Structural Analysis of a Milling Cutter Using FEA

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Abstract:

Milling is a process of producing flat and complex shapes with the use of multi-tooth cutting tool, which is called a milling cutter and the cutting edges are called teeth. The axis of rotation of the cutting tool is perpendicular to the direction of feed, either parallel or perpendicular to the machined surface. The machine tool that traditionally performs this operation is a milling machine. Milling is an interrupted cutting operation: the teeth of the milling cutter enter and exit the work during each revolution. This interrupted cutting action subjects the teeth to a cycle of impact force and thermal shock on every rotation. The tool material and cutter geometry must be designed to withstand these conditions. Cutting fluids are essential for most milling operations.In this Paper the design aspects of milling cutter is analyzed. The objective considered is the design and modeling of milling cutter and to analyse various stress components acting on it. Various designing strategies are considered to design the effective milling cutter like outer diameter, inner diameter, radius, teeth angle etc .The design and analysis is carried out using the softwares like CATIA V5 and ANSYS.

Keywords: *ANSYS, CATIA, cutting fluids, cutting edges, High Speed Steel, Milling Speed, machined surfaces, surface milling cutter.*

I. INTRODUCTION

Milling, for example, has its own particularities, such as variation on the unreformed chip thickness (*h*), interrupted cuts, etc. Models developed for turning and adapted to milling, working with average chip thickness, can yield reasonable results in terms of force. There are operations, however, where a more accurate result is needed and then, the discrepancies may become unacceptable. That is the case with high speed milling, which uses very low chip thickness. In this case, the cutting edge radius almost equals the unreformed chip thickness and the rake angle tends to be highly negative. The material seems to be removed like in abrasive processes (Shaw 1996). Additionally, the main parameters describing the models are a function of other ones related to the tool (material, geometry, coating, etc.) and the machine (rigidity, speed, position control, etc.). In order to investigate the end milling process in some cutting conditions, at any particular combination tool-machine-work piece, a simple and fast method is needed to find the main parameters of the classical existing models and study some new ones. Milling is a process of producing flat and complex shapes with the use of multi-tooth cutting tool, which is called a milling cutter and the cutting edges are called teeth. The axis of rotation of the cutting tool is perpendicular to the direction of feed, either parallel or perpendicular to the machined surface. The machine tool that traditionally performs this operation is a milling machine. Milling is an interrupted cutting operation: the teeth of the milling cutter enter and exit the work during each revolution. This interrupted cutting action subjects the teeth to a cycle of impact force and thermal shock on every rotation. The tool material and cutter geometry must be designed to withstand these conditions. Cutting fluids are essential for most milling operations.

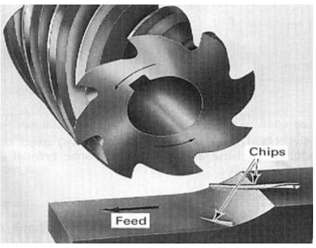

Fig 1: Milling Cutter

1.1 Types of milling

There are two basic types of milling, are as follows

- Down (climb) milling: It is type of milling in which the cutter rotation is in the same direction as the motion of the work piece being fed. In down milling, the cutting force is directed into the work table, which allows thinner work parts to be machined. Better surface finish is obtained but the stress load on the teeth is abrupt, which may damage the cutter. In conventional milling, friction and rubbing occur as the insert enters into the cut, resulting in chip welding and heat dissipation into the insert and work piece. Resultant forces in conventional milling are against the direction of the feed. Work-hardening is also likely to occur.

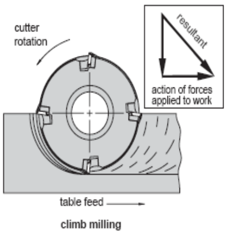

Fig 2: Climb Milling

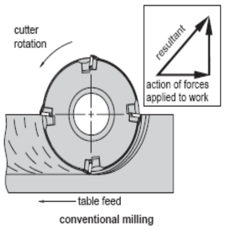

Fig 3: Conventional Milling

- Up (conventional) milling: It is the type of milling in which the work piece is moving towards the cutter, opposing the cutter direction of rotation. In up milling, the cutting force tends to lift the work piece. The work conditions for the cutter are more favorable. Because the cutter does not start to cut when it makes contact (cutting at zero cut is impossible), the surface has a natural waviness. The insert enters the work piece material with some chip load and produces a chip that thins as it exits the cut. This reduces the heat by dissipating it into the chip. Work-hardening is minimized. Climb milling is preferred over conventional milling in most situations.

