Design, Modelling and Analysis of Helical Gear Pair using ANSYS and AGMA Standards for Calculating a Bending and Contact Stress on Gear Profiles.

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Abstract

Gear failure can be controlled by their tooth surface strength; the bending effects and wear effect are major parameters, affected in any gear system to minimize or reduce the failure. In this paper aims to provide information on the bending and contact stress analysis of helical gear pair with used of two steel materials. Thus, the analysis of stress, bending effects and contact effects to minimize or reduce the failure of gears. Therefore, paper focuses on the theoretical and finite element method to calculate bending and contact (Root and Flank safety) stresses on the tooth geometry of major effected parameters on helical gear pair. Authors have to use the various approaches to calculate the wear and bending effects of gear failure cause in static condition using finite element analysis, AGMA standard and ANSYS. A helical gear has to checked their root and flank safety by calculating their strength to followed by the Lewis's equation to check by manually, and KISSSOFT SOFTWARE have to calculated strength of any type of gear system. This paper contains theoretical, numerical and analytical methods for the helical gear pair analysis.

Keywords *Helical gear pair, AGMA, ANSYS, contact stress, bending stress, bending strength, surface fatigue strength, tooth surface strength of gear*

1.1 Introduction

Gears are needful to the modern global economy and are used in almost all applications where power transmission is required, such as industrial equipment, automobile industry, marine vessels, aerospace industry, aircraft industry, automotive industry and other industries. Gears with involute teeth are widely used in industry because of the low cost of manufacturing. For transmitting power and motion from one shaft to another shaft, gears are used. Gears are mostly used to transmit torque and angular velocity.

Helical apparatus are vital parts for any transmission (Figure 1). In present times, helical gears are being utilized as a power transmitting gears because of their moderately smooth and quiet Operation, huge load conveying limit and higher working velocity and smoother engagement of teeth; power can be exchanged between two non-parallel shafts, they are highly effective and so on. Their tooth twisting anxiety and surface contact push had dependably been one of the explorations engaged, and numerous researchers have done a considerable measure of work on it. The tooth bending stress and surface contact stress of these gears had always been one of the major areas of research for scholars. The designing of a helical gear pair is a complex process. Generally, it needs a large number of iterations and datasets. Helical gear can fail due to excessive bending stress at root of gear tooth or surface contact stress. This can be changed by minimizing bending stress and contact stress or by modifying the geometry or parameters of the gear tooth.

The large helix angle provides a smoother operation than the spur gears to these helical gears as it increases the length of the contact lines. But the stresses occur when the two gears come in contact during the process of power transmission. Due to meshing between two gears, contact stresses are evolved, which is calculated by using ANSYS, software used for this kind of analysis.

Fig. 1: Helical Gear pair.

1.2 Literature review

Gear analysis is one of the most significant issues in the machine elements theory particularly in the field of gear design and gear manufacturing. Many of the researchers have proposed several concepts for gear design optimization to enhance the performance of gear systems. **S. Jyothirmai, et.al., [1]** mentioned **"A Finite Element Approach to Bending, Contact and Fatigue Stress Distribution in Helical Gear Systems"** objective of paper is comparative study on helical gear design and its performance based on various performance metrics through the finite element analysis and Theoretical analysis by AGMA standard. Than after FEA & theoretical results compared to each other. **J. Venkatesh, et.al., [2]** mentioned **"Design and Structural Analysis of High Speed Helical Gear Using Ansys"** also started the methods that used to calculating the Bending and Contact stresses of involute helical gear pair. And model is generated a then helical gear pair to find out their ANSYS and AGMA calculation and results are compare to each other. **A. Sathyanarayana Achari, et.al., [3] "A Comparison of Bending Stress and Contact Stress of a Helical Gear as Calculated by AGMA Standards and FEA"** To estimate the bending stress at the tooth root Lewis beam strength method was used. NX CAD 8.5 modeling software package is used to create the 3D solid model of helical gear pairs. NX Nastran 8.5 software package is used to analyze the gear tooth root bending stress. Contact stresses are calculated by AGMA standards. NX Nastran 8.5 software package is used to analyze the surface contact stress. Ultimately, these two methods, tooth root bending stress and contact stress results are compared with each other. **Juha hedlund, et.al., [4] "Modeling of helical gear contact with tooth deflection"** focuses on the modeling of helical gear contact with tooth deflection detailed friction, wear and life studies. A calculation model for helical gear contact analysis for constructed of tool geometry by simulating the hobbing process. **K. Mao [5]** mentioned a **"Gear tooth contact analysis and its application in the reduction of fatigue wear"** A wear is produced by the shaft misalignment and assembly deflection effects on gear surface. The tooth profile will be generated mathematically though using the finite element analysis (FEA) software instead of importing from other computer aided design (CAD) software in order to achieve high accuracy of the gear pair. Real rolling and sliding contact simulations have been achieved by the use of latest non-linear FEA techniques. The solution for the wear is consequently proposed based on gear micro-geometry modification approach, i.e. tip relief, face width crowning and lead correction. **B. venkatesh, et.al., [6]** the author mentored that in this paper **"Investigate the combined effect of gear ratio, Helix angle face width and module on bending and compressive stress of steel alloy helical gear"** the work is to focus on investigating the combined effect of gear ratio, helix angle, face width and normal module on bending and compressive stress of high speed helical gear pair. **Kailash Bhosale [7]** had done the **"Analysis of bending strength of helical gear by FEM"** In this work bending strength of helical gear is found out with the help of three dimensional photo elasticity. A solid modeling is done with CATIA and then by using the hyper mesh meshing is done. Analysis is done with Ansys Workbench 12.1. The theoretically bending equation calculated by the used of Lewi's equations to calculated a one pair of helical gear. Both results are compare to each other.

