Effect on Strength of Involute Spur Gear by Changing the Number of Teeth Using FEA

Ashwini Joshi, Sanjay Jain

***Abstract*— The gear tooth fillet is an area of maximum bending stress concentration. However, its profile and accuracy are marginally defined on the gear drawing by typically very generous root diameter tolerance and, in some cases, by the minimum fillet radius, which is difficult to inspect. In fact, tooth bending strength improvement is usually provided by gear technology case hardening and shot peening to create compressive residual stress layer, rather than gear geometry. The gear tooth fillet profile is typically the generating cutting tool (gear hob or shaper cutter) tooth tip trajectory, also called trochoid. If the cutter parameters are chosen or designed to generate the involute flank profile, which must work for the certain gear application and satisfy certain operation conditions, the fillet profile is just a byproduct of the cutter motion. Present work deals with the effect on gear strength with variation of root fillet design using FEA. Circular root fillet design is considered for analysis. The loading is done at the edge of the face of gear tooth.**

***Index Terms*— Gear Design, Circular Fillet radius, Gear Strength and Finite Element Analysis.**

I. INTRODUCTION

Historically, gear geometry improvement efforts were concentrated on the working involute flanks. They are nominally well described and classified by different standard accuracy grades, depending on gear application and defining their tolerance limits for such parameters as run out, profile, lead, pitch variation, and others. Working involute flanks are also modified to localize a bearing contact and provide required performance at different tolerance combinations and possible misalignment as a result of operating conditions (temperature, loads, etc.). Their accuracy is thoroughly controlled by gear inspection machines.

A pair of teeth in action is generally subjected to two types of cyclic stresses: bending stresses inducing bending fatigue and contact stress causing contact fatigue. Both these types of stresses may not attain their maximum values at the same point of contact. However, combined action of both of them is the reason of failure of gear tooth leading to fracture at the root of a tooth under bending fatigue and surface failure, like pitting or flaking due to contact fatigue. These types of failures can be minimized by careful analysis of the problem during the design stage and creating proper tooth surface profile with proper manufacturing methods.

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The finite element method is capable of providing this information, but the time needed to create such a model is large. In order to reduce the modeling time, a preprocessor method that creates the geometry needed for a finite element analysis may be used, such as that provided by Pro Engineering. It can generate models of three-dimensional gears easily. The finite element method is very often used to analyze the stresses in an elastic body with complicated geometry, such as a gear.

In this work the effect on strength of involute spur gear with change in the design of root fillet radius is studied. The gear is modelled with circular fillet and then finite element analysis is carried out by taking the load at the edge of the face of the single tooth contact using Pro/ENGINEER wildfire software. The maximum and the minimum distortion produced at the fillet are studied.

II. MODELLING OF GEAR

In total 15 number of gears are modeled in Pro/ENGINEER Wildfire [6], which are having the following parameters.

Module 5mm; Three set of gears having number of teeth 14,18 and 30; Each set of gear having pitch circle diameter 70mm, 90mm, and 150mm; Radius of circular fillet for each set of gear 0.5mm, 1mm, 1.5mm, 2mm, 2.25mm; Pressure angle 20^0; Load at highest point of single tooth contact 100kN; Gear Material f_e 20. The following steps are showing the procedure to model the gear of 18 number of teeth with the combination of the all above mentioned parameters in the Pro/ENGINEER Wildfire, other set of gears are modeled in the similar way.

Part parameters are the basic parameters defining the gear. These part parameters determine all the other parameters that define the gear tooth profile by using the Tools/Relation menu. Figure 2 showing the part parameters.

