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SIMULATION AND ANALYSIS OF GEAR FAULTS USING FINITE ELEMENT ANALYSIS SOFTWARE

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ABSTRACT

Gears are a major part of every mechanical system and research methods aimed at gear fault analysis is an important sphere of research. A new direction in research in gear fault analysis can help better the existing trend. ANSYS simulation of gear faults has been rarely followed as a practice of helping to diagnose and analyse gear faults. This paper is purposeful in achieving the said task of using ANSYS.inc software to analyse the effects of various types of gear faults on the gears using finite element analysis.

Keywords: gears, faults, ANSYS, finite element analysis.

INTRODUCTION

Gears are the fundamental building blocks of every mechanical machine which aims to create a mechanical advantage. Their vitality to the industry is indispensible. Fault prognosis of sub systems like gears is a rapidly growing field of research today. In accordance with “Gear Failure Modes-Importance of Lubrication and Mechanics” in 1976 [1], any rational approach to gear design must consider, as a minimum, the impact of the various modes of gear-tooth failure on gear performance; operating life and reliability; and size, weight, and cost. Gear teeth may fail basically by either strength-related or lubrication-related causes.

To understand the various modes of gear failure thoroughly we need to consider the works of Lester E. Alban in “Systematic Analysis of Gear Failures” [2] and Eugene E. Shipley in “Gear Failures” [3]. These works give a complete knowledge base that is required to understand the various gear faults and the cause behind them.

The predominant research done in the prognosis of gear failure has been done through acoustic and vibration techniques. “Early detection of gear failure by vibration analysis i. calculation of the time-frequency distribution” [4] by W.J. Wang *et al*. in 1993 and “Effectiveness and Sensitivity of Vibration Processing Techniques for Local Fault Detection in Gears” [5] by G. Dalpiaz *et al*, in 2000 have shown promising results towards this direction. G. Dalpiaz states that the sensitivity of the demodulation technique is strongly dependent on the proper choice of the filtering band which seems to vary for different types of faults and also its intensity. The methods though promising are complex and require rigorous iteration to get the appropriate filtering band.

With increasing cost and time involved in pursuing these vibration based detection of gear faults, D. Ho *et al*., gave an innovative idea of simulating the vibration on gears where bearing fault vibrations were modelled as a series of impulse responses of a single-degree-of-freedom system and comparing them with actual bearing fault signals in the paper “Optimisation of Bearing Diagnostic Techniques Using Simulated and Actual Bearing Fault Signals” [6].

“Dynamics Modelling for Mechanical Fault Diagnostics and Prognostics” [7] followed a similar approach but by using dynamic modelling technique instead of a vibrational simulation to compare with the experimental analysis and Finite Element methods importance in diagnosis and prognosis has been highlighted by the results of the paper.

It has become increasingly apparent that Dynamics Modelling is the more effective course research must be headed. It is a definite improvement to the existing experimental vibrational analysis techniques which are both time consuming and more expensive. With tremendous improvement in technology we must look to the dynamic modelling and detection of faults rather than depend on the tradition vibrational experiment techniques. Performance of modern engineered systems due to increased design cycle accuracy and testing capabilities will also increase greatly.

EXPERIMENT

Simulation of gears requires the designing of a gear. The foundation of designing a gear lay in its application. Hence we have taken the application of a speed reducer used in the industry. The gear is designed for a 7.5 kW engine running at 1000 rpm. The design calculations were done manually, the results of which are given below.

The data that was assumed based on the application in the industry is shown in Table-1.

Table-1.

Power	7.5 Kw
Speed	1000 rpm
Centre distance (a)	250 mm
Material	50C4 carbon steel
Starting torque	1.5 x rated torque
Pressure angle	20 degrees
Factor of safety	2

From the given conditions, a gear was designed by referring to the values in the Machine Design Data Book by K. Lingaiah. A gear was designed which could easily bear the stresses and work efficiently in application whose parameter are as shown in Table-2.

Table-2.

Module based on beam strength	3.86 mm ≈ 4 mm
Number of teeth	25
Pitch circle diameter	100 mm
Addendum	4 mm
Dedendum	5 mm
Tooth thickness	6.2832 mm
Fillet radius	1.6mm
Velocity of gear	5.236 m/s
Dynamic load	6448.3 N
Effective load	8596.89 N
Actual factor of safety	1.48
Surface hardness	360 BHN

There are several different types of faults that occur in gears of which few of those which commonly occur have been selected for the following research purposes.

Wear is a surface phenomenon in which layers of metal are removed from the contact surface of the gear teeth [2]. It occurs when metal is worn away from the contact areas of the gear teeth in a more or less uniform manner [8]. There are different types of wearing based on severity like Polishing, Moderate wear and Excessive wear.

Pitting is a surface fatigue failure which occurs when the endurance limit of the material is exceeded. A failure of this nature depends on the surface contact stress and the number of stress cycles. The different types are initial pitting, destructive pitting and Spalling [2].

Scoring is a rapid wear resulting from the failure of the oil film due to overheating of the mesh. Produces alternate welding and tearing which removes metal rapidly. The different types are initial, moderate and destructive scoring [2].

