Chapter 1

GEAR BOX DESIGN

The objective of this part of the project was to design a couple of rugged, efficient, and lightweight middle drive wheels integrated with a gearbox that can provide the needed torque and speed for the AGV.

Key objectives included:

1. To design the system in SolidWorks.
2. Check for structural integrity at operational loads.
3. Analyze gearbox performance for the required torque and speed to achieve a gear ratio of 20:1.
4. Simplify design for manufacturability and assembly.

1.1 LITERATURE SURVAY

AGVs are driverless transport systems used in the manufacturing industry, warehouses, and logistics. According to Groover (2015), in ”Automation, Production Systems, and Computer-Integrated Manufacturing,” an AGV would have a navigation system, a drive system, and sensors to operate autonomously. The driving system is the major component of an AGV, which provides the stability of the robot, the load-carrying capability, and the accuracy of motion.

In AGVs, middle drive wheels are important for balance and drive. Jazar's study, ”Vehicle Dynamics: Theory and Applications”, presented in the year 2019, gave much importance to wheel type, selection of motor, and gearbox that affects energy efficiency in a robot, how much load a robot can carry, adaptation on various kinds of terrain. A gearbox allows for the delivered torque and speed to the wheel for smooth, accurate movement.

Research on gearbox design for robotics has highlighted the requirement for compact, high-efficiency mechanisms. Kauffenberger et al. (2018) studied gear mechanisms in small mobile robots and found that among them, spur gears are the most used due to their simplicity, high load capacity, and ease of manufacturing. Their study also discussed the trade-off between gear ratios and torque output, noting that planetary gear systems provide higher torque.

The design of the drive wheel is critical for traction, maneuverability, and load-carrying capability. Bloss (2017), in ”Mobile Robotics: Principles and Design,” has discussed the role of drive wheels in robots, and he mentioned that material, tread pattern, and diameter of the wheel have a direct influence on performance. The wheels for AGVs are designed to meet both lightweight and high durability to allow for continuous operation with various loads.

The CAD tools utilized for the design of robot systems are quite popular, due to their advanced modeling and simulation capabilities. Das and Jana 2020, in the work ”Application of CAD Tools in Robotic Design”, have shown the capability of solid works to model complex assemblies such as gearboxes and also to simulate their motions.

Material selection is one of the most critical aspects in mechanical design. Ashby, 2011, ”Materials Selection in Mechanical Design” described a criterion for material selection that was based on strength, weight, cost and environmental considerations. Since this project dealt with drive wheels it mostly utilized rubberized materials, hence a thick rubber material was chosen, while gears are made from hardened steel preferred for its wear resistance and strength, it was also considered in my material selection.

1.2 REALISTIC CONSTRAINTS

In designing the two middle drive wheels with a gearbox in CAD, (SolidWorks), considerations to realistic constraints must be made to ensure the design is practical, manufacturable, and functional. Many a time, these constraints are classified into technical, material, economic, environmental, and human factors.

1.3 DESIGN CONSTRAINTS

1.3.1 Technical Constraints

These refer to limitations pertaining to the design's feasibility and functionality.

Dimensional Accuracy: The dimensions need to be precise so that the fitted parts inside assemble well.

Load Bearing Capacity: The wheels and gearbox should bear the expected loads without deforming or failing.

Speed and Torque Requirements: The gear ratio and wheel design must be such that desired performance is achieved.

Compatibility with Other Components: Ensure that the design fits well with the AGV chassis, sensors, and other systems.

Assembly and Maintenance: The design must ensure ease assembly, disassembly, and maintenance.

Simulation Accuracy: Limitations of CAD software may affect the accuracy of stress, motion, or thermal simulations.

1.3.2 Material Constraints

The choice of materials impacts weight, durability, and cost.

Strength and Durability: Materials must be able to handle the mechanical stresses without failure.

Weight: Lighter materials are always preferred for efficiency, but without sacrificing strength.

Availability: Materials selected must be available to the required quantity.

Cost: The high-performance material may be beyond the budget and therefore some compromise may be necessary.

1.3.3 Manufacturing Constraints

The design should consider the limitations of manufacturing methods.