All of the above works have attempted to enhance effectiveness of gear systems through weight reduction, wear reduction, vibration and noise reduction. Studies have also been performed mostly using involute and asymmetric gear tooth profiles. In addition, most of these works have estimated tooth bending stress and contact stress. The estimation of allowable surface fatigue stress, contact stress, surface fatigue strength, tooth surface strength of gear and pinion and permissible bending stress have not received much attention. The performance of alternative tooth profiles such as circular and cycloidal, generally not in use on account of manufacturing difficulties or reduced strength at root, have also not received much attention.

1.3 Input parameters

This input parameter has to use to generated a helical gear pair with used of solid work software.

Nomenclature	Notation	Equation	pinions	wheel
Helix angle	β	8 to 25 degree	15deg R.H	15deg L.H
Normal module	m_n	$m_n = 2a \cos\beta/Z_1 + Z_2$	1.25	
Center distance	a	$a = m_n Z_1 + Z_2 / 2 \cos\beta$	50	
Transverse module	m_t	$m_t = 2a / Z_1 + Z_2$ or $m_n / \cos\beta$	1.2970	
Bottom clearance	c	$C=0.25\ m_n$	0.3125	
Tooth depth	h	$h= 2.25\ m_n$	2.8125	
Pitch circle diameter	d	$d_1 = m_n Z_1 /\cos\beta$, $d_2 = m_n Z_1 /\cos\beta$,	38.82	60.82
Number of teeth	Z_1 Z_2	$Z_1 = 2a \cos\beta /m_n (i+1)$, $Z_2 = i\ Z_1$ $(i=Z_2 /Z_1)$	30	47
Width	b	-	22	14
Pressure angle	Φ		20deg	
Power	P	-	0.25Kw to 2.2 Kw	
Speed	N	n_1, n_2	1370	874.47

Table-1 Input

1.4 Strength compression of Gear material by KISSSOFT software

In existing helical gear design are 16MnCr5 nitride case2 this design has to lower strength over the 20MnCr5 of helical gear due to analysis of the power transmission rating table show in below. The table has known that a helical gear has to two materials are strength wises compression of 20Mncr5 and 16Mncr5 the calculated a material bending and wear safety factor.

Strength calculation by factor of safety								
Power (KW)	**Speed (RPM)**	**Torque (Nm)**	**KISSSOFT Calculation**				**Manually calculation (20Mncr5)**	
			20MnCr5		**16MnCr5**			
			bend	**wear**	**bend**	**wear**	**bend**	**wear**
0.25	**1370**	1.7426	**22.0405**	**6.0258**	16.4022	4.0172	**22.64**	**8.7731**
2.2	**1430**	14.6912	**2.6094**	**2.0721**	1.9419	1.3814	**2.726**	**1.0564**

Table -2 strength wises compression of KISSSOFT & Analytically of gear material

1.5 Modeling of helical gear systems Using solid work software to followed procedure

Set as geometric parameter

↓

Define number of teeth, diametral pitch, pressure angle, face width, helix angle, Helix handing, Addendum, dedendum size, Correction factor, Teeth thickness

↓

Create the basic geometry such as addendum, dedendum and pitch circles in support of the gear teeth

↓

Define the involute tooth profile with datum curve by equation using cylindrical coordinate system

↓

Create the teeth solid feature with a cut and extusion. additional helical datum curves are also required in this step to sweep helical gear teeth

↓

Pattern the teeth around the center line axis.

