International Journal of Engineering Research and General Science Volume 4, Issue 1, January-February, 2016
ISSN 2091-2730

Study of Static Cutting Forces in Face Milling And Simulation of Forces Using Matlab

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Abstract— **Due** to the extensive use of highly automated machine tools in the industry, the manufacturing requires reliable models for the prediction of output performance of machining processes. The prediction of cutting forces plays an important role in the manufacturing industry. The focus of this paper is to develop a program using MATLAB software for simulation and verification of cutting forces in face milling process. Though we have many types of indirect methods available, to carry out this process, a lot of experiment has to be done resulting in high cost and time requirement. This paper involves a procedure for the simulation of static and dynamic cutting forces in face milling operation. The mechanistic model which is selected for simulation and verification are the ones which take in to account the initial position errors of the inserts and spindle eccentricity for the analysis. The relevant equations are studied and static and dynamic model are simulated.

Keywords— MATLAB, face milling process, dynamometer, mechanistic model, simulation, initial position errors

1.INTRODUCTION

Manufacturing is an value added process that had always been of significant importance to human civilization. Machining operations comprise a substantial portion of the world's manufacturing infrastructure, making the enhancement and control of metal removal processes one of the main concerns of the industry [1]. Means of achieving the said enhancement is to estimate the product and process quality, tool life and stability of the machining process because they facilitate effective planning of machining operations, optimum performance, quality and cost and hence can lead to the proper selection of machining conditions, optimal fixture design and avoidance of tool failure. An accurate indicator of the mentioned factors is the cutting force resulting from the cutting process. Numerous attempts and methods have been proposed to predict the forces. In this study, The main objective is to study in detail the various techniques of analytic and mechanistic modeling of cutting force in face milling operation and develop a flexible program software by using a MATLAB. The current study is aimed at investigating the optimum method of predicting the cutting forces during the face milling operation. Different techniques have been used to predict cutting forces.

1. Study and analysis of mechanistic modeling of face milling process.
2. Development of generalized MATLAB program.
3. Validation of the program results with experimentally published data.

Investigation of cutting forces is a key part in the development of cutting technologyt. They are one of the main criteria for evaluating machinability of material and as such attract the attention of many researchers in this field. Knowledge of cutting forces beforehand is valuable as it leads to an efficient and automated process through the proper selection of machining parameters, fixture design and appropriate machines and tools used. These vary in their generality, accuracy and amount of data required as an input into the model. Analytical methods are hindered by their low accuracy in predicting forces and by their lack of generality as well as the large amount of experimental data needed for each work piece and tool material under various cutting conditions [1].This renders their use expensive and time consuming. Whereas, mechanistic methods have a higher accuracy in predicting cutting forces. The objective of this thesis is to study in detail the various techniques of analytic and mechanistic modeling of cutting force in face milling operation and develop flexible program software by using a MATLAB

2.Face milling

Face milling and face milling cutters have always been subjects for intensive study. Face milling is widely used for milling operations involving high rate of metal removal and hence any improvement in productivity of this process would have great impact on machining costs. Further the wide use of numerically controlled machines have necessitated a greater and more detailed understanding of this process. In face milling the cutter is mounted on a spindle having an axis of rotation is perpendicular to the workpiece surface. The cutter axis is vertical, but in the newer CNC machines it often is horizontal. In face milling, machining is performed by teeth on both the end and periphery of the face-milling cutter. Face milling is usually applied for rough machining of large surfaces.

3.Mechanistic Cutting Force Model

A number of different methods to predict cutting forces have been developed over the last fifty years. These models can be classified in to three major categories, Empirical, Analytical and Mechanistic methods. In the empirical method, a number of machine experiments are performed and performance measure such as cutting forces, tool life and tool wear are measured. These responses are then correlated to the cutting conditions using empirical functions. The empirical methods often require a lot of experiments and have limited extrapolation value. Analytical approximation model gives the physical mechanism that occurs during cutting. However, due to complex mechanism such as high stress values, high temperature gradients and combined elastic and plastic deformations the analytical model is unable to completely characterize the phenomena that occur on the rake and flank faces of the cutting insert. Mechanistic models predict the cutting force based on a method developed by Sabberwaal [2].

