ALGERIAN REPUBLIC DEMOCRATIC AND POPULAR

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

UNIVERSITY OF SAAD DAHLEB BLIDA 1

Faculty of technology

Department of Mechanical Engineering

MASTER THESIS

Specialty: Mechanical Construction

Static study and simulation of the final gear reducer for the Mi-171 helicopter

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Academic Year: 2023/2024

Acknowledgments

First and foremost, I shall start by expressing my sincere appreciation and gratitude to Allah for guiding me through my personal and professional life and for achieving this great work today.

I would like to acknowledge and give my warmest thanks to Prof. KIRAD Abdelkader, Dr. ZEDDAM Loukmane, and Mr. SEBKI Smail, for their guidance and support and for being the pillars of this work, without forgetting to offer my sincere thanks to Dr. KOBZILI Sadek for the time and effort he has invested in my development.

A special thanks to all our teachers for their serious contribution, leadership and for giving me the academic base that has enabled me to take up this study.

My thankfulness to the general director of the Aeronautical Equipment Renovation Establishment Mr. HEKKAR Abdelhamid.

Last and not least, I wish to thank my family and all my friends for their continuous support.

Dedication

I would like to dedicate this work to my parents, without whose support I would not have been able to complete this thesis, to my brother and my sister for their loving guidance and assistance.

I would also like to thank all who were there for me, thank you for your help and encouragement, caring and patient.

Abstract

A speed reducer is a type of power transmission device commonly in motorized machinery, vehicle systems, industrial equipment, and many other applications.

The main purpose of this work is to carry out a static study and simulation of the final gear reducer for the Mi-171 helicopter, comprising spiral bevel gear.

During our study, we calculated gear measurements and calculations of different elements using the concepts of the resistance of materials.
The design of the final gear reducer was made by “SolidWorks”, and “GearTeq” design software. The simulation of the gears was calculated by “ANSYS” software.

The results obtained were presented, discussed, and approved.

Keywords: Mi-171 helicopter; spiral bevel gear; transmission; simulation.

Résumé

Un réducteur de vitesses est un type de dispositif de transmission de puissance couramment utilisé dans les machines motorisées, les systèmes de véhicules, les équipements industriels, et de nombreuses autres applications.

L'objectif principal de ce travail est d’effectuer une étude et une simulation statique du réducteur final de l'hélicoptère Mi-171, comprenant un engrenage conique à denture en spirale.

Au cours de notre étude, nous avons calculé les mesures d'engrenage et les calculs des différents éléments en utilisant les notions de résistance des matériaux.

La conception du système de réducteur final a été réalisée à l’aide de logiciels de conception “SolidWorks” et “GearTeq”. La simulation des pignons a été calculée par le logiciel “ANSYS”.

Les résultats obtenus ont été présentés, discutés et approuvés.

Mots-clés : hélicoptère Mi-171 ; engrenage conique en spirale ; transmission ; simulation.

ملخص

مخفض السرعة هو نوع من أجهزة نقل الطاقة، يستخدم عادة في الماكينات الآلية وأنظمة المركبات والمعدات الصناعية والعديد من التطبيقات الأخرى.

الغرض الرئيسي من هذا العمل هو إجراء دراسة ومحاكاة ثابتة لمخفض التروس النهائي لطائرة الهليكوبتر Mi-171، والذي يشتمل على تروس مخروطية حلزونية.

في هذه الدراسة، قمنا بحساب قياسات التروس وحسابات العناصر المختلفة باستخدام مفاهيم مقاومة المواد.

تم تصميم نظام مخفض السرعة النهائي باستخدام برامج التصميم ”SolidWorks“ و ”GearTeq“.تم حساب محاكاة التروس باستخدام برنامج ”ANSYS“ .

تم عرض النتائج ومناقشتها والموافقة عليها.

الكلمات الرئيسية: مروحية Mi -171؛ ترس مخروطي حلزوني؛ إنتقال؛ محاكاة.

Contents:

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List of tables:

Nomenclatures:

P: Reference pitch

m: Module

L: Cone distance

b: Face width

δa: Tip angle

δf: $Root\ angle$

θa: Addendum angle

θf: Dedendum angle

h_a : Addendum

h_f : Dedendum

d_a : Tip diameter

d_f : Root diameter

eq: Equivalent

Introduction

Introduction:

A gear reducer is a mechanical system of gears in an arrangement such that input speed can be lowered to a slower output speed but have the same or more output torque. The operation of a gear reducer involves a set of rotating gears that are connected to a shaft with a high incoming speed, which is sent to a set of rotating gears where the speed or torque is changed. How many gears are in a gear reducer assembly is dependent on the speed requirements of the application.

We are going to build this work as a design office in the Aeronautical Equipment Renovation Establishment (ERMAéro). Our aim of this work is to verify the resistance of the final gear reducer for the Mi-171 Helicopter.

This work is built on four main chapters aiming to reach my specific fixed object of this study:

- We will begin by presenting the company, which integrates the working environment that helps us to acquire better professional skills.
- The second chapter is a bibliographical research that introduces general information about the helicopter and different types of gears and their uses.
- The third chapter deals with materials properties used, different final gear measurement and the calculation of different elements in the final gear reducer for the Mi-171 helicopter.
- The fourth last chapter will do the will do the modeling of the final gear reducer and the study resistance of the gears by the finite element method.
  Software used are: “GearTeq”, “SolidWorks” and “ANSYS”.
  This work will be finalized by a general conclusion and future perspectives.

Chapter I : Company presentation

I.1/ Introduction:

As part of the preparation of our end-of-study dissertation, we completed an internship at the Aeronautical Equipment Renovation Establishment (ERMAéro). The aim of these 40 days of internship is to integrate the working environment and acquire experience for our professional life.

The choice of this company was based on our desire to have a clear view of aeronautical machines, and to better understand the way of managing a workshop and its staff.

And of course the ultimate goal of our training and providing the necessary help and support to our army which can be translated by the studies and improvements made on frequently used aircraft in order to build a professional army based on science and development.

I.2/ Presentation of the company:

The Aeronautical Equipment Renovation Company is located in Dar el Beida, adjoining the Houari Boumediene international airport, built in 1939 as an aeronautical industrial workshop by the French, recovered in 1962 by the Algerian Republic then transferred to an establishment under the supervision of the Ministry of National Defense in 1977 and finally became an independent company in 1992. It was created to meet the needs of our military air fleet, and since the day it was put into operation, it has not stopped looking for developments in its units. It is a military company of an industrial and commercial nature with legal personality and financial autonomy. Which is considered the main means for the complete satisfaction of the needs of our air force and to have total independence regarding the renovation of Algerian military aircraft.

This company is economical in nature and has financial autonomy which will allow it to participate in the national economy, and opens the doors to the national and even international market.

I.3/ The history of ERMAéro since its creation in 1939:

- 1939-1945 ARMA: Aeronautical Equipment Repair Workshops whose mission is the maintenance of aeronautical war equipment used for the allies. Throughout the Second World War, it carried out maintenance on aeronautical equipment (Gull, junker, T-28, etc.) as well as an engine testing center located in Oued M'Barek.
- 1945-1962 AIA: The Air Industrial Workshops whose mission is to maintenance of aerial equipment used by the French army in Algeria. It ensures the repair of all aircraft used during the Algerian War (T-6 plane, junker, bushman, vampire, Mistral, Bell and Sikorski helicopter) as well as the general overhaul of piston, propeller and turbojet engines.
- 1962-1964 HELI SERVICE: Southern aviation subsidiary whose mission is to complete work in progress (overhaul of aircraft and engines) of aerial equipment before their transfer to France.
- 1964-1967 SOMEA: Mechanical and Aeronautical Company whose mission is the maintenance of flying club aircraft under the supervision of the Ministry of Industry.
  It will be responsible for carrying out the overhaul of flying club planes, the manufacture of small workshop tool machines as well as the manufacture of tractors called tractors SOMIA.
- 1967-1977 ECRM: Central Rolling Stock Repair Establishment whose mission is the maintenance of rolling stock for land forces as well as the maintenance of aerial equipment for military aircraft. This establishment then had three types of activity:

- Furniture manufacturing and foundry work.
- Renovation of rolling stock.
- Renovation of air force aeronautical equipment.

Such as: YAK-18, MIG-15, MIG-17, IL-28, MI-4 and off-line work.

- 1977-1992 ECRMA: Central Equipment Renovation Establishment

Aeronautics whose mission is the maintenance of aerial equipment supplied to the air forces.

- 1992 to that day ERMAéro: Aeronautical Equipment Renovation Establishment whose mission is the maintenance of the 1st, 3rd and 4th echelon level of aeronautical equipment in the air forces with transition from establishment status to professional status. company with financial autonomy EPIC-ERMAéro.

The company carries out general overhauls and overhauls of the various aircraft in the

MIG-17, MIG-15 and MI-4 fleet.

From 1983 to 1985 it carried out the general overhaul of the MI-8 helicopter and the

MIG-21 BIS and MF and MIG-23 BN and MF fighter planes, as well as support work for the air forces.

From 1992 to 2016 the company overhauls and repairs the following aircraft:

- MI-2 helicopter
- L-39 ZA/C aircraft
- MI 171 helicopter
- MI 17 helicopter
- MI 24 helicopter

I.4/ Mission of ERM Aero:

The main mission of the company is the overhaul and repair of military aircraft such as L- 39C/ZA fighter planes and MI2, MI17, MIl71 and squirrel helicopters and consists of:

- Overhaul aeronautical devices.
- Repair aeronautical parts and aircraft accessories for force bases aerial.
- Manufacture the tools necessary to achieve your object.

Conduct all studies in relation to its mission as such, the company carries out supply, production and marketing plans, as well as the acquisition and development of the necessary industrial resources.

I.5/ Operation of the company:

ERMAéro specializes in the maintenance and renovation of aeronautical equipment, it has very significant resources in terms of human resources and material resources.

The aircraft renovation procedure takes place in the following order:

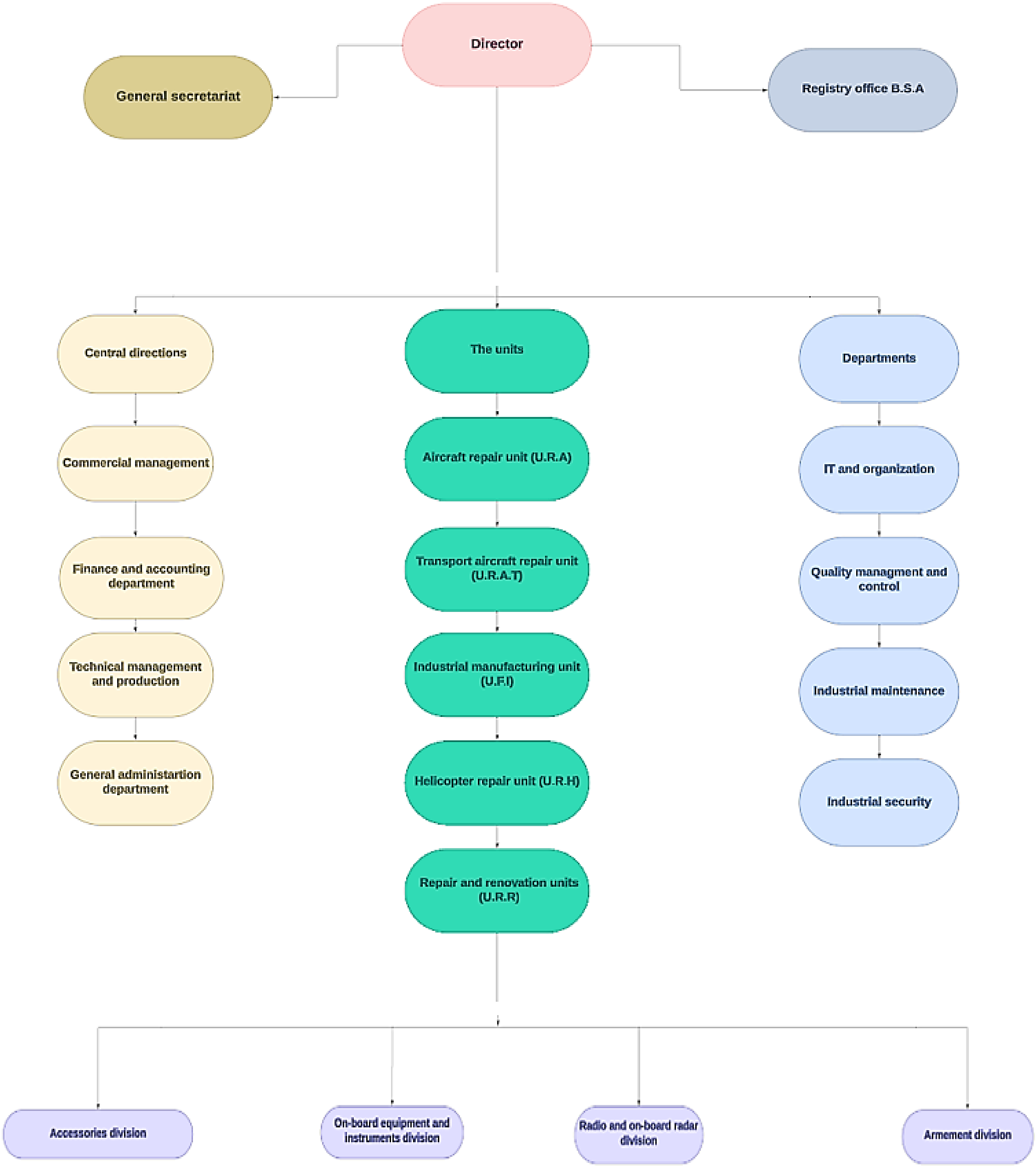
- Reception: reception of aircraft to be overhauled or repaired coming from the different air bases. A group of experts carries out a general check to see the initial state of the device, followed by a report;
- Dismantling: is done at the aircraft renovation unit (URA) after the fuel has been completely drained;
- Dispatching: send each disassembled part to the corresponding unit for

precise inspection and detect all breakdowns if they exist (accessory, radio, etc.);

- Repair: repair breakdowns in parts and check them according to the proper functioning parameters of each using special test benches;
- Adjustment: after the repair, the aircraft is climbed to the unit level (UA) to make the necessary adjustments before start-up;
- Flight testing: tested the repaired aircraft by flight testing;
- Delivery: if the flight test is successful, the aircraft will be authorized to return to its base with a new lifespan.

I.6/ Organization of ERMAéro:

One of the main bodies of the company is the technical management which is divided into four units namely: the URA, the URR, the UFI and the URAT


Director
General secretariat
Registry office B.S.A
Central directions
Commercial management
Finance and accounting department
Technical management and production
General administartion department
The units
Aircraft repair unit (U.R.A)
Transport aircraft repair unit (U.R.A.T)
Industrial manufacturing unit (U.F.I)
Helicopter repair unit (U.R.H)
Repair and renovation units (U.R.R)
Departments
IT and organization
Quality managment and control
Industrial maintenance
Industrial security
Accessories division
On-board equipment and instruments division
Radio and on-board radar division
Armement division

I.7/ Renovation and Repair Unit (URR):

This part of the company "enables the overhaul and repair of accessories and equipment for combat aircraft and helicopters provided within the Air Force". It is divided into several divisions. The mechanical accessories division.

Its main missions are the renovation and repair of accessories for mechanical, hydraulic, pneumatic, fuel and landing gear (hydraulic-pneumatic) transmission systems.

I.8/ Instructions for repair:

The repair instructions followed in the accessories division, and also throughout the company are instructions defined by the Russian manufacturer of the various aircraft (MI17, MI 24, MI 171) as well as the Czech manufacturer of the aircraft (L39ZA, L39C), and MI2 of POLISH designs.

It is in fact a maintenance which is defined as the set of operations intended to be carried out after the failure of an asset or the deterioration of its function, to enable it to perform a required function, at least temporarily. under given operating safety conditions. These activities are a combination of technical, administrative and management activities. These activities essentially consist of its diagnosis:

- Refurbishment without modification of the device;
- Checking the proper functioning of all the device's accessories.

I.9/ Repair method:

The different operations that a general overhaul of each accessory includes is the next:

- At the reception:

Upon receipt of each set of accessories constituting an airplane or helicopter, the controller and the head of the workshop must take care of noting all the information concerning the technical

and physical aspect of each accessory of each airplane, and detected each defect and noted it.

accessory.

- Disassembly:

Before dismantling each accessory, you must consult a repair guide for each device, and you must also respect the safety instructions defined by the manufacturer, and you must pay attention to the physical appearance of each accessory to avoid its degradation while using it. specific tools.

At the end of each dismantling of an accessory, the performer must throw each part subject to mandatory change into the waste disposal unit.

- Washing:

After each dismantling operation, we must systematically wash the parts and sub-assemblies, all using “white spirit”, or B70 gasoline, or kerosene, to enable us to determine the defects existing in the sub-assemblies. -sets and on the body of the accessory.

- Inspection:

The inspection stage is really essential in the revision of each accessory, because it is this which makes it possible to determine all the defects of the latter, citing as examples: (cracks, streaks, corrosion pits, jacks, shearing of screws, etc.). All these defects must be noted on the repair templates for each accessory.

- Repair:

After inspecting each part, the defects detected are repaired, following the method suggested by the manufacturer, which can easily be found in the repair guide for each accessory. If the manufacturer has not included a repair method in the guide, then we call the workshop technologist to resolve the problem. At the end of the operation we must write this method on the canvas.

- Micrometric measurements:

This part is very important in the renovation of parts because it allows you to find out about the wear of the accessory and its level of degradation, also determine its degree of mobility to ensure the proper functioning of the mechanism, without any problem, if the geometric or dimensional

tolerance of the parts or subassembly subject to micrometric measurements is not within the tolerance zone, the part is completely changed, the same for the other subassemblies.

- Magnetic control:

The list of parts subject to magnetic control are generally determined by the manufacturer of the device, and it mainly concerns the transmission parts, given that they are the key parts in the operation of the devices, for example citing: (the Main Rotor Hub, the Swashplate, the cell, the main, intermediate, final reduction gear, the transmission shafts, as well as certain fragile parts located inside the mechanisms, citing as an example parts in the hydraulic booster, etc.). The main purpose of this check is to determine the cracks found inside the parts to avoid their sudden breakage during the flight.

- Surface treatment:

The main functionality of surface treatment is to increase protection against corrosion and wear on different types of parts before their final assembly and commissioning. These operations then allow the parts concerned to comply with the regulations and standards that apply in aeronautics. At ERMAéro we master all surface treatments that apply to aeronautics: bichromate cadmium plating, phosphating, oxidation, anodizing, conversion and zinc-nickel, passivation, polishing.

- Bichromate cadmium plating:

Cadmium plating has the characteristics of increasing the resistance of parts to corrosion and reducing the effects of corrosion by galvanic couple. Its deposition is carried out by an electrolytic process, directly on the base metal without an undercoat. It is used for stainless steels with several finishes.

- Bichromate finish;
- White finish.

- Anodizing:

It is a surface treatment used for aluminum alloys such as duralumin alpax. It is achieved by the creation of an anodic layer is the result of the passage of a current in an electrolyte.

The anodizing basin contains a 15% acid solution sulfuric acid in which the armature is placed. A direct current is applied for a specific period to create the anodic layer.

- Passivation:

Passivation or passivity represents a state of metals or alloys in which their corrosion rate is significantly slowed down by the presence of a natural or artificial passive film, compared to what it would be in the absence of this film.

The parts are passivated using a nitric acid solution in a bath or by spraying. Rinsing carried out with clear water using a pressurized jet until water at the initial PH is obtained.

In ERMAero this treatment is used for copper as well as bronze.

- Chrome plating:

Hard chrome plating is used in mechanical applications where friction conditions are severe as an anti-wear, anti-corrosion coating. It is used for example for landing gear, aircraft door systems, etc.

- Editing:

After the previous steps, we proceed to the assembly of the assemblies constituting each mechanism, while using an overall drawing given by the manufacturer. And also by respecting the safety instructions given by the repair guide, we all ensure the conformity of the parts subject to mandatory change.

- Tests:

  In this step the technician must systematically put his device through the test bench, to check the operation and the technical parameters of the latter, based on a technological map.

- Finish:

At the end, the repair technician must brake each device, then cover it against dust, fill the canvas and the follower sheet, finally deliver it to the scheduling office after having inspected its condition by the controller of the ‘workshop.

I.10/ Transmission workshop:

Transmission system:

The helicopter is the flying machine that brings into play the most forces and laws of physics.

It has two sets of rotors. The first, commonly called rotor disk, or main rotor hub (MRH), installed horizontally, and which produces lift and thrust. This rotor can have two to eight blades depending on the type of helicopter. A second, smaller assembly, mounted vertically at the end of the tail, is the anti-torque rotor (ATR).

The function of the tail rotor is to counter the torque produced by the main rotor. Some helicopters do not have a tail rotor, but a second main rotor which turns in the opposite direction to the first. A main reduction gear which is connected to the chassis, inside the latter we find a transmission box sometimes called main reduction gear, on which two motors are mounted, which allows them to have the necessary rotation torque. Between the main gearbox and the anti-torque rotor (ATR), there are transmission shafts, an intermediate gearbox, and final gearbox, on which the anti-torque rotor (ATR) is mounted. As for the balance of the helicopter, it is compensated by the movement in the opposite direction of the blades. The main gearbox has two wheels to allow autorotation and separate the motor from the rotor in the event of a breakdown. The main rotor or blade performs a rotational movement composed of a vertical movement and a horizontal movement. Another rotor, also called Anti Torque Rotor (ATR), is located at the rear of the device to prevent it from rotating on itself. It ensures the flexibility and stability of the helicopter. The helicopter can fly in all directions by tilting the main rotor and tail rotor in the desired direction using the control levers.

A/ The main rotor hub:

The main rotor hub is an element composed of several blades which, through its rotation, allows lift (rolling, yaw, and pitching), piloting and propulsion of a helicopter.

The rotor must allow:

- Driving the rotating blades;
- The beat joint;
- The articulation of the dumpers;
- The pitch change articulation (timing).

These different articulations respond to the problems of the behavior of the blade in flight, namely:

- The flapping joint to overcome the problems of asymmetry of lift between advancing and retreating blades;
- Articulation of the dumpers equipped with a shock absorber, to compensate for the effects of the force generated by the beating of the blades;

- The pitch changes joint to change the pitch angle of the blade. Rotation of the main rotor hub tends to rotate the airframe in the opposite direction. This movement must then be centered and stabilized using a suitable anti-torque rotor (ATR) type device.

The different parts constituting the Main Rotor Hub are:

- Five axial hinges;
- Five horizontal hinges;
- Five vertical hinges;
- Five stirrups;
- Five hydraulic shock absorbers (dumper).

Each joint is made up of a set of rings, bearings, sealing rings, axle. The whole assembly is immersed in an oil bath of different viscosities and shades, for example for horizontal and vertical hinges we use hypoid oil (NL-05) at a temperature of (50 - 55) °C, for the axial hinge we use (AS-100).

