Metal cutting process

Chapter 1: Introduction

1. 1 Background

Manufacturing of products has been done throughout history by the process of metal cutting. Through the advancement in technology over the years, significant improvements have been made in the metal cutting process. Currently, the main method employed in the metal cutting operation is the work-piece is worked on by the cutting tool on a machine. [1 the book]

During the process of machining, the cutting tool wears out considerably. The wearing out of the cutting tool is an important aspect to the manufacturers as it has major financial and production implications. Therefore, the prediction of cutting tool life is widely researched.

Cutting tool models are developed to aid in the prediction of the cutting tool life. This approach enables better design and cutting tool parameters to be implemented to ensure efficient use to extend the cutting tool life to as much as possible.

Cutting force coefficients play an important role in determining the cutting forces which are primary in determining the cutting tool life. However, cutting force coefficients vary during the milling process. Therefore, cutting force coefficients are significant factors that need to be considered accurately during the cutting tool modelling.

1. 2 Process of Milling

Milling is a process of cutting away material by feeding a work-piece past a rotating multiple tooth cutter. The cutting action of the teeth around the milling cutter provides a fast method of machining. The surface produced may be milled to any combinations of shape while the surface may also be angular, curved or flat. [2 website http://www. mfg. mtu. edu/marc/primers/milling/index. html]

There are three main types of milling that is used in practice, namely, face-milling operation, up-milling operation and down-milling operation. In face milling, the entry and exit angles of the cutter relative to the work-piece are non-zero whereas in up-milling and down-milling the entry and exit angles are zero respectively. Both up and down-milling operations are also known as peripheral or end-milling operations. [1]

1. 3 Ball Nose Milling

An end mill is a type of a milling cutter that is used in industrial milling applications. A wide variety of materials are used to produce the cutting tools. Carbide inserts are very common because they are good for high production milling. High speed steel is used when a special tool shape is needed however it is not usually used for high production processes. Ceramic inserts are typically used in high speed machining with high production. Diamond inserts are typically used on products that require high tolerances, typically consisting of high surface qualities, such as non ferrous or non-metallic materials. [3 http://en. wikipedia. org/wiki/Endmill]

A ball nose end mill cutter is a type of cutter that is used in the industry. Below shown in 4 are the different types of end mill cutters available.

A ball-nose end mill is well suited for milling various types of materials from plastics to steel alloys. The rounded edge design gives the ball nose an edge over the other cutters because it is more tough and durable. Another advantage is that it can handle high feed rates giving it greater productivity for current industrial applications. The round tip of the cutter allows for lesser impact forces during cutting ensuring that the tendency to fail under pressure is lesser. This translates into cost savings as the time taken for the cutter to fail is longer therefore making it more attractive to consumers. [4 http://www. wisegeek. com/what-is-a-ball-end-mill. htm]

Ball end mills are mostly made of tungsten carbide with a protective coating. The coatings are applied to reduce wear and friction and can also prevent significant damage to the cutting surface. [4] However, after prolonged use, the ball end mill will eventually wear and will need to be replaced.

1. 4 Scope of Research

This research is conducted to achieve certain objectives:

Ø Understanding the application of mechanistic cutting model to oblique and end mill cutting

Ø Application of the cutting force model by conducting experiments to validate the algorithm

Ø Prediction of cutting force coefficients from the cutting force data

Ø Deriving an algorithm to predict cutting force coefficients from experiments

Ø Understanding the variations in cutting force coefficients over tool life

Chapter 2: Literature Review

2. 1 Mechanics of Orthogonal Cutting

Mathematically, if two vectors are referred to as orthogonal, it means they are perpendicular to each other (i. e form right angles with each other). This theory holds for orthogonal cutting as well. In orthogonal cutting, the material is removed by a cutting edge that is perpendicular to the direction of the work-piece motion.

Though this concept is only considered in two dimensional terms, this lays the foundation for metal cutting. 5 below shows the orthogonal cutting in progress. Chip formation is the formation of the cut material from a work-piece.

Since orthogonal cutting is two-dimensional, the cutting forces are only exerted in the directions of the cutting velocity and the uncut chip thickness known as tangential force and feed force respectively. [1] The tangential and feed forces are shown in 6 represented by Fp and Fn respectively.

There are three deformation zones in the cutting process. The primary zone is the area where the edge of the tool penetrates into the work-piece to form the chip. The secondary zone is where the chip moves along the rake face of the tool. The tertiary zone is the friction area where the flank area of the tool rubs on the newly machined surface. [1] 7 below shows the three zones with the tertiary zone indicated by the third deformation zone.