Process Feasibility: The parts must be manufacturable using available processes such as CNC machining, casting or 3D printing.

Tool Accessibility: Shapes that include internal grooves or undercuts may not easily be machined due to complexity.

Surface Finish: Very complicated surfaces may be expensive or time-consuming to produce.

Assembly Difficulty: Designs that include many parts or tight clearances may be more difficult to assemble because of mating with specific part which may not be possible if there are too tight.

Standard Components: Using off-the-shelf components such as bearings and shafts rather than customized components simplifies production and reduces cost.

1.3.4 Economic Constraints

The design should be within the financial scope of the project.

Material Cost: High-quality materials can also raise costs.

Manufacturing Cost: Complex geometries and tight tolerances raise production costs.

Time Constraints: Designs, prototyping, and testing may be too time-consuming and hence may require simplifications.

1.3.5 Environmental Constraints

The design must ensure a minimal impact on the environment.

Energy Efficiency: The system shall minimize energy losses, for example, frictional losses or heat dissipation.

Material Sustainability: Materials used should be recyclable or eco-friendly wherever possible.

Waste Management: Waste generated in manufacturing is minimized.

Operating Environment: The system should be able to put up with all forms of environmental conditions, including humidity, dust, or an extreme temperature.

1.3.6 Human Constraints

The human factors bear on the usability and safety.

Ergonomics: The system shall be easy to handle during assembly and maintenance.

Safety: Ensure the design minimizes sharp edges or exposed moving parts that could cause injury.

User Expertise: The design shall take into consideration the expertise of the operators or assemblers.

Documentation: Clear assembly and operating instructions are essential for effective use.

1.4 METHODOLOGY

The methodology followed for the project in brief is given below:

1. Determination of dimensions, number of all gear teeth , and gear ratio.
2. 3D Modeling: Detailed CAD modeling of wheels, gears, shafts, and housing on SolidWorks.
3. Simulation: motion analysis to validate the design.
4. Optimization: Refined design for performance and manufacturability.

1.4.1 Dimensions

Ring gear which is the bigger gear has a dimater of 190 teeth
The planet gear has a diameter of 90mm
The sun gear has a diameter of 10mm