4.Theoretical Modeling of Cutting Forces

Here a procedure for the simulation of static and dynamic cutting forces in face milling operation are studied. Major factors like initial position errors of the inserts and spindle eccentricity are considered for the analysis. The relevant equations are studied for both static and dynamic condition. The cutting force systems in face milling have been extensively studied both analytically and empirically. Most of the researchers have dealt with development of force equation and the modeling of specific cutting pressure under the simplest conditions such as plane surface, limited consideration of cutter geometry, and no run out considerations. A force model which deals with more complicated machining situation should be systematically organized and computerized. In this view, general approach to develop a mechanistic face milling force model is presented by Kling and Devor [3, 4].

4.1 Static forces Analysis in Face Milling Operation

The instantaneous static force can be obtained as the resultant of all the forces acting on the individual inserts engaged in cutting at a certain instant [2]. Based on the conventional static force model assumption the initial position errors of inserts and the eccentricity of spindle are taken into consideration for the model development. Figure 4.1(b) shows cutter and cutter geometry in face milling operation. Figure 4.1(a) clearly indicates the various cutter geometry such as axial rake angle γA, radial rake angle γR and lead angle γL. Since feed rate is much smaller than the cutter radius the path of face milling cutter can be approximated as a circle without much loss of accuracy [2].

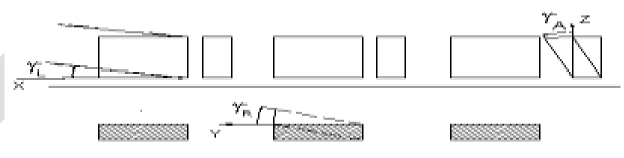


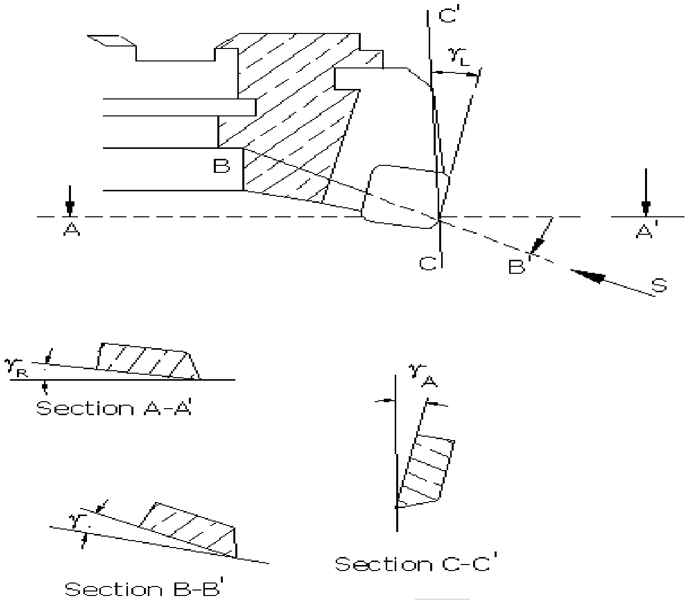
Figure 4.1(a) Lead, Radial and Axial Inclination of the Cutter Tip

Fig. 2 illustrates a typical face milling process in which the various cutting force components are marked on single insert. Ft ,Fr and Fa are the tangential, radial and axial forces acting on the tip of the insert respectively. Figure 4.1(c) shows a Cutting Force Components on I^{th} Insert at Angleθ.

