Contact Stress Analysis & Stress Reduction of spur gear by using Analytical & Experimental Method

Tushar Narawade, ME student, Siddhant College of Engineering Sudumbare, Pune

Prof. S.S.Jewargi, Siddhant College Of Engineering Sudumbare, Pune

***Abstract*— Gears are very important in industrial applications and automobiles. They are widely used in many applications like textile looms, aviation industries, automobile gear box and machine tool application for purpose of the transmitting power. Gears are very useful for converting input provided by prime mover into an output with lower speed and with higher torque. Spur gears are very efficient for transmitting the power up to velocity ratio is ten. This phase they derive high stress at the contact surface. A pair of teeth in action is generally subjected to contact stresses causing failure of gear tooth. The main purpose of this experiment is to reduce the contact stress of gear by modifying the module of gear. One Spur gear line is selected for analysis purpose. The Contact stress of existing gear line or train is calculated and compared with the help of fatigue strengths of gear material. If this stress on gears are higher than fatigue strengths means gears are failed due to fatigue. By increasing the module of gear reduces the contact stress .The contact stress is calculated by Hertz's Equation and Strain gauge is used for the experimental investigation of the stress field. Hence stress reduction take place with the help of analytical as well as experimental method for better performance and increasing efficiency of module.**

***Index Term*— Spur gear train, Pitting, Hertz' contact stress, Module, Molding and casting, Strain gauge, Gear ratio.**

I. INTRODUCTION

Gears are very important in industrial applications. They are regularly used for transmitting the power from one shaft to another shaft in automobile transmission system as well as machine tools application. The breakdown of the gear in power transmission is very major problem in industrial application. The gears are failed if contact stresses in the gear are higher than the fatigue strength of gear is called wear failure of the gear. The selected spur gear train is frequently failed due to wear failure of gear. To reduce the wear failure of gear contact tresses are reduce up to the limited value by modifying the module of gear. The contact stresses of the gear are calculated by Analytical, FEA & Experimental Method. These contacts stresses are compared with wear strength of the gear. If contact stresses are higher than wear strength of the gear means gear is failed due to wear failure. This chance of failure is reduce by increasing the module of the gear. The power is transmitting from prime mover to machine with increasing or decreasing the speed as per requirement of application. The gears are mostly used for transmitting the power because gears are contain positive drive, compact, reliable & transmit high power with higher efficiency. Hence performance is good. Gear is most important as well as demanding components in a mechanical power transmission system. The gears are mostly classified into following types spur, helical, bevel & worm gear. Spur gears are very simple for designing and manufacturing .hence cost of spur gear is low. The spur gears are normally used for transmitting the power between two parallel shafts because teeth of gears are parallel to axis of revolution of gear.

A force on the tooth of driven gear was exerted by the tooth of driving pinion and power is to be transmitted between both shaft means driving & driven shaft. This force is always working with the pressure line at pitch point called as a normal force or traceable force. This normal force is classified in tangential & radial component of gear in horizontal & vertical plane respectively. Calculation of torque & power of spur gear train was done by using tangential component of force. The gear was induced by the contact stress and bending stress due to the tangential load acts on the gear. Contact stress is considering during pitting failure .hence If contact stress on the gear is greater than the wear strengths of the gear material gear breakdown is take place called as erosion or pitting failure of the gear.

Erosion is dynamic removal of metal from the surface. The tooth is fragile down and gets weakened. Misalignment in the shaft is occurs due to wear .other causes of wear or erosion are wrong viscosity oil selection & contact stress exceeding the surface fatigue or weakness strength of the material. A surface fatigue failure of the gear tooth was by pitting. Material in the weak region gets removed in the form of pit.

The stress concentration is increase & crack is developed over the tooth surface. The size of crack is increase due to cyclic load acts on the gear. The size of crack is very high up to gear tooth is insufficient to absorb the load acts on it & finally it get beak. That type of failure is called as wear failure. The life of the gear drive is reducing due to the wear failure. To increase life of the gear analysis is very important against the wear failure. The wear failure in the gear is take place due to the contact stress. The contact stress of the gear is reducing up to the limiting value by increasing the module of the gear. The contact stress of the gear is calculated analytically by using hertz's contact stress theory& Experimental method by using Strain gauge. The results obtain by all these methods are comparing and find the deviation in between them.