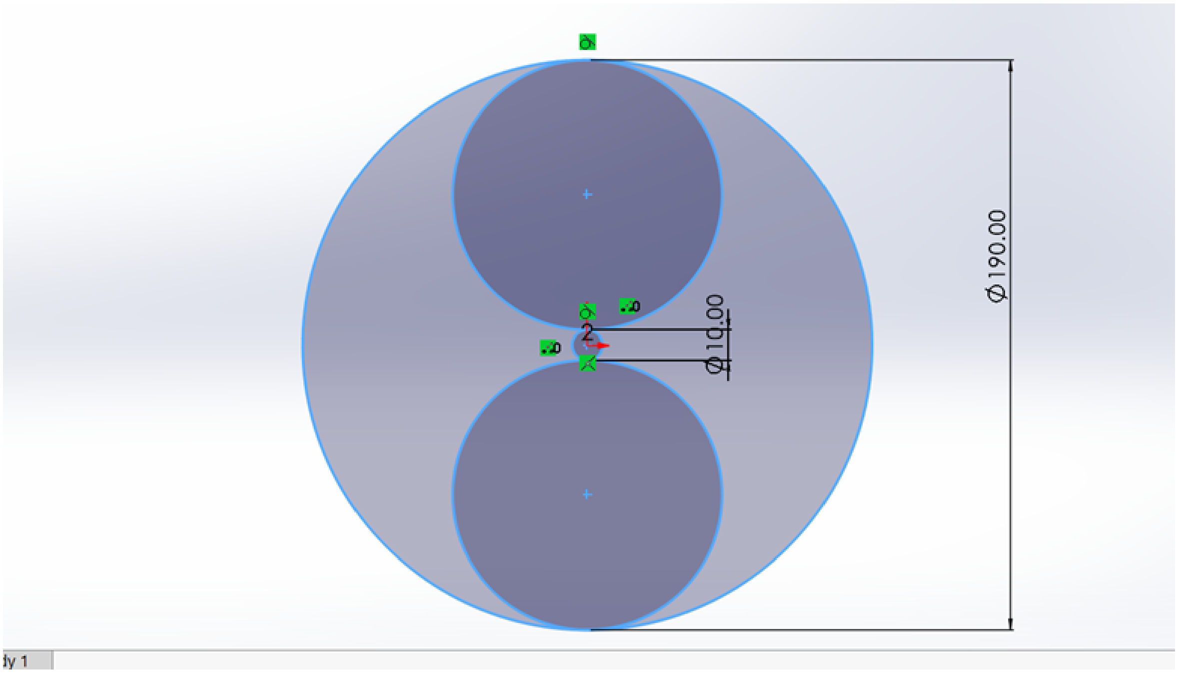


Figure 1.1: Add caption here

1.5 3D MODELING

Following components were modelled using SolidWorks:

1.5.1 Middle Drive Wheels:

For Traction and load-carrying capacity. Which is made of natural rubber has the ability to withstand high load and relatively not so heavy. The wheels for AGVs are designed to meet both lightweight and high durability to allow for continuous operation with various loads.

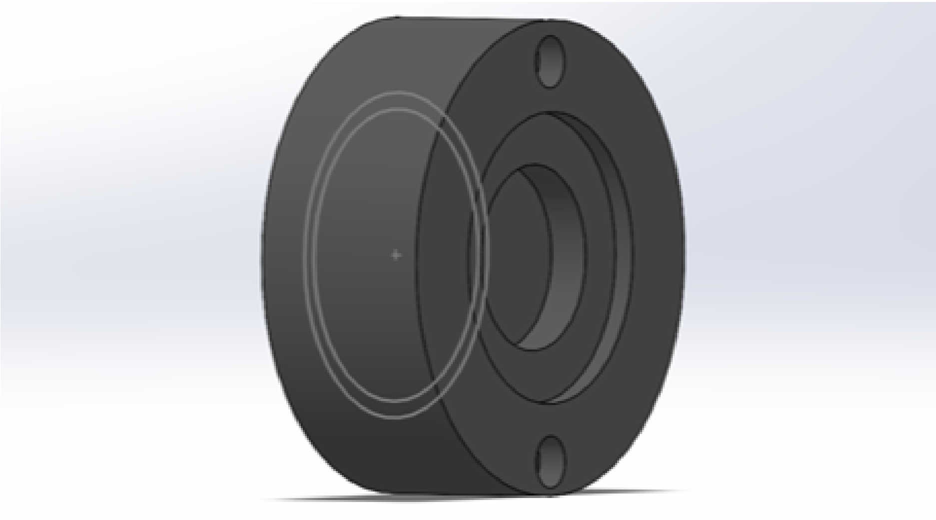


Figure 1.2: Caption 1

1.5.2 Gearbox:

Compact design with spur gears for efficient transmission. Studies shows spur gears are the most used due to their simplicity, high load capacity, and ease of manufacturing. Their study also discussed the trade-off between gear ratios and torque output, noting that planetary gear systems provide higher torque.

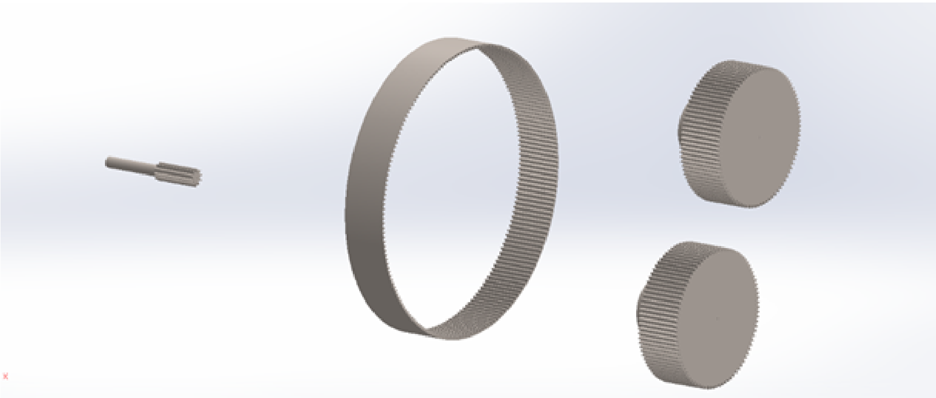


Figure 1.3: Caption 1

1.5.3 Shafts and Bearings:

For smooth rotation and distribution of loads. I made use of both skf bearing 108tn92 and skf bearing 1210ektn9202 while for the wheel holder it was made with hard steel for firmness and durability.

