Design and Development of Automatic Gun Barrel Cleaning SPM

Major Project Report

Submitted in partial fulfillment of the requirements for the degree of **Master of Technology in Mechanical Engineering (Design Engineering)**

By

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This is to certify that

1. This thesis comprises my original works toward the degree of Master of Technology in Mechanical Engineering (Design Engineering) at Nirma University and has not been submitted elsewhere for a degree.
2. Due acknowledgment has been made in the text to all material used.

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ABSTRACT

This abstract introduces the design and development of a specialized 155mm gun barrel cleaning machine, employing a novel approach utilizing a worm gear assembly to achieve forward and backward motion, coupled with rotating wire brushes for effective particle removal. The accumulation of copper and carbon particles within gun barrels poses significant challenges to artillery system performance and longevity, necessitating an efficient cleaning solution.

Our cleaning machine employs a unique mechanism wherein a worm gear assembly facilitates controlled forward and backward motion along the length of the barrel. This motion ensures comprehensive coverage of the barrel interior, reaching areas typically inaccessible by conventional cleaning methods. Rotating wire brushes attached to the mechanism effectively dislodge and remove copper and carbon deposits, aided by the motion provided by the worm gear assembly.

The design prioritizes simplicity, reliability, and ease of operation, making it suitable for deployment in diverse field conditions. By leveraging mechanical principles and minimizing reliance on complex automation, our solution offers a cost-effective and practical approach to gun barrel maintenance.

Experimental validation demonstrates the machine's efficacy in thoroughly cleaning the barrel interior, enhancing weapon performance, accuracy, and service life. This innovative development represents a significant advancement in artillery maintenance technology, offering a versatile and efficient solution for cleaning 155mm gun barrels in military and defense applications.

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Acronyms

SPM	Special purpose machine
DOF	Degree of Freedom
FOS	Factor of Safety
MPa	Mega Pascal
N	Newton
BC	Boundary Condition
SWL	Safe working load
s_{ut}	Ultimate tensile strength
s_{yt}	Ultimate yield strength
σ_t	Tensile strength
σ_c	Compressive strength

Chapter 1 Introduction

1.1 History

The National Guard armor company was outfitted with M-48 A5 tanks in the mid to late 1980s. When conducting gunnery training that required using the main gun—which wasn't often because 105 ammo was pricey and the closest tank range was eight hours' drive away from armory—the crew had to use a massive bore brush that was dipped in a special type of bore cleaning oil and held on a long staff. This required them to jam the bore down and then pull out. To ensure that the bore was clean, that normally needed to be done multiple times

Figure 1. 1 manual barrel cleaning process [1]

1.2 Automatic Barrel Cleaning SPM

Specifically, the cleaning and washing of an Internal Surface of a gun barrel is performed in such way that a brush is fixed to one end part of a connecting rod, and the reciprocating operation of the connection rod into the gun barrel removes stuck Substances remaining in the gun barrel after firing. This cleaning process requires lots of hands and men power, and thus takes too many hours to clean. Automatic barrel cleaning is used for internal surface cleaning of battle tank gun bore the gun barrel after 300 rounds of firing in battel field.

The steel brush at the end of a long pole that is physically inserted down the barrel several times by multiple people is the current way of cleaning the barrel. Perfect cleaning was never possible with this manual procedure because of its linear movement, especially when it came to the tilted structure inside the rifled barrels. Even in this manner, barrel damage is significant.

Numerous factors, including the amount of labor available and time constraints, may affect the quality of cleaning, reducing accuracy and longevity and raising the possibility of misfiring and explosions.

The performance of the barrel may be impacted by manual cleaning in settings like practice, NBC, radioactive, night combat, and high activity regions. Proper cleaning is necessary to guarantee ideal operating circumstances.

Soo sung Defense Industries' automatic bore cleaning is the solution to these issues.

Figure 1. 2 Automatic Barrel Cleaning SPM [3]

1.3 Types of Automatic Gun Barrel Cleaning Machine:

There many types of barrel cleaning machine according to their working process they are categories as below:

a. **Rotary Brush**: This type of rotary brush barrel cleaning machine has only one operation, which is to provide rotary motion to the brush. Those brush helps to clean the internal surface of gun barrel of tank. This process takes lots hours to clean a single barrel.

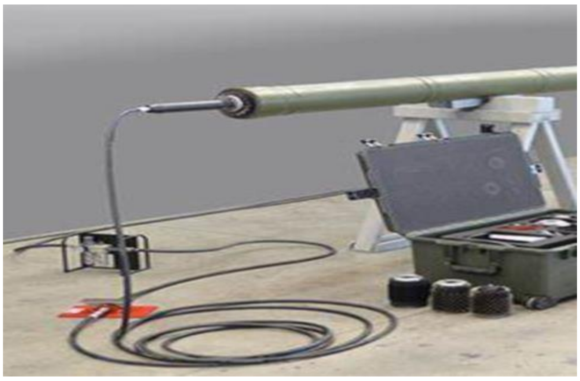

Figure 1. 3 Rotary Brush [4]

b. **Pneumatic based:** in this type of design, Manufacturing and supply of barrel cleaning Machine

(Hydraulic) consisting of power pack, hydraulic linear actuator, electric prime mover, brush head items and accessories & frame mountings. Specific use of the machine is for cleaning the barrels of the tank gun by reciprocating motion generated by hydraulic linear actuator and controlled by proximity switches.

