International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 03 | Mar 2021 www.irjet.net p-ISSN: 2395-0072

ESTIMATION OF LOAD CARRYING CAPACITY IN HIGH CONTACT RATIO GEAR

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Abstract - *Modern day's research is more focused on vehicles weight reduction and increasing load carrying capacity within the same or less occupied volume. Transmission system plays an important role in defining load carrying capacity of any vehicle. Gear is one of the most reliable machine elements for power transmission in many applications. Gears which are used in the vehicles transmission system should have high load carrying capacity, lesser vibrations and noise. However helical gears are meeting the requirements, they are prone to axial thrust. High contact ratio (HCR) is one such concept, which can be used for attaining high power-to-weight ratio, smooth running with same or less volume occupancy. The contact ratio more than2.0 in HCR gearing leads to lower bending stresses than NCR gears. The present study shows generating a HCR gear pair with slight modifications in the existing parameters of gears, within the limits of the widely accepted design standards. The study also presents the comparison of bending stress for NCR and HCR using finite element analysis of gear pairs having same module, center distance and number of teeth.*

Key Words: NCR (Normal contact ratio),HCR(High contact ratio),Contact ratio, Pressure angle, Addendum coefficient, Number of teeth, Bending stress.

1. INTRODUCTION

The power to weight ratio of gear trains has improved progressively over the years. One of the recent improvements lies in the area of design, where sharing the load among more teeth (by increasing the contact ratio) is possible, under certain conditions, to increase the load carrying capacity of a gear set without substantially increasing its weight [17].Majority of the vehicles used in the transportation applications are having gears with contact ratio less than 2.0 [1]. Physical significance of the contact ratio lies in the fact that it is a measure of average number of teeth in contact during the period in which a tooth comes and goes out of contact with the mating gear. To ensure smooth and continuous operation the contact ratio must be as high as possible, which the limiting factors permit [2]. The common gearboxes used in the transportation applications have contact ratios ranging from 1.3 to 1.6.i.e., the number of tooth engagements is either one or two. But high contact ratio gears having a contact ratio greater than 2.0 have load sharing between two or three teeth during engagement and lower load per tooth [3, 4]. A literature survey showed that HCR gearing was designed [5] and effectively used in helicopter transmissions [6] to improve the power-to-weight ratio of the transmission. In HCR gears, because of greater number of teeth share the load [7], the concept appears to be simple and has wide, potential applicability. The analysis of static and dynamic transmission errors in high precision heavy loaded standard gears, HCR gears of standard tooth height and HCR gears with slightly increased tooth addendum showed that in the last type of gears the static and dynamic transmission errors can be almost excluded [8]. Many researchers worked on HCR gears, but not much significant work was done on finding the variation in contact ratio due to the combined effect of decreased pressure angle and increased addendum coefficient. In this we are going to study the combined effect of variation of pressure angle and addendum co-efficient on HCR gear pair by analysing the load distribution in gear pair after varying the parameters which are affecting the contact ratio.

Study of contact ratio by varying different gear Parameters:

Contact ratio of a gear pair is defined as the average number of teeth in contact during engagement. The contact ratio of the gear pair plays an important role in increasing the load carrying capacity of gears.

Contact ratio is given by the following formula:

$$CR = \frac{\sqrt{(r_1 + a)^2 - r_1^2 \, \mathrm{COS}^2 \, \alpha}}{\pi m \cos \alpha + \frac{\sqrt{(r_2 + a)^2 - r_2^2 \, \mathrm{COS}^2 \, \alpha} - (r_1 + r_2) \sin \alpha}{\pi m \cos \alpha}}$$

Where:

CR- Contact ratio

r1, r2 - pitch radius of pinion and gear α- Pressure angle

m – Module

a – addendum

Mainly high contact ratio can be attained by:

1. Increasing the addendum factor

2. Lowering the pressure angle

3. Increasing the number of teeth [1, 9, 8, and 10].

The variations in contact ratio by varying these parameters are plotted in the graphs shown below. All these plots are obtained by varying parameters on the same set of gear pairs, which has module-2.5, gear ratio 1.08, no of teeth on pinion-50.

The parameters are given as input in an excel file and the graphs are plotted based on the results obtained.

1.1 Variation in contact ratio due to varying addendum coefficient:

Module- 2.5mm; Gear ratio-1.08
Pressure angle-20°; Number of teeth on gear-54
Addendum coefficient – Variable.

