Design and Analysis of Spur Gear Transmission for a Multi-Spindle Drilling and Tapping Special Purpose Machine

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Abstract

Special Purpose Machines (SPMs) have become essential in modern manufacturing environments, particularly where high-volume, repetitive machining operations like drilling and tapping are required. A critical subsystem of such machines is the power transmission unit, often achieved through gear drives. This research focuses on the detailed design and analysis of a spur gear transmission for a multi-spindle drilling and tapping SPM. The system is developed to ensure precise, efficient, and durable torque transmission from the motor to the spindle array. Key aspects such as material selection, gear geometry, load and stress calculations, and performance under working conditions are examined using established gear design principles, including the Lewis equation. This paper also presents the implications of gear design on system performance, cost, and longevity. The proposed design ensures long-term service with minimal maintenance, making it suitable for industrial applications.

Keywords

Spur Gear, Special Purpose Machine, Gear Design, Power Transmission, Lewis Equation, Stress Analysis, Productivity

1. Introduction

In today's competitive industrial environment, efficiency, precision, and reliability in production processes are paramount. The manufacturing industry increasingly relies on Special Purpose Machines (SPMs) to achieve high throughput and consistent quality. A multi-spindle drilling and tapping SPM is one such solution used for simultaneous operations on multiple components, significantly reducing cycle time and manual intervention.

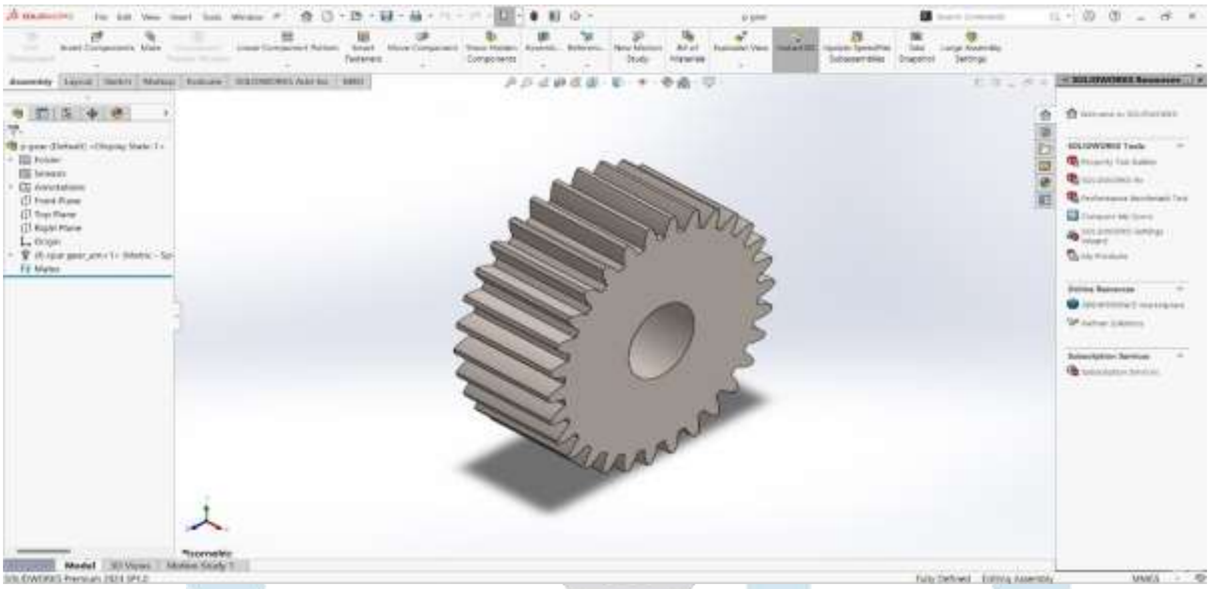
At the heart of the SPM lies the power transmission system. Gears are used to transmit motion and torque from the electric motor to the spindle heads. Spur gears, being one of the simplest and most commonly used types of gears, are widely applied for this purpose due to their straightforward design, ease of manufacturing, and high mechanical efficiency. This research paper focuses on the analytical design and stress analysis of the spur gear system used in such a machine.

