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# A Review on Failure of Gears (Cluster Gears Shaft) and its Preventions

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**Abstract- There are various reasons due to the gear may fail, few of them could be application error, design error, manufacturing error or application error. According to American gear manufacturing association, the failures of gear can be classified into four major categories namely surface fatigue, wear, plastic, and breakage. It has been observed that in most of the cases the failure starts from the bearing. The statistics of gear failure shows that 2.8% of the gear fails due to handling errors, 6.9% due to overload, 17.7% due to installation error, 19.6% due to contamination, and 34.4% of the gears fails due to inadequate lubrication. An in depth review of failure of gears along with its reasons and precautions are carried out in this article. In addition, the failure of cluster gear shaft mounted in a tractor gear box is discussed.**

**Keywords- gear failure, wear, lubrication, misalignment.**

## I. INTRODUCTION

The gears are mainly used to transmit the power over a short distance. This is one of the effective methods of power transmission and economical too. The gears are almost in most of the mechanical machineries for transmitting the power. In various machines the gears are mainly used to transmit the power and forces from one shaft to other. The gears are mainly identified by two parameters namely, number of teeth and radius of gear. The gears are typically mounted on either on the shaft or base. According to orientation of the axes the gears are typically classified in three categories; parallel axis (spur gear, helical gear), intersecting axis (bevel gear), non-intersecting axis (spiral gear).

The basic function of the gear is to transmit the torque and motion from one component to other in a mechanical device. The gears can change the direction of motion as well as increase or decrease the output torque or speed. Depending on the applications where the gears are used, it is made up of variety of materials. Steel, aluminum, wood, plastic brass is few of the common materials used for gear manufacturing. The gears are commonly made up of steel as they are more or less ductile, has a high modulus of elasticity, high tensile strength while the cast iron have high compressive strength, low modulus of tensile strength and ductility.

In worm and worm wheel assembly, the worm is made up of steel while the worm wheel is of brass. The brass is used for manufacturing of the worm wheel because it is easy to replace if the failure occurs. When the worm and worm wheel comes in contact and wear occurs then the worm brass wheel wear out quickly as compare to steel worm.

Some of the common examples where the gears are used are analog watches, bicycles, drill machines, vehicles etc. The basic parameters which are considered while designing the gears are gear ratio, number of teeth, and profile of gear, addendum, pressure angle, and damping ratio. The objective of this paper is to review the failures of gear and present the design modification of cluster gear shaft of synchromesh gear box in tractor.

## II. LITERATURE REVIEW

Gear analysis is one of the important stages in the gear design and its manufacturing. Several concepts have been proposed by various researchers to increase the performance of the gearing system.

**Netpu et al. [1]** analyzed helical gear that is used in continuous hot rolling mill and subjected a premature failure. Detail investigation revealed that the gears are failed due to pitting corrosion and excessive loading. In order to roll thicker billets the existing 300KW motor was replaced by new motor with 600KW capacity without being thoroughly analyzed. The contact stresses on the helical gear were 3.2 higher than allowable stress of the material due to replacement of motor.

**Siddiqui et al.[2]** investigated rear wheel gear hub of an aircraft to find the exact cause of failure. The microstructure showed the river pattern at the crack and the finite element analysis revealed that the stress concentration was at the same place near the crack.

**Kadir Cavdar et al. [3]** tried to minimize the bending stresses on the involute gear tooth profile. The authors have developed the computer program to investigate the contact ratio and bending stresses variations. Various factors such as tool radius, pressure angle etc. were selected to determine the value of stress concentration factor and tooth form. Involute gear tooth profile has certain disadvantages such as poor pitting resistance, noise during operation and low bending strength. Thus, non-involute have been recommend [4, 5], but they are insensitive to center distance. The bending strength of the involute gear tooth can be improved by doing modifications in the design of addendum of the pinion or the mating gears [6–8].

**Gagandeep Singh [9]** tried to analyze the life of gear and noise frequency when the gear material changed from C-45 to 19mncr5. Buckingham formula and Lewis equation was used to design the profile of the gear tooth. It was concluded that tangential load and dynamic load should be less than tangential force and endurance load respectively. The author was succeeding to reduce the noise level from 90 dB to 80 db.

