

10. STUDIES ON CUTTING FORCE COEFFICIENTS IN PERIPHERAL MILLING OF TITANIUM ALLOY

S.Madhava Reddy¹ and A.Chennakesava Reddy²

¹Associate Professor
Department of Mechanical Engineering, MGIT,
Gandipet, Hyderabad - 500 075

²Associate Professor
Department of Mechanical Engineering,
JNTU College of Engineering,
Kukatpally, Hyderabad - 500 031

ABSTRACT

Titanium is one of the most widely used metals in the aircraft and turbine manufacturing industries. Accurate predication of cutting forces is important in controlling the dimensional accuracy of thin walled aerospace components. The effects of chip thickness, rake angle and cutting geometry on chip flow, rake face friction and pressure and cutting forces are analysed. For a given set of cutting conditions and tool geometry, the model predicts the cutting forces accurately for the chip thickness and rake angle ranges tested.

Keywords: Machining, titanium alloy, cutting force coefficients, cutting geometry.

1. INTRODUCTION

Peripheral milling operations are most common in the aerospace industry, where aircraft wing parts and engine components are milled using end mills. Titanium based jet engine compressor blades are milled by carbide, helical end mills at low spindle speeds and feed rates [1]. Low speeds are used to minimize the thermal heating of the tool and chatter vibrations, low chip loads are employed to minimize static deformations in order to maintain tolerance integrity of thin blades. A study of cutting forces at low chip thickness for a given tool geometry and is used in optimizing cutter geometry in order to minimize the normal cutting forces causing the static deformation of thin webs during peripheral milling operations [2]. A study of cutting force coefficients, variable friction and pressure distribution on the rake face, and the chip flow angle are elevated using the cutter geometry and measured actual cutting forces is presented in this paper [6].

2. EXPERIMENTAL WORK

A series of dry cutting experiments was conducted using single - fluted carbide end mills in milling of a titanium alloy. The material properties of carbide cutter and the titanium alloy are given in table-1 [3]. The cutters have an identical helix angle of 30° and a diameter of 19.06 mm. At a constant spindle speed of 500 rev/min. axial depth of cut of 7.5 mm and full immersion, cutters with various rake angles were tested at a feed rate range of 12.7 - 101.6 μm . The machining experiments were conducted on a CNC machining center and the cutting forces were measured with a dynamometer. The cutting forces were low pass filtered at 200 Hz in order to smooth and influence of slight vibrations before being recorded by a PC based data acquisitions system. The experiments were conducted under chatter free cutting conditions.

Table 1 : Cutting conditions and the average cutting forces for the dry slot cutting tests.

| rake angle [degrees] | Feed rate (mm) | Average forces | | |
|-------------------------|-------------------|----------------------|----------------------|----------------------|
| | | $\overline{F_y}$ [N] | $\overline{F_x}$ [N] | $\overline{F_z}$ [N] |
| 0 | 0.0127 | 149.02 | 112.50 | -29.57 |
| 0 | 0.0254 | 177.12 | 164.84 | -52.86 |
| 0 | 0.1016 | 282.85 | 425.08 | -189.28 |
| 5 | 0.0127 | 105.31 | 95.24 | -33.59 |
| 5 | 0.0254 | 125.79 | 144.43 | -57.74 |
| 5 | 0.0508 | 162.05 | 232.47 | -104.42 |
| 5 | 0.1016 | 181.51 | 385.33 | 163.35 |
| 12 | 0.0127 | 113.40 | 96.49 | -28.38 |
| 12 | 0.0254 | 117.84 | 138.73 | -46.94 |
| 12 | 0.0508 | 140.10 | 220.03 | -84.64 |
| 12 | 0.1016 | 182.49 | 393.64 | -167.61 |
| 12 | 0.2032 | 224.89 | 723.49 | -315.05 |
| 15 | 0.0127 | 99.06 | 92.25 | -27.18 |
| 15 | 0.0254 | 108.85 | 135.05 | -45.42 |
| 15 | 0.0508 | 124.37 | 210.89 | -83.44 |
| 20 | 0.0127 | 99.00 | 91.54 | -29.37 |
| 20 | 0.0254 | 113.33 | 137.22 | -48.56 |
| 20 | 0.0508 | 138.26 | 212.93 | -83.24 |
| 20 | 0.1016 | 163.81 | 338.54 | -159.96 |

Width of cut = 19.06 mm, axial depth of cut = 7.62 mm, cutting speed 30 m/min. Workpiece material: titanium ally (6% Al, 4% V), Young's modulus = 110 GPa, Poisson's ratio = 0.34, tensile strength = 900 MPa. Carbide cutter: helix angle = 30°, diameter = 19.06 mm. 1 flute, material properties: 90% WC, 10% Co. hardness = 92 Rockwell.