The one gear pair is selected for the analysis which is frequently failed during working. The analytical method is used to calculate contact stress of gear pair for finding the causes of failure. Compares of this stress with wear strength of the gear material take place. Gear is failed due to the wear failure indicates that If contact stresses are higher than the wear strength. To reduce the wear failure of the gear contact stress of gear are reducing by increase the module of gear. The gears are redesign for new value of module selected form the slandered series of module and again calculate the contact stress of gear and compared it with wear or erosion strengths of gear material.

II. LITERATURE SURVEY

Bharat Gupta etal.[1] explained the relation of gear contact stresses and the wear strength of the gear with failure. Dimensions of gears determine from contact stress. Pitting occurs when fatigue cracks are initiated on the tooth surface or just below the surface. Gearing in industry is one of the most complex components in mechanical power transmission systems. Hertz's equations are used in current analytical methods of calculating gear contact stresses which were originally derived for contact between two cylinders. So it's necessary to develop and to determine appropriate models of contact elements for CONTACT STRESSES, and to calculate contact stresses using ANSYS and compare the results with Hertzian theory. He is observing the result and concludes relations between maximum contact stress and module of gear. The contact stresses is maximum at the pitch point of the gear.

M.Raja Roy etal. [2] explained the analysis of contact stresses induces on the spur gear train for analyzes different value of module. The contact stresses are calculating with the help analytical method using hertz's contact stress, FEA method by using Solidwork&Ansys FEA software. In this research paper developed one VISUAL BASIC program for calculate the contact stresses for different parameter which are related to gear performance like module, power & speed etc.. The result obtained by all this methods are compared and concluded that difference is within permissible limit. The Last conclusion of this paper is if module of the gear is increasing the contact pressure is decreasing.

Ali Raad Hassan etal.[3] presented the contact stresses are calculated each 3° rotation of pinion from first location of contact at 0° to last location 30° total 10 such cases are produce. Each case was represented a sequence position of contact between these two teeth. The contact stresses for all this cases are calculated by developing one computer base program in QBASIC language based on analytical method using hertz's contact stress theory. The result can express by plotting the graph of selected cases Vs max. contact stresses. The observation of result gives the high value of contact stress in the beginning of the contact, and then it starts to reduce until it reaches the location of single tooth contact, then it increased to the maximum value of the contact at pitch point, after that stresses start to reduce the contact ratio reduces.

Yadav S.H etal. [4] presented gear is important parameter of the power transmission system. If the contact stress in the gear is higher than the surface endurance limit of the gear pitting failure is take place. To reduce this failure contact stress should be less than limiting value. The model of the gear train is formed in the CAD software & import in the ansys for calculates the contact stress. That stress is compare with surface endurance limit of the gear. He can found that contact stress is higher than surface endurance limit of the gear. To reduce the contact stress of the gear module of the gear is increase and redesign the gear. The contact stresses are reducing up to the lower than surface endurance limit of the gear material. He was increase the life of planetary gear train by reducing the contact stress up to the limiting value of the stress.

V.Rajaprabakaran etal. [5] presented analysis of calculating contact stresses of gear by experimental method using photoelasticty. For this research work four specimens of gear were manufactured by ISO standard having different no of teeth with same module and width. The contact stresses of these specimens are calculated by photo elasticity experiment. The same calculation is done by FEA method. The modeling of specimen is done in CAD software and imported in Ansys for calculating the contact stresses. The result of both methods are compared and found satisfactorily within permissible limit.

Ali KamilJebur etal. [6] explained the maximum contact stresses of spur gear are calculated for different position. For research purpose selecting three spur gear trains having different number of teeth for analysis. The model of spur gear is formed in CAD software & imported in the Anasys for calculate the contact stresses for different position. The result was express by plotting the graph between maximum contact stresses Vs contact position. The experimental analysis is done by using the D.C servomotor and planting the strain gages in the tooth of the gear made form polyimide materials. The result of both methods are compared and concluded that difference is within reasonable limit.

III. METHODOLOGY OF SYSTEM

A. Analytical method.

Technical data:

1. Type: - Spur gear train.
2. Input power: - 2000 Wt.
3. Reduction ratio: - 2.54: 1
4. Input speed: - 250 rpm
5. Output speed: - 98.21 rpm.
6. Modulus of elasticity (E)(MPa) = 110000
7. Fatigue strength (MPa) = 630

Table 1: Dimension of spur gear train

Input parameter	Pinion	Gear
No. Of teeth	22	56
Module (mm)	2	
P.C.D.(mm)	44	112
Face width (mm)	20	
Pressure angle	20˚	
Base Dia.(mm)	41.39	105.24
Tip Dia. (mm)	48	116