In the study reported by **Kahraman et al.[10],** the surface of helical tooth profile was investigated by employing surface wear prediction model to check the influences of tooth deviations caused due to manufacturing processes. FEM techniques were used in the wear model which was able to predict sliding distance computation algorithm, contact pressure and wear between the contacting surfaces. The authors proposed a design formula which considered mismatch in slope of contacting surfaces to predict the wear rate.

Tooth undercutting problem is more common in spur and helical gear with small number of teeth. In power transmission devices the gears with small number of teeth are not typically used. However, helical gears are extensively used in industry, and may be generated by hobs, shapers and rack cutters.

In order to obtain higher load capacity, **Akira et al. [11]** investigated a pair of gear with a pinion with 4 teeth and tested with 10 x $10^6$ rotation on gear tester machine. It was observed that the gear with more than six number of teeth have more efficiency, about 93%, than the gear with 3 teeth when tested under normal condition. The contact ratio and the gear strength is substantially reduced due to gear undercutting. On well-known method to reduce the gear undercutting is to increase the number of teeth, but sometimes use of more number of teeth is not possible.

**Chen et al. [12]** developed a mathematical model for the helical gears with small number of teeth and modified root and tooth fillet as well as included the clearance between the pinion gears. It was observed that gear shifting is the prime parameter behind the gear shifting. In last two decade, more research is focused on the usage of polymer gears, as the metallic gears have some limitations like, efficiency, lubrication, weight, noise and cost [13, 14].

The polymer gears have some advantages over metallic gears such as high resilience, capabilityto work with no or little lubrication, possesses good damping capacity [15, 16]. Due to these mentioned advantages in terms of technical aspects and economics, these gears are now commonly used in various applications like, automotive industry, kitchens machineries, textile industries etc.

A research reported that the usage of polymer gears reduced the mass, inertia and fuel consumption in automotive industry by 70%, 80% and 8% respectively [17]. The commonly used gear material for the manufacturing of polymer gears are Acrylonitrile butadiene styrene (ABS), Polyamide (PA), nylon, acetal, High density polyethylene (HDPE) etc.

In following sections the mode of the failures of the gear, the effect of lubrication on the gear performance, the fault diagnosis of gear failure, and the various remedies to avoid the gear failure has been discussed in detail.

## III. MODES OF GEAR FAILURE

When two gears mesh with each other, the larger gear is called as gear while the smaller gear is known as pinion. The gears are manufactured by variety of manufacturing processes namely, blanking, casting, powder metallurgy, extrusion, and forging. The gears are known as positive drive and the velocity remains constant while power transmission. The efficiency of gear drive is very high when comparing to other drives and this can be used for slow speed applications. The gears are compact in nature and can transmit high torque.

Fig 1. Modes of gear failure.

When the gears are not able to perform the function for which it is designed then we can say that the gear failure occur. The gear failure ranges from the excessive wear to catastrophic failure. Figure 1 shows the various modes of gear failure. When the layers of metal are worn away or

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removed from the contacting surface, such phenomenon is known as polishing wear. The wear occurs at very slow rate due to metal to metal contact between the gears. This situation occurs generally at low speed and lubrication between the gears is not sufficient. This condition can be avoided by operating the gears at high speed or by using a lubricant with higher viscosity etc.

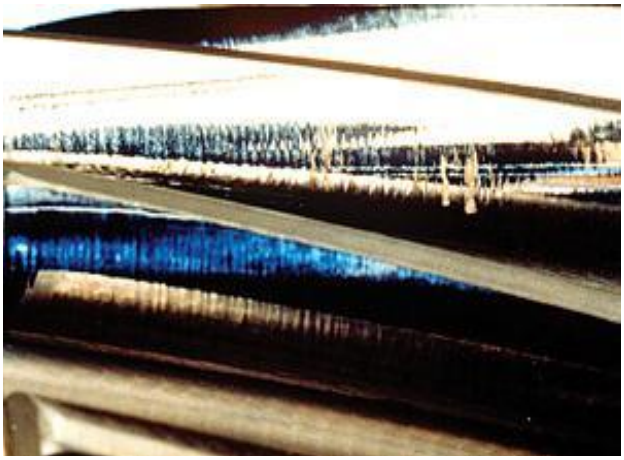

Fig 2. Polishing wear.