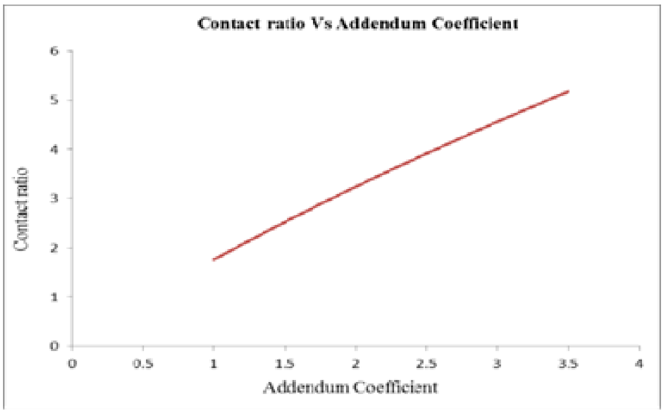

Chart -1: Contact Ratio Vs Addendum coefficient

From the Graph-1,we can infer that the variation in addendum coefficient has greatly influenced the contact ratio.Increasing the addendum is normally recommended for increasing the contact ratio since this can be achieved by simply adjusting the cutter depth [13, 14, and 12]. The maximum permissible addendum modification coefficients are obtained by iteratively varying the addendum modification coefficient of the pinion and gear until the top land thickness is equal to the minimum allowable limit [15].M. Ramesh Kumar et al [1, 4] demonstrated that, to attain the contact ratio more than 2.0 for a gear pair with identical center distance and pressure angle, the addendum factor of the gears pair should be increased from a standard value. He also reported that the maximum bending stress, contact stress is less and the load carrying capacity is high as compared to a NCR gear [10].

1.2 Variation in contact ratio due to varying pressure angle:

Module- 2.5mm; Gear ratio-1.08; Addendum coefficient -1.25
Number of teeth on gear-54; Pressure angle-Variable

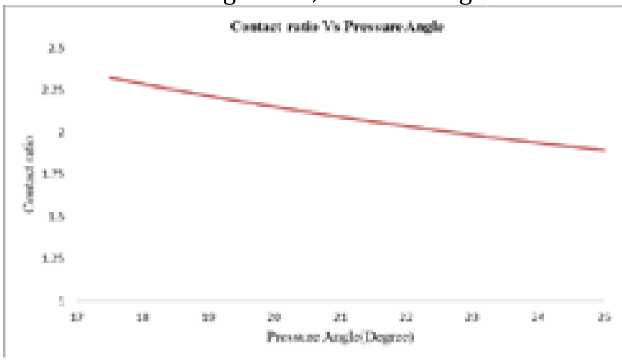

Chart -2: Contact Ratio Vs Pressure angle

From the Graph-2 we can infer that the variation in pressure angle has a significant influence on the contact ratio. When designing gears, with the lower the pressure angle leads to higher the surface compressive and bending stresses. This lowers the bending and surface fatigue lives, and these are successful in operating at reduced noise levels primarily because of contact ratio greater than 2.0.If the pressure angle is increased the gear tooth become stronger, but still considerable amount of noise is observed [9],tooth and axial pressure increases, while contact ratio and overlap decreases [2].With increase in the pressure angle, the stress levels are reduced in the gears [11, 10, and 12].

1.3 Variation in contact ratio by varying Number of teeth

Module- 2.5mm; Gear ratio-1.08
Pressure angle-20°; Addendum coefficient -1.25 Number of teeth on gear-Variable