Nominal torque on pinion shaft (T) :
T = 9550* P/n1 = 9550*(2000/250)
T = 76.39 Nm

Tangential Force (Ft):
Ft = 2000 * T /d = 2000*76.39 / 44
Ft = 3472.27 N

For module 2 mm:
Hertz's contact stresses:

$$Pp=\sqrt{\frac{Ft}{b*d1}*\frac{u+1}{u}}*Ym*Yp$$

1. The material Co-efficient

$$Ym=\sqrt{0.35*\frac{2E1E2}{E1+E2}}$$

Ym = 196.21

2. The Pitch point Co-efficient:

$$Yp=\sqrt{\frac{1}{\cos\alpha*\cos\alpha*\tan\alpha w}}$$

Yp = 1.76

Hertzian contact stress (Pp) = 809.81 MPa

These contact stresses are compared with fatigue strength of the gear material. The maximum contact stress of spur gear train is 809.81 MPa is higher than Fatigue Strength of steel 630 MPa. The gears are failed due to the wear or pitting failure. To reduce the contact stress of gear up to the limiting value by increases the module of the gear and redesign.

For module 3:
Hertz's contact stresses:

$$Pp=\sqrt{\frac{Ft}{b*d1}*\frac{u+1}{u}}*Ym*Yp$$

1. The material Co-efficient

$$Ym=\sqrt{0.35*\frac{2E1E2}{E1+E2}}$$

Ym = 196.21

2. The Pitch point Co-efficient:

$$Yp=\sqrt{\frac{1}{\cos\alpha*\cos\alpha*\tan\alpha w}}$$

Yp = 1.11

Hertzian contact stress (Pp) = 417.012 MPa
These contact stresses are compared with fatigue strength of the gear material. The maximum contact stress of spur gear train is 417MPa is less than Fatigue Strength of steel 630 MPa. Hence contact stresses of gear are reducing up to the limiting value by increases the module of the gear.

Table 2: Result of Analytical method

Contact Stress (N/mm2)	Contact Stress (N/mm2)	Wear strength (N/mm2)
Module - 02	Module - 03	steel
809.81	417	630

B. Finite Element Analysis

1) Flow chart
As shown in figure 2 flow of system, design of gear take place with the help of design parameter. CATIA V5 software is use for 3D modelling. Finite element analysis takes place using ANSYS software. If minimum stress conditions satisfied, then go for implement physical setup. If does not satisfy minimum stress condition, repeat procedure changing dimensions.

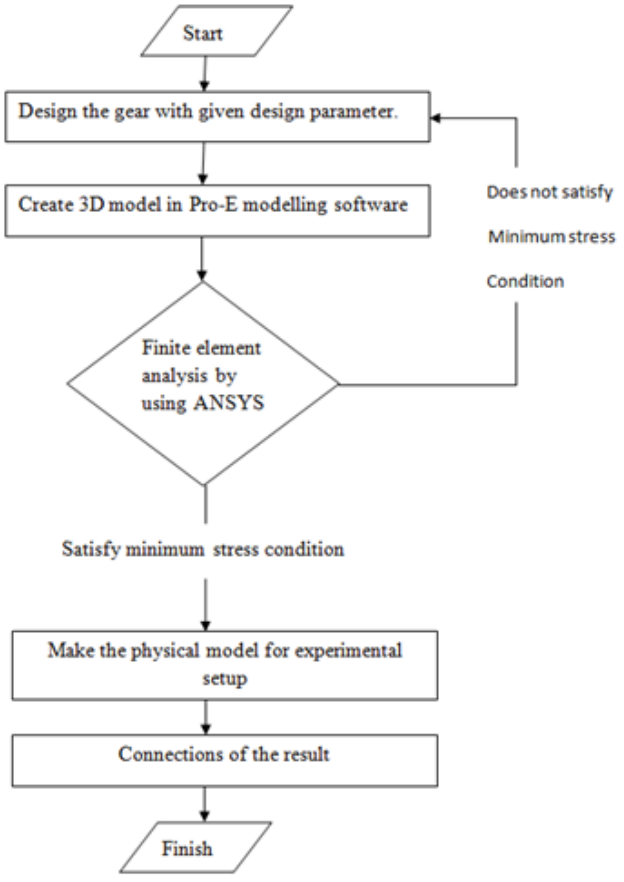

Fig. 1flow chart of system

As shown in flow of system, finite element analysis takes place using ANSYS software. This software is used to calculate the contact stresses of spur gear train. The method of

calculating gear contact stress by Hertz's equation originally derived for contact between two cylinders by using Hertz' s contact stress theory. This contact stress is compared with fatigue strength of gear material. The contact stresses of gear are decreases by increasing the module.