Moderate wear is occurred due to inadequate lubrication, thin film. One more probable reason for the moderate wear can be dirt in the lubrication. This type of wear can be avoided by using a lubricant with more viscosity or by employing a gear material with higher wear resistance. In moderate wear the material get removed from the addendum and dedendum area[18].

In abrasive wear, the contact surface shows groves, radial scratch marks or sign of lapped finish. The foreign particle in the lubricating film between the contacting surfaces can be the probable reason for abrasive wear. This type of wear can be avoided by carefully cleaning the gear box and lubricating system[19].

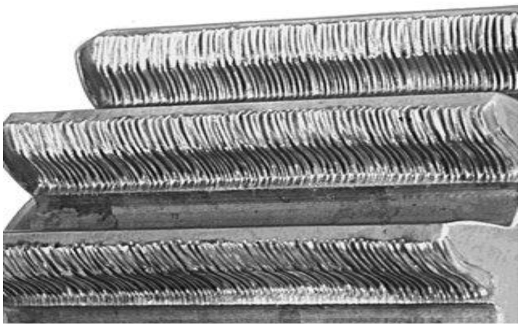

Fig 3. Abrasive wear.

The corrosive wear is caused due to chemical action and the contact surface gets deteriorated. Sometime the lubricating material may contain moisture, additives, acid which causes chemical action and the corrosive wear takes place. The lubricating film break and the chemical come in contact with the surface due to which pitting takes place at the surface. This wear can be avoided by regularly cleaning the gear box and changing the lubricating oil.

Fig 4. Corrosive Wear.

One more reason for the gear failure is fracture failure in which entire tooth or the substantial part of the tooth break away. The failure starts from the crack that starts from the root of the gear and then propagates. This type of failure occurs due to excessive loading which substantially higher than the endurance limit of the gear. It can be avoided by designing the gear tooth in such a way that it should distribute the load so that it should be less than endurance limit. Another way to avoid the fracture failure is select proper heat treatment to attain top structure to minimize stresses.

Fig 5. Fatigue fracture.

## IV. EFFECTS OF LUBRICATION ON GEAR PERFORMANCE

The main purposes of gear lubrication are to reduce friction, improve efficiency, increase durability and reduce contact fatigue and wear between the mating surfaces of the gears. The commonly used lubricants are mineral oils, ester oil, greases etc. According to cann et al. [20], the lubrication provided by the greases is considerably different than the lubrication provided by oil and starvation is one of the important parameter in the lubrication. There are different industrial grades of lubricating oil available in the market. In order to compare the performance of paraffinic mineral oil and biodegradable non-toxic ester Martins et al. [21]

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conducted the test and found out that coefficient of friction and the mass loss has been considerably reduced with the usage of biodegradable non-toxic ester. In the another research conducted by Cardoso et al.[22] , it was fond that the biodegradable ester oils given better micropitting resistance when compared with the mineral oil. The authors conducted the experiment on the nitriding steel gears and evaluated micro pitting damages. Figure 7 shows the various types of lubrication systems in gear. Bartels et al. [23] concluded that the synthetic lubricants such as synthetic hydrocarbons reduces the friction and temperature between the mating surfaces when compared with the mineral oils. The literature review showed that even at high operating temperature grease and ester gear oil enhances efficiency.

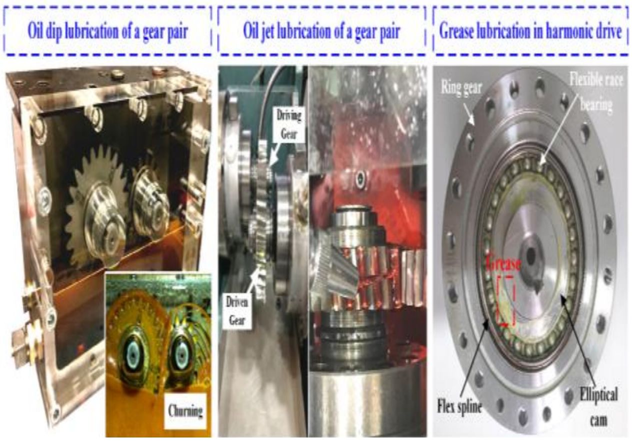


Fig 6. Types of lubrication systems.

