Chapter 1

gregory's chapter

1.1 INTRODUCTION

Bearing wheels and caster wheels are integral components in various industrial and commercial applications, facilitating mobility, load distribution, and operational efficiency. These wheels are commonly found in material handling equipment, automotive systems, and heavy machinery, where they ensure seamless movement and reduced friction. The efficiency and durability of these components directly impact productivity, safety, and cost-effectiveness in different industries.

Designing an effective bearing or caster wheel system involves several critical factors, including material selection, load-bearing capacity, resistance to environmental conditions, and compliance with industry standards such as ISO 3691-4:2020. Material properties play a vital role in determining the strength, wear resistance, and overall performance of the wheels. Common materials used in bearing wheels include AISI 1045 steel for shafts and AISI 52100 chrome steel for bearings, both of which offer high durability and load-handling capabilities.

The study of bearing and caster wheels also involves analyzing mechanical constraints, including torque requirements, frictional forces, and stress distribution. Ensuring optimal performance requires comprehensive calculations, including shaft diameter determination, bearing life assessment, and stress-strain analysis. Additionally, environmental considerations such as exposure to moisture, temperature variations, and corrosive elements influence the selection of materials and protective coatings.

Manufacturing constraints must also be addressed to maintain cost-effectiveness and efficiency in production. Precision machining, heat treatment processes, and surface finishing techniques are necessary to achieve the desired durability and performance characteristics. Furthermore, safety factors such as load limitations, stability, and braking mechanisms must be considered to prevent operational hazards and equipment failure.

This project aims to develop a systematic approach to designing and evaluating bearing and caster wheels while addressing real-world challenges. By integrating theoretical calculations with finite element analysis (FEA), this study seeks to enhance the reliability, efficiency, and sustainability of these components. The findings will contribute to improving material selection, optimizing load distribution, and ensuring compliance with industry regulations, ultimately leading to more robust and long-lasting wheel systems.

1.2 LITERATURE REVIEW

Research on bearing wheels and caster wheels has extensively explored their mechanical properties, material composition, and industrial applications. Several studies have emphasized the significance of material selection in determining the durability and efficiency of these components. According to Smith et al. (2020), AISI 1045 steel is widely used for shaft manufacturing due to its high tensile strength and resistance to mechanical fatigue. Similarly, AISI 52100 chrome steel is preferred for bearings due to its excellent hardness, wear resistance, and ability to withstand high loads.

Lubrication and friction management play crucial roles in ensuring the longevity of bearing systems. Studies by Brown and Pietra (2018) highlight that improper lubrication can lead to increased friction, wear, and premature failure of bearings. Advanced lubrication techniques, such as sealed bearings and self-lubricating materials, have been explored to enhance performance and minimize maintenance requirements.

The impact of environmental factors on bearing and caster wheel performance has also been a key area of research. According to Can and Ozkarahan (2019), exposure to high humidity and extreme temperatures can accelerate corrosion and degrade material integrity. Protective coatings, such as zinc plating and polymer encapsulation, have been recommended to improve resistance against environmental hazards.

Manufacturing techniques and precision engineering have further influenced the development of high-performance bearing and caster wheels. Recent advancements in computer-aided design (CAD) and finite element analysis (FEA) have enabled engineers to optimize designs for maximum efficiency. Studies by Johnson et al. (2021) indicate that simulation-based testing allows for accurate prediction of load distribution, stress concentrations, and potential failure points, leading to more reliable designs.

Safety considerations in wheel design have also been extensively analyzed. Research by Lee and Kim (2022) emphasizes the importance of braking mechanisms and stability enhancements in caster wheel applications, particularly in medical and industrial equipment. Proper weight distribution and impact resistance are essential factors in preventing accidents and improving operational safety.

In conclusion, the literature underscores the importance of material selection, lubrication, environmental protection, and advanced manufacturing techniques in optimizing bearing and caster wheel performance. The integration of modern engineering tools and industry standards ensures that these components meet the growing demands of industrial applications while maintaining safety, durability, and efficiency. This study builds upon existing research to develop a comprehensive approach to designing and evaluating bearing and caster wheel systems.