1.2 Milling of complex surfaces

Milling is one of the few machining operations, which are capable of machining complex two and three-dimensional surfaces, typical for dies, molds, cams, etc. Complex surfaces can be machined either by means of the cutter path (profile milling and surface contouring), or the cutter shape (form milling).

- Form milling: In form milling, the cutting edges of the peripheral cutter (called form cutter) have a special profile that is imparted to the work piece. Cutters with various profiles are available to cut different two-dimensional surfaces. One important application of form milling is in gear manufacturing.
- Profile milling: In profile milling, the conventional end mill is used to cut the outside or inside periphery of a flat part. The end mill works with its peripheral teeth and is fed along a curvilinear path equidistant from the surface profile.
- Surface contouring: The end mill, which is used in surface contouring has a hemispherical end and is called ball-end mill. The ball-end mill is fed back and forth across the work piece along a curvilinear path at close intervals to produce complex three-dimensional surfaces. Similar to profile milling, surface contouring require relatively simple cutting tool but advanced, usually computer-controlled feed control system.

II. Classification of milling cutters according to their design

- HSS cutters: Many cutters like end mills, slitting cutters, slab cutters, angular cutters, form cutters, etc., are made from high-speed steel (HSS).
- Brazed cutters: Very limited numbers of cutters (mainly face mills) are made with brazed carbide inserts. This design is largely replaced by mechanically attached cutters.
- Mechanically attached cutters: The vast majority of cutters are in this category. Carbide inserts are either clamped or pin locked to the body of the milling cutter.

III. Geometry of milling cutter

The milling cutter is a multiple point cutting tool. The cutting edge may be straight or in the form of various contours that are to be reproduced upon the work piece. The relative motion between the work piece and the cutter may be either axial or normal to the tool axis. In some cases a combination of the two motions is used. For example, form-generating milling cutters involve a combination of linear travel and rotary motion. The figure below shows the various angles and geometry of a milling cutter.

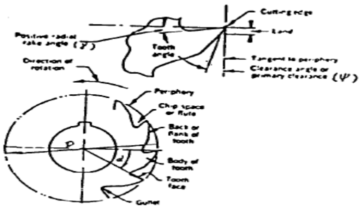

Fig 4: A Plain Milling Cutter

IV. THE GENERATED MODEL OF A MILLING CUTTER USING CATIA

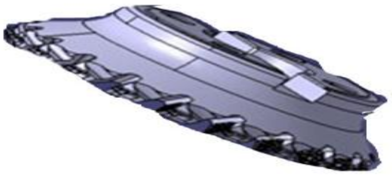

Fig 5: 3D-Model of milling cutter

V. ANALYSIS OF MILLING CUTTER

The basic steps for performing analysis are listed below:

- Create the model geometry and mesh
- Identify the contact pairs
- Designate contact and target surfaces
- Define the target surface
- Define the contact surface
- Set the element KEYOPTS and real constants
- Define/control the motion of the target surface (rigid-to-flexible only)
- Apply necessary boundary conditions
- Define solution options and load steps
- Solve the contact problem
- Review the results

