***Paper ID:516***

# Design and Finite Element Analysis of 12-Speed Gearbox

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## Abstract

*This research presents an in-depth examination of a 12-speed gear train system, focusing on the mechanical properties and performance of components fabricated from alloy steel (maraging 300) for the spur gears and annealed carbon steel (1095) for the shafts. The investigation utilizes finite element analysis (FEA) to examine essential factors including gear deformation, stress distribution, and gear teeth critical locations. The results indicate a minimal total deformation of $1.7085e^{-5}$m and a maximum principal stress of $2.0395e^{+8}$Pa when subjected to the applied torque, highlighting the system's stability and structural integrity during operational conditions. The selected material properties for fabricating the 12-speed gear train exhibited significant resilience and suitability for load-bearing applications. To further improve, the research investigates essential performance factors such as gear speed, load, torque, mesh stiffness, and gear tooth contact stress, offering significant insights for the optimization of gear design and the improvement of performance in diverse industrial applications.*

Keywords: Finite Element Analysis (FEA), Gear train, Stress distribution, Mechanical deformation, Gearbox.

## “1. Introduction”

Gearbox has significant importance in a wide range of industrial machinery, automobiles, and wind turbines. A gearbox transforms speed and torque from a rotating power source, transmitting the output of internal combustion engines to vehicle drive wheels via a transmission system. Elements such as gear configuration, material characteristics, and lubricants affect energy transfer efficiency. Optimized lubricants may improve energy efficiency and decrease emissions in mechanical systems [1]. Gear teeth are sensitive to pressure, especially upon contact. Gear teeth pressure may cause Hertzian stresses, which can cause fatigue and wear. Loaded transmission error, maximum tooth contact stress, and maximum tooth root stress increase as mesh stiffness decreases. When gears are misaligned, contact locations on the tooth edge experience concentrated pressure [2] . Fatigue failure occurs after many loading cycles, even if the applied stresses are significantly lower than the material's ultimate strength [3]. Under some circumstances, gears may experience undesired deformation and stresses, which might compromise their effectiveness and durability.

Researchers employ FEA to analyze gear tooth contract load, system vibrations, deformation, fatigue, and critical location in the geartrain system. A. P. Agrawal et al. [4] investigated spur gear using ANSYS under cyclic loads. The findings demonstrated that geartrain failure predominantly arises from fatigue, wherein cyclic stresses surpass the endurance limit of the gear tooth, resulting in tooth fracture. Moreover, M. Li et al.[5] analyzed the fatigue load associated with large wind power gear systems through the application of a multidimensional finite element method. Recently, Jam et al.[6] used the finite element approach to examine tooth surface contact, validating theoretical computations. Results suggest that the contact angle for internal gear pairs with double contact points should be less than 12.5°, and the pressure angle should range from 20° to 30°. However, gear speed substantially influences deformation and stress. A. Ghayal et al.[7] investigated a 9-speed geartrain system and, using certain materials and torque, found that deformation and stresses remained within acceptable ranges.

Although the majority of studies focus on finite element analysis to evaluate geartrain deformation and maximum stress there is a notable shortage of research regarding 12-speed geartrains. The present research aims to fill the existing gap by fabricating a 12-speed spur geartrain utilizing certain components and conducting an analysis using ANSYS. This study assesses deformation, maximum stress, and critical tooth contact locations to determine whether the material properties, gear speed, and forces can endure within acceptable limits without experiencing failure

## "2. Experimental section"

### 2.1 Mechanical condition of 12-speed gear trains for Finite elemental analysis

Gear trains are in 56 RPM to 667 RPM speed range with 12-speed steps at 60KW power supply — applied torque 1.560N.m to 100 N.m.

### 2.2 Material selection

Six material performance indicators are developed for material selection using a set of main gear design requirements. These are the bending fatigue limit index, the bending fatigue lifetime index, the abrasive wear index, the surface fatigue lifetime index, and the machinability index [8].