B/ The anti-torque rotor:

An anti-torque rotor is a small auxiliary rotor located at the rear of a helicopter (mounted on the tail), and whose blade pitch is actuated by the pedals of a rudder used to control the movements of the machine around the yaw axis:

- In translational flight to counter the torque induced by the main rotor hub (MRH) which tends to make the cell rotate in the opposite direction;
- In hover to perform a turning movement (stability).

It can be of different types:

- **Conventional two-blade rotor on light helicopters**, up to five blades on heavy helicopters.

Heavy helicopters have a mechanical connection on the flight controls, between the “yaw” chain and the “collective” chain, which allows the yaw chain to be corrected according to the application of collective pitch. Indeed, any variation in collective pitch generates a variation in power, which is felt at the level of the torque transmitted to the rotor head, and therefore, the cell will rotate in one direction on an increase in pitch and in the opposite direction on a decrease in pitch. not.

- **Streamlined multi-blade rotor (8 to 13)**, This type of rotor has several advantages:
  - Drag reduction in cruising flight: the rotor being hidden in the fin it does not create drag. Note also that the Gazelle type fenestron is asymmetrical and it relieves the ATR at high translation speed;
  - Better safety: the rotor being shrouded, it is more difficult to access for hands, cables, and others.

The different parts constituting the Anti-Torque Rotor are:

- Body;
- Control lever:
- Journal;
- Grease sleeve;
- Cardan;
- Hinge body;
- Hinge shaft;
- Slide guide star;
- Blades.

There are resistors on each of the blades for anti-icing at the leading edge and at the trailing edge, in the event of a drop in temperature in cold countries, they can prove useful. As well as counterweights on the control levers.

At the end of the Anti-Torque Rotor renovation operation, we finish by wedging the blades to avoid the appearance of vibrations.

C/ The cyclic plate:

The swashplate is an essential element for piloting a helicopter. It allows the control orders given by the pilot to be transmitted to the MRH blades by means of the control levers (collective and cyclic) or by the autopilot which acts directly on the servo controls has.

1. Working principle:

The difficulty of this transmission comes from the fact that the movement must pass from a “stationary” lower system (the helicopter cell) to a rotating upper system (the main rotor).

To do this, the two systems are only in contact with each other at the level of the cyclic plates, one of the plates of which is integral with the cell and the other with the so-called “dynamic” elements.

The “plate” assembly is composed of two superimposed half plates sliding and rolling around the axis of the main rotor mast, which is driven in rotation by the motor(s) through the main transmission box, and ends with a hub on which the blades are fixed. On the upper (movable) half plate is fixed pitch links, each of which is connected to a blade to vary its angle of incidence according to the cyclic commands, and mobile compasses which cause the plate to rotate because they are fixed on the rotor hub. On the lower half-plate are fixed the servo controls (booster),

and a fixed compass which prevents rotation around the rotor axis. This plate is articulated on the

rotor axis thanks to a ball joint allowing the rolling and movement of the plates relative to the rotor axis. A vertical movement of the plate assembly will cause the angle of incidence of all the blades to change at the same time, and by the same amount. This movement is controlled by the so-called collective lever, which is activated by the pilot's left hand and is intended to raise or lower the aircraft.

If we tilt the plate towards one side, we increase the angle of incidence of the blades on the side which must rise and conversely, we reduce that of the blades located on the side which must lower. When the angle of incidence of a blade increases and that of the opposite blade decreases, the lift increases on one side and decreases on the other. This has the effect of tilting the plane described by the rotation of the blades, called the rotor disk, and of tilting the component of the overall lift force, which then tends to pull the aircraft. This means that a helicopter can be steered with a joystick (pull towards you to go up, push to go down, etc.). With the particularity that the helicopter can be given a translational movement in any direction. However, the speed will be very low in directions other than forward, for many reasons:

➢ Main rotor wash with that of the anti-torque rotor;

➢ Limited needs for maneuvers in a confined space in hovering flight;

➢ Visibility, etc. These movements are generated using the so-called cyclic control lever,which the pilot operates with his right hand.

Because of the gyroscopic effect, the blade must have the required incidence of 90° before the point of application of the desired reaction (maximum incidence in the left azimuth so that the reaction is made on the front azimuth).

The cyclic and collective flight controls are independent of each other, but they must be able to act together on the wing. To do this, the connecting rods of the flight control chains are joined at the level of the combiner, which allows the cyclic and collective corrections to be superimposed in order to attack the three main servo controls. There are always use three servo controls to orient the swashplate: in fact, it must be considered to orient a plane, three support points are required (a static system in mechanics).

There are always three servo controls to orient the swashplate; in fact, to orient a plane, three support points are required (a static system in mechanics).

D/ The main gearbox:

The main gearbox (MGB), or main reducer, is a mechanical assembly that allows for a helicopter:

- The transmission of power from the engines to the main rotor hub (MRP), which provides the lift and movement of the aircraft;
- Returns the angle between the engine power take-off and the rotor shaft
- Power supply to accessories (hydraulic pump, alternator, rotor brake, compressor, etc.).

The MGB is fixed to the MRP frame. This mechanical connection absorbs the variations in rotor torque and, in some cases, the permanent vibrations of the rotor head.

The power kinematics of a MGB are made up of gear systems (spiral, epicyclic gear, straight teeth, etc.).

For example, an input rotation of a 22,000 rpm engine and an output rotation of a 265 rpm rotor on MRP.

Helicopters are often equipped with two other gearboxes:

E/ The intermediate transmission box:

It serves as an angle transmission, or reducer, between the horizontal transmission and the rear transmission box on helicopters where the anti-torque rotor is located above the tail boom.

It consists of an input pinion (the driving pinion) and an output pinion (the driven pinion), bearings, circlips, shims, sealing rings, filing sensors, and oil temperature sensors.

F/ The rear gearbox:

It serves as a reducer between the intermediate gearbox and the rotor hub.
The rear anti-torque rotor consists of an input pinion (the driving pinion) and an output pinion (the driven pinion), bearings, circlips, shims, sealing rings,
filing sensors, oil temperature sensors, a worm screw that is free to rotate, and which communicates between the anti-torque rotor and the final reducer, and using a chain that is located in the final reducer, the angle of attack of the blades of the RAC is varied, therefore changing the direction of the helicopter using the rudder pedals, which are located in the cell.

G/ Reduction frame:

This is the main support on which the main transmission organs are fixed; it
contains eight counter plugs and five flanges for the Mi-24 and Mi-171 helicopters. Inside the helicopter is placed the main reduction gear that can be fixed to the chassis of the
cell using the latter.

H/ Hydraulic Tank:

This is a part incorporated into the vibration damper; it serves as an oil tank.
that compensates for the lack of oil in the dumpers. They communicate using the hoses.
This tank is equipped with a sight glass that allows the pilot to visually check the oil level.

Chapter II: Bibliographic research

II.1/ Generality about helicopter:

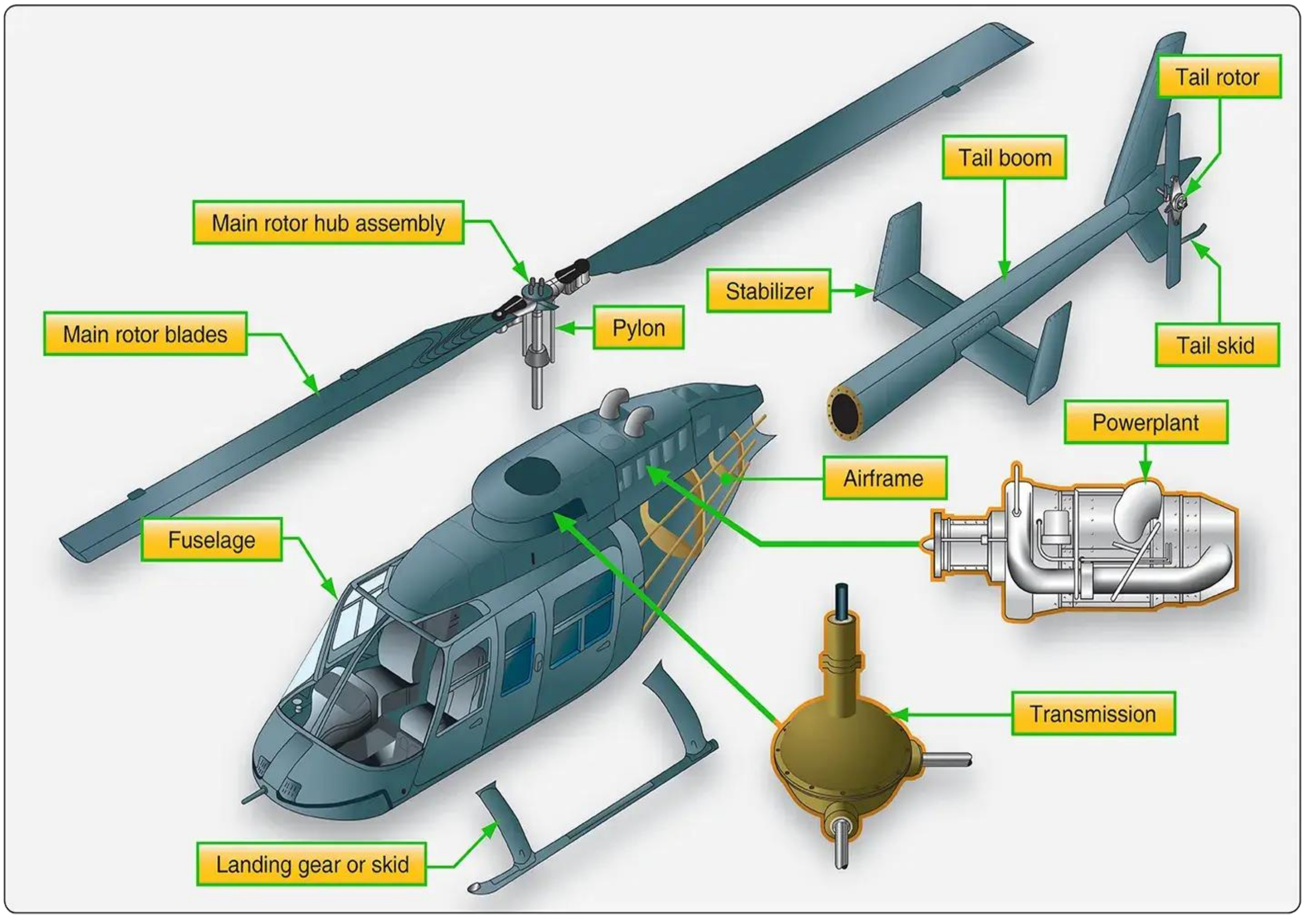


Figure II.1. Decomposition of a helicopter [1]

II.1.1/ Introduction:

A helicopter is a type of aircraft that uses rotating, or spinning, wings called blades to fly. in contrast an airplane or glider, a helicopter has wings that move. in contrast a balloon, a helicopter is heavier than air and uses a motor to fly. A helicopter’s rotating blades, or a rotor, permit it to do things an airplane cannot.

Once a helicopter is off the ground, four aerodynamic forces act on it: Weight, thrust, drag and lift.

- Weight is the combined load of the helicopter, which includes the weight of the helicopter itself, its crew and the cargo. This force pulls the helicopter descending as a result of gravity.
- Thrust is the force produced by the rotation of the helicopter's blades. Its direction can be forward, rearward, sideward or vertical.
- Drag is the force that opposes the movement of the helicopter through the air.
- Finally, lift is the upward force acting on a helicopter that pushes it up and keeps it in the air. [2]

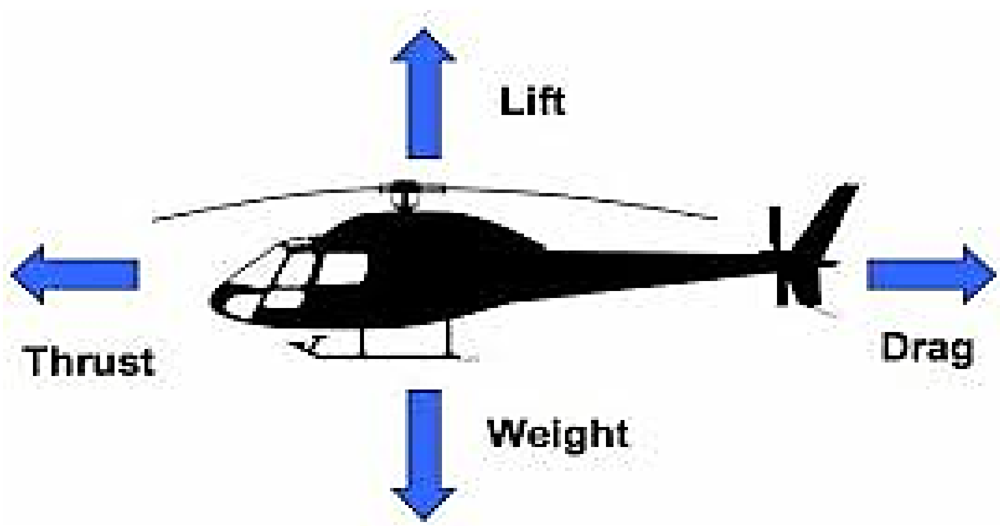


Figure II.1.1.1. The four forces of flight include drag, lift, thrust, and weight [3]

❖ **Airfoils:**

The shape of the airfoil area may take many different forms. This shape influences the flight characteristics of the aircraft. Certain air-foils are noted for high speed, while others are known for low speed, high lift, and supersonic characteristics diverse forms. [4]

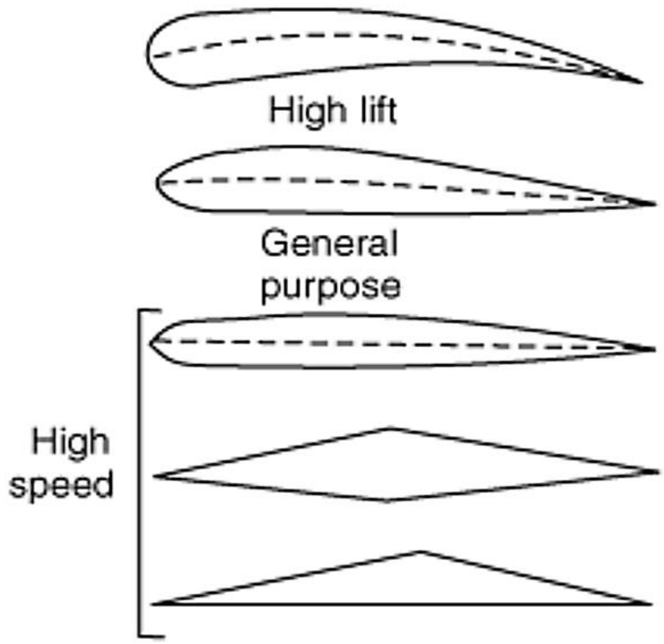


Figure II.1.1.2. Various airfoil cross sections [4]

❖ **Protection:**

Most helicopters have covers that can be installed if it is to remain outside overnight. The most commonly used covers are inlet and exhaust covers for the turbine engines and a pitot tube cover. Additional covers may be applied when the helicopter will be exposed to the weather for long periods of time or to severe weather conditions. These include windshield protectors, blade covers, and rotor head protection. Most of the time such added protection is not required, unless extreme weather conditions exist. [5]

II.2/ Transmission system:

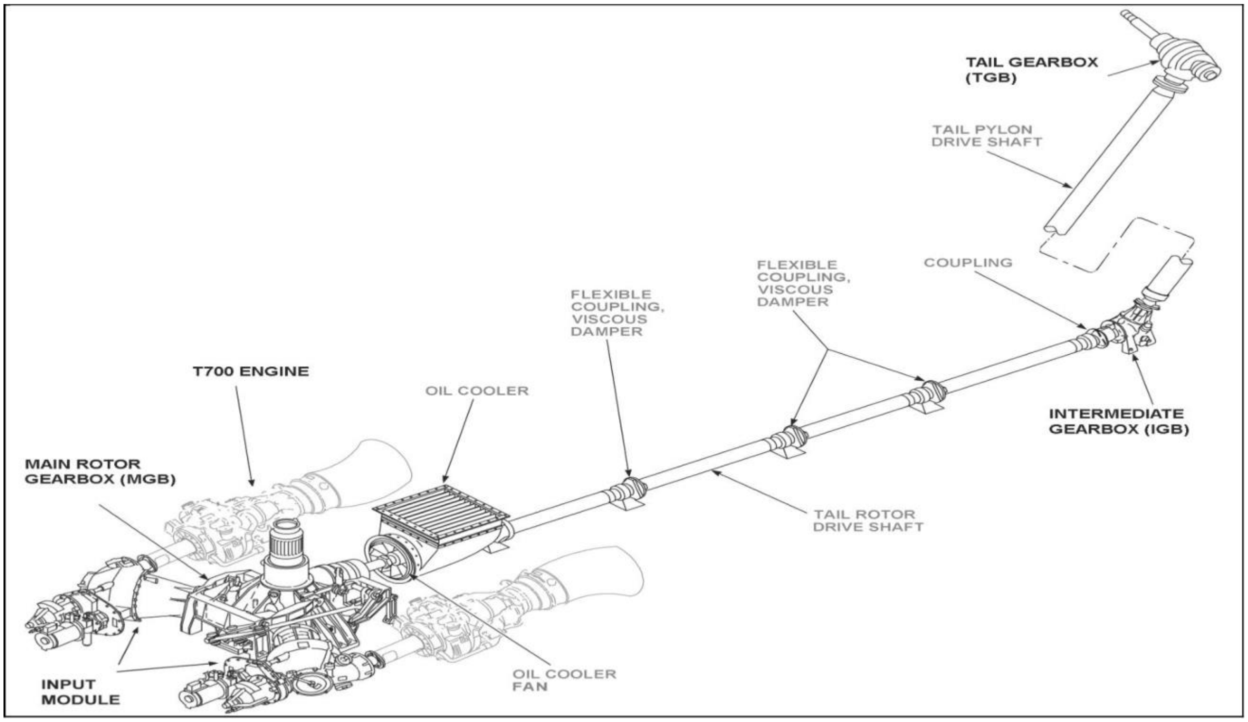


Figure II.2.1. Transmission system [6]

The transmission system transfers power from the engine to the main rotor, tail rotor, and other accessories during normal flight conditions. The fundamental components of the transmission system are the main rotor transmission, tail rotor drive system, clutch, and freewheeling unit. The freewheeling unit, or definitive clutch, allows the main rotor transmission to drive the tail rotor drive shaft during autorotation. [7]

- Main Gearbox (MGB):

In helicopters, power transfer work from the engine to Main Rotor, Tail Rotor and other essential accessories is performed by the Main Gearbox, generally known as Transmission as well. The main reason of a helicopter main gearbox or transmission is to reduce output rpm of the engine to most suitable level for driving the main rotors and tail rotors of a helicopter.

- Intermediate Gearbox (IGB):

The intermediate gearbox is found on the tail boom at the end of the vertical blade.
It transmits torque and changes the angle of drive from the main transmission gearbox to the tail gearbox. In the intermediate gearbox typically each shaft is supported by two cylindrical roller bearings and a finding angular contact ball bearing. Other configurations are possible however, such as shaft systems supported by tapered roller bearings. Preload is required to give a precise gear mesh and system stiffness.

- Tail Rotor Gearbox (TGB):

The tail rotor gearbox also known as the 90-degree gearbox is found at the top of the vertical blade. The reason of the gearbox is to provide 90 degree change in direction of drive and a 2.6:1 speed (RPM) reduction between input and output drive shaft which mounts and drives the tail rotor. The gearbox also houses the pitch change mechanism, oil filler cap (vent breather), an oil level sight gauge, and a drain plug with a magnetic insert.

- Oil System:

Similarly, Transmissions of helicopters generally have their own lubrication system and functions of which include lubrication, cooling and inner cleaning of inner components. Level of oil is checked through a sight gauge which may be two or more at different areas depending upon the design of a specific transmission. Several main gearboxes have chip detectors as well, found at sump for detection and early caution of the wear and tear of internal components. Chips detectors are electrically connected to caution lights in the pilot’s instrument panel that light up to warn pilots in the event of an internal failure, wear and tear happening inside the gearbox, transmission assembly.

In modern helicopters, chip detectors may have a burn-off capability which may rectify the situation without a pilot activity or remedial measure. Otherwise, pilot has to refer to the specific emergency procedure of that helicopter in order to choose further course of action.

II.3/ Basics of Gears:

II.3.1/ Definition:

Reducers also refer to as speed reducers are components in many mechanical, electrical and hydraulic systems. The general purpose of gears is to transmit motion and/ or power from one shaft to another.

In addition, gears have three primary usages in a system.

First is speed ratio, by using different sized gears the input (driver) to output (driven) rotational speed of shaft can be changed efficiently. Size doesn't matter, a small gear can drive a big gear or a big gear can drive a small gear.

The second usage is for adjusting the torque ration of the system.

Lastly, Gears are useful means for changing the direction of rotation or converting a rotational motion to translation motion.

Figure II.3.1.1. Function of gears

II.3.2/ Classification of Gears:

Gears can be classified by shaft positions as: parallel, intersecting, non-parallel and non-intersecting

Primarily there will be two types of loads acting on a shaft/gear: Axial load and radial load.

As it can be seen from the figure, radial load acts perpendicular to the axis of the shaft while axial load acts along the axis. Gear performance is largely affected by the type of load acting on it. [8]

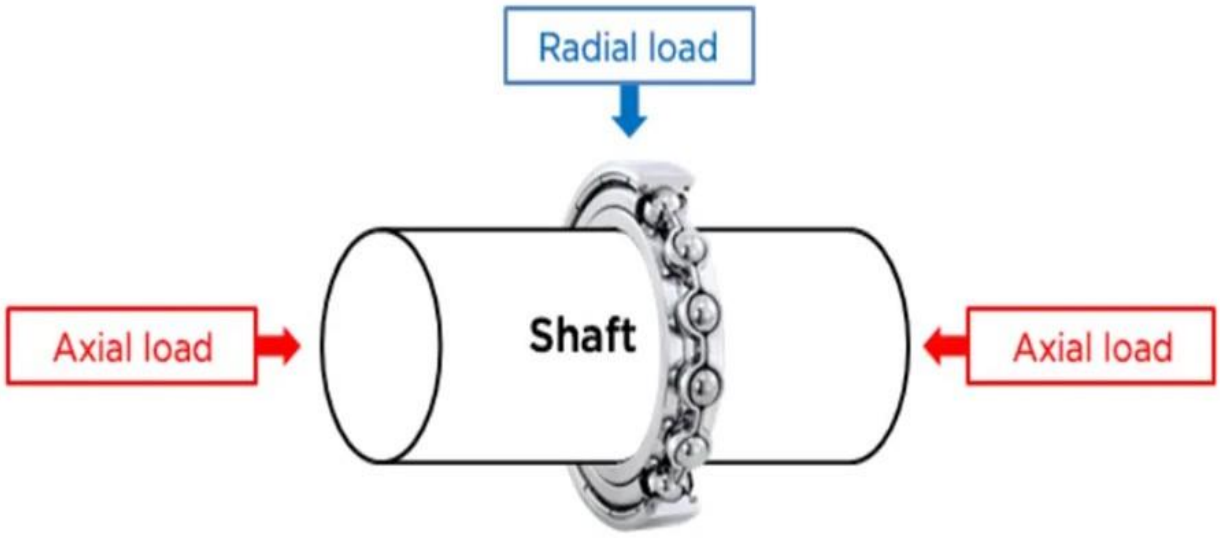


Figure II.3.2.1. The radial and axial loads [8]

- **Parallel shaft gears:**

Spur gears: are the most commonly used gears. They transmit power through shafts that are parallel. The teeth of the spur gears are parallel to the shaft axis, this causes the gears to make radial reaction loads on the shaft, but not axial loads.