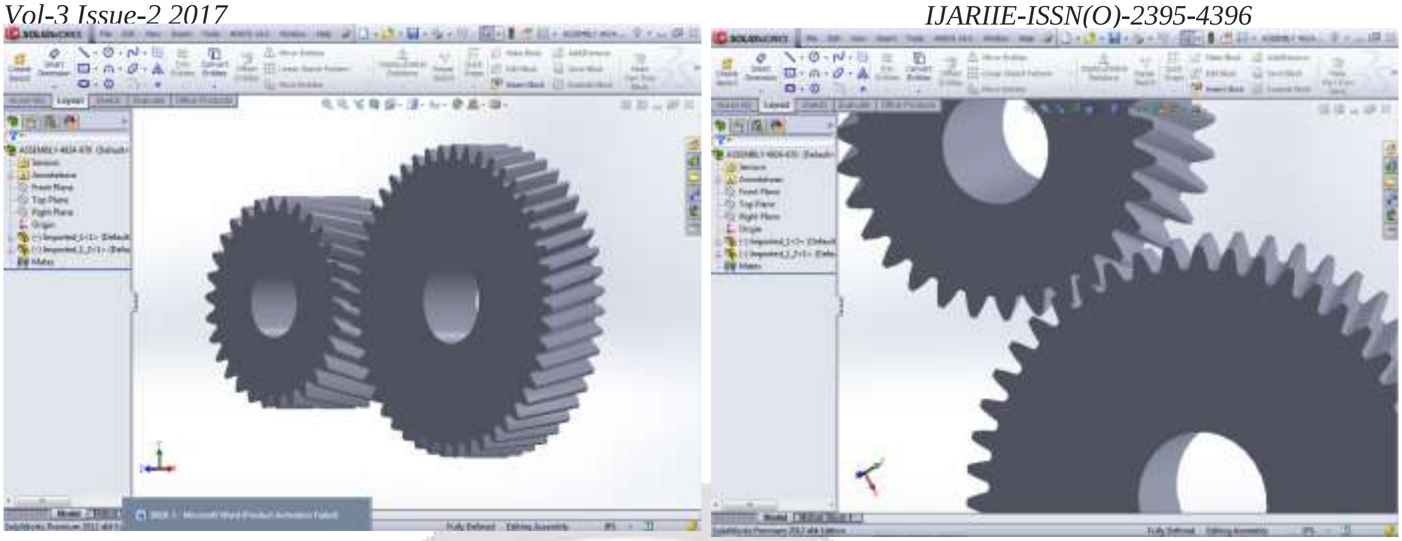

Fig-2 Solid model of Helical gear pair (meshed condition) generated by Solid work software

1.6 Finite element analysis of helical gears pair and their procedure

ANSYS is an engineering simulation software which offers an entire range of multi-physics numerical solvers, providing access to virtually any field of engineering simulation that a design process may require. There is different type of analysis system in the ANSYS WORKBENCH like Fluid flow, linear buckling, rigid dynamics, explicit dynamic, static structural, thermal-electric and etc. for the static structural analysis uses FEA tool for product design validation. Computational analysis methodology that helps to determine the strength of a product (one part or both in pair) in response to loading that would typically be experienced in its operating environment. ANSYS static structural provide the ability to simulate every structural aspect of the product like linear static analysis that simply provides stresses or deformations.

The geometry of the gear to be analyzed is imported from solid modeler (STEP file) format this is compatible with the ANSYS.

↓

The element type and materials properties such as Young's modulus and Poisson's ratio are specified.

↓

Meshing the three-dimensional gear model. Figure 4.2 shows the meshed 3D solid model of gear.

↓

The boundary conditions and external loads and moments are applied.

↓

The solution is generated based on the previous input parameters.

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Finally, the solution is viewed in a von-misses stress, deformation, tool life by used fatigu tool, contact tool find stress and shear stress.