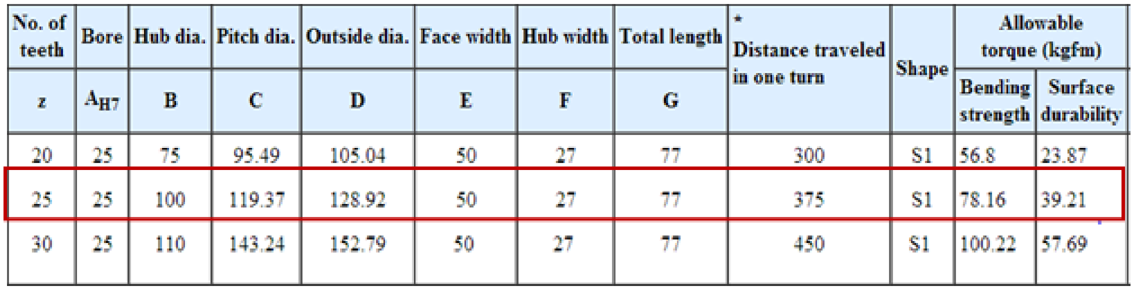
Fracture Failure is caused by the breakage of a whole tooth or a substantial portion of the tooth. It can result from overload, or more commonly, by cyclic stressing of the gear tooth beyond the endurance point [2]. The above have been chosen for testing purposes.

The above gear faults were than emulated on a CAD platform SolidWorks. SolidWorks is solid modelling CAD (computer-aided design) software that runs on Microsoft Windows and is produced by Dassault Systèmes SolidWorks Corp. This software was chosen because of it was functional and easier to design the required faults on.

The faults were designed based on the visually observed gears which contained the respective faults. "Failure Analysis Gears-Shafts-Bearings-Seals" by Rexnord Industries a leading research giant in the gear industry formed the literature basis of our designs [9]. The detailed analysis pinpoints the location and the effect for each of the gear faults we have considered.

The gear of the above dimensions was than verified to exist in the market as shown in Table-3.

Table-3.



No. of teeth	Bore	Hub dia.	Pitch dia.	Outside dia.	Face width	Hub width	Total length	* Distance traveled in one turn	Shape	Allowable torque (kgfm)	
z	A_{H7}	B	C	D	E	F	G			Bending strength	Surface durability
20	25	75	95.49	105.04	50	27	77	300	S1	56.8	23.87
25	25	100	119.37	128.92	50	27	77	375	S1	78.16	39.21
30	25	110	143.24	152.79	50	27	77	450	S1	100.22	57.69

ANSYS, Inc. is engineering simulation software in which the designed gears with faults were imported into to analyse their results under simulated conditions. ANSYS, Inc uses a finite element analysis method to obtain its results. The simulation parameters were taken as per Table-1 and real time conditions. The load was applied on a single tooth of the gear only.

First the control case was checked for deformation and stress distribution and the results obtained were as shown in Figure-1 and Figure-2 respectively.

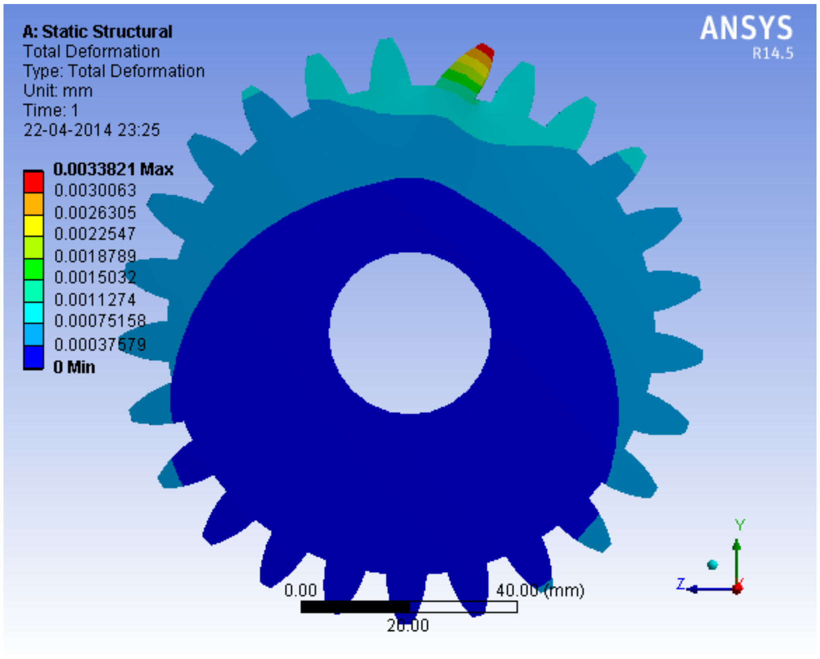


Figure-1.