Are suitable for the velocity ratio of 1:1 to 1:3.

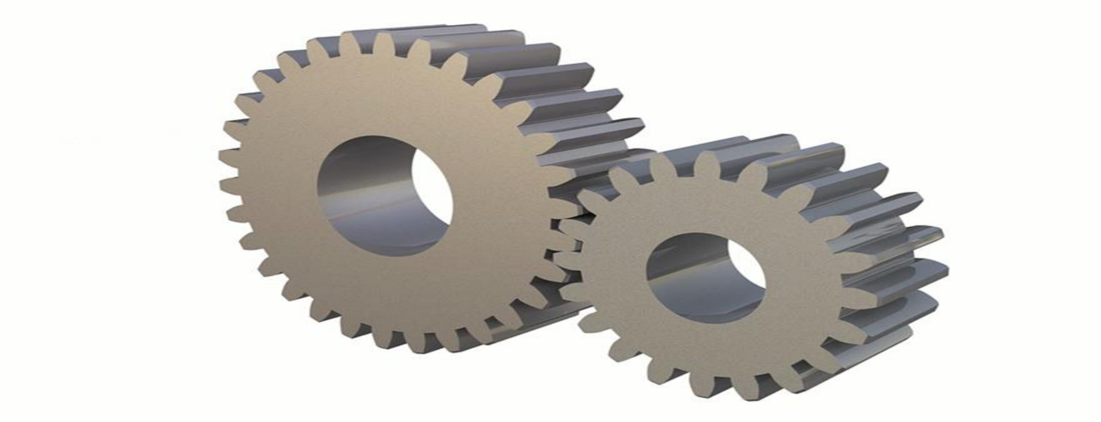


Figure II.3.2.2. Spur gears

Applications:

- Low and medium-speed applications which are usually up to 3600 rmp, they are not very often used in high-speed applications due to the loud noise they produce;
- Convert rotational movement into electrical energy by driving generators and other equipment in power generation systems;
- Printing and packing machinery to drive rollers, transporters, and other moving parts;
- Their credibility and capability in aircraft engines, landing gear mechanisms, and flight control systems are crucial to ensure smooth and safe operation. **[9]**

Helical gears: are used similar to spur gears. However, helical gears have teeth that are oriented at an angle to the shaft, unlike spur gears which are parallel. This causes more than one tooth to be in contact during operation and helical gear can carry more load than spur gears.

Due to the better teeth, this makes them a better choice for high-speed applications. Also, they operate smoother and quieter than spur gears.

Are suitable for the velocity ratio of 1:1 to 1:5.

Figure II.3.2.3. Helical gears [10]

Applications:

- They are generally used in high-speed applications where there is a necessity to transmit high power from one shaft to another;
- Making the gear arrangements of four-wheeler and two-wheeler vehicles in the automotive sectors;
- Turbines, cranes and marine drives. **[10]**

Rack & pinion gear: is a type of linear actuator that comprises a circular gear (the pinion) engaging a linear (the track), which operates to translate rotational motion into linear motion. Driving the pinion into rotation causes the rack to be driven linearly. **[11]**

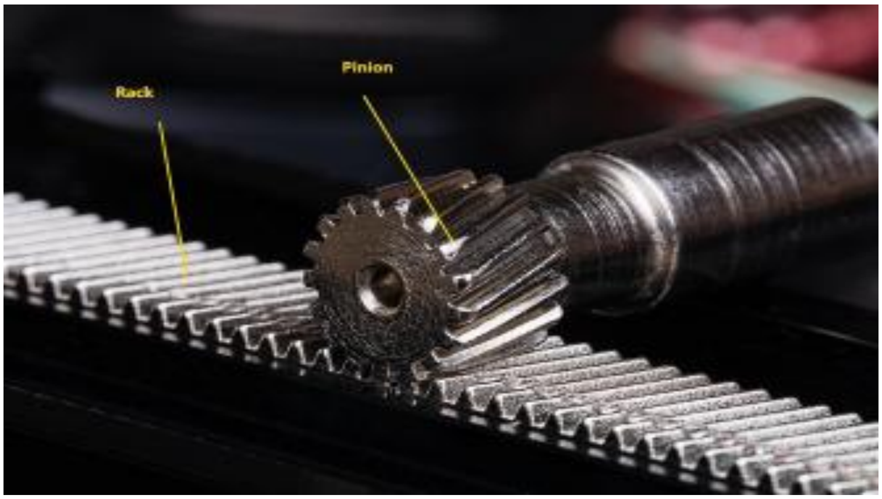


Figure II.3.2.4. Rack and pinion gear [11]

Applications:

- In elevators: when the pinion moves by turning, powered by an electric engine, its teeth fit into the rack and make it rise or fall, in this way allowing the movement of the cabin.
- Motorized toys like RC cars;
- Smart antenna systems;
- Guiding cars and small trucks. **[12]**

- **Intersecting shaft gears:**

Bevel gears: are gears that are used to change the direction of shaft rotation, reduce speed, and increase torque between non-parallel spinning shafts. They are used on shafts with intersecting axes, especially when the shafts intersect at a 90-degree angle. The angle between the shafts can be anything except zero or 180 degrees. A bevel gear is approximately like a right circular cone with most of its tip deleted.

Bevel gears enforce radial and thrust loads on the shafts. They enable power transmission at 90° and give a quite operation. These gears are highly effective. But, these gears experience greater loads as both radial and axial loads act on the gears. This means, that axial bearings are required to be used, increasing the weight of the system. **[8]**

The teeth of a bevel gear can be either straight or spiraled (curved):

Figure II.3.2.5. Straight teeth bevel gears

Figure II.3.2.6. Spiral teeth bevel gears

Straight teeth bevel gear	Spiral teeth bevel gear
Elements of the teeth are in the form of a straight line, which focalizes on a common apex.	Elements of the teeth are in the form of a spiral curve, which focalizes on a common apex.
Contact between teeth of two meshing gears happens suddenly.	Contact between teeth of two meshing gears happens gradually.
Due to sudden engagement, teeth are subjected to impact loading.	Due to gradual engagement, teeth are subjected to gradual loading.
Sudden engagement of teeth also causes vibration and noise.	Operation of spiral teeth is smooth and quite.
Load carrying capacity is comparatively low.	Load carrying capacity is comparatively high.
Are suitable for low to moderate speed applications.	Can be utilized at high speed applications.
They have a shorter life as it is subjected to impact loading and vibration.	They have a longer life

Table II.3.2.1. Differences between straight and spiral bevel gears

Applications:

- High rpm applications;
- Special steel and processes;
- Pre-heater gearboxes;
- High control thickness applications;
- Polythene foil production;
- Material upgrades;
- Ground teeth for smooth running, lower noise, lower vibration;
- Mill drives;
- Straight and spiral bevel options in robotics. [13]

- **Non-parallel and non-intersecting shaft gears:**

Worm gear: is a gadget consisting of a strung shaft that mates with a gear wheel, so that rotary motion can be transferred between two shafts at right angles to each other.

A worm gear can have a massive reduction ratio with small effort - all one must do is add circumference to the wheel. Hence you can use it to either greatly increase torque or greatly reduce speed. It will typically take different reductions of a conventional gear set to achieve the same reduction level of a single worm gear - meaning users of worm gears have lesser moving parts and lesser places for failure. [14]

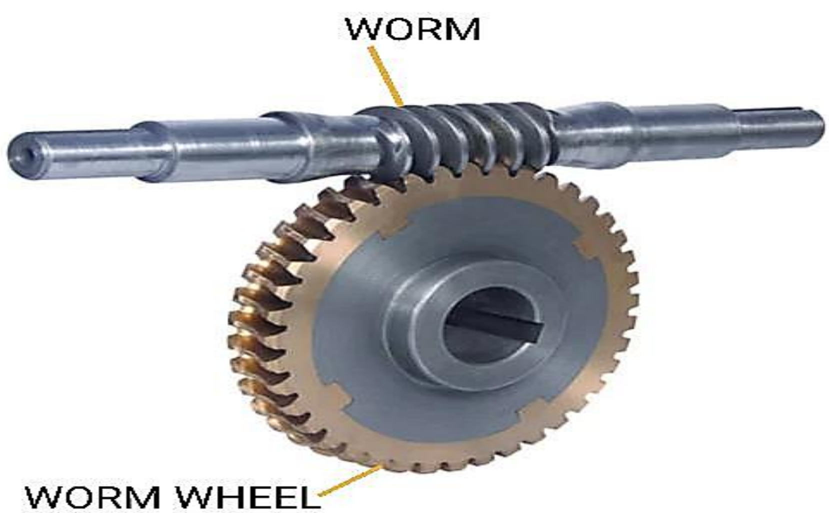


Figure II.3.2.7. Worm and worm wheel gear

Applications:

- Elevators: Due to their compressed size and non-reversible characteristics, worm gears are generally found in the gadget used to work lifts. This kind of adapt works as an auxiliary braking system as the pressure cannot transmit motion back through the worm/hoist.
- Conveyor belts: As standard worm drives can turn in one direction, they will not move in reverse when they are affixed and not being used. This indicates that worm drives are ideal to be used on conveyor belts.
- Conveyor security gates: One worm drive is used to open the gate, and one is used to nearby it. This indicates that the gate can be locked in each direction and cannot be beached or forced. [15]

Hypoid gears: are a one of a kind of spiral bevel gears that are used to transmit rotational power between two shafts at right angles.

Hypoid gears are compact, high speed, high torque, high efficiency, extreme precision, low noise, low heat, and long life. The combination of these characteristics has made hypoid gearing an increasingly popular speed reduction solution for the growing demands of today’s power transmission and motion control industries.

Are suitable for the velocity ratio of 3:1 to 10:1 [16]

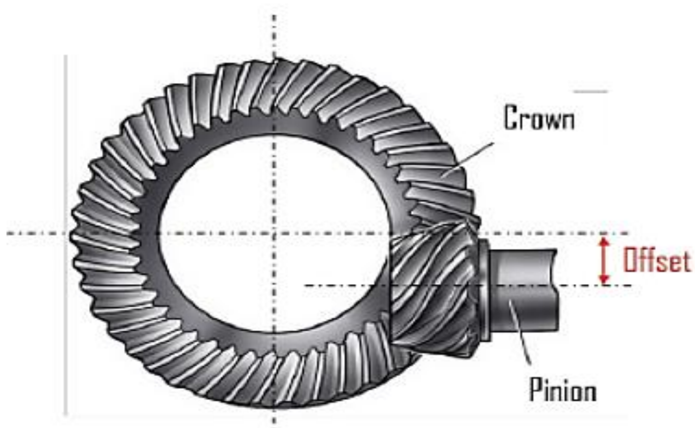


Figure II.3.2.8. Hypoid gears [16]

Applications:

- In marine applications: hypoid gears are used in marine propulsion systems, such as boat motors and marine transmissions. Their capacity to handle high torque and reduce noise contributes to smooth and effective boat propulsion.
- In automotive industry: where they are used in rear axles, particularly for large trucks. With a left-hand spiral angle on the pinion and a right-hand spiral angle on the crown, these applications have what is known as a “below-center” balanced, which permits the drive shaft to be found lower in the vehicle. This brings down the vehicle’s center of gravity, and in some cases, reduces obstructions with the interior space of the vehicle.
- In compressors and pumps: where high torque transmission and smooth operation are necessary for effective fluid handling. [17]

Chapter III: Characteristics of the final gear reducer for the Mi-171 helicopter

III.1/ Introduction:

The gear reducer we have chosen is fitted with a spiral bevel gear. We will proceed during this chapter to define its description and characteristics.

III.2/ The kinematic diagram:

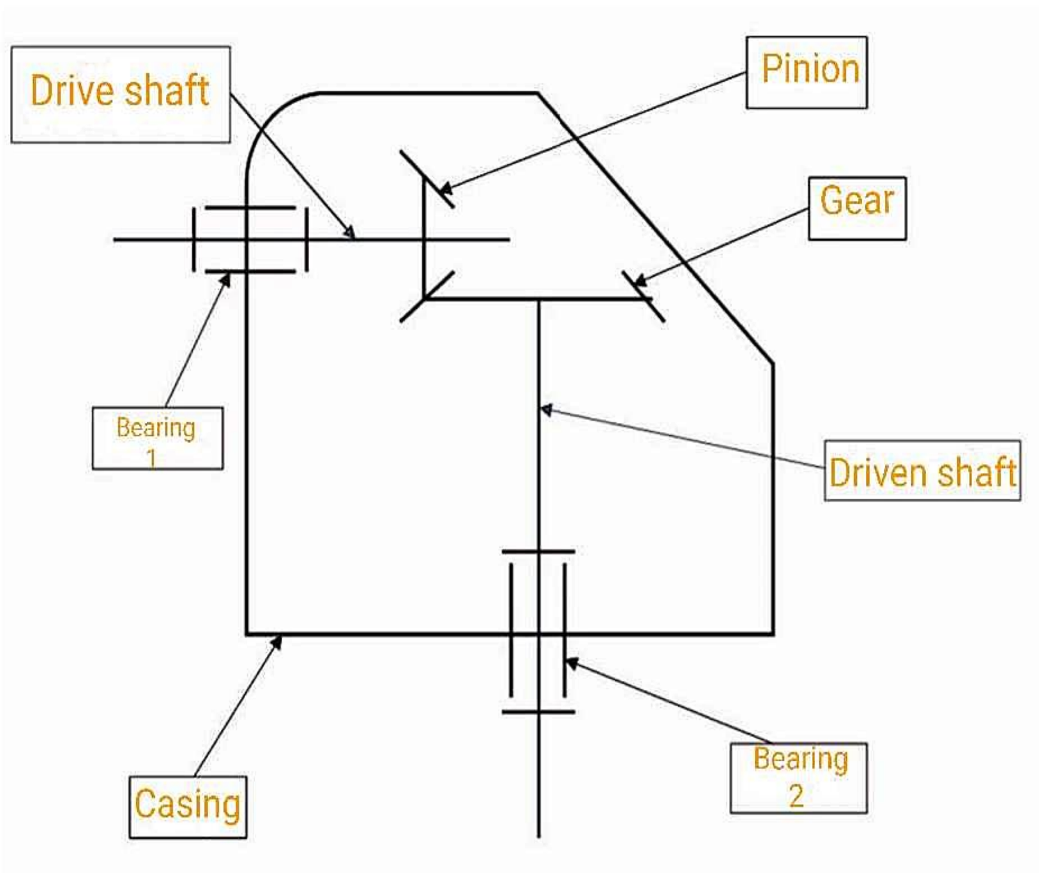


Figure III.2. Kinematic diagram of the final gear reducer [18]

III.3/ Specifications:

Direction of rotation	Left	
Input speed	N_1 = 2589 rpm	
Output speed	N_2 = 1124 rpm	
Pressure angle	$\alpha_n = 20°$	
Helix angle	$\beta = 30°$	
Number of teeth (Z_1 pinion) (Z_2 wheel)	Z1= 19	Z2= 44
Gear ratio	i= 0.43	
Couple moment	C= Mt= 3138.128 N.m	

Table III.3.1. Specifications of the final gear reducer

III.3.1/ Lubrication:

- Maximum allowable oil temperature in the gear reducer: 110 ° C.
- Type of oil used in cold weather: a mixture of 2/3 hypoid oil and 1/3 AMG-10 oil.
- Type of oil used in hot weather: hypoid oil.
- Oil level in the gear reducer at the top line of the oil dipstick: 1.3 Kg. [18]

III.3.2/ Properties of materials:

For the shafts: we used the 1.6511 (36CrNiMo4), is a heat treatable low alloy steel. It belongs to a category of steels called nickel-chromium molybdenum (Ni-Cr-Mo) steels due to its key alloying elements.

Machinability:

Machining is best done with this steel in the annealed or normalized and tempered condition. It can be machined by all conventional methods.

Corrosion Resistance:

This is a low alloy steel and not a corrosion resistant alloy. applying suitable coatings or using this material in controlled environments is necessary.

Welding:

The alloy can be fusion or resistance welded. Preheat and post heat weld procedures should be followed when welding this alloy by established methods.

Applications:

- For permanently stressed components with large cross sections and high tensile strength, good fatigue resistance, and toughness are required,
- Heavy machinery such as high load of axial, turbine shaft, helicopter rotor shaft, turbojet engine turbine shaft, blade and high load of transmission parts.

For the gears: we used the 1.2316 (X36CrMo17), is a stainless high alloy steel. It belongs to a category of steels called martensitic stainless steels due to its chromium content ranging between 15.5% and 17.5%.

Machinability:

Has fair to poor machinability due to its high chromium content and tendency to form long, gummy chips.

To improve the machinability of this steel, we can use some of these strategies: machining in the annealed condition, using specialized tooling, and optimizing machining parameters.

Corrosion Resistance:

It has an exceptional corrosion resistance, which sets it apart from conventional steels, whether it's exposure to corrosive chemicals or harsh weather conditions, this steel variant offers unparalleled protection against degradation, ensuring the longevity of the components it forms.

Welding:

can be welded, but it's considered a moderately difficult weldable steel due to crack sensitivity and hydrogen embrittlement.

Applications:

- All kinds of silicon steel sheet and high-speed blanking die.
- plastic injection molds, in connection with chemically aggressive and acidic plastics such as thermoplastics extrusion tools and compressor parts.

III.4/ Terminology and calculation:

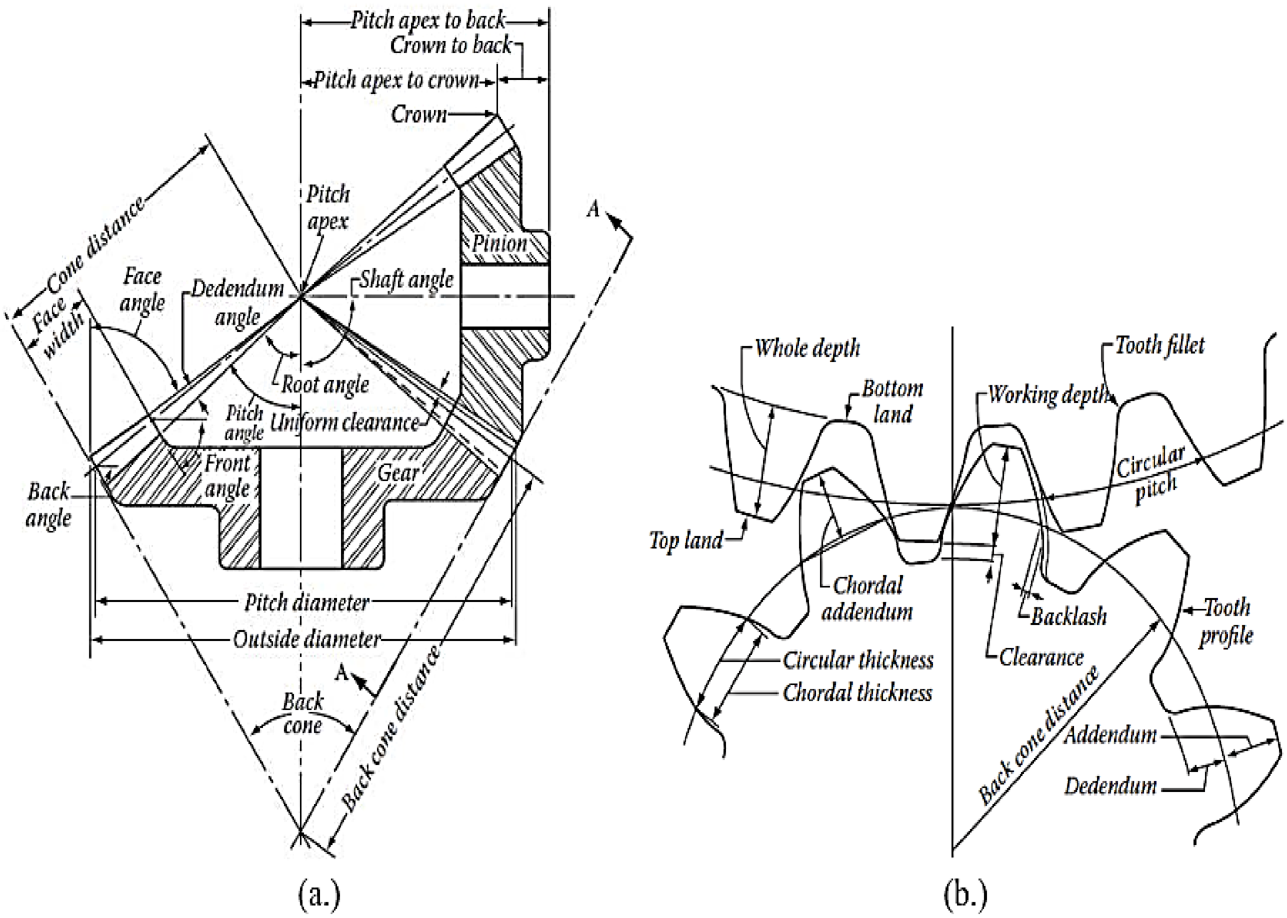


Figure III.4.1 Spiral bevel gear terminology [19]

Calculation:

Item	Symbol
Angular Velocity (rad/s)	ω
Module (mm)	m
Reference pitch (mm)	p
Reference diameter (mm)	d_1 *(pinion)* d_2 *(wheel)*
Reference angle (deg)	δ_1 *(pinion)* δ_2 *(wheel)*
Tip angle (deg)	δ_a
Root angle (deg)	δ_f
Addendum angle (deg)	θ_a
Dedendum angle (deg)	θ_f
Tooth angle (deg)	θ
Cone distance (mm)	L
Face width (mm)	b
Addendum (mm)	h_a
Dedendum (mm)	h_f
Tooth Depth (mm)	h
Tip diameter (mm)	d_a
Root diameter (mm)	d_f

Table III.4.1. Symbols used in spiral bevel gear calculations

Input angular Velocity:

$$\omega_1 = \frac{\pi \times N1}{30} = \frac{3.14 \times 2589}{30} = 270.98 \text{ rad/s}$$

Output angular Velocity:

$$\omega_2 = \frac{\pi \times N2}{30} = \frac{3.14 \times 1124}{30} = 117.64 \text{ rad/s}$$