The power pack is to be driven by single phase AC motor. Cleaning brush will be attached at the end of the pushing pole which in-turn will be connected to piston rod of the machine. As the machine has to work in desert the power pack is to be perfectly sealed for dust and dirt.

Figure 1. 4 wire brush & Pneumatic machine [5]

c. **Foam Based**: foamed cleaning liquid. The cleaning agent composition contains tensides as well as alkanol-amide and/or nitrate salt as an agent for removing shell residue. Alkanol-amides have proved to be better agents for removing copper residue, and nitrate salts for removing zinc residue. In some cases, this technique significantly reduces the need for mechanical cleaning process, but especially in the case of large-caliber guns, mechanical cleaning is still requires.

Figure 1. 5 Foam based cleaning process [6]

1.4 Tank Gun Barrel

History: Gun barrels are usually made of some type of metal or metal alloy. However, during the late Tang dynasty, Chinese inventors discovered gunpowder, and used bamboo, which has a strong, naturally tubular stalk and is cheaper to obtain and process, as the first barrels in gunpowder projectile weapons such as fire lances.

Construction: A gun barrel must be able to hold in the expanding gas produced by the propellants to ensure that optimum muzzle velocity is attained by the projectile as it is being pushed out.

Working: Rounds are loaded into the chamber. A primer ignites a larger charge, which then creates really high pressure behind the projectile. The projectile leaves the barrel travelling high speed. Industries are adopting and evolving more and more to get the maximum output with less time, so they adopt this method quite frequently making this process their priority.

The way a tank gun barrel works is dependent on a number of important factors pertaining to ballistics principles, design, and operation. This is a synopsis:

1. **Design of Barrel**:

Length: In order to maximize projectile acceleration and raise muzzle velocity, tank gun barrels are typically lengthy.

Rifling: The majority of tank barrels are rifled, which means that they have spiral grooves inside of them that give the projectile a stabilizing spin and increase accuracy.

2. **Filling and Lighting**:

Loading Mechanism: Manual or automatic loading mechanisms are commonly seen in tanks. In contrast to manual systems, which need the crew to load each round, autoloaders load the next round into the breach automatically after they fire.

Breech Mechanism: The rear of the barrel, where the round is loaded, is known as the breech. To keep the explosive force inside, it is sealed while firing.

Firing Mechanism: To start the propellant in the cartridge, tanks use firing mechanisms like electrical igniters or firing pins.

3. **Armaments**:

Projectile: The tank gun's actual projectile was discharged. It could be another type of specialized round, a high-explosive shell, or a kinetic energy penetrator (a solid metal rod).

Propellant: The projectile is propelled out of the barrel by a chemical mixture that, when ignited, generates a significant amount of gas.

4. Ballistics:

Muzzle velocity is the bullet's speed when it exits the barrel. The shot's accuracy and range are largely dependent on the muzzle velocity.

Projectile trajectory is affected by a number of variables, including gravity, aerodynamics, projectile weight, and muzzle velocity.

Ballistic coefficients: These factors influence the projectile's flight path by indicating its drag and stability properties.

5. **Backlash**:

Recoil Mechanism: The force produced by a tank firing causes it to recoil. To regulate and control this recoil, tanks are equipped with recoil devices, such as hydraulic systems or recoil buffers.

6. **Precision and Focusing**:

Fire Control Systems: To enhance accuracy when the tank is in motion, advanced fire control systems are fitted to tanks. These systems include stabilizers, ballistic computers, and rangefinders.

Gun Stabilization: To reduce the impact of the tank's movement on the gun's accuracy, certain tanks are equipped with gun stabilization systems.

7. Maintenance:

Barrel Wear: Constant shooting can wear down the barrel, which will compromise accuracy. To guarantee peak performance, routine inspections and maintenance are required.[7]

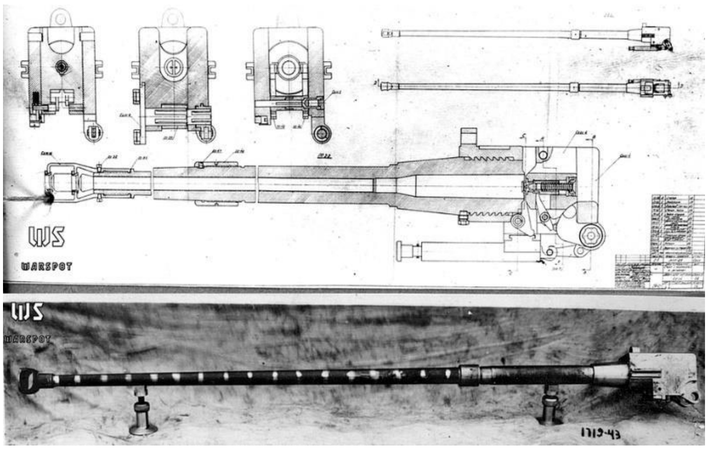

Figure 1.6: barrel components [7]

1.5 Types of tank gun barrel

There are several varieties of tank barrels, each intended for particular uses and tastes. The main difference between barrels for tank guns is whether they are smoothbore or rifled. The primary categories are as follows:

Design: The projectile spins as it goes down a rifled barrel because spiral grooves are carved into the inside of the barrel. By stabilizing the bullet while in flight, this spin increases accuracy.