- **Material for Gear: Alloy steel, maraging, 300.**
- **Material for Shaft: Carbon steel, 1095, annealed.**

### 2.3 Speed progression ratio and speed selection

**($N_{max}$ / $N_{min}$) = $\phi^{n-1}$| $N_{max}$ = 667 RPM| $N_{min}$ = 56 RPM| Step Φ = 1.2526**

### 2.4 Structural Formula, Kinematic Arrangement and Ray Diagram

**Table 1.** Speed selection according to geometric progression ratio.

| | |
|---|---|
| **N1** | **56** |
| **N2** | **70.16** |
| **N3** | **87.86** |
| **N4** | **110.05** |
| **N5** | **137.86** |
| **N6** | **172.68** |
| **N7** | **216.30** |
| **N8** | **270.94** |
| **N9** | **339.38** |
| **N10** | **425.10** |
| **N11** | **532.49** |
| **N12** | **667** |

| | | |
|---|---|---|
| **(i) 2(1) 2(2) 3(4)** | **(ii) 2(6) 2(1) 3(2)** | **(iii) 2(3) 2(6) 3(1)** |
| **(iv) 3(1) 2(3) 2(6)** | **(v) 3(4) 2(1) 2(2)** | **(vi) 3(2) 2(6) 2(1)** |
| **(vii) 2(1) 3(2) 2(6)** | **(viii) 2(6) 3(1) 2(3)** | **(ix) 2(2) 3(4) 2(1)** |

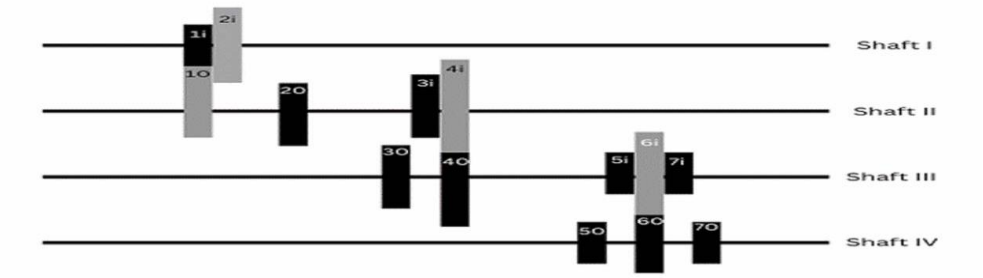



**Fig.1.** Kinematic diagram of 12-speed gear Box.

Table 1 represents the selection of speeds using a geometric progression ratio. Single input speeds are divided according to user specifications. Fig 1 depicts the kinematic diagram. In stages, input speeds are split into 12 speeds. Ray Diagram: Fig 2 exhibits the structural formula. The speed of the stage gear, the transmission ratio, and the total speeds are represented.

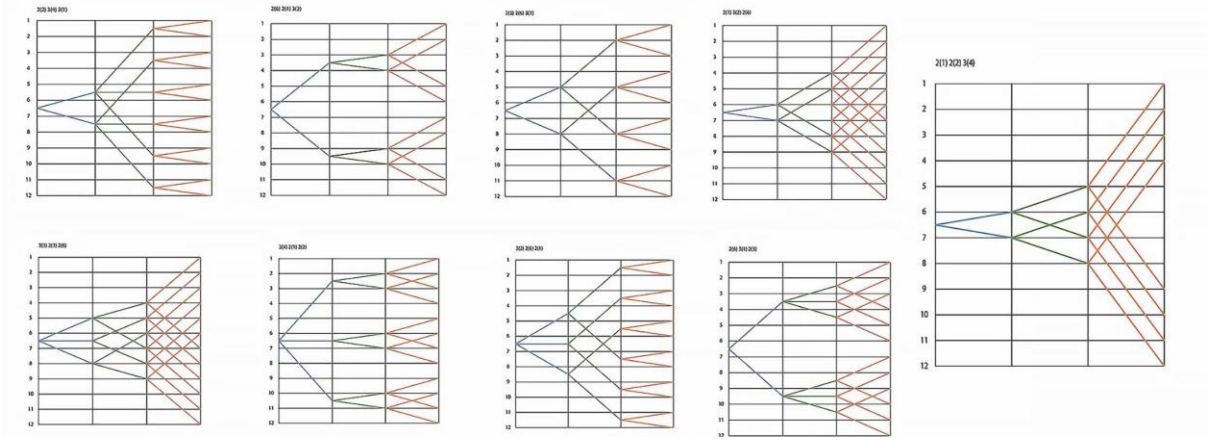


**Fig.2.** Ray diagram of the 12-speed gear train.

## 2.5 Calculation of the number of teeth, pitch diameter and shaft diameter.

Using structural diagrams Table 2 demonstrates the optimal node and calculated gear pair data.
To calculate the number of teeth on a gear pair, We used the following formula:

$N_{pinion} / N_{gear} = Z_{gear} / Z_{pinion}$

**Table 2.** Nodal analysis for optimal structural formula & Number of teeth, pitch, and shaft diameter**.**

| Structural Diagram | Highest Node No. | | | | ∑Node no. |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| **i** | 6.5 | 7 | 8 | 12 | 33.5 **(Optimal)** |
| **ii** | 6.5 | 9.5 | 10 | 12 | 38 |
| **iii** | 6.5 | 8 | 11 | 12 | 37.5 |
| **iv** | 6.5 | 7.5 | 9 | 12 | 35 |
| **v** | 6.5 | 10.5 | 11 | 12 | 40 |
| **vi** | 6.5 | 8.5 | 11.5 | 12 | 38.5 |
| **vii** | 6.5 | 7 | 9 | 12 | 34.5 |
| **viii** | 6.5 | 9.5 | 10.5 | 12 | 38.5 |
| **ix** | 6.5 | 7.5 | 11.5 | 12 | 37.5 |

| From Left to Right Gear Diameter | Gear Teeth's |
|---|---|
| **Shaft -1** | |
| **$D_{11}$ = 90mm** | **$T_{11}$=36** |
| **$D_{12}$ = 80mm** | **$T_{12}$=32** |
| **Shaft -2** | |
| **$D_{21}$ = 80mm** | **$T_{21}$ = 32** |
| **$D_{22}$ = 90mm** | **$T_{22}$ = 36** |
| **$D_{23}$ = 62.5mm** | **$T_{23}$ = 25** |
| **$D_{24}$ = 50mm** | **$T_{24}$ = 20** |
| **Shaft-3** | |
| **$D_{31}$ = 50mm** | **$T_{31}$ = 20** |
| **$D_{32}$ = 62.5mm** | **$T_{32}$ = 25** |
| **$D_{33}$ = 110mm** | **$T_{33}$ = 44** |
| **$D_{34}$ = 77.5mm** | **$T_{34}$ = 31** |
| **$D_{35}$ = 45mm** | **$T_{35}$ = 18** |
| **Shaft-4** | |
| **$D_{41}$ = 45mm** | **$T_{41}$ = 18** |
| **$D_{42}$ = 77.5mm** | **$T_{42}$ = 31** |
| **$D_{43}$ = 110mm** | **$T_{43}$ = 44** |
| **Shaft diameter and gear thickness** | **10mm** |

## "3. Finite elemental analysis of gear train"

Finite elemental analysis of the 12-speed gear train using ANSYS simulation. The aim is to identify and calculate the stresses and deformation on individual gear.
The gear train is made using the diameter and teeth calculation of the 12-speed gearbox. The parts and arrangement of the design are modeled in SOLIDWORKS. Fig 3 represents the 12-speed gear train.

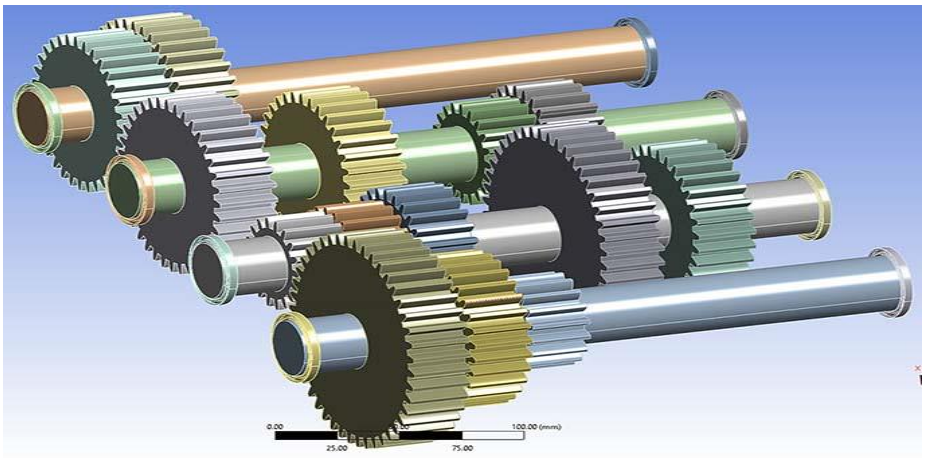


**Fig.3.**12-speed gear train arrangement.

High mesh nodes are crucial factors for the precise evaluation of the material. To calculate a more accurate result, the gear train mesh consisting of (nodes 383660& element 356092) is applied. Fig 4 depicts the applied mesh structure.