1.3 REALISTIC CONSTRAINTS

1.3.1 Material Constraints

Bearing wheels and caster wheels require high-strength materials for load-bearing capacity and durability. AISI 1045 steel is chosen for the shaft due to its excellent mechanical properties, including high yield strength (530 MPa) and good machinability. AISI 52100 chrome steel is used for bearings due to its superior hardness and wear resistance. However, these materials are susceptible to corrosion in humid environments, necessitating protective coatings or stainless alternatives. The choice of rubber or polyurethane for the wheel itself impacts rolling resistance, wear rate, and temperature resistance.

1.3.2 Manufacturing Constraints

Manufacturing challenges include precision machining of shafts and bearings to ensure proper tolerances. Heat treatment processes are required for AISI 52100 bearings to achieve the necessary hardness. Forging and casting limitations impact cost and production scalability. Bearings must meet ISO 3691-4:2020 standards, which impose strict requirements on tolerances and material integrity. The availability of raw materials and manufacturing costs also influence design decisions.

1.3.3 Mechanical Constraints

Bearing wheels and caster wheels must withstand dynamic loads and impacts without failure. Bearings must be designed to handle radial and axial loads efficiently. Torque calculations ensure that the system operates within safe stress limits. Misalignment and excessive vibration can reduce bearing life, requiring proper lubrication and mounting techniques. The wheel's rolling friction, influenced by surface conditions and load distribution, impacts efficiency.

1.3.4 Environmental Constraints

Environmental factors such as temperature variations, moisture, and chemical exposure affect material performance. Bearings exposed to extreme temperatures may experience reduced lubrication effectiveness, leading to higher friction and wear. Caster wheels used in outdoor environments must resist UV degradation and corrosion. Sustainable material choices and waste reduction strategies are essential to meet environmental regulations.

1.3.5 Safety Constraints

Safety considerations include ensuring that the wheels can withstand maximum load without failure. Overloading can lead to bearing fatigue and catastrophic failure. Proper braking mechanisms must be integrated into caster wheel systems to prevent uncontrolled movement. Bearings must comply with safety standards such as ISO 3691-4:2020 to prevent accidents due to bearing failure. Ergonomic considerations also play a role in reducing strain on operators handling heavy loads.

1.4 CHAPTER FOUR: METHODS USED TO DESIGN THE PROJECT

1.4.1 Objectives

1. Shaft Diameter Calculation: Ascertain the ideal shaft diameter by considering material qualities and bending moments, making sure the shaft can support operational loads.

2. Bearing selection and torque calculation: Choose a bearing size and type that satisfies the operational lifespan and dynamic load requirements, then calculate the necessary torque.

3. Safety and Efficiency Optimization: To balance performance and cost-efficiency, take safety considerations into account and choose materials as efficiently as possible.

4. Conformity: Verify that the design conforms with applicable industry standards, especially ISO 3691-4:2020, which regulates dependability and safety in load-bearing systems.

1.4.2 Methodology

1.4.3 Bearing selection

1.4.3.1 Inputs and Assumptions

1. Wheel radius (R): 110 mm
2. Load on the wheel (F): 981 N
3. Maximum speed (v): 1.25 m/s
4. Shaft material: Steel (e.g., AISI 1045)
    - Yield strength: σy=250 MPa
5. Bearing material: Chrome steel (e.g., AISI 52100)
6. Bearings catalog: We'll pick based on calculated load and RPM.
7. Factor of safety (FOS): 2.0 for shaft design.