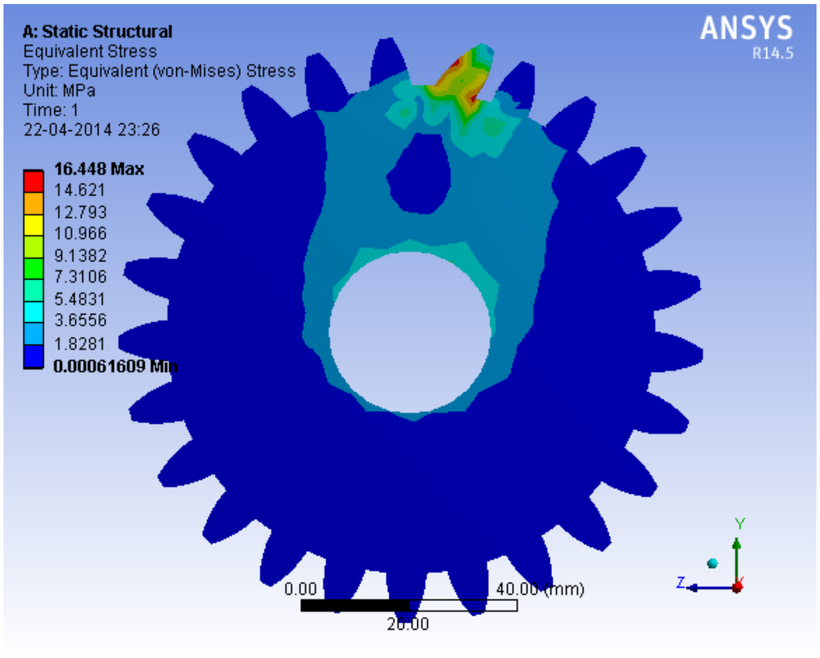


Figure-2.

The above procedure was iterated for the different gears that were designed to emulate the faults as discussed before. The Figures numbered from 3 to 10 show the results of the extreme cases that were considered. Each of the result was tabulated in Table-4.

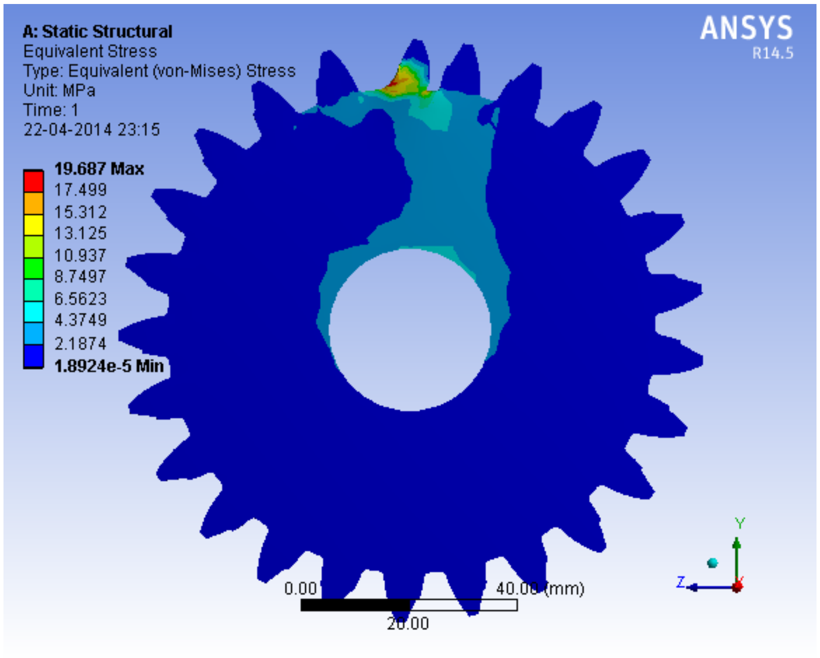


Figure-3. Excessive wear - equivalent stress.

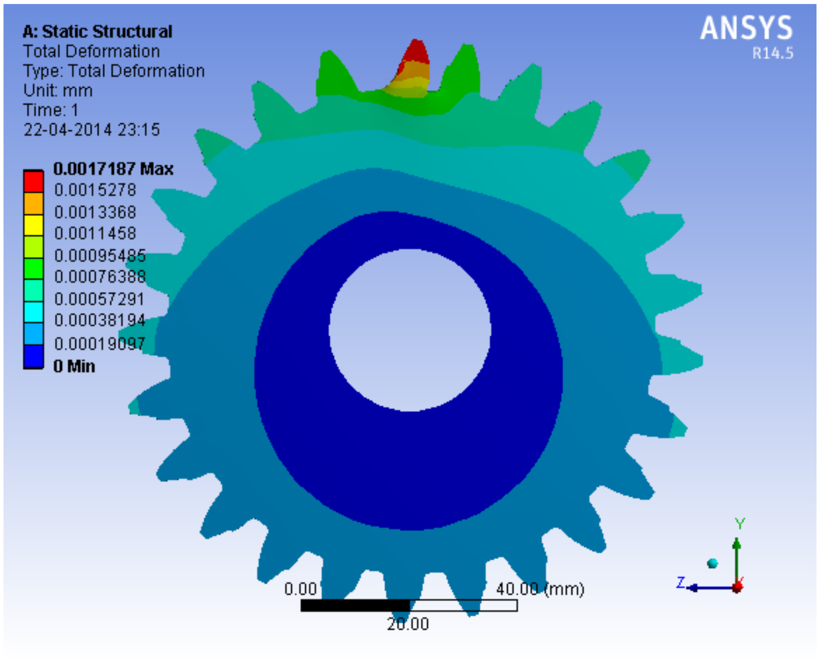


Figure-4. Excessive wear - total deformation.