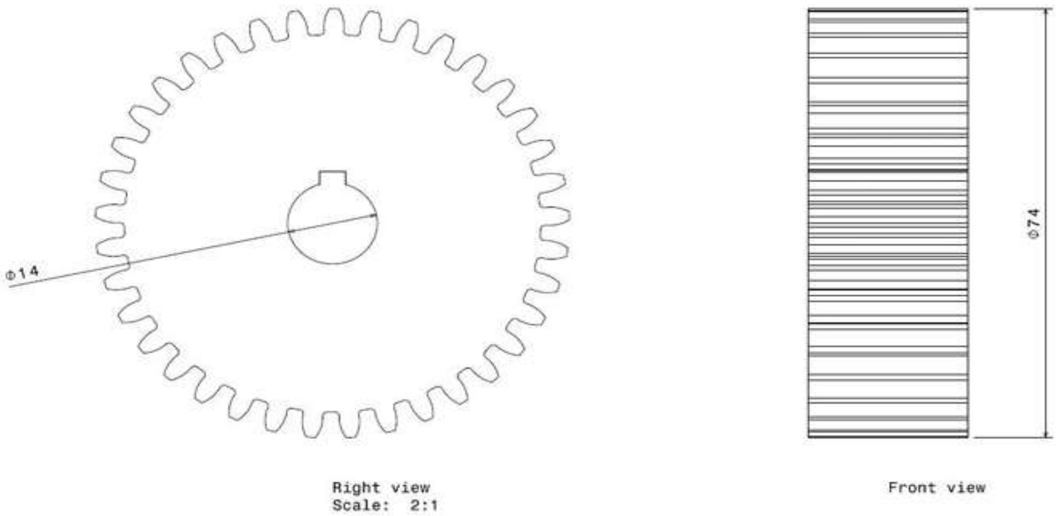
2. Overview of the Machine and Transmission System

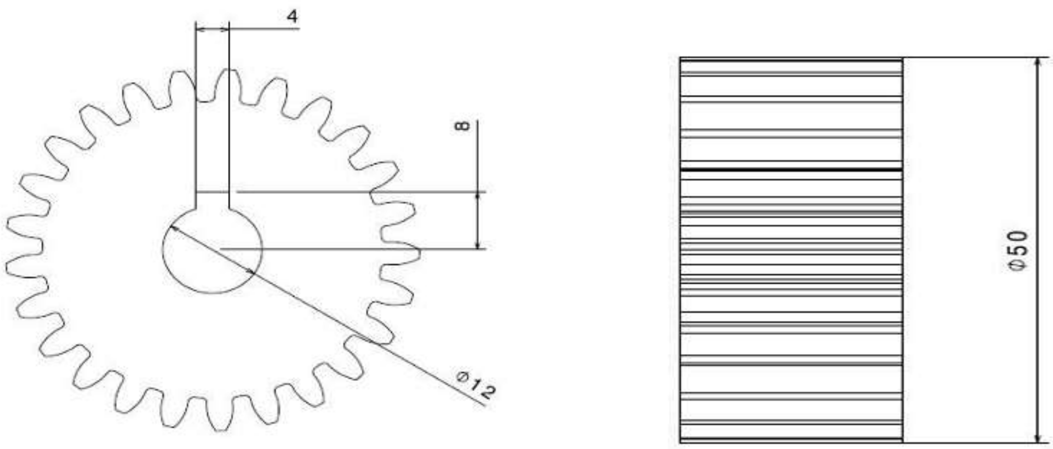
The Multi-Spindle Drilling and Tapping SPM is designed to operate under industrial conditions where it must function continuously for 8 hours a day over a lifespan of at least three years. The power source is a 0.37 kW motor operating at 1380 rpm. The power transmission must ensure torque amplification and synchronized operation of multiple spindles.