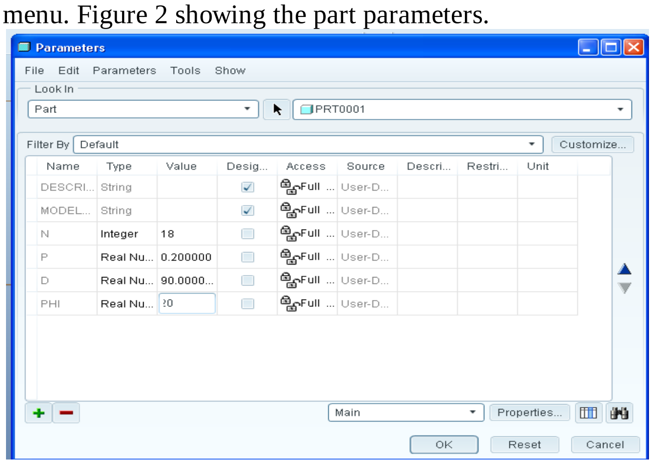

Figure 2: Part Parameters

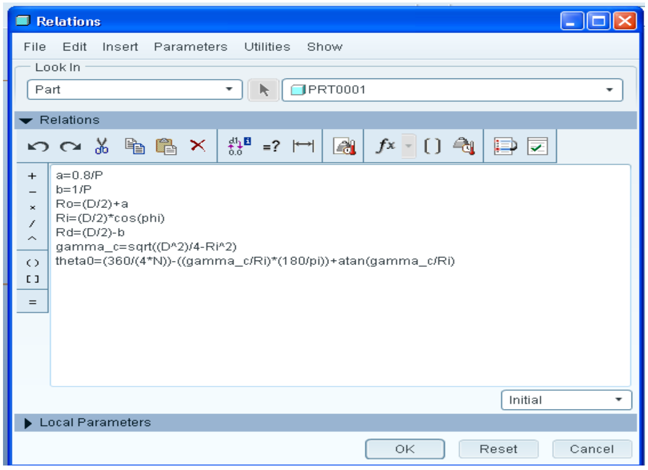

Figure 3: Tools / Relations menu

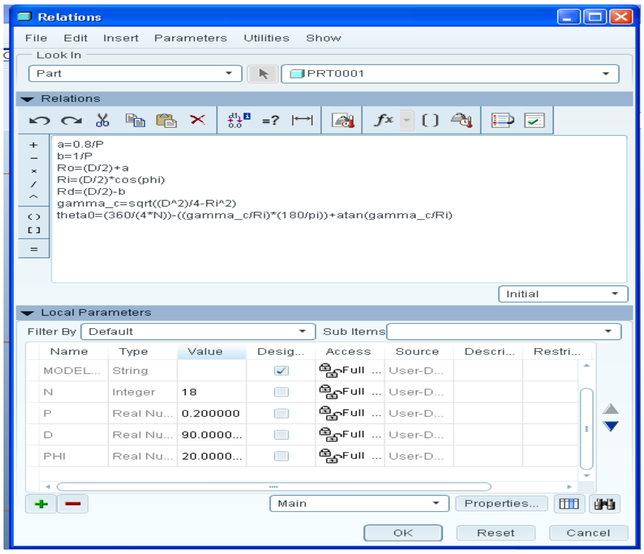

Figure 4: Part Relations

Drawing the circle centered on the sketch references for the extrusion profile and taking the extrusion depth equals to the thickness of gear. By using the Tools / Relations Menu we define relations between the sketch dimensions and the part parameters. Figure 3 is showing the Tools/ Relations Menu. After defining these relations, the circle should have the diameter equals to the diameter of the addendum diameter of the gear blank. Figure 4 is showing the part relations for getting the addendum diameter and the Figure 5 is showing the gear blank.

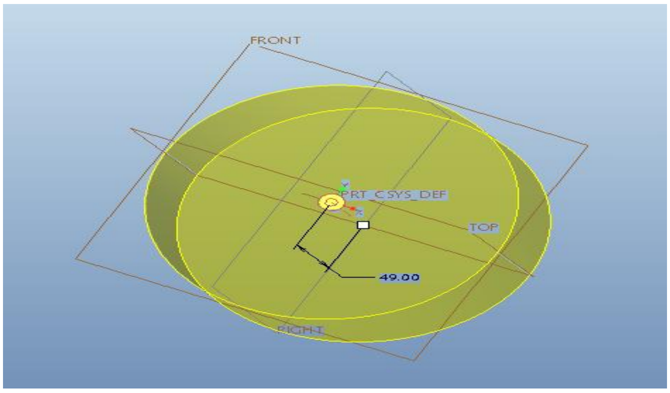

Figure 5: Gear Blank

Selecting from equation from the Insert/ Model Datum/ Curve Menu. We take "PRT_CSYS_DEF" as a default coordinate system. Taking coordinate system cylindrical type. In this point a Notepad window will pop up where we can enter all equations for the datum curve. As shown in the Figure 6. The preview after entry of all the parameters will show the involute curve over the gear blank as shown in the Figure 7.