2. 2 Mechanistic Modelling of Cutting Forces

Mechanistic modelling is a method used to estimate the average cutting forces. With the data of the cutting forces, the tool's design life and the analysis of specific cutting processes can be carried out. The advantage of the mechanistic force model is its ability to calculate the cutting forces over a range of cutting conditions with a reasonable accuracy while using a minimal number of orthogonal cutting tests. [5Yong HuangAssistant Professor, Department of Mechanical Engineering, Clemson University, Clemson, SC 29634-0921Modeling of Cutting Forces UnderHard Turning Conditions Considering Tool Wear Effect]

In the two dimensional approach used in orthogonal cutting, there are two main forces that contribute to the resultant force (i. e tangential and feed force). As such, these two forces can be expressed in the terms of their tool geometry, cutting conditions and material dependant terms:

Therefore the cutting coefficients are represented by, However, the prediction of shear angles is still under much research. Therefore, due to the inaccuracy that might be present in the prediction of the shear angle, the cutting forces are defined mechanistically as, The cutting constants and edge coefficients will be calibrated from, specific tool and work-piece combination, metal cutting experiments.

2. 3 Oblique Cutting

Oblique cutting differs from orthogonal cutting in that cutting velocity is perpendicular to the cutting edge in orthogonal cutting whereas in oblique cutting, it is inclined at an acute angle i to the plane normal to the cutting edge.[1]

7 depicts the oblique cutting process with chip flow angle () being shown above. Chip flow angle represents the angle at which the sheared chip

moves over the rake face plane measured from a vector on the rake face but normal to the cutting edge. Since there are now three planes to consider, the forces exist in all three directions in oblique cutting.

The oblique cutting parameters can be calculated based on three main principles; A theoretical shear angle prediction approach proposed by Altintas and Shamoto, the minimum energy principle used in two-dimensional orthogonal cutting mechanics and the empirical approach based on empirical chip flow direction and other empirical assumptions.[1]

Once the oblique cutting parameters have been resolved, the cutting forces can be predicted using equations based on Armarego's classical oblique model.

Hence the corresponding cutting constants are, The following equations can be used to predict the oblique cutting forces from the orthogonal cutting database. [1]

2. 4 Helical End Mill

With the inception of helical end mills in the experiments, the changing chip load has to be accounted for along the helical flutes of the end mill. As such, the lag angle is used to evaluate the forces.

Lag angle is the angle at which a particular point on the axis of the cutting edge is lagging behind by with respect to the helix angle.

2. 5 Cutting Force Model

In machining certain variables like the depth of cut is constantly changing. Though there are machining handbooks that provide averaged values, the cutting geometry for each tool and work-piece pair is different. To evaluate values for each is time consuming and financial absurd. To overcome this problem, researchers come up with cutting force models to predict the forces for particular tool work-piece pair.

The ball end mill cutter used in the following experiments has the particular geometry as shown in 9 below.

Most of the cutting force models use a semi-mechanistic approach. The cutting edge is divided into discrete cutting edge elements. The cutting forces acting on engaged cutting edge elements are then calculated. Once the cutting forces on each element is obtained, the resultant cutting force is calculated by numerical integration of cutting forces acting on the engaged cutting edge elements. [6Estimation andexperimentalvalidationofcuttingforcesinball-endmilling of sculpturedsurfaces YuwenSun _, FeiRen, DongmingGuo, ZhenyuanJia]

Chapter 3: Experimental Setup and Procedures

3. 1 Experimental Setup

The experimental setup for the tests to be carried out included the milling machine, tool and work-piece pair, dynamometer, data acquisition unit and three charge amplifiers.

The three axis vertical milling machine (Roeders Tec 760) was used together with the tool which is a 6mm diameter ball nose end mill cutter (Mitsubishi Materials Corporation) while the work piece was Stavax Steel. The forces applied during the experiments were measured by the dynamometer (Kistler – Type 9254) and this data was then amplified so that the data can be collated. Three charge amplifiers are required to represent the forces from the three directions. The data is then collated and stored in the data acquisition unit (2980 Dewetron). For the initial experiment, the conditions are tabulated in Table 1 below.

Table 1: Cutting Conditions

Cutting Tool

6mm Ball Nose End Mill Cutter

Rake Angle

14º

Clearance Angle

13º

Feed Rate

0. 05mm/flute

Helix Angle

30

Spindle Speed

800rpm

Depth of Cut

1. 5mm