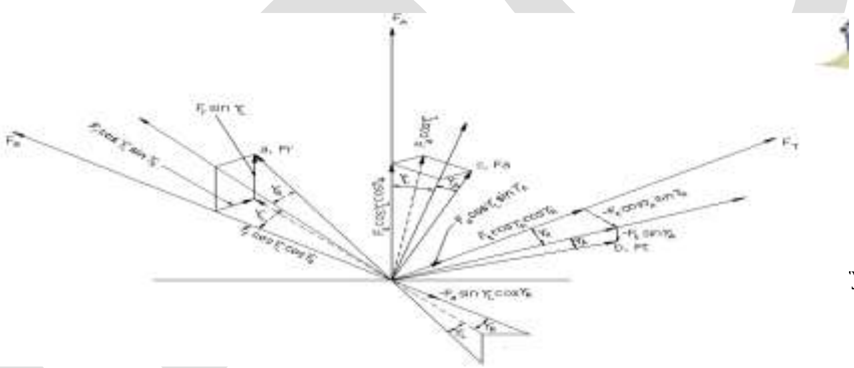
The cutting edge enters the work piece at an entry angle $\boldsymbol{\delta_1}$leaves at exit angle $\boldsymbol{\delta_2}$The included angle $\boldsymbol{\psi}$ within which the cutting tooth and the work piece are in contact can be expressed as [14]:

$$\psi = \delta_2 - \delta_1 = Sin^{-1}\left[\frac{2m}{D}\right] + Sin^{-1}\left[\frac{2(b-m)}{D}\right] \qquad (1)$$

Where **m** is the distance between work piece edge and centre of the cutter, **D** is the diameter of the cutter and **b** is the width of the work piece. Using the equation (1) the number of inserts simultaneously in contact with the work piece can be determined.



For instance, consider the tangential force $\mathbf{F_T}(i,\varphi)$ in global coordinate system which can be obtained as the summation of the force components tangential force $\mathbf{F_t}$, radial force $\mathbf{F_r}$, and axial force $\mathbf{F_a}$ acting on the insert. The $\mathbf{F_t}$ component can be resolved first into axial rake angle γ_A and then to radial rake angle γ_R as $\mathbf{F_t}$ **Cos** γ_A **Cos** γ_R. Similarly, $\mathbf{F_r}$ components resolved to $\mathbf{F_r}$ **Cos** γ_L **Sin** γ_R and axial component to $\mathbf{F_a}$ **Cos** γ_L **Sin** γ_A. Summation of the force components gives:



y

FT (i, ϕ) = Ft C

FR (i, ϕ) =Ft Cos A Sin R Fr CosL Cos R Fa Sin LCos R

FA (*i*, ϕ) =*Ft Sin A Fr Sin L Fa Cos LCos A*

Development of Program Using Matlab

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

5.1 Wilson Theta Method

Wilson theta method is used for numerical analysis. To carry out step-by-step numerical integration of linear or non linear equation of motion Wilson -Theta method was employed. Two very important properties of the numerical integration are stability and accuracy which is good using Wilson –Theta method.

5.2 Program Details for STATIC Force Computation

The static force modeling for the face milling operation are simulated by the use of the MATLAB program developed based on the mechanistic model, Flow charts for developing the static cutting forces are given below.