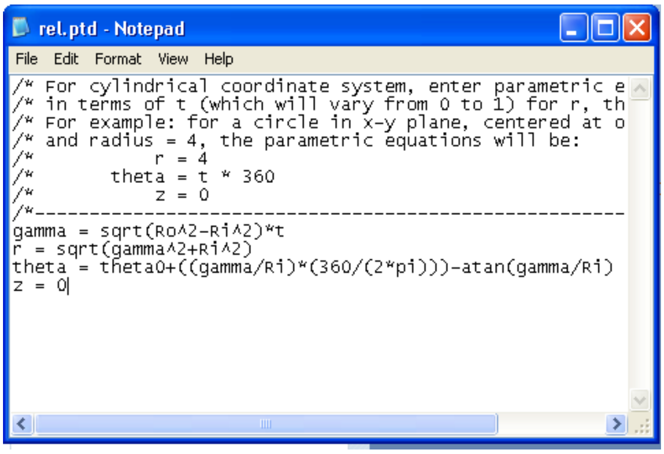

Figure 6: Datum Curve Relations

Now we have an involute curve at one side of the gear blank, by mirroring the curve about the axis we get the C shaped profile made up of made up of two involute profiles. In next step going to the Tools/ Relations menu and setting the inner arc to the value of parameter Rd. After extruding the C shaped profile through the whole depth of the gear blank finally we get the space between the two gear teeth. Figure 8 is showing the space between the two gear teeth.

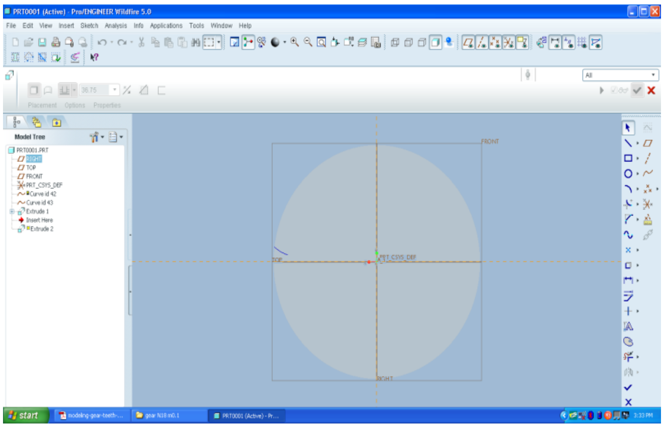

Figure 7: Involute Profile over the Surface of Gear Blank

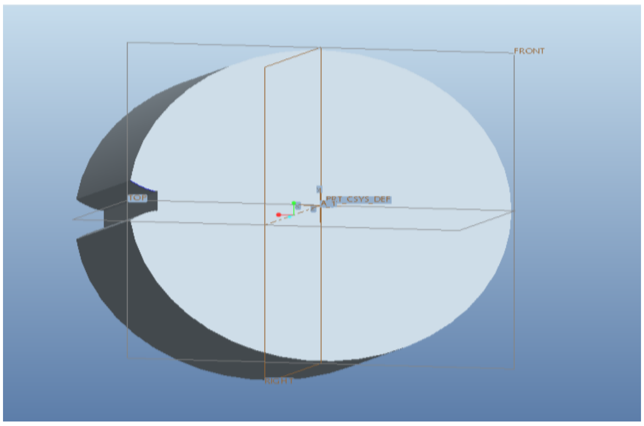

Figure 8: Gear Blank with Tooth Space

From the newest extruded feature in the model tree and selecting the pattern, in the top dashboard we select the following parameters;

1. Pattern type : Axis pattern
2. Axis for pattern: A_1 at the center of the gear.
3. Number of copies: Equals to the number of teeth here 18.
4. Included angle of the pattern: 360^0

After accepting the settings we get the involute gear with the desired number of the teeth. As shown in the Figure 9.

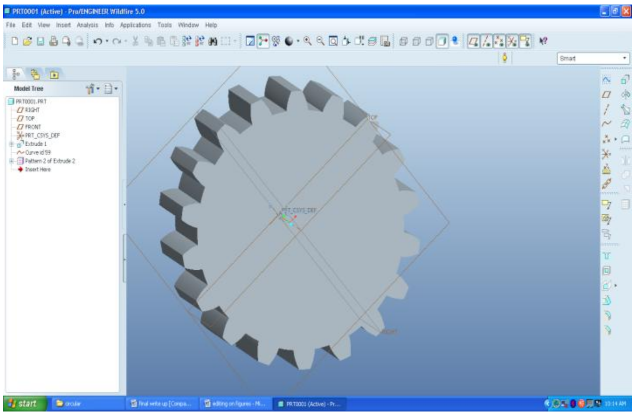

Figure 9: Gear Model

As per the value of the coordinates calculated from the mathematical model [3]. a part having the bottom edges equals to the radius of the circular fillet is cut from the base gear model; as shown in the Figure 10. The subtracted part gives the circular fillet at the root of the gear as shown in the Figure 11.