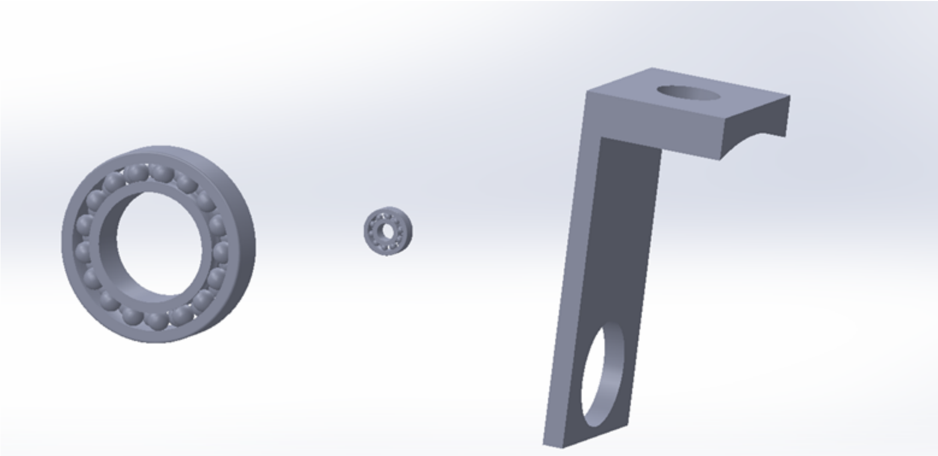
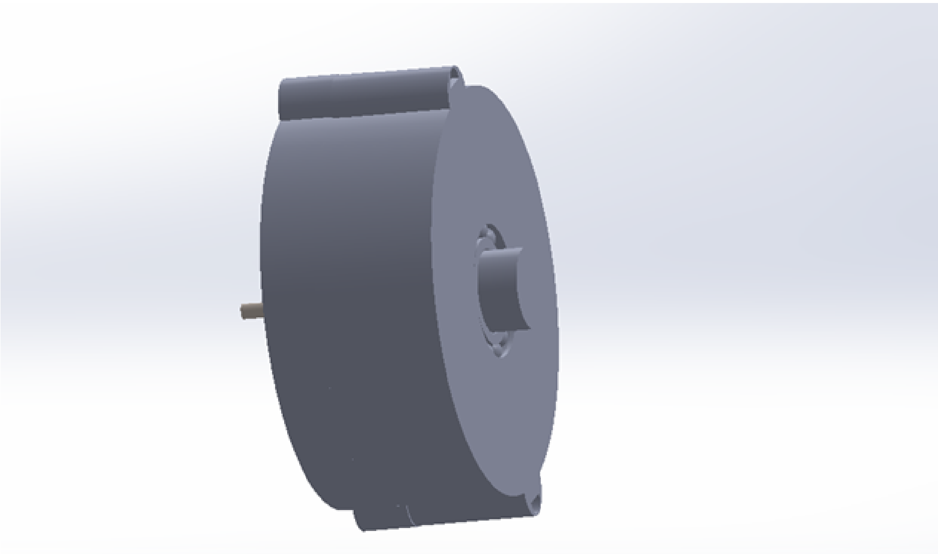


Figure 1.4: Caption 1

1.5.4 Housing:

Enclosed system for protection against dust and debris. Which lightweight aluminum were used to reduce the weight of the gear box.



