# MENG 410

## Speed Reducer Project

Prof. Nidal Abu-Hamdeh

SPRING 2021

Sections: FA

### Team 4

| No. | Name | ID |
|---|---|---|
| 1 | **Faris Abdullah Al-Ghmadi** | 1845529 |
| 2 | **Sultan Mohammed Mizjaji** | 1846364 |
| 3 | **Sameer Abdulaziz Almarghalani** | 1846002 |
| 4 | **Ibrahim Khaled Al-Zahrani** | 1847424 |
| 5 | **Jayez Fayez Al-Rashidi** | 1847488 |
| 6 | **Ahmed Jamal Al-Harbi** | 1847432 |
| 7 | **Abdulrahman Fahad Al-Ghamdi** | 1848002 |
| 8 | **Fouad Muneer Bakhdlaq** | 1741548 |

# Table of Contents

# List of Tables

# List of Figures

# 1. Business Case

## 1.1 Executive summary

Online retailing is one of the largest types of commerce in the market today, but there are still many people who prefer the traditional way of shopping, especially for sensitive products and this is due to They fear that these products will be damaged during production lines or shipping operations. Amazon is planning to design a gearbox that helps reduce speed while moving between delivery lines. The main objective of this delivery line is to make the goods delivered to the buyer in the best way without delay. The team will have the skill to achieve the proper solution to the client's requirement.

Alternatives for this project were generated as the following, first alternative we have 4 shafts and 5 gears (helical, and bevel) and 3 bearings which make them in overall 3 stages. Second alternative is mechanism consists of three stages, 4 shafts and 6 helical gears and 8 bearing, the reduction ratio in the first stage is 10. Third alternative the system will include 8 bearing, 4 shafts, 4 spur gears,1 bevel gear and housing for the gearbox, the input shaft has double bearing to increase the stability of the gearbox. After compare the three alternatives with each other using Kepner Trego Decision Analysis (KTDA) technique, we chose Spur and bevel mechanism it is considered the third alternative.

The project has four basic phases. The initiation phase, planning phase Implementation phase and the closure phase. The initiation phase has the team formation and the kickoff meetings with the project advisor and client. The planning phase is where the project is divided from phases into major tasks and then sub tasks.  In addition, the use of MS Project aids the team in allocating tasks with time Project management tools such as the One Page Project Manager sheet and teamwork com were used to help keep track of the progress of tasks The Implementation phase is where the team starts the design calculation and use engineering software to help analyze the design in case of critical errors. After that modifications are made, and the manufacturing of the project is implemented the closure phase is where all deliverable is submitted for approval from client, advisor and coordinator and recommendations for further development are mentioned.

## 1.2 Literature review

Gearboxes are composed of many elements such as shaft, gears, and bearings. An electric motor has a specific force specified in horsepower (HP) and has an operational speed for the output shaft, in this section, we will introduce some of the literature reviews that has been done throughout the years regarding gears. One of the reasons why theoretical and numerical methods are preferred is because experimental testing can be particularly expensive. Wilcox and Coleman [1] conducted a study using finite element modeling for the stress analysis of gear tooth and according to their obtained results they suggested a new formula to determine root stresses. Elkholy [2] introduced a method to determine tooth load sharing especially for high contact ratio spur gearing. Mohanty [3] suggested an analytical method to calculate the individual tooth load during meshing cycle. He also referred to determination of the locations and sizes of contact zones along the path of contact for high contact ratio gearing ($2<C.R<3$).

## 1.3 Situational analysis

Our project client is Amazon, Amazon is one of the largest e-commerce sites and is also the largest online retailer in the world, Amazon is considered a good and useful option for those who like to buy their various needs from one place and in complete comfort. Amazon has recently joined the Saudi market, and the demand of delivering products is increasing massively. The company wants to start a new delivery line to keep up with the high demand, they have a motor already, but since they deal with various of products they asked us to design a gearbox to reduce the motor’s speed from 1800 rpm to 45 so the products will be delivered safely. the positive impact on society is that this delivery line will speed up the period of product delivery, and the person will be satisfied upon receiving the product and it is in good condition and does not suffer from scratches. This is what makes people trust in this store, and when you gain people's trust, the demand will increase and the profit for the company will increase.

## 1.4 Problem (Opportunity)

Online retailing is one of the largest types of commerce in the market today, and this is due to saving a lot of time and effort, as well as the great diversity of products within the electronic store sites, but there are still many people who prefer the traditional way of shopping, especially for sensitive products and this is due to They fear that these products will be damaged during delivery lines or shipping operations. Amazon is planning to design a gearbox that helps reduce speed while moving between delivery lines for you to suit all products, whether sensitive or otherwise.

The company's realistic evidence for the problem was based on a recent survey passed on to a large number of people who concluded that shopping online saves a lot of time and effort, but many people mentioned that they had bad experiences in shopping online because there are some damages to the products, especially Sensitive product.

This problem may affect the company in many ways. On the electronic level, the number of visitors to the site is decreasing, due to the lack of interest of customers in the services provided on it, and we do not forget that the site is a source of income for the company. Financially, the company loses its customers because of these concerns and this bad reputation that drives them to go to competitors.

## 1.5 Problem Analysis

### 1.5.1 Identify Needs

We are required to make a complete design of the speed reducer system attached to the system to drive the packing machine., Input rotation speed 1800 rpm, system output power 5 kW, required rotation speed for the designed system is 45 rpm, the system will have high reliability and quality, the design will also have limited space.

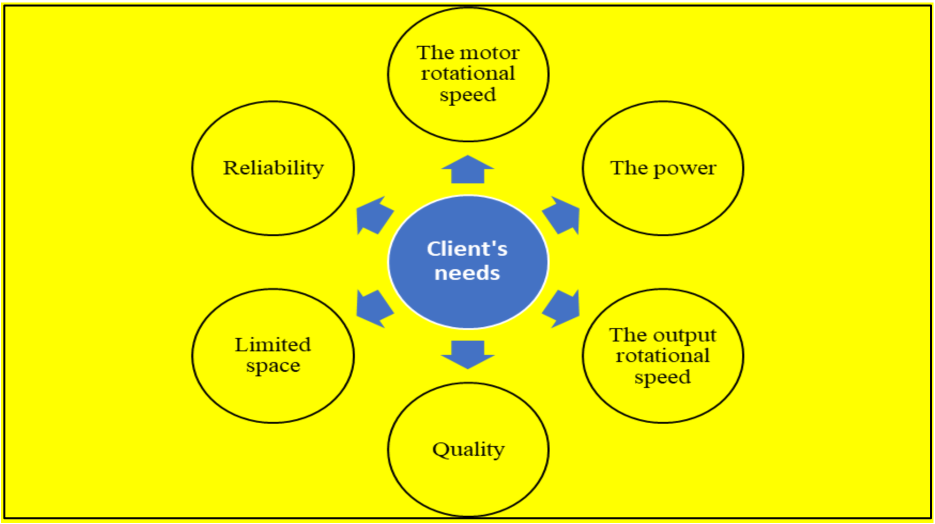



*Figure 1 Client's needs*

### 1.5.2 Design Parameters & Specifications

In this part we will show what are the client's needs and their design parameters and specifications.

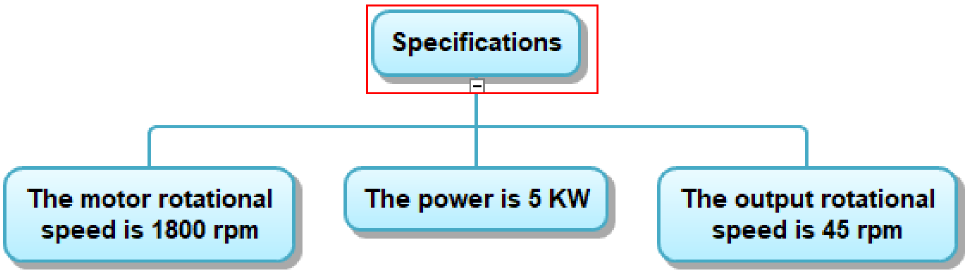



*Figure 2 Design Specifications*

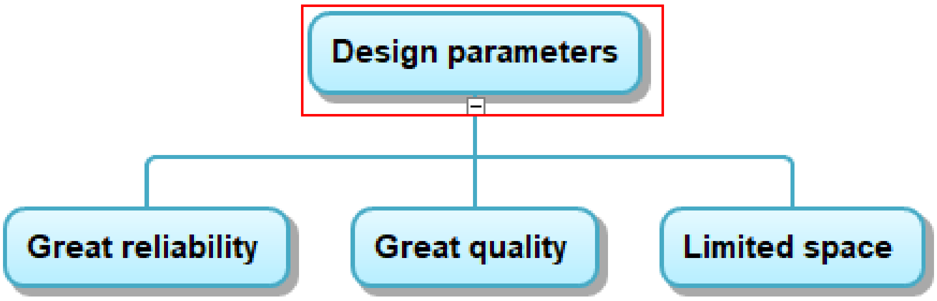



*Figure 3 Design parameters*

### 1.5.3 Musts & Want

In this part, we will discuss what are the musts and wants that the client mentioned to us, so that we will place for each want weight and we will not put a weight for it until the must is achieved, and we took into consideration that, where the musts represent the specifications, and the wants represent the design parameters.

*Table 1 Musts and Wants*

| Client's needs | Design parameters | Specifications | Musts & Want (weight) |
|---|---|---|---|
| Reliability | Satisfies reliability | - | Want (23) |
| Quality | Satisfies quality | - | Want (25) |
| Limited space | Minimum size | - | Want (25) |
| Motor speed | - | 1800 rpm | Must |
| Output power | - | 5 kw | Must |
| Output speed | - | 45 rpm | Must |

### 1.5.4 Realistic Constraints

As in engineering ethics there are some constraints we should have in our design, and these constrains will help us to achieve our client's needs.

*Table 2 Realistic constrains*

| Realistic Constraints | Design Parameters | Must & Want (Weight) |
|---|---|---|
| Safety | Select the factor of safety based on standards or best practice | Must |
| Environment | Maximize green design parts or recyclable | Want (7) |
| Easy to maintain | Minimize the needed time and effort | Want (10) |
| Easy to use | Reduce the time required to operate the system | Want (10) |

### 1.5.5 Standards

We are going to implement the STANDARDS in our design analysis (ANSI, DIN, SKF, ISO, ...etc).

## 1.6 Available Options

In this section we will provide a full listing of all solution options. We will provide specific information about each option.

### 1.6.1 Alternative 1 – Three stage speed reducer (Helical and bevel gears).

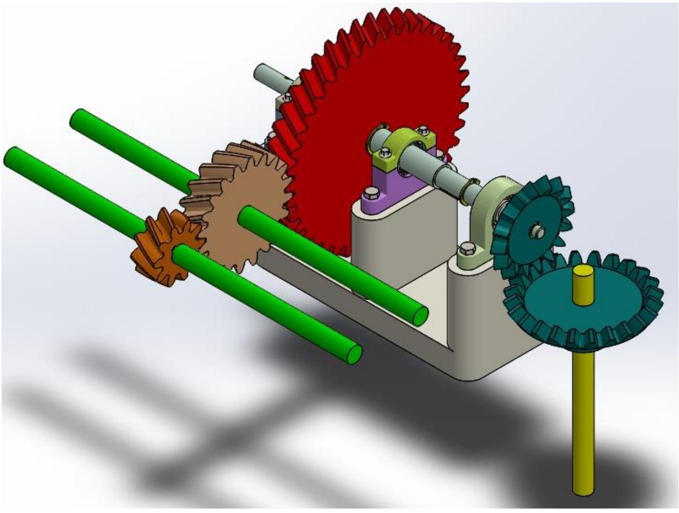


*Figure 4 Alternative 1*

### Description

In This alternative we have 4 shafts and 5 gears which make them in overall 3 stages, to elaborate more on our first alternative, this alternative will help to reduce the speed from 1800 rpm to 45 rpm, in first stage the speed will reduce from 1800 rpm to 360 rpm by using gear ratio 5, in second stage we will reduce the speed from 360 rpm to 90 rpm by applying gear ratio 4, in last stage the speed is going to reduce from 90 rpm to 45 rpm as we have been ask from the client, the 5 gears that we are using in this alternative are helical and bevel.

### Feasibility

Since Amazon might deliver sensitive products that are damaged by high speed while moving in delivery lines, which increases the company's loss, and this solution presented above reduces the speed and thus preserves the product more.

*Table 3 Alternative 1 of Alternative 1*

| Component | Rating (1-10) | Method Used to Determine Feasibility |
|---|---|---|
| New customers | 6 | Survey was completed to assess customer satisfaction currently. |
| Operational | 7 | • Helical gears are used to operate silently, damp and reduce the noise and vibration.<br>• Helical gears can handle more load and obtain high torque with lower stress than other gears.<br>• Maintenance of spur gears is easy.<br>• Using bevel gear will reduce the limit space. |

### Benefits

In this part, we will explain the benefit taken from this alternative, and the benefit will be of value in order to clarify the benefit further as you can see in the table below.

*Table 4 Benefits of Alternative 1*

| Category | Benefit | Value |
|---|---|---|
| **Fanatical** | Reduce the speed which will reduce the cost | 200\$-300\$ |
| **Operational** | • Reducing noise generated.<br>• Less operational down-time. | starting time will be less than 2 minutes |

| | | |
|---|---|---|
| **Market** | Additional competitive advantage | Boosting the company's name by satisfying the customers |

### Cost

In this part, we will describe the cost for the alternative 1, the cost is important to be defined. Which will help the clint to make his own decision.

*Table 5 Cost of Alternative 1*

| Category | Item | Value | Budgeted |
|---|---|---|---|
| **People** | Salaries of project staff | 2500 $ | No |
| | Salaries of installation and operation | 500$ | Yes |
| **Physical** | Electric motor | 600$ | Yes |
| | Helical gears | 20$ | Yes |
| | Shafts | 72$ | Yes |
| | Bearings | 200$ | Yes |
| | Housing | 100$ | Yes |
| | Design equipment (software) | 130$ | Yes |
| | Bevel gears | 100$ | Yes |
| | **Total** | **1722$** | |

## Risks

Risks are any problem that will happen in future, it is important to know the risks of you design before you make your own decision.

*Table 6 Risks of Alternative 1*

| Description | Priority | Resolution Actions |
|---|---|---|
| **Difficulties in MIT program** | High | Learn the MIT Program and try to validate with the hand calculation |
| **Required to manufacture an internal tooth gear** | High | Schedule the manufacture time |

## Issues

Issues are any problem that will happen currently in this alternative, and the different between the issues and risks that the issue will occur currently. On the other hand, they are similar in the importantly.

*Table 7 Issues of Alternative 1*

| Description | Likelihood | Impact | Mitigating Actions |
|---|---|---|---|
| **Corrosion problem** | Low | High | Coating the system with anti-corrosion spray |
| **Premature teeth wear** | Low | High | Keeping the gears lubricated |

### Assumptions

The major assumptions associated with the adoption of the conceptual design include:

1- All parts that need to be selected are standardized available in the local or international market.
2- Prices of raw materials and needed parts will not increase during this project.
3- There will be no legislative, businesses strategy or policy changes during this project.

### 1.6.2 Alternative 2 – Three stage speed reducer (Helical gears).

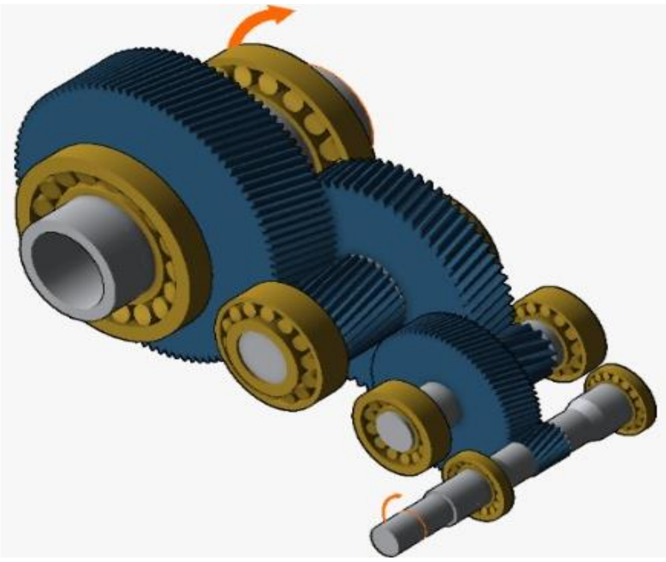


*Figure 5 Alternative 2*

### Description

The mechanism consists of three stages, 4 shafts, 6 helical gears and 8 bearing. The input shaft which is connected to the electrical motor, First stage contains of one helical gears which is also in input shaft, The reduction ratio in the first stage is 10 and the speed with redaction ratio 10. And the second stage will reduce the speed from 180 rpm to 90 rpm with redaction 2. In last stage the speed will be 45 rpm with ratio 2. And we have different dimeter in this alternative.

## Feasibility

Since Amazon might deliver sensitive products that are damaged by high speed while moving in delivery lines, which increases the company's loss, and this solution presented above reduces the speed and thus preserves the product more.

*Table 8 Feasibility of Alternative 2*

| Component | Rating (1-10) | Method Used to Determine Feasibility |
|---|---|---|
| **New Technology** | 8 | A small prototype was created and test it to see if the resultant match those expected from the exercise |
| **Operational** | 7 | • All gears are helical gears, which helps in ease of operation<br>• The difference in the dimeter also helps in the flexibility of productivity |

## Benefits

In this part, we will explain the benefit taken from this alternative, and the benefit will be of value in order to clarify the benefit further as you can see in the table below

*Table 9 Benefits of Alternative 2*

| Category | Benefit | Value |
|---|---|---|
| **Financial** | Reduce cost | 100$-200$ |
| **Design** | Limited space | *reducing the require space by 20%. |

**Cost**

In this part, we will describe the cost for the alternative 2, the cost is important to be defined, which will help the clint to make his decision.

*Table 10 Cost of Alternative 2*

| Category | Cost | Value | Budgeted |
|---|---|---|---|
| **People** | Salaries of project staff | 2500 $ | No |
| | Salaries of installation and operation | 500$ | Yes |
| **Physical** | Electric motor | 600$ | Yes |
| | Helical gears | 20$ | Yes |
| | Shafts | 72$ | Yes |
| | Bearings | 200$ | Yes |
| | Design equipment (software) | 100$ | Yes |
| | **Total** | **1495$** | |

## Risks

Risks are any problem that will happen in future, and it is important to know the risks of you design before you make your own decision.

*Table 11 Risks of Alternative 2*

| Description | Likelihood | Impact | Mitigating Actions |
|---|---|---|---|
| **Helical gear Corrosion problem** | Low | High | Coating the system with anti-corrosion spray |
| **Premature teeth wear** | Low | High | Keeping the gears lubricated |
| **All of the gears is Helical** | Medium | High | Maintenance is expensive |

## Issues

Issues are any problem that will happen currently in this alternative, and the different between the issues and risks that the issue will occur currently. On the other hand, they are similar in the importantly.

*Table 12 Issues of Alternative 2*

| Description | Priority | Resolution Actions |
|---|---|---|
| Difficulties in MIT program | High | Learn the MIT Program and try to validate with the hand calculation |
| Difficulties in hand calculations | High | Understand the slides of MENG410 and MENG 310 |
| Some components might not be available in the local market | Medium | Order the components from international market as soon as possible |

## Assumptions

The major assumptions associated with the adoption of the conceptual design include:

1- All parts that need to be selected are standardized available in the local or international market.

2- Prices of raw materials and needed parts will not increase during this project.

3- There will be no legislative, businesses strategy or policy changes during this project.

### 1.6.3 Alternative 3 – Three stage speed reducer (spur and bevel mechanism).

*Figure 6 Alternative 3*

#### Description

The system will include 8 bearing, 4 shafts, 4 spur gears, 2 bevel gears. To elaborate more on our third option, the input shaft will be connected to the electric motor and the input shaft has double bearing to increase the stability of the gearbox and the input shaft has the bevel gear which will rotate the input shaft 90°. Additionally, this alternative will help to reduce the speed from 1800 rpm to 45 rpm, in first stage the speed will reduce from 1800 rpm to 360 rpm by using gear ratio 5, in second stage we will reduce the speed from 360 rpm to 90 rpm by applying gear ratio 4, in last stage the speed is going to reduce from 90 rpm to 45 rpm as we have been asked from the client.

## Feasibility

Since Amazon has sensitive products that are damaged by high speed, while moving between production lines, which increases the company's loss, and this solution presented above reduces the speed and thus preserves the product more.

*Table 13 Feasibility of Alternative 3*

| Component | Rating (1-10) | Method Used to Determine Feasibility |
|---|---|---|
| **New processes** | 9 | Use bevel gear to rotate the input shaft |
| **Operational** | 8 | Small porotype was created and tested to achieve clint need |
| **Fanatical** | 7 | Compere between best practice and our design |

## Benefits

In this part, we will explain the benefit taken from this alternative, and the benefit will be of value in order to clarify the benefit further as you can see in the table below

*Table 14 Benefits of Alternative 3*

| Category | Benefit | Value |
|---|---|---|
| **Fanatical** | Reduce cost | 160$-250$ |
| **Design** | Changing input shaft direction | *90 degree |

### Cost

In this part, we will describe the cost for the alternative 3, the cost is important to be defined. Which will help the client to make his decision.

*Table 15 Cost of Alternative 3*

| Category | Cost | Value | Budgeted |
|---|---|---|---|
| **People** | Salaries of project staff | 2500 $ | No |
| | Salaries of installation and operation | 500$ | Yes |
| **Physical** | Electric motor | 600$ | Yes |
| | Shafts | 72$ | Yes |
| | Bearings | 200$ | Yes |
| | Housing | 100$ | Yes |
| | Design equipment (software) | 130$ | Yes |
| | Bevel gears | 100$ | Yes |
| | Spur gears | 15$ | yes |
| | **Total** | **$1717** | |

### Risks

Risks are any problem that will happen in future, and it is important to know the risks of your design before you make your own decision.