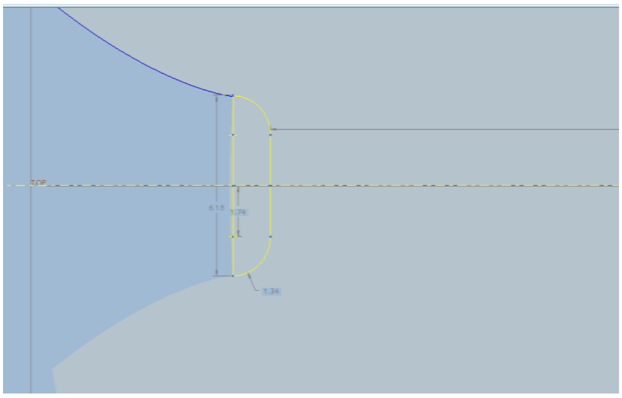

Figure 10: Circular Fillet

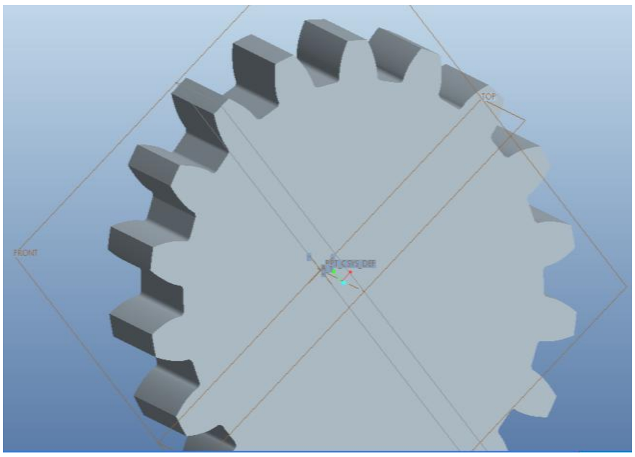

Figure 4.21: Gear with circular Fillet

III. STRUCTURAL ANALYSIS

The structural analysis of the spur gear tooth model is carried out using the finite element analysis in Pro/Mechanica which is a application of Pro/Engineer. All degree of freedom of the surfaces both side of the tooth being constrained. Figure 6, is showing the displacement constraint. At the Aspect Ratio of 7 the Mess is generated with tetrahedron nodes. Total 38430 elements and 7880 nodes are created. Figure 7, is showing mess generation. Maximum element size of 5 mm is selected for the Mess Control. By applying the analysis over the surface which is facing the load we get the maximum and minimum distortion in the numeric as well as in the form of colour scheme. Figure 8, is showing the element quality check, the highlighted part which is the root of the gear is showing weak part of the gear it also describes the number of poorly shaped elements. Figure 9, showing the finite element analysis in terms of the colour scheme with value of distortion produced due to loading.

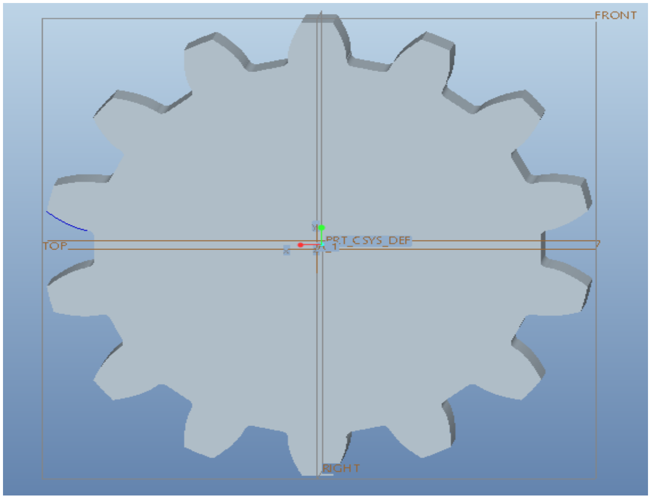

Fig. 4: Gear Model with circular fillet.