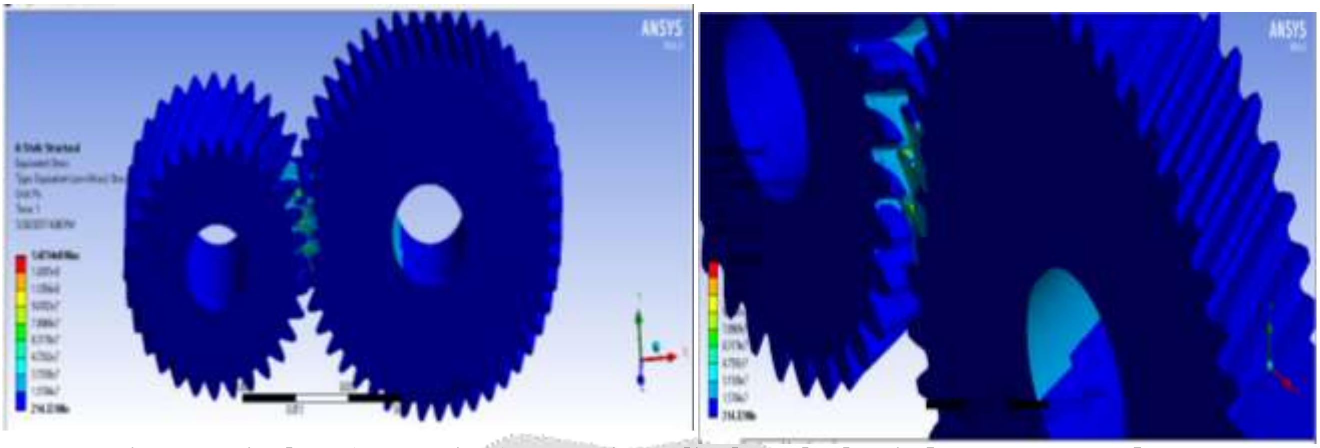

Fig-3 Equivalent (Von-Mises) Stress in Helical meshed pair [Contact Stress]

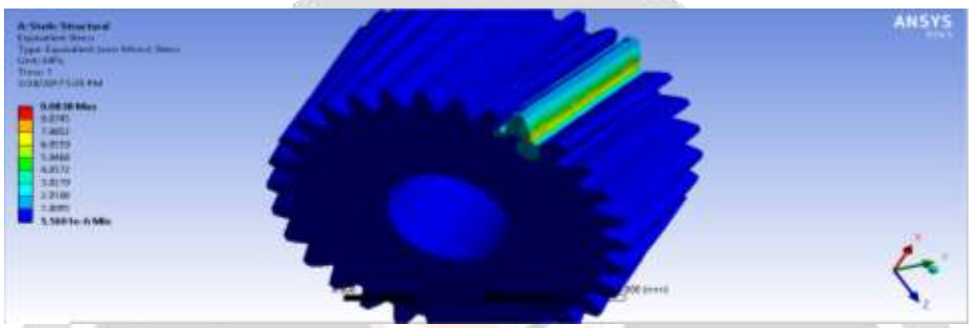

Fig-4 Equivalent (Von-Mises) Stress in Helical gear [stress of pinion]

1.7 Results of Involute Gear Tooth Bending and Contact Stress Analysis by AGMA and ANSYS

To verify the result of bending and contact analysis obtained from ANSYS it is compared with the value calculated from AGMA formula. The maximum difference between these two outcomes is very small, therefore the developed FEA models are good enough for the stress analysis.

Number of Teeth	σAGMA (MPa)	σANSYS (MPa)	Total Deformation (m)
14	14.42	12.854	$2.41x10^{-7}$
16	12.82	11.594	$2.51x10^{-7}$
28	10.97	7.9822	$2.65x10^{-7}$
30	10.49	9.0838	$2.14x10^{-7}$

Table-3 Bending stress calculation for AGMA and ANSYS Power(0.25KW) life ($1x10^6$)

Helix angle (Degree)	σAGMA (MPa)	σANSYS (MPa)	$\tau_{Max\ shear}$ (MPa)	Total Deformation (m)	Equivalent Strain (m/m)	Safety Factor (Min/Max)
14^0	137.1893	130.08	67.089	$5.9x10^{-6}$	$6.71x10^{-4}$	0.69/15
15^0	142.00	142.14	81.85	$5.02x10^{-6}$	$6.8791x10^{-4}$	0.692/15