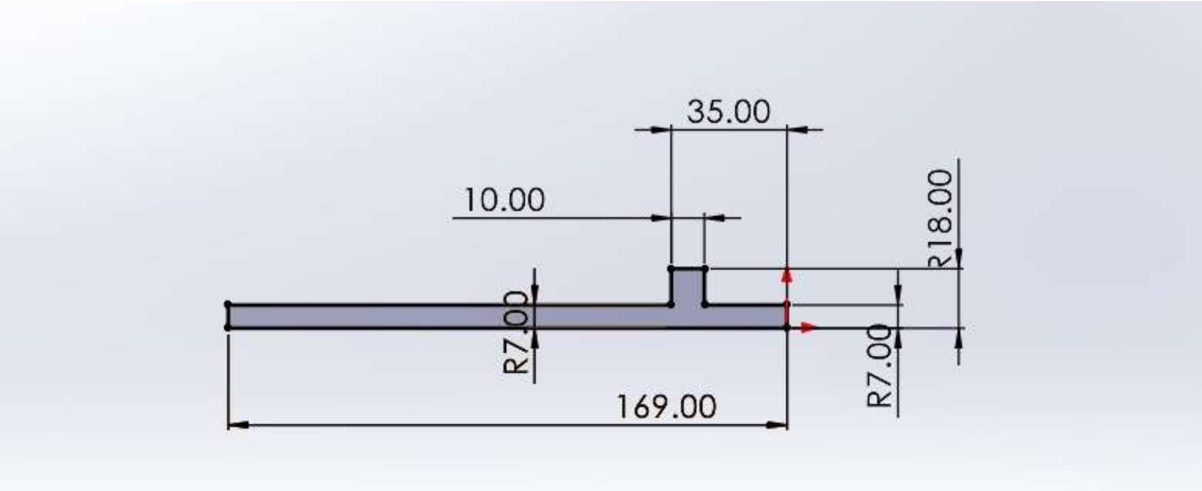
To achieve this, a gear ratio of 1.5 is selected. The gear system comprises a pinion with 30 teeth and a gear with 47 teeth, both fabricated from heat-treated C40 steel. The gears are aligned on parallel shafts and transmit power through direct contact using involute tooth profiles. The choice of spur gears over helical or bevel gears is guided by the need for simplicity, low maintenance, and compatibility with the required operating speeds and torque.

3. Gear Design Methodology





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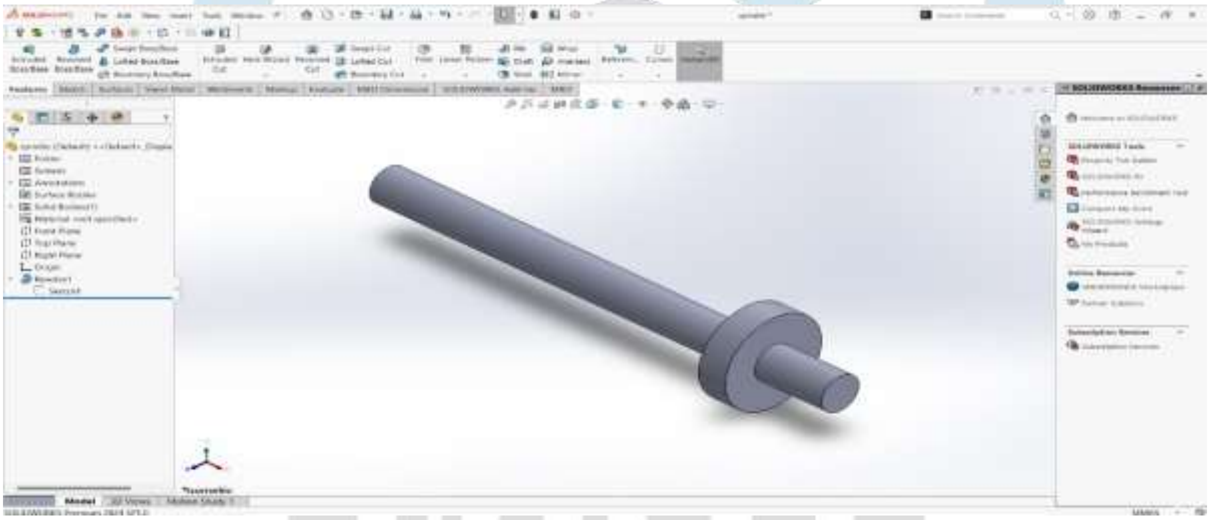