3. RESULTS AND DISCUSSION

3.1. The Effect of Feed Rate

The feed rates were varied from 0.0127 mm / tooth to 0.2030 mm/ tooth while keeping rake angle = 12° cutting forces as a function of spindle rotation angles at various feed rates is plotted in Fig.1. The cutting forces are increasing with the increased feed rate or uncutchip thickness, the trend is not linear. The non linear trend is not evident at low feeds.

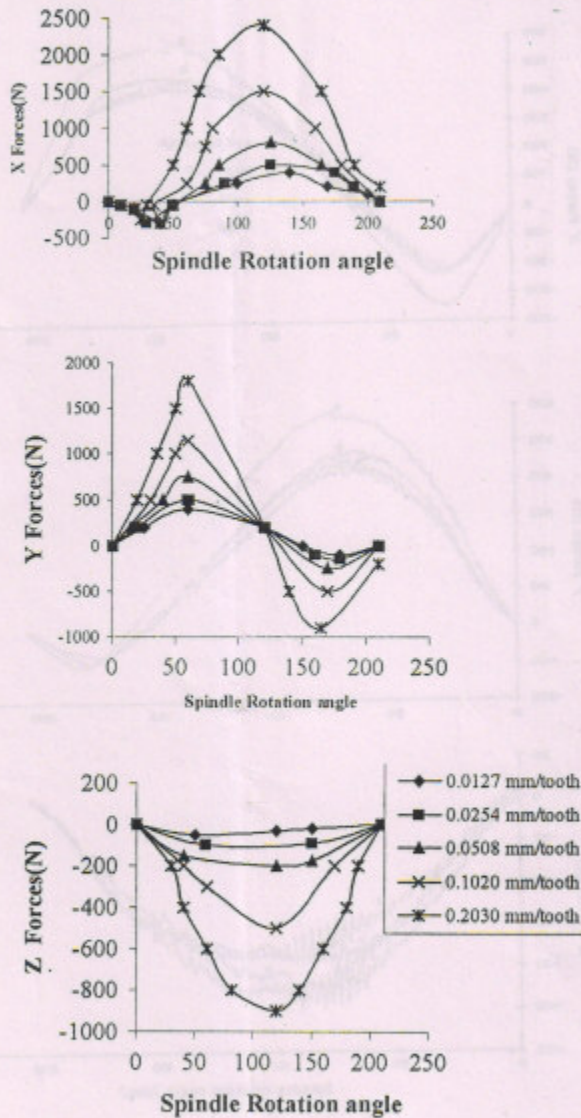


Fig.(1) Measured cutting forces at various feed rates (Rake angle = 12° , see table 1 for the remaining cutting conditions)

3.2 Variation of Rake angle as a function of Cutting Forces

The rake angles were varied from 0° to 15° while keeping the feed rate is constant at $12.7\mu\text{m}$ or 0.0127 mm / tooth cutting forces as a function of spindle rotation angles at various rake angles is plotted in Fig.2. Owing to larger shear angles, the cutting force are lower for the higher rake angles. The dependency of forces on the rake angle is more evident at a rake angle of $0-5^\circ$. There is no visible reduction in the force amplitude when the rake angles are increased beyond 5° .