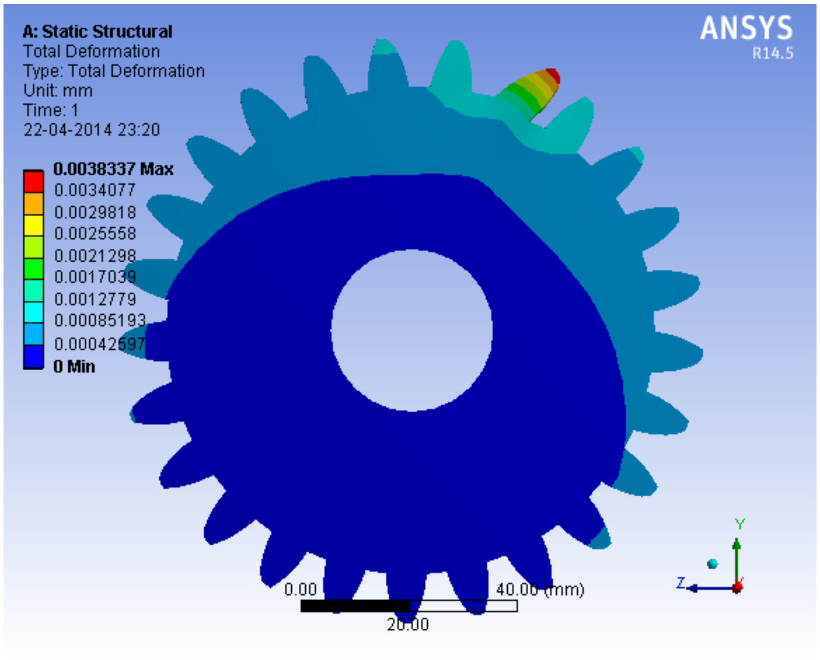


Figure-5. Excessive scoring- total deformation.

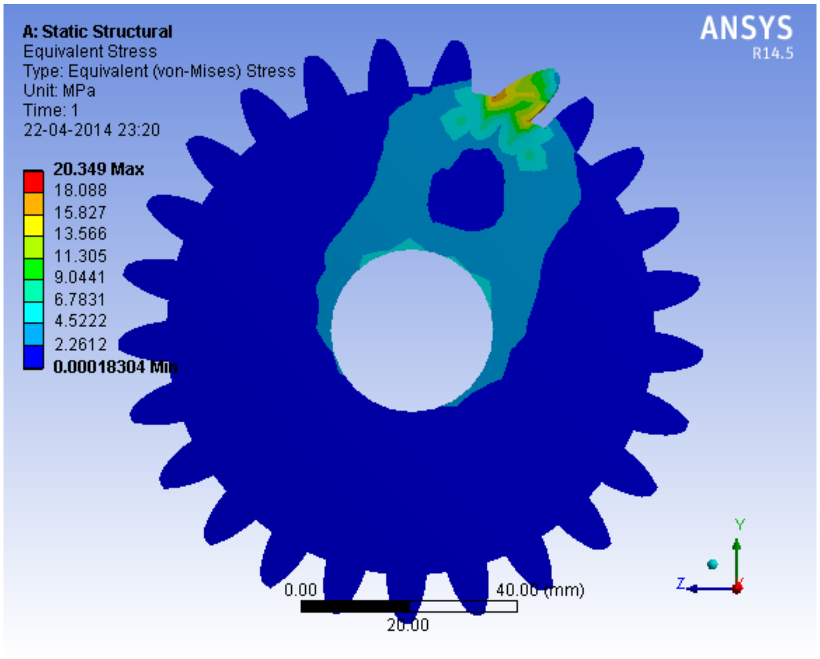


Figure-6. Excessive scoring- equivalent stress.

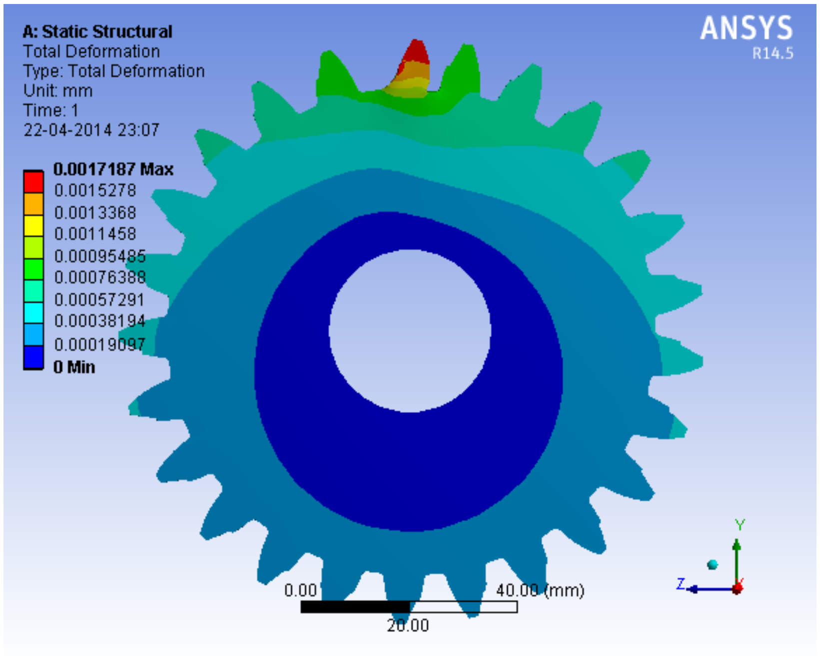


Figure-7. Extreme pitting - total deformation.