*Table 16 Risks of Alternative 3*

| Description | Likelihood | Impact | Mitigating Actions |
|---|---|---|---|
| **Gears Corrosion problem** | Low | High | Coating the system with anti-corrosion spray |

| | | | |
|---|---|---|---|
| **Premature teeth wear** | Low | High | Keeping the gears lubricated |
| **Shaft problems (misalignment)** | Medium | High | Eliminate the error by the advisor guide |

## Issues

Issues are any problem that will happen currently in this alternative, and the different between the issues and risks that the issue will happen currently. On the other hand, they are similar in the importantly.

*Table 17 Issues of Alternative 3*

| Description | Priority | Resolution Actions |
|---|---|---|
| **Difficulties in MIT program** | High | Learn the MIT Program and try to validate with the hand calculation |
| **Required to manufacture an internal tooth gear** | High | Schedule the manufacture time |
| **Some components might not be available in the local market** | High | Order the components from international market as soon as possible |

## Assumptions

The major assumptions associated with the adoption of the conceptual design include:

1- All parts that need to be selected are standardized available in the local or international market.
2- Prices of raw materials and needed parts will not increase during this project.
3- There will be no legislative, businesses strategy or policy changes during this project.

## 1.7 Recommended Alternative

In this part, we will compare the three alternatives with each other using Kepner Trego Decision Analysis (KTDA) technique. This table shows us the musts and wants we want it in our project. We made a list of 4 musts and 6 wants, then we see what will GO and NOT GO. After evaluating we did a calculation between the weight and score to make the Total. We did all this to the three alternatives and see which one it has the best Total and the worst.

*Table 18 KTDA table*

| Must | | Helical and Bevel gears | | Helical gears | | Spur and bevel mechanism | |
|---|---|---|---|---|---|---|---|
| **Motor speed** | | GO | | GO | | GO | |
| **Output power** | | GO | | GO | | GO | |
| **Output speed** | | GO | | GO | | GO | |
| **Safety** | | GO | | GO | | GO | |
| | | | | | | | |
| **Wants** | **Wight** | **Score** | **W*S** | **Score** | **W*S** | **Score** | **W*S** |
| **quality** | 25 | 10 | 250 | 10 | 250 | 10 | 250 |
| **limited space** | 25 | 7 | 175 | 7 | 175 | 8 | 200 |
| **reliability** | 23 | 9 | 207 | 8 | 184 | 9 | 207 |
| **Easy to use** | 10 | 8 | 80 | 8 | 80 | 10 | 100 |
| **Easy to maintain** | 10 | 5 | 50 | 6 | 60 | 8 | 80 |
| **Environment** | 7 | 10 | 70 | 10 | 70 | 10 | 70 |
| **Total** | **100** | **832** | | **819** | | **907** | |

After completing the Kepner Trego Decision Analysis (KTDA) technique and according to the above table, we can see that the last alternative (Spur and bevel mechanism) got a total of 907 and is the highest, so it is considered the best alternative for our project.

## 1.8 Implementation Approach

### Project Initiation

The project was first presented to the team upon submitting course MENG 410 (Mechanical Design). The team is made of seven members from the mechanical engineering faculty. The project advisor is Prof. Nidal Abu Hamdeh. An initial meeting with the client was conducted afterwards to introduce the requirements of the projects, needs and the deliverables. The business case along with the project charter will be submitted to the client for approval.

### Project Planning

Planning techniques and programs must be used in order to complete the project before the deadline. Techniques used are dividing the project into stages with specific tasks and then simplifying them into smaller subtasks and also using the Gantt chart from MS Project to aid in tracking the progress of the tasks through the specified time period. Project Management tools such as the One Page Project Manager sheet are used to keep track of the project progress.

### Project Execution

After designing the components of the project (hand calculations and MITcal), the use of the Finite Element Analysis will be performed to identify if any critical design errors occur. If results show no critical errors, a detailed draft drawing will be provided to the customer to manufacture a prototype. Then the evaluation for errors will be performed and if any error or mistake occurs, adjustments and modifications will be made.

## Project Closure

Upon completion of the project, recommendations for needed further improvement of the project will be provided. Afterwards, the team will submit the work seeking approval from the academic advisor, project coordinator and the client.

## Project Management

This part explains how we ensure the success of this project.

- **Time Management**

The project has a due date set by the client to finish and to deliver the results, so it is an important issue to manage the time in this project. The team has Team Meeting Minutes (TMM) to aid in managing their meetings on time, also the Advisor Meeting Minutes (AMM) to help us with prioritizing tasks and inform us about what is left to be done. Also, Project Status Reports (PSR) will be a guide to us by presenting our progress after each week and highlighting key tasks to be done.

- **Cost Management**

The client did not provide a limit to the cost of the project but as engineers we know the project should be with the least cost and highest quality.

- **Quality Management**

Quality is essential in any engineering system. Producing a system with high quality ensures its operation for longer life and makes it more desirable in the market and meets the client's requirement. This could be accomplished by designing all element based on standards and best practice.

- **Change Management**

The team will try to resolve any unexpected difficulties that may arise during executing the work. The team will seek the advisor's input to solve these issues, and the team would adopt any necessary changes in the project if needed.

- **Risk Management**

Risks are potential problems that may occur in the future. So to make sure we prevent as much of them, design calculations will be reviewed and caution measurements will be installed.

- **Issue Management**

Issues are problems that happen now, as previously stated. When they occur, they are immediately dealt with in order for them to not grow to bigger issues. If the team fails in solving any issue, outside help will be sought from the project advisor or the course coordinator.

- **Communications Management**

Communication between team members and advisor and client must be agreed on from the beginning. Emails and WhatsApp will be the most suitable way for communication between members and also between the team and the academic advisor. Communication between the team and the client is not allowed unless authorized by the project advisor or project coordinator.

- **Acceptance Management**

The final deliverables of the project will be presented to the client for reviewing and approval. There are three main steps to ensure the acceptance. Firstly, the team will make sure that all tasks have been completed. Secondly, the team will make sure that all tasks have been documented. Lastly, the team is planning to deliver a good presentation for the client to secure his approval for the final report.

# 2. Project Charter

## 2.1 Executive Summary

Amazon is one of the biggest companies in the world, and every year they grow bigger and expand in many countries other than US and Europe. Recently, Amazon has joined the Saudi market and they intend to dominate here as they usually do in other regions. The company aims to expand their distribution line so they can keep up with the high demand and growth in the Saudi Arabia and avoid late shipments to their clients since costumer service is a major concern in this business and they want to gain their trusts to rely on the company for any product they need. Our objective is to design a speed reducer for the company so they can establish a new distribution line to help achieve their goal of delivering without damaging the products and delay to their customers.

For our project, the client is Amazon, and their representative is Eng. Ahmad Al-Haffar and he is the person who will state the companies' needs and receive the project within the deadline. Our advisor is Prof. Nidal Abu-Hamdah and he will guide us throughout this project and make sure we are on the right path.

During this project we have two main parts of the project's scope, the in scope and out scope. These two will demonstrates what are the team's responsibility and what is not. The team is responsible for designing and selecting all the components of this project, along with submitting the necessary manufacturing process sheets for any part. After submitting the design, the team is not in charge of manufacturing and assembling the project, also for any future maintenance and modification of the project.

This project consists of four main stages, initiation, planning, execution and closure. The first stage is initiation which will be in organizing the team and review the requirements of the client. Then, the planning which consists of creating the business case to come up with a final alternative for the client, then creating the project charter to manage the flow of the project. Third, the execution phase which in it we will design the project including technical calculations, parts drawing and simulation analysis. Finally, in the closure along with submitting the project we will prepare a poster and a PowerPoint show to display the whole project to the client.

## 2.2 Project Definition

### 2.2.1 Vision

Design the required speed reducer to use it in the client's new delivery line.

### 2.2.2 Objectives

There are three main objectives to accomplish in this project which are the following:

1. Business objectives
    - Capability of establishing the new delivery line of the client.
    - Keep up with the high demand of deliveries.

2. Technological objectives
    - Design the whole gearbox according to the speed asked by the client.
    - Achieve high quality and reliability of the design.
    - Design a compact gearbox of the possible minimum weight.

3. Academic objectives
    - Achieve the ability to design a whole system by using various of methods and analytical programs.
    - Being able to write technical reports for any project in the future.

### 2.2.3 Scope

This part will clearly demonstrates what are the team's responsibilities, and what are not.

- In scope
    - Designing the gears.
    - Designing the shafts.
    - Selecting suitable bearings.

    - Submit the design calculations.
    - Provide all the technical drawings of the parts.
    - Submit the process sheets for manufacturing the parts.
- Out scope
    - Manufacturing the necessary parts will be the client's responsibility.
    - Assembly of the design will be done by the client.
    - Testing the design is conducted by the client.
    - The team is not responsible for the maintenance of the project.
    - The team's task is done with submitting the design, and not responsible for modifying the project.

### 2.2.4 Deliverables

These are the important items that will be delivered to the client after finishing the project.

*Table 19 Project deliverables*

| Items | Components | Description |
|---|---|---|
| Documents | Project Technical Report | A report showing all the steps of the design process for the speed reducer. |
| | Design Calculations | All the analysis we conducted for the design to guarantee the safety of the design. |
| | Technical Drawings | The detailed drawings for each designed part. |
| | Electronic Poster | A poster showing all the important information regarding our design. |
| Project Logbook | Weekly reports | • Advisors meeting minutes (AMM).<br>• Team meeting minutes (TMM).<br>• Project status report (PSR) |

## 2.3 Project Organization

### 2.3.1 The Client

*Table 20 The client*

| **Client** | **Representative** |
| --- | --- |
| Amazon | Eng. Ahmed Al-Haffar<br>Innovation and Project Management Department |

### 2.3.2 Stakeholders

Will show who has relation has any interested in the project but does not communicate with the time directly.

*Table 21 Project stakeholders*

| **Stakeholders** | **Interested in** |
| --- | --- |
| CEO | Achieving compony vision and planes |
| Financial Controller | Keeping the expenses in the range of the budget |
| Health and Safety Office | Make sure everyone follows safety standers |
| Government body | Compliance with legislation |
| Industry body | Following engineer's ethics |

### 2.3.3 Roles

The table below identifies everyone working on the project and what is his job

*Table 22 Roles of people involved in the project*

| Role | Organization | Resource Name | Assignment status | Assignment Date |
|---|---|---|---|---|
| Client | Amazon | Eng.Ahmed Al-Haffar | Assigned | 20/2/2021 |
| Advisor | King Abdulaziz University | Prof. Nidal Abu-Hamdeh | Assigned | 20/2/2021 |
| Project manger | | Faris Abdullah Al-Ghmadi | Assigned | 20/2/2021 |
| Team members | | Sultan Mohammed Mizjaji | Assigned | 20/2/2021 |
| | | Sameer Abdulaziz Almarghalani | Assigned | 20/2/2021 |
| | | Ibrahim Khaled Al-Zahrani | Assigned | 20/2/2021 |
| | | Jayez Fayez Al-Rashidi | Assigned | 20/2/2021 |
| | | Ahmed Jamal Al-Harbi | Assigned | 20/2/2021 |
| | | Abdulrahman Fahad Al-Ghamdi | Assigned | 20/2/2021 |

### 2.3.4 Responsibilities

The generic responsibilities for each role identified.

Project Sponsor

- Defining the vision and high-level objectives for the project
- Approving the requirements, timetable, resources and budget

- Authorizing the provision of funds / resources (internal or external)
- Approving the project plan and quality plan
- Ensuring that major business risks are identified and managed
- Approving any major changes in scope
- Receiving Project Review Group minutes and acting accordingly
- Resolving issues escalated by the Project Manager / Project Review Group
- Ensuring business / operational support arrangements are put in place
- Ensuring the participation of a business resource (if required)
- Providing final acceptance of the solution upon project completion. ©

Project Advisor

- Assisting the Project Sponsor with the definition of the project vision and objectives
- Undertaking Quality Reviews prior to the completion of each project milestone
- Ensuring that all business risks are identified and managed accordingly
- Ensuring conformance to the standards and processes identified in the Quality Plan
- Ensuring that all appropriate client/vendor contractual documentation is in place prior to
- The initiation of the project.

Project Manager

- Documenting the detailed Project Plan and Quality Plan
- Ensuring that all required resources are assigned to the project and clearly tasked
- Managing assigned resources according to the defined scope of the project
- Implementing the following project processes: time / cost / quality / change / risk / issue.
- procurement / communication / acceptance management
- Monitoring and reporting on project performance (re: schedule, cost, quality and risk)
- Ensuring compliance with the processes and standards outlined in the Quality Plan

- Reporting and escalating project risks and issues
- Managing project interdependencies
- Making adjustments to the detailed plan as necessary to provide a complete picture of
- the progress of the project at any time.

Project Team Member

- Undertaking all tasks allocated by the Project Manager (as per the Project Plan)
- Reporting progress of the execution of tasks to the Project Manager on a frequent basis
- Maintaining all documentation relating to the execution of allocated tasks
- Escalating risks and issues to be resolved by the Project Manager.

### 2.3.5 Structure

Showing everyone involved in the project and his title job.

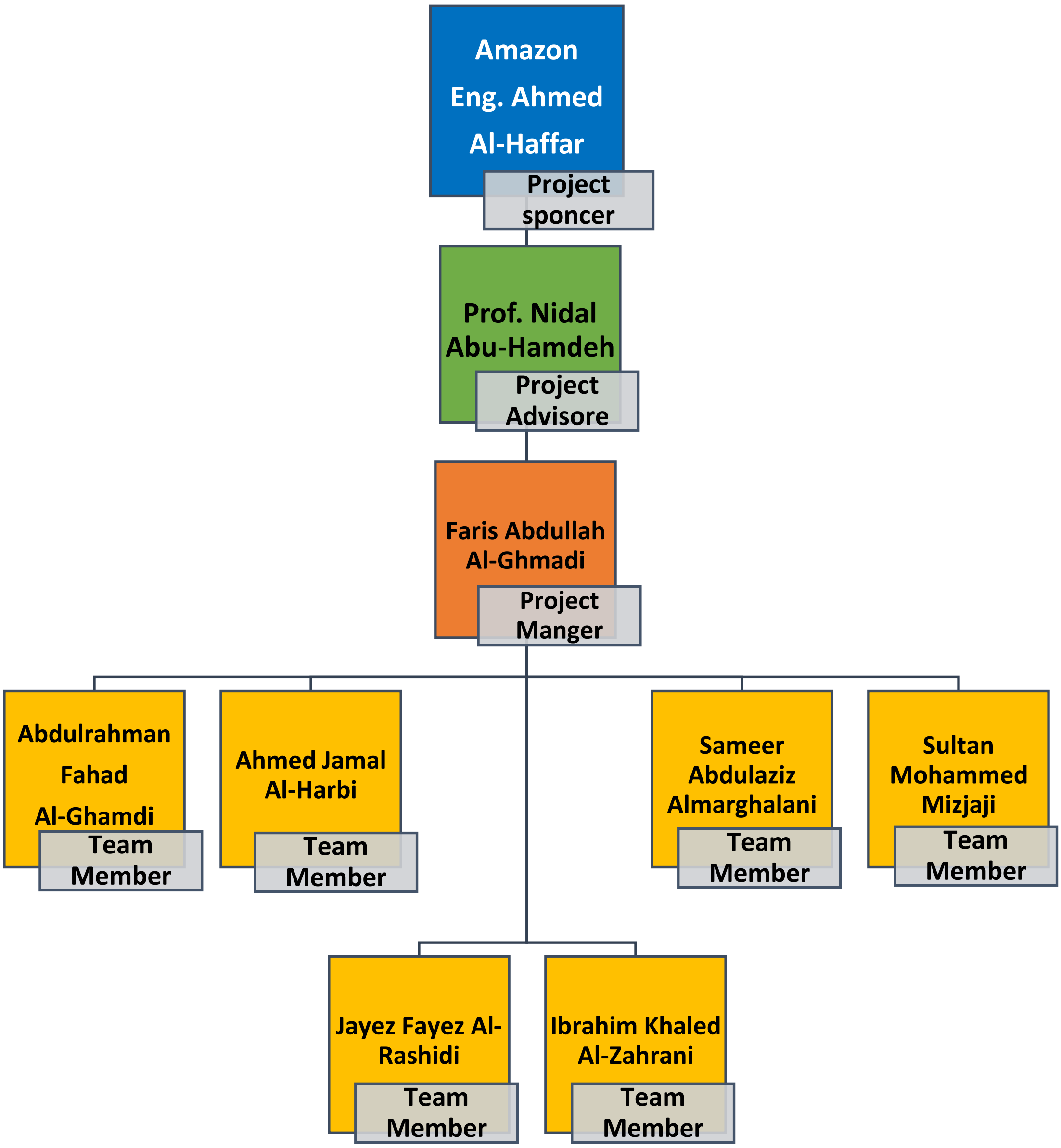



*Figure 7 Structure of group members*

## 2.4 Project Plan

### 2.4.1 Project Approach

Describe the approach to be taken to implement each of the phases within the project.

*Table 23 Project approach*

| Phase | Approach |
|---|---|
| **Initiation** | When the team receive the project statement from the clint they set meeting with the advisor as first meeting for the project. |
| **Planning** | Know every week we will be meeting to discuss the progress and making sure of that we are moving with the schedule and making Gantt chart to make easier to monitor the progress. Checking that the materials and toles are available in the market and having the business case. |
| **Execution** | The project is divided into stages. Once finishing the first stage then we start the second and we might start more than one stage if they do not depend on each other. This phase also includes the BOM, technical drawings and details of the project along with calculation sheets. |
| **Closure** | Subedited the final report and the artifact and present the product to the client. |

## 2.4.2 Overall Plan

This part provides our plan's outlining with the main and sub tasks and the duration of them.

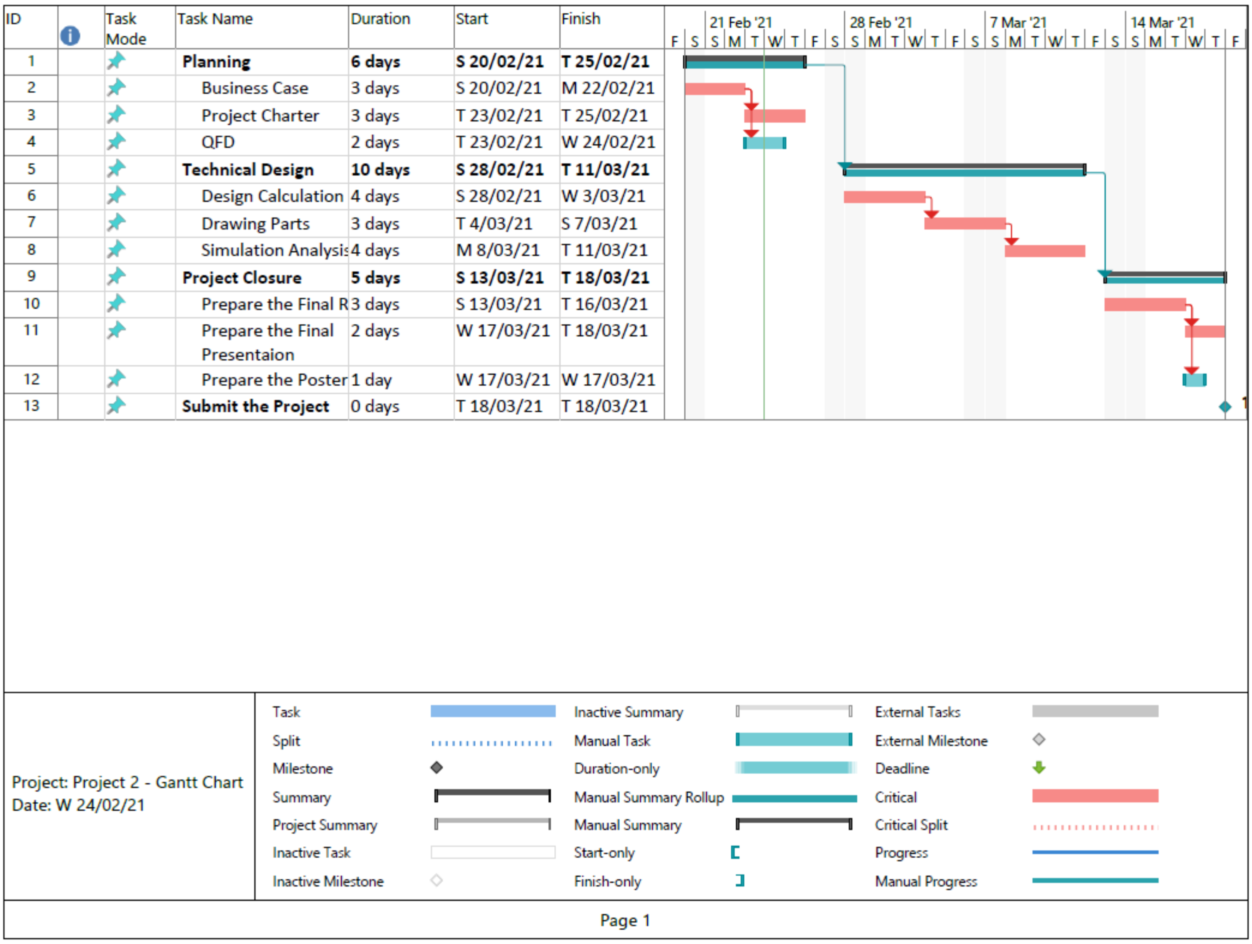



*Figure 8 Gantt chart*

*Table 24 Overall plan*

| Task Name | Start | Finish |
|---|---|---|
| **Planning** | **(Sun) 20/2/2021** | **(Thu) 25/2/2021** |
| • Business Case | (Sun) 20/2/2021 | (Tue) 22/2/2021 |
| • Project Charter | (Tue) 23/2/2021 | (Wen) 25/2/2021 |
| • Quality Function Deployment | (Wen) 23/2/2019 | (Wen) 24/2/2021 |
| **Technical Design** | **(Sun) 28/2/2021** | **(Thu) 11/3/2021** |
| • Design Calculations | (Sun) 28/2/2021 | (Wen) 3/3/2021 |
| • Drawing the Parts | (Thu) 4/3/2021 | (Sun) 7/3/2021 |
| • Simulation analysis | (Mon) 8/2/2021 | (Thu) 11/3/2021 |
| **Project Closure** | **(Sat) 13/3/2021** | **(Thu) 18/3/2021** |
| • Prepare the final report | (Sat) 13/3/2021 | (Tue) 16/3/2021 |
| • Prepare the final presentation | (Tue) 16/3/2021 | (Thu) 18/3/2021 |
| • Prepare the poster | (Tue) 16/3/2021 | (Wen) 17/3/2021 |
| **Submit the project** | **(Thu) 18/3/2021** | |

### 2.4.3 Milestones

The table below shows the major stages and when to be accomplished

*Table 25 Project milestones*

| Milestone | Date | Description |
|---|---|---|
| Requirements Review | 20/2/2021 | Review the problem and identify the requirements |
| Business Case, Project Charter and QFD | 25/2/2021 | • The business case defines the problem and gives alternatives for the solutions and choose the best one.<br>• The project charter describes the project plan and the approach of the team.<br>• QFD helps to improve the design to suit the client's needs. |
| Design calculations and analysis | 4/3/2021 | This stage assure that our design is safe and will no fail. |
| Parts drawing | 11/3/2021 | All the parts included in the design will be drawn and presented with details drawing sheets |
| Final report submission and presentation | 18/3/2021 | Submitting the report and presenting all what we accomplished. |

### 2.4.4 Resource

Listing the date started and percentage of work been done by each team member.

