake angle value was given, cutting force acting in tangential force (F_P) increased. On the contrary, when a positive back rake angle value was given, cutting force increased accordingly. That means cutting force acting in tangential force (F_P) varied with the value of back rake angle (Zou et al., 2009; Grzesik et al., 2013; Nutnang & Yiemchaiyaphum, 2018; Pritcharda et al., 2019). Similarly, consideration of contributing factors like feed and depth of cut having an effect on oblique cutting acting in tangential force found that the cutting force increased more with increasing feed and depth of cut. The increase in both values caused more *thickness of chips* and the thickness of chips has a direct effect on the cutting force acting in tangential force (F_P). The cutting force value from the experiment was brought to make a U-shaped curve as follows:

Figure 3: Result of the Cutting Force Acting in Tangential Force (F_P)
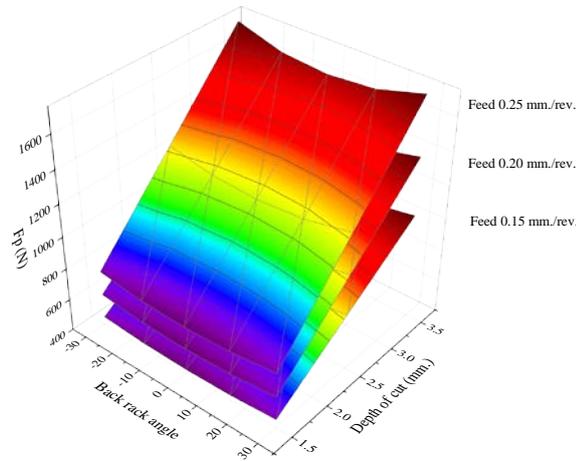
The result from bringing the obtained data to find the equation of cutting force acting in potential force in the form of polynomial equation as seen in the equations 1, 2 and 3, indicated that rake angle had an effect on tangential force (F_P) after cutting force acting in radius force (F_R). Meanwhile, cutting force acting in tangential force (F_P) contained the lowest value. *If cutting force acting in tangential force (F_P) can decrease, the torque of a lathe can decrease and the cost of production can be reduced accordingly. However, if cutting force acting in tangential force (F_P) decreases too much, wear rate may be accelerated around cutting edges and the end of wedge angles of tool inserts easily.*

$$F_{P,b1.5} = 564 + 4.9258 \times 10^{-16}\lambda + 0.0398\lambda^2 + 2.0254 \times 10^{-18}\lambda^3 \qquad (1)$$

$$F_{P,b2.5} = 940 + 4.4408 \times 10^{-16}\lambda + 0.0664\lambda^2 - 1.3037 \times 10^{-18}\lambda^3 \qquad (2)$$

$$F_{P,b3.5} = 1{,}316 + 6.4409 \times 10^{-16}\lambda + 0.0930\lambda^2 - 5.5286 \times 10^{-19}\lambda^3 \qquad (3)$$

After the equations 1, 2, and 3 were obtained, total equation could be determined using numerical methods of cutting force acting in tangential force by calculating from the fundamental equation as Fp = τbt multiplied by a collective condition parameter as seen in equation 4 as follows:

$$F_P = \frac{\tau bt\{\cos(\mu_n - \gamma) + \tan\lambda\tan\lambda_n\sin\mu_n\}}{\sin\theta\sqrt{\cos^2(\theta + \mu_n - \gamma) + \tan^2\lambda_n\sin^2\mu_n}} \qquad (4)$$

where τ = shear strength
   b = chip widthness
   t = chip thickness
   λ = back rack angle
   γ = side rack angle
   θ = shear plane angle
   μ_n = normal friction plane angle
   λ_n = normal back rack angle; $\lambda_n = \lambda$

4.2 Influence of contributing factors of back rake angle to feed and depth of cut on oblique cutting acting in radius force (F_R)

In relation to the experimental conditions as mentioned earlier, it was found that with an increase of back rake angle as well as feed and depth of cut, the cutting force measured along the x, y, and z axes increased accordingly while both positive and negative back rake angles gave the same value. The obtained information was calculated to find the cutting force acting in radius force and created a graph as seen in Figure 4. The graph is a U-shaped curve similar to the result of the cutting force acting in tangential force. Consideration of contributing factors in terms of feed and depth of cut showed that the result was similarly consistent. Such contributing factors caused the size of chips to have direct variation and direct effect on the cutting force acting in radius force that would have direct variation as well.

