ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 10, October 2014

Comparative Analysis for Bending and Contact Stresses of Girth Gear By Using AGMA Standard& Finite Element Analysis

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ABSTRACT:Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. Traditionally, gears are designed using AGMA (American Gear Manufacturers Association) or ISO (International Organization for Standardization) standards and followed by manufacturing. FEA has beena useful tool in recent days not only to validate design; it can also use to optimize design. The present work is aimedat analytical designof girth gear byusing AGMA standard. Bending & contact stresses on the gear teeth are calculated.The validation of thestresses is done by usingANSYSsoftware. The values of the bending stress and contact stress determined using AGMA found to be in agreement with ANSYS results and corresponding error observed is less than 5%.

KEYWORDS:Bending stress, contact stress, Girth gear, AGMA, FEA.

I. INTRODUCTION

Girth gears are large ring gears which are normally fitted to the outside of the mills or kilns to provide the primary rotational drive. Girth gears are considered to be one of the most important components in the entire gear drive assembly of such mills. For designing Girth Gears and pinions, today several standards are available.The most common and popular standards are AGMA 6004, AGMA 2101and ISO 6336. The two things that form the test of the gear design are surface durability (pitting) and tooth bending strength. Girth gears can be manufactured in 2, 3, 4, 5, 6 or 8 or more segments and for both T and Y section gears. A girth gear can be single or double pinion driven. A pinion is manufactured as a single part with an integrated shaft. The pinion can also be separate and mounted on a separate shaft, supported by bearings. The girth gear drive system is a "lifeline" for cement producers. With the increased emphasis on operating efficiency, the dependable and reliable operation of these drive systems is essential. No one needs the cost or headaches associated with unscheduled downtime or inefficient machinery operation [1].

There isa great deal of research on gear design and analysis. The design data required for gear design has been widely available from many textbooks and journals for nearly three decades. Dudley [2], Buckingham [3], Merritt [4], and Tuplin [5] have spent enormous effort in detail the procedure involved in the design of gears. Kasuba [6] determined dynamic load factors for gears that were heavily loaded based on one and two degrees of freedom models.

AGMA based or ISO based calculation method of gear strength is commonly used. None of these authors have givenany importance to a computer-aided approach.

Computer-aided design became important in late 70's. Parametric model of gears using commercial CAD tools reduces repetitive gear modeling efforts drastically [7-9]. Errichello [10] and Ozguven and Houser [11] discussed on the development of a variety of simulation models for both static and dynamic analysis of different types of gears. Vijayarangan and Ganesan [12] studied static contact stress analysis, including the effect of friction between the mating gear teeth. Kelenz [13] investigated a spur gear set using FEM in which contact stresses were examined using a two dimensional FEM model. In this paper, bending and contact stress analysis of girth gear using AGMA standard is discussed. The stresses are also verified by using ANSYS software. Comparison of stresses calculated by AGMA standard & ANSYSis also presented.

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II MATERIAL & METHOD

❖ **Material:-**

In this paper, a pair of girth gear & pinion (used for cement mill application) is selected for analysis.
Specification of girth gear& pinionis as follows:

- No. of teeth on pinion, T_P=27
- No of teeth on gear, T_G= 202
- Face width of gear, b=750mm
- Center distance, C=3480 mm
- Module, m= 30
- Mill speed, N_G= 17.1 RPM
- Backlash = 2.2 to 2.5
- Power = 2200 KW

Material used for girth gear is high strength cast steelGr.2 CS 700 which is equivalent to IS: 2644 Gr.2& for pinion is case hardened steel 18CrNiMo6. Mechanical properties of the material for gear & pinion are given in table no. 1.

Table 1: Mechanical properties of gear & pinion

Type of Gear			Girth Gear	Pinion
Sr. No.	**Material Property**	**Unit**	**Cast Steel**	**Case Hardened Steel**
1	Tensile Strength	MPa	700	1160
2	Yield Strength	MPa	580	950
3	Elongation	%	14	15
4	Brinell Hardness	HB	207	340
5	Charpy/Izode	J	25	51

❖ **Methodology:-**

A pair of gear teeth is subject 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 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. In general, gear analysis is multidisciplinary, including calculations related to the tooth stresses and to tribological failures such as wear or scoring.
In the present study, bending & contact stress analysis of Girth gear was carried out through following three steps.