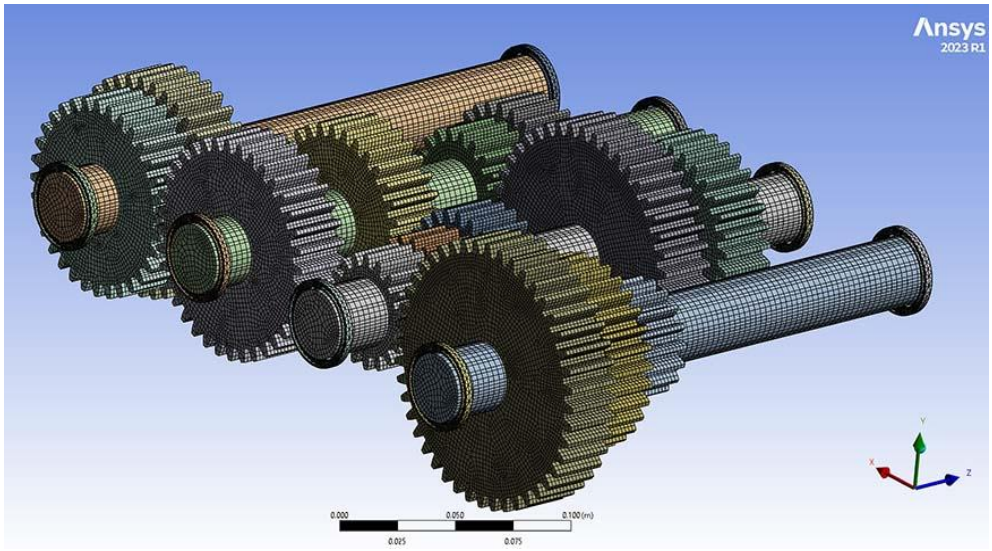



**Fig.4.**Applied mesh on 12-speed gear train arrangement.

Fig 5 shows Total deformation, Fig 6 shows Direction deformation, and Fig 7 shows Maximum principal stress. Mathematical models are used to analyze the gear train properties. Based on the acquired applied power supply & rpm, 100 N.m torque is applied on shaft 1, 1.956 N.m torque is applied on shaft 2, and 1.560 N.m torque is applied on shaft 3. Using the calculated gear pair data the manufactured 12-speed gear train is shown in Fig 8.