2) Modeling of spur gear and Finite element analysis.

Table 3: For Module -02

Sr.No.	Input Parameter	Symbol	Value
1	Module (mm)	m	2
2	Nominal input power (Wt.)	P	2000
3	Gear Ratio	u	2.54
4	Pinion speed (R.P.M.)	n	250
5	No. of teeth on pinion	Z	22
6	Pressure angle	α	20˚
7	Face width (mm)	b	20
8	Material for Pinion	Steel	
9	Material for gear	Steel	

The modeling of spur gear train is carried out in CATIA V5 R-21 CAD software. This is advance computer aided design software manufacture by Dessolt System. This is one of the best software used for solid modeling for widely used in industry. The model of spur gear is form by following three steps:

I. Draw 2D sketch of gear
II. Convert 2D sketch of gear to 3D part
III. Assembly of spur gear train

Assembly of spur gear train (Module-02)

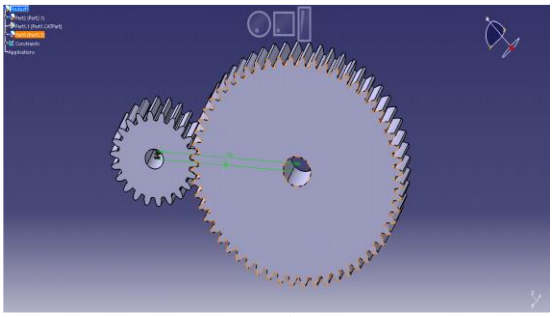

Fig.2 Assembly of spur gear train

The assembly of pinion & gear is done by using assembly module of the software. The assembly is created by giving fix, contact & offset constrain. The assembly is saving in .step format.

After this boundary conditions are applied as follows:

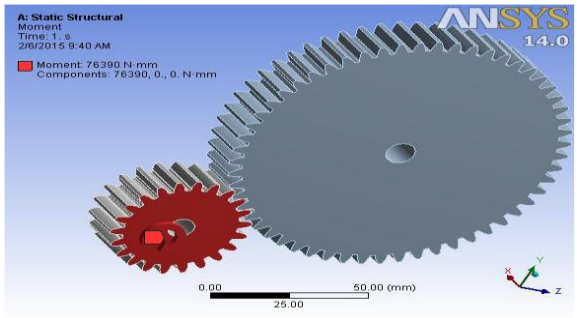

Fig.3.Boundary Conditions for Analysis

Von-miss strains (Module- 02)

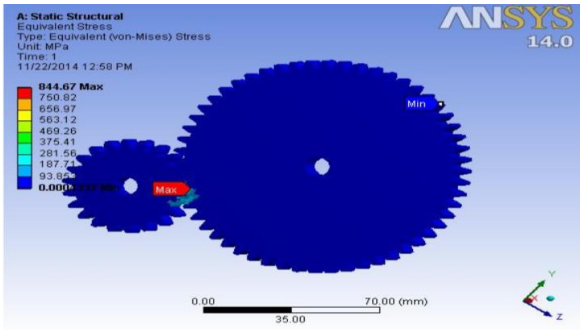

Fig.4.Von -miss strains

For Module -03

Assembly of spur gear train (Module-03)

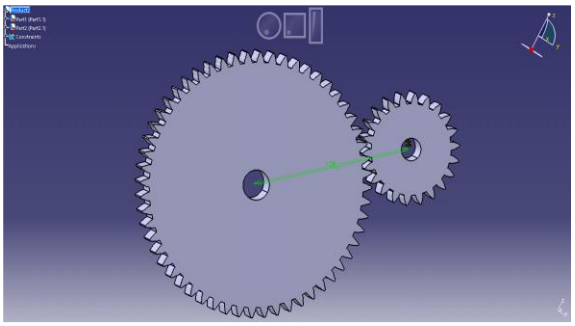

Fig.5Assembly of spur gear train

Von-miss strains (Module- 03)

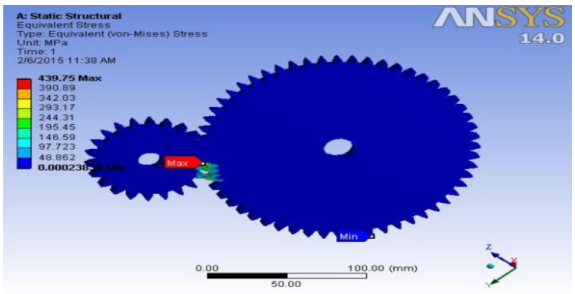

Figure 6: Von-miss strains

Table 4: Result & discussion of FEA method:

Contact Stress(N/mm2)		Wear strength(N/mm2)
Module - 02	Module - 03	Steel
844.67	439.75	630

The contact stress of the spur gear train at module - 02 is 844.67. is reduce up to the 439.75Mpa by taken higher value of module 03.This value is less than the wear strength of the steel 630 Mpa of the gear material.