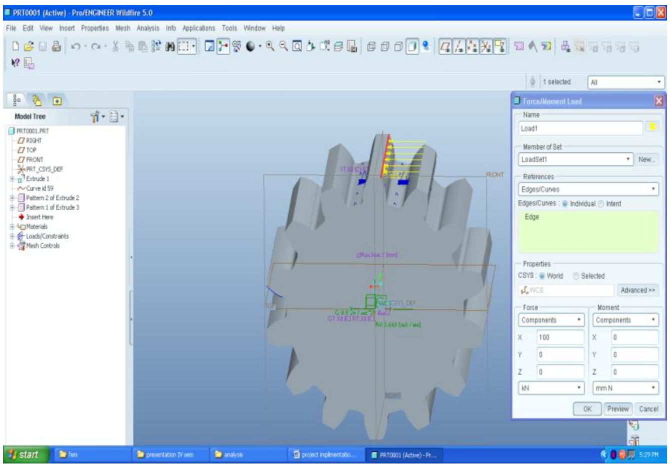

Fig. 5: Load on the Tip of Gear 100 kN.

IV. RESULTS AND DISCUSSION:

A comparative study has been carried out between the gears of the different number of teeth having different fillet radius. These teeth are having 14, 18 and 30 numbers of teeth with 0.5mm, 1.0mm, 1.5mm, 2.0mm and 2.25mm fillet radius. The effect of change of fillet radius on the strength of spur gear involute teeth is investigated in ProEngineer by taking the load of 100 kN at the highest point of single tooth contact.

By keeping all the degree of freedom of the surfaces both side of the tooth constrained and applying the quality checks for the generated mess, we get the list of the poorly shaped elements out of the total generated mess. We get the distortion of the each poorly shaped Tetrahedron Element. As Shown in Figure 8.

In graph shown in the figure 10, the effect of change in fillet radius to the gears of different number of teeth is investigated; it shows the distortion produced in the gears of 14, 18 and 30 number of teeth. The gears having the lower value of the fillet radius are showing the lesser distortion, on the other hand the gear having the higher value of the fillet radius are showing the greater distortion on the same gear parameters.

Maximum distortion is shown by the gear having the maximum number of the tooth i.e. by the gear of 30 numbers of teeth and minimum distortion is produced in the gear of least number of teeth i.e. in the gear of 14 number of teeth.