Common Calibers: 120mm and 125mm are common calibers for rifled tank barrels.

Design: Rifling on smoothbore barrels is not present on rifled barrels. The production process is made simpler and easier to load fin-stabilized projectiles due to the lack of rifling.
Benefits: Smoothbore barrels are good for shooting fin-stabilized kinetic energy penetrators and are frequently linked to higher muzzle velocity.

Typical Calibers: 120mm and 125mm are typical calibers for smoothbore tank barrels. Designs that combine elements of both Certain tank barrels have hybrid designs that combine the best aspects of smoothbore and rifling. With these designs, the benefits of both systems—like higher precision and simpler loading are intended to be achieved.

Experimental Electromagnetic Railguns: Electromagnetic railguns for use as tank weapons are still being researched and are not yet commonly used in operating tanks. Instead of using traditional gunpowder, these railguns shoot projectiles using magnetic fields.

1.6 Types of surface defects in barrel

For a rifle to operate safely and correctly, the surface of the barrel is essential. Accuracy, structural integrity, and general performance can all be impacted by surface imperfections. The following are some typical surface flaws on gun barrels that could arise.
Pitting: The formation of tiny, localized craters or dimples on the barrel's surface is known as pitting. Rust, corrosion, and exposure to unfavorable environmental conditions are frequently the causes.

Impact: Pitting may result in decreased accuracy and have an impact on the barrel's structural integrity.

The corrosion: Corrosion is the slow, chemical reaction that occurs when metal comes into contact with moisture and salt in the environment.

Impact: The performance of the barrel might be negatively impacted by extreme cases of corrosion, which weaken the metal and cause pitting or rusting.

Rust: The reddish-brown layer that appears on iron or steel surfaces when they are exposed to moisture and oxygen is called rust.

Impact: Rust may adversely affect accuracy and jeopardize the barrel's structural integrity. Rust can be avoided with routine cleaning and appropriate storage.

Description: Blockages in the barrel may be caused by foreign objects or debris. This can include fouling, dirt, or the remains of earlier rounds.

Impact: Blockages in the bore can cause hazardous malfunctions, such as the barrel bulging or bursting when the gun is fired.

Description: Projectile passage repeatedly abrades the interior of the bore, causing erosion. It may cause the bore diameter to gradually increase.

Impact: Over time, erosion can exacerbate barrel wear and compromise accuracy. Description: A number of things, such as stress, fatigue, or manufacturing flaws, can cause cracks to appear on the barrel's surface.

Impact: The structural integrity of the barrel may be jeopardized by cracks, which presents a serious safety risk. It's critical to find cracks early on and fix them.

Fouling: The term "fouling" describes the build-up of residue—such as metal deposits and burnt powder inside the barrel following firing.

Impact: If excessive fouling isn't cleared on a regular basis, it might reduce accuracy and raise chamber pressure.

1.7 Preamble

A tank gun barrel cleaning machine's preamble would normally describe the equipment's main functions, scope, and objectives. It functions as a concise introduction to the tank gun barrel cleaning machine document or presentation. As an illustration, consider this:

Introduction to Tank Gun Barrel Cleaning Equipment

To ensure that armored vehicles with powerful tank guns continue to function at their best and remain safe, it is important to design a sophisticated Tank Gun Barrel Cleaning Machine. This state-of-the-art technology is evidence of the dedication to superior military equipment upkeep. The Tank Gun Barrel Cleaning Machine has been carefully crafted to fulfill the vital requirement of cleaning tank gun barrels in an effective and comprehensive manner. Its main goals are to prolong the barrels' life, improve fire accuracy, and reduce the possibility of malfunctions brought on by corrosion, fouling, or other surface flaws.

Scope: This paper outlines the Tank Gun Barrel Cleaning Machine's complete functionalities, design requirements, and operational parameters. The scope includes a comprehension of the machine's capabilities and applications from its user-friendly interface to the details of the cleaning process.

Important characteristics: Automated Cleaning Processes: To minimize human interaction and increase efficiency, the machine uses cutting-edge automation to optimize and streamline the cleaning processes.

Adaptive Cleaning Techniques: Making use of cutting-edge technologies, the machine modifies its cleaning methods to target particular surface flaws including pitting, corrosion, and fouling, guaranteeing a comprehensive and specialized approach.

Safety Procedures: To protect operators and minimize any possible risks related to the cleaning process, the equipment is designed with strict safety procedures in place.

Compatibility: The apparatus is designed to accommodate a wide variety of tank gun barrel diameters, offering flexibility and adjustability to different armored vehicle setups.