*Table 26 Project resources*

| Member | Start Date | End Date | % Effort |
|---|---|---|---|
| Faris Abdullah al-Ghmadi | 21/2/2021 | 14/3/2021 | 100% |
| Sultan Mohammed Mizjaji | 21/2/2021 | 14/3/2021 | 100% |
| Sameer Abdulaziz Almarghalani | 21/2/2021 | 14/3/2021 | 100% |
| Ibrahim Khaled Al-Zahrani | 21/2/2021 | 14/3/2021 | 100% |
| Jayez Fayez Al-Rashidi | 21/2/2021 | 14/3/2021 | 100% |
| Ahmed Jamal Al-Harbi | 21/2/2021 | 14/3/2021 | 100% |
| Abdulrahman Fahad Al-Ghamdi | 21/2/2021 | 14/3/2021 | 100% |

### 2.4.5 Financial Plan

In the table below shows what is our financial plan for the project.

*Table 27 Project's financial plan*

| Category | Cost | Value | Budgeted |
|---|---|---|---|
| People | Salaries of project staff | 8000 SAR | No |
| | Salaries of installation and operation | 1700 SAR | Yes |

| | | | |
|---|---|---|---|
| **Physical** | Electric motor | 2200 SAR | Yes |
| | Shafts | 300 SAR | Yes |
| | Bearings | 700 SAR | Yes |
| | Housing | 400 SAR | Yes |
| | Design equipment (software) | 350 SAR | Yes |
| | Bevel gears | 300 SAR | Yes |
| | Spur gears | 100 SAR | Yes |
| | **Total** | **14050 SAR** | |

### 2.4.6 Quality Plan

This part demonstrates how we ensure the success of this project.

*Table 28 Project quality plan*

| **Process** | **Description** |
|---|---|
| Quality management | All standards parts must be bought from the local market. |
| Risk management | Plans must be prepared in case of emergencies. |
| Issues management | Problems occur during the project must be solved immediately not later. |
| Document management | Regular progress documentation is a must during the project. |
| Acceptance management | Identify all tasks of the project and look out for the time to finish on time. |
| Financial management | Register every expense to calculate the cost perfectly. |
| Timesheet management | Using MS Project to monitor the progress of the project perfectly. |

| | |
|---|---|
| Project Reporting | All the progress must be submitted to the advisor. |
| Project Communication | Communication will be through our WhatsApp and by online meeting via Zoom or MS Teams. |

## 2.5 Project Consideration

### 2.5.1 Risks

Risks are any problem that will happen in future, and it is important to know the risks of your design before you make your own decision.

*Table 29 Project's risks*

| Description | Likelihood | Impact | Mitigating Actions |
|---|---|---|---|
| **Gears Corrosion problem** | Low | High | Coating the system with anti-corrosion spray |
| **Premature teeth wear** | Low | High | Keeping the gears lubricated |
| **Shaft problems (misalignment)** | Medium | High | Eliminate the error by the advisor guide |

### 2.5.2 Issues

Issues are any problem that will happen currently in this alternative, and the different between the issues and risks that the issue will happen currently. On the other hand, they are similar in the importantly.

*Table 30 Project's issues*

| Description | Priority | Resolution Actions |
|---|---|---|
| **Difficulties in MIT program** | High | Learn the MIT Program and try to validate with the hand calculation |
| **Required to manufacture an internal tooth gear** | High | Schedule the manufacture time |
| **Some components might not be available in the local market** | High | Order the components from international market as soon as possible |

### 2.5.3 Assumptions

The major assumptions associated with the adoption of the conceptual design include:

1. All parts that need to be selected are standardized available in the local or international market.
2. Prices of raw materials and needed parts will not increase during this project.
3. There will be no legislative, businesses strategy or policy changes during this project.

### 2.5.4 Constrains

List of the major constraints identified with the project to date.

- The gear box should not consume power more than 5 kw.
- The output angular velocity should be 45 rpm.
- Deliver the product safely without any damage.

# 3. QFD

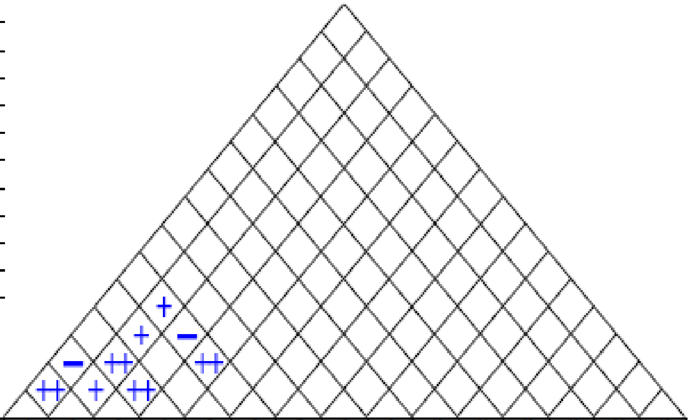
Title: project 2

Author: team 4

Date: 2/25/2021

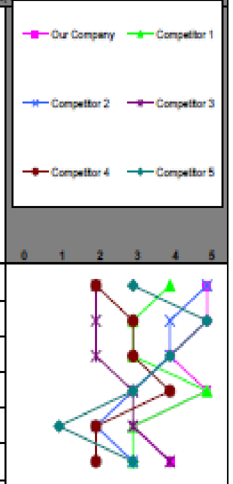
Notes:

| Legend | | |
|---|---|---|
| Θ | Strong Relationship | 9 |
| O | Moderate Relationship | 3 |
| ▲ | Weak Relationship | 1 |
| ++ | Strong Positive Correlation | |
| + | Positive Correlation | |
| − | Negative Correlation | |
| ▼ | Strong Negative Correlation | |
| ▼ | Objective Is To Minimize | |
| ▲ | Objective Is To Maximize | |
| X | Objective Is To Hit Target | |



| Row # | Max Relationship Value in Row | Relative Weight | Weight / Importance | Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") | 1 time | 2 speed | 3 size | 4 weight | 5 cost | 6 stress | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Our Company | Competitor 1 | Competitor 2 | Competitor 3 | Competitor 4 | Competitor 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x) | ▼ | ▼ | ▼ | ▲ | X | X | | | | | | | | | | | | | | | |
| 1 | 9 | 21.1 | 4.0 | Reliability | Θ | ▲ | | ▲ | | | | | | | | | | | | 5 | 4 | 5 | 2 | 2 | 3 |
| 2 | 9 | 26.3 | 5.0 | Quality | O | Θ | | Θ | ▲ | ▲ | | | | | | | | | | 5 | 3 | 4 | 2 | 3 | 5 |
| 3 | 9 | 26.3 | 5.0 | Limited space | | O | Θ | O | Θ | | | | | | | | | | | 4 | 3 | 4 | 2 | 3 | 4 |
| 4 | 3 | 5.3 | 1.0 | Environment | | | | ▲ | ▲ | O | | | | | | | | | | 5 | 5 | 3 | 3 | 4 | 3 |
| 5 | 9 | 10.5 | 2.0 | Easy to maintain | Θ | Θ | ▲ | Θ | | | | | | | | | | | | 3 | 3 | 2 | 3 | 2 | 1 |
| 6 | 3 | 10.5 | 2.0 | Easy to use | ▲ | ▲ | O | | | | | | | | | | | | | 4 | 3 | 3 | 4 | 2 | 3 |
| 7 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | | | | | | | |

Competitive Analysis (0=Worst, 5=Best)




| Column # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Target or Limit Value | 20 m | 45 rpm | 20 x 30 cm | 15 kg | 1750 sr | 100.0 Pa | | | | | | | | | |
| Difficulty (0=Easy to Accomplish, 10=Extremely Difficult) | 3 | 2 | 8 | 9 | 4 | 4 | | | | | | | | | |
| Max Relationship Value in Column | 9 | 9 | 9 | 9 | 9 | 3 | | | | | | | | | |
| Weight / Importance | 373.7 | 442.1 | 278.9 | 436.8 | 268.4 | 42.1 | | | | | | | | | |
| Relative Weight | 20.3 | 24.0 | 15.1 | 23.7 | 14.6 | 2.3 | | | | | | | | | |

Powered by QFD Online (http://www.QFDOnline.com)

# 4. Design Analysis

Now we will start designing the parts for our gearbox and it will cover five main sections which are motor selection, gear design, shaft design, bearings selection and finally keys design.

## Motor selection

At first, we need to specify the needed power $P_{needed}$ to run this gearbox and give an output of 5 kW. And we will use the following formulas to calculate the needed power.

$$P_{req} = \frac{P_{out}}{(n_{bearing})^{n1} \times (n_{gear})^{n2}} \quad (1)$$

where,

$n_{bearing}: is\ the\ bearing\ efficiency$

$n_{gear}: is\ the\ gear\ efficiency$

$n_1: is\ the\ number\ of\ bearings$

$n_2: is\ the\ number\ of\ gear\ stages$

$$P_{req} = \frac{5}{0.99^8 \times 0.95^3}$$

$$P_{req} = 6.32\ kW$$

$$P_{needed} = \frac{P_{req}}{0.85} \quad (2)$$

$$P_{needed} = \frac{6.32}{0.85}$$

$$P_{needed} = 7.44\ kW$$

## Gear Design

### Stage 1 Bevel Gear

First, we need to find the dimensions of both pinion and gear, which will help us in force and stress analysis for the bevel gears. All formulas were from

Assume

Module $m = 3\ mm$

Pinion number of teeth $N_p = 20\ teeth$

Gear ratio $i = 5$

Pitch diameter of pinion:

$$d_p = m \times N_p \ (3)$$

$$d_p = 3 \times 20$$

$$d_p = 60 \ mm$$

Number of teeth for gear:

$$\frac{N_g}{N_p} = \frac{d_g}{d_p} = i \ (4)$$

$$N_g = N_p \times \ i$$

$$N_g = 20 \times 5$$

$$N_g = 100 \ teeth$$

Pitch diameter of gear:

$$d_g = m \times N_g \ (5)$$

$$d_g = 3 \times 100$$

$$d_g = 300 \ mm$$

Pitch angle of pinion:

$$\delta = \tan^{-1} \frac{d_p}{d_g} \ (6)$$

$$\delta = \tan^{-1} \frac{60}{300}$$

$$\delta = 11.31°$$

Pitch angle of gear:

$$\Gamma = \tan^{-1} \frac{d_g}{d_p} \ (7)$$

$$\Gamma = \tan^{-1} \frac{300}{60}$$

$$\Gamma = 78.69°$$

This condition validates our solution:

$$\Gamma + \delta = 90°$$

Diametric pitch:

$$P_d = \frac{N_g}{d_g} \ (9)$$

$$P_d = \frac{100}{300}$$

$$P_d = \frac{1}{3} \ mm$$

Whole depth of tooth:

$$h_t = \frac{2.188}{P_d} + 0.002 \ (10)$$

$$h_t = \frac{2.188}{0.333} + 0.002$$

$$h_t = 6.566 \ mm$$

Working depth of tooth:

$$h_k = \frac{2}{P_d} \ (11)$$

$$h_k = \frac{2}{0.333}$$

$$h_k = 6 \ mm$$

Clearance:

$$C = \frac{0.188}{P_d} + 0.002 \ (12)$$

$$C = \frac{0.188}{0.333} + 0.002$$

$$C = 0.566 \ mm$$

Addendum gear:

$$ag = \frac{0.54}{P_d} + \frac{0.46}{P_d \times \left(\frac{N_g}{N_p}\right)^2} \ (13)$$

$$a_g = \frac{0.54}{0.333} + \frac{0.46}{0.333 \times (5)^2}$$

$$a_g = 1.6752 \ mm$$

Addendum pinion:

$$a_p = h_k - a_g (14)$$

$$a_p = 6 - 1.6752$$

$$a_p = 4.325\ mm$$

Outside diameter gear:

$$O_{d\ gear} = d_g + 2 \times a_g \cos \Gamma \ \ (15)$$

$$O_{d\ gear} = 300 + 2 \times 1.6752 \times \cos 78.69°$$

$$O_{d\ gear} = 300.627\ mm$$

Outside diameter pinion:

$$O_{d\ \text{pinion}} = d_p + 2 \times a_p \cos \delta \ \ (16)$$

$$O_{d\ gear} = 60 + 2 \times 4.325 \times \cos 11.31°$$

$$O_{d\ gear} = 68.482\ mm$$

Outside cone diameter:

$$OCD = \frac{d_g}{2 \sin \Gamma} \ (17)$$

$$OCD = \frac{300}{2 \sin 78.69°}$$

$$OCD = 152.97\ mm$$

Face width:

$$F \leq \frac{10}{P_d} \ (18)$$

$$\mathrm{F} \leq \frac{10}{\frac{1}{3}}$$

$$\mathrm{F} \leq 30\ mm$$

Mean radius for pinion:

$$r_m = \frac{d_p}{2} - \frac{F}{2}\sin\delta \;\; (19)$$

$$r_m = \frac{60}{2} - \frac{30}{2}\sin 11.31°$$

$$r_m = 27.058\ mm$$

Mean radius for gear:

$$R_m = \frac{d_g}{2} - \frac{F}{2}\sin\Gamma \; (20)$$

$$R_m = \frac{300}{2} - \frac{30}{2}\sin 78.69°$$

$$R_m = 135.29\ mm$$

Torque on pinion [4]:

$$T_p = \frac{P}{\left(\frac{2\pi}{60} \times n_p\right)} \;\; (21)$$

$$T_p = \frac{7.44 \times 1000}{\left(\frac{2\pi}{60} \times 1800\right)}$$

$$T_p = 39.47\ N.m$$

Tangential force on pinion [4]:

$$W_{tp} = \frac{T_p}{r_m} \;\; (22)$$

$$W_{tp} = \frac{39.47}{27.058}$$

$$W_{tp} = 1.315\ N$$

Assume the pressure angle as $\vartheta = 20°$

Radial force on pinion [4]:

$$W_{rp} = W_{tp} \times \tan\vartheta \times \cos\delta \;\; (23)$$

$$W_{rp} = 1.315 \times \tan 20° \times \cos 11.31°$$

$$W_{rp} = W_{ra} = 0.5206 \cancel{k}N$$

xg

Axial force on pinion [4]:

$$W_{xp} = W_{tp} \times \tan\vartheta \times \sin\delta \quad (24)$$

$$W_{xp} = 1.315 \times \tan 20° \times \sin 11.31°$$

$$W_{xp} = W_{xa} = 0.10412 \cancel{k}N$$

rg

The resultant force on the pinion:

$$W = \sqrt{{W_{tp}}^2 + {W_{rp}}^2 + {W_{xp}}^2} \quad (25)$$

$$W = \sqrt{1.315^2 + 0.5206^2 + 0.10412^2}$$

$$W = 1.55 \cancel{k}N$$

Now we will begin with stress analysis section. First, we will calculate the contact stress $\sigma_H$ to get the contact factor of safety and check if our design is safe or not. We will use the following formula to get $\sigma_H$, this law was from Shigley's Mechanical Engineering Design [4].

$$\sigma_H = Z_E \left( \frac{1000 \times W^t}{b \times d \times Z_I} K_A K_v K_{HB} Z_x Z_{xc} \right)^{1/2} (26)$$

First assume the material as steel carburized Grade 1 with allowable contact stress of $\sigma_{H\ all} = 1380\ MPa$

15-4 ⇒ 779

**Overload Factor $K_A$**

Assume this value as $K_A = 1$ since the load is uniform. 15-2

**Dynamic Factor $K_v$**

$$K_v = \left( \frac{A + \sqrt{200 \cdot v_{et}}}{A} \right)^B (27)$$

$$v_{et} = 5.236 \cdot (10^{-5}) \cdot d_p \cdot n$$

$$v_{et} = 5.236 \times 10^{-5} \times 60 \times 1800$$

$$V_{et} = 5.655\, m/s$$

$$\mathrm{B} = 0.25(12 - Q_v)^{2/3}$$

Assume: $$Q_v = 5$$

$$\mathrm{B} = 0.25(12 - 5)^{2/3}$$

$$\mathrm{B} = 0.9148$$

$$A = 50 + 56 \cdot (1 - B)$$

$$A = 50 + 56 \cdot (1 - 0.915)$$

$$A = 54.77$$

$$K_v = \left(\frac{54.77 + \sqrt{200 \times 5.655}}{54.77}\right)^{0.9148}$$

$$K_v = 1.55$$

**Size Factor $Z_x$**

Since the face width of our gears are assumed as 30mm the following formula will be used:

15-9 eq

$$Z_x = 0.00492 \cdot F \pm 0.4375$$

$$Z_x = 0.00492 \times 30 \pm 0.4375$$

$$Z_x = 0.59$$

Load-distribution Factor $K_{HB}$

Assume $K_{mb} = 1$

F

$$K_{HB} = K_{mb} + 5.6 \times 10^{-6} \times b^2(28)$$

$$K_{HB} = 1 + 5.6 \times 10^{-6} \times 30^2$$

$$K_{HB} = 1.005$$

Assume for properly crowned teeth $Z_{xc} = 1.5$ $\longrightarrow$ 15-12

The material is steel, so the value of $Z_E = 190$

780

From figure 15-6 in Shigley's Mechanical Engineering Design [4].

$$Z_I = 0.0958$$

$$\sigma_H = 190\left(\frac{1000 \times 1.31479}{30 \times 60 \times 0.0958} \times 1 \times 1.55 \times 1.005 \times 0.59 \times 1.5\right)^{1/2}$$

$$\sigma_H = 616.21 \text{ Mpa}$$

Assume the number of load cycles $n_L = 10^9$

Stress-cycle for pitting resistance $Z_{NT}$

$$Z_{NT} = 3.4822 \times n_L{}^{-0.0602} = 1.001$$

$$Z_{NT} = 1.001$$

**Hardness Ration Factor $Z_W$**

$$Z_W = 1$$

**Reliability Factor $Z_z$**

Assume reliability $R = 99.9$

$$Y_z = 0.5 - 0.25\log(1 - R) = 1$$

$$Y_z = 0.5 - 0.25\log(1 - 99.9) = 1$$

$$Z_z = \sqrt{Y_z}$$

$$Z_z = \sqrt{1} = 1$$

Substitute in the following equation to get the contact factor of safety $S_H$

$$\boxed{\sigma_H = \frac{\sigma_{H\,all} \times Z_{NT} \times Z_w}{S_H \times K_\theta \times Z_z} \quad (30)}$$

$$641.4 = \frac{1380 \times 1.001 \times 1}{S_H \times 1 \times 1}$$

$$S_H = 2.24$$

As seen from the factor of safety our design was safe, but it is too safe for our standards.

The following equation is for the bending stress $\sigma_F$ on the gears [4].

$$\boxed{\sigma_F = \frac{1000 \times W^t}{6} \times \frac{K_A \times K_V \times Y_X \times K_{HB}}{m \times Y_B \times Y_J} \quad (31)}$$

**Size Factor for bending $Y_X$**

$$Y_X = 0.4867 + 00.08339 \cdot m_{et}$$

module

$$Y_X = 0.4867 + 00.08339 \times 3$$

$$Y_X = 0.5117$$

**Lengthwise Curvature Factor for Bending $Y_B$**

$$Y_B = 1\ for\ straith\ bevel\ gears$$

$$Y_J = 0.23$$

$$\sigma_F = \frac{1000 \times 1.31479 \times 1 \times 1.55 \times 0.5117 \times 1.005}{30 \times 3 \times 1 \times 0.23}$$

$$\sigma_F = 50.61\ Mpa$$

$$\sigma_{FP} = \frac{\sigma_{F\ all} \times Y_{NT}}{S_F \times K_\theta \times Y_z} \quad (32)$$

According to our material this is the value for the allowable stress for bending

$\sigma_{F\ all} = 205\ Mpa$ 15-6

Stress cycle factor for bending stress $Y_{NT}$

$Y_{NT} = 1.3558 \times n_L{}^{-0.0178}$

$Y_{NT} = 0.9375$

$$50.61 = \frac{205 \times 0.9375}{S_F}$$

$$S_F = 3.797$$

The same here bending factor of safety it is very safe and that is expensive to accomplish.