Module:

$m = \frac{P}{\pi} = \frac{19}{\pi} = 6$ mm

Reference diameter:

$d_1 = m \times z_1 = 6 \times 19 = 114$ mm

$d_2 = m \times z_2 = 6 \times 44 = 264$ mm

Reference angle:

$\delta_1 = \tan^{-1}(\frac{z1}{z2}) = \tan^{-1}(\frac{19}{44}) \Rightarrow \delta_1 = 23.27°$

$\delta_2 = \tan^{-1}(\frac{z2}{z1}) = \tan^{-1}(\frac{44}{19}) \Rightarrow \delta_2 = 66.59°$

Addendum angle:

$\tan\theta_a = (\frac{2 \times m \times \sin\delta1}{d1}) = (\frac{2 \times m \times \sin\delta2}{d2}) = (\frac{2 \times 6 \times \sin(66.59)}{264}) = 0.04 \Rightarrow \theta_a = 2.29°$

Tip angle:

$\delta_{a1} = \delta_1 + \theta_a = 23.27 + 2.29 = 25.56°$

$\delta_{a2} = \delta_2 + \theta_a = 66.59 + 2.29 = 68.88°$

Dedendum angle:

$\tan\theta_f = (\frac{2.5 \times m \times \sin\delta1}{d1}) = (\frac{2.5 \times m \times \sin\delta2}{d2}) = (\frac{2.5 \times 6 \times \sin(66.59)}{264}) = 0.05$

$\Rightarrow \theta_f = 2.86°$

Root angle:

$\delta_{f1} = \delta_1 - \theta_f = \delta_{f1} = 20.41°$

$\delta_{f2} = \delta_2 - \theta_f = \delta_{f2} = 63.73°$

Tooth angle:

$\theta = \theta_a + \theta_f = 2.29 + 2.86 = 5.15\ °$

Cône distance :

$L = \frac{d1}{2\times\sin\delta1} = \frac{d2}{2\times\sin\delta2} = \frac{264}{2\times\sin(66.59)} \Rightarrow L = 143.84$ mm

Face width:

$\frac{L}{4} \leq b \leq \frac{L}{3} \Leftrightarrow 35.96 \leq b \leq 48$ (Actually b equals to 40 mm)

Addendum:

$h_a = m = 6$ mm

Dedendum:

$h_f = 1.25 \times m = 7.5$ mm

Tooth Depth:

$h = h_a + h_f = 6 + 7.5 = 13.5$ mm

Tip diameter:

$d_{a1} = d_1 + 2 \times m \times \cos \delta_1 = 114 + 2 \times 6 \times \cos (23.27) \Rightarrow d_{a1} = 125.04$ mm

$d_{a2} = d_2 + 2 \times m \times \cos \delta_2 = 264 + 2 \times 6 \times \cos (66.59) \Rightarrow d_{a2} = 268.77$ mm

Root diameter:

$d_{f1} = d_1 - 2.5 \times m \times \cos \delta_1 = 114 - 2.5 \times 6 \times \cos (23.27) \Rightarrow d_{f1} = 100.22$ mm

$d_{f2} = d_2 - 2.5 \times m \times \cos \delta_2 = 264 - 2.5 \times 6 \times \cos (66.59) \Rightarrow d_{f2} = 258.04$ mm

III.5/ Force analysis: [20]

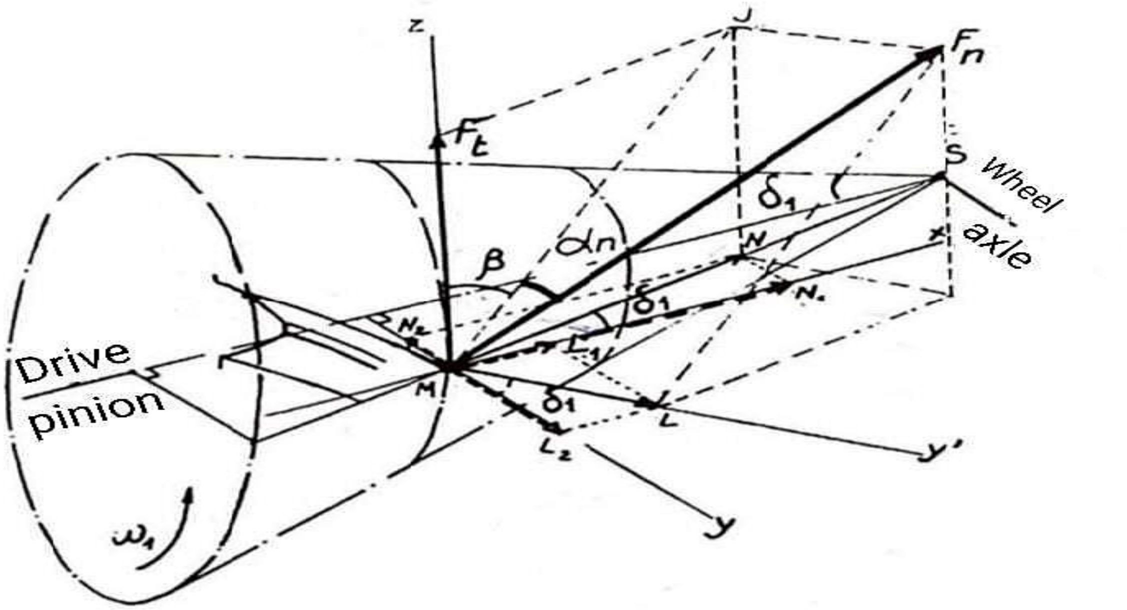


Figure III.5.1. Force analysis of spiral bevel tooth [20]

Tangential force:

$$Ft = \frac{P1 \times 1020}{v1}$$

P: power transmitted

1020: a conversion factor

v_1: linear velocity

power transmitted: $P_1 = c \times \omega_1$

c: torque, it equals to 3138.128 N.m [18]

$\omega_{1:}$ input angular velocity

$$P_1 = 3138.128 \times 270.98 = 850.38 \text{ Kw}$$

Linear velocity: $v_1 = \omega_1 \times r_1$

r_1: reference radius

$r_1 = 0.5 \times m \times z_1 = 0.5 \times 6 \times 19 = 57$ mm

$$v_1 = 270.98 \times 57 \times 10^{-3} = 15.45 \text{ m/s}$$

$$\Rightarrow Ft = \frac{850.38 \times 1020}{15.45} = 56141.59 \text{ N}$$

Normal force:

Along Mx: $N_1 = Ft \times \tan\beta \times \cos\delta_1 = 850.38 \times \tan(30) \times \cos(23.27) = 29776.64$ N

Along My: $N_2 = Ft \times \tan\beta \times \sin\delta_1 = 850.38 \times \tan(30) \times \sin(23.27) = 12805.37$ N

Radial force on the wheel:

$Fr_2 = N_1 + L_1 = 29776.64 + 9321.55$

$L_1 = \frac{Ft}{\cos\beta} \times \tan\alpha n \times \sin\delta_1 = \frac{850.38}{\cos(30)} \times \tan(20) \times \sin(23.27) = 9321.55$ N

$$\Rightarrow Fr_2 = 39098.19 \text{ N}$$

Axial force on the wheel:

$Fx_2 = -N_2 + L_2 = -12805.37 + 21675.62$

$L_2 = \frac{Ft}{\cos\beta} \times \tan\alpha n \times \cos\delta_1 = \frac{850.38}{\cos(30)} \times \tan(20) \times \cos(23.27) = 21675.62$ N

$$\Rightarrow Fx_2 = 8870.25 \text{ N}$$

- The axial force of the pinion corresponds to the radial force of the wheel
- The radial force of the pinion corresponds to the axial force of the wheel

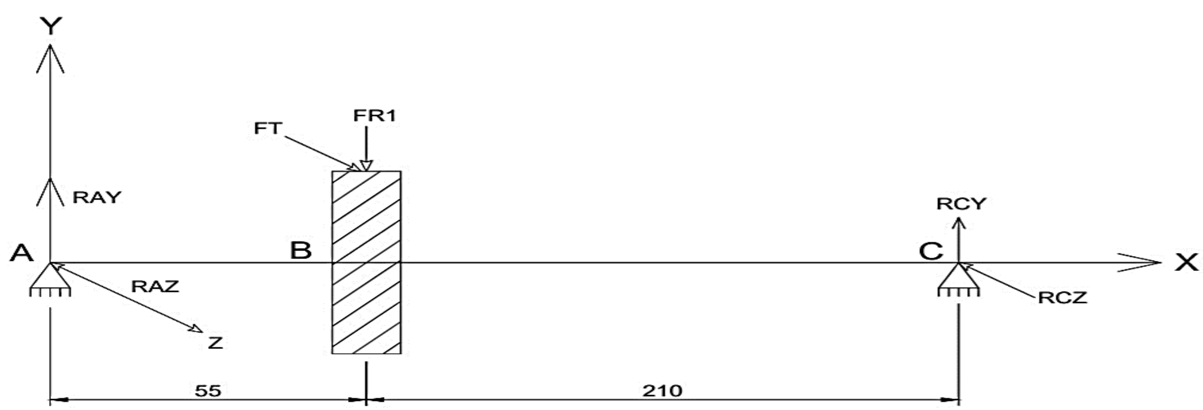
=> F_{x1} = 39098.19 N and F_{r1} = 8870.25 N

Normal force on the tooth:

$$F_n = \frac{Ft}{\cos \alpha n} = \frac{56141.59}{\cos(20)} = 59744.63 \text{ N}$$

❖ **Calculation of reactions at supports and bending moments:**

Drive shaft:



Balance along OXY:

$\sum \vec{F}_Y = \vec{0}$ <=> RAY – FR1 + RCY = 0

$\sum \vec{M}_A = \vec{0}$ <=> - FR1 × 0.055 + RCY × 0.265 = 0 => RCY = $\frac{8870.25 \times 0.055}{0.265}$

=> RCY = 1841 N

RAY = FR1 – RCY <=> 8870.25- 1841

=> RAY = 7029.25 N

0 ≤ X ≤ 0.055 m

$\sum M_{O'}$ = 0 => M_f = RAY × X

For X = 0 => M_f = 0

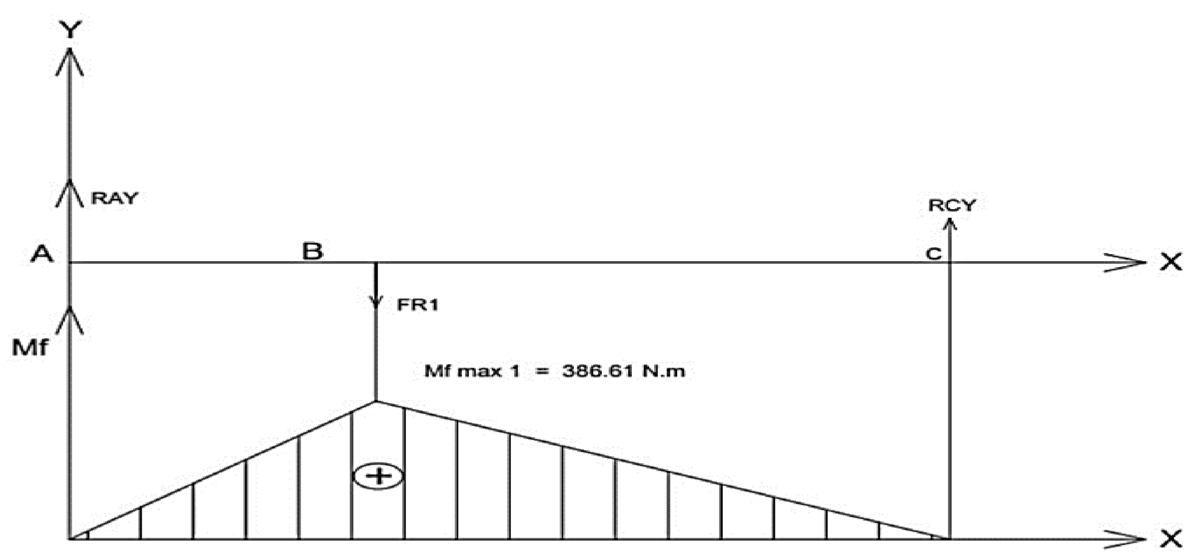
For X = 0.055 => Mf = 386.61 N.m

0.055 m ≤ X ≤ 0.265 m

$\sum M_{O'}$ = 0 => M_f = RAY × X – FR1 (X - 0.055)

For X = 0.055 => M_f = 386.61 N.m

For X = 0.0265 => M_f = - 0.00125 N.m



Balance along OXZ:

$\sum \vec{F}_Z = \vec{0}$ <=> - RAZ + FT - RCZ= 0

$\sum \vec{M}_A = \vec{0}$ <=> FT × 0.055 - RCZ × 0.265 = 0 => RCZ = $\frac{56141.59 \times 0.055}{0.265}$

=> RCZ = 11652.1 N

RAZ = FT – RCZ <=> 56141.59 – 11652.1

=> RAZ = 44489.49 N

0 ≤ X ≤ 0.055 m

$\sum M_{O'}$ = 0 => M_f = - RAZ × X

For X = 0 => M_f = 0

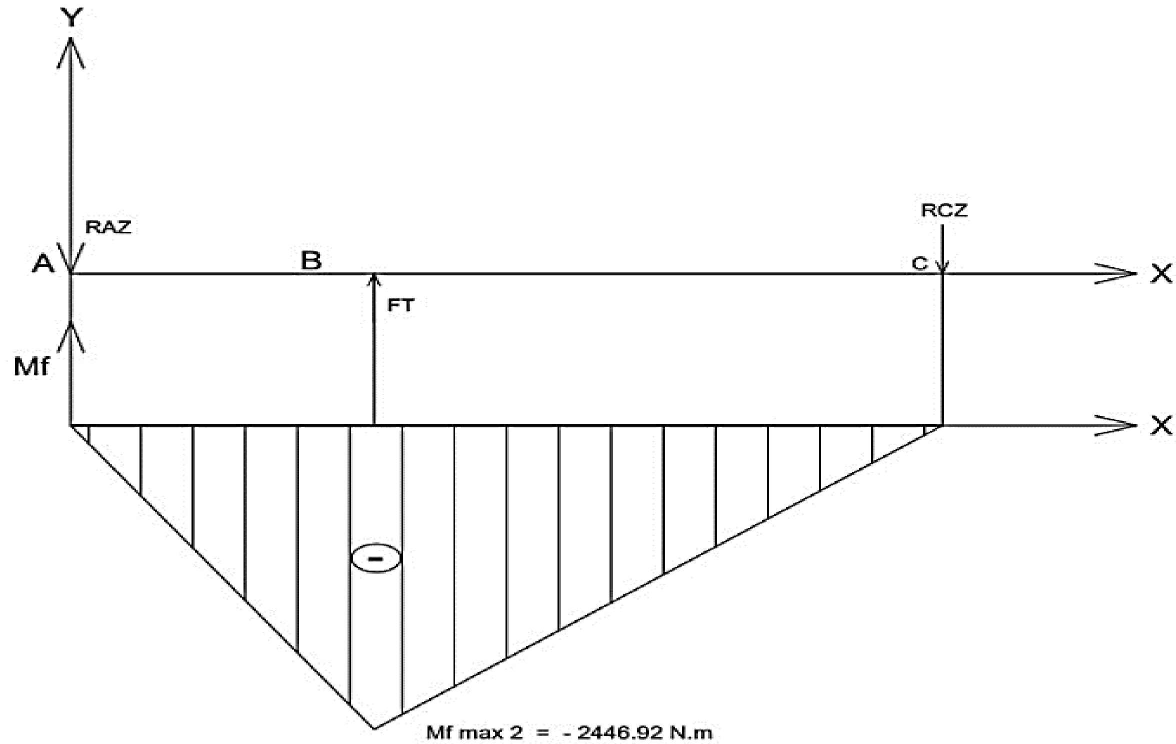
For X = 0.055 => Mf = - 2446.92 N.m

0.055 m ≤ X ≤ 0.265 m

$\sum M_{O'}$ = 0 => M_f = - RAZ × X + FT (X - 0.055)

For X = 0.055 => M_f = - 2446.92 N.m

For X = 0.0265 => M_f = 0.02 N.m

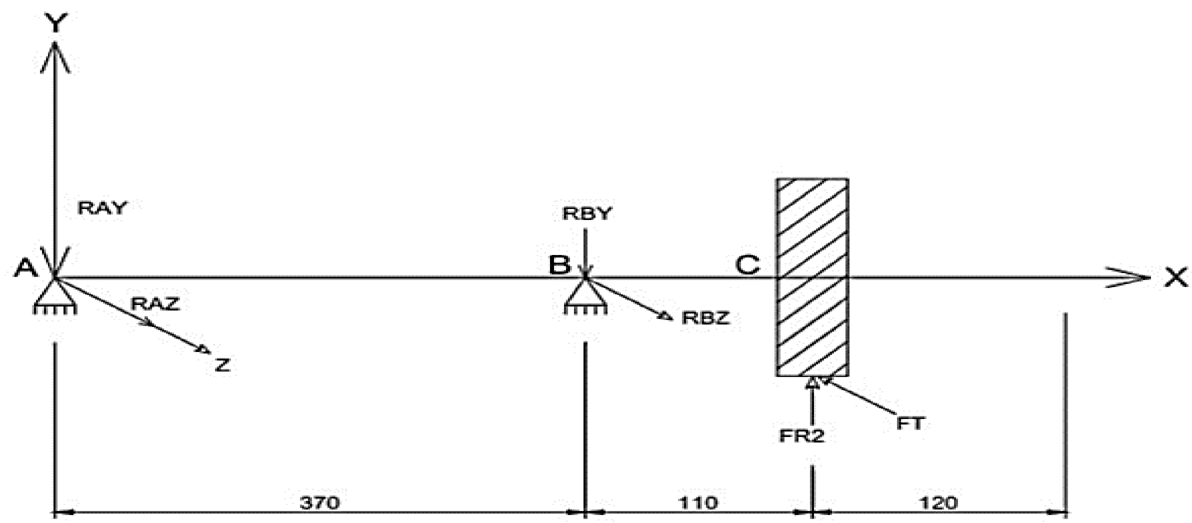


❖ **Calculation of equivalent bending moment:**

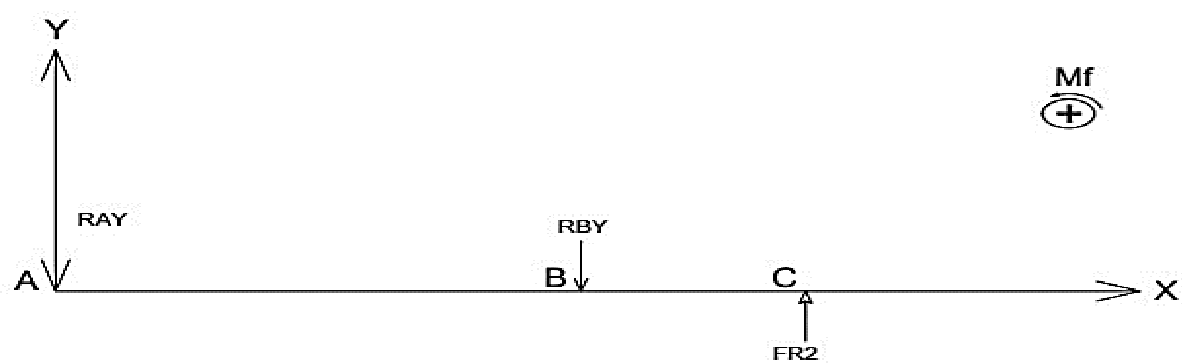
$$M_{f\,eq} = \sqrt{(M_{f\,max\,1})^2 + (M_{f\,max\,2})^2} = \sqrt{(386.61)^2 + (-\,2446.92)^2}$$

$$\Rightarrow M_{f\,eq} = 2477.27 \text{ N.m}$$

Driven shaft:



Balance along OXY:



$\sum\vec{F}_Y = \vec{0}$ <=> - RAY – RBY + FR2 = 0

$\sum\vec{M}_A = \vec{0}$ <=> - RBY× 0.37 + FR2 × 0.48 = 0 => RBY = $\frac{39098.19 \times 0.48}{0.37}$

=> RBY = 50721.98 N

RAY = – RBY + FR2 <=> - 50721.98 + 39098.19

=> RAY = - 11623.79 N

$0 \leq X \leq 0.37$ m

$\sum M_{O'} = 0 \Rightarrow M_f = -RAY \times X$

For X = 0 => $M_f = 0$

For X = 0.37 => Mf = 4300.8 N.m

$0.37 \text{ m} \leq X \leq 0.48$ m

$\sum M_{O'} = 0 \Rightarrow M_f = -RAY \times X - RBY(X - 0.37)$

For X = 0.37 => M_f = 4300.8 N.m

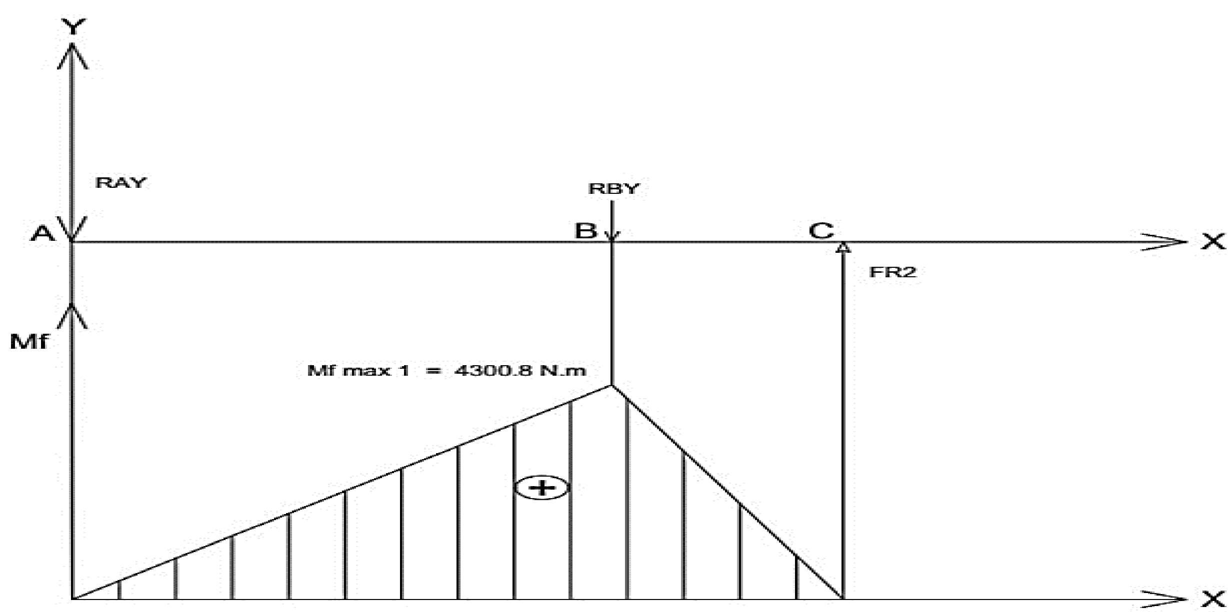
For X = 0.48 => M_f = 0.0014 N.m

$0.48 \text{ m} \leq X \leq 0.6$ m

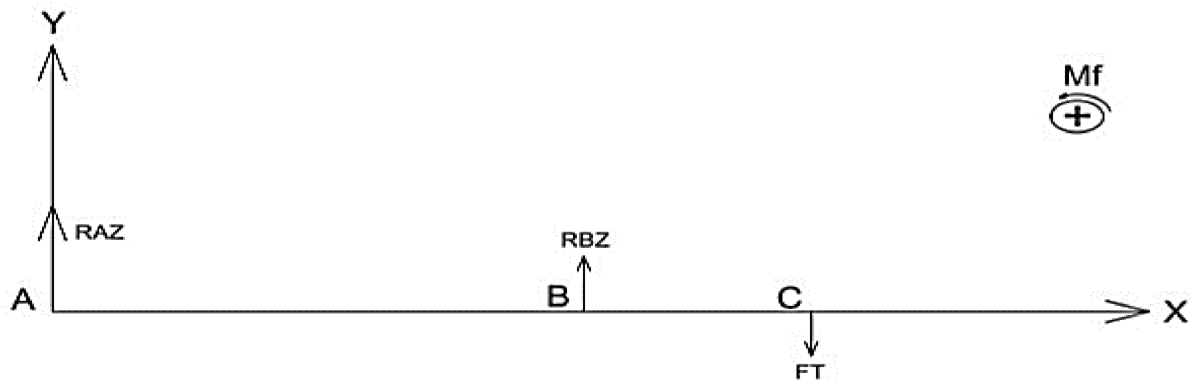
$\sum M_{O'} = 0 \Rightarrow M_f = -RAY \times X - RBY(X - 0.37) + FR2(X - 0.48)$

