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Modeling and Analysis of a Plain Milling Cutter Using Finite Element Analysis

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Abstract:- Milling machine is one of the important machining operations. In this operation the work piece is fed against a rotating cylindrical tool. The rotating tool consists of multiple cutting edges (multipoint cutting tool). Normally axis of rotation of feed given to the work piece. Milling operation is distinguished from other machining operations on the basis of orientation between the tool axis and the feed direction; however, in other operations like drilling, turning, etc. the tool is fed in the direction parallel to axis of rotation. The cutting tool used in milling operation is called milling cutter, which consists of multiple edges called teeth. The machine tool that performs the milling operations by producing required relative motion between work piece and tool is called milling machine. It provides the required relative motion under very controlled conditions. These conditions will be discussed later in this unit as milling speed, feed rate and depth of cut. Normally, the milling operation creates plane surfaces. Other geometries can also be created by milling machine. Milling operation is considered an interrupted cutting operation teeth of 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 bear the above stated conditions.
In this project work the design aspects of plain milling cutter is analyzed. The objective considered is the design and meshing of plain milling cutter and to analyze various stress components acting on it. Various designing strategies are considered to design the effective plain milling cutter like diameter, thickness, face width etc. The design and analysis is carried out using software's like CATIA V5 and ANSYS. 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.

Keywords: **-** Plain Milling, Surface Milling.

I. INTRODUCTION

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. The cutter is lifted to show the chips, and the work, transient, and machined surfaces. The cutter design being presented in this paper is useful for single point as well as for multi-point cutters such as those used for turning and milling. In fact, the design principles for both single and multi-point cutters are similar. The design parameters such as rake angle, clearance angle of tooth, and height of tooth are common in both single point and multi-point cutters. Additionally, parameters such as speed of rotation, feed, and depth of cut are also similar. However, parameters such as diameter of the cutter, number of teeth on the cutter, and angular spacing of teeth are exclusively associated with milling cutters. In the family of milling operations such as plain milling, slot milling, side milling, end milling, face milling, and form milling, design parameters differ only in their numerical values. In every case, the teeth of milling cutters have cutting edges and angles related to edges. In effect each tool acts like single point tool mounted on a cylindrical hub. The teeth on the milling cutters are mostly evenly spaced.

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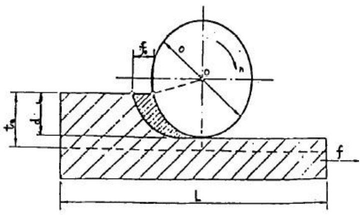

Fig1. Working motions of plain milling operation

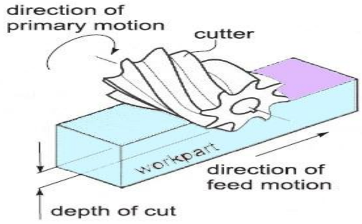

Fig.2 Depth of cut of plain milling cutter

II. TYPES OF MILLING PROCESSES

- 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.

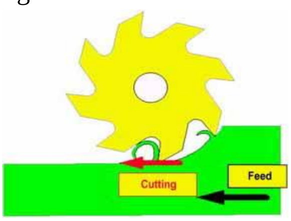

Fig.3 Down Milling (Climb Milling)

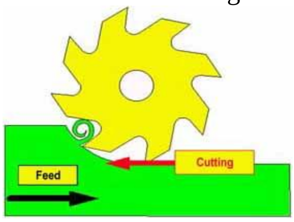

Fig.4 Up cut Milling (Conventional Milling)

- 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 favourable. 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.

III. CUTTING CONDITIONS IN MILLING

In milling, each tooth on a tool removes part of the stock in the form of a chip. The basic interface between tool and work part is pictured below. This shows a only a few teeth of a peripheral milling cutter.

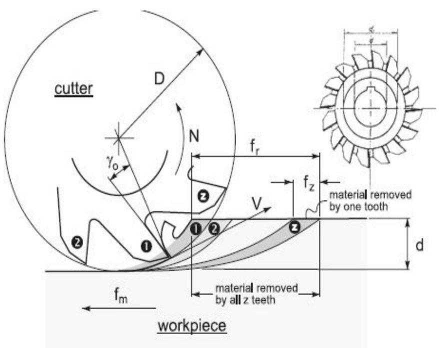

Fig.5 26-teeth Plain Milling Cutter Used for Peripheral or Slab Milling

Cutting velocity V is the peripheral speed of the cutter is defined by $V = \pi DN$

Where D is the cutter outer diameter and N is the rotational speed of the cutter.