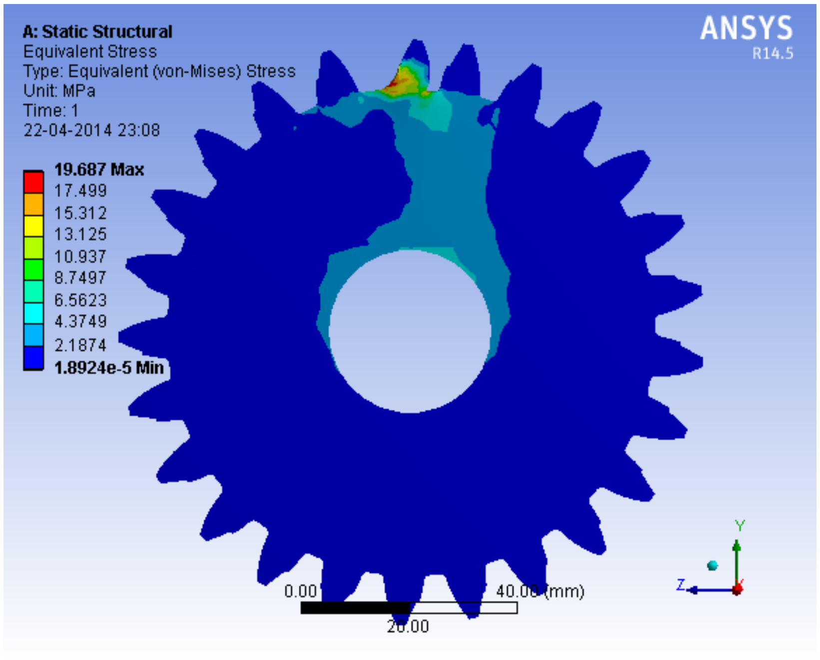


Figure-8. Extreme pitting - equivalent stress.

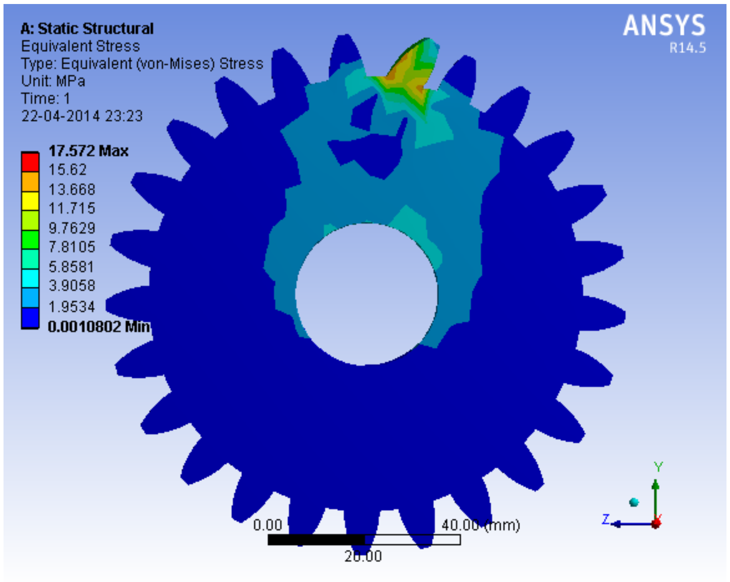


Figure-9. Fracture- equivalent stress.

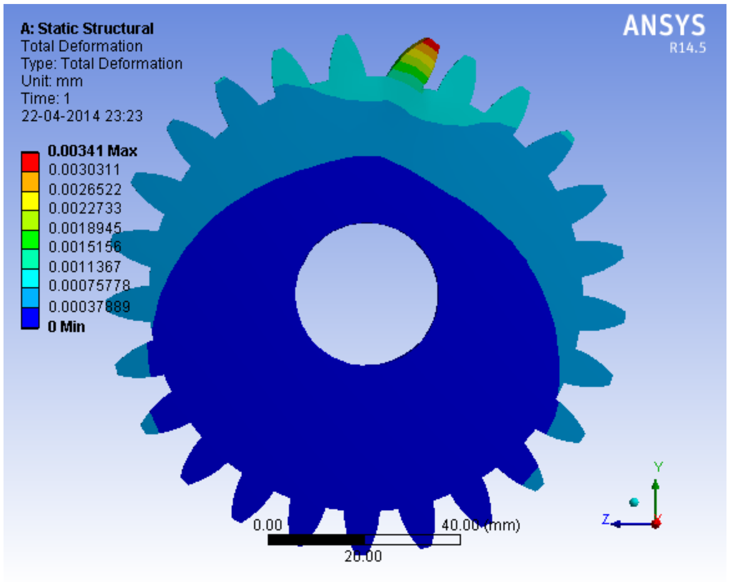


Figure-10. Fracture- total deformation.