Part of mechanism

1. Worm gear: It is a rotation rolling element bearing that typically supports a heavy load.
2. Gear Motor: It is combination of gear box and AC motor.
3. Bevel gear: Transfer the Rotational Motion into Linear Motion.
4. Gear cover: The purpose of this is to assist with the installation of a Slewing Ring for rotational movement and also to provide support for heavy loads.

5. Structural parts: Frame is a structural part for the supporting and mounting foundation forall parts of the mechanism.

6. Supporting Parts: Collars, Bushes are Spacers are main parts to connect linkages with eachother.

1.8 Problem Definition

Tank gun barrel cleaning is a crucial maintenance process that keeps military tanks operating at their best and lasting a long time. The remnants that build up inside the gun barrel after rounds are fired include carbon deposits, propellant fouling, and other impurities. The tank's weaponry's accuracy, range, and overall effectiveness may be negatively impacted by these residues.

Creating a cleaning solution that effectively gets rid of these residues while putting the least amount of strain on the gun barrel itself is the difficult part. Military activities may face logistical issues due to the labor-intensive and time-consuming nature of traditional cleaning methods. Inadequate cleaning can also result in decreased muzzle velocity, increased barrel erosion, and degraded ballistic performance.

In order to solve this issue, a thorough grasp of the chemical and physical characteristics of the residues is needed, in addition to creative engineering solutions for the creation of cleaning systems that are both practical and efficient. In order to maintain the tank's firepower's accuracy and dependability in a variety of operational scenarios, the solution must strike a compromise between the necessity of a complete cleaning and the realistic limitations of military field settings. For armored troops to operate as effectively as possible on the battlefield and to maintain military readiness, an effective tank gun barrel cleaning procedure must be developed.

Objectives of this project

- To develop the concept of a minimum time required to clean barrel.
- To Design the compact & reliable machine.

- To Analyze the designed accordingly FEA results.

1.9 Methodology

A methodical and comprehensive approach is used in the design of a tank gun barrel cleaning machine to guarantee effectiveness, dependability, and compliance with military operational specifications. A thorough method is outlined in the steps that follow: after doing this.

Analysis of Requirements: Specify your cleaning goals: Give specific instructions on how the tank gun barrel must be cleaned.

Recognize the operating limitations: Think about things like compatibility with different tank models, portability, and ease of use in the field.

Reliability Evaluation: Analyze residues in great detail: Determine the kinds of residues that are commonly discovered in tank gun barrels so that the cleaning procedure can be adjusted appropriately.

Examine the adhesion of residues: Recognize how residues stick to the barrel's surface while choosing a cleaning technique.

Compatibility of Materials: Examine barrel material: Take into account the gun barrel's substance to make sure that the cleaning procedure won't deteriorate or harm the structural integrity of the barrel.

Choosing a Cleaning Mechanism: Examine cleaning techniques: Examine and compare several cleaning methods, such as solvent flushing, brushes, and cutting-edge technology like ultrasonics.

Aim for efficiency through optimization: Select a technique that will remove residue effectively while causing the least amount of barrel wear possible.

Robotics & Automation: Think about automation: Investigate integrating robotics or automation to reduce the need for manual labor and achieve consistent, effective cleaning.

Create interfaces that are easy to use: Make sure that military personnel in the field can easily use and maintain the equipment.

Design for Portability: Give portability first priority: Build the cleaning apparatus with portability and compatibility for various tank models and setups in mind.

Think about weight and size: Optimize the weight and size to satisfy military deployment specifications.

Talk about environmental issues: Select cleaning solutions that meet military specifications and are safe for the environment.

Reduce problems with garbage disposal: Create a system that allows cleaning residues to be disposed of properly without harming the environment.

Test the prototype: Put the cleaning machine through a rigorous testing process in both simulated and actual environments.

Obtain comments: Get input from military personnel so that the design can be improved and refined based on real-world user experiences.

Records and Instruction: Write instruction manuals for users: Provide thorough operating, maintenance, and troubleshooting documentation for the cleaning machine.

Give instruction: Teach military personnel how to operate and maintain the cleaning equipment properly.

Iterative Enhancement: Gather performance information: Keep an eye on the cleaning machine's performance in the field and gather information for further development.

Iterative design: Address any problems or potential improvements by using data and feedback to iteratively improve the design.

1.10 Thesis Organization

The entire thesis consists of 5 chapters

Chapter 1 gives the brief introduction of project, objective and methodology.

Chapter 2 is all about the literature review.

Chapter 3 Conceptualization and Ideation.

Chapter 4 will explain the results and discussion, further explain the future scope. List of reference is presented at the end.

Chapter 5 Results and Discussion.

Chapter 2 Literature review

2.1 Introduction

Automatic tank barrel cleaning machines are sophisticated pieces of equipment designed to maintain and clean the interiors of tanks, particularly those used in industrial, military, and manufacturing settings. These machines are engineered to perform thorough and efficient cleaning processes, often without the need for manual intervention, thereby ensuring consistent hygiene and operational standards while enhancing safety and efficiency.