**Stage 2 Spur Pinion**

Assume module $m = 2\,mm$

Gear ratio $i = 4$

Assume Number of teeth for pinion $N_p = 18\;teeth$

Number of teeth for gear $N_g = 72\;teeth$

Pitch diameter of the pinion $d_p = 36\,mm$

Pitch diameter of the gear $d_g = 144\,mm$

Diametric pitch

$$P_d = \frac{N_g}{d_g}$$

$$P_d = \frac{1}{2}$$

The tangential force on the gears

$$W^t = \frac{60000 \times 7435}{\pi \times 36 \times 360}$$

→ Pred W

$$W^t = 10.96\,kN$$

The radial force on the gears

Assume pressure angle $\vartheta = 20°$

$$W_r = W_t \times \tan\vartheta$$

$$W_r = 10.96 \times \tan 20°$$

$$W_r = 3.99\,kN$$

Assume face width $b = 25\,mm$

Assume overload factor $k_o = 1$

**Dynamic Factor $k_v$**

$$k_v = \left(\frac{A + \sqrt{200 \cdot v_{et}}}{A}\right)^B$$

dp

$$V = \frac{d}{2} \times \frac{2\pi}{60} \times n$$

$$V = 0.6785 \; {}^{m}/_{s}$$

$$B = 0.25(12 - Q_v)^{2/3}$$

Assume: $$Q_v = 7$$

$$B = 0.25(12 - 7)^{2/3}$$

$$B = 0.73$$

$$A = 50 + 56 \cdot (1 - B)$$

$$A = 50 + 56 \cdot (1 - 0.73)$$

$$A = 65.064$$

$$K_v = \left(\frac{65.064 + \sqrt{200 \times 5.655}}{65.064}\right)^{0.73}$$

$$K_v = 1.12775$$

**Assume the size factor as $K_s = 1$**

**Load-distribution factor $K_H$**

$$K_H = 1 + C_{mc}(C_{pf}C_{pm} + C_{ma}C_e)$$

$$C_{mc} = 1$$

$$C_{pf} = \frac{F}{10d_p} - 0.025$$

inche

$$C_{pf} = 0.044$$

$$C_{pm} = 1$$

$$C_{ma} = A + BF + CF^2$$

inche

$$C_{ma} = 0.1423$$

$$C_e = 1$$

$$K_H = 1 + 1 \times (0.0444 \times 1 + 0.1423 \times 1)$$

$$K_H = 1.1867$$

**Surface Condition Factor $Z_R$ assume as:**

$$Z_R = 1$$

$$\frac{N_G}{N_P} = \frac{d_G}{d_P}$$

**Surface strength geometry factor $Z_I$**

$$\boxed{Z_I = \frac{\cos\varphi \sin\varphi}{2m_N} \times \frac{m_G}{m_G + 1}}$$

$=1$

$$Z_I = \frac{\cos 20 \sin 20}{2} \times \frac{4}{4+1}$$

$$Z_I = 0.12856$$

**The Elastic Coefficient $Z_E$ since we use steel gears, we pick it as follows:**

$$Z_E = 191\sqrt{Mpa}$$ 14-8

Now we substitute in the stress contact formula to get the stress [14]:

$$\sigma_c = Z_E \left( \frac{K_H K_s K_v K_O Z_R W^t}{b d_w Z_I} \right)^{1/2} \quad (33)$$

$d_P$

$$\sigma_c = 191 \times \left( \frac{1.1867 \times 1.1278 \times 1 \times 1 \times 1 \times 10960}{25 \times 36 \times 0.12856} \right)^{1/2}$$

$$\sigma_c = 2150.56\ Mpa$$

ASTM 48 gray cast iron Class 40 with $H_B = 201$ 14-7

**Allowable Contact stress $S_c$**

$$S_c = 2.22 \times 201 + 200$$

$$S_c = 646\ Mpa$$

**Hardness-ratio Factor $Z_w$**

Assume it as $Z_w = 1$

**Stress cycle factor $Z_N$**

Assume $N = 10^8$

$$Z_N = 1.4488N^{-0.023}$$

$$Z_N = 0.9484$$

**Reliability Factor $Y_z$**

Assume reliability =0.99

$$Y_z = 1$$

**Temperature factor $Y_\theta$ for temperatures under 120℃ assume as [4]:**

$$Y_\theta = 1$$

Now substitute in this equation to find the factor of safety for contact stress:

$$\sigma_{c\ all} = \frac{S_c \times Z_N \times Z_w}{S_H \times Y_\theta \times Y_z} \quad (34)$$

$$\boxed{1195.42} = \frac{646 \times 0.9484 \times 1}{S_H \times 1 \times 1}$$

$$S_H = 0.5$$

As seen from the factor of safety our design is not safe at all and need modification.

Now we will calculate the bending stress, and the formula for it is as shown below [4].

$$\sigma_{bending} = W^t K_s K_V K_o \times \frac{1}{bm_t} \times \frac{K_H K_B}{Y_J} \quad (35)$$

Bending stress geometry factor $\boldsymbol{Y_J}$,we bring this factor from figure 14-6 in Shigley's Mechanical Engineering Design [4].

$$Y_J = 0.32$$

Rim thickness factor $K_B$, it will be 1 since we use the same material in pinion and gear.

$$K_B = 1$$

$$\sigma_{bending} = 10960 \times 1.1279 \times 1 \times \frac{1}{25 \times 2} \times \frac{1.1867 \times 1}{0.32}$$

$$\boxed{\sigma_{bending} = 917\ Mpa}$$

In this equation we can find the factor of safety for bending stress [4].

$$\boxed{\sigma_{all} = \frac{S_t \times Y_N}{S_F \times Y_\theta \times Y_z} \quad (36)}$$

**Allowable bending stress $S_t$**

$$S_t = 0.533 \times 201 + 88.3$$

Fig 14-2

$$S_t = 195\ MPa$$

**Stress cycle factor $Y_N$**

$$Y_N = 1.3558\ N^{-0.0178}$$

1.8

$$Y_N = 0.976$$

Now substitute in equation (36) to find the factor of safety:

$$28\cancel{3}.28 = \frac{195 \times 0.976}{S_F \times 1 \times 1}$$

$$S_F = 0.208$$

## Stage 3 Spur Pinion

This stage has the same process as stage 2 so we will be quick in here will not elaborate much.

Assume module $m = 2\,mm$

Speed n = 90 RPM

Gear ratio $i = 2$

Assume Number of teeth for pinion $N_p = 17\,teeth$

Number of teeth for gear $N_g = 34\,teeth$

Pitch diameter of the pinion $d_p = 34\,mm$

Pitch diameter of the gear $d_g = 68\,mm$

Diametric pitch

$$P_d = \frac{N_g}{d_g}$$

$$P_d = \frac{1}{2}$$

The tangential force on the gears

$$P = \frac{\pi d}{N}$$

$$P = 2\pi$$

Assume face width $b = 25\,mm$

$$W^t = \frac{60000 \times 7435}{\pi \times 34 \times 90}$$

$$W^t = 46404.59\,N$$

Assume overload factor $k_o = 1$

**Dynamic Factor $k_v$**

$$k_v = \left(\frac{A+\sqrt{200\cdot v_{et}}}{A}\right)^B$$

$$\text{B} = 0.25(12-Q_v)^{2/3}$$

$$Q_v = 7$$

B= 0.731

A= 50+56 (1-B)

A=65.064

$$\text{V}=\frac{d}{2}w$$

$$\text{V}=0.16022\ {}^{m}/_{s}$$

$$K_v = 1.063$$

**Assume the size factor as $K_s = 1$**

**Load-distribution factor $K_H$**

$$K_H = 1 + C_{mc}(C_{pf}C_{pm} + C_{ma}C_e)$$

$$C_{mc} = 1$$

$$C_{pf} = \frac{F}{10d_p} - 0.025$$

$$C_{pf} = 0.0338$$

$$C_{pm} = 1$$

$$C_{ma} = 1 + A + BF + CF^2$$

$$C_{ma} = 0.1394$$

$$C_e = 1$$

$$K_H = 1 + (0.0338 + 0.1394)$$

$$K_H = 1.1732$$

**Surface Condition Factor $Z_R$ assume as:**

$$Z_R = 1$$

**Surface strength geometry factor $Z_I$**

$$Z_I = \frac{\cos\varphi \sin\varphi}{2m_N} \times \frac{m_G}{m_G + 1}$$

$$Z_I = 0.1071$$

**The Elastic Coefficient $Z_E$ since we use steel gears, we pick it as follows:**

$$Z_E = 163\sqrt{Mpa}$$

Now we substitute in the stress contact formula to get the stress [14]:

$$\sigma_c = 163\sqrt{\frac{46404.59 \times 1.063 \times 1.1732}{34 \times 20 \times 0.1071}}$$

$$\sigma_c = 4594.85 \text{ MPa}$$

ASTM 48 gray cast iron Class 40 with $H_B = 201$

**Allowable Contact stress $S_c$**

$S_c = 2.22 \times 201 + 200$

$S_c = 646.22$ MPa

**Hardness-ratio Factor $Z_w$**

Assume it as $Z_w = 1$

**Stress cycle factor $Z_N$**

Assume $N = 10^8$

$$Z_N = 1.4488N^{-0.023}$$

$$Z_N = 0.9484$$

**Reliability Factor $Y_z$**

Assume reliability =0.99

$$Y_z = 1$$

**Temperature factor $Y_\theta$ for temperatures under $120$℃ assume as [4]:**

$$Y_\theta = 1$$

Now substitute in this equation to find the factor of safety for contact stress:

$$\sigma_{c\ all} = \frac{S_c \times Z_N \times Z_w}{S_H \times Y_\theta \times Y_z} \ (34)$$

$$S_H = \frac{646.22 \times 0.9484}{4594.85}$$

$$S_H = 0.133$$

Here we got even smaller factor of safety than the previous stage, it is not safe at all

Now we will calculate the bending stress, and the formula for it is as shown below [4].

$$\sigma_{bending} = W^t K_s K_V K_o \times \frac{1}{bm_t} \times \frac{K_H K_B}{Y_J} \ (35)$$

Bending stress geometry factor $\boldsymbol{Y_J}$,we bring this factor from figure 14-6 in Shigley's Mechanical Engineering Design [4].

$$Y_J = 0.295$$

Rim thickness factor $K_B$, it will be 1 since we use the same material in pinion and gear.

$$K_B = 1$$

$$\sigma_b = 4904.382\ Mpa$$

In this equation we can find the factor of safety for bending stress [4].

$$\sigma_{all} = \frac{S_t \times Y_N}{S_F \times Y_\theta \times Y_z} \ (36)$$

**Allowable bending stress $S_t$**

$$S_t = 0.533 \times 201 + 88.3$$

$$S_t = 195\ MPa$$

**Stress cycle factor $Y_N$**

$$Y_N = 1.3558\ N^{-0.0178}$$

$$Y_N = 0.976$$

Now substitute in equation (36) to find the factor of safety:

$$S_f = \frac{195 \times 0.976}{4904.382}$$

$$S_f = 0.039$$

This factor of safety is acceptable at all, and we will try and modify it in the MITCalc section.

## MITCalc Gears

After we made hand calculations for each pinion in all stages, we used MITCalc to redo the calculations again and address the mistakes we made before.

### Stage 1 Bevel

After we failed to obtain a suitable factor of safety in hand calculations, we managed here find out the mistake we made before. We found that the number of teeth were too small to withstand the load on the gears, we increased them and acquired the proper numbers for factors of safeties.

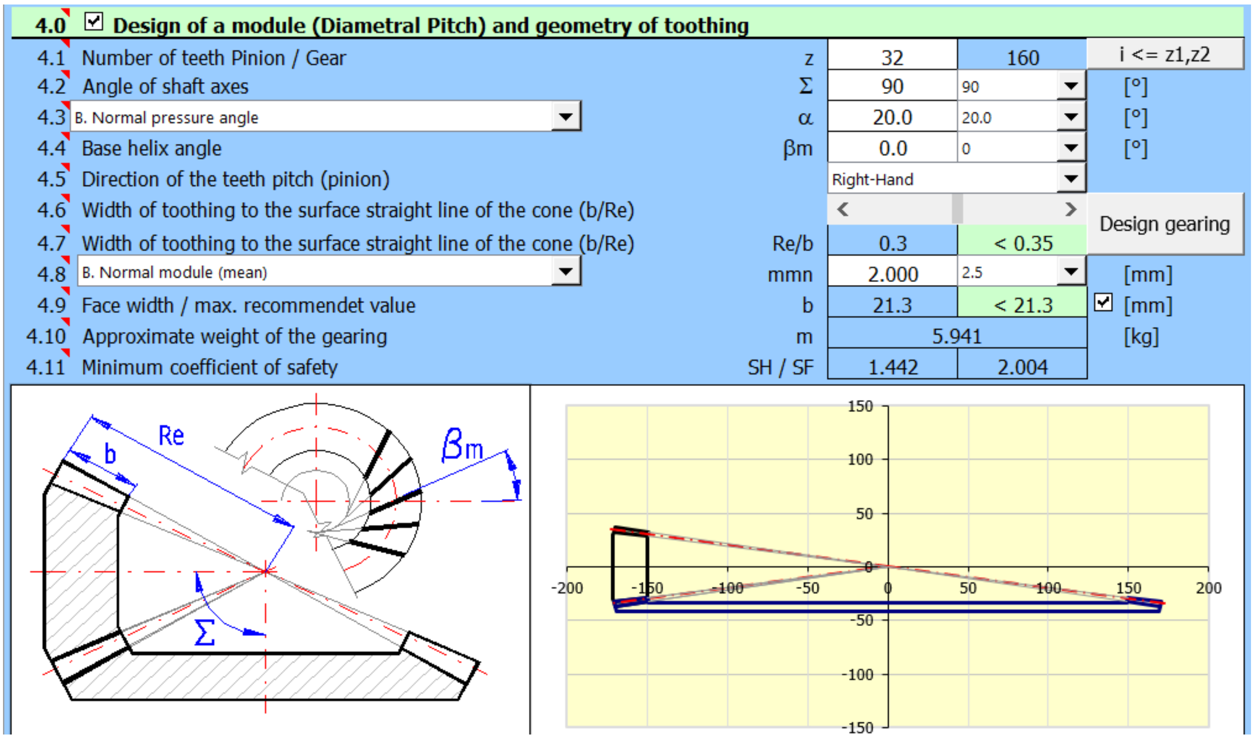



*Figure 9 MITCalc Stage 1*

## Stage 2 Spur

The same here with stage 2 gears, we increased the number of teeth and got nearly the required factor of safety which are 1.5 contact factor of safety and 2 for bending factor of safety.

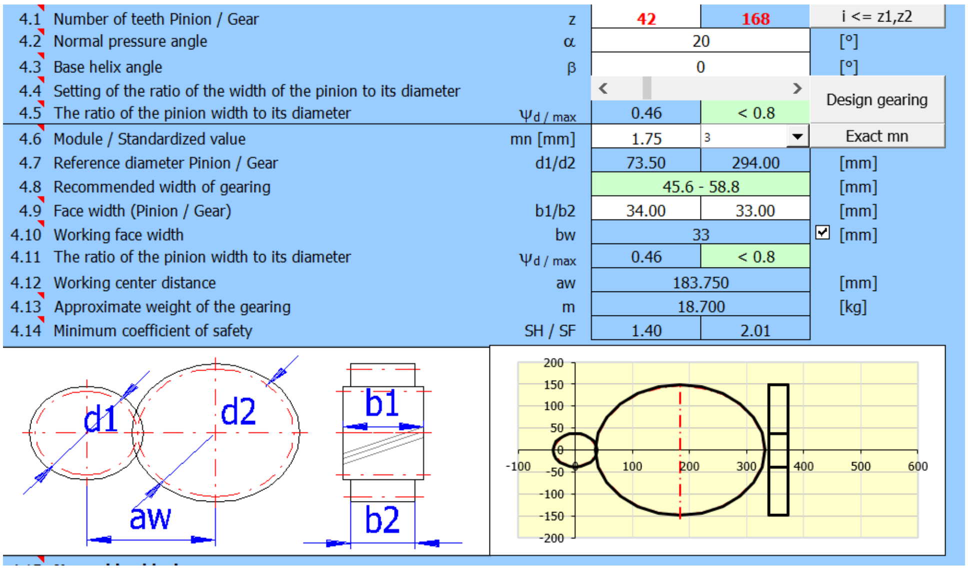



*Figure 10 MITCalc Stage 2*

## Stage 3 Spur

The main problem for all of our gears design was the number of teeth for the gears which will affect the diameter and by that affect the stresses for bending and contact. Here we increased the number of teeth which increased the diameter and reduced the stresses.

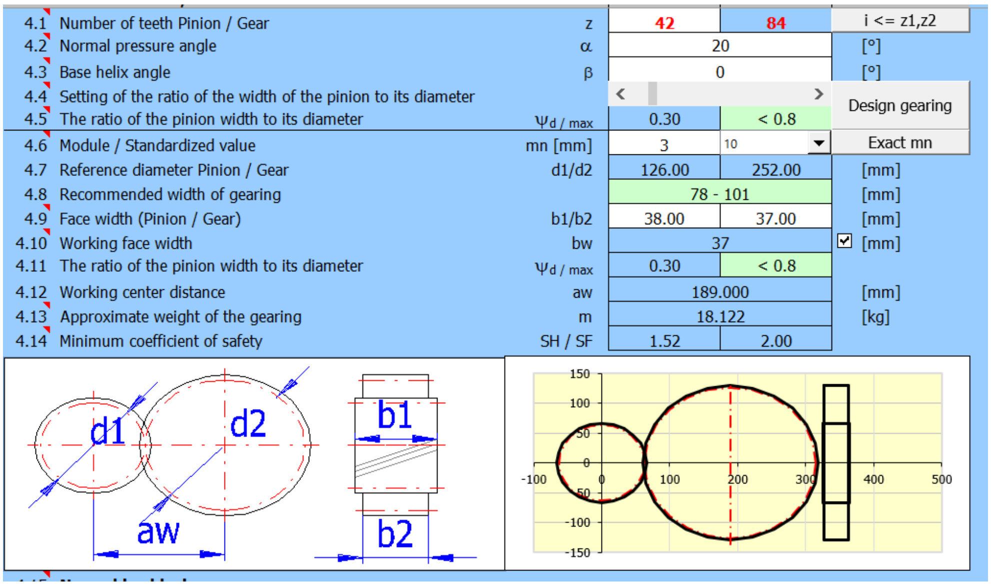



*Figure 11 MITCalc Stage 3*

## Shaft Design

Now we will start the hand calculations of only the input shaft which is number 1. The rest of the shafts will be designed by using MITCalc software.

### Shaft 1

Now we will start designing a suitable shaft by using hand calculations and the method we learned from Shigley's Mechanical Engineering Design [4]. We will use *DE-Goodman* [4] equation to find a suitable diameter "$d$" for our shaft.

$$d = \left(\frac{16n}{\pi}\left\{\frac{1}{S_e}\left[4(K_f M_a)^2 + 3(K_{fs} T_a)^2\right]^{\frac{1}{2}} + \frac{1}{S_{ut}}\left[4(K_f M_m)^2 + 3(K_{fs} T_m)^2\right]^{\frac{1}{2}}\right\}\right)^{\frac{1}{3}}$$

(37)

To use *DE-Goodman* equation, we need to find the values to substitute in it. We will start with the value of the endurance limit $S_e$. Too find the endurance limit we have to use the Marine equation [4] as shown in the following formula.

$$S_e = k_a \cdot k_b \cdot k_c \cdot k_d \cdot k_e \cdot k_f \cdot S_e{}' \quad (38)$$

Where,

$k_a$ *is the surface modification factor*

$k_b$ *is size modification factor*

$k_c$ *is load modification factor*

$k_d$ *is tempretaure modification factor*

$k_e$ *is reliability factor*

$k_f$ *is miscellaneous − effects modification factor*

$S_e'$ *is rotary − beam test speciman endurance limit*

### Surface Factor $k_a$

To get the surface factor we must use the following equation [4].

$$k_a = a \cdot S_{ut}^{b} \quad (39)$$

To get the ultimate tensile strength $S_{ut}$ assume the material of the shaft as G10500 CD with $\boldsymbol{S_{ut} = 690\ MPa}$. As for the values of "$a$" and "$b$" we can get them from (Table 6-2) for the cold drawn surface finish [4].