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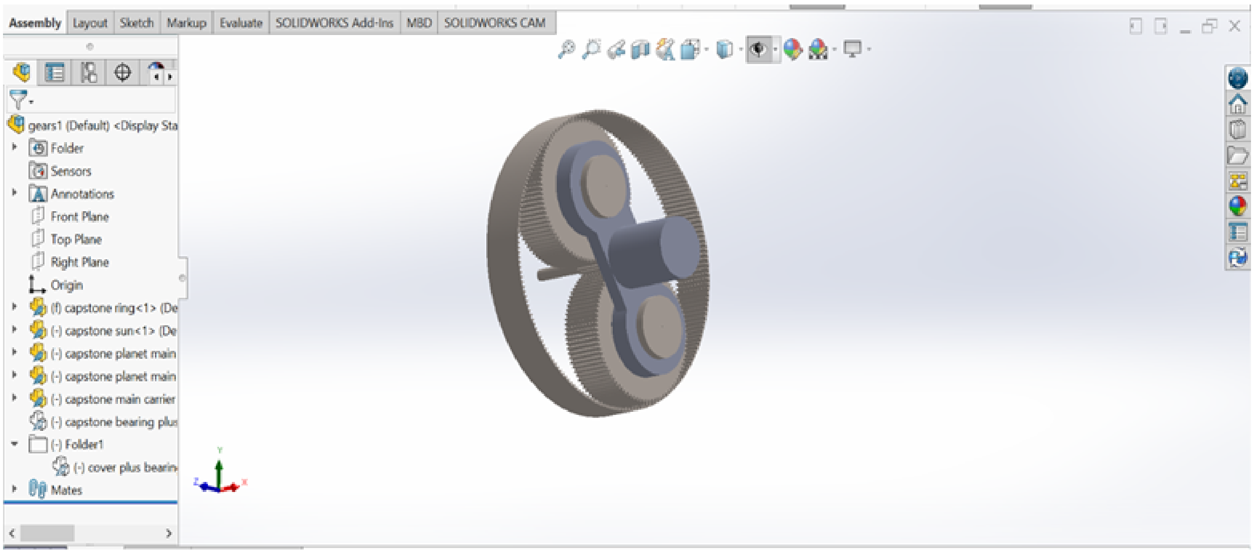
1.5.5 Assembly

The parts were then assembled in SolidWorks for a check on appropriateness and compatibility.



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1.6 CALCULATION AND ANALYSIS

Simulations done in SolidWorks to test performances of the design:

1.6.1 GEARBOX CALCULATION

- ring gear $\rightarrow$ 190 Teeth [120 mm ϕ] [Tr]
- PLAMET Gear $\rightarrow$ 90 Teeth [Tp]
- Sun gear $\rightarrow$ 10 Teeth [Ts]

GEAR RATIO : NOTE I want a high ratio of 20 : 1

$$20 = 1 + \frac{T_r}{T_s}$$
$$\frac{T_r}{T_s} = 19$$
$$T_r = 19T_s$$

The planet does not affect the ratio but determines the spacing of the sun and ring gears. Rearanging:

$$\frac{T_r}{T_s} = 19$$
$$IF\ T_s = 10$$
$$T_r = 19 * 10 = 190$$

from $T_r - T_s = 2T_p \rightarrow$ Spacing in the ring

$$\begin{aligned} 190 - 10 &= 2T_p \\ T_p &= 90 \\ \rightarrow 1 + \frac{T_r}{T_s} &\Rightarrow 1 + \frac{190}{10} = 20 \\ &\rightarrow 20:1 \end{aligned}$$

$\rightarrow$ 1500 input speed $\div 20(\mathit{gear\ ratio}) \Rightarrow 75 rmp$ output speed

Considering

Nema 23 stepper motor

Nominal power $\rightarrow$ 240 Watts

Nominal voltage $\rightarrow$ 484

Nominal current $\rightarrow$ 5 A

Maminal rotation $\rightarrow$ 1500rpm

$$T_{\text{in}} = \frac{P \times 60}{2\pi \times N} = \frac{240 \times 60}{2\pi \times 1500} \Rightarrow T_{\text{in}} = 1.53Nm$$