Blaža Stojanović1,Aleksandar Vencl.[1] The most significant factor affecting efficiency is the kind of material used in the meshed gears. The worm gearbox efficiency varied from 0.51-0.62 for the worm gear pair 42CrMo4/ZA12 to 0.45-0.57 for the worm gear pair 42CrMo4/A356, accounting for various operating conditions. The values of the worm gearbox's efficiency with the worm gear pair 42CrMo4/ZA12 are greater by 9% to 13% when compared to the previous worm gear pair, depending on the load level and circumferential speeds of the gears. In comparison to the 42CrMo4/A356 worm gear pair, the 42CrMo4/ZA12 worm gear pair has superior efficiency, which results in fewer power losses in the gear mesh between 16% and 24% and lower friction coefficient values between 25% and 34%.

Congqing LI1, Shijie DAI.[2]The ZW-1 material used in worm gear provides enough resistance to fracture under static load. Twenty-three times as much load can be supported by the Archimedes ZW-1 worm gear as by the bronze worm gear (Q/ZB125-73). The anti-fracture capability of Archimedes worm gear is equal to that of Arc tooth worm gear. As a result, ZW-1 material is an excellent replacement for bronze in worm gear.

Đorđe MILTENOVIĆ, Milan TICA,[3] Worm shaft bending is prevented and wear safety is increased by shortening the worm shaft bearing's distance.

Worm tooth width decrease.

The worm gear's tooth breakage limitation increases noticeably at mx s. Nothing about the other restrictions changes with it.

Wear and tooth breakage are limited by changes in pressure angle. Increases the pitting limits to a lesser extent. However, concurrently raises the worm shaft's load

By substituting pressure lubrication for splash lubrication and implementing the other previously indicated adjustments, load capacity satisfies every requirement. The pitting limitation represents an exception, wherein the pitting safety marginally deviates from the limit values. Regarding this a method by which load capacity can be increased by 50%.

Edward. E. Osakue1 , Lucky Anetor.[4] It can be seen from the three design examples that this method produces highly favorable comparisons between the contact and root bending stress results.

AGMA outcomes. Likewise, there is a tight match between the approximations derived during design verification using the AGMA approach and the corresponding values for the mesh overload, internal overload, and service load for design sizing.

As a result, the initial spur gear design seems to have used a reasonable design strategy. Gurkan IRSEL.[5] Based on tooth root bending and contact stress, the analytical gear calculation techniques DIN 3991: 1988, ISO 10300: 2001 Method B, and AGMA 2003 B97 make their calculations. Despite the fact that analytical approaches are predicated on comparable computations, it was shown that the safety factor and characteristic parameters' numerical variable approach leads to variations in the outcomes.

Permissible gear fatigue data is not provided by ANSYS.

However, despite their differences, ISO, DIN, and AGMA offer relevant data that has been verified by experimentation using the appropriate protocols.

Timothy J. Lisle⁎ , Brian A. Shaw[6] It is challenging to incorporate axial ($k_{H\beta}$ $k_{F\beta}$) and transverse ($k_{H\alpha}$ $k_{F\alpha}$) stress-increasing elements using general-purpose, non-gear-specific FEA software like ANSYS.Kv dynamic loads are not taken into consideration.Peak load factors (KA) do not have a consideration.No data on acceptable gear fatigue is offered by ANSYS. Despite their differences, ISO and AGMA offer significant material data that has been established through experimentation utilizing their respective methodologies. The findings of this study suggest that producing safety factors by combining ANSYS stresses with ISO or AGMA material data would be erroneous.

Paras Kumara,*, Harish Hiranib[7] • The induced bending fatigue stress is higher and more uniform in single tooth contact, whereas the induced contact fatigue stress reaches its greatest value at the lowest point of single tooth contact (LPSTC). • The transmitted force and contact pressure reach their maximum values in the single tooth contact zone.Compared to case-hardened gear, the bending fatigue life of through-hardened gear (1 X 1011 revolutions) is superior. With respect to contact fatigue life, the opposite pattern is seen. 4.2 ç 106 revolutions is the contact fatigue life of case-hardened gear, which is higher than that of through-hardened gear. The single tooth contact zone has the highest risk of contact/bending fatigue failure, and contact fatigue life is less than bending fatigue life.

S.Prabhakaran1,a, Dr.S.Ramachandran.[8] Through the use of theoretical calculations and three-dimensional finite element analysis, the geometry of the spur gear of two distinct modules was compared. The outcome shows that the stress values calculated using finite element analysis and theory were safe and within the acceptable upper bound. According to both theoretical and finite element model approaches, the bending stress for steel C45 and steel 40Ni 2Cr1Mo28 is within the permissible limit. The data unequivocally demonstrates that, in comparison to Steel C45, Steel 40Ni 2Cr1Mo28 experiences a weight decrease of almost 22%. Mark Bundy, Julius Pitts[9] The new GI brush cleaning technique can clean an M256 barrel in about a third of the time, according to testing results displayed in figures 3 and 4. 20 versus 60 minutes, divided into 15 versus 30 minutes for the real brushing period and 5 versus 30 minutes for the cleaning setup period for both protocols, in turn.