1) Theoretical calculation of bending & contact stresses by the analytical method(AGMA standard)

The tooth load carrying capacity was calculated according to the AGMA standard. According to AGMA,the bending failure is avoided by considering the beam strength and the pitting failure (contact stress) is avoided by considering the wear strength. Gear design will be safe if Eq. 1 and 2 are satisfied.

Bending strength criteria: $\boldsymbol{\sigma} \leq \boldsymbol{\sigma}_{all}$ (1)

Pitting strength criteria: $\boldsymbol{\sigma}_c \leq \boldsymbol{\sigma}_{c\ all}$ (2)

Where

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

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$$\sigma = W^t K_o K_v K_s \frac{1}{b\,m}\frac{K_H K_B}{Y_J} \quad (3)$$

$$\sigma_c = Z_E \sqrt{W^t K_o K_v K_s \frac{K_H}{d_{w1}\,b}\frac{Z_R}{Z_1}} \quad (4)$$

$$\sigma_{all} = \frac{S_t}{S_F}\frac{Y_N}{Y_\theta Y_Z} \quad (5)$$

$$\sigma_{c\,all} = \frac{S_c}{S_H}\frac{Z_N Z_W}{Y_\theta Y_Z} \quad (6)$$

Nomenclature

K_o is the overload factor K_v is the dynamic load factor

K_s is the size factor K_H is the load distribution factor

K_B is the rim thickness factor Y_J is the geometry factor for bending strength

Z_E is an elastic coefficient (N/mm^2) Z_R is the surface condition factor

d_{W1} is the pitch diameter of the pinion Z_1 is the geometry factor for pitting resistance

b is the face width of the narrowest member m is the module

S_t is allowable bending stress Y_N is the stress cycle factor for bending

Y_θ is temperature factor Y_Z is the reliability factor

S_F is the AGMA factor of safety S_c is allowable contact stress

Z_N is stress life factor Z_W is hardness ratio factor for pitting

S_H is the AGMA factor of safety

AGMA Factor Calculations by using AGMA Standard

AGMA factors were calculated& tabulated in table no. 2

Table 2: AGMA Factor Calculations

Type of Gear			**Girth Gear**	**Pinion**
Sr.No.	**Description**	**Symbol**	**Value**	**Value**
1	Dynamic factor	K_V	1.2	1.14
2	Load distribution factor	K_H	1.86	1.86
3	Geometry factor	Z_I	0.1417	0.1417
4	Geometry factor	Y_J	0.46	0.46
5	Rim thickness factor	K_B	1	1
6	Elastic coefficient	Z_E	189.77	189.77
7	Surface condition factor	Z_R	1	1
8	Size factor	K_S	1.51	1.502
9	Load cycle factor	Y_N	0.889	0.72
10	Load cycle factor	Z_N	0.99	0.95
11	Temperature factor	Y_θ	1	1
12	Reliability factor	Y_Z	0.83	0.83
13	Hardness ratio factor	Z_W	1	1
14	Overload factor	K_o	1	1
15	Allowable bending stress (MPa)	S_t	258.52	352.02
16	Allowable contact stress (MPa)	S_c	735.87	1056.4

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$$\mathrm{Wt} = \frac{\mathrm{Power}}{\mathrm{Velocity}} = \frac{(2200 \times 1000)}{5.4974} = 400189.1803\ \mathrm{N}$$

$$\mathrm{Wt} = 400189.1803\ \mathrm{N}$$

AGMA based design is carried out for pinion as it is smaller in size,

Bending Criteria:

Putting all factors in Eq. 3:

$$\sigma = 400189.1803 \times 1 \times 1.14 \times 1.502 \times \frac{1}{750 \times 30} \times \frac{1.86 \times 0.65}{0.46}$$

$$\sigma = 80.13\ \mathrm{MPa}$$

Similarly, putting all factors in Eq. 5:

$$\sigma_{all} = \frac{352.02 \times 0.72}{1 \times 0.83}$$

$$\sigma_{all} = 305.37\ \mathrm{Mpa}$$

As ($<\sigma_{all}$ is satisfied the design is safe for bending loading.