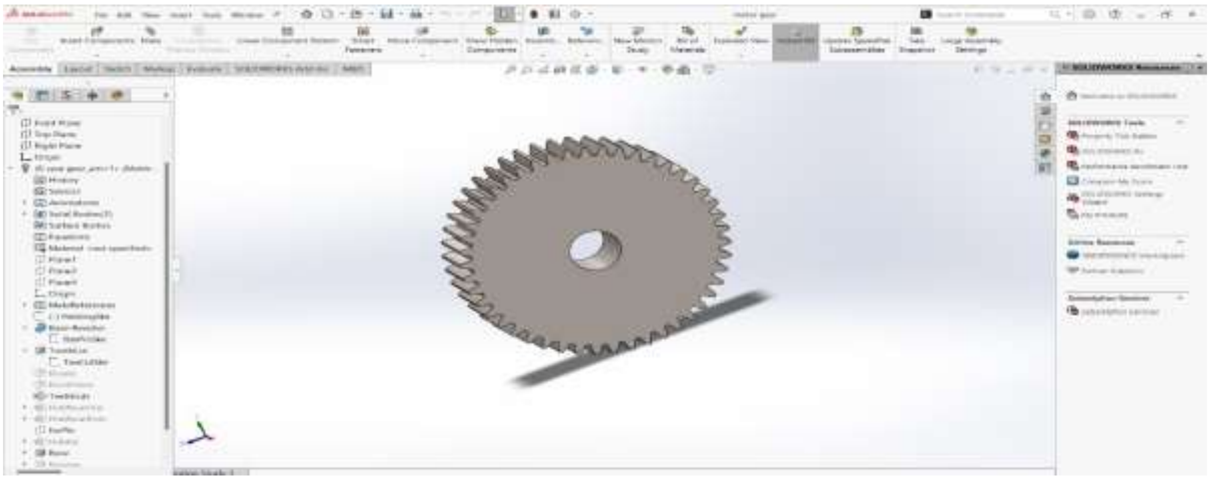

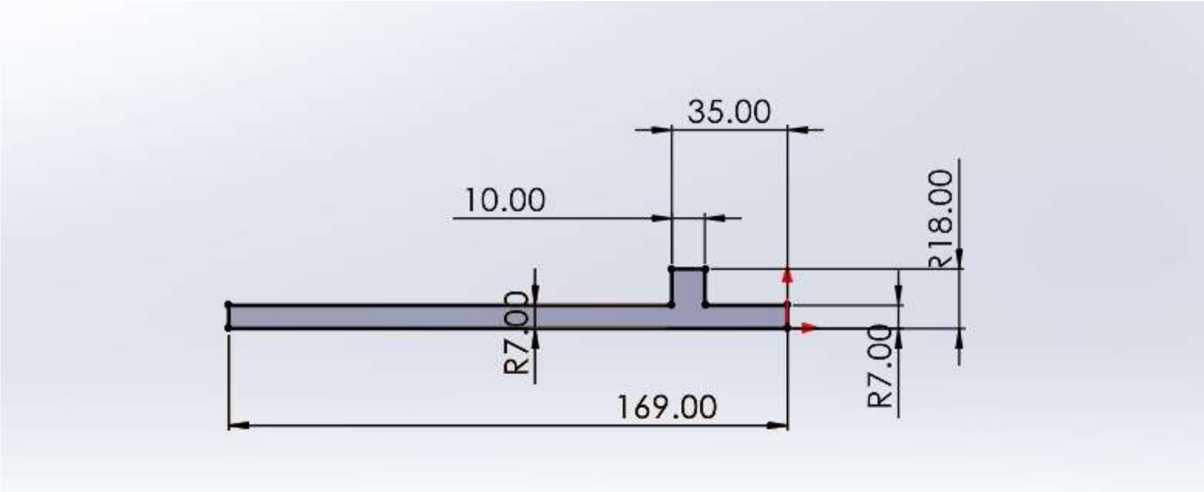