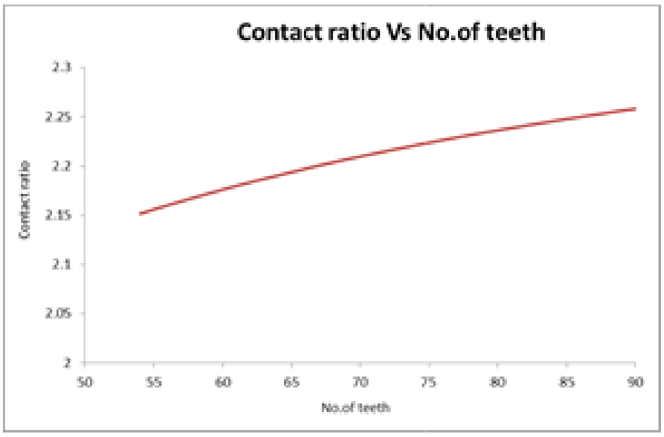

Chart -1: Contact Ratio Vs No. of Teeth

From the Graph-3 we infer that variation in number of teeth doesn't have any significant influence on contact ratio. It is also observed that size of gear is increasing while increasing number of teeth which results in a heavier assembly occupying larger volume of space. Increasing the number tooth also gives the high contact ratio. Selection of number of teeth of mating gear is critically important. First it provides the required gear ratio. Second, when the gear ratio and center distance are specified, selected number of teeth defines the gear tooth size that is described by a module. The gear tooth size is a main parameter in the definition of the bending stress. Third, the number of gear teeth is a major factor in the definition of gear mesh efficiency. Along with the gear mesh parameters(pressure angle, contact ratio, etc.),a tooth number selection allows providing sufficient safety factors for bending and contact stresses, and wear resistance to optimize a gear pair design[16].The analysis of stresses generated in gear teeth is considered as a limiting factor for gear designers. So according to the analysis of generated stresses, transmitted load, running speed, tooth geometry and other design considerations can be determined [17].

From the above study Decrease in the pressure angle and Increase in addendum coefficient greatly influence the contact ratio. Finally we have selected pressure angle to be17.5°and Addendum co-efficient to be 1.1. Although the pressure angle is usually set to 20 degrees, 14.5° or 17.5° can be used in specific applications [18]. As we know lowering the pressure angle leads to increase in stress, but at the same time increase in contact ratio is also observed. In addition to this, increase in addendum coefficient also results in High contact ratio. Because of this reason the load is distributed on more number of teeth, number of teeth in contact increase and result in lower noise and smoother operation.

The parameters of Normal contact and High contact ratio gear pairs are listed below:

S No.	Parameters	NCR	HCR
1	Gear Profile	Involute	Involute
2	Pressure angle(degree)	20°	17.5°
3	Module(mm)	2.5	2.5
4	Gear ratio	1.08	1.08
5	Number of teeth in gear	54	54
6	Number of teeth in pinion	50	50
7	Center distance(mm)	130	130
8	Face width(mm)	20	20
9	Addendum factor	1	1.1
10	Contact ratio	1.76	2.07

2 GEAR DESIGN

The standard involute toothed profile gearswere modeled in Catia V5 R20. Parameters used for the modeling gear pairs are listed below.

1. Circular pitch, p = π*D/N (N-no of teeth)
2. Module, m = D/N (D-pitch circle dia)
3. Addendum circle diameter, Da= D+2*m
4. Dedendum circle diameter, Dt = D− (2×1.25*m)
5. Base circle diameter, Db = D × cos ϕ
6. Addendum, ha = 1*m
7. Dedendum, hf= 1.157·m
8. Clearance, c = 0.157*m
9. Fillet radius, r = 0.4*m
10. Face width, B = 8*m
11. Working depth, hk= 2*m
12. Whole depth, ht=2.157*m
13. Tooth thickness on pitch circle, s = (π* m)/2

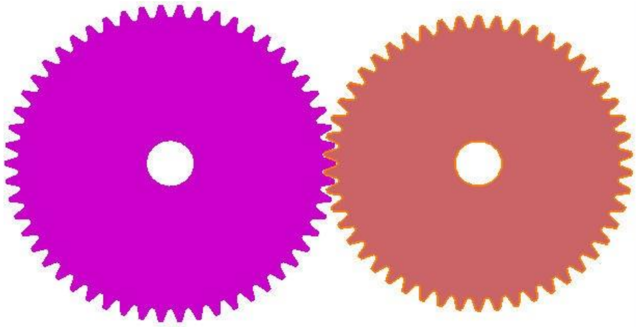

Fig -1: Normal Contact Ratio (NCR) Gear pair

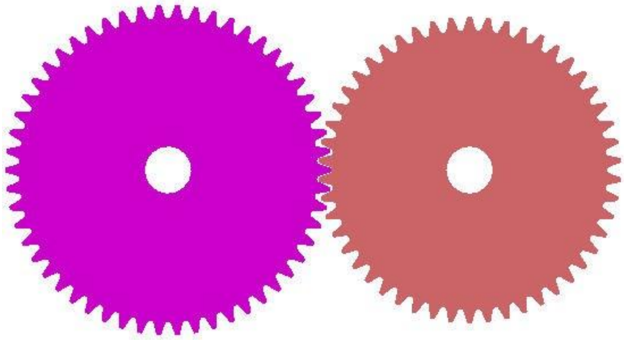

Fig -2: High Contact Ratio (HCR) Gear pair

2.1 Finite Element Analysis

ANSYS 15.0 was used to analyze the gear pairs. The cad model prepared in catiaV5 R20 was imported and analysis was performed.