Lubrication failure remains one of the major reasons for any of the gear faults discussed; hence simulation of an oil film was necessary to observe the effect of the induced gear faults on the lubricating film. Figures 11 and 12 shows the control case where there is no adverse effect on the lubrication but Figures 13 and 14 show the lubricating film as observed on the faulted gears due to excessive pitting.

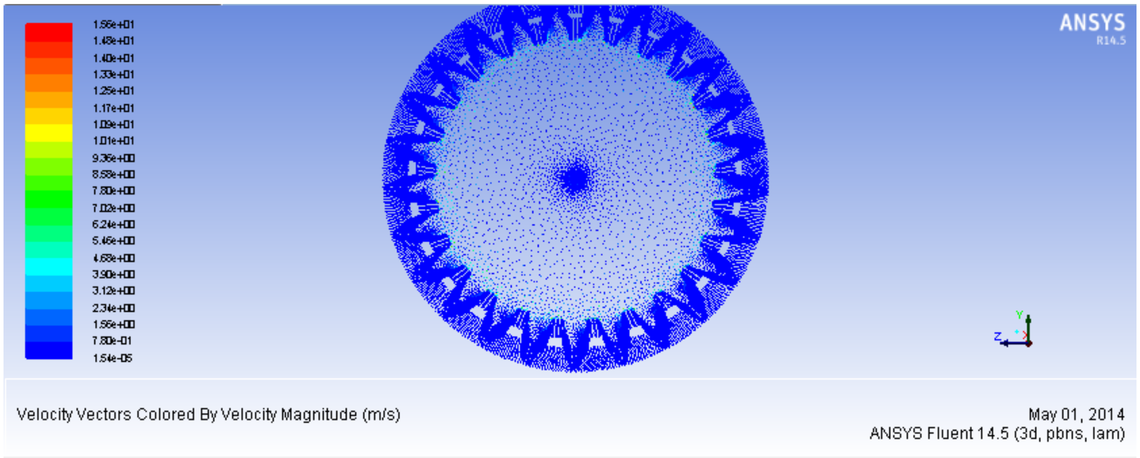


Figure-11. Velocity magnitude.

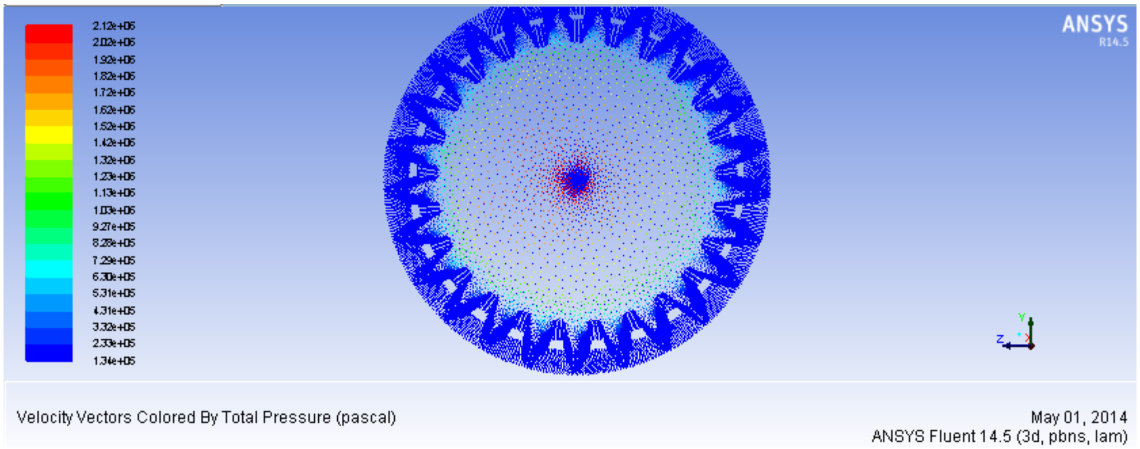


Figure-12. Total pressure.

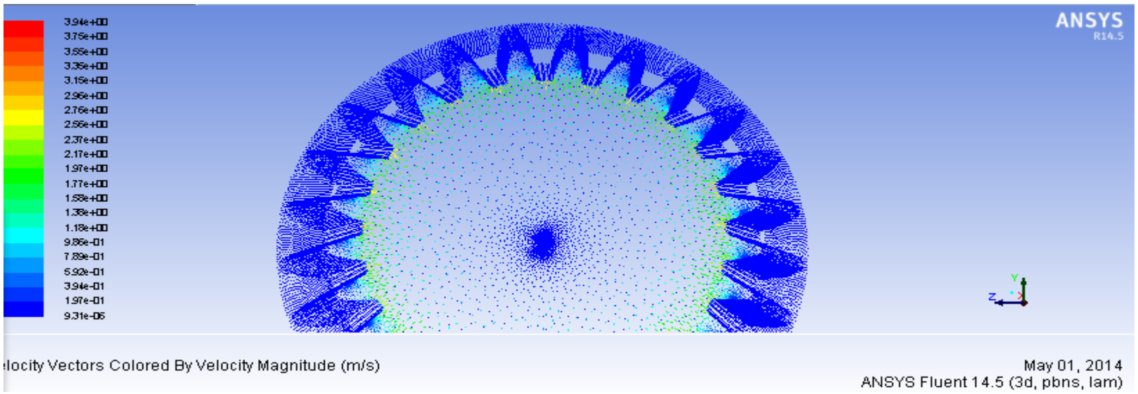


Figure-13. Velocity magnitude excessive pitting.