A-20

619

287

$$a = 4.51\ , b = -0.265$$

$$k_a = 4.51 \times 690^{-0.265}$$

$$k_a = 0.797$$

### Size Factor $k_b$

Since the size factor depends on the diameter of the shaft and it is unknown, we will assume it as:

$$k_b = 0.9$$

### Load Factor $k_c$

Since we have combined loading of bending and torsion on the shaft the value of the load factor will be [4]:

$$k_c = 1$$

### Temperature Factor $k_d$

Assume this factor as

$$k_d = 1.$$

**Reliability Factor $k_e$**

$$k_e = 1 - 0.08 \cdot z_a \ (40)$$

To get the value of $z_a$we assume a reliability of 99.9%, then from (Table 6-5) we get $z_a$ as:

$$z_a = 3.091$$

$$k_e = 1 - 0.08 \times 3.091$$

$$k_e = 0.753$$

**Miscellaneous-effect Factor $k_f$**

The value of this factor has not been established yet, so we will put it as [4]:

$$k_f = 1$$

**Rotating-beam Specimen $S'_e$**

Since the value of $S_{ut}$ is less than 1400 MPa, we use the following equation:

$$S'_e = 0.5 \cdot S_{ut} \ (41)$$

$$S'_e = 0.5 \times 690$$

$$S'_e = 345 \ MPa$$

After finding all the necessary factors we substitute in the endurance limit equation:

$$S_e = 0.797 \times 0.9 \times 1 \times 1 \times 0.753 \times 1 \times 345$$

$$S_e = 186.34 \ MPa$$

**Stress Concentrations Factors $K_f, K_{fs}$**

$K_f$ and $K_{fs}$ are the fatigue stress-concentration factors for bending and torsion, respectively. These two factors depend on the diameter of the shaft, so we will assume their values according to our experience.

$$K_f = 1.4 \qquad K_{fs} = 1.25$$

**Shaft Force Analysis**

We will assume the length of the shaft as **300mm** to help us calculate the necessary forces and reactions. Since we have a completely reversed stress on the shaft the values of the mean bending moment "$M_m$" and the amplitude torsion "$T_a$" are equal to zero.

First, we will find the mean torsion "$T_m$" using the following formula from Shigley's Mechanical Engineering Design [4].

$$T_m = \frac{P}{\omega} = \frac{P}{\frac{2\pi}{60} \times n} \text{ (42)}$$

Pred

$$T_m = \frac{7435 \times 10^3}{\frac{2\pi}{60} \times 1800}$$

$$T_m = 39444 \ N \cdot m$$

Then we calculated the reactions to find the maximum bending moment applied on the shaft "$M_a$". The gear is placed at point C and the reactions are at A and B.

**xy-plane**

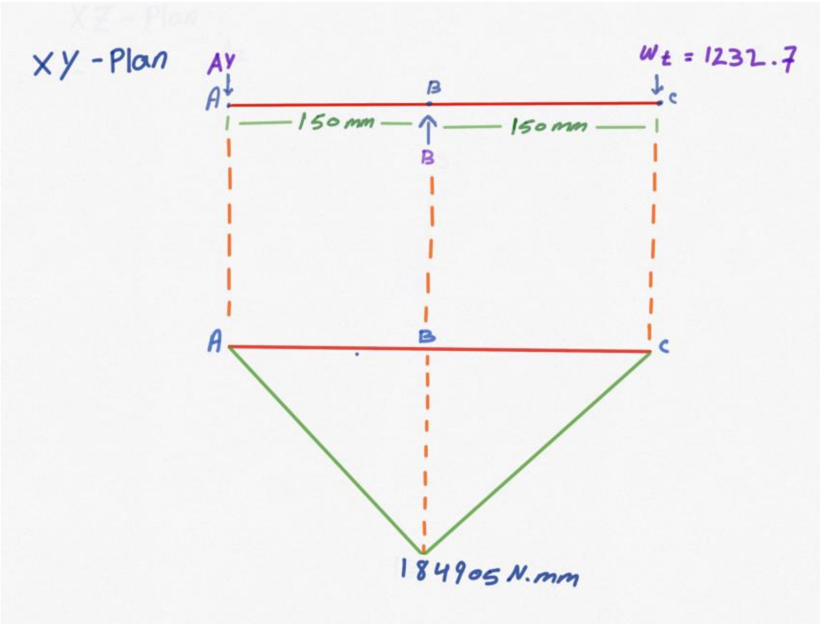



*Figure 12 Moment diagram xy-plane*

We take moment about point A to find the reaction at B and A:

$$\sum M_A = 0 \rightarrow B_y \cdot (150) - 1232.7 \times 300 = 0$$

$$B_y = 2465.4\ N\ \uparrow$$

$$A_y = B_y - W_t$$

$$A_y = 2465.4 - 1232.7$$

$$A_y = 1232.7\ N\ \downarrow$$

From the moment diagram of XY-plane we can see the maximum moment location is at point B, and we can substitute by the following equation find its value:

$$M_{a_{xy}} = A_y \cdot (150)$$

$$M_{a_{xy}} = 1232.7 \times 150$$

$$M_{a_{xy}} = 184905\ N \cdot mm$$

**xz-plane**

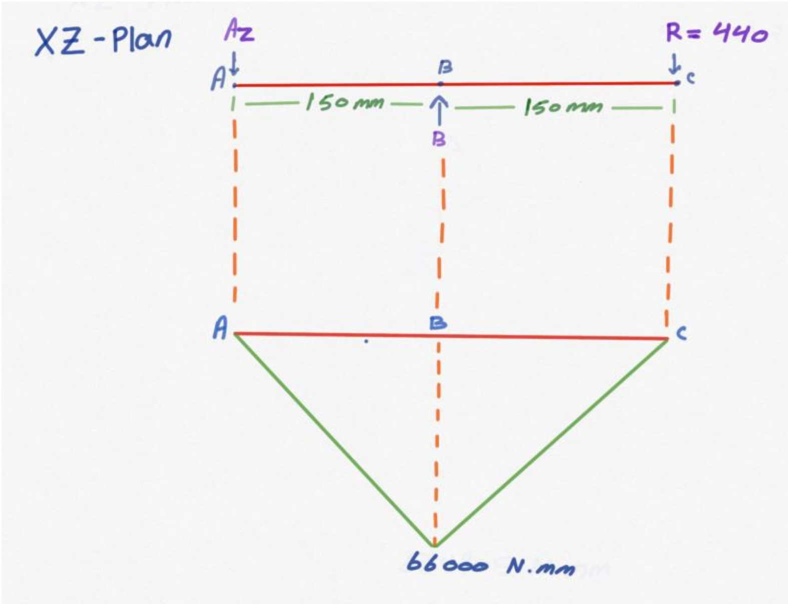



*Figure 13 Moment diagram xz-plane*

The same procedure will be done here to find "$M_{a_{xz}}$".

$$\sum M_A = 0 \;\rightarrow\; B_z \cdot (150) - 440 \times 300 = 0$$

$$B_z = 880\ N$$

$$A_z = B_z - 440$$

$$A_z = 880 - 440$$

$$A_z = 440\ N$$

$$M_{a_{xz}} = A_z \cdot (150)$$

$$M_{a_{xz}} = 440 \times 150$$

$$M_{a_{xz}} = 66000\ N \cdot mm$$

After finding the bending moment about xy and xz planes, now we take the resultant between them:

$$M_a = \sqrt{{M_{a_{xy}}}^2 + {M_{a_{xz}}}^2} \quad (43)$$

$$M_a = \sqrt{184905^2 + 66000^2}$$

$$M_a = 196331\ N.mm$$

Now substituting in *DE-Goodman* equation:

Assuming factor of safety:

$$n = 2.5$$

$$d = \left(\frac{16 \times 2.5}{\pi}\left\{\frac{1}{186.34} \times [\,4(1.4 \times 196331)^2 + 0\,]^{\frac{1}{2}} + \frac{1}{690}[\,0 + 3(1.25 \times 39444)^2\,]^{\frac{1}{2}}\right\}\right)^{\frac{1}{3}}$$

$$d = 22.32\ mm$$

Take the diameter according to the standard so,

$$d = 25\ mm$$

## MITCalc Shafts

For each shaft we made shoulders for the gears to fix one side of the gear, the diameter of these shoulders were increased by 5mm of the whole shaft diameter.

### Shaft 1

Here are the results of shaft 1 from the MITCalc software. As shown from the picture below our hand calculations for shaft1 were correct and came up with shaft diameter od 30mm the same as MITCalc.

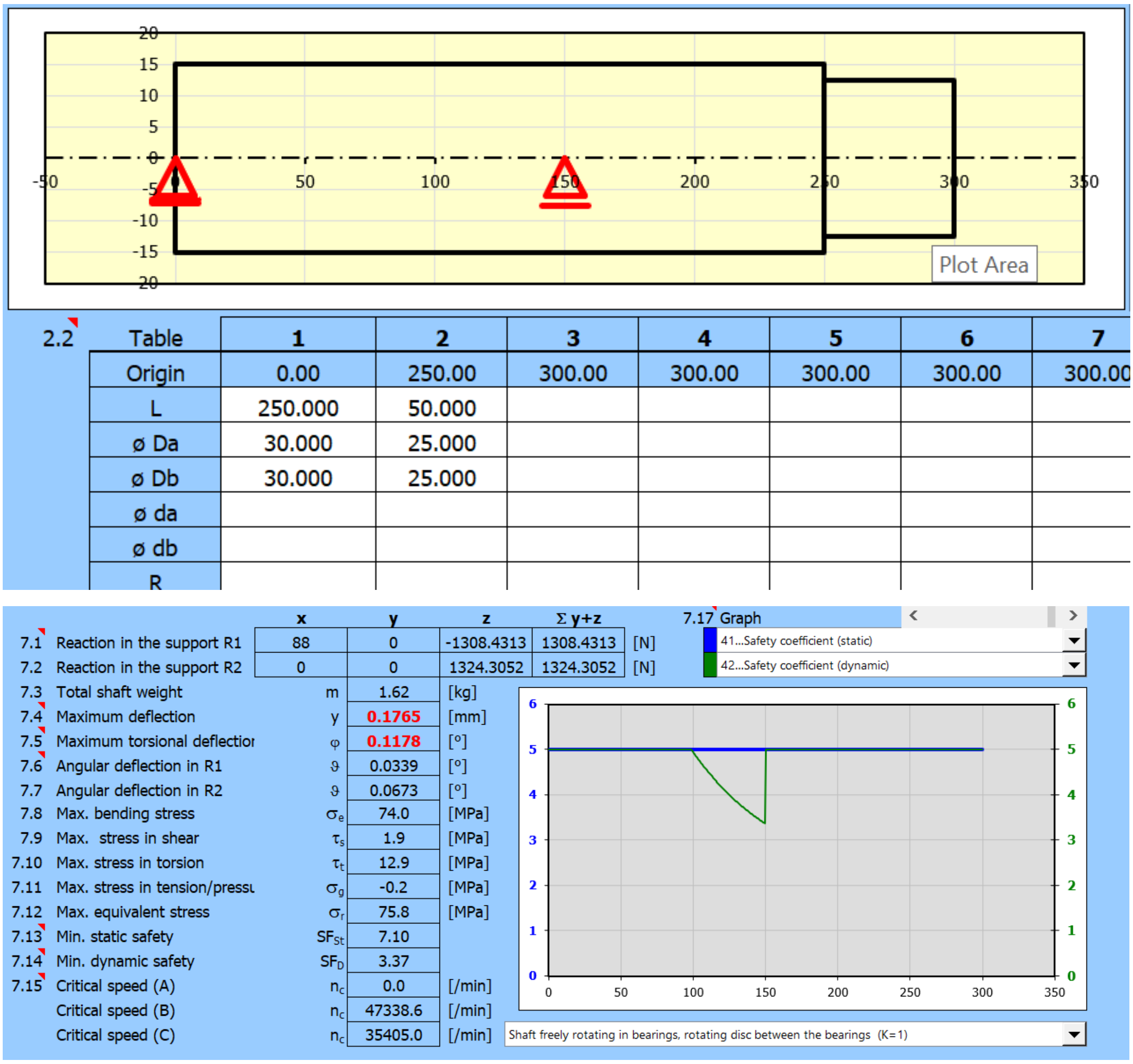



*Figure 14 MITCalc Shaft 1*

## Shaft 2

From the MITCalc we got a shaft diameter of 60mm with static factor of safety 17.57 and dynamic factor of safety 2.55.

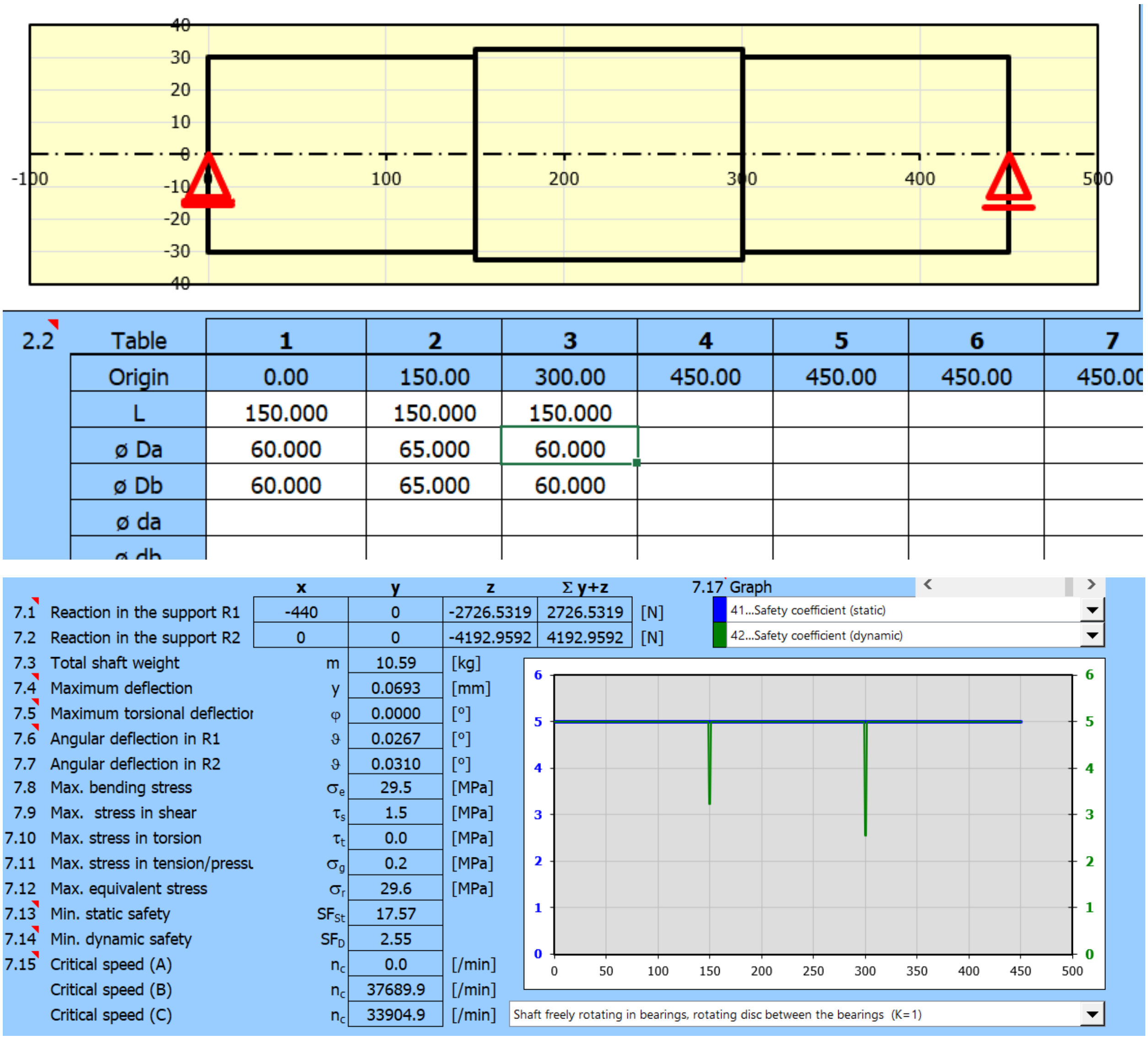
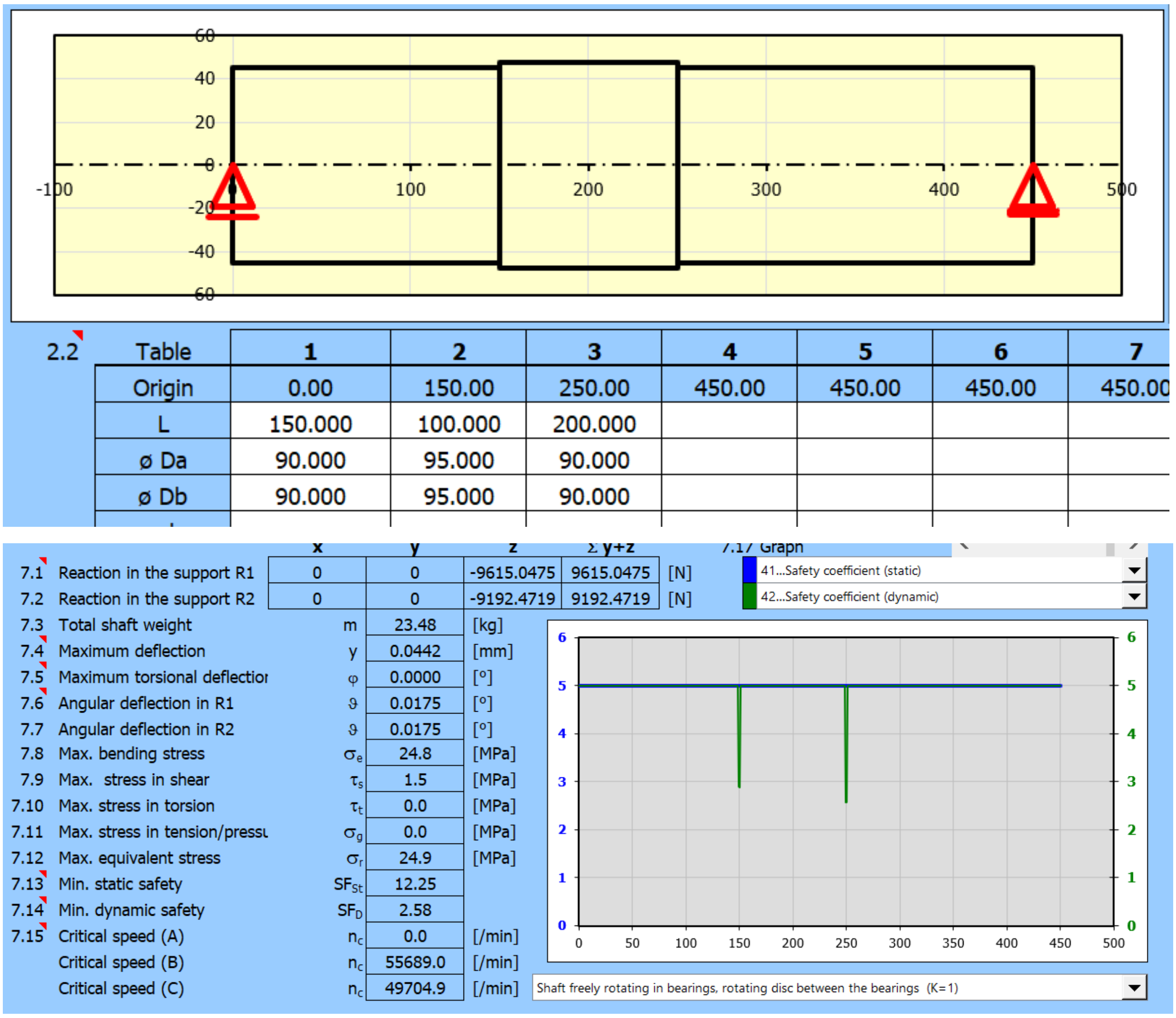



*Figure 15 MITCalc Shaft 2*

## Shaft 3

The base diameter of the third shaft is 90mm with factor of safeties of 12.25 and 2.58 for static and dynamic, respectively.




| 2.2 Table | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Origin | 0.00 | 150.00 | 250.00 | 450.00 | 450.00 | 450.00 | 450.00 |
| L | 150.000 | 100.000 | 200.000 | | | | |
| ø Da | 90.000 | 95.000 | 90.000 | | | | |
| ø Db | 90.000 | 95.000 | 90.000 | | | | |

| | | | x | y | z | Σ y+z | |
|---|---|---|---|---|---|---|---|
| 7.1 | Reaction in the support R1 | | 0 | 0 | -9615.0475 | 9615.0475 | [N] |
| 7.2 | Reaction in the support R2 | | 0 | 0 | -9192.4719 | 9192.4719 | [N] |
| 7.3 | Total shaft weight | m | | 23.48 | [kg] | | |
| 7.4 | Maximum deflection | y | | 0.0442 | [mm] | | |
| 7.5 | Maximum torsional deflectior | φ | | 0.0000 | [°] | | |
| 7.6 | Angular deflection in R1 | ϑ | | 0.0175 | [°] | | |
| 7.7 | Angular deflection in R2 | ϑ | | 0.0175 | [°] | | |
| 7.8 | Max. bending stress | $\sigma_e$ | | 24.8 | [MPa] | | |
| 7.9 | Max. stress in shear | $\tau_s$ | | 1.5 | [MPa] | | |
| 7.10 | Max. stress in torsion | $\tau_t$ | | 0.0 | [MPa] | | |
| 7.11 | Max. stress in tension/pressu | $\sigma_g$ | | 0.0 | [MPa] | | |
| 7.12 | Max. equivalent stress | $\sigma_r$ | | 24.9 | [MPa] | | |
| 7.13 | Min. static safety | $SF_{St}$ | | 12.25 | | | |
| 7.14 | Min. dynamic safety | $SF_D$ | | 2.58 | | | |
| 7.15 | Critical speed (A) | $n_c$ | | 0.0 | [/min] | | |
| | Critical speed (B) | $n_c$ | | 55689.0 | [/min] | | |
| | Critical speed (C) | $n_c$ | | 49704.9 | [/min] | | |

*Figure 16 MITCalc Shaft 3*

## Shaft 4

As for the final shaft we got 90mm as base diameter and static factor of safety of 12.90 and dynamic factor of safety 2.65.