Figure 4: Result of Cutting Force Acting in Radius Force (F_R)
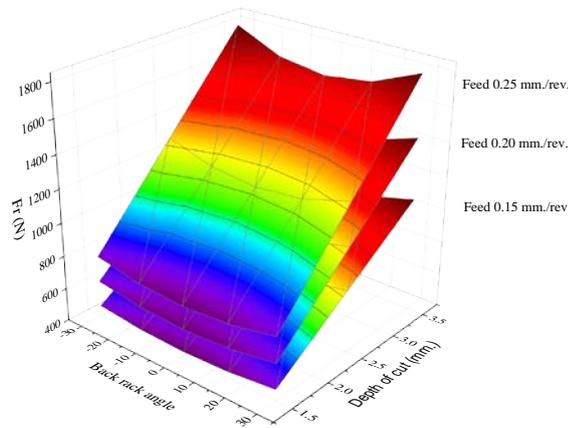
As shown in the experimental result and data collection of the cutting force acting in radius force, the obtained data was measured by equation of the cutting force acting in radius force. And it was found that back rake angle had influence on the cutting force acting in radius force more than other angles of tool inserts, because the back rake angle would deviate the direction of cutting force acting in radius force and cause the cutting force acting in tangential force to decrease with polynomial variation in accordance with the size and volume of back rake angle. The equations 5, 6, and 7 calculated with numerical methods are shown as follows:

$$F_{R,b1.5} = 564 + 3.8962 \times 10^{-16}\lambda + 0.0609\lambda^2 - 3.9232 \times 10^{-19}\lambda^3 \qquad (5)$$

$$F_{R,b2.5} = 940.66 + 2.9654 \times 10^{-16}\lambda + 0.1016\lambda^2 + 1.5740 \times 10^{-18}\lambda^3 \qquad (6)$$

$$F_{R,b3.5} = 1{,}317 + 9.7262 \times 10^{-16}\lambda + 0.1423\lambda^2 + 1.5956 \times 10^{-18}\lambda^3 \qquad (7)$$

In the meantime, the overall value of cutting force acting in radius force (F_R) can be calculated using fundamental equation as $F_R = \tau bt$ multiplied by collective condition parameter as seen in equation 8.

$$F_R = \frac{\tau bt\{\cos(\mu_n-\gamma)\tan\lambda - \tan\lambda_n \sin\mu_n\}}{\sin\theta \cos\lambda\sqrt{\cos^2(\theta+\mu_n-\gamma)+\tan^2\lambda_n \sin^2\mu_n}} \qquad (8)$$

4.3 Influence of contributing factors of back rake angle to feed and depth of cut on oblique cutting acting in feed force (F_Q)

The results from the experimental conditions showed that the cutting force acting in feed force (F_Q) increased and decreased according to the value of back rake angle and contributing factors were feed and depth of cut. When the contributing factors increased, the value of cutting force acting in feed force increased accordingly. An increase in both contributing factors caused the larger size of chips. The larger volume of chips caused more compression on the contact surface of a lathe cutting tool. The value of the cutting force from the experiment was calculated and created a graph as seen in Figure 5. The graph was a U-shaped curve. The cutting force acting in feed force had the least value compared to the cutting force acting in radius force (F_R) and tangential force (F_P), respectively as follows:

Figure 5: The Result of Cutting Force Acting in Feed Force (FQ)
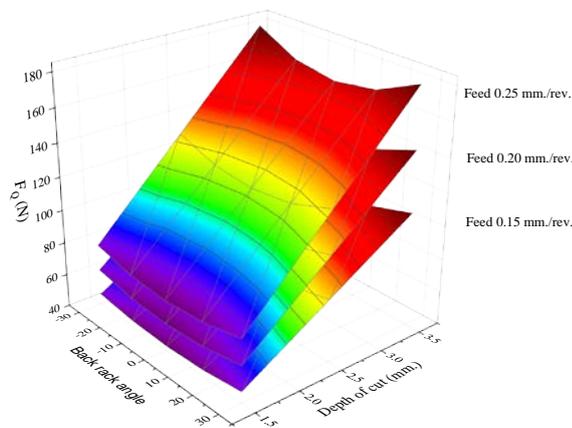
The obtained data from the experimental results was brought to design back rake angle to have low value, and the cutting force acting in feed force was low accordingly. The low cutting force resulted in a decrease in force acting on the spindle of a lathe machine. In this regard, wear rate of the machine can be reduced. Polynomial equations 9, 10, and 11 calculated with numerical methods are shown as follows:

$$F_{Q,b1.5} = 56.66 - 1.2861 \times 10^{-18}\lambda + 0.0060\lambda^2 + 1.7736 \times 10^{-19}\lambda^3 \qquad (9)$$

$$F_{Q,b2.5} = 94.33 - 4.6862 \times 10^{-17}\lambda + 0.0101\lambda^2 + 4.6384 \times 10^{-19}\lambda^3 \qquad (10)$$

$$F_{Q,b3.5} = 132 + 1.0708 \times 10^{-16}\lambda + 0.0142\lambda^2 - 2.4845 \times 10^{-20}\lambda^3 \qquad (11)$$