VI. RESULTS & DISCUSSION

- CASE 1: Analysis of High Speed Steel Milling cutter for W=10000 N

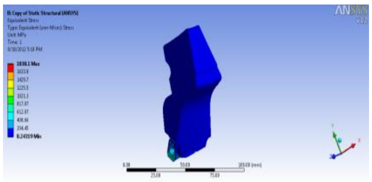

Fig 6: Stress values

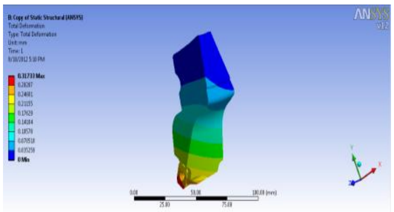

Fig 7: Deformation

- CASE 2: Analysis of High Speed Steel Milling cutter for W=250 N

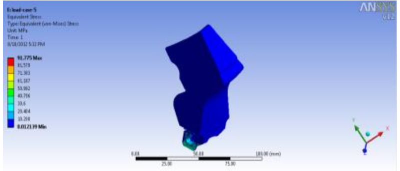

Fig 8: Stress values

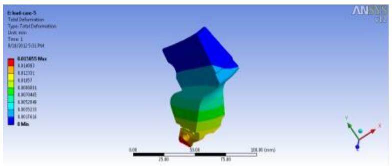

Fig 9: Deformation

- CASE 3: Analysis of Tungsten Carbide Milling cutter for W=10000 N

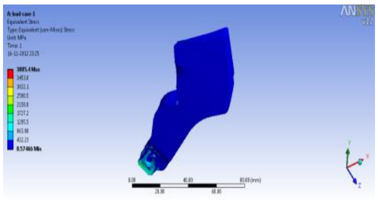

Fig 10: Stress value

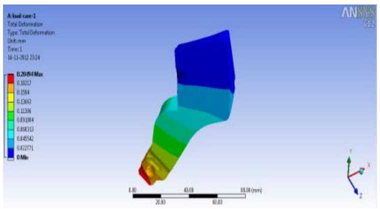

Fig 11: Deformation

- CASE 4: Analysis of Tungsten Carbide cutter for W=250 N

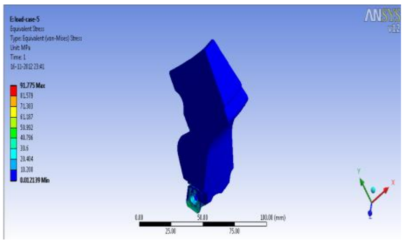

Fig 12: Stress values

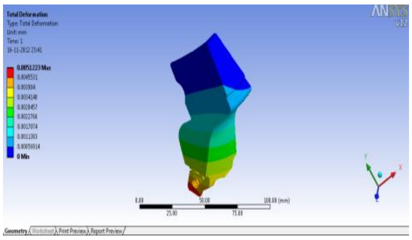

Fig 13: Deformation

SR.NO.	LOAD	STRESS	STRAIN
1	10000	3885.4	0.20494
2	250	91.775	0.005122

Table 1: Load vs Stress for High Speed steel

SR.NO.	LOAD	STRESS (Model)	STRESS (Theoretical)
1	10000	3676.4	2209.4
2	250	91.775	55.04

Table 2: Load vs Stress for Tungsten Carbide

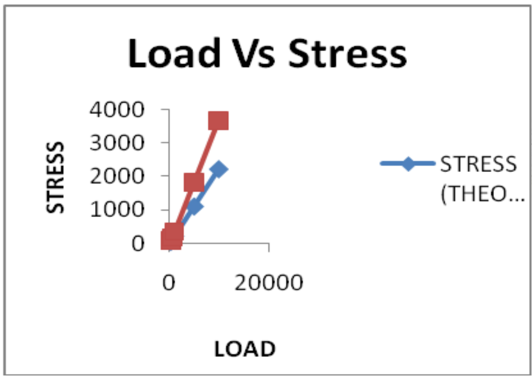

Fig 14: Load vs Stress for High Speed steel.

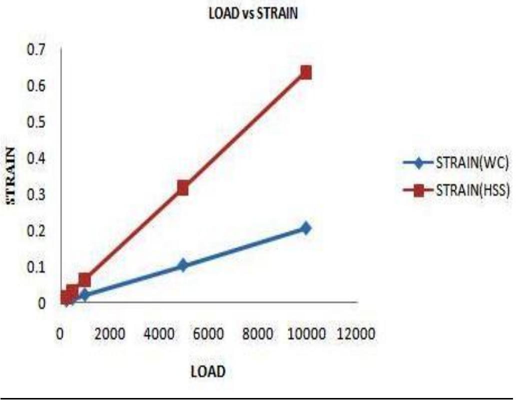

Fig 15: Load vs Stress for Tungsten Carbide

VII. Conclusion

In this study the design and analysis is carried out for two different cutter materials and they are High Speed Steel and Tungsten Carbide. In this analysis the loads acting on the cutter and speed is varied and the results obtained are compared. Finally the design and analysis is carried out using the software's CATIA V5, ANSYS.It could even be ventured that this approach can be used to design any complex mechanical component or system. Specifically for the cutter design, it produced the cutting variables that yield the minimum cost of manufacturing. The different design activities, such as design, solid modelling, and finite element analysis, have been integrated. As is evident, approach presented in this paper is flexible and easy to use.

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