The gear box efficiency can be improved with spray lubrication than the dip lubrication. The surface fatigue life of the gear can be improved by using higher viscosity lubricant and extreme pressure oil additives. The noise and vibration of the mating gears can be reduced by using the lubricants with higher viscosity. The lubricant oil viscosity is decrease with the increase in the temperature and causes rattle oscillations[24–29].

In gear box, different gears mesh with each other and produce vibrations. During working, the other elements such as bearings, shafts also produce vibrations and these vibrations may hide or weak the vibrations caused due to gears. Hence, it is important to unmask the vibrations caused due to other elements and segregate multi-mode vibrations. It is important to develop the condition monitoring system to detect the faults at the beginning which are caused due to varying loads and speeds.

It is common to mount the accelerometer on the gear box housing as shown in figure 8 to detect the vibration signature. As the gears are meshes with each other and according the shaft rotates, but it is difficult to mount the accelerometer on the rotating component. So it is difficult to detect the exact vibration signature and hence it is important to develop suitable system[30].

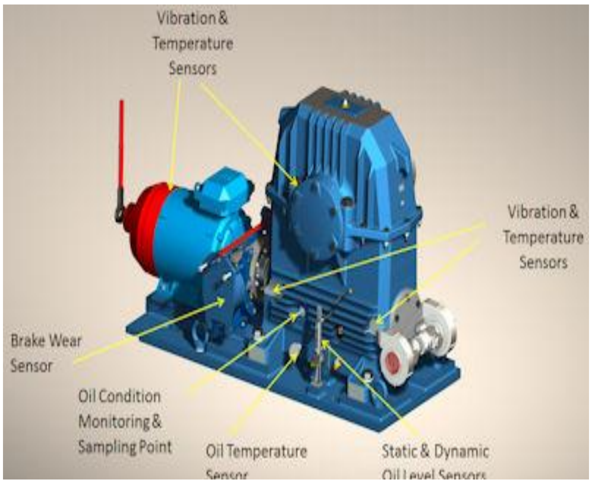


Fig 7. Mounting of sensors on machineries.

## V. REDUCTION OF STRESSES IN GEAR USING STRESS RELIEF FEATURES

The fatigue failure occurs at the root of the tooth because of the repetitive tensile stresses and it is always challenging to increase the life of the gear tooth. The research indicated that there are various ways to improve the design of gear tooth profile such as advance material usage, varying pressure angle, modify the root geometry, apply the heat treatments to improve surface properties, shot peening to improve surface characteristics etc. But considering the interchangability, all these methods are not sufficient. The stress relief features like circular, aero fin or elliptical shaped in the stress zone can be an effective method to reduce the stresses.

### 1. Minimizing Bending Stresses:

The literature shows that the gears experiences bending stress at the root of the tooth due to transmitted load. Ram et al. [31] presented optimum locations and dimensions of stress relieving features to increase the fatigue life and minimize the stresses. The authors employed finite element techniques and reduced the bending stresses by 21% and doubled the fatigue life. Another research reported a reduction in bending stresses by 30% when optimized fillet profile of the gear tooth [32–34].

### 2. Stress reduction for asymmetric gear:

Ingole et al. [35]found out a new method of reducing stresses by drilling a circular hole in a more stressed area. The authors observed that there is a reduction in the root fillet stresses with the change in the diameter of the circular hole as it redistributed the line of force and regulated the stresses. Jadhav et al. [36]created an elliptical shaped feature to reduce the stresses in symmetric and asymmetric spur gear and observed that there is a reduction in stresses by 9.52% and 3.92% in symmetric and asymmetric spur gear respectively. Xiao et al. optimized the fillet shape by modifying its geometry with B spline fillet shape and observed a reduction in

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bending stresses by 19% which would increase the durability and strength of the gear tooth.