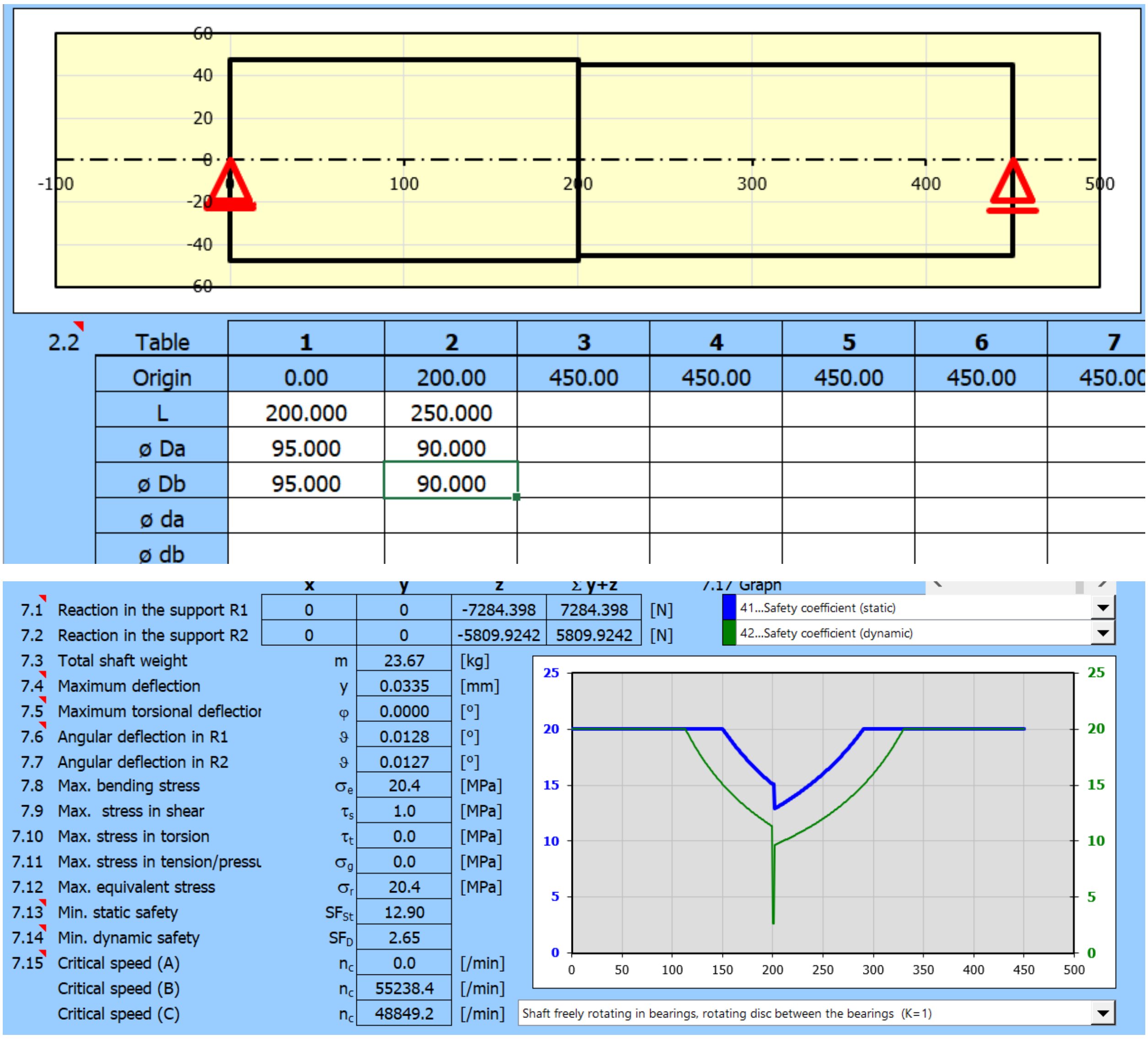



*Figure 17 MITCalc Shaft 4*

## Bearings Selection

For selecting bearings, we made hand calculations only for one bearing, while the other bearings we used MITCalc software to select them.

### Bearing for Shaft 1

This bearing must withstand both radial and axial loads, so for that we selected a tapered roller bearing because it is suitable for these two types of loads on bearings.

First assume the lifetime for the bearing in hours which is:

$$\boxed{L_{10h} = 20000\ hours}$$

Then calculate the number of revolutions made by the bearing by the following formula:

$$L_{10} = \frac{60 \cdot n \cdot L10h}{10^6} \quad (44)$$

$$L_{10} = \frac{60 \times 1800 \times 20000}{10^6}$$

$$L_{10} = 2160 \quad Millions\ of\ revolutions$$

Then we found the radial load $F_r$ and the axial load $F_a$ by using MITCalc software in force analysis section for shaft 1.

$$\boxed{F_r = 2624\ N \qquad F_a = 88\ N} \rightarrow B_y, B_z$$

Then we find the value of ratio of axial load to radial load.

$$\frac{F_a}{F_r} = 0.0355$$

Choose bearing $\mathbf{30205}$ with bore diameter $\boldsymbol{d = 25\ mm}$ and $\boldsymbol{e = 0.37}$ and compare between the value of "$e$" and "$\frac{F_a}{F_r}$" and specifications as following [5]:

$$C = 38.1\ kN \qquad\qquad C_o = 33.5\ kN$$

$$if \begin{cases} \dfrac{F_a}{F_r} \leq e & \rightarrow \quad P = F_r \\ \dfrac{F_a}{F_r} \geq e & \rightarrow \quad P = XF_r + YF_a \end{cases}$$

$0.0355 \leq 0.37$ then,

$$P = F_r = 2624\ N$$

$$C' = P \cdot (L_{10})^{1/k} \ (45)$$

$$k = \frac{10}{3}\ for\ roller\ bearings$$

$$C' = 2624 \times 10^{-3} \times (2160)^{\frac{1}{10/3}}$$

$$C' = 26.26\ kN$$

Since $C' \leq C$ we will see a bearing that has lower dynamic than this one, and bigger of equal to the value we obtained.

After looking into the table, we found bearing **32005X** with $\boldsymbol{C = 33.2\ kN}$ and this bearing is the most cost efficient.

## MITCalc Bearings

In this section we found the suitable bearing for each shaft by using MITCalc software for bearings selection.

### Bearing for Shaft 1

For this bearing we selected the bearing by hand calculations, after that we used the MITCalc to check whether our work is correct or not. After inserting the necessary data the software selected the same bearing that we came up with which is tapered roller bearing 32005-X with bore diameter of 25mm.

| ID | d | D | T | C | C0 | nr | nmax | Bearing |
|---|---|---|---|---|---|---|---|---|
| 11 | 25.0 | 47.0 | 15.0 | 33200 | 32500 | 12000 | 14000 | 32005 X * |

| 2.2 | **Bearing parameters** | | | | | |
|---|---|---|---|---|---|---|
| 2.3 | Basic dynamic load rating | C | 33200 | [N] ☑ | d | 25 |
| 2.4 | Equivalent dynamic load | P | 2624 | [N] | D | 47 |
| 2.5 | Basic rating life | L10h | 43701 | [h] | T | 15 |
| 2.6 | Basic static load rating | C0 | 32500 | [N] | C | 11.5 |
| 2.7 | Equivalent static load | P0 | 2624 | [N] | B | 15 |
| 2.8 | Static safety factor | s0 | 12.39 | | ramax | 0.6 |
| 2.9 | Permissible radial load | Frmax | - | [N] | rbmax | 0.6 |
| 2.10 | Permissible axial load | Famax | - | [N] | Damax | 42 |
| 2.11 | Reference speed | nr | 12000 | [/min] | Damin | 40 |
| 2.12 | Limiting speed | nmax | 14000 | [/min] | damax | 30 |
| 2.13 | Power loss | NR | 11.13 | [W] | dbmin | 31 |
| 2.14 | Bearing mass | g | 0.11 | [kg] | Dbmin | 44 |

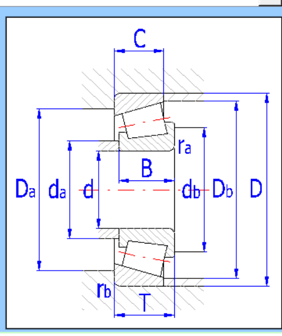



*Figure 18 MITCalc Bearing for shaft 1*

### Bearings for Shaft 2

This shaft has axial forces so we will also pick tapered roller bearings for it. After using MITCalc we found that the two bearings here are the same which is 32911 with bore diameter of 55mm.

| ID | d | D | T | C | C0 | nr | nmax | Bearing |
|---|---|---|---|---|---|---|---|---|
| 81 | 55.0 | 80.0 | 17.0 | 51700 | 69500 | 6300 | 7500 | 32911 * |

| 2.2 | **Bearing parameters** | | | | | |
|---|---|---|---|---|---|---|
| 2.3 | Basic dynamic load rating | C | 51700 | [N] ☑ | d | 55 |
| 2.4 | Equivalent dynamic load | P | 2778.3 | [N] | D | 80 |
| 2.5 | Basic rating life | L10h | 790529 | [h] | T | 17 |
| 2.6 | Basic static load rating | C0 | 69500 | [N] | C | 14 |
| 2.7 | Equivalent static load | P0 | 2778.3 | [N] | B | 17 |
| 2.8 | Static safety factor | s0 | 25.02 | | ramax | 1 |
| 2.9 | Permissible radial load | Frmax | - | [N] | rbmax | 1 |
| 2.10 | Permissible axial load | Famax | - | [N] | Damax | 73 |
| 2.11 | Reference speed | nr | 6300 | [/min] | Damin | 73 |
| 2.12 | Limiting speed | nmax | 7500 | [/min] | damax | 62 |
| 2.13 | Power loss | NR | 5.18 | [W] | dbmin | 62.5 |
| 2.14 | Bearing mass | g | 0.28 | [kg] | Dbmin | 76 |

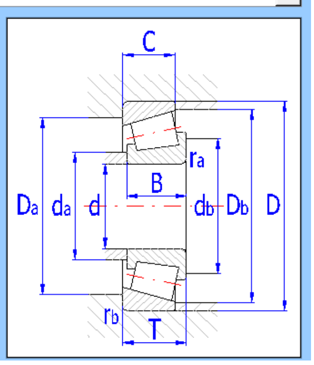



*Figure 19 MITCalc Bearing for shaft 2*

## Bearings for Shaft 3

This shaft does not have any axial forces due to the use of spur gears, so we will use deep grove ball bearings for both bearings. We found that the two bearings are the same which is bearing 6017 with bore diameter of 85mm.

| ID | d | D | B | C | C0 | nr | nmax | Bearing |
|---|---|---|---|---|---|---|---|---|
| 162 | 85.0 | 130.0 | 22.0 | 52000 | 43000 | 11000 | 6700 | 6017 * |

| No. | Bearing parameters | | Value | Unit | | |
|---|---|---|---|---|---|---|
| 2.3 | Basic dynamic load rating | C | 52000 | [N] ☑ | d | 85 |
| 2.4 | Equivalent dynamic load | P | 9730.5 | [N] | D | 130 |
| 2.5 | Basic rating life | L10h | 28263 | [h] | B | 22 |
| 2.6 | Basic static load rating | C0 | 43000 | [N] | ramax | 1 |
| 2.7 | Equivalent static load | P0 | 9730.5 | [N] | Damax | 123 |
| 2.8 | Static safety factor | s0 | 4.42 | | damin | 92 |
| 2.9 | Permissible radial load | Frmax | - | [N] | | |
| 2.10 | Permissible axial load | Famax | - | [N] | | |
| 2.11 | Reference speed | nr | 11000 | [/min] | | |
| 2.12 | Limiting speed | nmax | 6700 | [/min] | | |
| 2.13 | Power loss | NR | 5.85 | [W] | | |
| 2.14 | Bearing mass | g | 0.89 | [kg] | | |

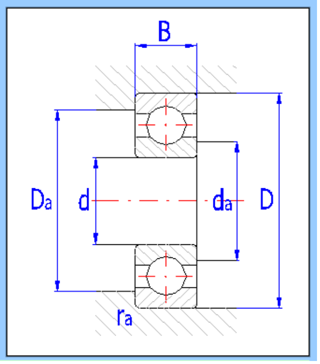



*Figure 20 MITCalc Bearing for shaft 3*

## Bearings for Shaft 4

The two bearings used here have different diameters due to the shaft design, the first one is bearing 61918 with bore diameter 90mm, the second one is bearing 61917 with bore diameter 85mm.

| ID | d | D | B | C | C0 | nr | nmax | Bearing |
|---|---|---|---|---|---|---|---|---|
| 167 | 90.0 | 125.0 | 18.0 | 33200 | 31500 | 11000 | 6700 | 61918 |

| No. | Bearing parameters | | Value | Unit | | |
|---|---|---|---|---|---|---|
| 2.3 | Basic dynamic load rating | C | 33200 | [N] ☑ | d | 90 |
| 2.4 | Equivalent dynamic load | P | 7404 | [N] | D | 125 |
| 2.5 | Basic rating life | L10h | 33393 | [h] | B | 18 |
| 2.6 | Basic static load rating | C0 | 31500 | [N] | ramax | 1 |
| 2.7 | Equivalent static load | P0 | 7404 | [N] | Damax | 119 |
| 2.8 | Static safety factor | s0 | 4.25 | | damin | 96 |
| 2.9 | Permissible radial load | Frmax | - | [N] | | |
| 2.10 | Permissible axial load | Famax | - | [N] | | |
| 2.11 | Reference speed | nr | 11000 | [/min] | | |
| 2.12 | Limiting speed | nmax | 6700 | [/min] | | |
| 2.13 | Power loss | NR | 2.36 | [W] | | |
| 2.14 | Bearing mass | g | 0.59 | [kg] | | |

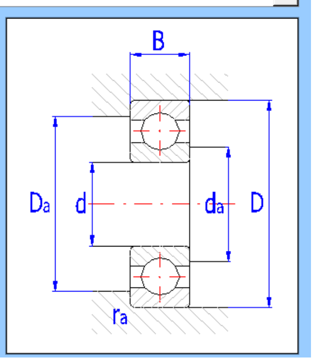
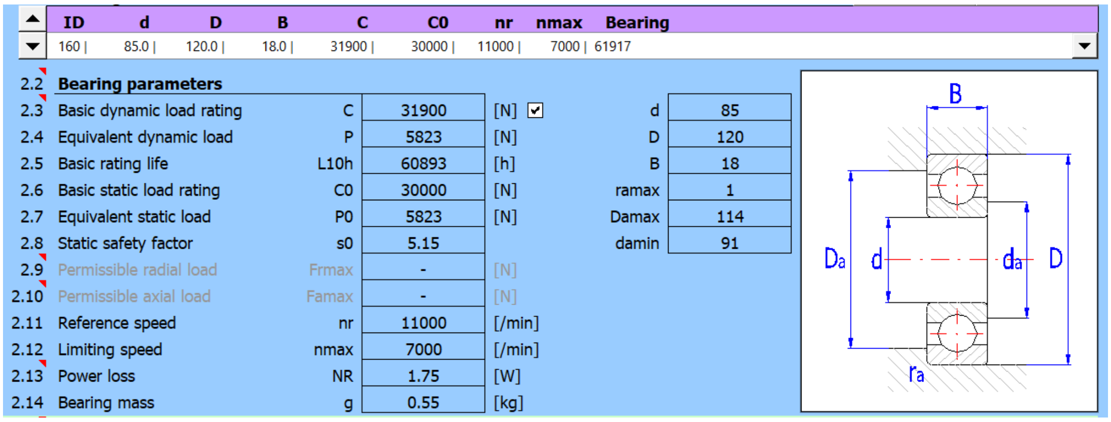



*Figure 21 MITCalc Bearing 1 for shaft 4*



| ID | d | D | B | C | C0 | nr | nmax | Bearing |
|---|---|---|---|---|---|---|---|---|
| 160 | 85.0 | 120.0 | 18.0 | 31900 | 30000 | 11000 | 7000 | 61917 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2.2 | **Bearing parameters** | | | | | |
| 2.3 | Basic dynamic load rating | C | 31900 | [N] | d | 85 |
| 2.4 | Equivalent dynamic load | P | 5823 | [N] | D | 120 |
| 2.5 | Basic rating life | L10h | 60893 | [h] | B | 18 |
| 2.6 | Basic static load rating | C0 | 30000 | [N] | ramax | 1 |
| 2.7 | Equivalent static load | P0 | 5823 | [N] | Damax | 114 |
| 2.8 | Static safety factor | s0 | 5.15 | | damin | 91 |
| 2.9 | Permissible radial load | Frmax | - | [N] | | |
| 2.10 | Permissible axial load | Famax | - | [N] | | |
| 2.11 | Reference speed | nr | 11000 | [/min] | | |
| 2.12 | Limiting speed | nmax | 7000 | [/min] | | |
| 2.13 | Power loss | NR | 1.75 | [W] | | |
| 2.14 | Bearing mass | g | 0.55 | [kg] | | |



*Figure 22 MITCalc Bearing 2 for shaft 4*

## Key Design

The key is an important element to transmit torque between the gear and the shaft. So, in this section we will talk about how to design a key for a gear and shaft.

### Key for Shaft 1

In the beginning, we have to determine the shaft's diameter to help us select a size for the key.

The diameter of the first shaft is $d_1 = 25\ mm$. According to the standards we have to pick the size:

Key size:

$$w \times h$$

$$8 \times 7$$

Where "$w$" is the width of the key and "$h$" is the key height.

Then we assume the key material as G10300 CD with $S_y = 390\ MPa$

The next step is to find the minimum length of the key according to the bending and torsional moment by using the following formulas.

Length for Bending Moment

$$L_c = \frac{4 \cdot n \cdot T}{S_y \cdot h \cdot d} \quad (46)$$

Length for Torsion

$$L_s = \frac{4 \cdot n \cdot T}{S_y \cdot w \cdot d} \quad (47)$$

Where,

$T$ *is the torque on the key*

$n$ *is the factor of safety assumed as* $= 3$

$d$ *is the shaft's diameter*

N.mm

Now we substitute for equation

$$L_c = \frac{4 \times 3 \times 39470}{390 \times 7 \times 25}$$

$$L_c = 6.94\ mm$$

Substitute in equation

$$L_{\cancel{c}} = \frac{4 \times 3 \times 39470}{390 \times 8 \times 25}$$

S

$$L_{\cancel{c}} = 6.07\ mm$$

S

Now, since we got the lengths for each case we will pick a length that is bigger than them and matching for key size standards.

$$L = 18\ mm$$

**Key for Shaft 2**

The second key is on shaft 2 and we have to keys in this case and we will design the for both since the diameter and torque is the same.

Key size: $18\times 11$

$$L_c = \frac{4 \times 3 \times 197350}{390 \times 11 \times 60}$$

$$L_c = 9.2\, mm$$

$$L_s = \frac{4 \times 3 \times 197350}{390 \times 18 \times 60}$$

$$L_s = 5.6\, mm$$

Pick Length:

$$L = 20\, mm$$

**Key for Shaft 3**

We will design the keys for shaft 3, and they will be the same.

Key size: $25\times 14$

$$L_c = \frac{4 \times 3 \times 789410}{390 \times 14 \times 90}$$

$$L_c = 19.3\, mm$$

$$L_s = \frac{4 \times 3 \times 789410}{390 \times 25 \times 90}$$

$$L_s = 10.8\, mm$$

Pick Length:

$$L = 32\, mm$$

**Key for Shaft 4**

On shaft 4 we have only one gear, so only on key for this part.

Key size: $25\times 14$

$$L_c = \frac{4 \times 3 \times 1578820}{390 \times 14 \times 90}$$

$$L_c = 38.6 \ mm$$

$$L_s = \frac{4 \times 3 \times 1578820}{390 \times 25 \times 90}$$

$$L_s = 21.6 \, mm$$

Pick Length:

$$L = 40 \, mm$$

## Technical Drawings

In this part we will show you a drawing of our project that was chosen with the dimensions and measurements that were worked on above, and we will also show you the assembly and sub-assembly drawings and some parts of our drawing, and this part is very important for any engineer to know the dimensions of the drawing and how to understand the drawing better, and we drew the Figure below using Solid Work.