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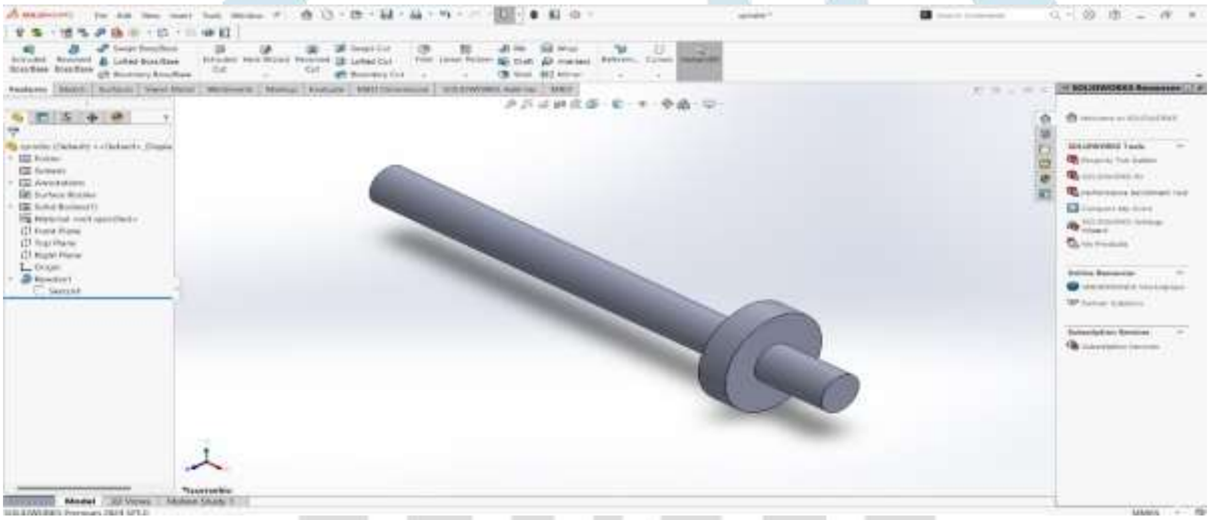
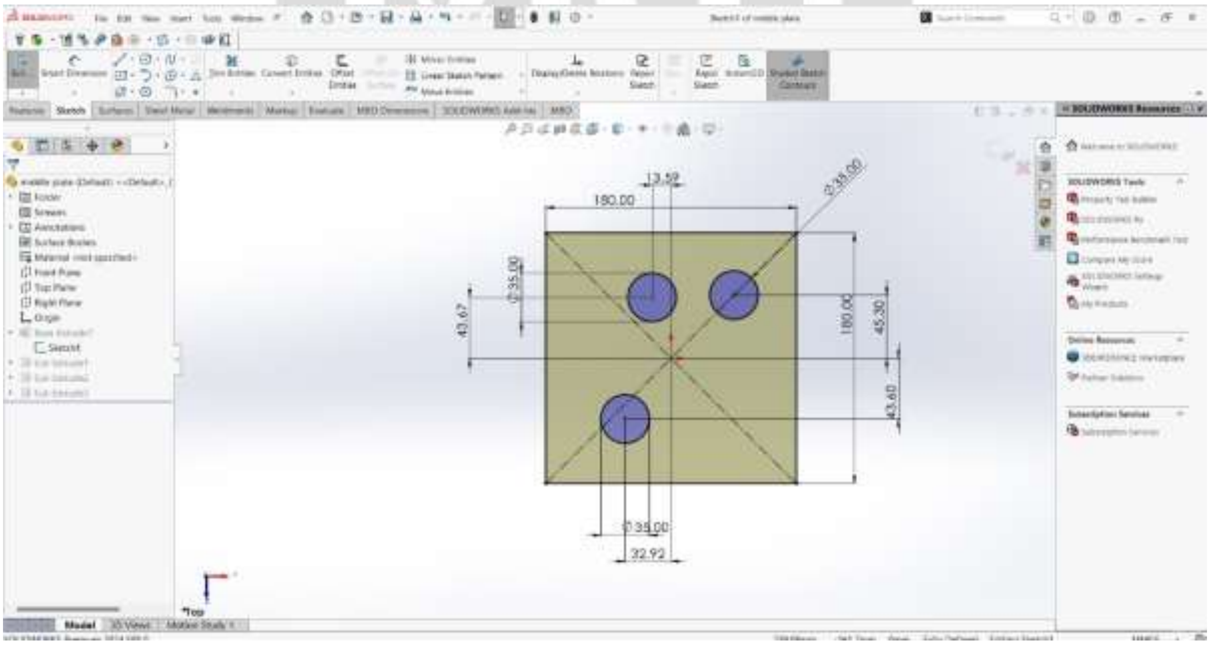