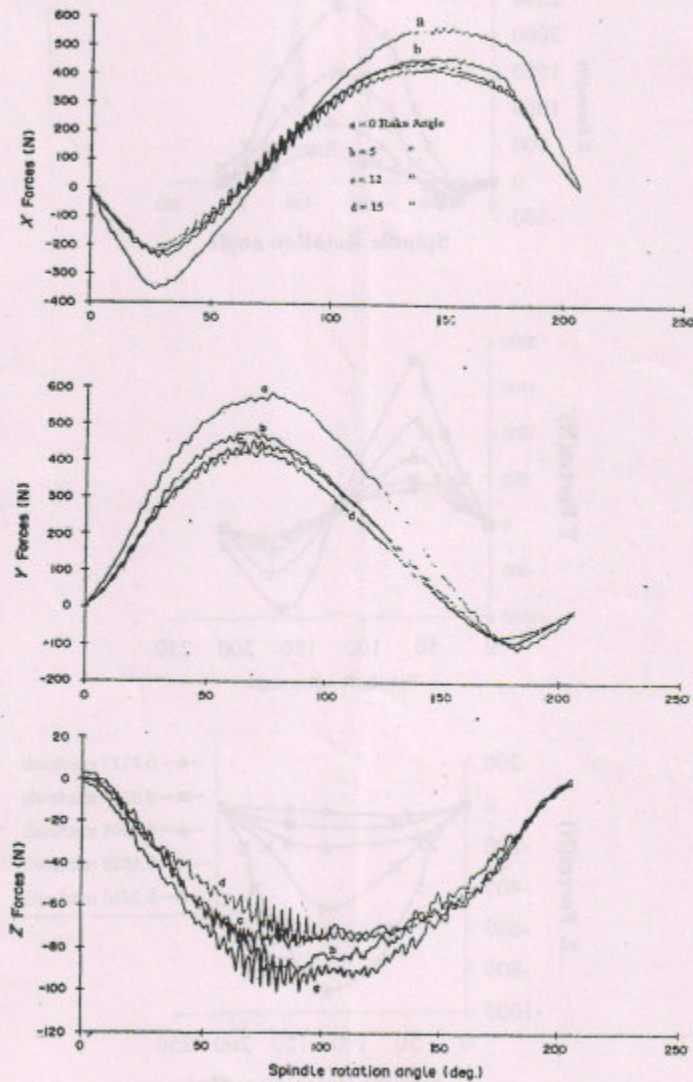


Fig. 2. Measured cutting forces at different rake angles. (Feed rate = 0.0127 mm/tooth ; see table 1 for the remaining cutting conditions)

3.3 Variation of Undeformed Chip Thickness

The effects of variation of undeformed chip thickness on the cutting force coefficients are studied by setting the parameters as Rake angle = 12° , feed rate = 0.0127 mm / tooth to 0.203 mm / tooth. Cutting force factors as functions of undeformed chip thickness at various feed rates are Shown in Fig.3. Using 6th order polynomials, cutting force coefficients K_1 , K_2 and K_3 are estimated from the milling tests for each rake angle. Each continuous curve represents a test with one feed rate value. It is evident that cutting force coefficients change smoothly in up milling, but discontinuously in the down milling cycle. This is attributed to the differences governing the metal removal mechanics in up and down milling model [5]. This behavior is observed to be more significant at higher rake angles.

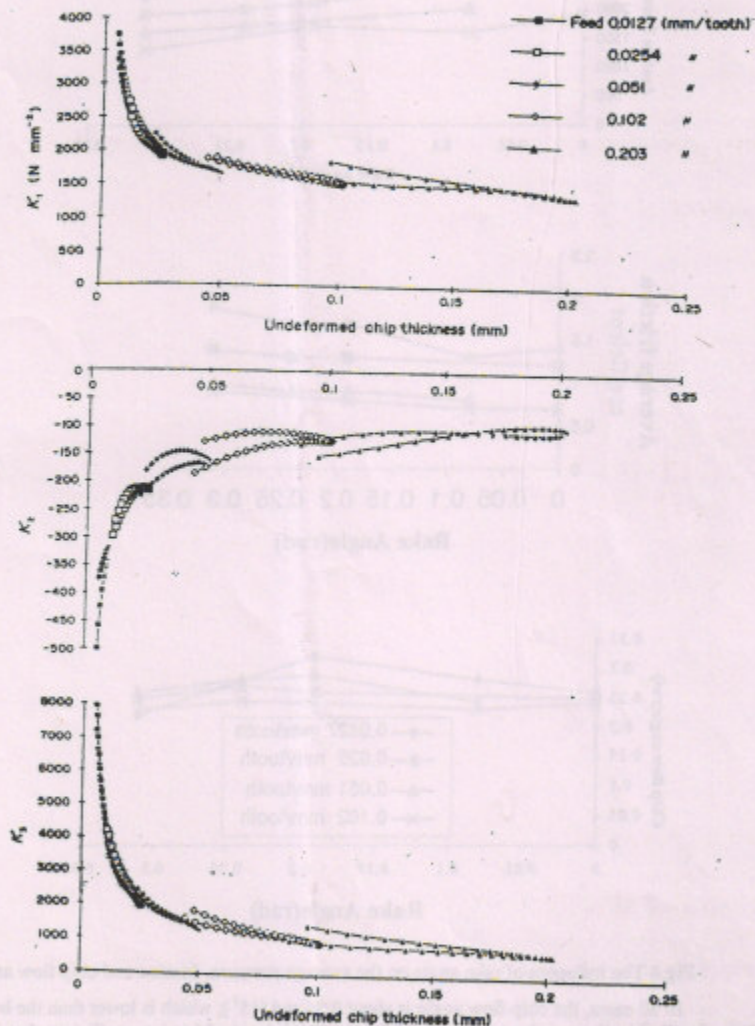


Fig.3. The Variation of cutting force factors with undeformed chip thickness. (Rake angle = 12° ; see table 1 for the remaining cutting conditions)

3.4 Variation of Rake Angle

The average friction and pressure coefficients and the average chip flow angle for the slot cutting tests are shown in Fig.4. The average friction coefficient increases while the pressure coefficient decreases with the increasing rake angle.