2.2 Meshing of Gears

Meshing is a very important criteria in solving Finite Element Analysis (FEA) problems. The basic theme of Finite Element Method is to make calculations at only finite number of points and interpolating the results of entire surface or volume of a body or an object.

The gear pairs are meshed with hexahedron meshing, which is commonly known as Hex-Dominant mesh type or Brick type meshing in FEA. This type of meshing has the advantage that they can be highly controlled and also can be generated automatically for optimal solution efficiency and accuracy [19].

2.3 Mechanical properties of Gear and pinion:

1) Material=Structural steel

2) Density= 7850kg/m3

3) Young's Modulus=2×105MPa

4) Tensile Ultimate Strength= 460 MPa

5) Tensile Yield Strength=250MPa

6) Poisson's ratio= 0.3.

3. RESULTS

3.1 Bending Stress Analysis:

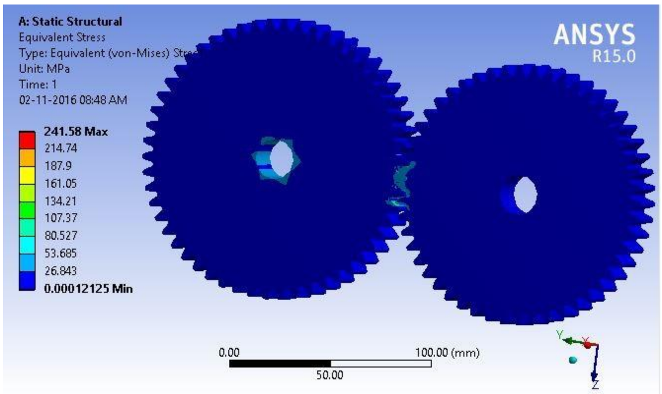

Fig -3: Maximum Bending stress of NCR Gear pair

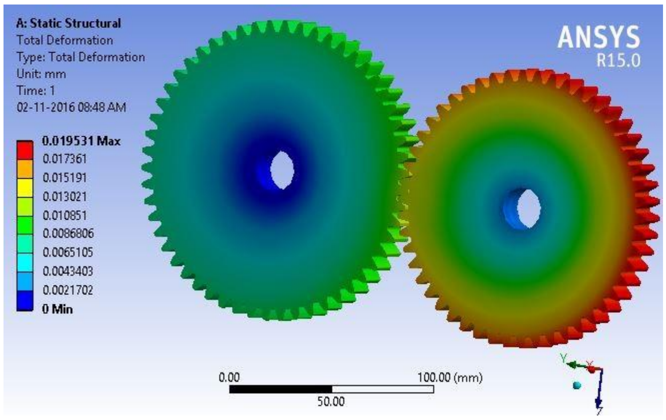

Fig -4: Maximum Deformation of NCR Gear pair

Based on the failure stress, the maximum allowable load is calculated and applied on the gear pair. The corresponding stress and deformation values are recorded. The load is given in the form of moment on the pinion.