**3. Circular, elliptical-shaped stress relief features:**
Hamdeh et al. [37]modelled the gear tooth with and without hole,and calculated the stresses by varying various parameters like diameter of holes, number of holes and orientation of holes (Figure 9). The authors observed that there is a stress reduction, when the numbers of holes and diameter is increased.

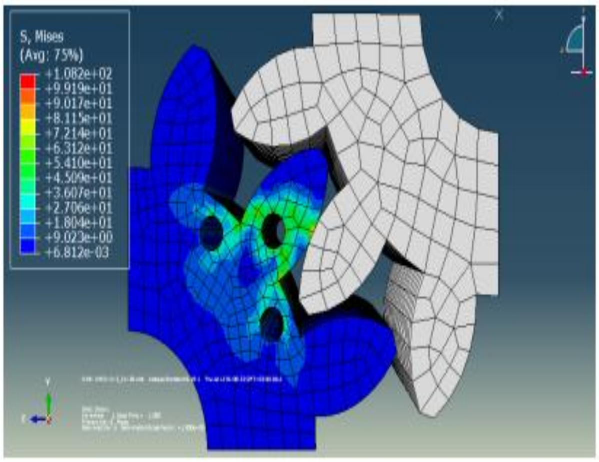


Fig 8. Hole model result of maximum Von Mises stresses.

In order to reduce the stresses on the gear of terrain vehicle Srivatsa et al have created a pocket on the gear with different radii. The authors simulated new geometries of the teethby using finite element method and optimized the radius of the pocket for the minimum stresses on the gear teeth.

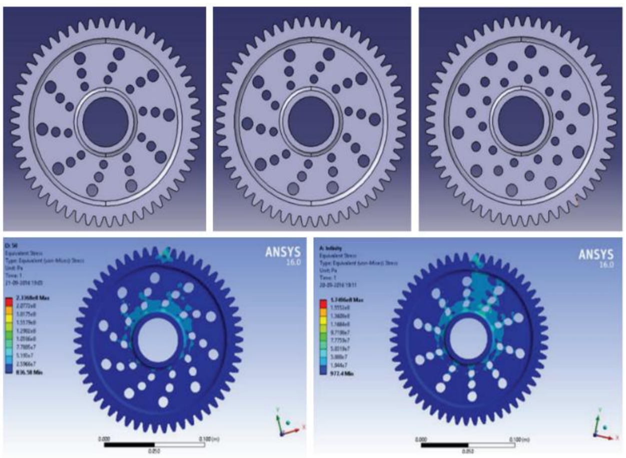


Fig 9. With different pocket radius and its FEM analysis.

According to Singh et al.[38] the location of stress relieving feature is very important and they experimented it by creating acircular features between two teeth below the root circle diameter and observed a stress reduction by 42%. Hence, the size, orientation and the location of feature decides the distribution of the stresses.

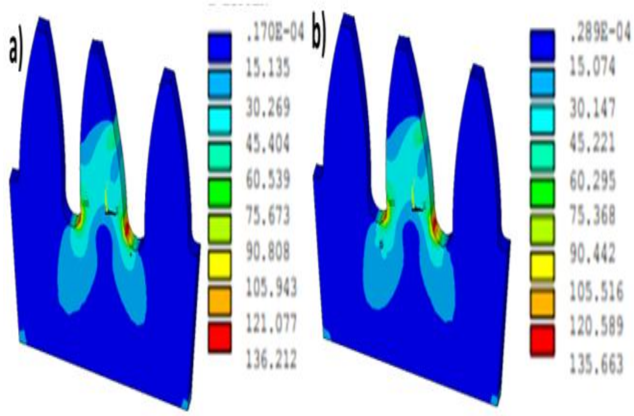


Fig 10. a) FEM analysis of gear teeth without circular feature b) FEM analysis of gear teeth with circular feature

## VI. METHODOLOGY

Based on the discussion made in the above section the case study of the failure of cluster gear shaft of a synchromesh gear box in tractor is discussed. A cluster shaft is a rotating member/machine element, which is used to transmit power from one place to another. A cluster shaft is a shaft that runs parallel to the main shaft in a gearbox, and carries the pinion wheels. A shaft is a manual transmission shaft driven by the clutch shaft and its input gear.