Table-4 Contact Stress calculation for AGMA and ANSYS Power (0.25KW)

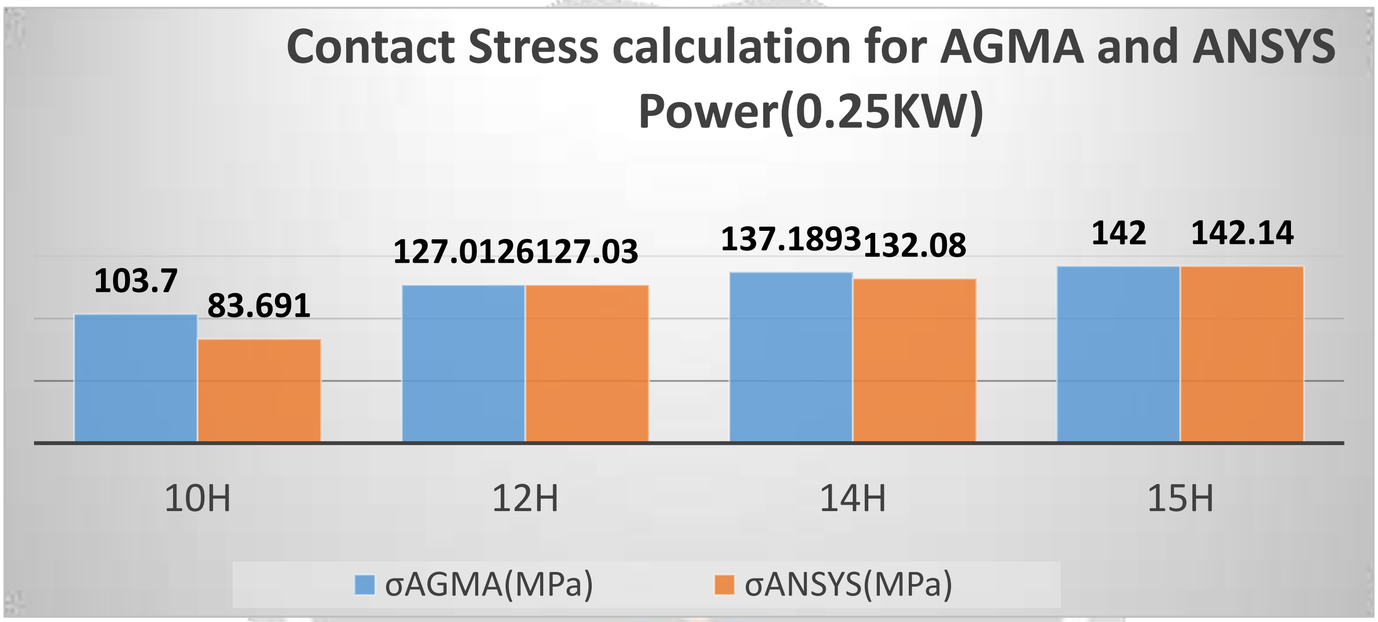

Fig-5 Contact stress results are compared with ANSYS and AGMA.

1.8 To Enhance power transmission rating (0.25KW to 2.2KW).

To calculation of bending and contact stress for previous chapter to 0.25 Kw power of motor. Results to find the MAX/MIN of stress of helical gear. In this section to calculated a bending stress and contact stress of power rating are **0.25Kw to 2.2 Kw** (**range of p-series of helical gear box for depends on safety factor)** show in the table-5.5 bending stress calculation of pinion Z-30, helix angle-15degree with the range of speed and tangential force compeered results of AGMA and ANSYS. And table-5.6 contact stress calculation of pinion Z-30, helix angle-15degree with the range of speed and tangential force compeered results of AGMA and ANSYS.