For X = 0.48 => M_f = 0.0014 N.m

For X = 0.6 => M_f = 0.0014 N.m



Balance along OXZ:



$\sum \vec{F}_Z = \vec{0}$ <=> RAZ + RBZ - FT = 0

$\sum \vec{M}_A = \vec{0}$ <=> RBZ × 0.37 - FT × 0.48 = 0 => RBZ = $\frac{561411.59 \times 0.48}{0.37}$

=> RBZ = 72832.33 N

RAZ = FT – RBZ <=> 56141.59 – 72832.33

=> RAZ = - 16690.74 N

0 ≤ X ≤ 0.37 m

$\sum M_{O'} = 0$ => M_f = RAZ × X

For X = 0 => M_f = 0

For X = 0.37 => M_f = - 6175.57 N.m

0.37 ≤ X ≤ 0.48 m

$\sum M_{O'} = 0$ => M_f = RAZ × X + RBZ (X – 0.37)

For X = 0.37 => M_f = - 6175.57 N.m

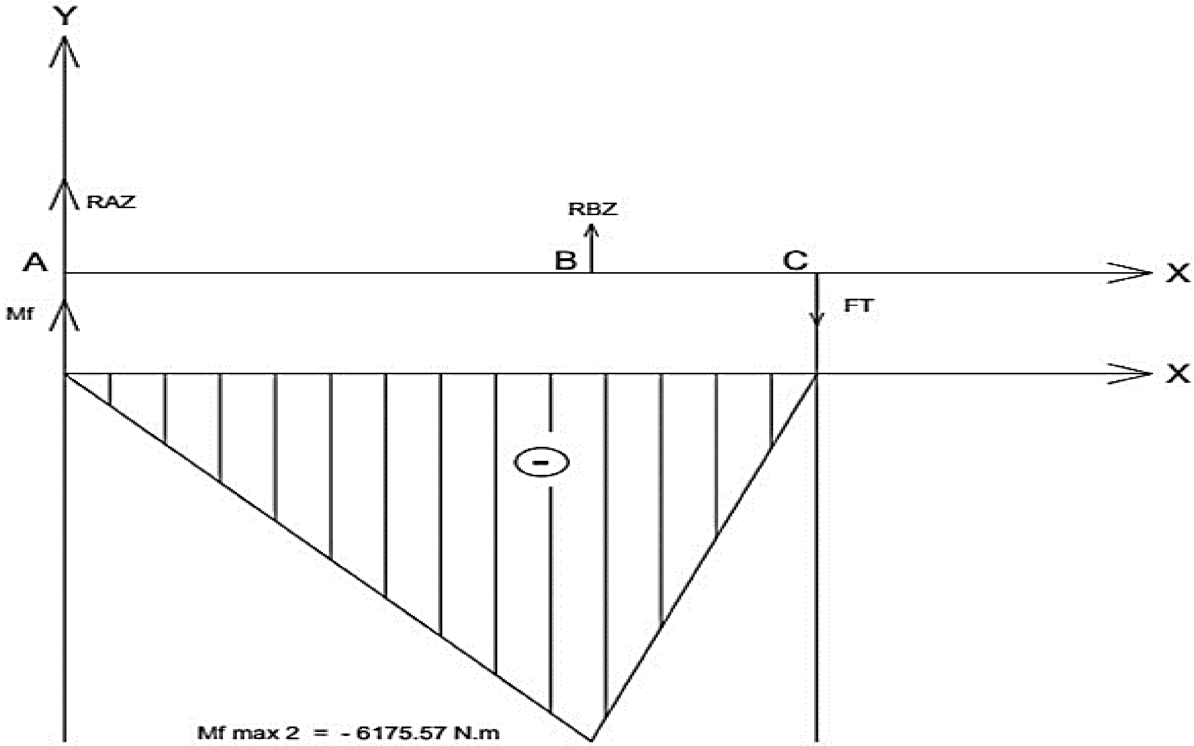
For X = 0.48 => Mf = 0.001 N.m

$0.48 \leq X \leq 0.6$ m

$\sum M_{O'} = 0$ => M_f = RAZ × X + RBZ (X – 0.37) – FT (X - 0.48)

For X = 0.48 => M_f = 0.001 N.m

For X = 0.6 => M_f = 0.001 N.m



❖ Calculation of equivalent bending moment:

$$M_{f\,eq} = \sqrt{(M_{f\,max\,1})^2 + (M_{f\,max\,2})^2} = \sqrt{(4300.8)^2 + (-\,6175.57)^2}$$

$$\Rightarrow M_{f\,eq} = 7525.59 \text{ N.m}$$

❖ **Shafts resistance:**

Drive shaft:

Bending:

$$\sigma = \frac{Mf}{I_{GZ}} \times y$$

$$d = \sqrt[3]{\frac{10\sqrt{(Mfeq)^2+(Mt)^2}}{\sigma_e}} = (\sqrt[3]{\frac{10\sqrt{(2477.27)^2+(3138.128)^2}}{7\times10^8}}) \times 10^3 = 38 \text{ mm}$$

$$y = \frac{d}{2} = 19 \text{ mm}$$

$$I_{GZ} = \frac{\pi \times d^4}{64} = \frac{\pi \times 38^4}{64} = 102353.87 \text{ mm}$$

$$\sigma = \frac{2446.92\times 10^3}{102353.87} \times 19 \Rightarrow \sigma = 454.22 \text{ MPA}$$

Torsion:

$$\tau = \frac{Mt}{I_0} \times \frac{d}{2}$$

$$I_0 = \frac{\pi \times d^4}{32} = \frac{\pi \times 38^4}{32} = 102353.87 \text{ mm}$$

$$\tau = \frac{3138.128\times 10^3}{204707.75} \times 19 \Rightarrow \tau = 291 \text{ MPA}$$

Verification:

$$\sigma_{eq} = \sqrt{\sigma^2 + 3\tau^2} \le \frac{\sigma_e}{2S}$$

S: safety factor = 2.3

$$\sigma_{eq} = \sqrt{(454.22)^2 + 3(291)^2}$$

$$\sigma_{eq} = \sqrt{(454.22)^2 + 3(291)^2} \le \frac{7\times10^{14}}{2\times2.3}$$

$\Rightarrow \sigma_{eq} = 678.5$ MPA $\le 1.54 \times 10^{14}$ MPA

the shaft can safely resist

Driven shaft:

Bending:

$\sigma = \frac{Mf}{I_{GZ}} \times y$

$d = \sqrt[3]{\frac{10\sqrt{(Mfeq)^2+(Mt)^2}}{\sigma_e}} = (\sqrt[3]{\frac{10\sqrt{(7525.59)^2+(3138.128)^2}}{7 \times 10^8}}) \times 10^3 = 50$ mm

$y = \frac{d}{2} = 25$ mm

$I_{GZ} = \frac{\pi \times d^4}{64} = \frac{\pi \times 50^4}{64} = 306796.16$ mm

$\sigma = \frac{6175.57 \times 10^3}{306796.16} \times 25 \Rightarrow \sigma = 503.23$ MPA

Torsion:

$\tau = \frac{Mt}{I_0} \times \frac{d}{2}$

$I_0 = \frac{\pi \times d^4}{32} = \frac{\pi \times 50^4}{32} = 613592.31$ mm

$\tau = \frac{3138.128 \times 10^3}{613592.31} \times 25 \Rightarrow \tau = 127.86$ MPA

Verification:

$\sigma_{eq} = \sqrt{\sigma^2 + 3\tau^2} \leq \frac{\sigma_e}{2S}$ S: safety factor = 2.2

$\sigma_{eq} = \sqrt{(503.23)^2 + 3(127.86)^2}$

$\sigma_{eq} = \sqrt{(503.23)^2 + 3(127.86)^2} \leq \frac{7 \times 10^{14}}{2 \times 2.2}$

$\Rightarrow \sigma_{eq} = 549.8$ MPA $\leq 1.6 \times 10^{14}$ MPA the shaft can safely resist

III.6/ Conclusion:

In this chapter, we have seen the different characteristics of the final gear reducer and the materials that have been used, calculated its dimensions, applied effort, and studied the moments verifying the resistance of shafts to bending and torsion.

Chapter: IV Modeling and simulating the final gear reducer

IV-1/ Introduction:

In this chapter, we will first present an overview of the software programs used for modeling and simulation, then we will present the results obtained from the static analysis.

IV-2/ GearTeq software:

Definition:

Is a gear component design add-in that creates standard and non-standard gear components. GearTeq provides the designer with advanced tools for creating solid models of drive components and assemblies. More than a library program, it creates each part model with its specific requirements, just as a designer would, but takes seconds rather than hours or days**.** Since 2007, it has been available for SolidWorks.

Features:

- Create solid models of spur, helical, rack and face gears, bevel gears, worm gears, involute splines, timing belt pulleys, chain sprockets, and V-belt pulleys,
- Multiple gears created as a single SolidWorks part,
- Internal splines can be used as a bore on all components,
- Automatically create assemblies in SolidWorks with proper mating.

IV-3/ SolidWorks software:

Definition:

is a 3D parametric design software that is used to design all sorts of products such as automobiles, marine equipment, airplane parts, cell phones, cameras, furniture, electrical assemblies, glasses, lighting fixtures, toys, vacuum cleaners, or any other like product you can think of**.**

Features:

- Create fast and accurate designs, including 3D models and 2D drawings of complex parts and assemblies,
- Design for cost and manufacturing with cost estimation tools and manufacturability checks,
- Interact with team members and control revisions with standardized data management tools,
- Eliminate errors and rework by using integrated motion and stress analysis tools.

IV-4/ Ansys software:

Definition:

Is a finite element analysis (FEA) software used to perform structural analysis using advanced solver options, including linear dynamics, nonlinearities, thermal analysis, materials, composites, hydrodynamics, explicit, and more.

Features:

- Reduce the solution time for thermo-mechanical fatigue. The software does it by analyzing the previous solving cycles and updating itself with the results,
- Open several CAD file types directly in the ANSYS software. The user can also control the degree of detail in the components of a model,
- Identify the optimal locations of the mesh node without changing the thickness or shape of the design,
- Save resources and time. Hence, resource prediction helps the user know the required amount of money, time to solve the problem, and other resources needed before testing.

IV-5/ Analysis Process:

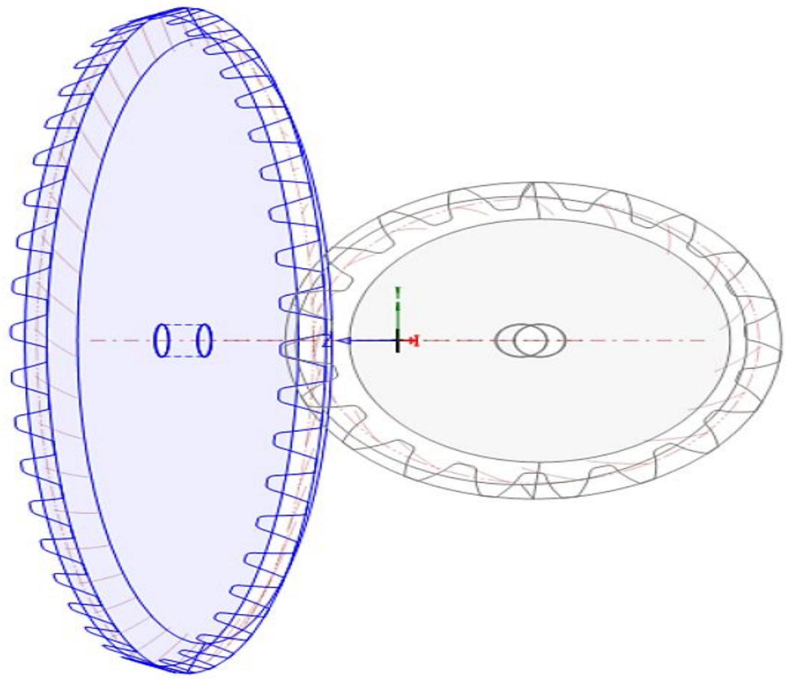


Figure IV.5.1: Assembly of gears in GearTeq

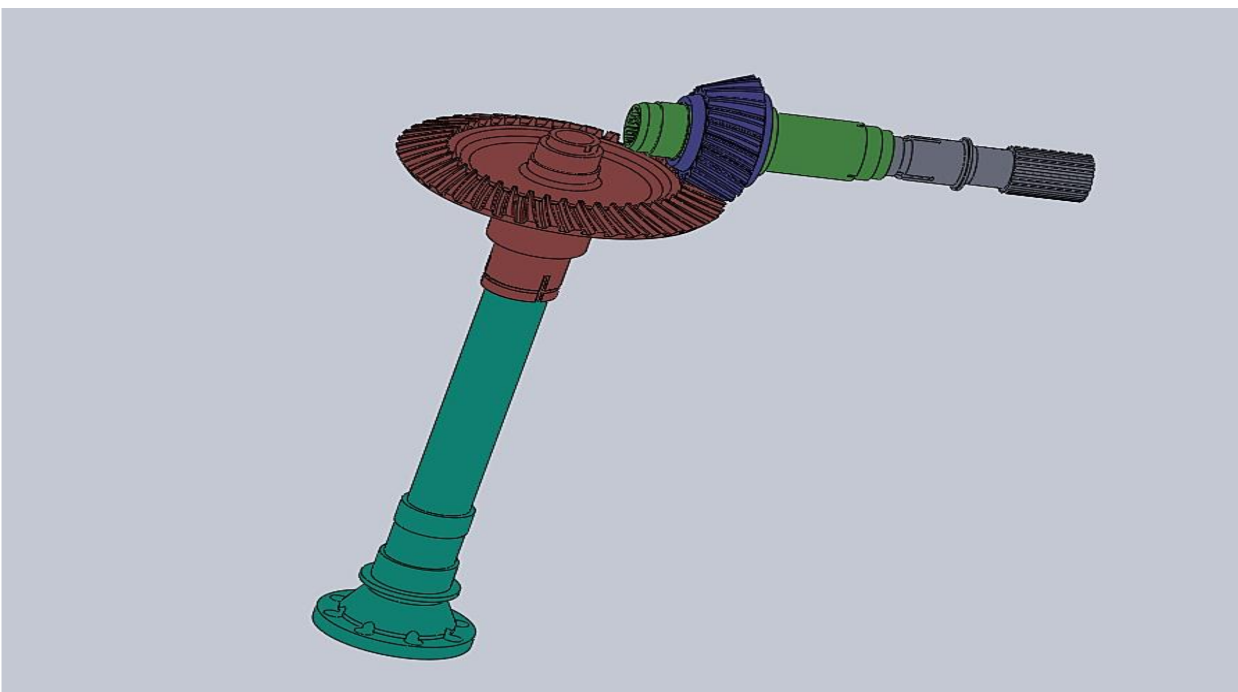
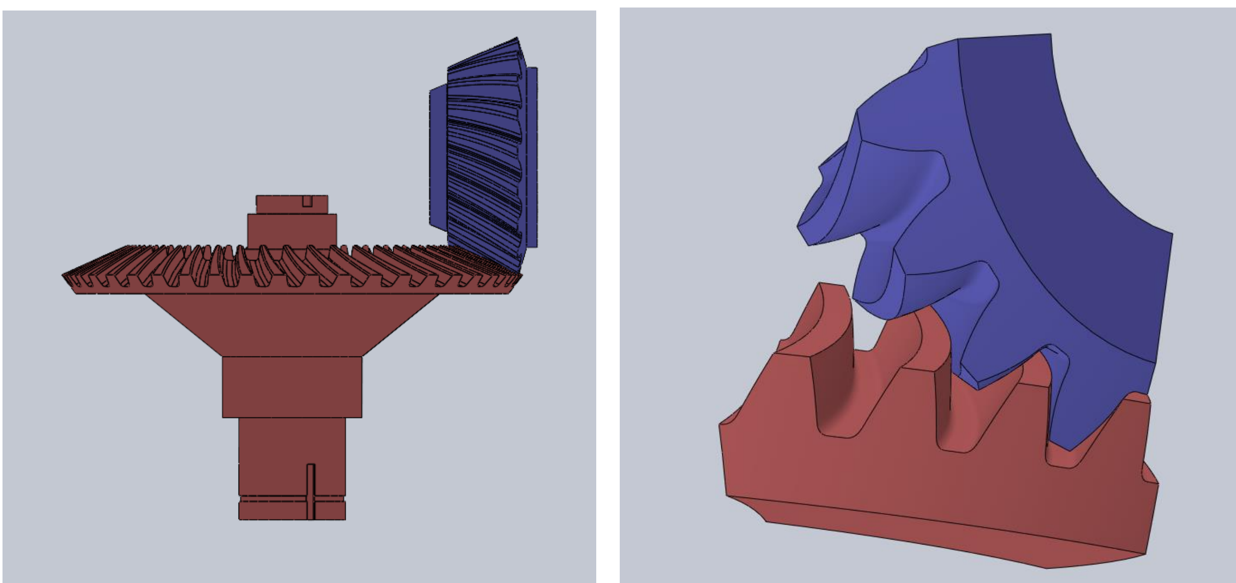


Figure IV.5.2: Assembly of the final gear reducer parts in SolidWorks

After the modeling step, followed by the analysis step using the Ansys software.

Gears have a number of major modes of failure that can result from lubrication inadequacy, flash temperatures, and contact stresses. Teeth represent one of the most complicated areas of tribology. Understanding the factors that contribute to each kind of failure provides end-users with a path toward predicting and avoiding these failures. For that reason, we chose to analyze the gears instead of the shafts.



a) Full CAD model **b) Reduced CAD model**

Figure IV.5.3: Obtained CAD model

• Ansys Workbench (version 19.0) is the one we will use in our simulation.

Model settings:

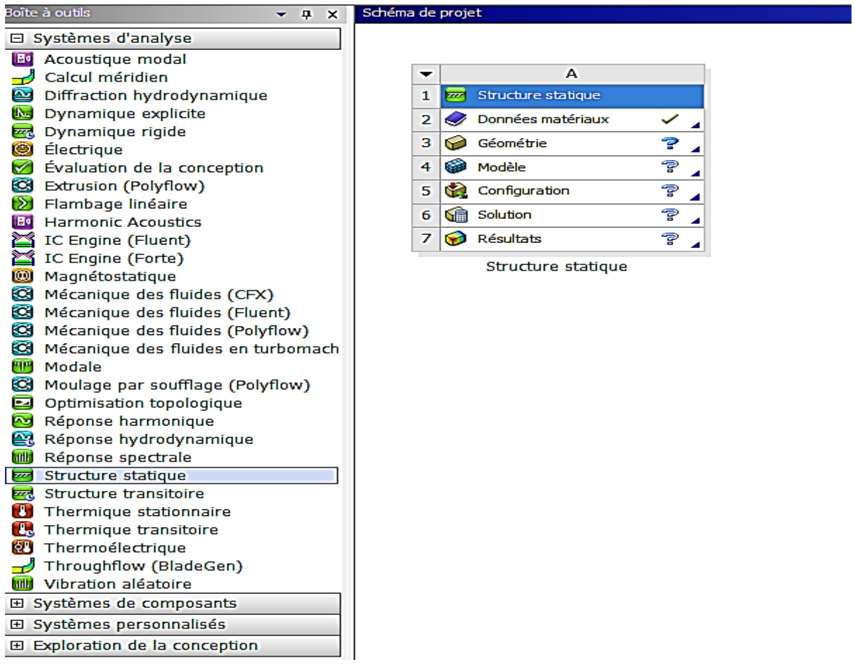


Figure IV.5.4. The cell of the static structural

Name	Young's Modulus (MPa)	Poisson's Ratio	Masse density (Kg mm^-3)	Shear Modulus (MPa)
X36CrMo17	2.07e+005	0.28	7,75e-006	79000

Table IV.5.1. Material characteristics

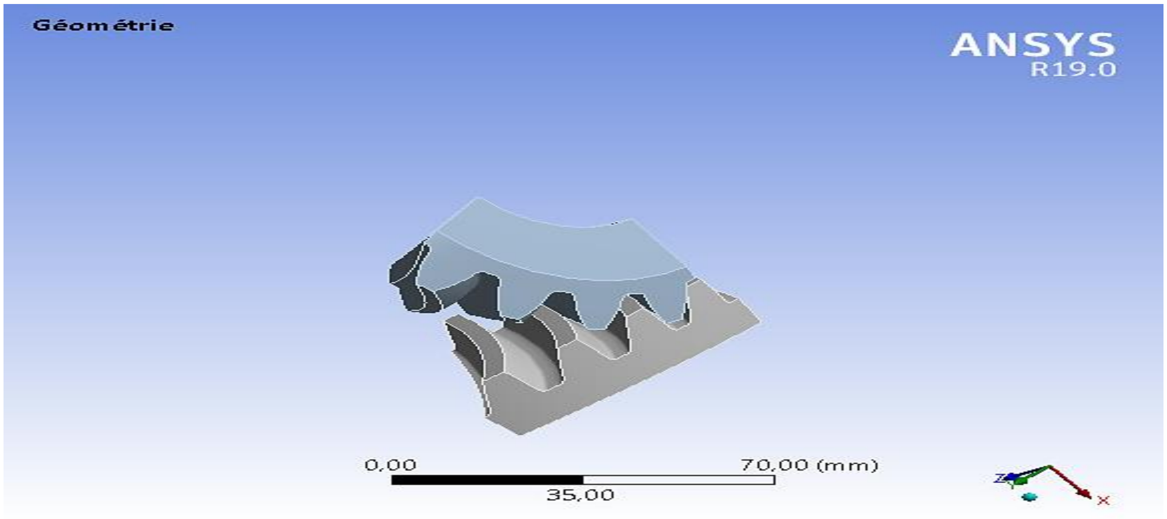


Figure IV.5.5. Imported geometry into Ansys

ANSYS software contains many formulations of contact between bodies, in our case, for penalty-based formulations with significant penetration, two implementations are present: "Pure Penalty" and "Augmented Lagrange".