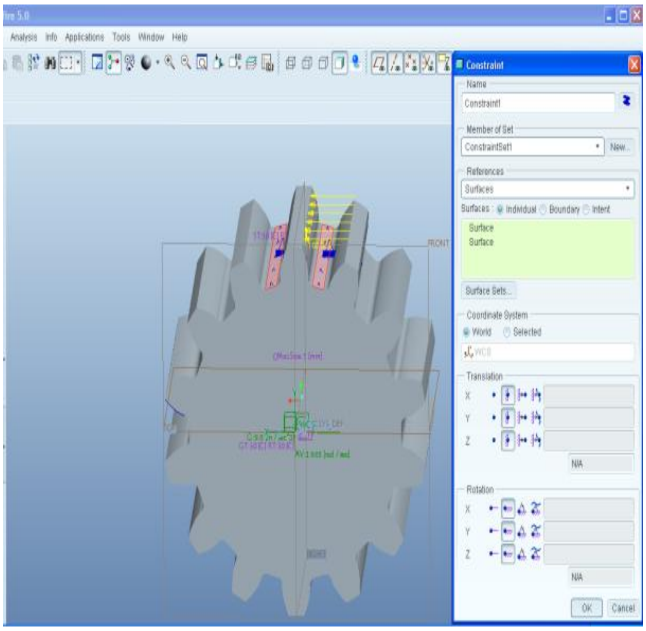

Fig. 6: Displacement Constraint

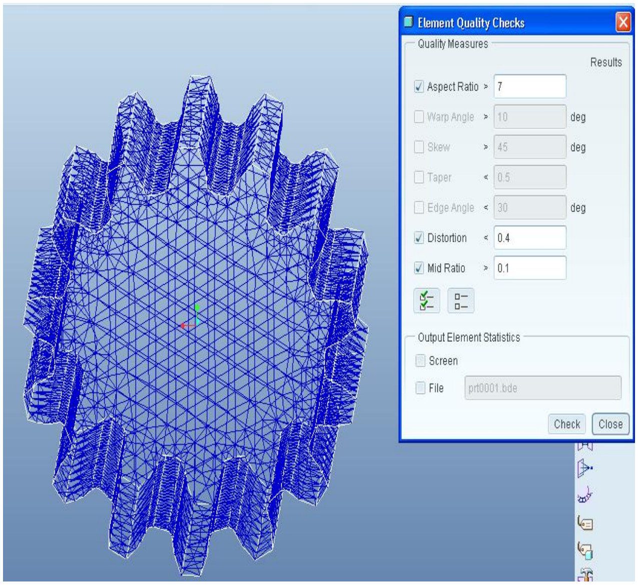

Fig. 7: Mess Generation

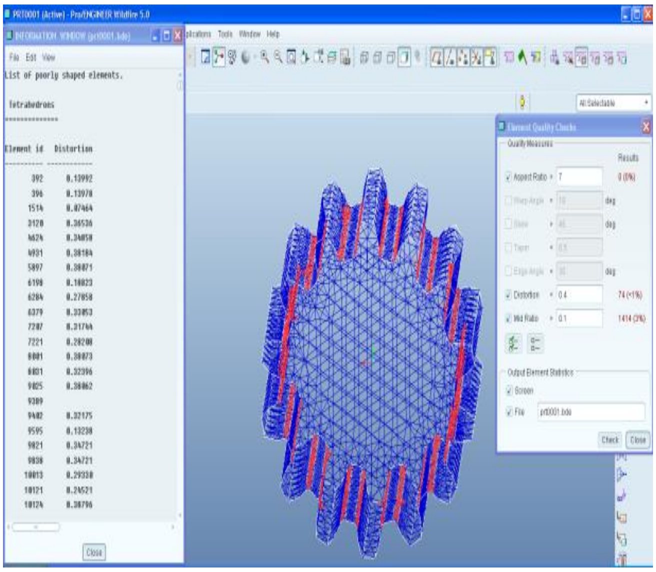

Fig. 8: Element Quality Check

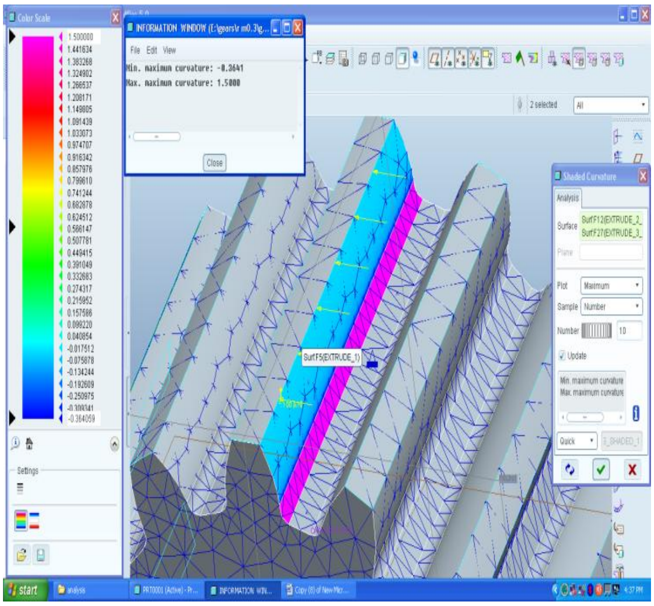

Fig. 9: Finite Element Analysis Result

Fillet radius In terms of module (m)	No. of Teeth (N)	Curvature deflection (Min)
0.1m	14	0.398
	18	0.3244
	30	0.2184
0.2m	14	0.3898
	18	0.3244
	30	0.2184
0.3m	14	0.3641
	18	0.2801
	30	0.2184
0.4m	14	0.3898
	18	0.3175
	30	0.2184
0.45m	14	0.3898
	18	0.3830
	30	0.2184

Table 1.Observation Table

V. CONCLUSION

The effect on the strength of spur involute gear by changing the radius of the circular fillet was investigated. Gears of different parameters but having same module and pressure angle is modelled and the distortion produced in the curvature due to the loading at the edge of the face of single tooth is analysed by using Finite Element Analysis.

From the table it is concluded that, as the number of teeth increases for the same fillet radius deflection decreases. It shows minimum deflection in the highest number of teeth of gear.

It is also concluded that, the value of the deflection in the curvature of the gear is more in the gear of more number of teeth.

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