The dry GI brushing procedure (as performed in this experiment) only requires one person, but an additional person may be needed to help with the post-brushing punchout and to make sure the cable does not bind. With the conventional steel brushing method, three persons are used. Kyung Hyun Nam1 Songil Lee.[10] It is also possible to lessen the possibility of an internal explosion brought on by improper gun barrel maintenance, which could result in harm to soldiers or equipment. A single soldier can swiftly and safely clean a rifle barrel thanks to the ABC method. of time. This allows artillery and tanks to be readied for firing faster. It is anticipated that the ABC system will improve military might and soldier safety.

M. A. BAKER[11] Low temperature plasmas are an efficient way to clean and etch surfaces, as demonstrated by experiments conducted on metal surfaces and carbon films. For process evaluation, a mass spectrometer proved to be an effective and sensitive tool that assisted in elucidate the methods used for plasma cleaning and etching.It is evident that chemisorbed pollutants, like bound carbon, necessitate the cautious application of plasma conditions, but physisorbed contaminants are very simple to eliminate through the action of plasma. specifically the work surface should be electrically organized in a way that allows it to be exposed to a sufficient amount of positive ions combined with a suitable reactive gas to create volatile byproducts that are simple to remove. A d.c. power supply is a practical and reasonably priced way to excite the plasma on conductive work surfaces. However, non-conductive surfaces require the use of an r.f. power source, which allows the surfaces to be negatively biased in order to produce positive ion bombardment.

Ramezanali Mahdavinejad, Mohammadreza Hatami[12] When the machined inner surface of the pipe is observed using a special camera during primary testing, the majority of them exhibit rejects and non-uniformity patterns with undesired surface quality as well as the challenges associated with gauge controlling operations. In this study, filtering and heating installation were used to alleviate these issues.

Chapter 3 Conceptualization and Ideation

This chapter consist major concept of automatic barrel cleaning process with help of new & advance SPM which is Develop & Design in such way that the SPM could get the high quality of surface cleaning with less time. The SPM consist worm gear, bevel gear, spur gear with help of these three types of gear mechanism the design of this automatic barrel cleaning SPM it has to be done.

3.1 Automatic gun barrel cleaning SPM

The main objective of designing of this SPM is to maintain the life of barrel with high accuracy & precise ammunition firing after a lot of firing. Accordingly, army protocols the army equipment & machine such as gun, tank, armors, rifles it should be in well in every condition. So the cleaning of tank gun barrel is the objective.

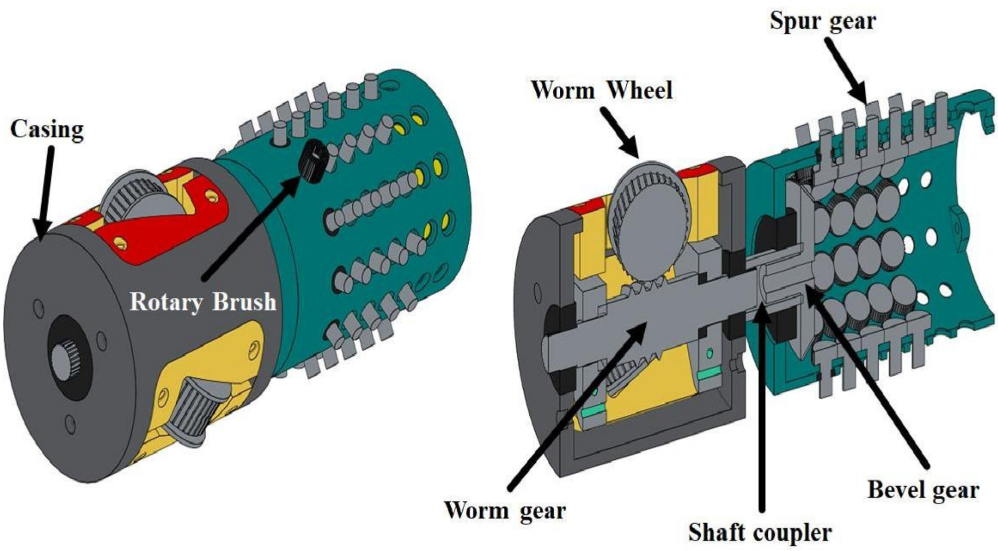

Figure 3. 1 Isometric View and Side view of automatic barrel cleaning SPM

3.2 Component wise explanation

In the ABC machine concept there are some small different and assembly included.

As follows: worm and worm wheel assembly for forward & backward motion inside the barrel. Worm gear are used to achieve high gear ratio reduction, also it provide the 90º perpendicular axis power transmission. With these advantages it is most suitable for this SPM in the case of this machine is require to get forward & backward direction motion & and that easily can get from this worm gear arrangement.

Worm gear is directly attached with the motor shaft its get power from that & due to that rotary motion worm wheel give forward & backward motion.

There are pair of adhesive wheel attached to the worm wheel which provide grip and frication to the internal surface of the barrel.