After the selection of the formulation, we define contact surfaces, and the contact type as «Frictionless».

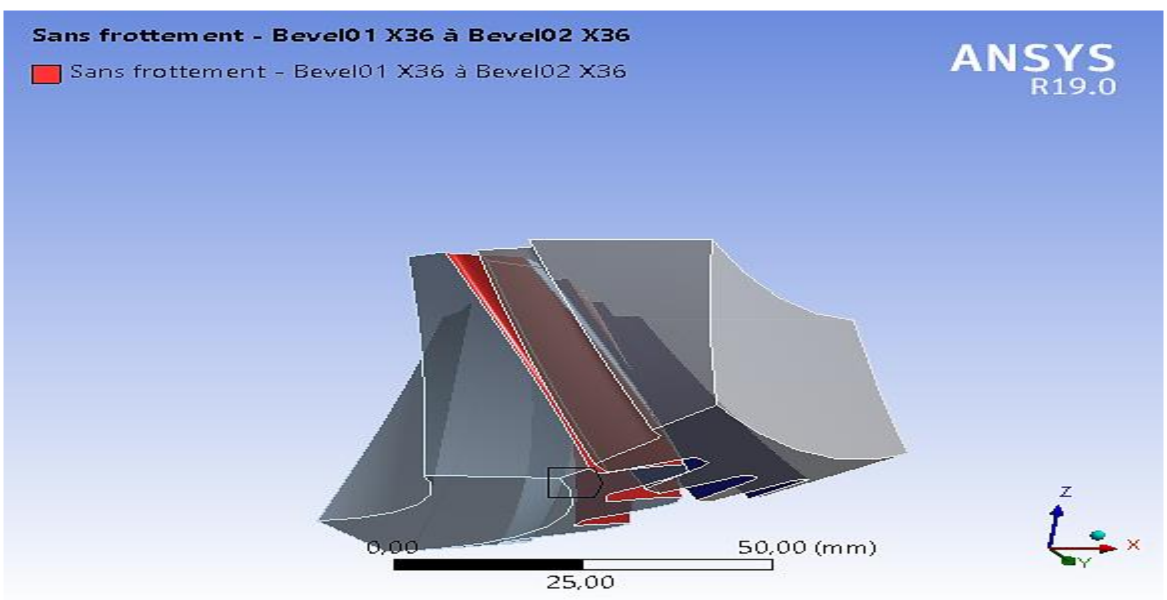


Figure IV.5.6. Contact surfaces definition

Mesh preparation:

Gearing FEM analysis are nonlinear due to contact phenomena, so the model results reliability is directly related to the mesh size and quality, especially on high bending and contact stress zones.

Détails de "Maillage"

Affichage	
Style d'affichage	Qualité de l'élément
Réglages par défaut	
Physique de préférence	Mécanique non-linéaire
Ordre des éléments	Contrôlé par le programme
Dimensionnement	
Taille des éléments	1,0 mm
Simplification du maillage	Non
Taux de croissance	Par défaut (1,50)
Capturer la courbure	Oui
Taille minimale de courbure	1,0 mm
Taille maximale	Par défaut (2,0 mm)
Angle normal de courbure	Par défaut (60,0 °)

Figure IV.5.7. Mesh settings

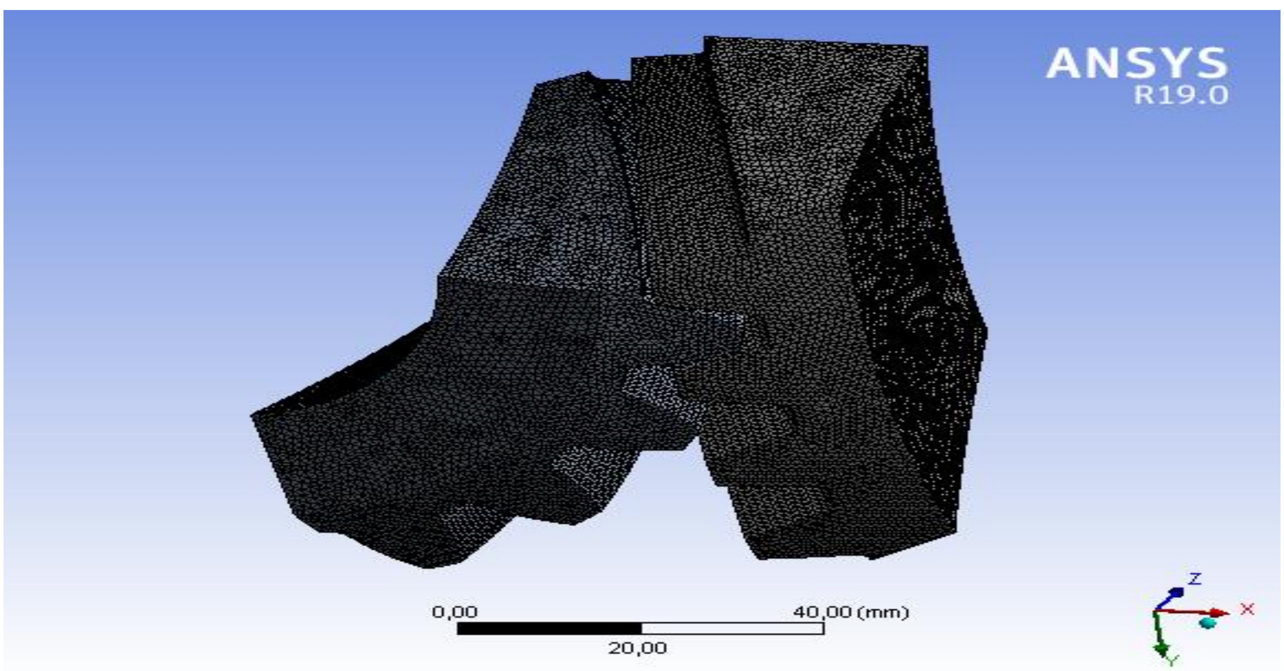


Figure IV.5.8. The mesh

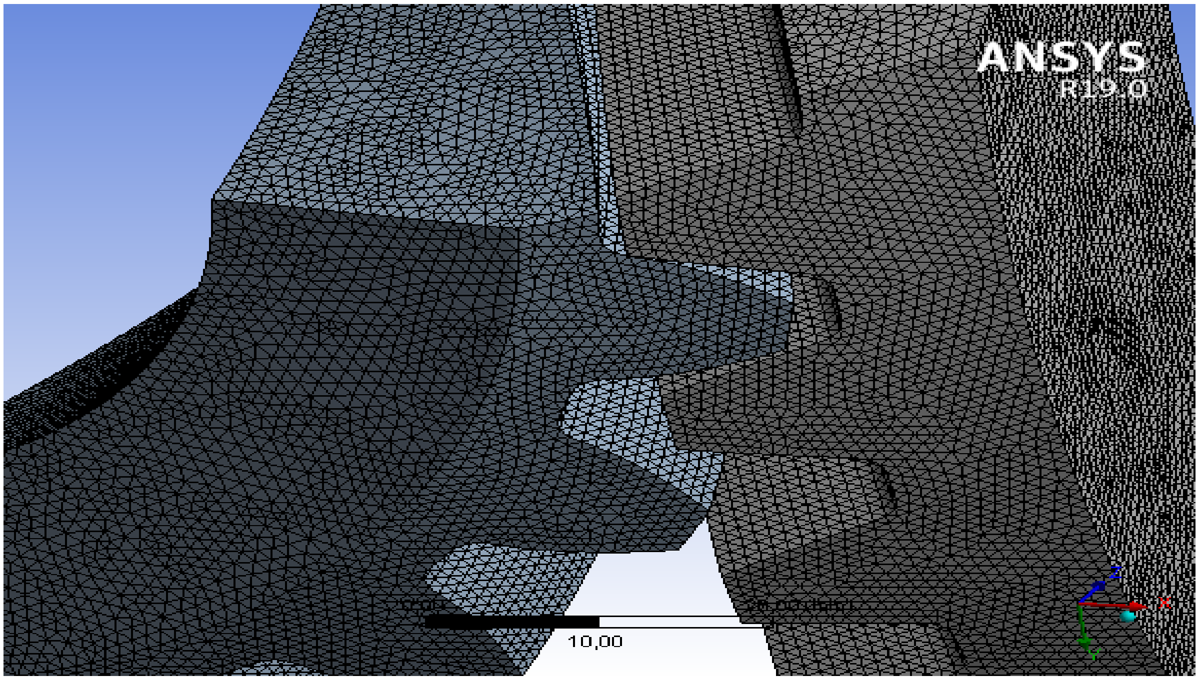


Figure IV.5.9. Zoom on the mesh

- To find out the number of elements and nodes, click on statistics in the details window of the mesh.

Statistiques	
Nœuds	609185
Eléments	411302

Figure IV.5.10. Mesh Statistics

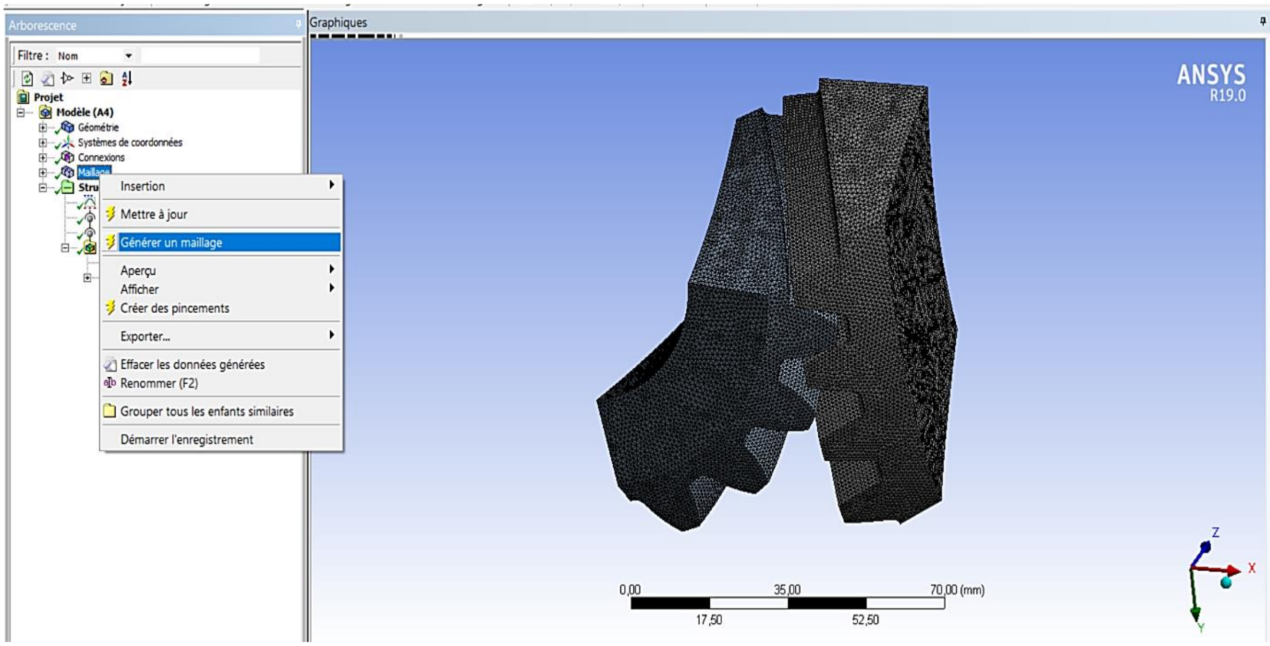


Figure IV.5.11. Generate a mesh

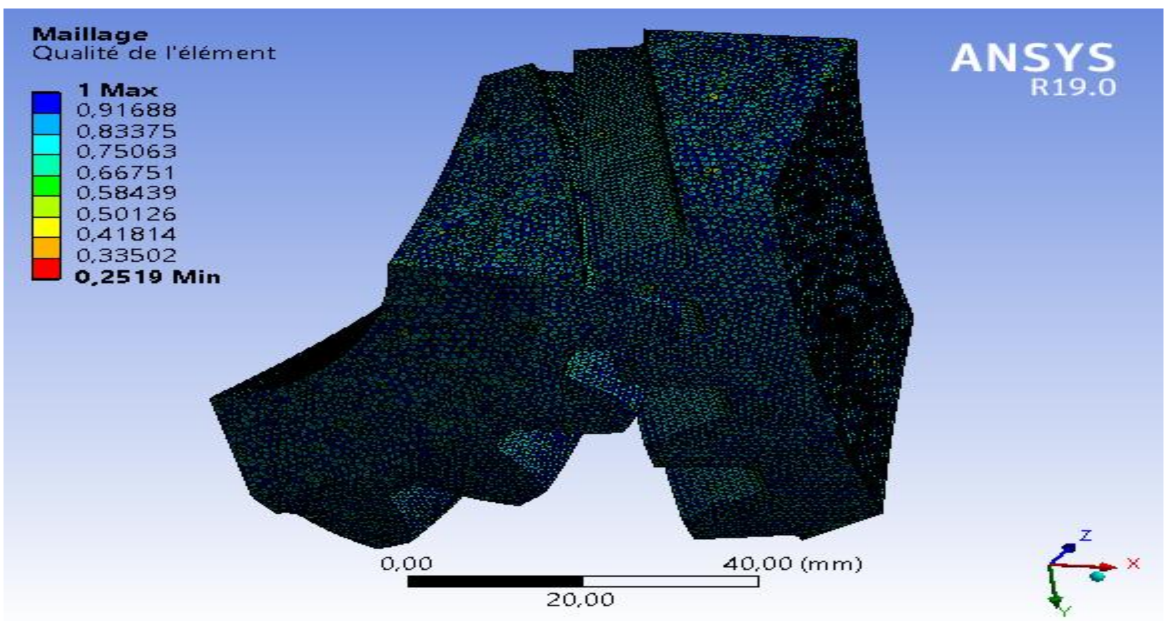


Figure IV.5.12. Mesh quality

Joints:

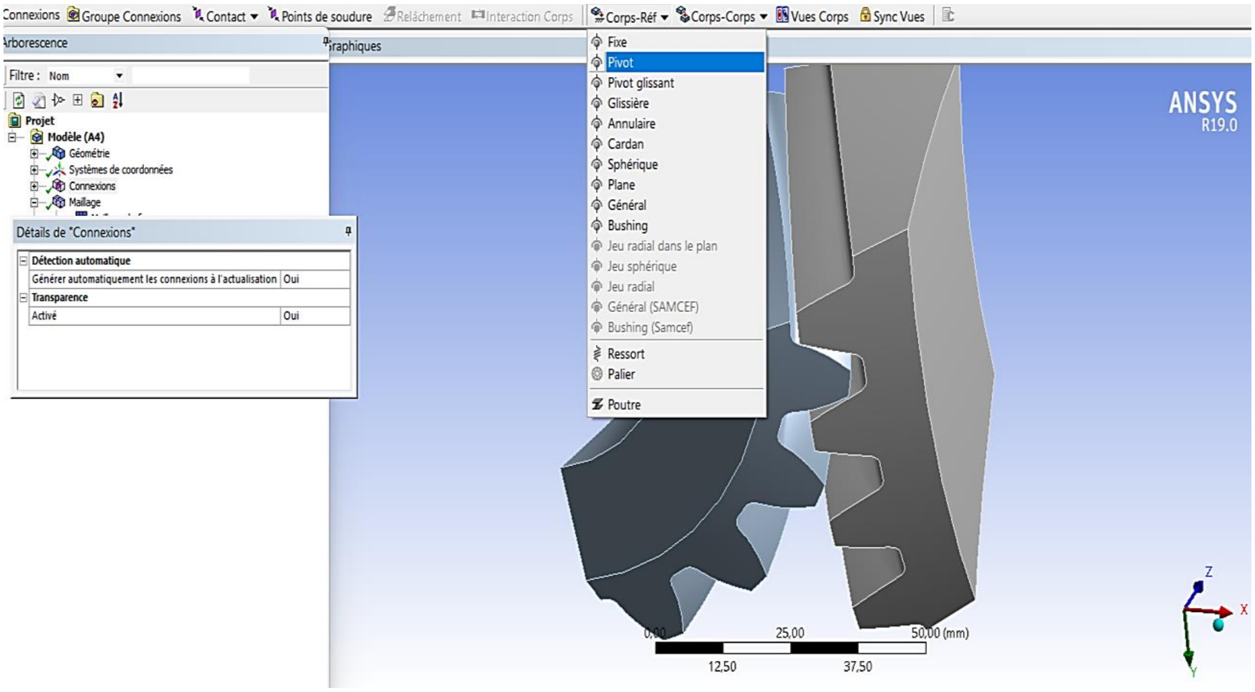


Figure IV.5.13. Applied loads

Détails de "Liaison - Rotation"

Champ d'application	
Liaison	Pivot - Référentiel à Bevel01 X36
Définition	
DDL	Rotation Z
Type	Rotation
Intensité	60, ° (exprimé sous forme de rampe)
Blocage à l'incrément de chargement	Jamais
Désactivé	Non

Figure IV.5.14. Setting of rotation load on revolute Joint

Détails de "Liaison - Moment"

Champ d'application	
Liaison	Pivot - Référentiel à Bevel02 X36
Définition	
DDL	Rotation Z
Type	Moment
Intensité	3,1381e+006 N·mm (exprimé sous forme de rampe)
Blocage à l'incrément de chargement	Jamais
Désactivé	Non

Figure IV.5.15. Setting of moment load on revolute Joint

Détails de "Réglages de l'analyse"

Contrôles d'incrément	
Nombre d'incréments	1,
Incrément courant	1,
Temps final pour cet incrément	1, s
Incrément de temps automatique	Activé
Défini par	Temps
Incrément de temps initial	5,e-002 s
Incrément de temps minimal	5,e-002 s
Incrément de temps maximal	5,e-002 s
Contrôles du solveur	
Type de solveur	Contrôlé par le programme
Ressorts de faible raideur	Désactivé
Vérification du pivot du solveur	Contrôlé par le programme
Grand déplacement	Activé
Equilibre dynamique	Désactivé