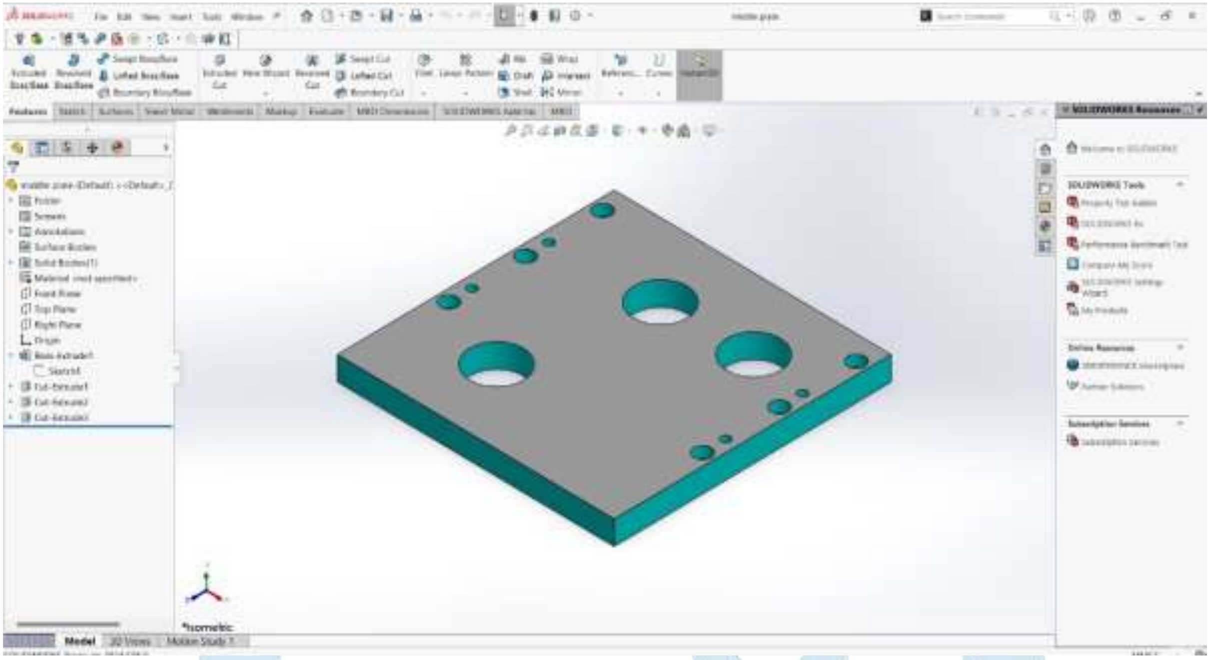
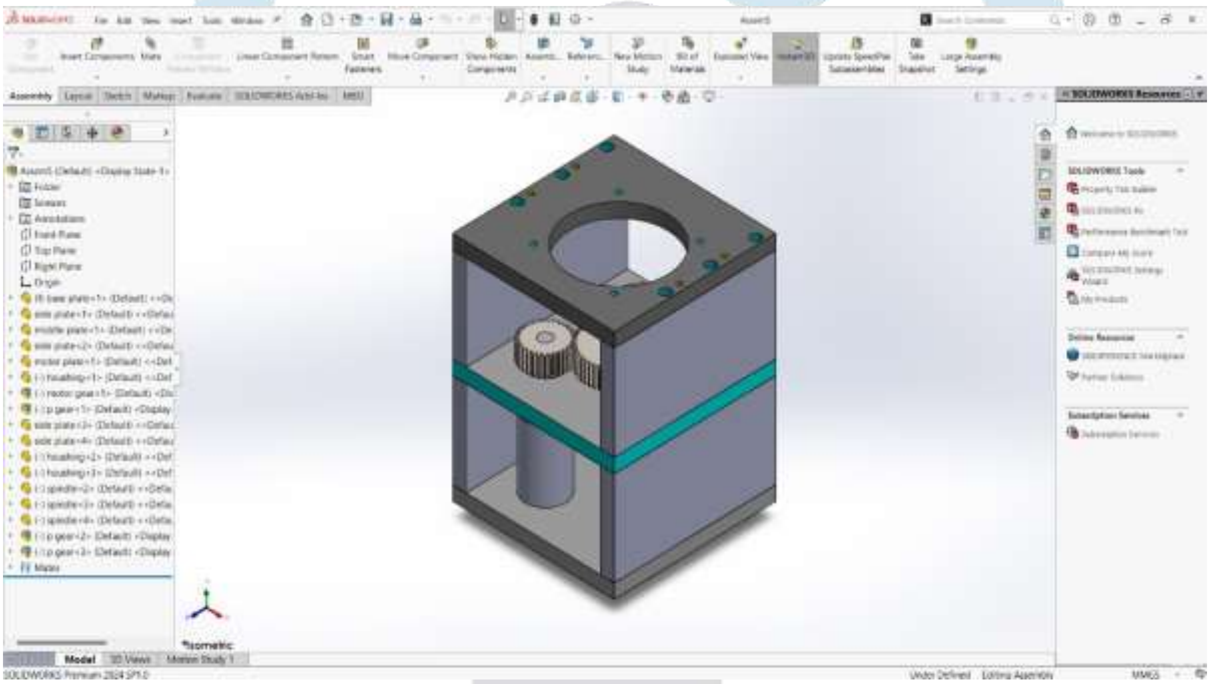