As in the case of turning, cutting speed V is first calculated or selected from appropriate reference sources and then the rotational speed of the cutter N, which is used to adjust milling machine controls, is calculated. Cutting speeds are usually in the range of 0.1~4 m/s, lower for difficult-to-cut materials and for rough cuts, and higher for non-ferrous easy-to-cut materials like aluminum and for finishing cuts.

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- **Cutting Speed**

Cutting speed of a milling cutter is its peripheral linear speed resulting from operation. It is expressed in meters per minute. The cutting speed can be derived from the above formula. Spindle speed of a milling machine is selected to give the desired peripheral speed of cutter. $V = (\pi dn)/1000$
Where d = Diameter of milling cutter in mm, V = Cutting speed (linear) in meter per minute, and n = Cutter speed in revolution per minute.

- **Feed Rate**

It is the rate with which the work piece under process advances under the revolving milling cutter. It is known that revolving cutter remains stationary and feed is given to the work piece through worktable. Generally feed is expressed in three ways

- **Feed per Tooth**

It is the distance traveled by the work piece (its advance) between engagement by the two successive teeth. It is expressed as mm/tooth (f_t).

- **Feed per Revolution**

Travel of work piece during one revolution of milling cutter. It is expressed as mm/rev. and denoted by $f_{(rev)}$.

Feed per Unit of Time

- Feed can also be expressed as feed/minute or feed/sec. It is the distance advances by the work piece in unit time (f_m).

Above described three feed rates are mutually convertible.
$f_m \times n \times f_{rev}$
Where n = rpm of cutter.
It can be extended further as

f_m □ n □ f_{rev} □ z □ n □ f_t where z = Number of teeth in milling cutter

Feed rate (F) is defined as the rate of travel of the work piece in mm/min. But most tool suppliers recommend it as the movement per tooth of the cutter (f). Thus,

F = f. u. N

where -- **F** = table feed in mm/min
f = movement per tooth of cutter in mm
u = number of teeth of cutter
N = R.P.M. of the cutter

IV. MILLING OPERATIONS

Owing to the variety of shapes possible and its high production rates, milling is one of the most versatile and widely used machining operations. The geometric form created by milling fall into three major groups:

- Plane surfaces: the surface is linear in all three dimensions. The simplest and most convenient type of surface;
- Two-dimensional surfaces: the shape of the surface changes in the direction of two of the axes and is linear along the third axis. Examples include cams;
- Three-dimensional surfaces: the shape of the surface changes in all three directions. Examples include die cavities, gas turbine blades, propellers, casting patterns, etc.

V. PLAIN MILLING OF FLAT SURFACES

- Peripheral milling: In peripheral milling, also called plain milling, the axis of the cutter is parallel to the surface being machined, and the operation is performed by cutting edges on the outside periphery of the cutter. The primary motion is the rotation of the cutter. The feed is imparted to the work piece. The basic form of peripheral milling in which the cutter width extends beyond the work piece on both sides is called slab milling.

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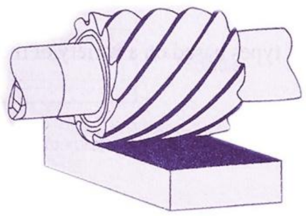

Fig.6 Slab or plain milling cutter

- Face milling: In face milling, cutter is perpendicular to the machined 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. Again up and down types of milling are available, depending on directions of the cutter rotation and feed. Face milling is usually applied for rough machining of large surfaces. Surface finish is worse than in peripheral milling, and feed marks are inevitable. One advantage of the face milling is the high production rate because the cutter diameter is large and as a result the material removal rate is high. Face milling with large diameter cutters requires significant machine power.

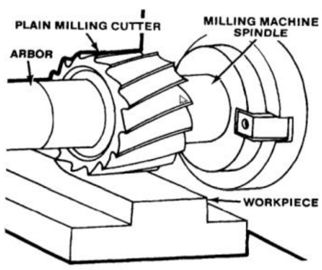

Fig.7 Flat surface of a plain milling cutter

- The end mill has helical cutting edges carried over onto the cylindrical cutter surface. End mills with flat ends (so called squire-end mills) are used to produce pockets, closed or end key slots, etc.:

VI. MILLING CUTTER NOMENCLATURE

Figure 8 show two views of a common milling cutter with its parts and angles identified. These parts and angles in some form are common to all cutter types.