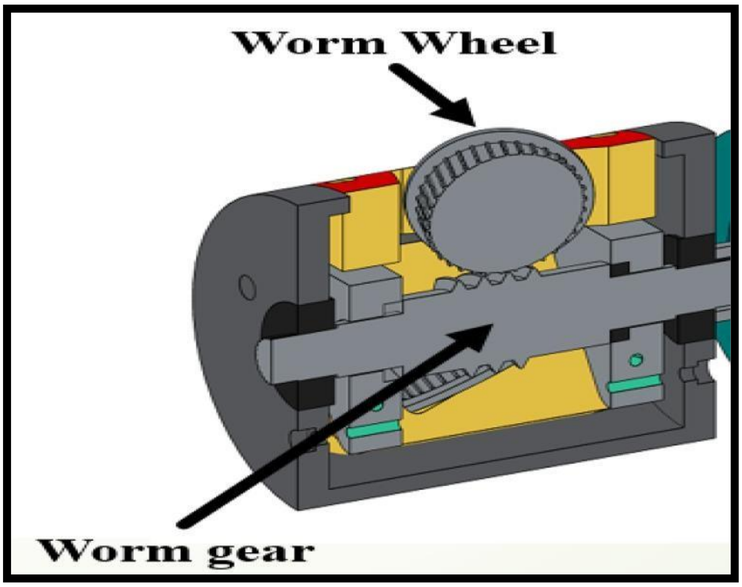

Figure 3. 2 Isometric view & cut section of worm gear assembly

Bevel gear is major part in this SPM because of it gives the rotary motion to whole brush mechanism which clean the internal grooves of the barrel. Bevel gear is connected to the worm gear with help of splined shaft coupler. It is transferring rotary motion from worm gear to bevel & spur gear which provide rotary motion further to spur gear. Bevel spur gear meshing provide the individual brush rotation according to inside spiral groove.

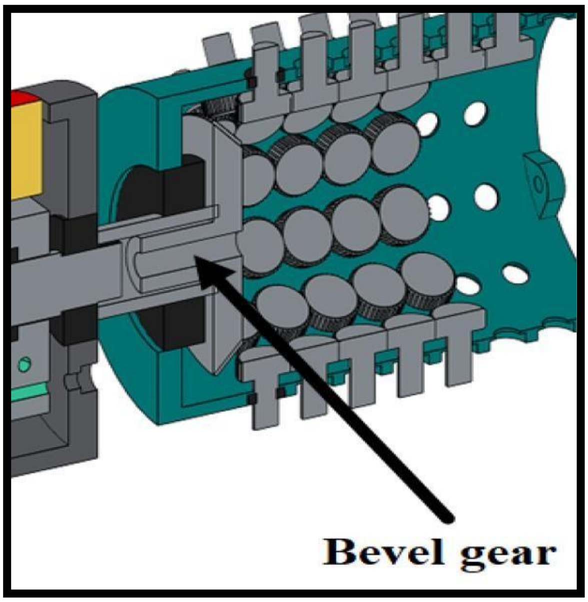

Figure 3. 3 bevel gear assembly

Spur gear assembly, in this case here two spur gear are used for transferring rotary motion from one end to another end. The spur gear which in mesh with bevel gear is combination of two gear of bevel & spur both are combine gear in which bevel gear is used for motion transfer from main bevel gear, other spur gear used for transfer power to the in other connected spur gear.

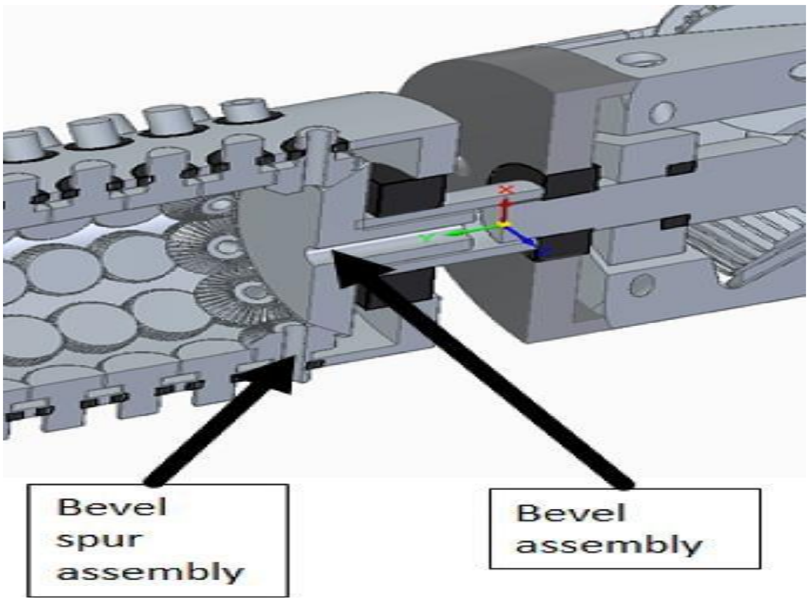

Figure 3. 4 spur bevel gear assembly

Rotary brush assembly, there is too many rotary brush provided which help to cleaning the individual spiral groove inside the tank gun barrel and the rotation is come from the circular arrangement of spur bevel gear assembly. The all brushes are connected to the spur gear with help circlips and for positive lock the bolts are also used.