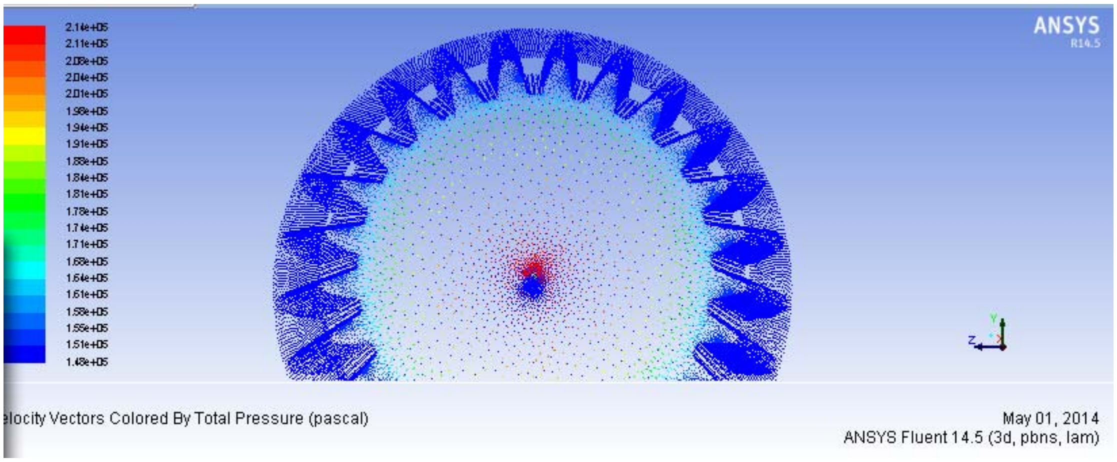


Figure-14. Total pressure excessive pitting.

RESULT AND CONCLUSIONS

Table-4.

Type of Gear fault	Total Deformation(mm)	Equivalent Stress(MPa)	Lubrication pressure(Pa)	lubrication Velocity(m/s)	Pressure variation(Pa)	Velocity Variation (m/s)
Normal Gear	0.0030063	5.8275	1.51E+05	9.40E-02	0	0
Pitting(0.25)	0.0006825	13.675	1.54E+05	1.10E+00	3.00E+03	1.01E+00
Pitting(0.5)	0.0030395	14.575	1.56E+05	1.13E+00	5.00E+03	1.04E+00
Pitting(0.1)	0.003151	54.875	1.64E+05	1.33E+00	1.30E+04	1.24E+00
Moderate wear	0.001348	11.01	3.15E+05	2.37E+00	1.64E+05	2.28E+00
Excessive wear	0.0016176	16.678	3.65E+05	3.12E+00	2.14E+05	3.03E+00
Extreme wear	0.0026522	15.62	3.75E+05	3.40E+00	2.24E+05	3.31E+00
Initial scoring	2.65E-03	13.61	4.46E+05	2.73E+00	2.95E+05	2.64E+00
Modeate scoring	2.89E-03	13.57	4.38E+05	2.53E+00	2.87E+05	2.44E+00
Extreme scoring	2.98E-03	15.879	4.64E+05	3.05E+00	3.13E+05	2.96E+00
tooth fracture centre 2	0.002435	9.7789	2.24E+05	1.34E+00	7.30E+04	1.25E+00
tooth fracture centre 2.5	0.002655	13.668	2.57E+05	2.01E+00	1.06E+05	1.92E+00
tooth fracture centre 5	0.002759	14.132	2.88E+05	2.57E+00	1.37E+05	2.48E+00

It was found as shown in Figure-15 that the equivalent stress induced was found to be maximum in the cases of pitting followed by scoring, wearing, tooth fracture and then finally the control case which has the least equivalent stress as expected. But for deformation the trend observed was contrary to what should have been expected leaving us to believe the large scope that can be tapped by such simulations. As shown in Figure-16 it was observe that though pitting offered the maximum deformation it was followed by the control case gear. This shows that wearing and scoring and tooth fracture in effect do not cause more deformation than the control case as expected. This can be attributed to the fact that less area was exposed to the tooth surface that resulting in lesser deformation.

It was also observed as shown in Figure-17 that initial pitting offered the least amount of deformation in the early stages of pitting when compared to the early stages of the other faults but offered the maximum in the extreme stages. This conformed to the real time situation where early pitting is often ignored as innocuous.

The other faults showed more or less a gradual increase in deformation across the stages with the exception of wear fault which showed a slight sharp increase in deformation in the final stages of the fault.

In the case of equivalent stress in Figure-18 again pitting showed a steep increase in the extreme stages to give the maximum stress while the rest of the faults showed comparatively gradual change.

Though it was observed that initial scoring resulted in a higher maximum stress than that was seen in wearing in the moderate stages this trend was reversed. In the final stages both the faults have almost the same stress. This leads us to conclude that the stress induced by both these faults in the final stages is equally pernicious.

