Modelling, Fabrication And Surface Modification of An Involute Spline Spur Gear

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Abstract - Today's Mechanical field is growing at a fast rate in designing to manufacture splines with Gears. Over the decades, numerous methods and manufacturing processes have been used in making the various kinds of Splines based on various criteria, including applications, reliability, life time, processing time and manufacturing cost. This paper is also carried out with the same notion of experimenting to manufacture an External Involute Spline gear using state-of-art CAD/CAM package and current trend machines like Hobbing Machine. This paper is deepening knowledge upon three distinct phases: (1) Analysis Phase (2) Manufacturing Phase and (3) Heat Treatment. The analysis phase is based on the study and simulation of involute splines spur gear, while the manufacturing phase covers the actual manufacturing process.

Key words- CAD (Computer-Aided Design), CAM (Computer-Aided Manufacturing), RPM (Revolution per Minute), RPT (Rise per Tooth), ANSI (American National Standard Institute).

1. INTRODUCTION

This paper is based on the designing of a gear and manufacturing involute splines gear [4]. Both gears and splines are manufactured with similar manufacturing processes and techniques. Involute profiled spur gears are having equally spaced teeth. But they are not straight sided. The teeth have an involute form, just like a gear tooth. The teeth do not have a same proportion as a gear tooth; they are shorter in height combined with involute form sides provide greater strength. They have a pressure angle of 30, 37.5 and 45 degrees. Though the Splines are manufactured in different ways, based on the criteria of machinery availability, time and money we chose to manufacture spline gear on the Hobbing machine and test it by cutting the external splines on a drive shaft [1].

In Hobbing- Hob teeth are shaped to match the tooth space and are interrupted with grooves to provide cutting surfaces. It rotates about an axis normal to that of the gear blank, cutting into the rotating blank to generate the teeth.

Finishing process - When high precision is required then we can perform secondary operation to gears made by any of the above roughing methods. Finishing operations typically removes little or no material but improves dimensional accuracy, surface finish, and or hardness.

Spur Gears - The two parallel and co-planar shafts connected by the gears. These gears are called spur gears. These gears have teeth parallel to the axis of the wheel.

The Paper is based upon the research by **Antoniadis A.** *et al.* work on the gear quality through three main stages i.e. the rough cutting, the heat treatment and the finishing process [16].

2. METHOD

Hobbing is one of the very old manufacturing techniques used to manufacture gears. Hobbing is a machining process for making gears, with splines as well as sprockets. The teeth or 22 splines are progressively cut into the work piece by a series of cuts made by a cutting tool called a hob. It is the most widely used spline cutting process for creating spur gears and helical [3].

It is the most accurate of the roughing processes since no repositioning of tool or blank is required ad each tooth is cut by multiple hob-teeth, averaging out any tool errors. Excellent surface finish is achieved by this method and it is widely used for production of gears.

After manipulation of data on the basis of Gearing Calculations, following parameters are made for Gear Designing- Pitch Diameter, Number of Teeth, Base Diameter, Diametral Pitch, Stub Pitch, Circular Pitch, Pressure Angle [2].

Besides the usual spline parameters, it is important to have the Parametric Spline parameters to get the profile of the spline tooth. In the parametric spline equations, and are the parameters which decides the length of the involute curve.

3. DESIGN PHASE-SOLIDWORKS

Design and analysis phase is the next important step in this paper. Here, in this phase of pre-manufacturing, actual models are built. All the built models are designed and iterated with different set of dimensions and machining parameters using design tables. To create a gear with the Involute Spline profile, first we need to design an Internal or External Spline [6]. Using that spline, a profile is generated on gear and is manufactured in the HOBBING phase. So this chapter discusses the steps involved in creating the Involute splines and the corresponding spline profile on the required machine insert. This chapter on pre-manufacturing using SolidWorks involves,

- ☐ Drawing an involute spline sketch
- ☐ Creating involute tooth profile

- Converting into External Involute Spline using circular pattern with required number of teeth
- Creating a Design table with number of teeth, diametral pitch and pressure angle as inputs

3.1 EXTERNAL INVOLUTE SPLINE

According to the paper objective defined, to manufacture a Spline gear we need to know the profile of the involute spline. For this, we need to make an external involute spline from which a spline profile is traced on to the cutting insert by using convert entities and SolidWorks assembly.

Initially, based on the parameters calculated in previous chapter, a preliminary sketch is drawn using 2-D SolidWorks sketch in part modeling. Making the sketch constrained, parts are modeled using extrusion command and converted into 3-Dimensionals figures [7]. Using the dimensions of the part and adding equation and relations to those dimensions a Design Table is created.

Here, parametric equations are used from spline command for sketching tool and after that the tooth thickness is measured in terms of angle, and a tooth profile is taken with major diameter, pitch circle and minor circle. Once the tooth form is generated then Extrude command is used for conversion to 3-D tooth.

3.2 DESIGN TABLES

The idea of this section is automating the whole process of designing the involute spline in SolidWorks. This makes an easy way to alter the dimensions of the spline. As a part of this, SolidWorks Design Tables are chosen as a tool to automate this whole process of designing a spline.