Figure IV.5.16. Analyses settings

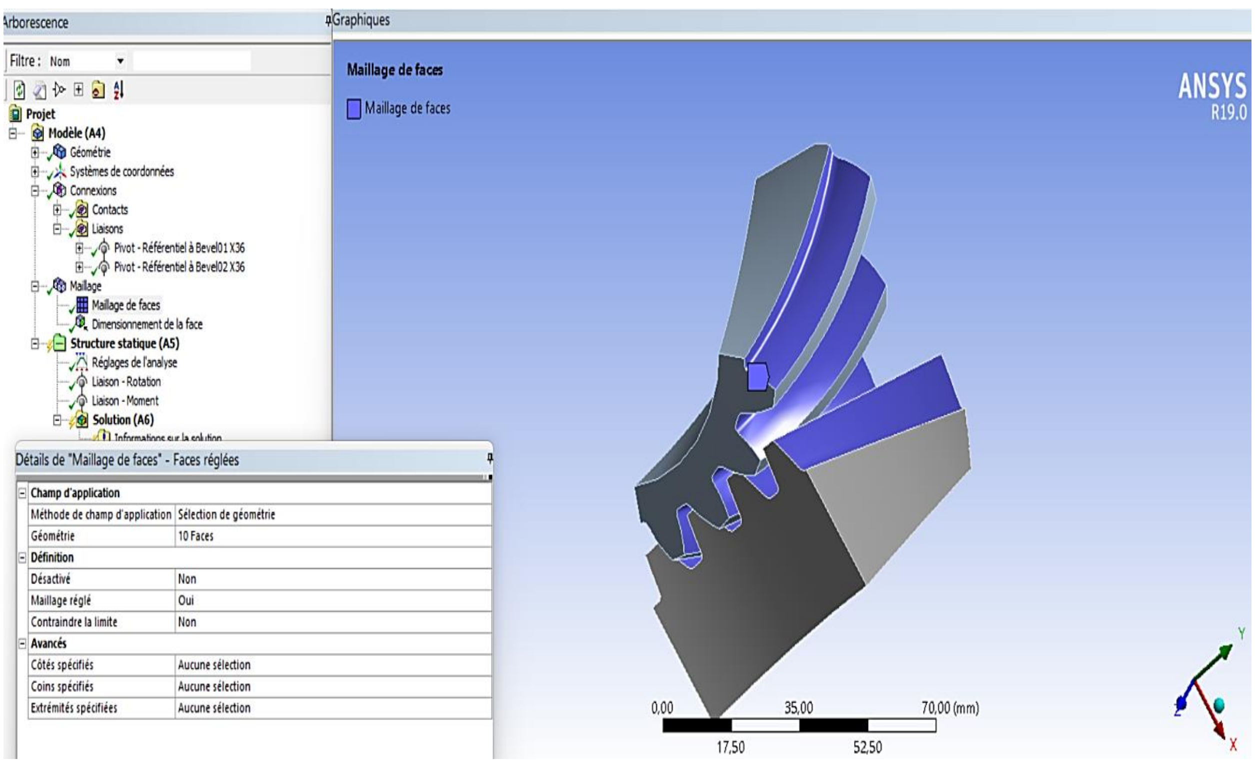


Figure IV.5.17. Setting of mapped face meshing

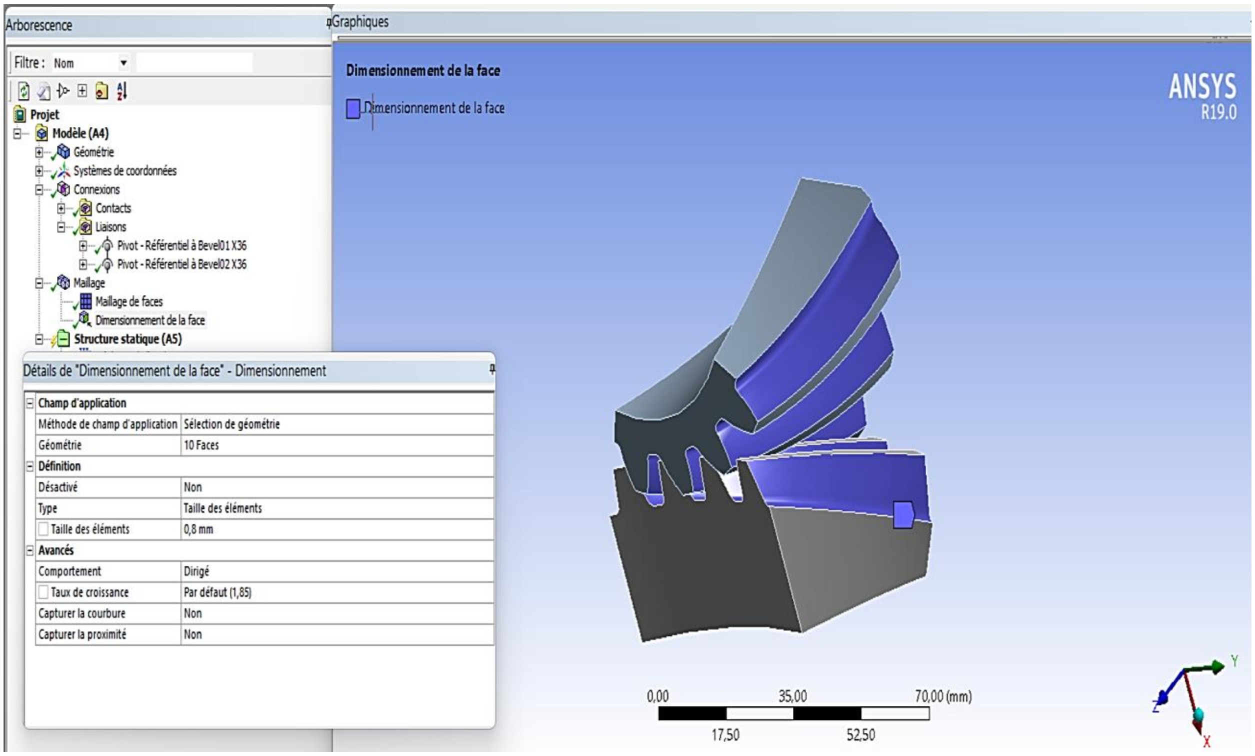


Figure IV.5.18. Sizing settings

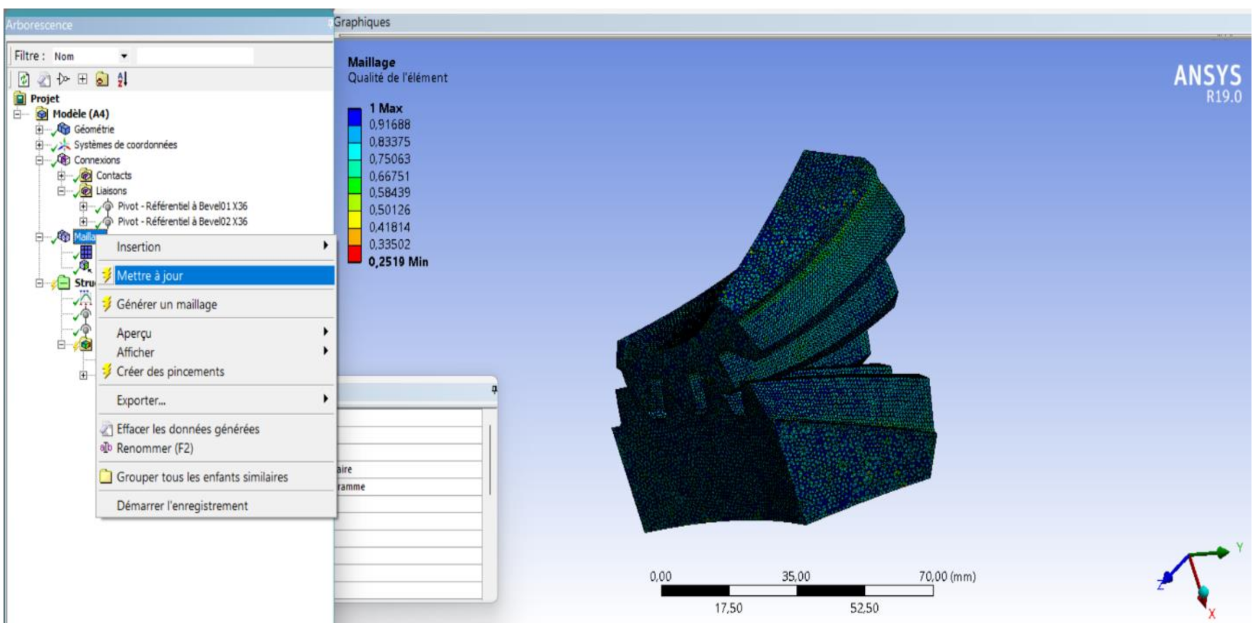


Figure IV.5.19. Updating the mesh

IV-6/ Results:

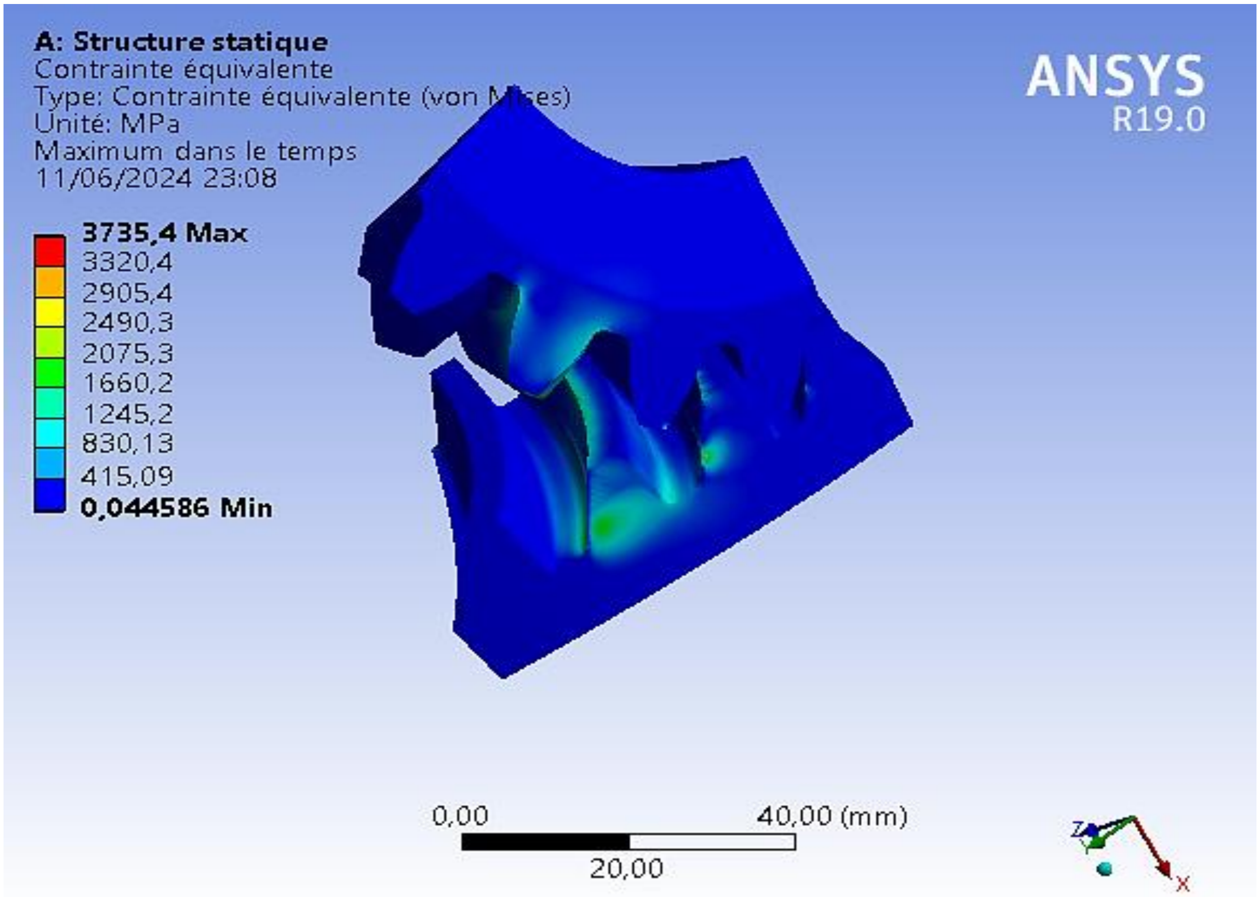
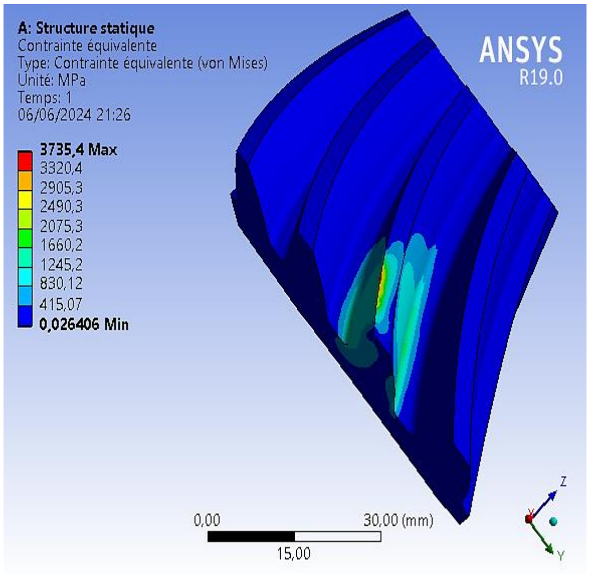
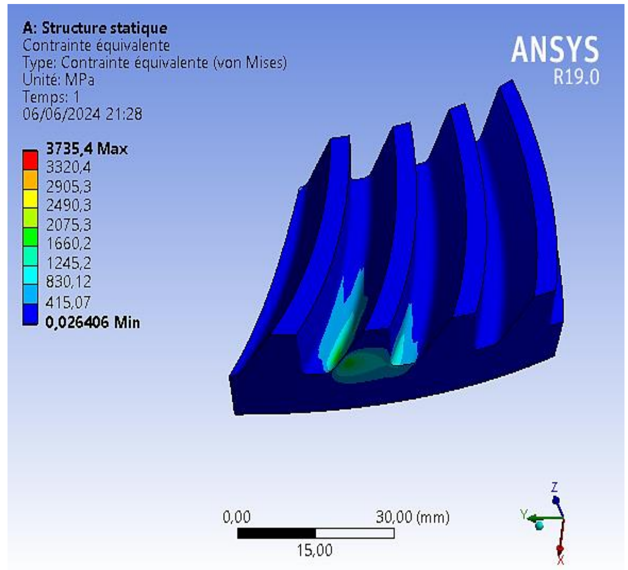


Figure IV.6.1. Equivalent strain (Von Mises)





a) Pinion **b) Wheel**

Figure IV.6.2. Equivalent strain (Von Mises)

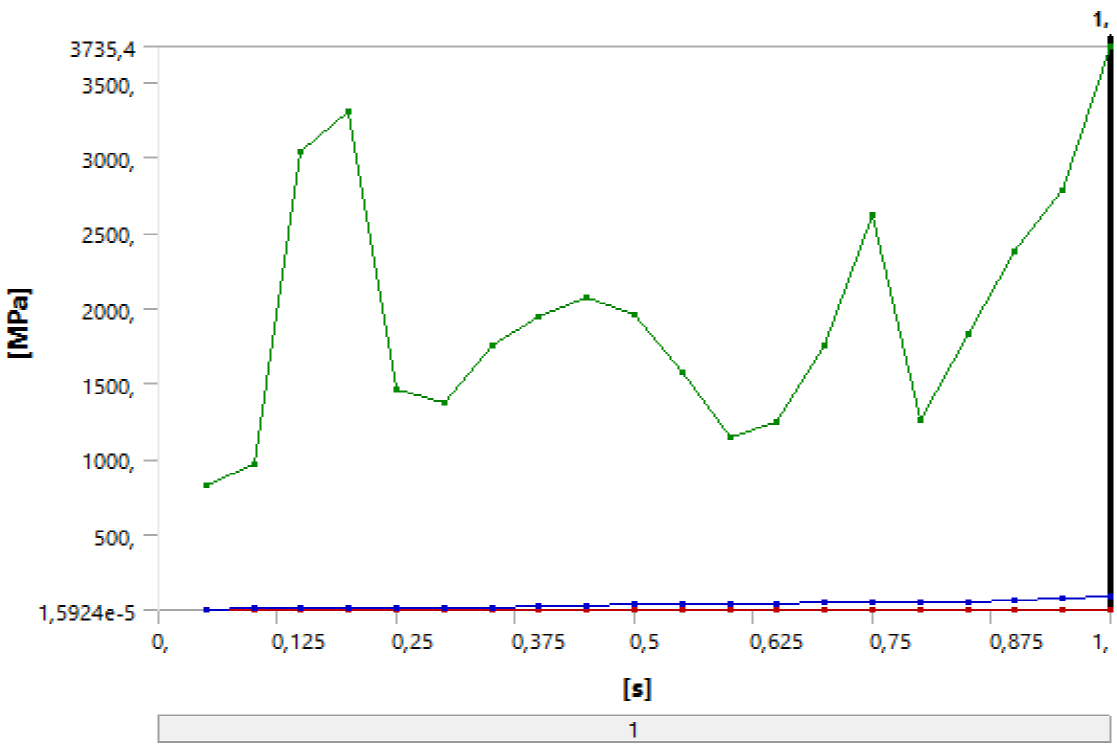


Figure IV.6.3. Equivalent strain graph

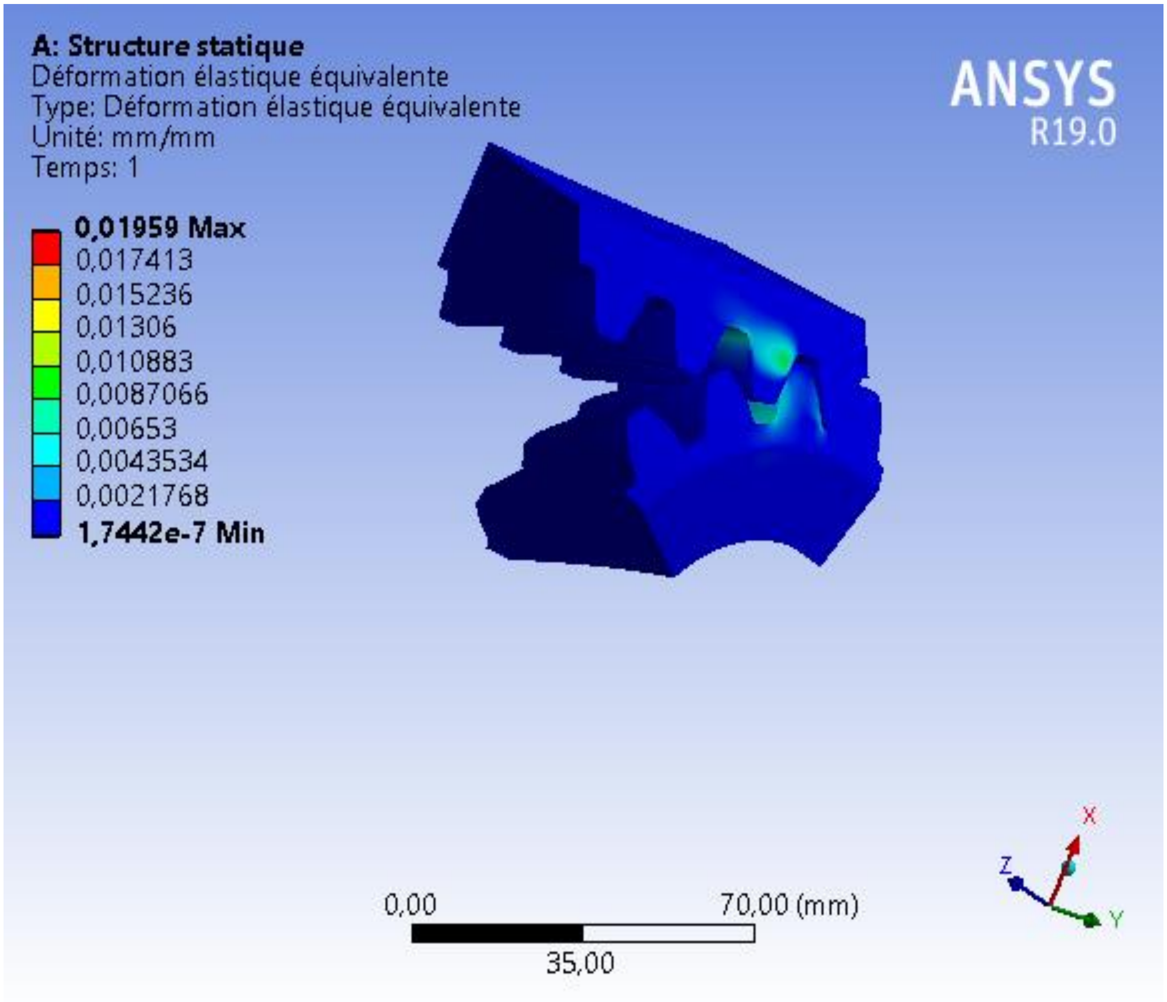
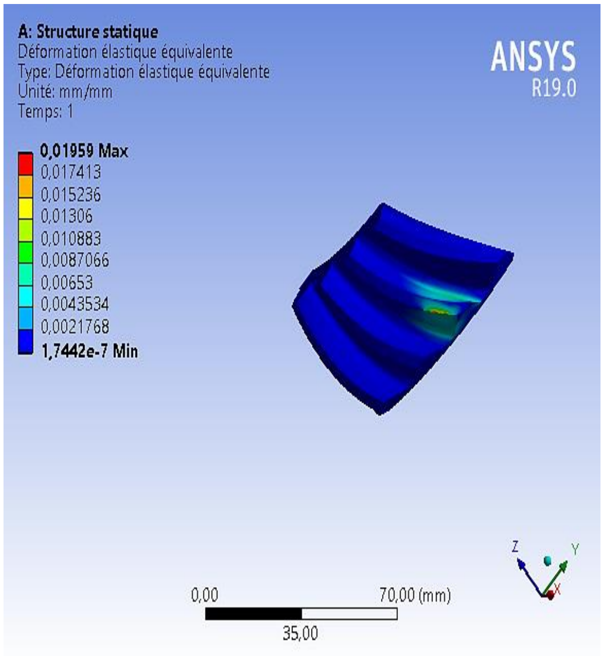
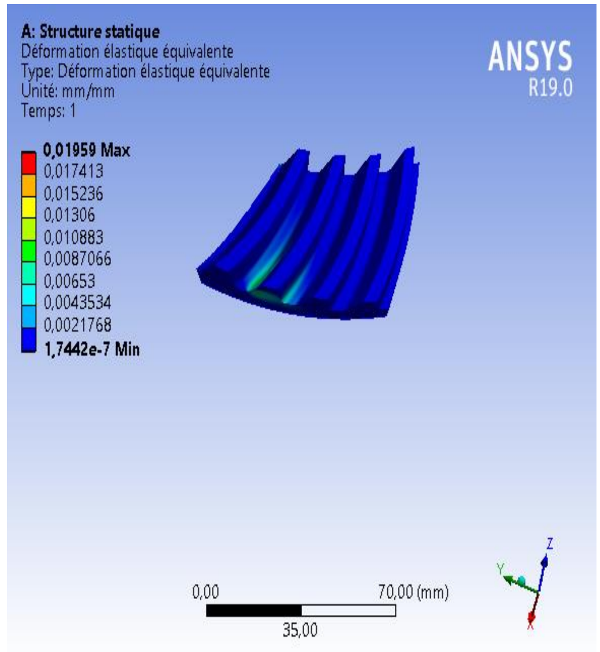


Figure IV.6.4. Equivalent elastic deformation



a) Pinion



b) Wheel

Figure IV.6.5. Equivalent elastic deformation

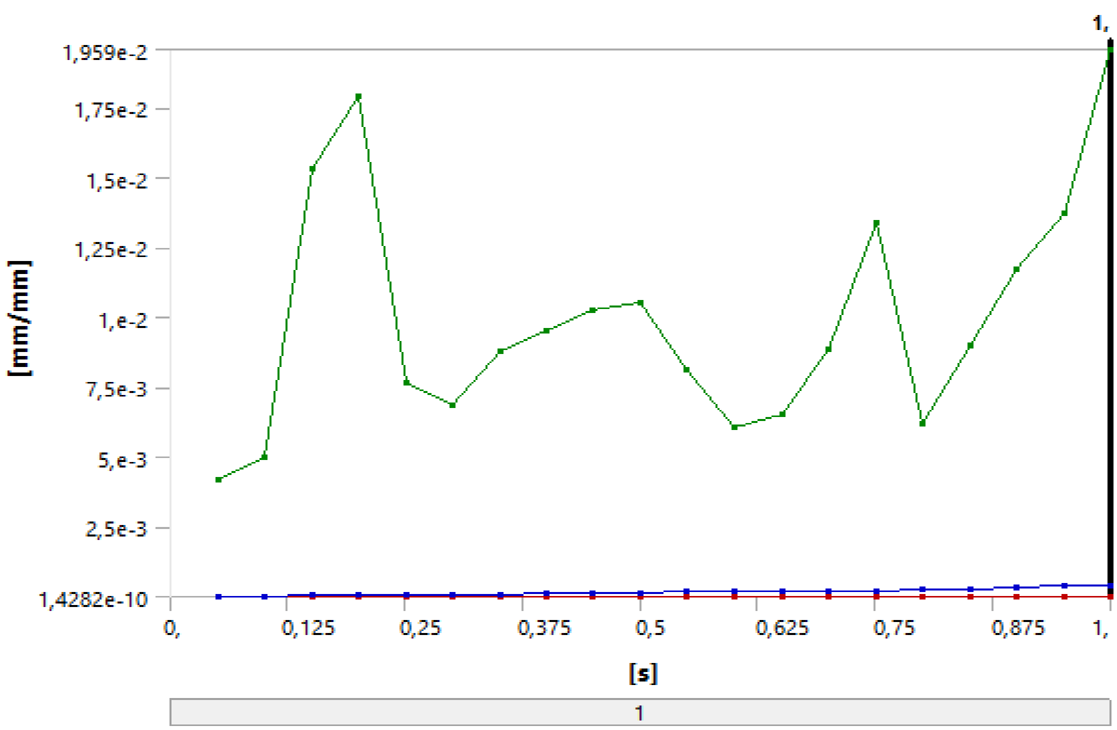


Figure IV.6.6. Equivalent elastic deformation graph

General Conclusion

General Conclusion :

During our study, we calculated the different elements making up the final gear reducer, comprising spiral bevel gears, by appealing to notions of the resistance of materials and mechanical construction. The different options and tips presented are the result of a study based on criteria that improve the safety and profitability of the different components that make up the final gearbox. Through this work, we have deepened our knowledge in a scientific and technical discipline, which is design. Ultimately, this work allowed us to improve our skills. More precisely, and thanks to this work, we have acquired the following skills:

- Complete mastery of SolidWorks software,
- learn to use calculation with the finite element method using ANSYS software,
- learn how to research a specific topic, and evaluate available references.