- The pitch refers to the angular distance between like or adjacent teeth.
- The pitch is determined by the number of teeth. The tooth face is the forward facing surface of the tooth that forms the cutting edge.
- The cutting edge is the angle on each tooth that performs the cutting.
- The land is the narrow surface behind the cutting edge on each tooth.
- The rake angle is the angle formed between the face of the tooth and the centreline of the cutter. The rake angle defines the cutting edge and provides a path for chips that are cut from the work piece.
- The primary clearance angle is the angle of the land of each tooth measured from a line tangent to the centreline of the cutter at the cutting edge. This angle prevents each tooth from rubbing against the work piece after it makes its cut.
- This angle defines the land of each tooth and provides additional clearance for passage of cutting oil and chips.
- The hole diameter determines the size of the arbor necessary to mount the milling cutter.
- Plain milling cutters that are more than 3/4 inch in width are usually made with spiral or helical teeth. A plain spiral-tooth milling cutter produces a better and smoother finish and requires less power to operate. A plain helical-tooth milling cutter is especially desirable when milling an uneven surface or one with holes in it.

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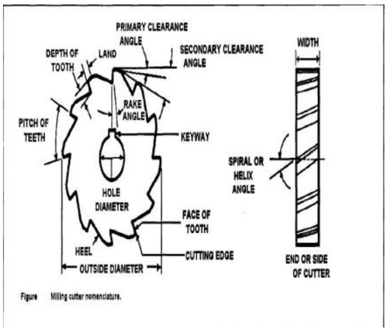


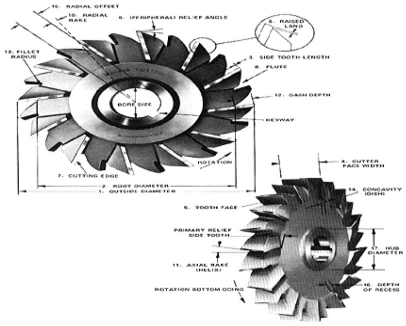
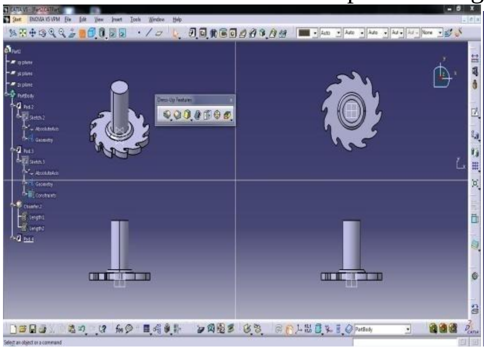


Fig.8 Nomenclature of 2d plain milling cutter **Fig.8** Nomenclature of 3d plain milling cutter

VII. MODELING OF PLAIN MILLING CUTTER USING CATIA

CATIA V5 is used to model the plain milling cutter and various views are presented in Fig. (9)



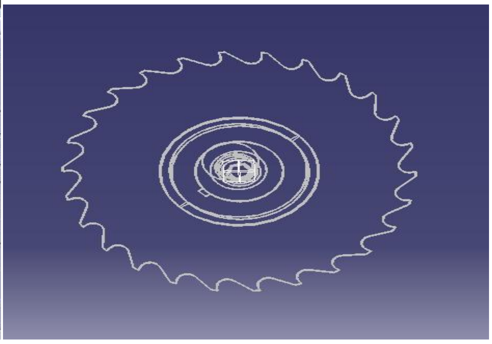
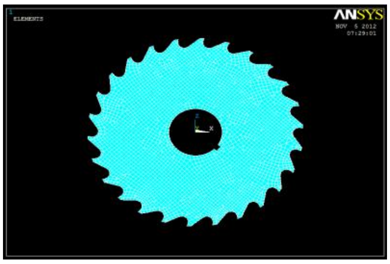


Fig.9 3D of the plain milling cutter **Fig.10** Model of the cutter in wire frame

VIII. ANALYSIS OF PLAIN MILLING CUTTER



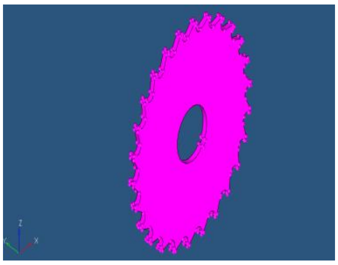
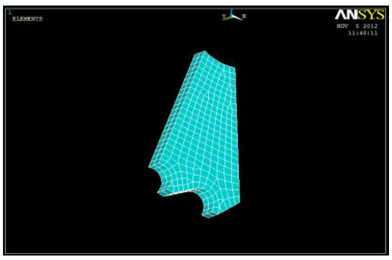