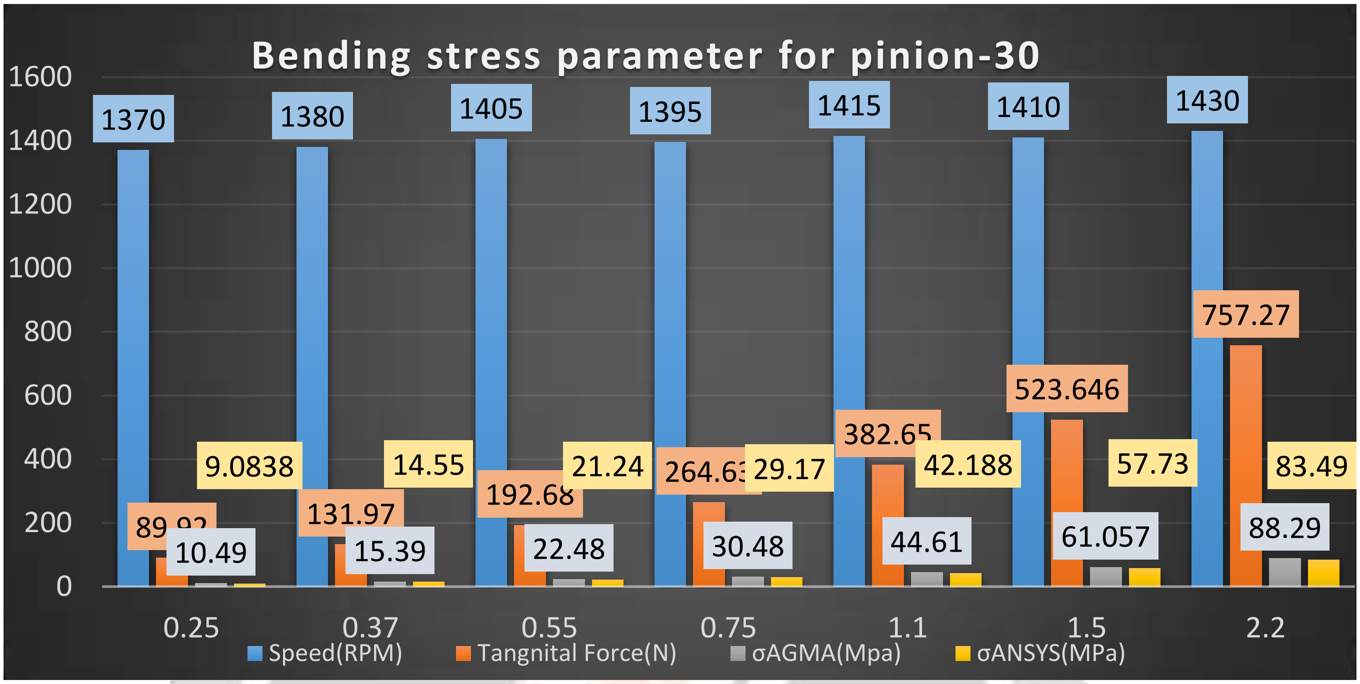

Fig-6 Bending results are compared with ANSYS and AGMA Power rating calculation.