In addition, the value of cutting force acting in feed force was calculated with the equation as

$F_Q = \tau bt$ multiplied by collective condition parameter as shown in equation 12.

$$F_Q = \frac{\tau bt \sin(\mu_n - \gamma)}{\sin\theta \cos\lambda \sqrt{\cos^2(\theta + \mu_n - \gamma) + \tan^2\lambda_n \sin^2\mu_n}} \qquad (12)$$

5. Conclusion

The results of the cutting force acting in tangential force (F_P), radius force (F_R), and feed force (F_Q) revealed that the influence of contributing factors of back rake angle to feed and depth of cut gave consistent results and evidently in the same direction. An increase in the mentioned contributing factors resulted in an increase in the cutting force acting in radius force, tangential force, and feed force, respectively. With an increase or a decrease in back rake angle, both positive and negative values, the value of cutting force was equal. As a result, back rake angle was a secondary factor having an effect on oblique cutting while the main factors were *feed and depth of cut*. Back rake angle had a direct effect on determining a flow direction of chips. The obtained information can be used to design back rake angle and the mentioned contributing factors widely to keep pace with technologies.

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7. The Authors

Chumphon Chaipradermsak and Suthep Yiemchaiyaphum are staff members of the Department of Production Engineering, Faculty of Engineering, Rajamangkala University of Technology Krungthep, Sathorn, Bangkok, Thailand. Their research interest is in Production Engineering, especially in the areas of back rake angle, oblique cutting force, and alloy steel.

8. References

Arshinov, V. & Alexseev, G. (1976). *Metal Cutting Theory and cutting Tool Design, 3.* Moscow: Mir Publishers 3.

Bharily, R.K., Malgaya, R., Patidar, L., Gurjar, R.K. & Jha, A.K. (2015). Study of optimized process parameters in turning operation through force dynamometer on CNC machine. *ScienceDirect Materials Today: Proceedings 2*, 2300-2305.

Bhattacharyya, A & Ham, I. (1969). *Design of Cutting Tools Use of Metal Cutting Theory.* Dearborn, Michigan: American Society of Tool and Manufacturing Engineers.

Fryderyk, E. & Gorczyca, P.E., C.Mfg.E. (1987). *Application of Metal Cutting Theory.* New York: Industrial Press.

Grzesik, W., Kowalczyk, D. & Żak, K. (2013). A new mechanistic friction model for the oblique cutting with tool wear effect. *Tribology International*, *66,* (October), 49-53.

Lin, Z. & Lin, Y. (1999). A study of an oblique cutting model. *Journal of Materials Processing Technology*, *86*, 119-130.

Lotfi, M., Amini, S. & AliSajjady, S. (2019). Development of a friction model based on oblique cutting theory. *International Journal of Mechanical Sciences, 160* (September 2019), 241-254.

Mikolajczyk, T., Latos, H., Paczkowski, T., Pimenov, D.Y. & Szynka, T. (2018). Innovative tools for oblique cutting. *Procedia Manufacturing, 22*, 166-171.

Nalbanta, M., Gokkayab, H., Toktasa, I.H. & Sura, G. (2009). The experimental investigation of the effects of uncoated, PVD- and CVD-coated cemented carbide inserts and cutting parameters on surface roughness in CNC turning and its prediction using artificial neural networks. *Science Direct Robotics and Computer-Integrated Manufacturing*, *25*, 211–223.

Nutnang, C. & Yiemchaiyaphum, S. (2018). *A Study Influencing of the Cutting Speed in Metal Machine with Single Cutting Edge for Chromium MolybdenumSteel.* Department of Production Engineering, Faculty of Engineering, Rajamangkala University of Technology Krungthep, Sathorn Bangkok, Thailand, AMM034,196-204.

Pritcharda, T., Smith , C., Ghadbeigi, H., Galindo-Fernandez, M., Gilbert, M. & Ayvar-Soberinas, S. (2019). Modelling orthogonal and oblique cutting via discontinuity layout optimization. *Science Direct Procedia CIRP, 82*, 37–42

Trent, E.M. & Wright, P.K. (2000). *Metal Cutting.* The Fourth Edition. Butterworth: Heinemann.

Wiriyakosol, S. (1999). *Machining Materials.* Faculty of Engineering, Prince of Songkla University, Hat Yai, Thailand.

Zou, G.P., Yellowley, I. & Seethaler, R.J. (2009). A new approach to the modeling of oblique cutting processes. *International Journal of Machine Tools and Manufacture*, *49*(9), (July 2009), 701-707.