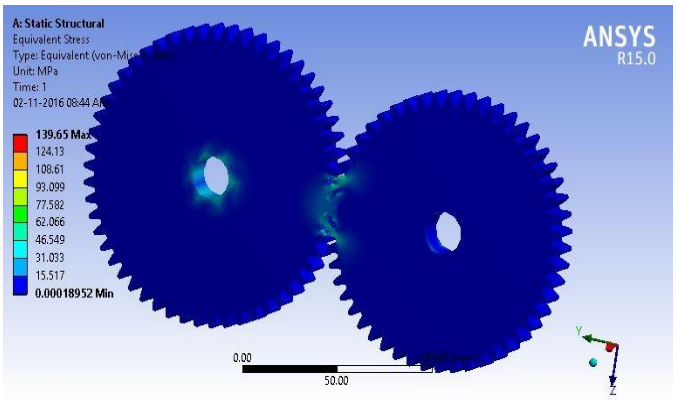

Fig -5: Maximum Bending stress of HCR Gear pair

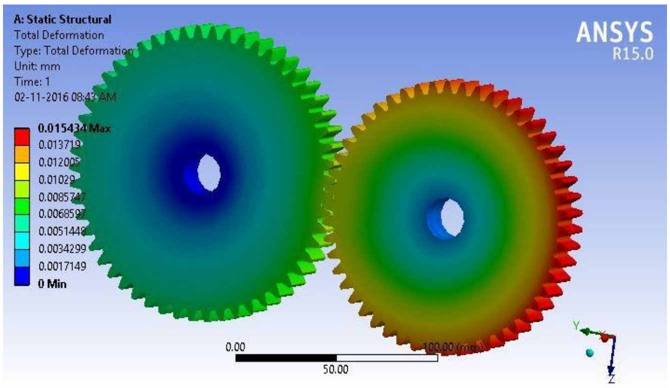

Fig -6: Maximum Deformation of HCR Gear pair

Same load was applied on HCR gear pair as on NCR gear pair and significant decrease in bending stress was observed as shown in Fig 5. This is observed due to the distribution of load on more number of teeth which are in contact.

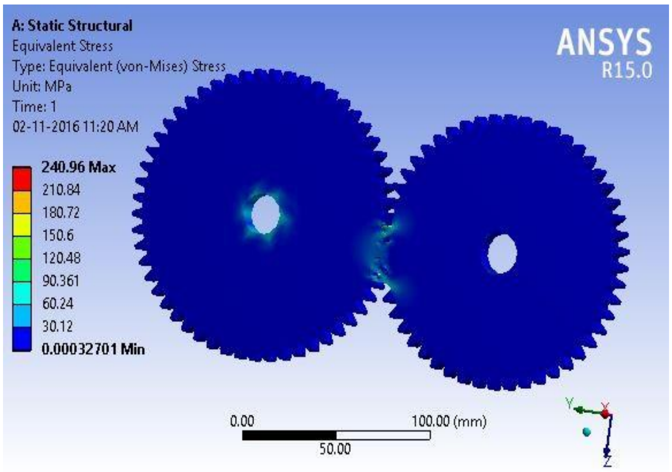

Fig -7: Maximum Bending stress of HCR Gear pair

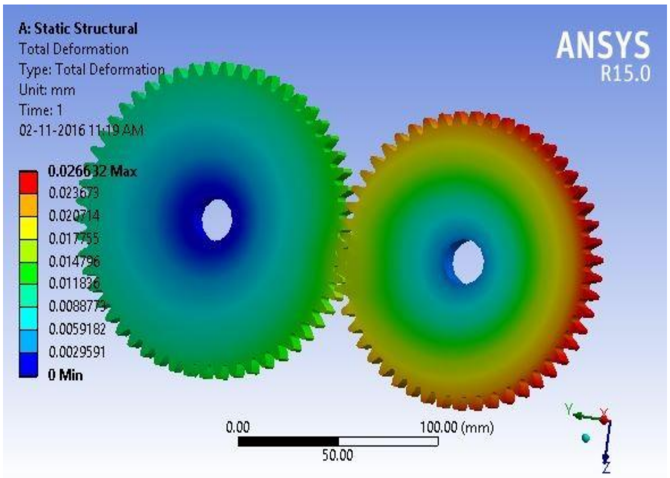

Fig -8: Maximum Deformation of HCR Gear pair

The maximum stress in the HCR gear pair is achieved at a load which is observed to be 70% more than load applied on NCR gear pair.

Both the bending stress and high load carrying capacity in HCR gear pair is due to higher contact ratio in which more number of teeth stay in contact. Thus the load is distributed among the teeth which are in contact, resulting lower bending stresses when compared to NCR as shown in Fig 5. From Fig 7 it is evident that load carrying capacity of HCR gear pair is increased which is due to load sharing among the number of teeth in contact.

4. CONCLUSIONS

The FEA of NC and HCR gear pair's reveals that the bending stresses are 40% less in HCR gears compared to NCR gears for same applied load. The load carrying capacity of HCR gearing could be increased to a maximum limit of 70% for the same weight and volume. Therefore, the concept of HCR gearing can be adapted to all the gear assemblies of the vehicle transmission for increasing the load carrying capacity of the transmission within the same envelope, as well as decreasing noise level.

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