Fig.11 Meshed model of the cutter **Fig.12** Geometry of the cutter



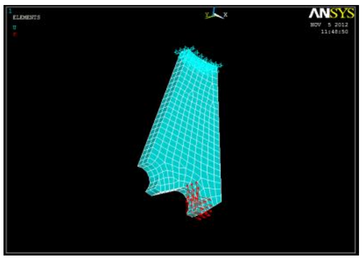


Fig.12 Meshed model of symmetry cutter **Fig.13** Loads applied on the symmetry of the cutter

IX. RESULTS AND DISCUSSION

Analysis of Milling Cutter:

The milling cutter is a symmetrical body hence the analysis is carried out considering a single tooth of the cutter. Here, the analysis is done for 5 different spindle speeds ranging from 50 to 2000 rpm. The loads at these speeds are calculated and the corresponding Stresses acting on the tooth are found.

Stress and deformation of the cutter at speed 50 rpm

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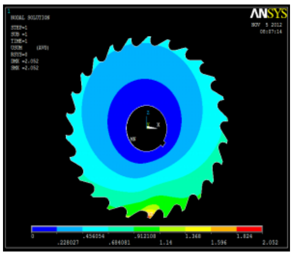

Fig.14 Deformation of the cutter at speed 50 rpm

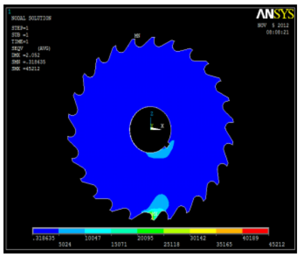

Fig.15 Stress at speed 50 rpm

Case 1: For W=2101.911 N, Here the speed is 50rpm for which the load is 2101.911 N. The following image represents FEA based stress and strain variations

Stress and deformation of the symmetry at speed 50 rpm

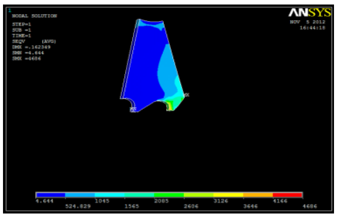

Fig.16 Stress of the symmetry at speed 50 rpm

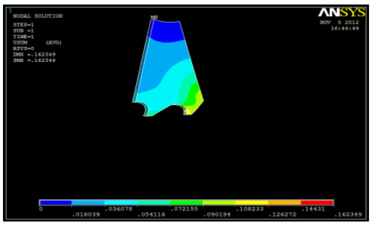

Fig.17 Deformation of the symmetry at speed 50 rpm

Case 2: For W=1050.955 N, Here the speed is 100 rpm for which the load is 1050.955 N. The following image represents FEA based stress and strain variations

Stress and deformation of the symmetry at speed 100 rpm

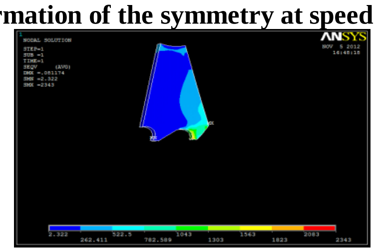

Fig.18 Stress of the symmetry at speed 100 rpm

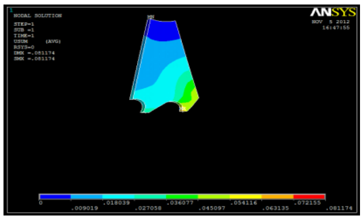

Fig.19 Deformation of the symmetry at speed 100 rpm

Case 3: For W=210.1911 N, Here the speed is 500 rpm for which the load is 210.1911 N. The following image represents FEA based stress and strain variations

Stress and deformation of symmetry at speed 500 rpm

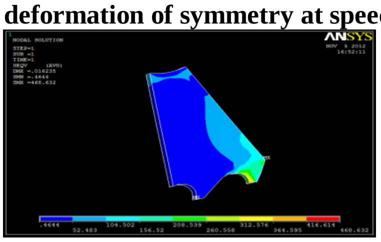

Fig.20 Stress of symmetry at speed 500 rpm

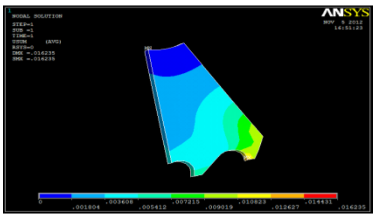

Fig.21 Deformation of symmetry at speed 500 rpm

Case 4: For W=105.0955 N, Here the speed is 1000 rpm for which the load is 105.0955 N. The following image represents FEA based stress and strain variations