Pitting or Contact Criteria:

Putting all factors in Eq. 4:

$$\sigma_C = 189.77 \times \sqrt{400189.1803 \times 1 \times 1.14 \times 1.502 \times \frac{1.86}{820.61 \times 750} \times \frac{1}{0.1417}}$$

$$\sigma_C = 725.47\ \mathrm{MPa}$$

Similarly, putting all factors in Eq. 6:

$$\sigma_{c,all} = \frac{1056.4 \times 1 \times 1}{1 \times 0.83}$$

$$\sigma_{c,all} = 1272.77\ \mathrm{MPa}$$

As $\sigma_c < \sigma c,_{all}$ is satisfied the design is safe from pitting or contact loading.

Hence, AGMA based safe design of girth spur gear is obtained for bending & contact stresses.

2) Parametric modelling of girth gear & pinion

The basic tooth geometry input data is taken for inputs to create a tooth co-ordinate generation. The tooth co-ordinate data defines a single tooth sector or a gear. From this single tooth co-ordinate, complete three dimensional gear modelsaregenerated. 3D model of Girth gear is created in two segments. 3D CAD model of girth gear and pinion assembly is created by using parametric modeling approach using CATIA V5. Present study assumes all teeth's are made of involute profile. Fig. 1shows the assembly of girth gear and pinion.The basic gear design parameters for gear & pinion model are presented in table no. 3

ISSN: 2319-8753

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Table No.3 Gear geometry parameters

Type of Gear		Girth Gear	Pinion
Sr. No.	Parameter	Value	Value
1	Pitch circle diameter	6139.39 mm	820.611 mm
2	Number of teeth	202	27
3	Face width	750	750
4	Working center distance	3480	3480
5	Backlash	2.2 to 2.5	2.2 to 2.5

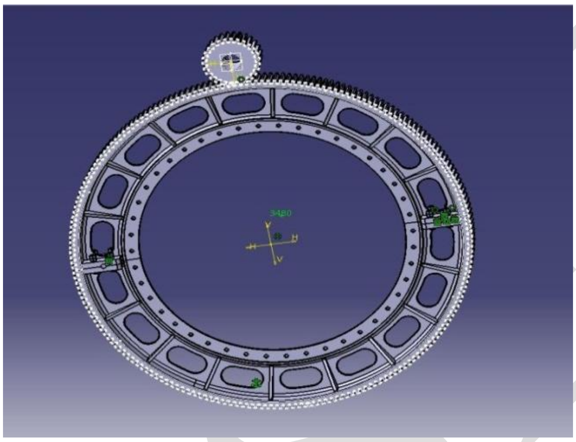

Fig.1Assembly of girth gear& pinion

3) Stress Analysis(by using ANSYS)

After completing the 3D CAD model in CATIA, the same model is imported in ANSYS. The stress analysis of girth gear is done by using ANSYS.This work uses simplified modelsfor tooth strength analysis. Fig. 2(a) shows the geometry of the tooth in mating condition created in ANSYS. 2D tooth geometry is meshed using 8-node SHELL elements. Thickness of shell is equal to face width of the tooth. Fig. 2(b) shows meshed model contains 5433 number of nodes and 1717 number of elements. As weight is applied as a load and contact defined.Analysis is performed and stress results are obtained.