The counter shaft rotates in a direction counter to engine rotation. After the industrial visit it was observed that, during the meshing of gear teeth at various rotating speed they failed to engage and made loud noise. The proper arrangement of gear shifting was not provided which resulted in damages. The existing gear box was unable to handle varying loading condition.


Fig 11. a) Gear box b) Damaged gear.

Based on the above observations and problems identification the following objectives have been decided. To solve the problems it is necessary to study existing design of cluster gear shaft used in synchromesh gear box in tractor. After studying the existing design and gathering all the data, new design and modelling of cluster gear shaft has to be carried out. The modified modelled has to be validated using suitable analysis software. Table 1 shows the material of cluster shaft and its properties. Figure 13 shows the cluster gear and its location on the gear box.

Table 1. Material of cluster shaft and its properties.

| | |
|---|---|
| Material | 20MnCr5 |
| Surface hardness | 58-62 HRc |
| Effective case depth at 530 HVI | 0.6-0.9 mm |
| Core hardness | 32-42 HRc |
| Microstructure | Tempered martensite, retained austenite< 15% |

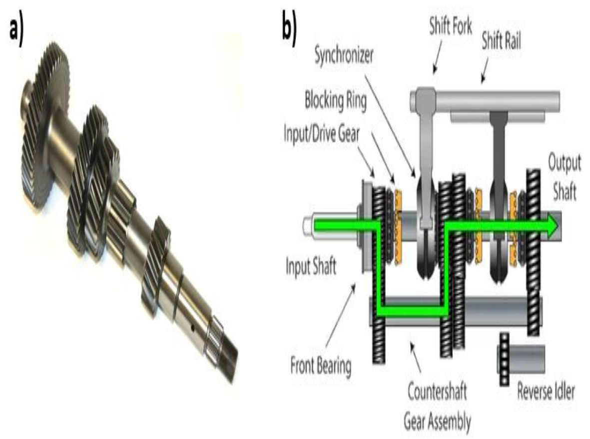


Fig 12. a) Cluster gear shaft b) Cluster gear shaft assembly.

## VII. CALCULATIONS

The cluster shaft is attached to an engine with the capacity of 50 HP, 2200 RPM, and number of cylinders 3.

The calculations are done by using this data.

- Engine power = 50 HP = 37.1 KW
- Number of teeth on pinion $T_p$ = 19
- Helix Angle $\alpha = 30.27^0$
- Pressure Angle = $20^0$
- RPM of pinion $N_p$ = 1800 RPM
- RPM of gear $N_G$= 600 RPM
- Overhang = 150 mm
- Shear stress $\tau$ = 50 MPa
- Normal stress $\sigma$ = 50 MPa
- Design of pinion and gear
- Torque transmitted by pinion and gear

$$T = \frac{P \times 60}{2\,\pi\,Np} = 196820 \text{ N-mm} \quad (1)$$

Since both the gears are made up of similar material, therefore, the pinion is weaker. Thus the design will be based on the pinion.

We know that,
Equivalent number of teeth

$$Te = \frac{Tp}{cos^3 \alpha} = 30 \quad (2)$$

Peripheral velocity,

$$V = \pi\, D_p\, N_p = 107.44 \text{ mm/min} \quad (3)$$

Module, m =3

$$\text{Face width, } b = 4\pi m = 75 \text{ mm} \quad (4)$$

$$\text{Pitch circle diameter } D_p = m\, T_p = 114 \text{ mm} \quad (5)$$

$$\text{Number of teeth on gear } T_g = 3\, T_p = 57 \text{ mm} \quad (6)$$

Pitch circle diameter of gear = 342 mm
Tangential load on pinion $W_t$ = 3452 N

$$\text{Axial load on pinion } W_a = W_t \tan\alpha = 2014.56 \text{ N} \quad (7)$$

- Since the overhang = 150 mm
- Bending moment on pinion shaft due to tangential load M1= $W_t$ x overhang = 517800 N-mm
- Bending moment on pinion shaft due to axial load $M_2$ = 114841 N-mm
- Equivalent moment = 530382 N-mm
- Equivalent torque = 565723 N-mm
- Diameter of pinion = 40 mm