Stress and deformation of symmetry at speed 1000 rpm

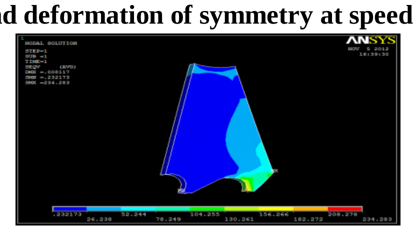

Fig 22 Stress of symmetry at speed 1000 rpm

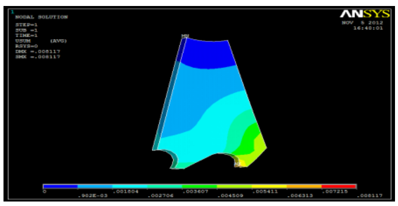

Fig.23 Deformation of symmetry at speed 1000 **rpm**

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Case 5: For W=52.5477 N, Here the speed is 2000 rpm for which the load is 52.5477 N. The following image represents FEA based stress and strain variations

Stress and deformation of symmetry at speed 2000 rpm

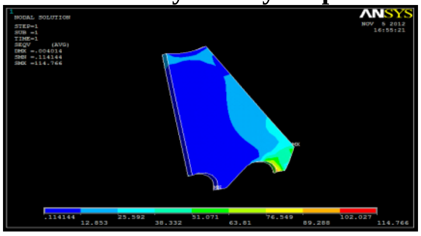

Fig.23 Stress of symmetry at speed 2000 rpm

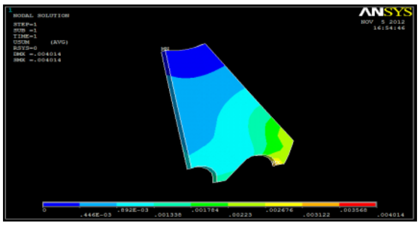

Fig.24 Deformation of symmetry at speed 2000 rpm

X. RESULTS OBTAINED

S.NO	DIA	SPEED	POWER	LOAD	STRESS (Ansys, Results)	STRESS (Theoretical)
1	100	50	5.50E+02	2101.911	4521	4056
2	100	100	5.50E+02	1050.955	2261	2207
3	100	500	5.50E+02	210.1911	2243	2220
4	100	1000	5.50E+02	105.0955	226.049	223.5
5	100	2000	5.50E+02	52.54777	112.485	108.19

Table.1 Results obtained from the analysis

Graphs between Load and Stresses:
Figure 25 Represents variation in stress with respect to variation in load for both FEA model and theoretical results

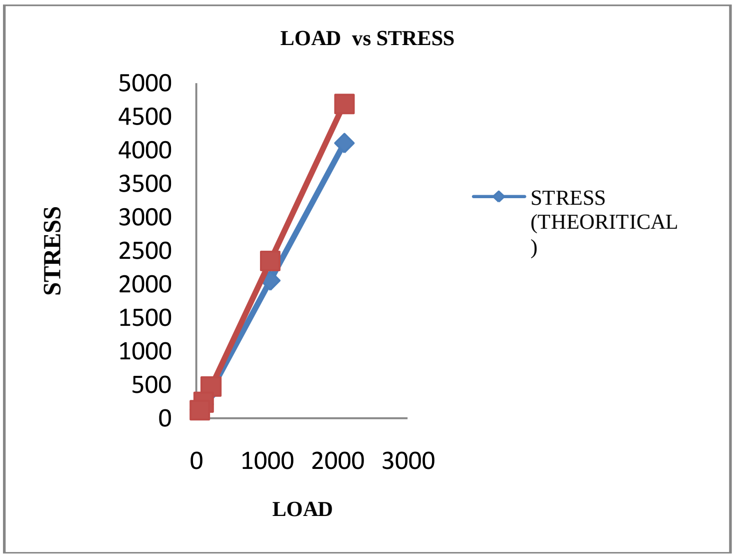

Fig.25 Plot Load Vs Stresses

XI. CONCLUSIONS

- The model of the cutter is designed in CATIA and analysis is carried out using ANSYS. The results obtained are tabulated in the result table 3.
- The input parameters taken for the analysis are diameter of cutter, speed, power and load in which diameter and power are kept constant and the speed and load are varied.
- The output values for stress and deformation obtained at different loads and speeds are tabulated in table no:3
- From the results table, it is observed that the stress and deformation of the cutter are decreasing with increase in the speed i.e. they are inversely proportional to each other.

- In this analysis the loads acting on the cutter and speed is varied and the results obtained are compared.

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