Bibliography

Bibliography:

[1] M.A. Khattak. (2019, January). Failure Analysis of Crashed Helicopter Main Components. Journal of Multidisciplinary Approaches.

[2] Team, N. S. (2014, MAY 14). What Is a Helicopter? (Grades 5-8).

[3] Ullah, Z., Ahmad, T., and Khan, M.H. (2018). Optimal Longitudinal Controller Design for Rotor craft under Different Flight Condition. First International Conference on Emerging Trends in Engineering, Management and science. Peshawar, Pakistan.

[4] Sai Pradyumna Reddy Gopavaram, J. S. (2019, July 2). Aerodynamic Investigation of Double Wedge Supersonic Airfoil. International journal of engineering research and technology.

[5] Schafer, J. (1980). Helicopter Maintenance (éd. subsequent).

[6] Kelly Azinge, C. C. (2020). Modernizing the AH-64 Tail Rotor. A regional Conference of the Society of Industrial and Systems Engineering. West Point, New York, USA.

[7] *Helicopter Transmission System*. (s.d.). Retrieved from: Aircraft Systems Tech: https://www.aircraftsystemstech.com/p/transmission-system.html?expand_article=1

[8] Anasune, A. (2022, Dec 05). *Gears: Types, Classification, and Applications*. Retrieved from:

https://medium.com/@aditya.anasune20/gears-types-classification-and-applications-ff549a7d4e5a

[9] Mechtex. (2024, April 04). *What are Spur Gears? | Types, Benefits and Applications*. Retrieved from: https://mechtex.com/blog/what-are-spur-gears-types-bemefits-and-applications

[10] Tom, M, (s.d), Pignon de haute précision de conception OEM pour Hubbing 45 degré pignon à denture hélicoïdale. Retrieved from:

https://fr.made-in-china.com/co_huanball-rubber/product_OEM-Design-High-Precision-Gear-Hubing-45-Degree-Helical-Gears_royniyhgg.html

[11] Sotoodeh, K. (2021). *Prevention of Actuator Emissions in the Oil and Gas Industry.*

[12] Simmons, E. (2020). WHAT ARE PINION GEARS? WHAT ARE THEY USED FOR? *koreindustries*.

[13] *APPLICATIONS*. (s.d.). Retrieved from: https://bevelgearsindia.com/applications/

[14] Black, A. (2007). Worm Gears Explained. *Machinery Lubrication*.

[15] TRANSMISSION, P. (2020, SEPTEMBER 22). *Everything to Know About Worm Gears and the Benefits of Collaborating With A Manufacturer*. Retrieved from:

https://premium-transmission.com/blog/everything-to-know-about-worm-gears-and-the-benefits-of-collaborating-with-a-manufacturer/

[16] Candy Controls, N. (2021). Hypoid Gears – A Long Way from Truck Axles to Motion Control.

Tech Briefs.

[17] Zhygear. (2023, August 4). *Applications of Hypoid Gears in Heavy Machinery and Industrial Systems*. Retrieved from:

https://www.zhygear.com/applications-of-hypoid-gears-in-heavy-machinery-and-industrial-systems/

[18] General revision guide of the final gear reducer (MI-171) of the establishment (E.R.M.AERO).

[19] Radzevich S P 2012 Dudley's Handbook of Practical Gear Design and Manufacturing, CRC Press.

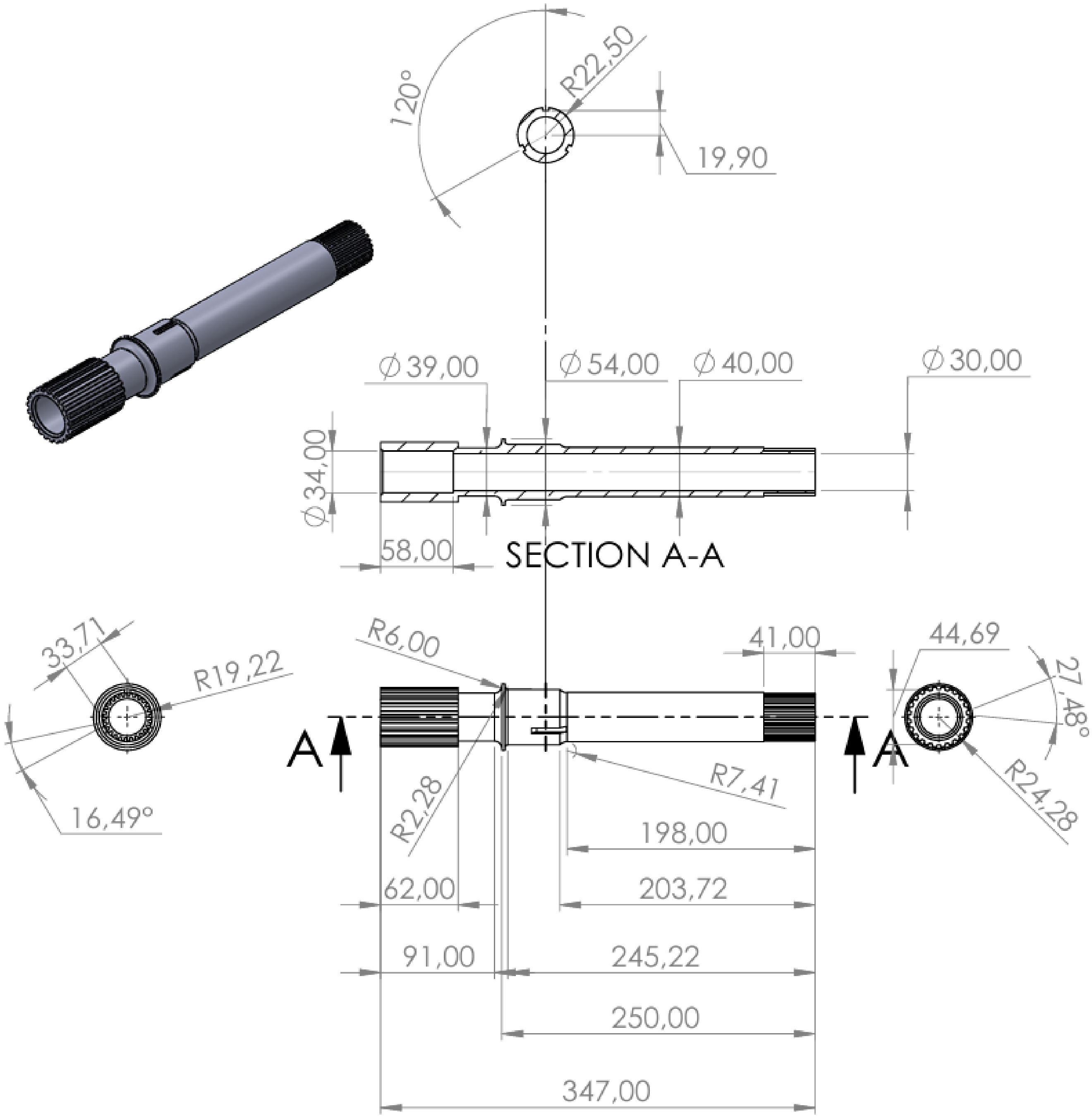
[20] Géorges Henriot, <<ENGRENAGES,Conception.Fabrication.Mise en œuvre>>,8e édition, Etude Dynamique, Efforts sur les dentures.

[21] D. Sadek KOBZILI. CONTRIBUTION A L'OPTIMISATION DES PROCESSUS DE

CONCEPTION DES ENGRENAGES SPIRO-CONIQUES. PhD thesis, Ecole Militaire Polytechnique, 2024.

[22] Inc ANSYS. ANSYS Mechanical User's Guide. ANSYS, 2017.

Appendix



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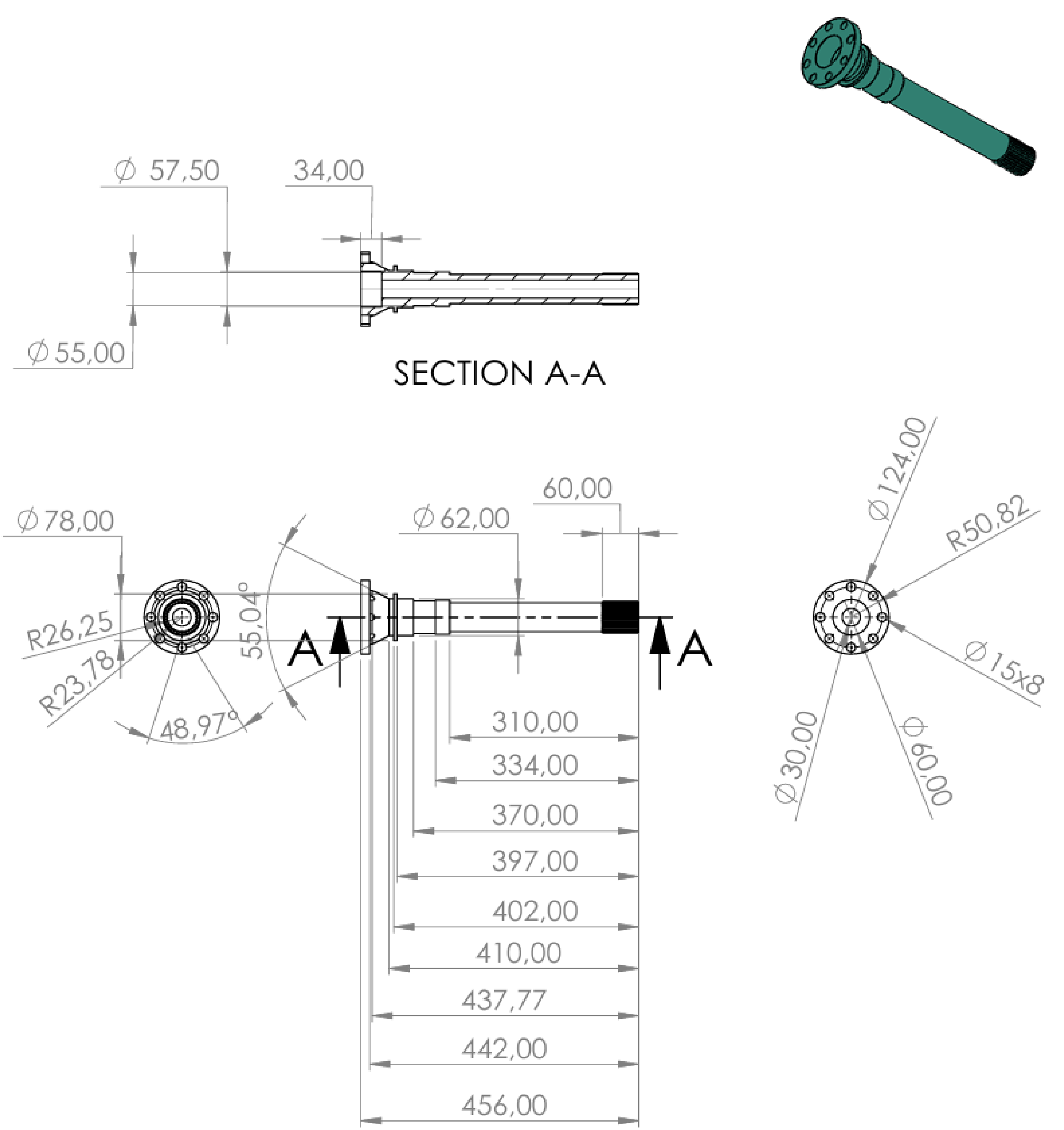
FORMAT: A4	DRIVE SHAFT	DESIGNED BY: HAMIDACHE SORAYA



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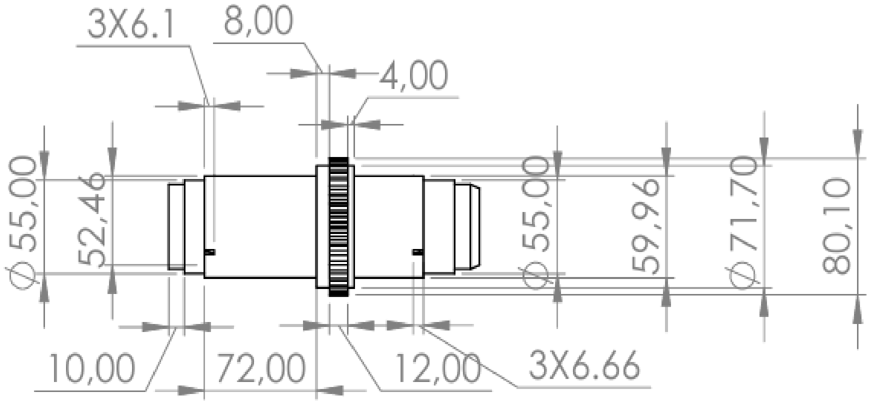
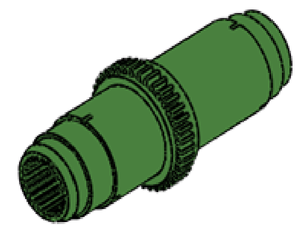
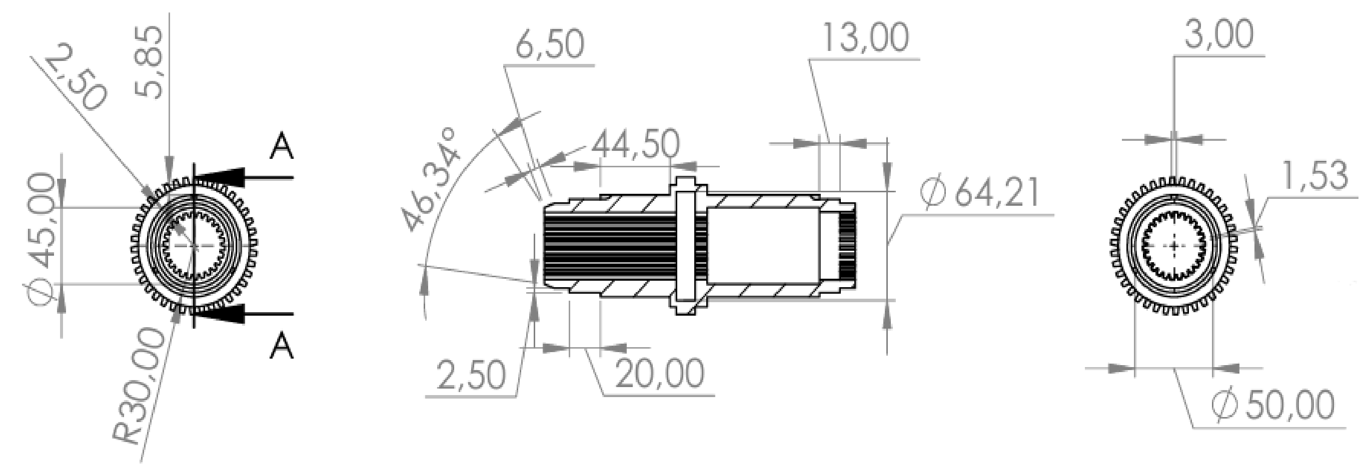
FORMAT: A4	DRIVEN SHAFT	DESIGNED BY: HAMIDACHE SORAYA

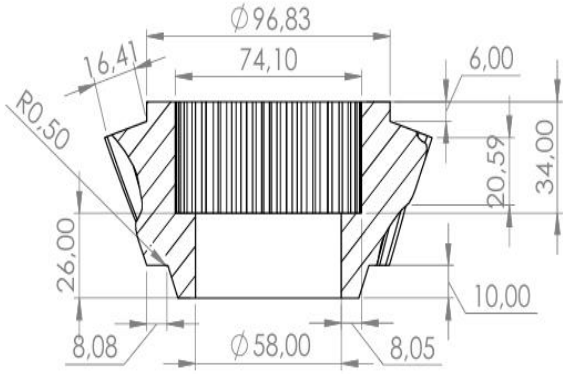




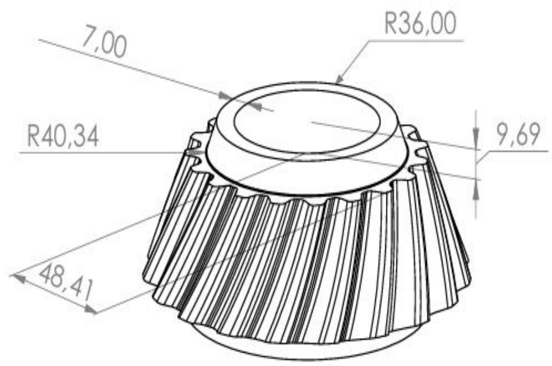


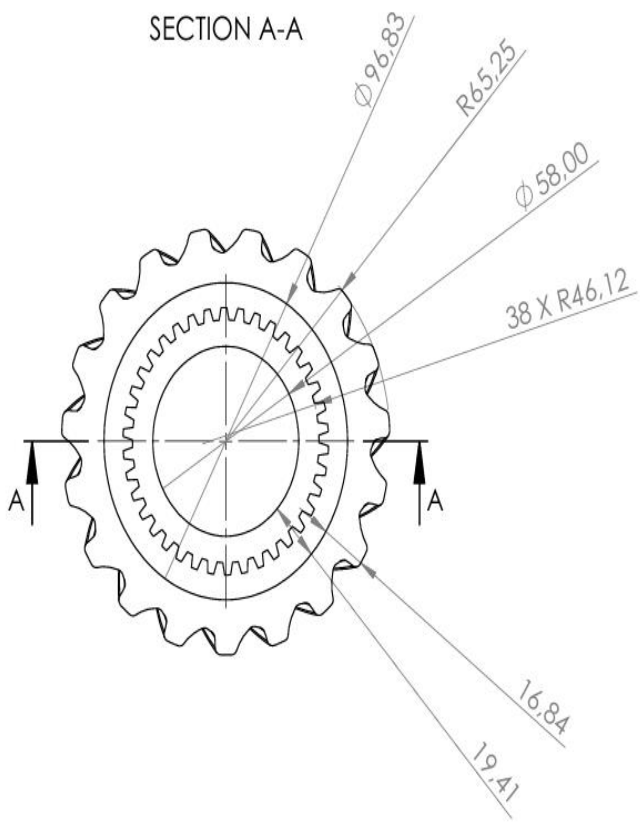
SECTION A-A

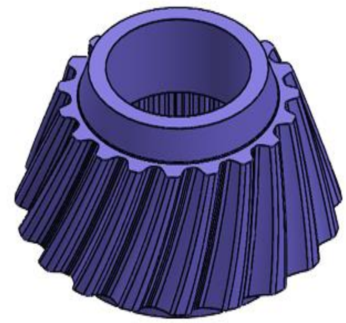
SCALE: 1:5	UNIVERSITY OF SAAD DAHLEB BLIDA 1	DATE: 21/05/2024
FORMAT: A4	DRIVE PINION SHAFT	DESIGNED BY: HAMIDACHE SORAYA



SECTION A-A







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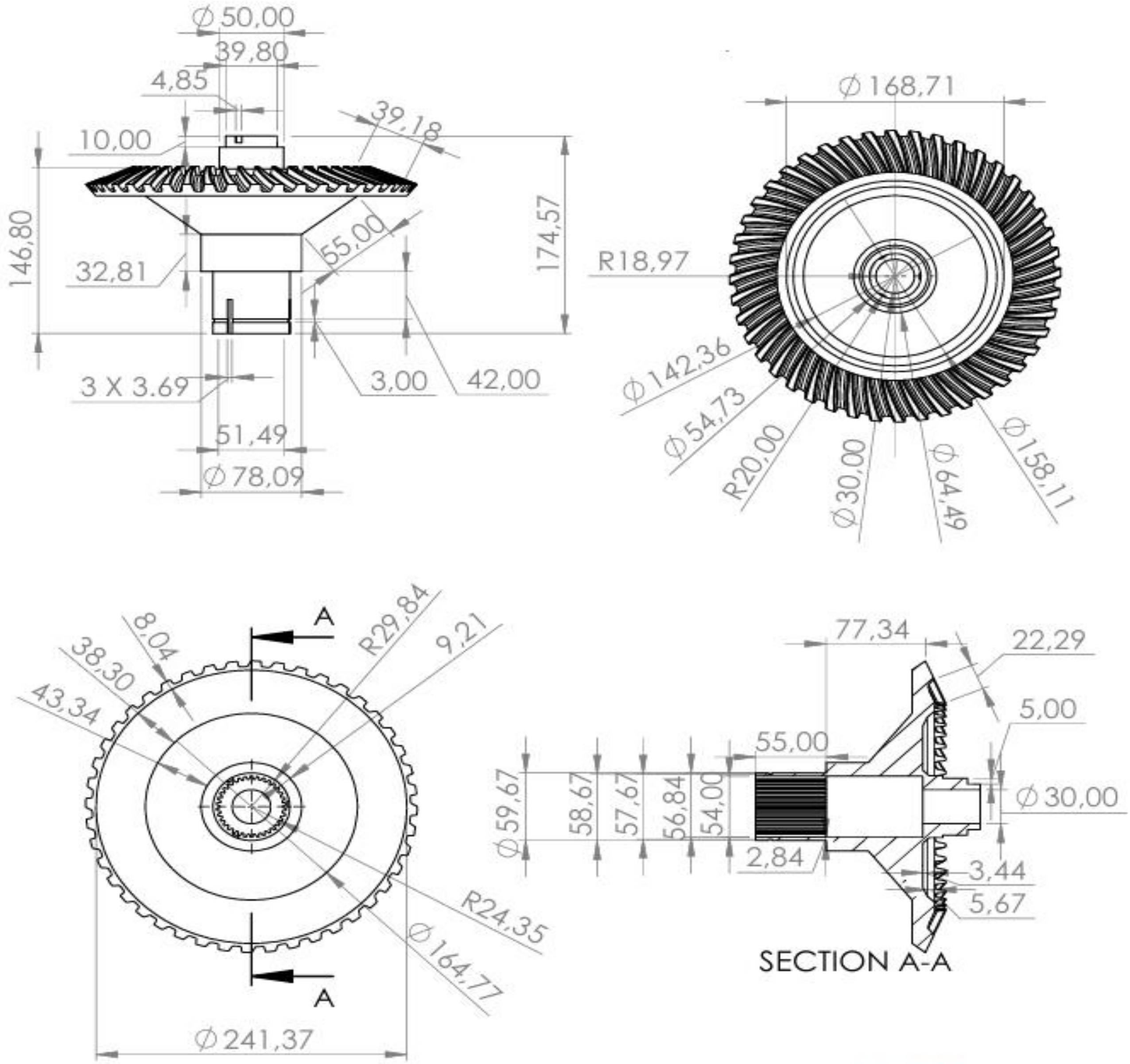
FORMAT: A4	PINION	DESIGNED BY: HAMIDACHE SORAYA



SCALE: 1:5	UNIVERSITY OF SAAD DAHLEB BLIDA 1	DATE: 21/05/2024
FORMAT: A4	WHEEL	DESIGNED BY: HAMIDACHE SORAYA