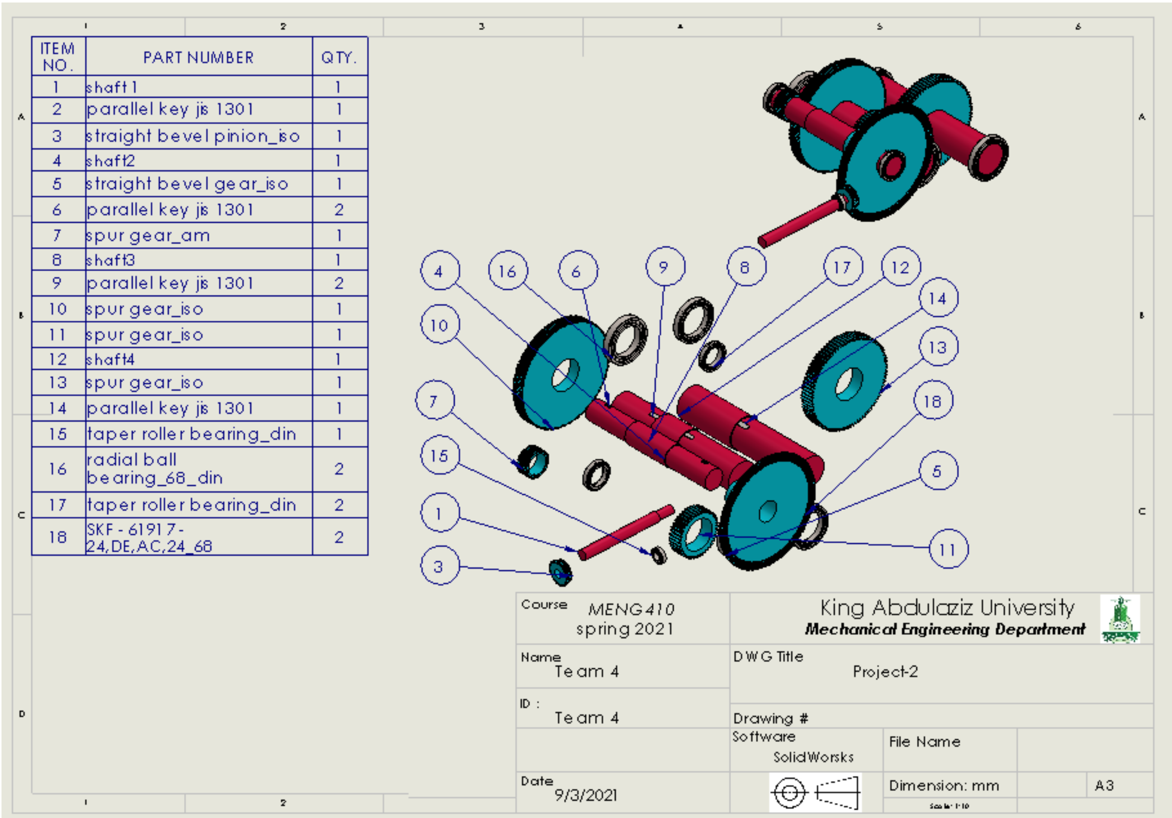



*Figure 23 Bill of material for gearbox*

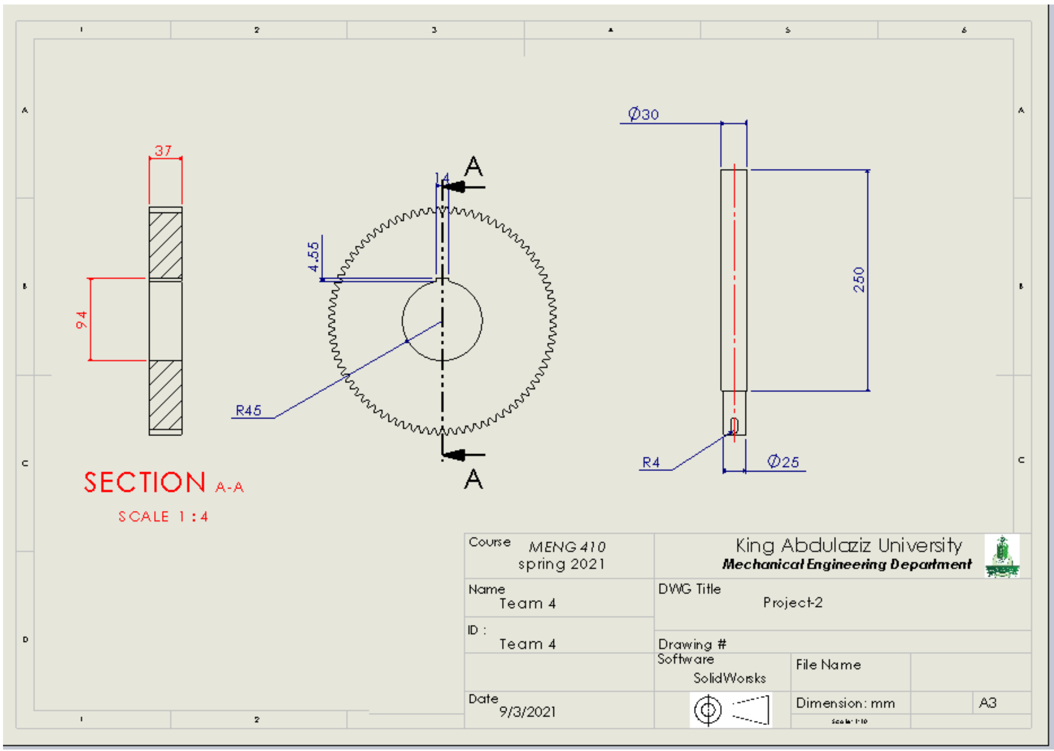



*Figure 24 Drawing sheet for gear*

In this part, we have two pictures from the sheet drawing, the first image shows us the assembly, and in this sheet, there are parts have been created and have been merged together, and also there are Ball of Materials. Finally, explode view were made for the customer to see the details of this drawing, and in the second image, we have some of the parts that have been worked on.

## Simulation

Structural mechanics solutions from ANSYS software provide the ability to Simulate every structural aspect of a product, including nonlinear static analysis that Provides stresses & deformations in addition to modal analysis that determines vibration characteristics. Using ANSYS software solutions, we will import geometries of complex assembly that was done using Solid works, to check the most critical points and parts in the design. ANSYS software was used to be certain that the system design is acceptable.

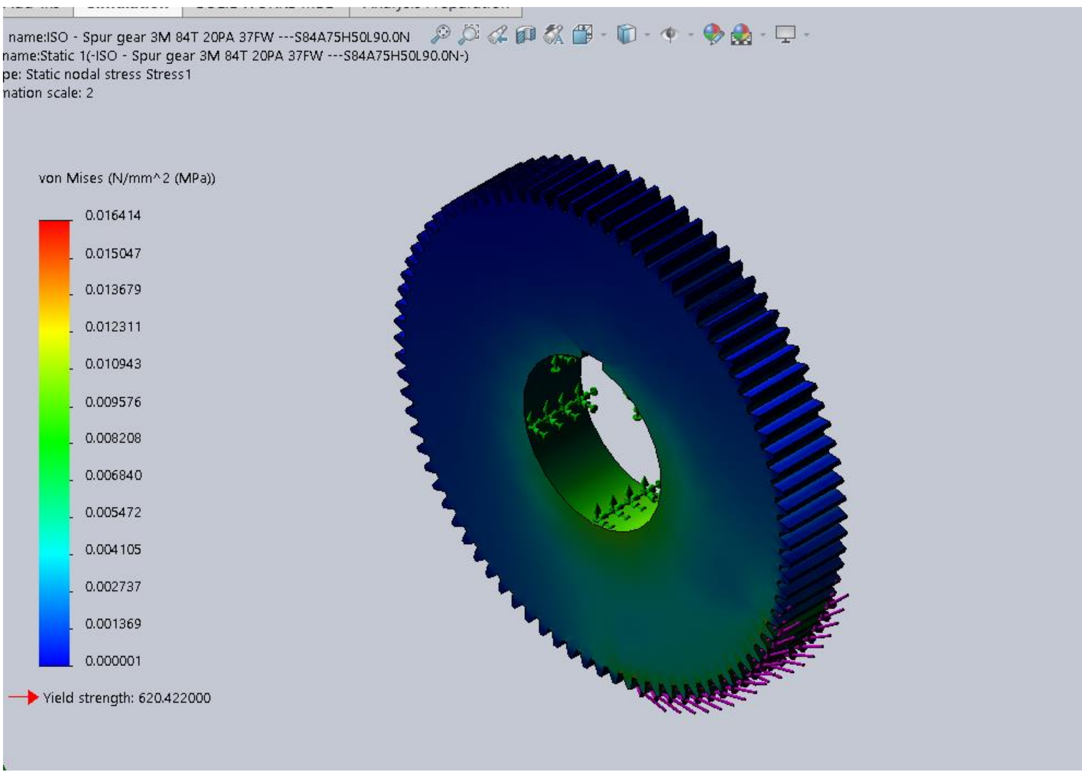



*Figure 25 Yield strength in simulation*

# Project Impacts

## Environmental Impact.

The environmental impact in this report is very important and must be presented for its importance. The speed reducer is placed in a wet environment, which may cause tool wear and affect the efficiency of the speed reducer.

## Social Impact

Speed reducer will be a new product in the market due to its inexpensive tools. It will increase competition between firms and reduce prices of speed reducers. Our project design emits medium noise, so it will depend on where the speed reducer is placed.

## Conclusion

First, the project objectives were to make a complete design of a three-stage speed reducer and there was a specific power should out of this gear box. We created an input rotational speed of 1800 rpm. The first shaft rotates with 1800 rpm. The next shaft rotates with 360 rpm. The third shaft rotates with 90 rpm and finally, the out shaft rotates with 45 rpm. And the input shaft has the bevel gear which will rotate the input shaft 90°

The speed reducer will consist of spur and bevel gears, it is cheap but makes some noise. A motor that has an output 5 kW has been used, also, 8 bearings.

The team gained experience during the implementation of the solution and new engineering skills. This project takes us 4 weeks to finish the whole design. We used solid work, Microsoft, and MIT calc to be sure of our calculation. At the end, we learnt a lot and gain more experience and skills that will help us in the future.

## Recommendations

We will be listing some recommendations for added safety and quality:

1. We have required continuous maintenance throughout the project.
2. Do not exceed the maximum load during operation.
3. To be used by a professional worker as it requires specific skills.

# References

1. Wilcox L., and Coleman W., “Application of Finite Element to the Analysis of Gear Tooth Stresses”, Journal of Engineering for Industry, Vol. 95, No. 4, pp. 1139 -1148, 1973.

2. Elkholy A.H., “Tooth Load Sharing in High Contact Ratio Spur Gears”, Journal of Mechanisms, Transmissions, and Automation in Design”, Vol. 107, No. 1, pp. 11-16, 1985.

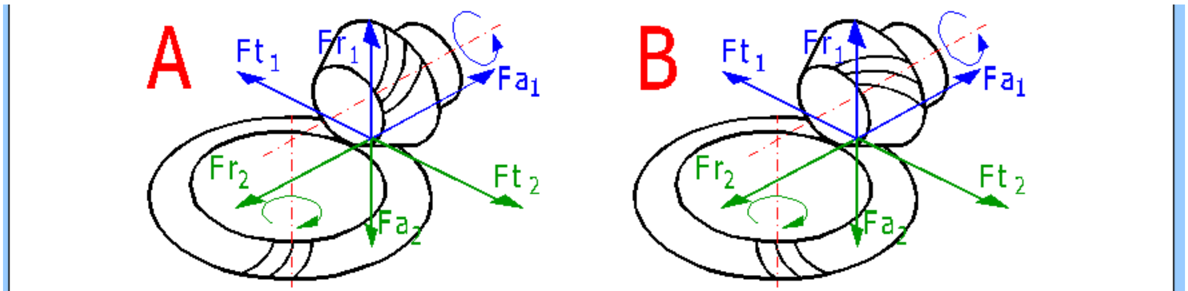
3. Mohanty S.C., “Tooth Load Sharing and Contact Stress Analysis of High Contact Ratio Spur Gears in Mesh”, national Convention of Mechanical Engineers, Roukela, 2002

4. Shigley’s mechanical engineering design. —Tenth edition / Richard G. Budynas, professor emeritus, Kate Gleason College of Engineering, Rochester Institute of Technology, J. Keith Nisbett, associate professor of mechanical engineering, Missouri University of Science and Technology

# Appendix

## Stage 1 Bevel

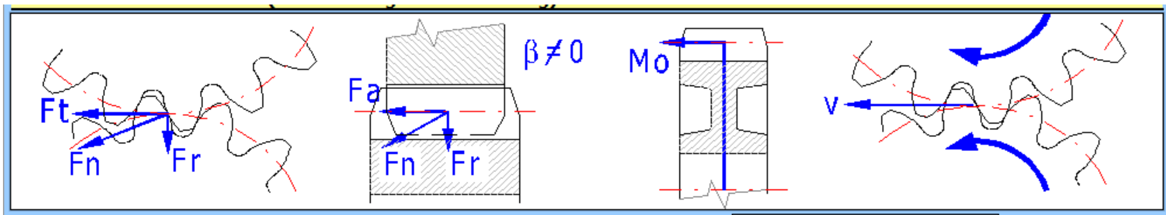
| | | | | | | |
|---|---|---|---|---|---|---|
| 6.1 | Number of teeth Pinion / Gear | z | | 32 | 160 | |
| 6.2 | Transverse module (outer, midle, inner) | met,mmt,mit | 2.1305 | 2.0000 | 1.8695 | [mm] |
| 6.3 | Normal module (outer, midle, inner) | men,mmn,min | 2.1305 | 2.0000 | 1.8695 | [mm] |
| 6.4 | Cone length (outer, midle, inner) | Re,Rm,Ri | 173.819 | 163.169 | 152.519 | [mm] |
| 6.5 | Pitch cone angle | δ | | 11.3099 | 78.6901 | [°] |
| 6.6 | Addendum cone angle | δa | | 12.3211 | 79.0833 | [°] |
| 6.7 | Dedendum cone angle | δf | | 10.7762 | 77.5385 | [°] |
| 6.8 | Tip diameter (outer) | dae | | 74.194 | 341.354 | [mm] |
| 6.9 | Tip diameter (midle) | dam | | 69.648 | 320.439 | [mm] |
| 6.10 | Tip diameter (inner) | dai | | 65.102 | 299.524 | [mm] |
| 6.11 | Pitch diameter (outer) | de | | 68.177 | 340.886 | [mm] |
| 6.12 | Pitch diameter (midle) | dm | | 64.000 | 320.000 | [mm] |
| 6.13 | Pitch diameter (inner) | di | | 59.823 | 299.114 | [mm] |
| 6.14 | Root diameter (outer) | dfe | | 65.002 | 339.516 | [mm] |
| 6.15 | Root diameter (midle) | dfm | | 61.019 | 318.713 | [mm] |
| 6.16 | Root diameter (inner) | dfi | | 57.036 | 297.911 | [mm] |
| 6.17 | Addendum angle | θa | | 1.0112 | 0.3933 | [°] |
| 6.18 | Dedendum angle | θf | | 0.5337 | 1.1516 | [°] |
| 6.19 | Addendum (outer) | hae | | 3.0680 | 1.1931 | [mm] |
| 6.20 | Addendum (midle) | ha | | 2.8800 | 1.1200 | [mm] |
| 6.21 | Addendum (inner) | hai | | 2.6920 | 1.0469 | [mm] |
| 6.22 | Dedendum (outer) | hfe | | 1.6192 | 3.4941 | [mm] |
| 6.23 | Dedendum (midle) | hf | | 1.5200 | 3.2800 | [mm] |
| 6.24 | Dedendum (inner) | hfi | | 1.4208 | 3.0659 | [mm] |
| 6.25 | Normal pressure angle | αn | | 20.0000 | | [°] |




| | | | | | |
|---|---|---|---|---|---|
| 11.1 | Tangential force | Ft | 1232.71 | | [N] |
| 11.2 | Normal force | Fn | 1311.83 | | [N] |
| 11.3 | Axial force - (rotation acc. to the picture) | Fa | 87.99 | 439.96 | [N] |
| 11.4 | Radial force (rotation acc. to the picture) | Fr | 439.96 | 87.99 | |
| 11.5 | Axial force (rotation opposite to the picture) | Fa | 87.99 | 439.96 | [N] |
| 11.6 | Radial force (rotation opposite to the picture) | Fr | 439.96 | 87.99 | |
| 11.7 | Peripheral speed on the pitch diameter | v \| vmax | 6.03 | < 5 | [m/s] |
| 11.8 | Specific load / Unit load | wt \| wt* | 68.09 | 34.04 | [N/mm \| MPa] |

## Stage 2 Spur

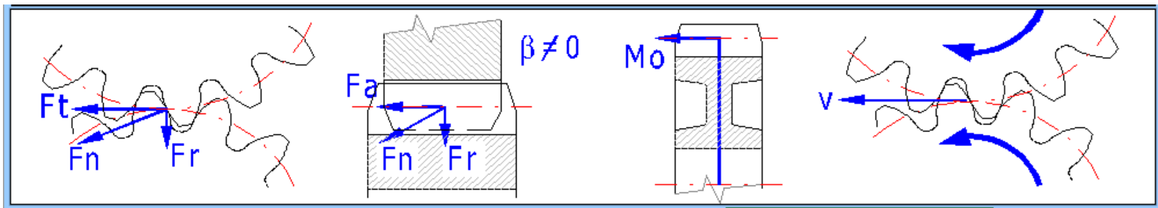
| | | | | | |
|---|---|---|---|---|---|
| 6.1 | Number of teeth Pinion / Gear | z | 42 | 168 | |
| 6.2 | Face width (Pinion / Gear) | b | 34 | 33 | [mm] |
| 6.3 | Normal module | mn | 1.75 | | [mm] |
| 6.4 | Transverse module | mt | 1.7500 | | [mm] |
| 6.5 | Circular pitch | p | 5.498 | | [mm] |
| 6.6 | Transverse circular pitch | pt | 5.498 | | [mm] |
| 6.7 | Base circular pitch | ptb | 5.166 | | [mm] |
| 6.8 | Center distance (pitch) | a | 183.7500 | | [mm] |
| 6.9 | Center distance (production) | av | 183.7500 | | [mm] |
| 6.10 | Center distance (working) | aw | 183.7500 | | [mm] |
| 6.11 | Pressure angle | α | 20.0000 | | [°] |
| 6.12 | Transverse pressure angle | αt | 20.0000 | | [°] |
| 6.13 | Pressure angle at the pitch cylinder | αwn | 20.0000 | | [°] |
| 6.14 | Transverse pressure angle at the pitch cylinder | αwt | 20.0000 | | [°] |
| 6.15 | Helix angle | β | 0.00 | | [°] |
| 6.16 | Base helix angle | β b | 0.0000 | | [°] |
| 6.17 | Tip diameter | da | 77.0000 | 297.5000 | [mm] |
| 6.18 | Reference diameter | d | 73.5000 | 294.0000 | [mm] |
| 6.19 | Base diameter | db | 69.0674 | 276.2696 | [mm] |
| 6.20 | Root diameter | df | 69.1250 | 289.6250 | [mm] |
| 6.21 | Operating pitch diameter | dw | 73.5000 | 294.0000 | [mm] |
| 6.22 | Addendum | ha | 1.7500 | 1.7500 | [mm] |
| 6.23 | Dedendum | hf | 2.1875 | 2.1875 | [mm] |




| | | | | | |
|---|---|---|---|---|---|
| 12.1 | Tangential force | Ft | 5366.91 | | [N] |
| 12.2 | Normal force | Fn | 5711.35 | | [N] |
| 12.3 | Axial force | Fa | 0.00 | | [N] |
| 12.4 | Radial force | Fr | 1953.40 | | [N] |
| 12.5 | Bending moment | Mo | 0.00 | 0.00 | [Nm] |
| 12.6 | Peripheral speed on the pitch diameter | v \| vmax | 1.39 | < 8 | [m/s] |
| 12.7 | Tangential load per unit tooth width / Unit load | wt \| wt* | 162.63 | 92.93 | [N/mm \| MPa] |

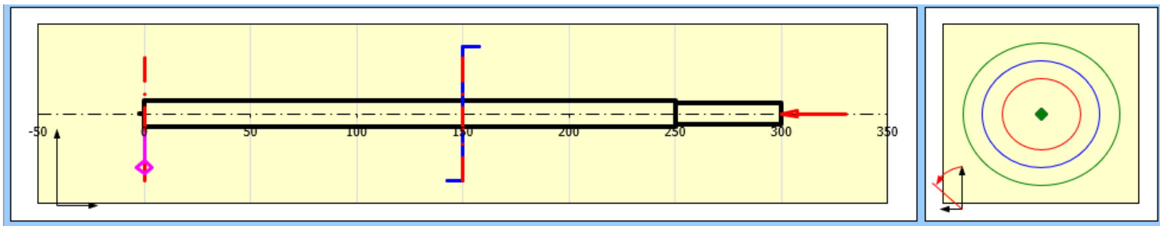
Stage 3 Spur

| | | | | | |
|---|---|---|---|---|---|
| 6.1 | Number of teeth Pinion / Gear | z | 42 | 84 | |
| 6.2 | Face width (Pinion / Gear) | b | 38 | 37 | [mm] |
| 6.3 | Normal module | mn | 3 | | [mm] |
| 6.4 | Transverse module | mt | 3.0000 | | [mm] |
| 6.5 | Circular pitch | p | 9.425 | | [mm] |
| 6.6 | Transverse circular pitch | pt | 9.425 | | [mm] |
| 6.7 | Base circular pitch | ptb | 8.856 | | [mm] |
| 6.8 | Center distance (pitch) | a | 189.0000 | | [mm] |
| 6.9 | Center distance (production) | av | 189.0000 | | [mm] |
| 6.10 | Center distance (working) | aw | 189.0000 | | [mm] |
| 6.11 | Pressure angle | α | 20.0000 | | [°] |
| 6.12 | Transverse pressure angle | αt | 20.0000 | | [°] |
| 6.13 | Pressure angle at the pitch cylinder | αwn | 20.0000 | | [°] |
| 6.14 | Transverse pressure angle at the pitch cylinder | αwt | 20.0000 | | [°] |
| 6.15 | Helix angle | β | 0.00 | | [°] |
| 6.16 | Base helix angle | β b | 0.0000 | | [°] |
| 6.17 | Tip diameter | da | 132.0000 | 258.0000 | [mm] |
| 6.18 | Reference diameter | d | 126.0000 | 252.0000 | [mm] |
| 6.19 | Base diameter | db | 118.4013 | 236.8025 | [mm] |
| 6.20 | Root diameter | df | 118.5000 | 244.5000 | [mm] |
| 6.21 | Operating pitch diameter | dw | 126.0000 | 252.0000 | [mm] |
| 6.22 | Addendum | ha | 3.0000 | 3.0000 | [mm] |
| 6.23 | Dedendum | hf | 3.7500 | 3.7500 | [mm] |




| | | | | | |
|---|---|---|---|---|---|
| 12.1 | Tangential force | Ft | 12522.80 | | [N] |
| 12.2 | Normal force | Fn | 13326.48 | | [N] |
| 12.3 | Axial force | Fa | 0.00 | | [N] |
| 12.4 | Radial force | Fr | 4557.93 | | [N] |
| 12.5 | Bending moment | Mo | 0.00 | 0.00 | [Nm] |
| 12.6 | Peripheral speed on the pitch diameter | v \| vmax | 0.59 | < 15 | [m/s] |
| 12.7 | Tangential load per unit tooth width / Unit load | wt \| wt* | 338.45 | 112.82 | [N/mm \| MPa] |