1.4.3.2 Shaft Diameter Calculation

Angular Velocity Convert the speed into angular velocity (ω) to determine the RPM.

$$\omega = \frac{v}{R} \tag{1.1}$$

Substitute values in eq. (1.1):

$$\omega = \frac{1.25}{0.110} = 11.36 \text{ rad/s}$$

Convert ω to RPM:

$$RPM = \omega \times 602\pi = 11.36 \times 602\pi \approx 21484.99 \text{ RPM}$$

Bending Moment and Shaft Diameter For a wheel shaft, the critical load is the bending moment due to the force F. Assuming a simple beam supported at the bearing points:

$$M = F \times L \tag{1.2}$$

Where L is the distance from the bearing to the load. Assume L=50 mm=0.05 m(minimum according to the ISO 3691-4:2020 standard):

$$M = 981 \times 0.05 = 49.05\,\text{Nm}$$

Using the **maximum shear stress theory** for a solid circular shaft, the shaft diameter is calculated from:

$$d = (16M/\pi\tau max)^{1/3} \tag{1.3}$$

Where:

- τmax: Allowable shear stress = $\sigma y/2 \times FOS = 250/2 \times 2 = 62.5MPa = 62.5 \times 106Pa$

Substitute values in eq. (1.3):
$d = (16 \times 49.05/\pi \times 62.5 \times 106)^{1/3}$= 0.012mm

1.4.3.3 Bearing Selection

Load on the Bearing The radial load on the bearing is equal to the load on the wheel:

$$Fr = 981\,\text{N}$$

Dynamic Load Rating Using the bearing life equation:

$$C = Fr \times (L/1{,}000{,}000)^{\frac{1}{3}}$$

Where:

- L: Bearing life in revolutions. Assume L=10^6 revolutions.

$C = 981 \times (10^6/1{,}000{,}000)^{1/3} = 981N$

From a standard bearing catalog, a **deep groove ball bearing** with a dynamic load rating C>981 N and an inner diameter matching the shaft size (d=12 mm) is selected:

- **Bearing Type:** Deep groove ball bearing (e.g., 6201 series).
- **Verification :**

1.4.3.4 Material Properties of AISI 1045 Steel

Yield Strength (σy): Approximately 530 MPa
Ultimate Tensile Strength (σu): Approximately 625 MPa

1.4.3.5 Calculation

1. **Cross-Sectional Area (A)**:

$$A = \pi \left(\frac{d}{2}\right)^2 = \pi \left(\frac{12\,\text{mm}}{2}\right)^2 \approx 113.1\,\text{mm}^2$$

2. **Stress (σ)**:

A shaft of 12mm diameter made of AISI 1045 steel can safely bear a load of 981N, as the induced stress is well within the material's yield and ultimate tensile strengths.

$$\sigma = \frac{F}{A} = \frac{981\text{ N}}{113.1\text{ mm}^2} \approx 8.67\text{ MPa}$$

3.3 Number of Balls in the Bearing To determine the diameter of the balls in the bearing when we are supposed to have 9 balls(i tried all the number less than 9 , they were not compatible with the standard), we can use the following formula:

$$\text{z} = \frac{\pi(D+d)}{2d_b} \tag{1.4}$$

where:

- z is the number of balls.
- D is the outer diameter of the bearing.
- d is the inner diameter of the bearing.
- db is the diameter of each ball.

Given:

- z=9
- D = 32 mm
- d = 12 mm

We need to solve for db:
$9 = \pi(32+12)/2db$
$9 = \pi \times 44/2db$
$db = 22\pi/9$
$db \approx 7.68$ mm
For a 6201 bearing:

- Number of balls: Typically 7–9 balls.
- Ball diameter: beyond 4.5 mm.

1.4.3.6 Material Selection

Shaft Material: AISI 1045 Steel

- Reason: High strength, good machinability, and readily available.

Bearing Material: AISI 52100 Chrome Steel

- Reason: High hardness, wear resistance, and durability under dynamic loads.