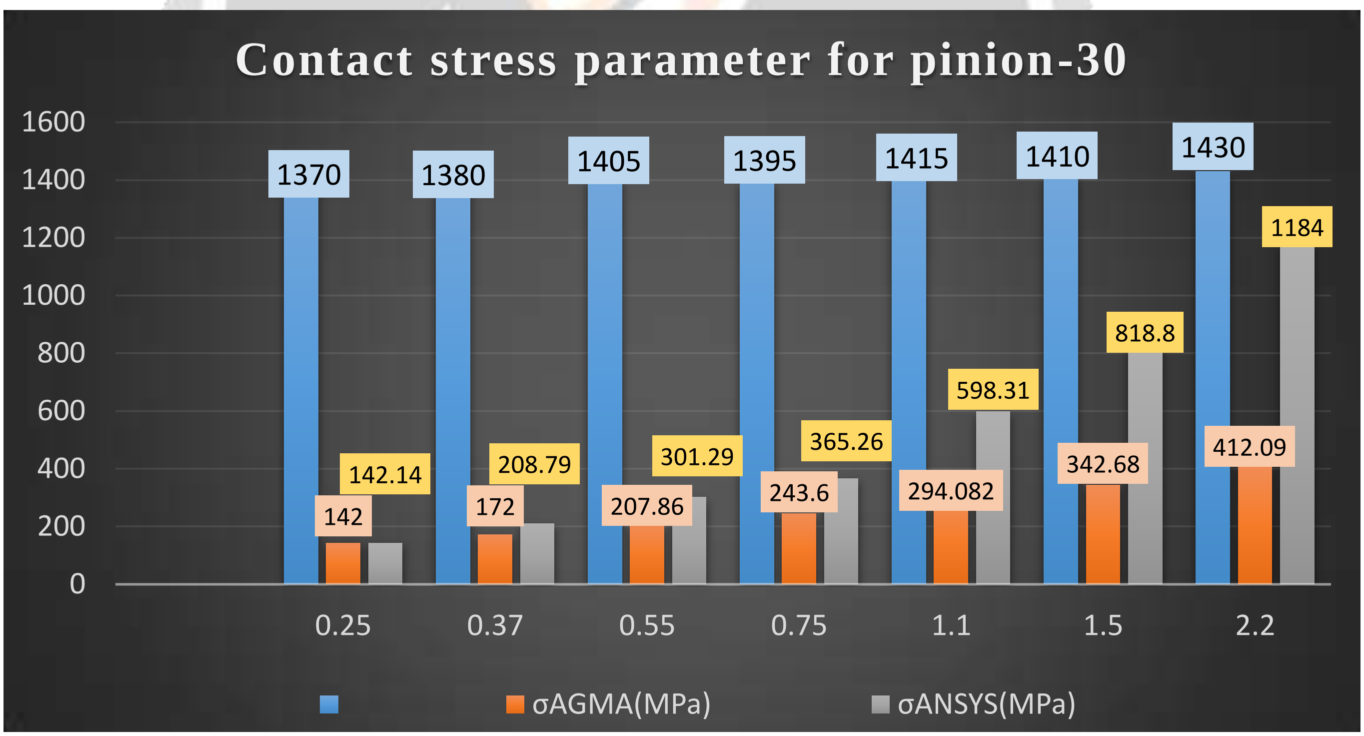

Fig-7 Contact stress results are compared with ANSYS and AGMA Power rating calculation.

1.9 Conclusion

In this paper, an attempt has been made to compare the performance of various helical gear systems for a given set of specification through an analytical approach based on AGMA standards as well as a finite element analysis approach. A helical gear systems namely single were evaluated. The developed FEA model was validated against the analytical approach and was found to be very close. Further stress analysis was carried out using FEA. It was found that the overall performance of helical gear pair depended on the parameters was found to be the best in terms of stress as well as tooth strength at low speeds and low loads. And final to calculated an enhancement power for small speed gear box for this small pair helical gear system. The concluded that the increased an efficiency of helical gear pair by enhancing to power transmission capacity and life will be increasing by calculated to bend and contact stress and their strength.

1.10 References

[1]. S. Jyothirmai, R. Ramesh, T. Swarnalatha, D. Renuka, "A Finite Element Approach to Bending, Contact and Fatigue Stress Distribution in Helical Gear Systems", 3rd International Conference on Materials Processing and Characterization, (ICMPC 2014). Procedia Materials science 6 (2014) 907-918 Contents Science Direct Elsevier

[2]. J. Venkatesh, Mr.P.B.G.S.N Murthy,"Design and Structural Analysis of High Speed Helical Gear Using Ansys",Int. Journal of Engineering Research and Application, Vol.4 ,Issue 3(Version 2),pp.01-05(2014)

[3].A.Sathyanarayana Achari, R.P.Chaitanya, Srinivas Prabhu "A Comparison of Bending Stress and Contact Stress of a Helical Gear as Calculated by AGMA Standards and FEA" (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 5, May 2014)

[4]. Juha hedlund, Arto Letovaara **"**Modeling of helical gear contact with tooth deflection" on journal science direct tribology international 40(2007)613-619

[5]. K. Mao "Gear tooth contact analysis and its application in the reduction of fatigue wear" 262 (2007) 1281–128

[6].B.venkatesh, S.V prabhakar Vattikuti, S.Deva Prasad "Investigate the combined effect of gear ratio, Helix angle face width and module on bending and compressive stress of steel alloy helical gear"material science 6(2014)

[7] Kailash Bhosale, "Analysis of bending strength of helical gear by FEM" ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online) Vol 2, No 4, 2011

[8] Shigley, J.E., and Mischke, C.R., Standard Handbook of Machine Design, McGraw-Hill, USA, 1996.

[9] Norton, R.L., Machine Design: An Integrated Approach, New Jersey: prentice- Hall Inc. 1996.

[10] Handbook-of-Gear-Design-G-Maitra-1

[11] Machine design- V B Bhandari

[12] Design of mechanical element: Nisbett Shigley's (mechanical engineering

[13] Design 8th edition, McGraw-Hill)