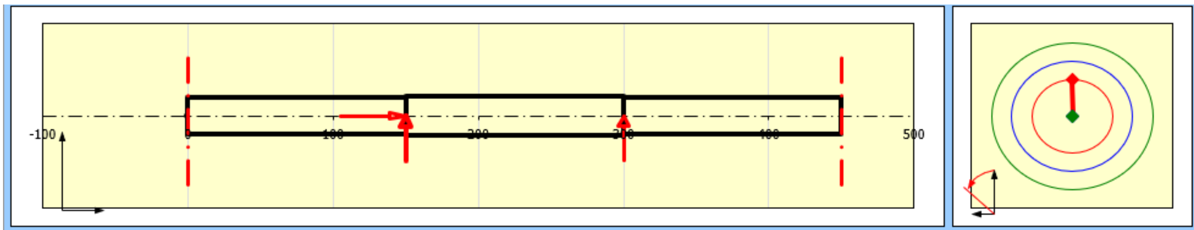
Shaft 1




4.1 Loading

| | X | Fx | F | alfa | Mt | Mb | alfa | Q | b | alfa |
|---|---|---|---|---|---|---|---|---|---|---|
| | [mm] | [N] | | [°] | [Nm] | | [°] | [N/mm] | [mm] | [°] |
| 1 | 150.00 | | | | | 196.33 | | | | |
| 2 | 0.00 | | | | 39.45 | | | | | |
| 3 | 300.00 | -88.0 | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | | | | | | | | | | |
| 9 | | | | | | | | | | |
| 10 | | | | | | | | | | |

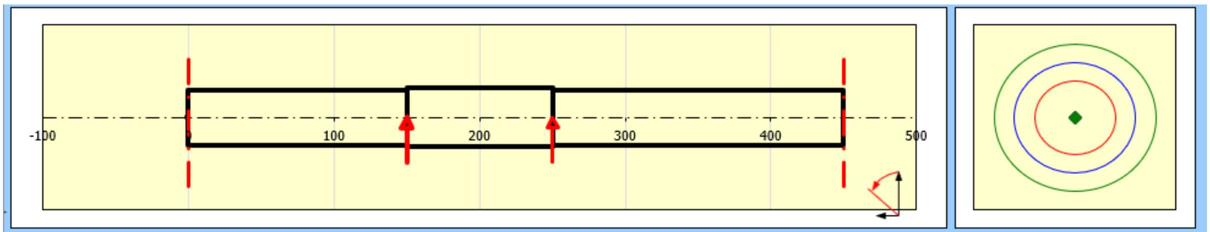
Shaft 2




4.1 Loading

| | X | Fx | F | alfa | Mt | Mb | alfa | Q | b | alfa |
|---|---|---|---|---|---|---|---|---|---|---|
| | [mm] | [N] | | [°] | [Nm] | | [°] | [N/mm] | [mm] | [°] |
| 1 | 150.00 | 440.0 | 1312.0 | | | | | | | |
| 2 | 300.00 | 0.0 | 5711.4 | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | | | | | | | | | | |
| 9 | | | | | | | | | | |
| 10 | | | | | | | | | | |

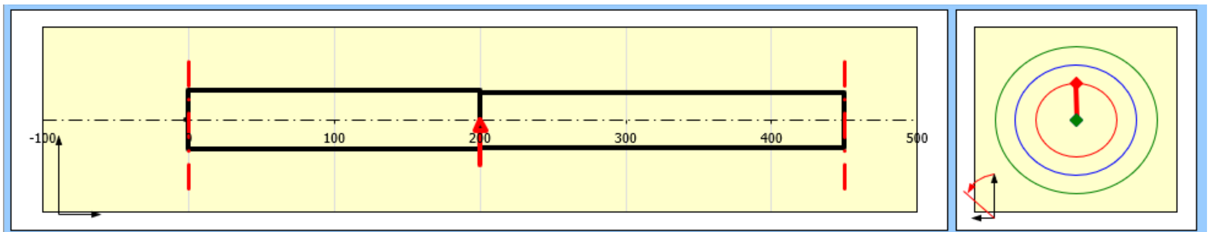
Shaft 3




4.1 Loading

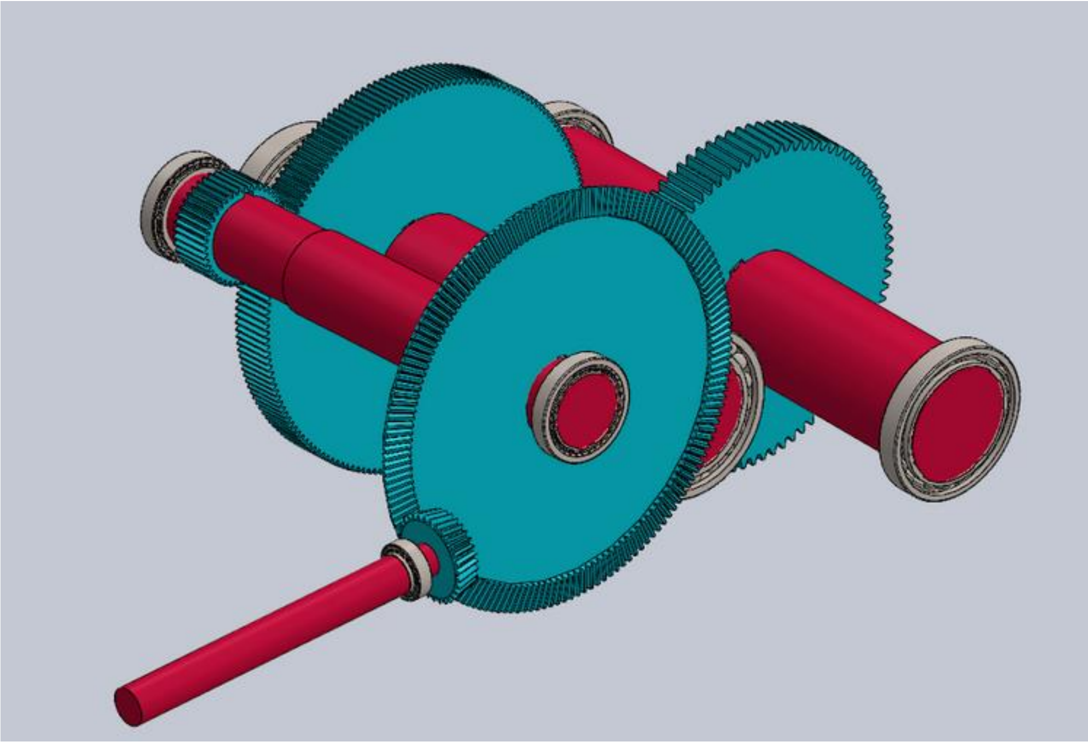
| | X | Fx | F | alfa | Mt | Mb | alfa | Q | b | alfa |
|---|---|---|---|---|---|---|---|---|---|---|
| | [mm] | [N] | | [°] | [Nm] | | [°] | [N/mm] | [mm] | [°] |
| 1 | 150.00 | | 5711.4 | | | | | | | |
| 2 | 250.00 | | 13326.5 | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | | | | | | | | | | |
| 9 | | | | | | | | | | |
| 10 | | | | | | | | | | |

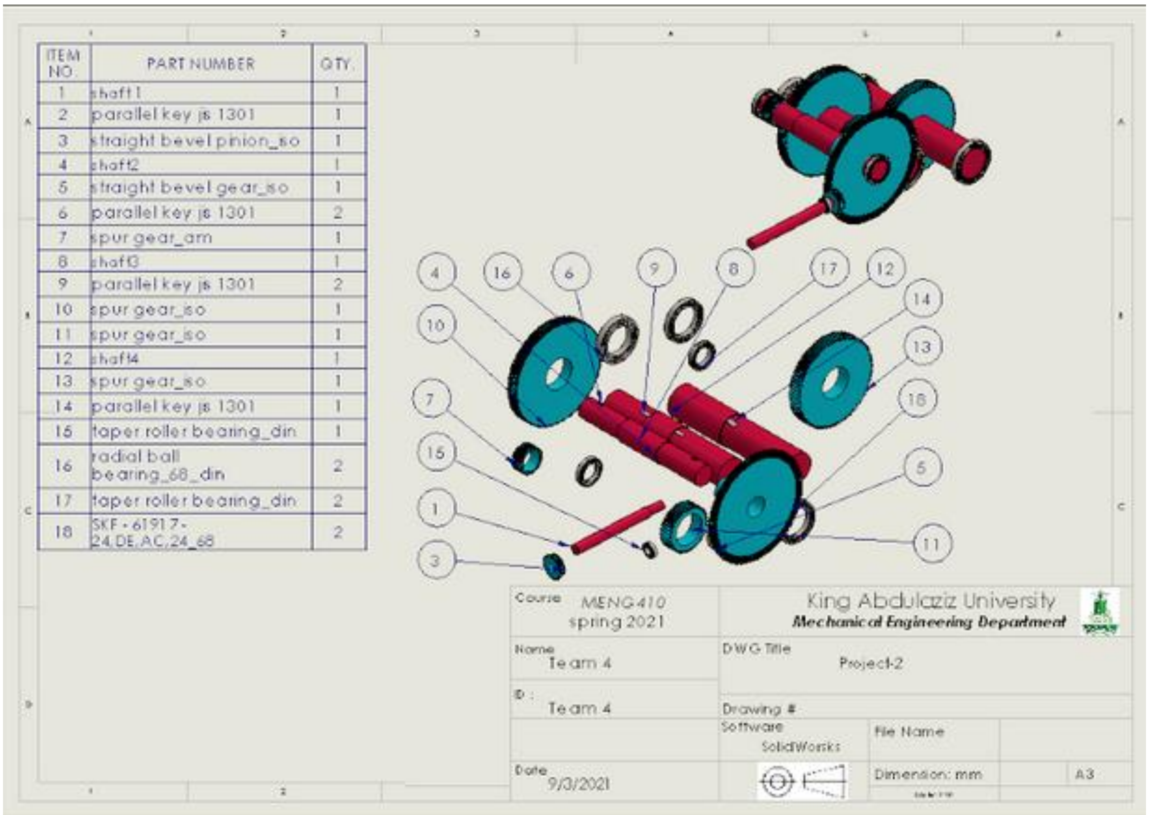
Shaft 4



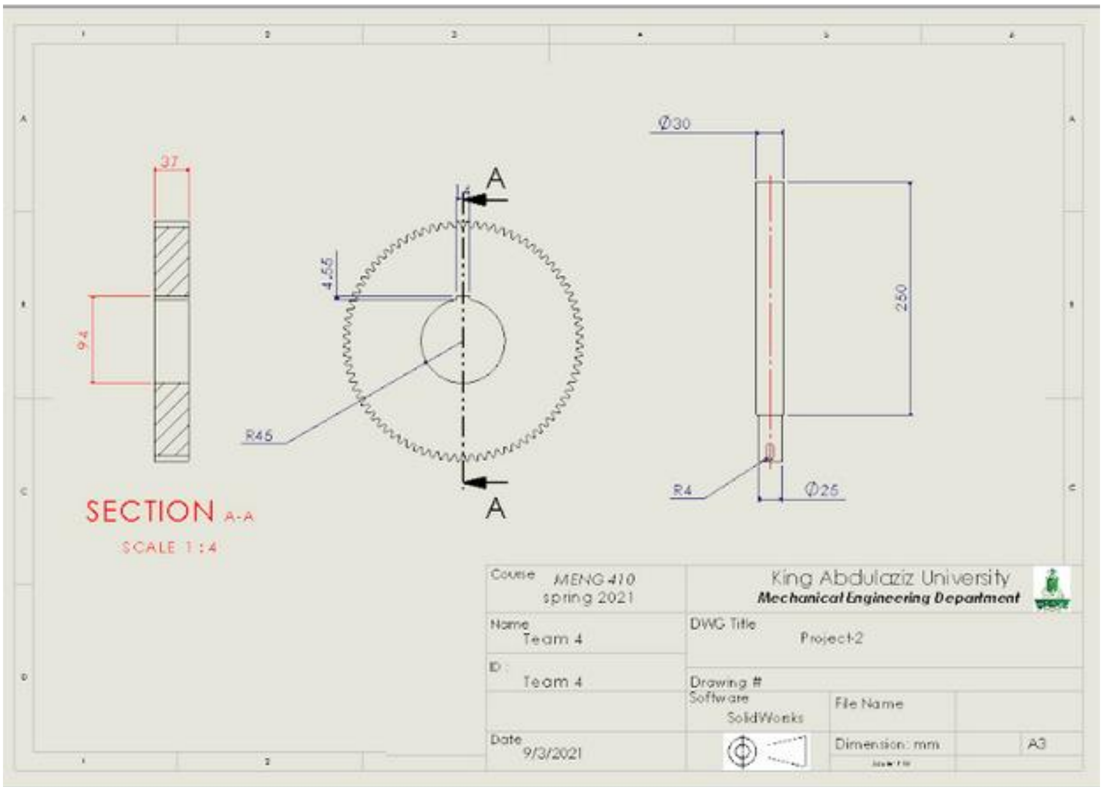

4.1 Loading

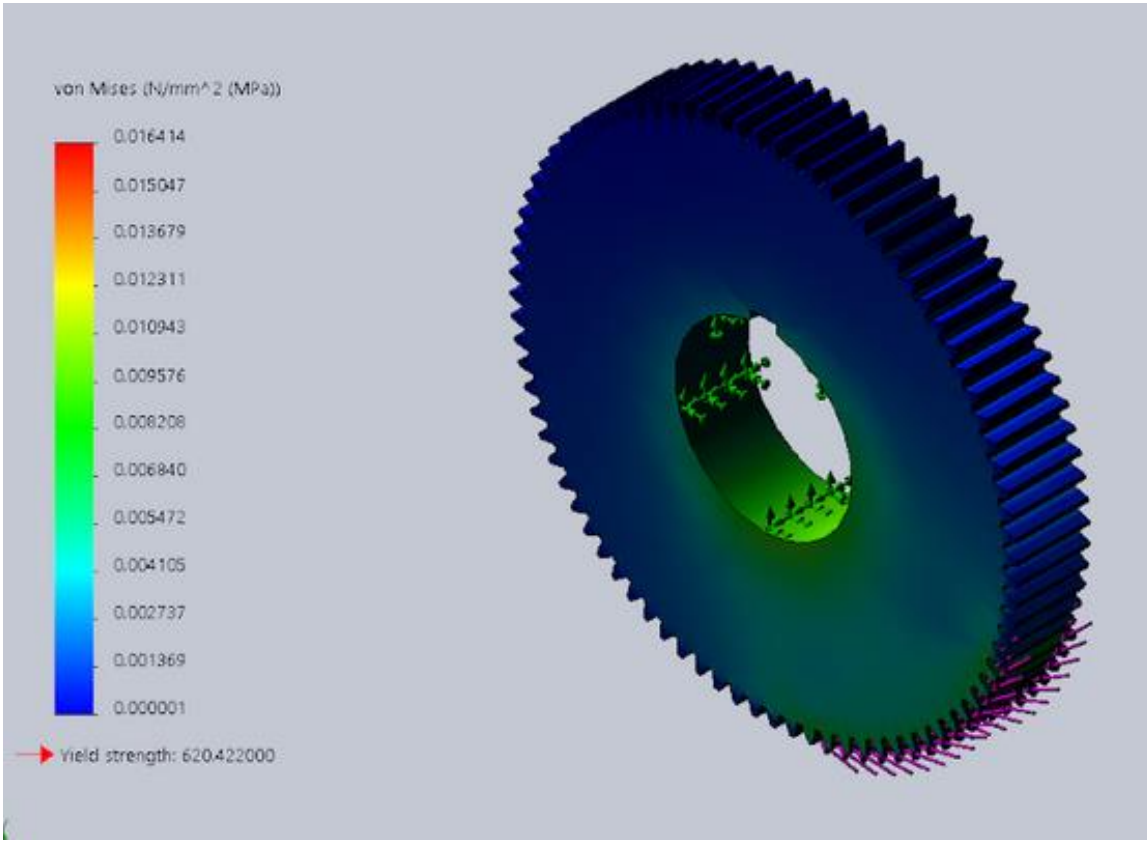
| | X | Fx | F | alfa | Mt | Mb | alfa | Q | b | alfa |
|---|---|---|---|---|---|---|---|---|---|---|
| | [mm] | [N] | | [°] | [Nm] | | [°] | [N/mm] | [mm] | [°] |
| 1 | 200.00 | | 13326.5 | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | | | | | | | | | | |
| 9 | | | | | | | | | | |
| 10 | | | | | | | | | | |

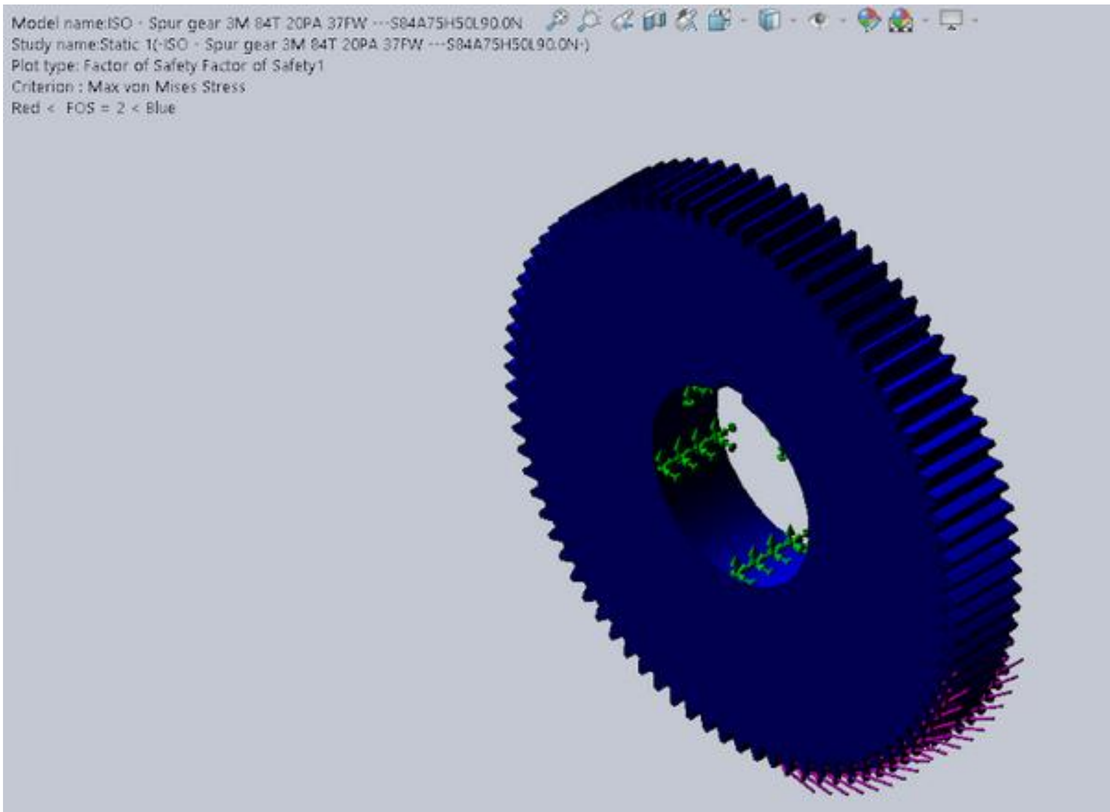




| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | shaft1 | 1 |
| 2 | parallel key js 1301 | 1 |
| 3 | straight bevel pinion_iso | 1 |
| 4 | shaft2 | 1 |
| 5 | straight bevel gear_iso | 1 |
| 6 | parallel key js 1301 | 2 |
| 7 | spur gear_am | 1 |
| 8 | shaft3 | 1 |
| 9 | parallel key js 1301 | 2 |
| 10 | spur gear_iso | 1 |
| 11 | spur gear_iso | 1 |
| 12 | shaft4 | 1 |
| 13 | spur gear_iso | 1 |
| 14 | parallel key js 1301 | 1 |
| 15 | taper roller bearing_din | 1 |
| 16 | radial ball bearing_68_din | 2 |
| 17 | taper roller bearing_din | 2 |
| 18 | SKF - 61917-24,DE,AC,24_68 | 2 |


Ø30
37
A
4.55
250
94
R45
R4
Ø25
SECTION A-A
SCALE 1:4
Course MENG 410
spring 2021
King Abdulaziz University
Mechanical Engineering Department
Name
Team 4
DWG Title
Project-2
ID
Team 4
Drawing #
Software
SolidWorks
File Name
Date
9/3/2021
Dimension: mm
A3


von Mises (N/mm^2 (MPa))
0.016414
0.015047
0.013679
0.012311
0.010943
0.009576
0.008208
0.006840
0.005472
0.004105
0.002737
0.001369
0.000001
Yield strength: 620.422000


Model name:ISO - Spur gear 3M 84T 20PA 37FW ---S84A75H50L90.0N
Study name:Static 1(-ISO - Spur gear 3M 84T 20PA 37FW ---S84A75H50L90.0N-)
Plot type: Factor of Safety Factor of Safety1
Criterion : Max von Mises Stress
Red < FOS = 2 < Blue