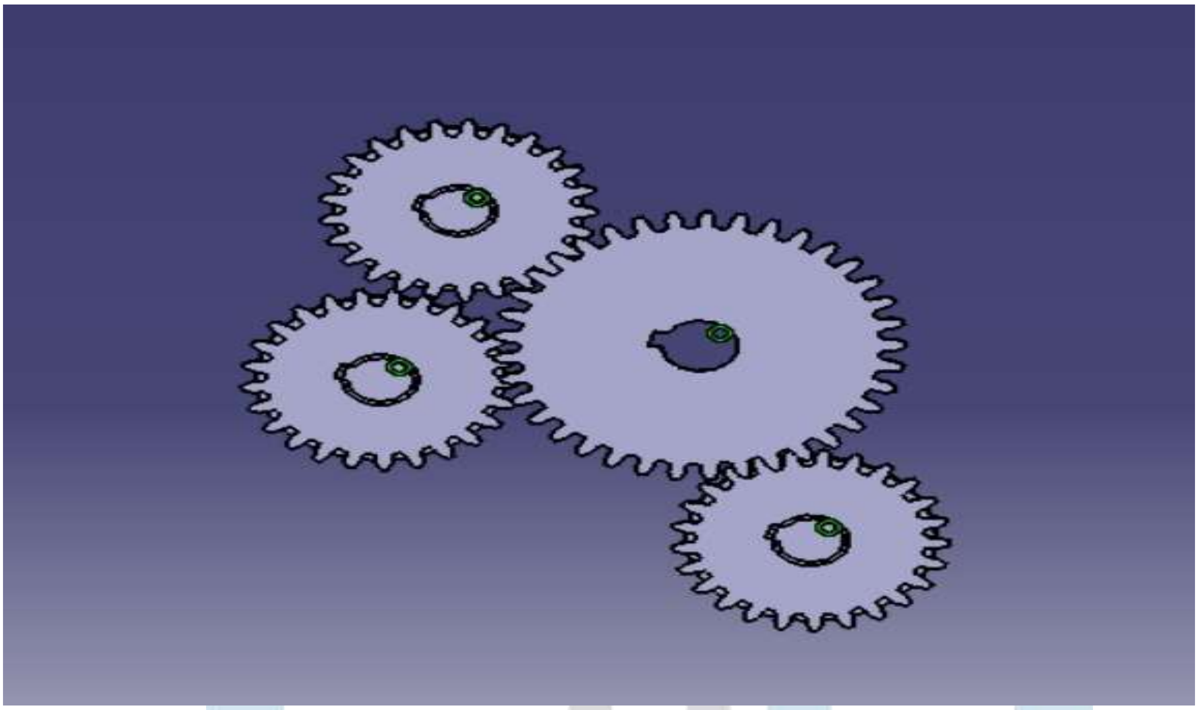




3.1 Selection of Parameter

Parameters	Value
Power (P)	0.37 kW
Speed of pinion (Np)	1380rpm
Speed of gear (Ng)	880rpm
Gear Ratio (i)	1.5
Number of teeth on pinion (Tp)	30
Number of teeth on gear (Tg)	47
Module (m)	1.5mm
Pressure angle (ϕ)	20°
Material	C40 Steel (heat treated)
Static Stress (σd)	196Mpa
Overload Factor	1.25

3.2 Gear Geometry



- Pitch Circle Diameter of Pinion (D_p):

  $D_p = m \times T_p = 1.5 \times 30 = 45$ mm

  Pitch Circle Diameter of Gear (D_g):

$D_g = 1.5 \times 47 = 70.5$ mm

- Center Distance (C):

$C = \frac{Dp+Dg}{2} = \frac{45+70.5}{2} = 57.75$ mm

3.3 Torque and Load Calculations

- Design Torque (with overload):

$T_d = \frac{5}{4} \times 0.37 \times \frac{1000\times60}{2\pi*1380} = 3.2$Nm

Tangential Load:

$F_t = \frac{2\times Td\times1000}{Dp} = \frac{2\times3.2\times1000}{45} = 142.23$ N

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4. Strength Analysis Using Lewis Equation

The Lewis equation relates the tangential load to gear tooth geometry and allowable stress:

$Ft = \sigma \cdot b \cdot y \cdot pc$

Where:

- σ: Permissible stress (MPa)
- b: Face width (mm)

- y: Lewis form factor
- p_c: Circular pitch (πm)