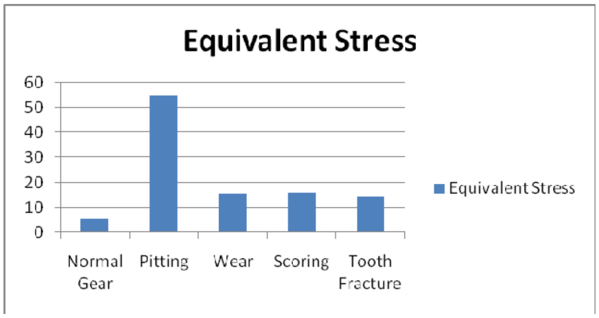


Figure-15. Equivalent stress in the extreme cases of faults.

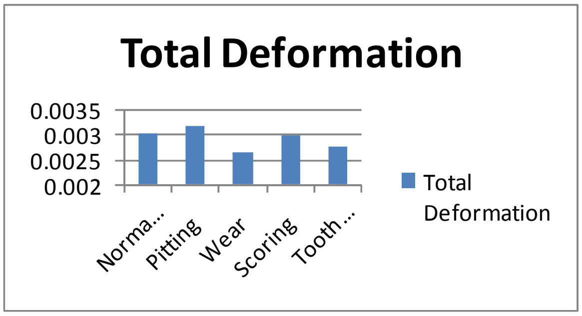


Figure-16. Total deformation in extreme cases of gear faults.

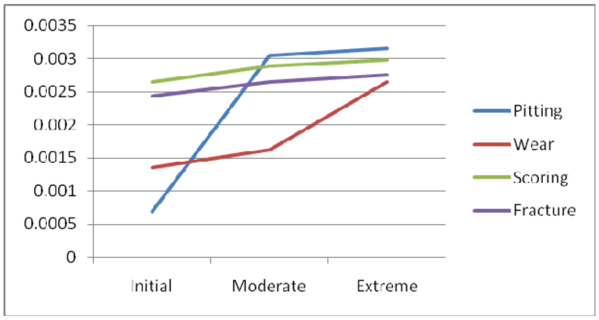


Figure-17. Total deformation at different stages of the fault.

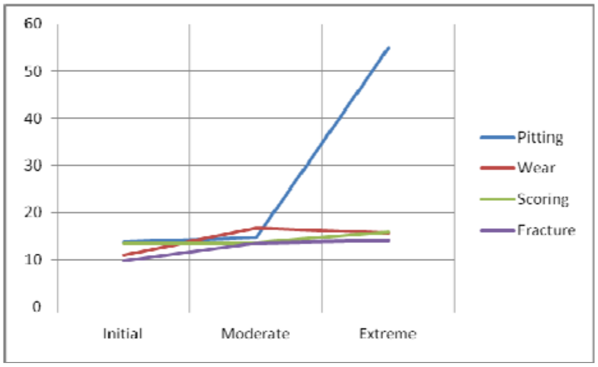


Figure-18. Equivalent stresses at different stages of the fault.

To conclude extreme pitting was found to be the most harmful of all faults. The usage ANSYS.inc to simulate and analyse gear faults by finite element method shows promising results.

From the above conclusions we can understand the scope of such a direction in research which is both cost effective and faster. Industry changing work can be done through this method whose results can be verified in the industry to give us a new and improved direction in fault diagnostic and prognostic methods not only in gears but in other fields of research too.

REFERENCES

[1] P. M. Ku. 1976. Gear Failure Modes-Importance of Lubrication and Mechanics. ASLE Transactions. 19(3): 239-249.

[2] Lester E. Alban. 1985. Systematic Analysis of Gear Failures. ASM International.

[3] Eugene E. Shipley Manger-Mechanical Transmissions. Mechanical Technology Inc. Latham, N.Y. Gear Failures. XTEK Inc., 11451 Reading Road Cincinnati, Ohio 45241.

[4] Wang W J and McFadden. 1993. Early Detection of Gear Failure by Vibration Analysis-I. Calculation of the Time Frequency Distribution. Mechanical Systems and Signal Processing. 7(3): 193-203.

[5] G Dalpiaz A Rivola and R Rubini. 2000. Effectiveness and sensitivity of vibration processing techniques for local fault detection in gears; Mechanical Systems and Signal Processing. 14(3): 387-412.

[6] D. Ho and R.B. Randall. 2000. Optimisation of Bearing Diagnostic Techniques Using Simulated and Actual Bearing Fault Signals; Mechanical Systems and Signal Processing. 14(5): 763-788.

[7] Colin D. Begg, Terri Merdes, Carl Byington and Ken Maynard. 1999. Dynamics Modeling for Mechanical Fault Diagnostics and Prognostics; Maintenance and Reliability Conference (MARCON 99), Gatlinburg, Tennessee.

[8] Gary DeLange. 2000. Failure Analysis for Gearing; Prager Inc., a Rexnord Geared Products Co., 472 Howard Ave., New Orleans, LA. 70130; (504):524-2363.

[9] 1978. Failure Analysis Geards-Shafts-Bearings-Seals; Rexnord Industries, LLC, Gear Group 3001 W. Canal St., Milwaukee, WI 53208-4200.