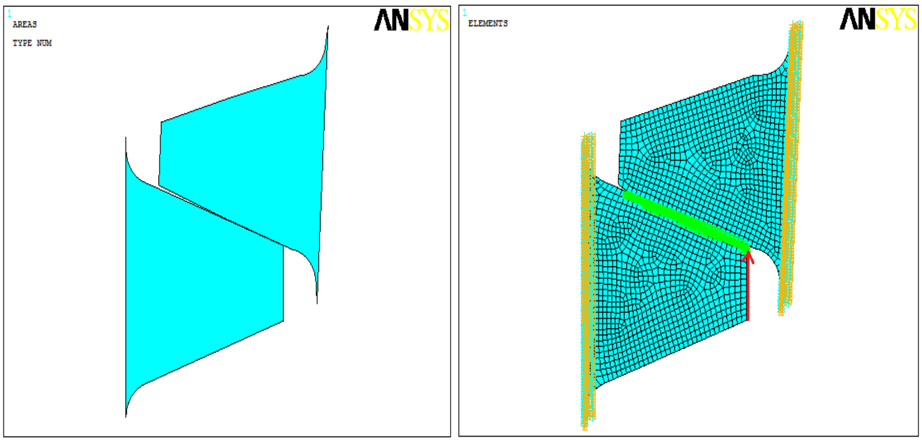

Fig. 2 (a): 2D-Geometry of mating tooth in ANSYSFig. 2 (b): FE meshed model

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The stress contour in gear and pinion tooth is as shown in fig.3. Bending stress is checked at the root of the tooth whereas contact stress is checked along the contact region. From analysis bending stress observed was 82.10 MPa and contact stress was 738.90 MPa

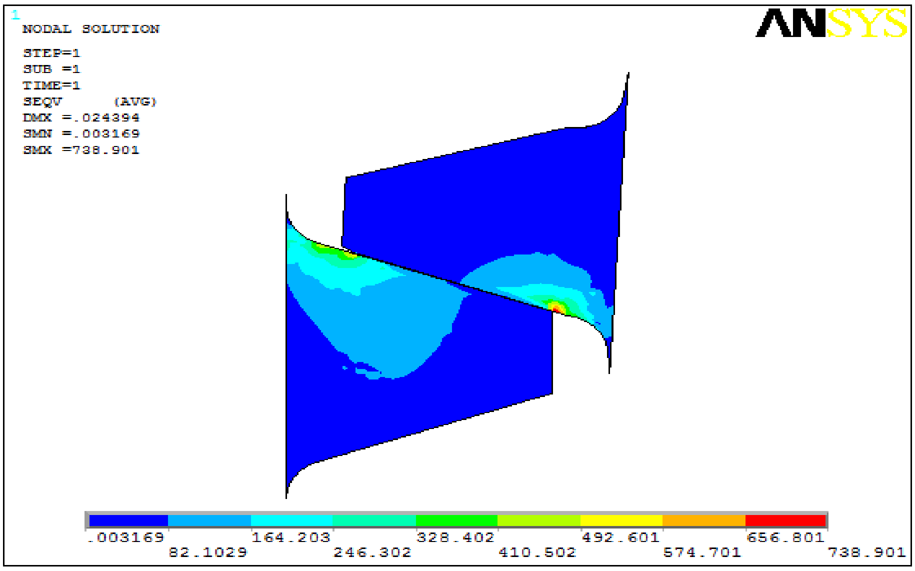

Fig.3: Bending and contact stress in tooth

III COMPARATIVE STRESS ANALYSIS

For the comparative stress analysis, the bending & contact stresses calculated by using AGMA standard & ANSYS software are presented in table no.4. The values of the bending stress and contact stress determined using AGMA & ANSYS, both arevery close. The percentage error between the stress values calculated by AGMA & ANSYS was observedvery less.

Table 4: Comparison of AGMA and ANSYS results

Type of Stress in MPA	AGMA	ANSYS	% Error
Bending	80.13	82.10	2.39
Contact	725.47	738.90	1.81

IV.CONCLUSION

The bending and contact stress analysis was carried out using AGMA standard and ANSYS software. Based on the study, the following conclusions are drawn.

- AGMA based design approach for stress analysis is formulated for girth gears.
- Successfully developed a parametric model in CATIA which reduces modelling efforts.
- AGMA based design calculations of girth gear are validated using ANSYS.
- In all cases bending & contact stresses calculated by ANSYS and AGMA are found in agreement and percentage error in stresses isobserved below 5%.

ISSN: 2319-8753

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