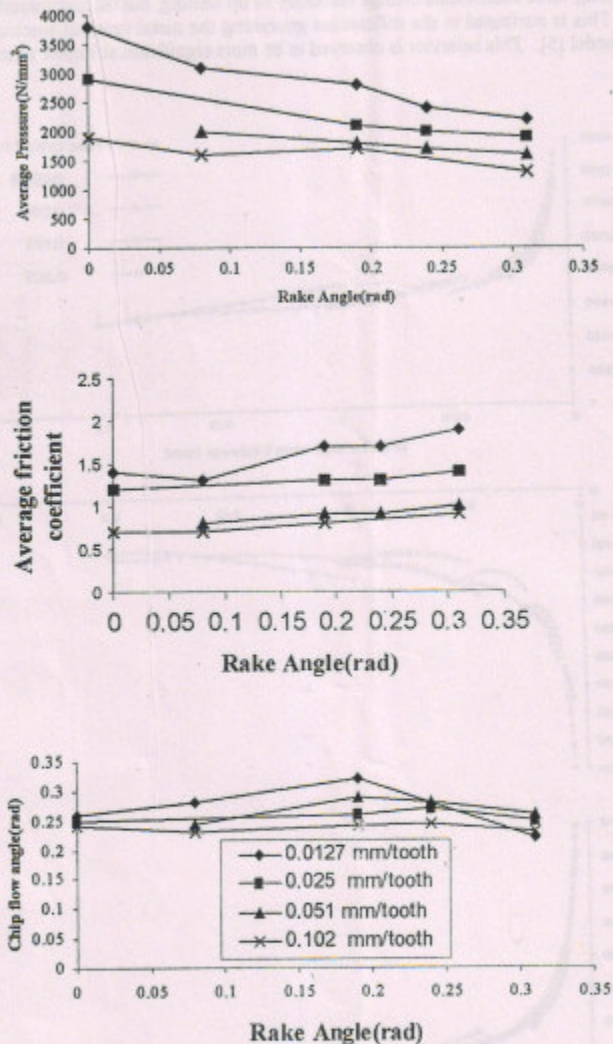


Fig.4 The influence of rake angle on the average pressure, friction and chip flow angle.

In all cases, the chip flow angle is about 0.26 rad (15°), which is lower than the helix angle of 30° . Small chip flow angles is a result of the very high level of friction coefficient that is present in machining titanium alloys. [4]. Very large friction coefficients are observed when the feed is low. This is attributed to the neglected friction between the flank face of the tool and the finished surface, which may contribute to the force as more than the shearing mechanism.

4. CONCLUSIONS

The important conclusions made from this work are as follows:

- ❖ Cutting forces increase marginally with an increase in feed rate or uncut chip thickness
- ❖ Rake angle increase with an decreases the pressure at the tool chip interface whereas the friction coefficient increases.
- ❖ For rake angles larger than 12° no significant change in the cutting forces is observed when machining titanium alloys.
- ❖ Average friction coefficient increases while the pressure coefficient decreases with the increasing rake angle.
- ❖ The cutting force coefficients indicate slightly different metal removal mechanisms for up and down milling operations.

REFERENCES

1. Yucesan G. and Altintas.Y. "Improved modelling of cutting forces in Milling", Int.J.Mech.Tools, Manufact, Vol.34, No.4, PP.473-487 (1994).
2. Montgomery.D and Altintas.Y. "Mechanism of cutting force and surface generation in dynamic milling"; ASME J.Engg Ind, 113, 160-168 (1991).
3. Koenigsberger.F and Sabberwal. A.J.P. "An investigation into the cutting force pulsations during milling operations". Int. J.Mach.Tool Design, Vo.01, PP.15-33 (1961).
4. Pandey P.C. and Sham.H.S., "Analysis of cutting forces in peripheral and face milling operations"; Int.J.Prod. Vol.10, PP.379-391 (1982).
5. Yucesan.G. Bayocemi A.E. and Kendali. L.A, 'An analytic cutting force model for milling'; Trans. NAMRC XVIII, PP 137 - 145 (1990).
6. Yucesan.G."Modelling of cutting forces for milling operations" Ph.D dissertations, Washington State University (1992).