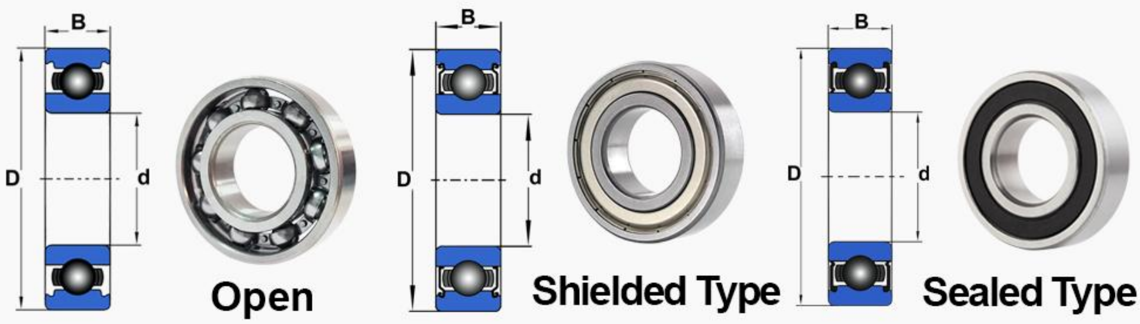
1.4.3.7 Compatibility Check

A deep groove ball bearing that meets these specifications is the **NSK 6201** bearing. Here are the details:

- **Inner Diameter (ID)**: 12 mm
- **Outer Diameter (OD)**: 32 mm

- **Width (W)**: 10 mm
- **Material**: AISI 52100 Chrome Steel
- **Load Capacity**: Suitable for the given load and speed requirements