Principle shear stress induced

$$\tau = \frac{16Te}{\pi Dp^3} = 45.01 \text{ MPa} \quad (8)$$

Direct stress due to axial load

$$\sigma = \frac{Wa}{\pi Dp^3} = 1.6 \text{ MPa} \quad (9)$$

$$\text{Principle shear stresses} = \frac{1}{2}\sqrt{\sigma^2 + 4\tau^2} = 51.35 \text{ MPa} \quad (10)$$

## VIII. MODELLING OF CLUSTER GEAR SHAFT

Based on the calculations mentioned in the above section the cluster gear shaft is modelled in CATIA software. There are four gears on the cluster shaft. Out of four gears one gear is spur gear and other three gears are helical gears. All four gears and shaft are modelled using CATIA V5 R21 software and assembled together. Figure 7 shows the CAD model of cluster gear shaft.

After modelling each gear and assembled together the drafting of each component is done using the drafting tool in the CATIA software. The drafting image shows the dimensions of each part. Figure 15 shows the drafting of cluster gear shaft.

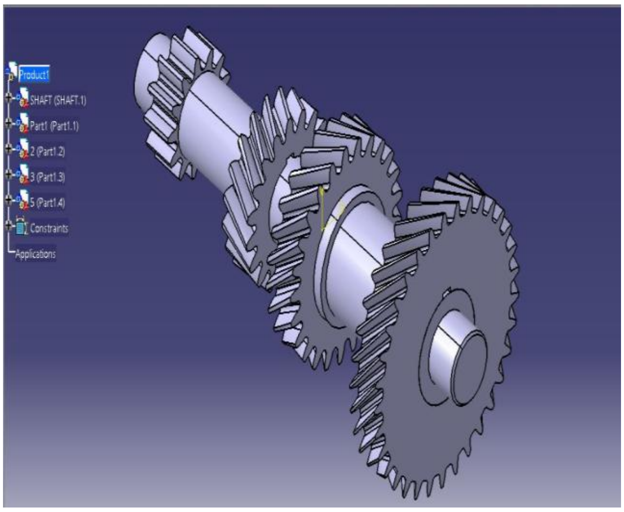


Fig 13. CAD Model of cluster gear shaft.

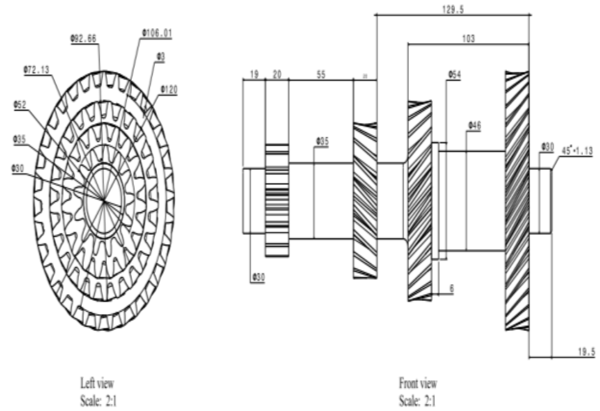


Fig 14. Drafting of cluster gear shaft.

The next step is to carry out the analysis of the cluster gear shaft with Ansys software and calculate the various parameters such as normal stress, von mises stresses, and total deformation. The possible solution to avoid the damage to the cluster gear is to change the material of the gear or make the necessary changes in the dimensions of the gear or shaft.

## IX. CONCLUSION

The literature review of the reasons of the failure of gear and its remedies has been done. The problem associated with the cluster gear shaft has been discussed and the CAD model of the cluster gear shaft has been developed by using the calculations. The following conclusions can be drawn from the literature review.

It is always better to do vibration analysis as compared to other techniques as it takes minimum cost and provides selective and sensitive data for online monitoring.

The stresses on the gear can be reduced by introducing a stress relieving features. It is always better to introduce more than one stress relieving features because a single stress relieving feature yields detrimental results.

In order to detect failure of polymer gear weight loss, surface conditioning monitoring, temperature detection and thermal damage are some of the important parameters. No study is without the scope for the improvement, in the future study the analysis of the cluster gear shaft will be carried out.

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