IV. Experimental setup

As shown in figure 7 the components of experimental set-up consist of Gear Set (Pinion and Gear), Strain gauge - 2Qty, DAS System (FFT Analyser), Display, Power Supply, Bearing - 4 Qty, Support stand, Leaver and Weight.

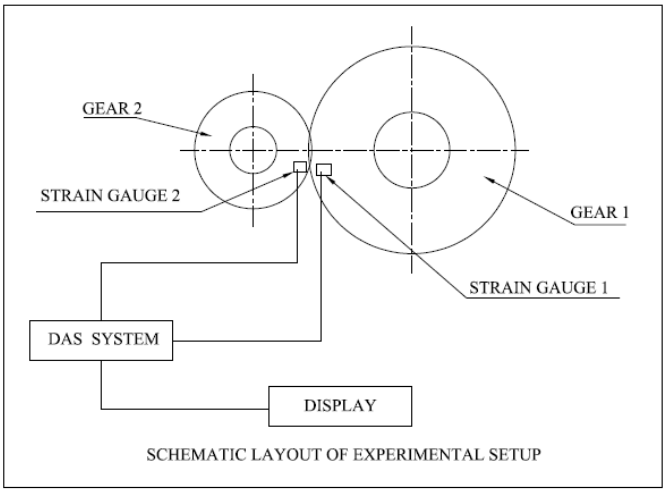

Fig. 7 Schematic Layout of Experimental Setup

1. FFT analyzer:

An FFT spectrum analyzer works in an different way. The input signal is digitized at a high sampling rate. It is similar to a digitizing oscilloscope.

Fig.8.FFT analyzer

2. Strain gauge mounting

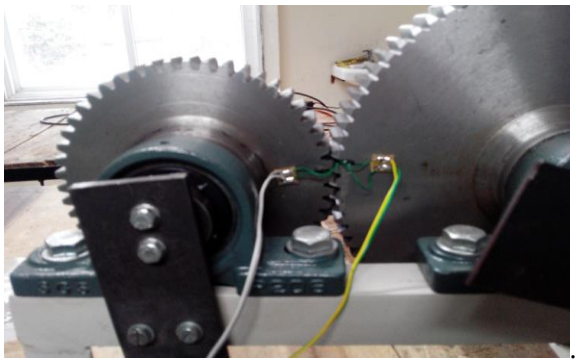

Fig.9. Strain gauge mounting

3. Strain gauge connections with DB9 connector

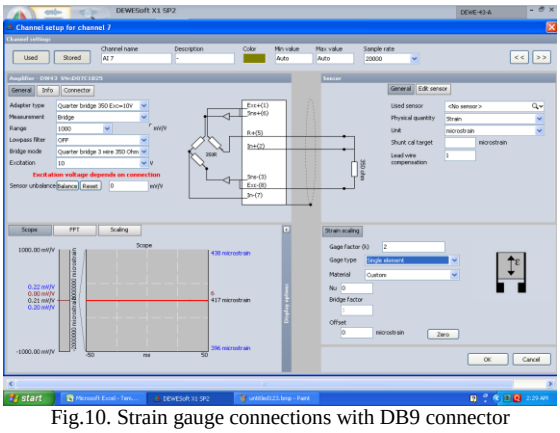

Fig.10. Strain gauge connections with DB9 connector

There are three wire connected to strain gauge with solder tab given to the gauge. The wire green and blue are short-circuited and yellow is connected separately to solder tab. In db9 connector green wire is connected to 5 no, blue is connected to 2 no, and yellow is connected to 8 no, these connections are standard as per given by software catalog information.

For Module 2

Modulus of elasticity of gear (Steel) = 110000 Mpa.