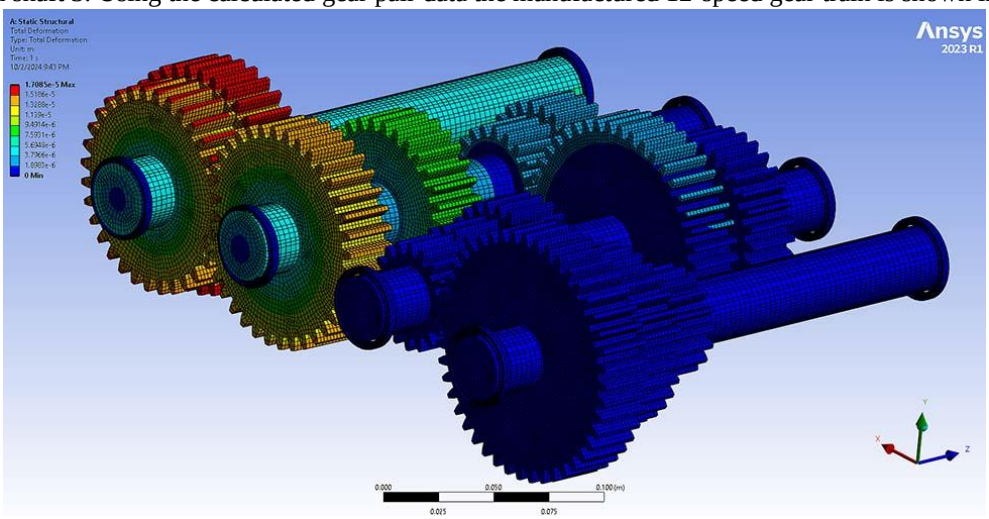



**Fig.5.**Total deformation of the 12-speed gear train.

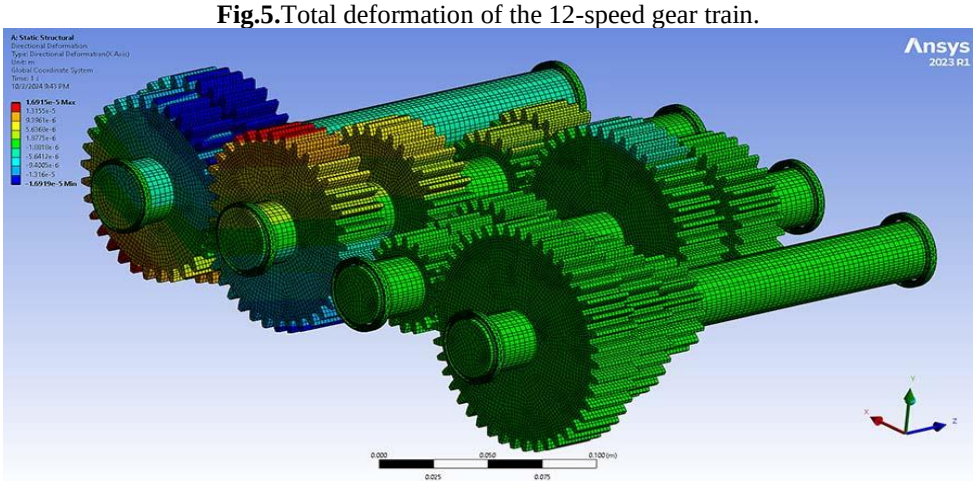



**Fig.6.**Directional deformation of the 12-speed gear train.

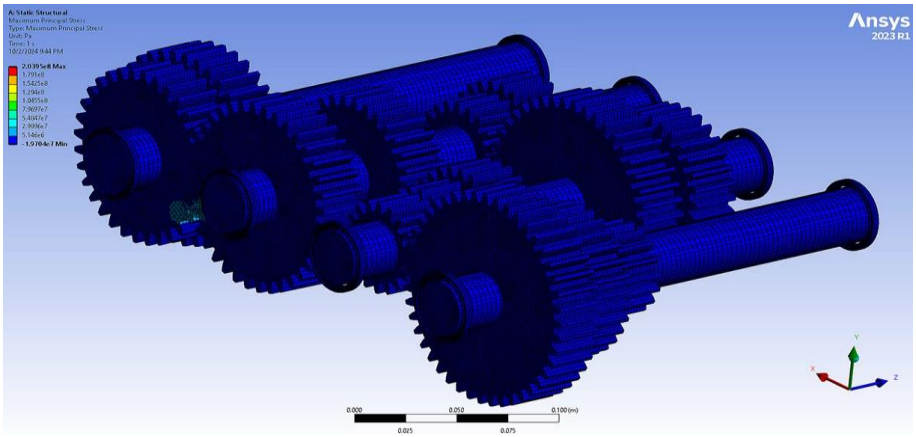



**Fig.7.**Maximum principal stress of the 12-speed gear train.



**Fig.8.** Manufactured 12-speed gear train arrangement.

## "4. Result"

The investigation of a twelve-speed gear train using an ANSYS simulation provides essential insights into its mechanical performance under various operating scenarios. The gear train operates within a speed range of 56 RPM to 667 RPM, supplied by a 60 kW supply, and encounters applied torque values from 1.560 N·m to 100 N·m. The material characteristics and the intricate mesh used in this simulation are crucial for analyzing the structural and stress performance of the gear train. The materials used, including maraging 300 alloy steel for the gears and carbon steel 1095 for the shafts, are recognized for their exceptional strength and endurance under significant loads, hence enhancing the overall structural integrity of the system. Table 3 demonstrates the Results of the simulations.