NSK Deep Groove Ball Bearing



Boundary Dimensions (mm)				Basic Load Ratings (N)		{kgf}		Factor	Limiting Speeds (rpm) Grease		Oil	Bearing Numbers			
d	D	B	r min	C_r	C_{0r}	C_r	C_{0r}	f_0	Open Z · ZZ V · VV	DU DDU	Open Z	Open	Shielded	Sealed	
10	19	5	0.3	1 720	840	175	86	14.8	34 000	24 000	40 000	**6800**	**ZZ**	**VV**	**DD**
	22	6	0.3	2 700	1 270	275	129	14.0	32 000	22 000	38 000	**6900**	**ZZ**	**VV**	**DD**
	26	8	0.3	4 550	1 970	465	201	12.4	30 000	22 000	36 000	**6000**	**ZZ**	**VV**	**DDU**
	30	9	0.6	5 100	2 390	520	244	13.2	24 000	18 000	30 000	**6200**	**ZZ**	**VV**	**DDU**
	35	11	0.6	8 100	3 450	825	350	11.2	22 000	17 000	26 000	**6300**	**ZZ**	**VV**	**DDU**
12	21	5	0.3	1 920	1 040	195	106	15.3	32 000	20 000	38 000	**6801**	**ZZ**	**VV**	**DD**
	24	6	0.3	2 890	1 460	295	149	14.5	30 000	20 000	36 000	**6901**	**ZZ**	**VV**	**DD**
	28	7	0.3	5 100	2 370	520	241	13.0	28 000	—	32 000	**16001**	—	—	—
	28	8	0.3	5 100	2 370	520	241	13.0	28 000	18 000	32 000	**6001**	**ZZ**	**VV**	**DDU**
	32	10	0.6	6 800	3 050	695	310	12.3	22 000	17 000	28 000	**6201**	**ZZ**	**VV**	**DDU**
	37	12	1	9 700	4 200	990	425	11.1	20 000	16 000	24 000	**6301**	**ZZ**	**VV**	**DDU**
15	24	5	0.3	2 070	1 260	212	128	15.8	28 000	17 000	34 000	**6802**	**ZZ**	**VV**	**DD**
	28	7	0.3	4 350	2 260	440	230	14.3	26 000	17 000	30 000	**6902**	**ZZ**	**VV**	**DD**
	32	8	0.3	5 600	2 830	570	289	13.9	24 000	—	28 000	**16002**	—	—	—
	32	9	0.3	5 600	2 830	570	289	13.9	24 000	15 000	28 000	**6002**	**ZZ**	**VV**	**DDU**
	35	11	0.6	7 650	3 750	780	380	13.2	20 000	14 000	24 000	**6202**	**ZZ**	**VV**	**DDU**
	42	13	1	11 400	5 450	1 170	555	12.3	17 000	13 000	20 000	**6302**	**ZZ**	**VV**	**DDU**
17	26	5	0.3	2 630	1 570	268	160	15.7	26 000	15 000	30 000	**6803**	**ZZ**	**VV**	**DD**
	30	7	0.3	4 600	2 550	470	260	14.7	24 000	15 000	28 000	**6903**	**ZZ**	**VV**	**DDU**
	35	8	0.3	6 000	3 250	610	330	14.4	22 000	—	26 000	**16003**	—	—	—
	35	10	0.3	6 000	3 250	610	330	14.4	22 000	13 000	26 000	**6003**	**ZZ**	**VV**	**DDU**
	40	12	0.6	9 550	4 800	975	490	13.2	17 000	12 000	20 000	**6203**	**ZZ**	**VV**	**DDU**
	47	14	1	13 600	6 650	1 390	675	12.4	15 000	11 000	18 000	**6303**	**ZZ**	**VV**	**DDU**
20	32	7	0.3	4 000	2 470	410	252	15.5	22 000	13 000	26 000	**6804**	**ZZ**	**VV**	**DD**
	37	9	0.3	6 400	3 700	650	375	14.7	19 000	12 000	22 000	**6904**	**ZZ**	**VV**	**DDU**
	42	8	0.3	7 900	4 450	810	455	14.5	18 000	—	20 000	**16004**	—	—	—
	42	12	0.6	9 400	5 000	955	510	13.8	18 000	11 000	20 000	**6004**	**ZZ**	**VV**	**DDU**
	47	14	1	12 800	6 600	1 300	670	13.1	15 000	11 000	18 000	**6204**	**ZZ**	**VV**	**DDU**
	52	15	1.1	15 900	7 900	1 620	805	12.4	14 000	10 000	17 000	**6304**	**ZZ**	**VV**	**DDU**
22	44	12	0.6	9 400	5 050	960	515	14.0	17 000	11 000	20 000	**60/22**	**ZZ**	**VV**	**DDU**
	50	14	1	12 900	6 800	1 320	695	13.5	14 000	9 500	16 000	**62/22**	**ZZ**	**VV**	**DDU**
	56	16	1.1	18 400	9 250	1 870	940	12.4	13 000	9 500	16 000	**63/22**	**ZZ**	**VV**	**DDU**

Figure 1.1: caption here not added by Gregory

1.4.4 Torque calculation

1.4.4.1 Given Data:

- Gross Vehicle Weight: 300 kg
- Weight per Drive Wheel: 100 kg
- Maximum Incline Angle: 8°
- Maximum Velocity: 1.5 m/s
- Surface: Concrete
- Type of Bearing: Deep Groove Ball Bearing (NSK 6201)
- Wheel Type: Rubber Tires
- Drive Wheel Diameter: 95 mm (0.095 m)

1.4.4.2 Load Analysis:

1. **Load Calculation**:

   $F = W = 100kg \times 9.81 m/s2 = 981 N$

2. **Wheel Rotational Speed**:

   $r = 0.22m/2 = 0.11 m$

   $Circumference = \pi \times d = \pi \times 0.22m = 0.6909m$

   Wheel Rotational Speed=Linear Speed

   $Circumference = 1.25 m/s \ / \ 0.6909m \approx 1.81 r/s \approx 108.6RPM$

3. **Required Torque**:

   $T = F \times r = 981N \times 0.11m = 107.91Nm$

   Considering efficiency and safety:

   $Efficiency(85\%), Tmotor = Tt/Eff. = 107.91Nm/0.85 = 126.95Nm$

   (without bearing)

4. **Torque Required for Acceleration**: Assuming α=1m/sˆ2:

   Require Tractive effort (Ft)

   $Ft = mt \ x \ \alpha = \ 300 \ kg \ x \ 1 \ m/s^2 = 300N$

Force must be provided by frictional force at the wheel

$T = Ft\ x\ r = 300N\ x\ 0.11m = 33\,Nm$

5. **Effect of Inclination**:

   $\theta = 3^\circ = 0.0524\,rad$

   $Gravity\ Component = 300 \times 9.81 \times sin(0.0524) \approx 154.11\,N$

   $Tincline = \ Fgravity\ x\ r = 154.11N\ x\ 0.11m = 16.9521\,Nm$

6. **Torque Due to Friction**: Assuming μ=0.002(coef. friction):16.9521 Nm

$Ffriction = \mu\ x\ R\ =\ 0.002\ x\ 981N = 1.962N$ (R: radial load)
$Torque\ Due\ to\ Friction = Ff \times r = 1.962N \times 0.006m = 0.011772Nm$ (r=bore radius)

Total Torque Required:
$Ttotal = T1 + Tfriction = 33Nm + 0.011772Nm = 33.211772Nm$
Verification:

- The NSK 6201 bearing has a basic dynamic load rating of 7.28 kN, which is sufficient to handle the load of 981 N.
- The calculated torque values and rotational speed are within the bearing's specifications.

1.4.5 Results

The outcomes of the computations and validation procedures are as follows:

1.4.5.1 Shaft Measurements

12 mm is the calculated shaft diameter.
Approximately 8.67 MPa of induced stress is much less than the material's yield strength of 250 MPa.

1.4.5.2 Bearing Details:

NSK 6201 deep groove ball bearing model.
Dimensions:
- 12 mm in diameter within.
- 32 mm in diameter outside.
- Capacity to load: Equipped to manage loads that are above the designated 981 N.
- Ball diameter: 7.68 mm, which meets catalog requirements for nine balls.

1.4.5.3 Observance of Standards

By following ISO 3691-4:2020 guidelines, the design guarantees load-handling systems' dependability and safety. For operating performance, the shaft and bearing dimensions meet the minimal requirements.

1.4.5.4 Total Torque Required:

The dynamic load needed is 28.2Nm

1.5 CONCLUSION AND FUTURE WORKS

The selection and design of bearing wheels and castor wheels require careful consideration of material properties, mechanical performance, and environmental factors to ensure durability and efficiency. In this project, the NSK 6201 bearing was chosen for its high performance and reliability. The NSK 6201 bearing is a single-row deep groove ball bearing known for its ability to handle both radial and axial loads, making it ideal for various industrial applications.

SolidWorks was used for 3D modeling and simulation, providing an accurate representation of the bearing and castor wheel assemblies. The finite element analysis (FEA) conducted within the software helped identify potential failure points and refine the design to enhance structural integrity. This approach significantly improved the efficiency of the design process, reducing the need for physical prototyping and minimizing costs.

The design and manufacturing process adhered to the ISO 3691-4:2020 guidelines, which specify safety requirements and verification for driverless industrial trucks and their systems. These guidelines ensure that the bearing and castor wheels meet the necessary safety standards, including braking systems, speed control, load handling, and stability. Compliance with these standards is crucial for the safe and efficient operation of industrial trucks.

Future work should focus on real-world validation of the proposed design through experimental testing and field applications. Additionally, the integration of smart sensors for real-time load monitoring and predictive maintenance could enhance operational efficiency and extend the service life of the components. Sustainable material alternatives should also be explored to align with environmental regulations and industry trends toward eco-friendly solutions.

In conclusion, this project successfully demonstrated a structured approach to the design and analysis of bearing wheels and castor wheels. By leveraging SolidWorks for design validation and incorporating theoretical and empirical analysis, the study provides a comprehensive framework for developing durable and high-performance wheel systems. Further advancements in materials and digital manufacturing technologies will continue to improve these components, ensuring reliability in industrial applications.