Excel file and can be saved as an external excel worksheet. Once the design tables are created, they can be modified or can be edited at any time with or without opening SolidWorks to change the configurations [8].

3.3 Methodology Implementation in SolidWorks for various profiles

After simulating the respective gear profile as shown in by rotating about z - axis at some angle and translating from right plane at some distance will give the sketch from the gear.

Rack to gear profile

Developing of rack to gear profile generation in SolidWorks software with (module = 10 mm) are done by relating the equation between the various parameters of rack e.g. module, number of teeth, pitch circle diameter, addendum, dedendum, pressure angle, circular pitch, tooth thickness etc.

4. ANALYSIS PHASE

HOBBING is the second and next phase of Pre-manufacturing process. All the models generated and created in SolidWorks phase are made compatible to open and imported into HOBBING. Here the machining parameters are defined to the SolidWorks models appropriately to the specific machining techniques we actually use during the real time machining. Hobbing machining techniques which we use as a part of this paper are defined with required parameters are given and the process is simulate. This chapter on pre-manufacturing using HOBBING tool involves:

- Choosing a gear
- Importing gear and involute tooth into SolidWorks Assembly
- Choosing a Involute spline profile of the cutter
- Importing new cutter into HOBBING
- Creating an auto-chain around the involute profile on the insert
- Creating „contour‟ operation under SolidWire
- Simulation of Hobbing process

4.1 GETTING INTO HOBBING

HOBBING's high performance capabilities include machining any part geometry (solid, surface, or wireframe), verification with dry runs rendered in dynamic solids for optimal part quality and consistency. Its fast, accurate and reliable dynamic solid verification eliminates the need for expensive dry runs on the machine. It is possible to verify machining process as we compare accurately rendered "as designed "as machined" parts [9].

- We choose the part type depending on which side of the part are we going to cut.
- Select the strategy of cut with the rough passes and number of skim passes if necessary. For the gear we machine in this paper, we chose one rough cut and one skim cut for better finish.
- Set the levels of the work piece bottom, thickness and reference plane where we hold the work piece and also the location of Machine.
- We define the primary cut strategy which is "Rough and 1Skim" in this project.
- We can also control the rough cut here in this tab by suppressing it.
- The primary cut settings like power and feed rate of the wire are defined here and also offset distance of the wire from work piece if necessary as shown in Figure.

5. MANUFACTURING

The material removal processes are familiar of shaping operations in which excess material is removed from a starting work piece so that what remains is the desired final geometry. In other words, cutting processes remove material from the surface of a work piece by producing chips. Machining is a manufacturing process in which a sharp cutting tool is used to cut away material to leave the desired part shape. The predominant cutting action in machining involves shear deformation of the work material to form a chip; as the chip is removed, a new surface is exposed [5].

5.1 MANUFACTURING PROCESS

The first and foremost step in HOBBING phase of manufacturing is creating an involute gear and simulating. A Parasolid model of Insert created in SolidWorks phase is imported into HOBBING with "Import as a Solid" options checked. This process is done using Hobbing Technique which is one of the advanced machining techniques. The gear hobbing process is widely applied for the construction of any external tooth form developed uniformly about a rotation center [10]. The kinematics principle of the process is based on three relative motion between the workpiece and the hob tool. To produce spur or helical gears, the workpiece rotates about its symmetry axis with certain constant angular velocity, synchronized with the relative gear hob rotation. Depending on the hobbing machine used, the worktable or the hob may travel along the work axis with the selected feed rate.

6. FINISHING

Finishing is done by heat treatment may be defined as an operation involving the heating of solid metals to definite temperature, followed by cooling at suitable rates in order to obtain certain physical properties which are associated with changes in the nature, form, size and distribution of the micro-constituents. Heat Treatment is a very important process in the various fabrication and manufacturing operations [12]. The purpose of heat treatment is to achieve one or more of the following objectives:

- To improve machinability
- To change grain size
- To improve mechanical properties
- To modify the structure to increase wear, heat and corrosion resistance
- To modify magnetic and electrical properties
- To remove trapped gases
- To remove coring and segregation
- To get rid of internal stresses produced on cold-working, casting, welding and hot-working operations
- Case Hardening
- Surface Hardening [13]

6.1 TEMPERING

To increase the ductility and hardness a method called Tempering is accomplished which consist of heating the hardened metal to some temperature for about an hour to produce tempered **martensite.**

Thus tempering is carried out to:

- ✓ Increase toughness
- ✓ Decrease hardness and increase ductility
- ✓ Stabilize structure
- ✓ Relieve internal stresses

6.2 CASE HARDENING

Gears are made tough, shock absorbing and capable of carrying high stresses using Case Hardening method called **Gas carburizing.** Case hardening is also known as a process of chemical heat treatment in which the saturation of the surface of low-carbon steel with a certain element (carbon) by diffusion of this element from the surrounding medium at a high temperature takes place [14].