4.1 Velocity Factor

- Pitch Line Velocity:

$$v=\frac{\pi D p N p}{60\times 1000}=3.25 \text{ m/s}$$

Velocity Factor (Cv):

$$Cv=\frac{1.5}{1.5+v}=\frac{1.5}{4.75}=0.316$$

- Permissible Stress:

$$\sigma= \sigma d \cdot Cv=196\cdot 0.316=61.93 \text{ MPa}$$

4.2 Form Factor and Face Width

- Lewis Form Factor:

$$Y=0.154-\frac{0.912}{Tp}=0.1236$$

- Circular Pitch:

$$pc=\pi \cdot m=\pi\cdot 1.5=4.71\text{mm}$$

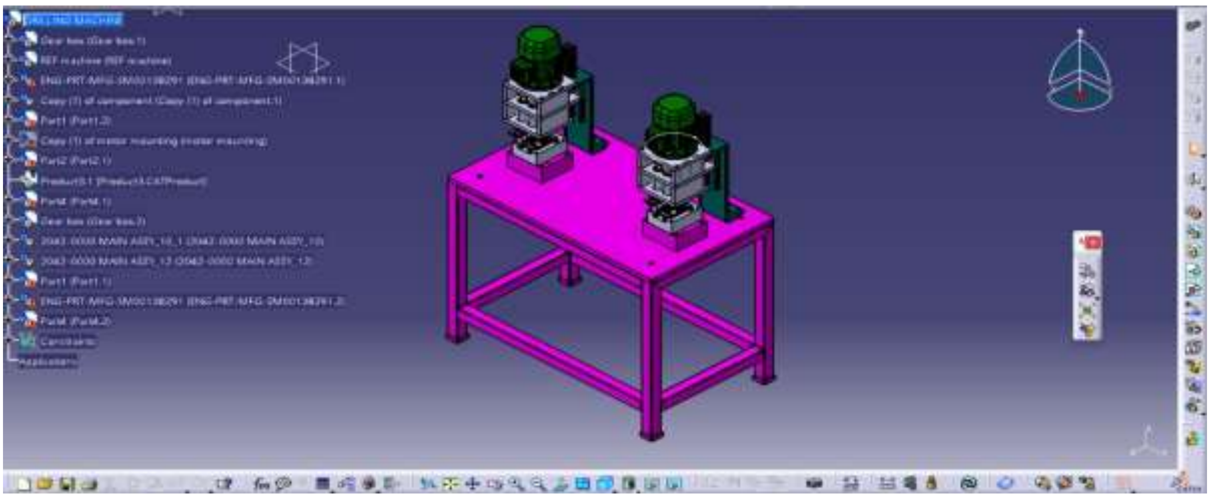
- Solving for Face Width:

$$b=\frac{Ft}{\sigma\cdot y\cdot pc}=\frac{142.23}{61.93\cdot 0.1236\cdot 4.71}=7.93 \text{ mm}$$

The final selected face width is rounded to **8 mm** for manufacturability and safety margin

5. Material Consideration

C40 steel is medium carbon steel, known for its strength and ability to be heat-treated to improve hardness and fatigue resistance. For this application, the gear teeth must endure repeated stress cycles, and C40 offers sufficient tensile strength (≈600 MPa) and wear resistance when appropriately treated.



The surface hardness is increased through carburizing or induction hardening to reduce wear and pitting under load. Moreover, it allows for effective tooth profiling and fine finishing post-heat treatment, contributing to noise reduction and transmission efficiency.

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6. Performance and Durability Analysis

6.1 Operating Life

The gears are designed to function:

- **8 hours/day**
- **6 days/week**
- **For 3 years**

Total operating hours:

$8 \times 6 \times 52 \times 3 = 7488$ hours

The selected material and geometry are adequate to support this operation under a moderate shock load condition with regular lubrication and alignment checks.

6.2 Noise and Efficiency

Spur gears inherently generate more noise than helical gears but are suitable here due to moderate speeds and the closed housing that dampens sound. The system achieves an efficiency of over 95% under steady-state operation.

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7. Advantages and Industrial Implications

The spur gear system offers the following advantages:

- Simple and low-cost manufacturing

- High mechanical efficiency and predictable performance
- Easy maintenance and inspection
- Compact design suited for automated machines

This makes it ideal for SPMs where reliability and repeatability are essential. The design also allows modularity, enabling adjustments in gear ratio for future process changes.

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8. Conclusion

This research presents a detailed study of spur gear transmission design for a multi-spindle drilling and tapping SPM. The approach combines theoretical calculation, material selection, and performance prediction to ensure a reliable power transmission system. The analysis confirms that a spur gear drive made from C40 steel, with a face width of 8 mm and an appropriate safety factor, can support prolonged industrial use. The proposed system enhances production efficiency while minimizing machine downtime and maintenance, fulfilling the critical needs of mass manufacturing.

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