**Table 3.** Results of simulations.

| Result | Total deformation (m) | Directional deformation (m) | Maximum principal stress (Pa) |
|---|---|---|---|
| **Maximum** | $1.7085e^{-5}$ | $1.6915e^{-5}$ | $2.0395e^{+8}$ |
| **Mean** | $3.3473e^{-6}$ | $-9.0313e^{-10}$ | $3.024e^{+5}$ |
| **Minimum** | 0 | $-1.6919e^{-5}$ | $-1.9704e^{+7}$ |

**Mesh Analysis:** The mesh analysis demonstrates a total of 383,660 nodes and 356,092 elements, indicating a detailed and accurate discretization of the model. However, the lowest Jacobian ratio at the corner nodes is recorded at 0.113, which, while above typical failure thresholds, indicates the possibility of mesh distortion, especially in areas of high deformation. The Jacobian ratio at the Gauss points is $-1e^{+00}$, perhaps indicating a problem with element quality or inversion in some areas of the model. These variables may influence the precision of stress and deformation results in highly localized regions and should be considered in further refinement phases, perhaps via enhanced mesh density or the use of adaptive meshing methods in crucial locations such as gears and bearings.

**Total Deformation:** The maximum total deformation recorded is $1.7085e^{-5}$ meters, occurring in the spur gear with 36 teeth and a diameter of 90 mm. The minimal total deformation is recorded as 0 meters, predominantly in the bearing regions where the gear train experiences more constrained motion.

The mean deformation is $3.3473e^{-6}$ meters, indicating a rather little overall displacement inside the gear train under operating loads. This outcome is advantageous since little deformation at high torque values indicates the material selection and design's effectiveness in dealing with mechanical stresses. It is crucial to concentrate on the region of maximal deformation, since the spur gear may be vulnerable to wear or strain over time due to constant high loads, despite minimal absolute deformation.

**Directional Deformation:** The directional deformation result demonstrates a maximum of $1.6915e^{-5}$ meters, a minimum of $-1.6919e^{-5}$ meters, and an average of $-9.0313e^{-10}$ meters. The occurrence of maximal directional distortion on the 36-tooth spur gear emphasizes its pivotal role in the system's mechanical reaction. The negative minimum directional deformation indicates a level of compression or a reversal of strain direction, potentially arising under variable load circumstances. This highlights the need for additional investigation on this gear regarding stress distribution and fatigue performance, since variable loads may result in localized failures over time.

**Maximum Principal Stress:** The maximum principal stress is measured at $2.0395e^{+8}$ Pa, occurring at the spur gear with 36 teeth and a diameter of 90 mm. The increased level of stress indicates that this gear is subjected to substantial mechanical strain, corresponding with the observed deformation values. The minimum principal stress is $-1.9704e^{+7}$ Pa, demonstrating compressive stresses in certain parts of the model, possibly around the bearings where restricted mobility may result in stress development.
The mean principal stress is $3.024e^{+5}$ Pa, much lower than the maximum stress, implying that the majority of the structure endures reduced stresses, but some regions, such as the gear teeth, withstand higher localized loads. This high distribution of stress at the spur gear should be carefully examined in terms of material fatigue and potential failure points. The maximum stress is well within the yield strength of maraging 300 alloy steel, which can handle stresses up to $2.1e^{+9}$ Pa. However, given the cyclic nature of gear loading, fatigue analysis is critical to ensure that the gear can withstand long-term operation without material degradation.

## “5. Conclusion”

The engineered 12-speed gearbox appears to be secure and adequate, allowing for the continuation of the manufacturing process. The FEA models and results demonstrate the mechanical stability and efficiency of the 12-speed gear train system. The total and directional deformations are within permitted limits; nevertheless, the significant stress concentration on the spur gear requires more investigation.
Furthermore, the mesh quality, especially the Jacobian ratio, must be enhanced to increase result accuracy in areas of significant deformation. The minimal deformation and stress results suggest that the chosen materials and design parameters are appropriate for the anticipated mechanical loads. The research highlights the significance of meticulous material selection and the optimization of gear design, which improve gear longevity and performance. These findings contribute valuable knowledge to gear system design, offering potential applications in industries requiring robust, high-performance gear mechanisms.

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