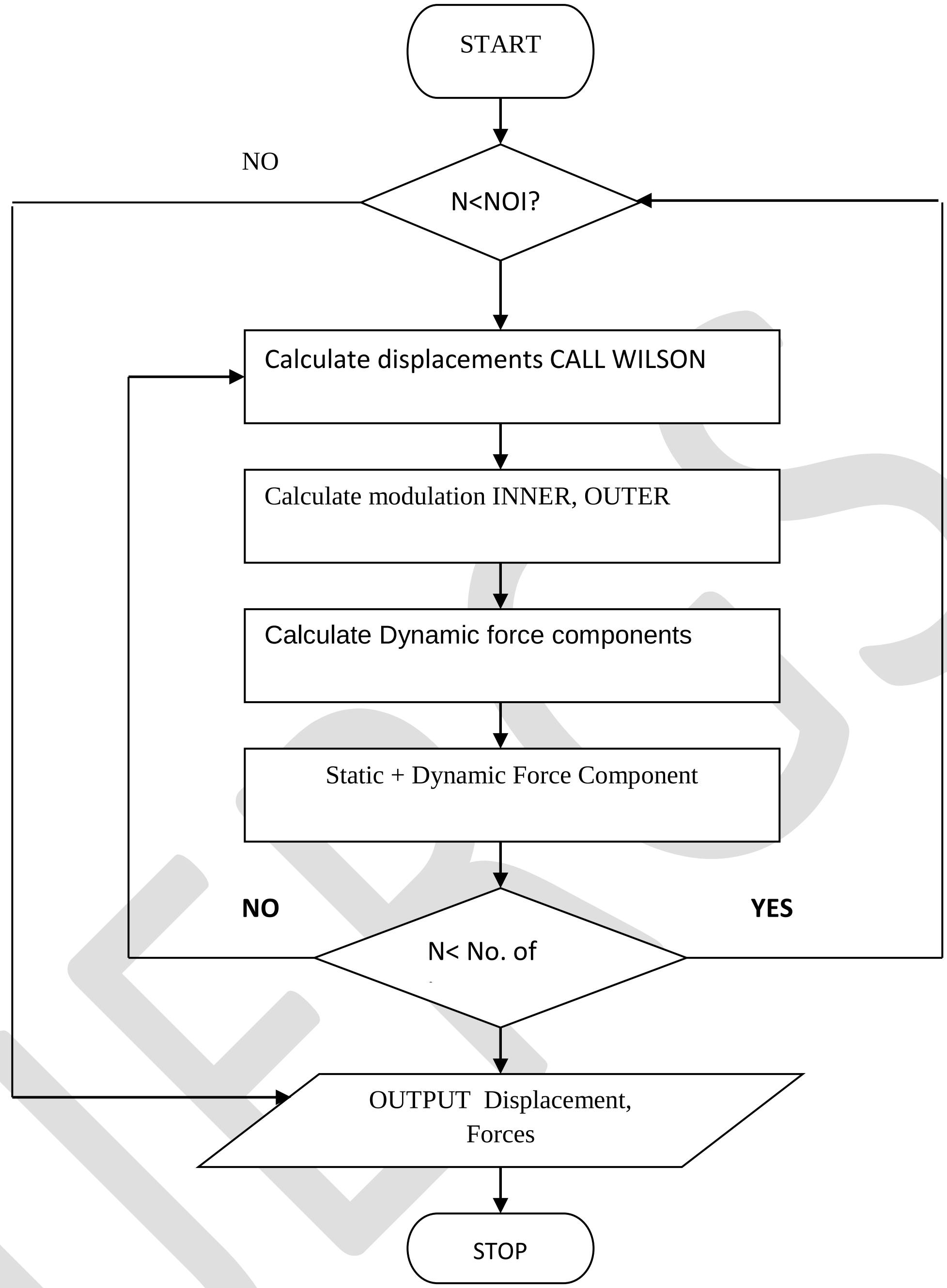


Figure 5.1 Flow Chart for Static Cutting force Calculation

CONCLUSIONS

This paper involves a procedure for the simulation of static cutting forces in face milling operation. The mechanistic model which is selected for simulation and verification are the ones which take in to account the initial position errors of the inserts and spindle eccentricity for the analysis. The relevant equations developed by researchers have been studied and compared with different mechanistic models for simulating both static forces. Program has been written using MATLAB software and Wilson Theta method is used for the numerical iteration process in the program. The simulated forces of static are closely scrutinized with the measured force given in references. The program developed has been tested and verified for its working and accuracy by running it using cutting conditions and modal parameters for different number of inserts and varying depth of cut and fed rate given by researchers whose simulated result itself has been validated by the experiments.

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