There are several methods of carburizing but the one that suits the requirement is Gas carburizing.

6.3 GAS CARBURIZING

It is a method in which directly applied carbon monoxide gas reacts with the surface of material to give a much more direct and rapid absorption of carbon. This is achieved by holding the component in an atmosphere of a mixture of CO, CO_2, hydrogen and other gases so proportioned that the maxi-mum rate of carbon absorption is attained [11].

Components are suspended from hooks in the atmosphere-controlled gas furnace over a quenching tank. By suitable release or lowering of suspension, the components may be quenched directly from the furnace without exposure to atmospheric oxygen which gives a quality of surface finish.

7. RESULTS AND ANALYSIS OF EXPERIMENTAL TESTS

7.1 Gas Carburizing

It was observed that using propane as the enriching gas provided a more rapid kinetics of the carburizing reactions, which shortened the time (Δt) for the carbon potential to stabilize]. Mixing propane and natural gas in equal proportions (CH) revealed an intermediate rate of carbon potential evolution during the enriching stage (34 min) compared to using either one of the pure component gases. [17]

Spectrometer Test Structure a.) Before & b.) After Heat Treatment Test Qualifies to Specifications of – 20MnCr5 on Program Fe-10-F before Heat treatment on Gear and the Material in Gear shows the analysis as shown in Table.1.

Table.1 Specifications of Spectro Test done Before Heat treatment

	C %	Si %	Mn%	Cr %	Mo %	Ni %	Cu %	Al %	S %	P %	V%
Value	0.218	0.265	1.258	1.141	0.056	0.06	0.029	0.0206	0.0106	0.0208	0.0

Table.2 Specifications of Spectro Test done After Heat treatment

	C %	Si %	Mn %	Cr %	Mo %	Ni %	Cu %	Al %	S %	P %
Value	0.710	0.2129	1.309	1.300	0.003	0.017	0.0096	0.0159	0.0121	0.0184

The Surface Hardness Test of Gear showed 10-20 HRC and its Macro Structure Test shows that the 22 Teeth gear was Duly Grinded, polished finely. On 3% Nital etch the matrix revealed **Pearlitic Grain in Ferritic and Grains were in Normalized condition**.

After Heat Treatment the data shown in Table.9 Changed to data shown in Table.2

The Surface Hardness Test of Gear showed 60-62 HRC and its Micro Structure Test shows that the specimen of gear having 22 Teeth got cut and Duly Grinded & polished finely. On 3% Nital etch the matrix revealed **Tempered Martensitic Structure.**

Before the heat treatment process the micro structure of the gear material is **Pearlitic and Ferritic and Grains were in Normalized condition** which is soft and has low hardness about 20- 30 HRC, it has low percentage of carbon as shown in the testing report of gear material [15].

After the gas carburizing process which is case hardening process the micro structure at the surface changes to **Tempered Martensitic Structure,** having hardness 60 HRC. The increased in hardness is due to increase in the percentage of carbon from 0.218 to 0.710 percentage and the formation of tempered martensite at the surface while the core structure remains Pearlitic and Ferritic which is soft and ductile.

8. CONCLUSION AND RECOMMENDATIONS

This paper has resulting in the designing, analyzing and manufacturing a spline gear by using the design tables from SolidWorks which reduced the amount of time taken for designing successfully. These design tables are created with Microsoft EXCEL spreadsheets embedded inside SolidWorks. Then, manufacturing process of gear using Hobbing machine and testing on machine was done.

As the first step of this paper, study was performed to automate the different spline configuration within the EXCEL spreadsheets using design tables without manually creating the models by user. One can enter the inputs like number of teeth, pressure angle and Diametral pitch to get the external splines. This automation process described above can be optimized in making splines as well as gears in future by using more powerful optimizing techniques using spreadsheets or any other techniques.

Later during the course of this paper, manufacturing process on Hobbing machine is carried out and successfully tested on hobbing machine to cut external involute splines on drive shafts. These shafts are perfect fit for the drive hubs with internal involute splines in it. The clearances of this manufacturing process came up to 0.010 inch to fit the drive shaft and drive hub. Gears are to be made; it is suitable for larger batch size. This method is automated using Parametric CAD software by defining proper relative relations during the generation of profile which provides accuracy without any human errors by generation of the profiles which actually shows the machining process. This meth-od replaces a designer, as only the parameters defining the job need to input, the generation of the profile is automated which leads to reduces the human inaccuracies, increases productivity and saves time also. Further moving on tempering and gas carburizing helped in giving the below mentioned advantages, which got proved by Spectro test and hardness testing.

Advantages:

- ✓ Increase toughness and relieve internal stresses
- ✓ Case depth obtained accurately in this rapid processing

9. FUTURE SCOPES

Based on vast studies and practical application of Computer operated software the designing and manufacturing of tools as wells as products. On the basis of research, a gear with any profile (Cycloid or Involute) can be made with high quality and quantity at a faster rate. Surface finishing reduces the rate of errors with an improvement in quality of product as gear.

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