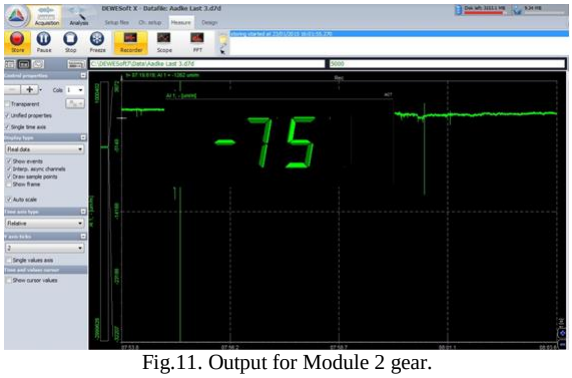

Fig.11. Output for Module 2 gear.

Stress (e) = Modulus of elasticity * strain

Stress (e) = 110000*0.0075

Stress (e) = 825 Mpa.

Maximum contact stress in spur gear is 825 Mpa is higher than steel 630 Mpa. due to this gear failed due to wear or pitting failuare. To reduce the contact stress of gear, module of gear increased.

For Module 3

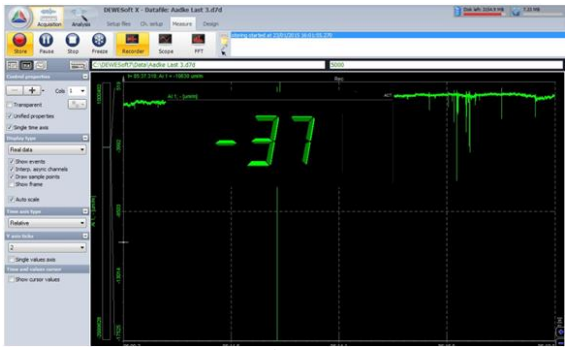

Fig.12. Output for Module 3 gear.

Stress (e) = Modulus of elasticity * strain
Stress (e) = 110000 * 0.0037
Stress (e) = 407 Mpa.

Maximum contact stress in spur gear is 407 Mpa is less than steel 630 Mpa. Hence contact stresses of the gear reducing up to limiting value by incresing the module of the gear.

Table 5: Result & discussion of Experimental method:

Contact Stress(N/mm2)		Wear strength(N/mm2)
Module - 02	Module - 03	Steel
825	407	630

The contact stress of the spur gear at module 2 is 825 Mpa. is reduce up to the 407Mpa by taken higher module 3. this value is less than the wear strength of the steel 630 Mpa of the gear material.

Comparison of Analytical, FEA & Experimental results:

Table 6: Comparison of Analytical, FEA& Experimental results.

Module	Contact Stress (N/mm2)		
	Analytical Method	FEA method	Experimental Method
02	809.81	844.67	825.0
03	417.0	439.75	407.0

V. CONCLUSION

The contacts stresses of the spur gear train are calculated by analytical method for module -2 are 809.81 Mpa. The gear material is steel having Fatigue strengths is 630 Mpa. If the contact stresses are higher than the fatigue strengths of the gear material wear is take place at the time of transmitting the power between the gears. To reduce the Fatigue failure of the gear the contact stresses are reduce up to the limiting value (Fatigue strength) Of the gear material. The contact stresses of the gear are reducing by increasing the module of the gear from 2 to 3 and adding the correction factor. The contact stresses of the gear for module -3 are 417 Map this are less than fatigue strength of the gear material and reduce the wear failure of the gear.

The model of spur gear train is formed in CATIA V5 R21. For module -2.This model is imported in Ansys Workbench 14.0 for calculates the contact stress of gear. The contact stresses by FEA Method for module-2 are 844.67 Mpa. From result it is found that the contact stresses of the gear are higher than the Fatigue strength of the gear material 630 Mpa. and concluded that contact stresses are cause of pitting failure of the gear. That pitting failure of the gear is reduce by increasing the module of the gear from 2 to 3 and adding the correction factor. The contact stresses for module 3 are 439.75 Mpa this are less than fatigue strength of the gear material. The pitting failure of gear is reduce by increasing the module of the selecting from standard table. The gear and pinion for module-2 are manufactured by hobbing method. The contact stresses are calculated on the Parallel axis gear-testing machine by using strain guage. The contact stresses of gear for module-2 are 825Mpa. This stresses are higher than fatigue strength (630 Mpa) of the gear material. The pitting failure is take place in the gear drive that can be reducing by increasing the module of the gear and adding the correction factor. The contact stresses for module-3 are 407Mpa this are less than fatigue strength of the gear material. The pitting failure is reduce by increasing the module of the gear selecting from standard table.

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