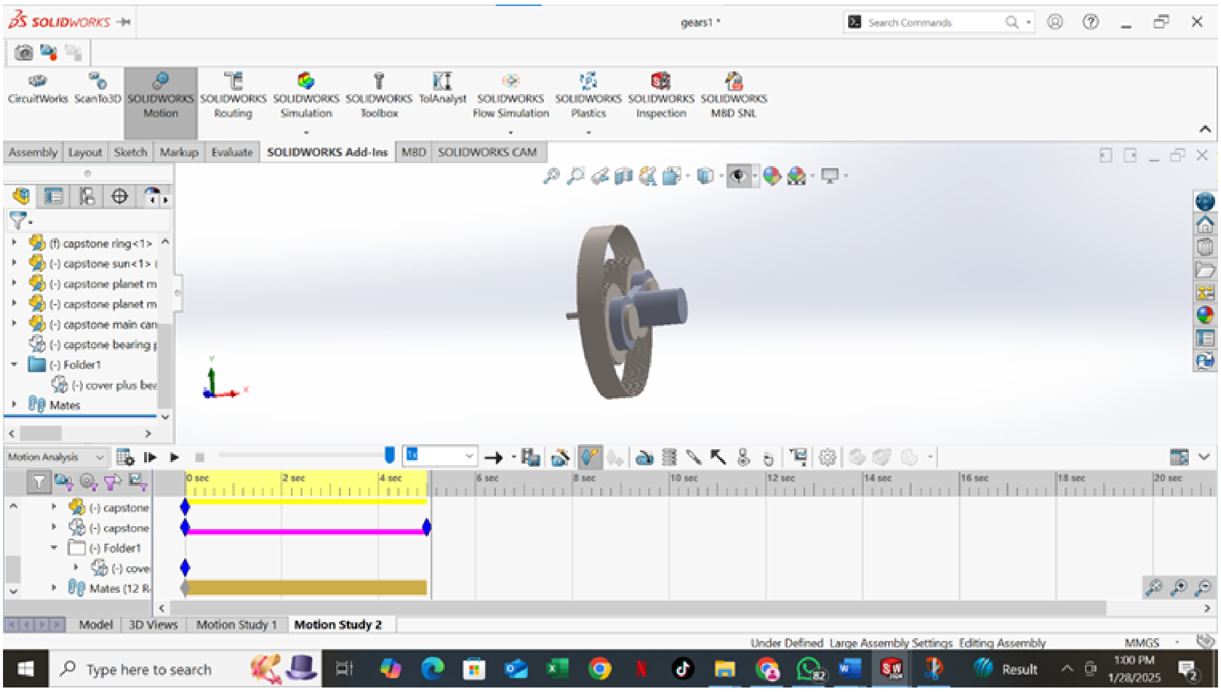
- This calalation is assumed 100% efficiency, Real - Idorly will be slightly lower due to losses [heat, friction]

$$\begin{aligned} T_{\text{out}} &= T_{\text{in}} \times R_{\text{atio}} \times \eta \\ &= 1.53 \times 20 \times 0.94 \\ &= 28.2Nm \end{aligned}$$

$$\begin{aligned} \eta[\text{ efficiency }] = \frac{\text{Out put power}}{\text{Input poise}} \times 100\% &= \frac{75 \times 28.2}{1500 \times 1.53} \\ &= \frac{2,115}{2,280} = 0.927 = 92\% \end{aligned}$$

1.7 MOTION ANALYSIS:

Wheels' rotation and torque transfer in the gearbox simulated.
Result: Smooth motion with efficiency in power transmission.



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Material Selection
Wheels: Natural rubber, corrosion resistant and high load capacity.
Gears: Hardened Steel for increased strength and wear resistance
Shafts: Steel for durability
Housing: aluminum protection
Results and Discussion

The final design was able to meet all the specified requirements, which included load capacity, torque output, and manufacturability. The simulations proved that the system was structurally sound and could operate without hitches under realistic conditions .

1.8 CONCLUSION

It should not only be functional, but also practical, manufacturable, and economic, taking into consideration all the constraints. The literature survey focuses on the fact that the gearbox-equipped drive wheel system is a main concern in the design of an AGV. Material selection, load-carrying capacity, torque optimization, and manufacturability are the key factors to be considered. In this paper, design and simulation for performance improvement of the AGV using SolidWorks are proposed to overcome these bottlenecks and help in the development of reliable high-performance drive systems for AGVs.

The middle drive wheels with an integrated gearbox were designed and further validated for use in an AGV. The system was reliable, efficient, and easy to manufacture. Future work can be the physical development of the prototype and performance testing at site applications..