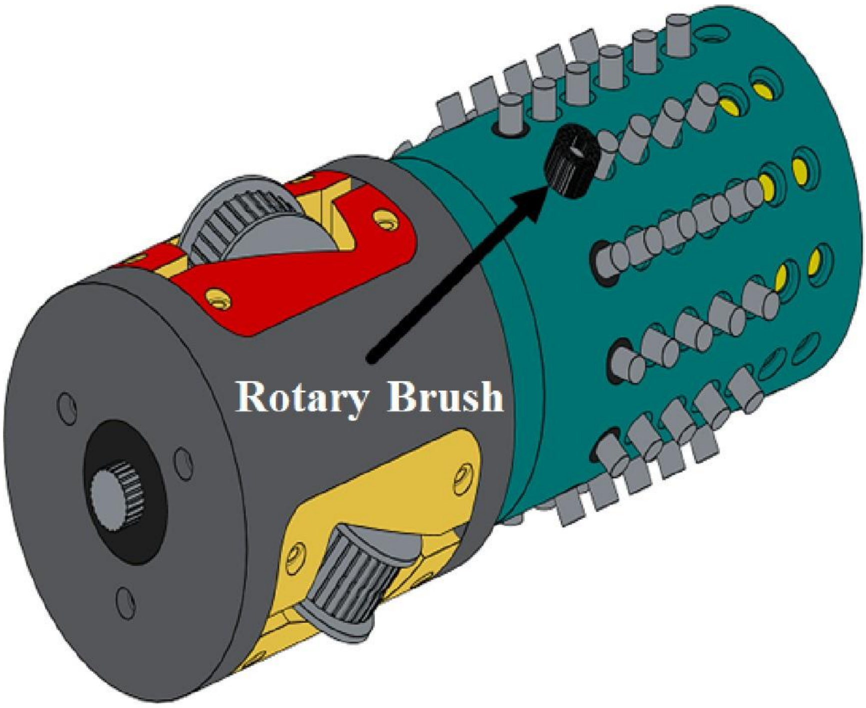

Figure 3. 5 spur bevel gear assembly

3.3 Automatic tank gun barrel cleaning SPM

This Automatic tank gun barrel cleaning SPM have many benefits over the other.

The advantage are as follows:

I. It makes process of barrel cleaning easier and faster than others.

II. No requirement of other process after using after this SPM.

III. Only one operator required for operating this machine.

IV. Cleaning rate will be higher.

V. Safety will be increased.

VI. Flexible as per different sizes of barrel diameter.

3.4 Parts used in this fixture

Worm gear casing: It is used to hold all three-worm wheel together on worm shaft.

Worm gear: It is used to transfer power from motor to the worm wheel for linear motion.

Ball bearing: to give support to the all-rotating components such as shaft, coupler & casing.
Bevel gear: it is transmitting the rotary motion which comes from worm gear to the individual spur gear.

Spur gear: that's provide the rotary motion to individual brush rotation.

Gear motor: the main power source is the gear motor which runs the whole machine.
Splined shaft coupler: For up-down and Forward-backward movement two differentlinear motion guideways are used to obtain such motion.
Circlips: those are used for to hold bearing, wheel & brush on their location.

Gear motor: used to rotate gear mechanism.

3.5 Working and Mechanism used

❖ **Step 1:** It is the initial stage of the process, for getting the forward it requires to maintain the reaction force of its own weight with help of spring which located under the all-worm gear wheel. When SPM in fits in the barrel at the starting point motor will start and which the of that power the worm wheel provides forward motion to whole SPM.

Figure 3. 6 putting SPM inside barrel

❖ **Step 2:** The next step is the same worm gear shaft will transmit power to the bevel gear shaft that bevel gear power to rotate the spur gears.

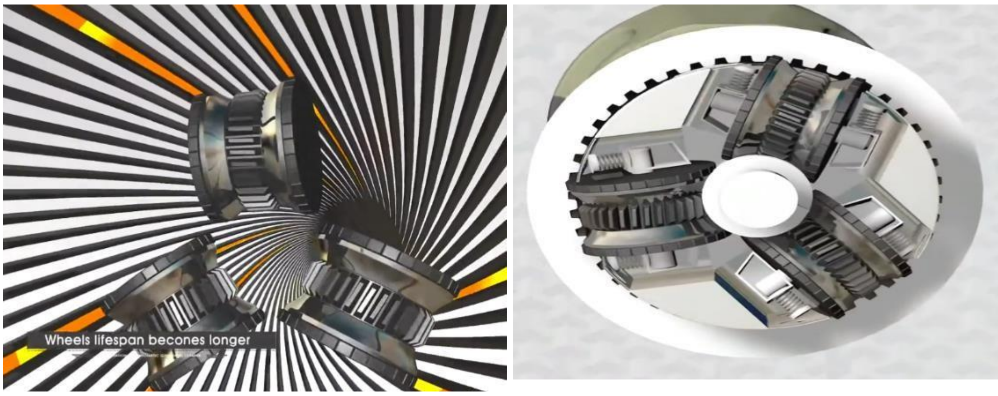

Figure 3. 7 worm gear assembly arrangement

❖ **Step 3:** The after dry cleaning step it requires to take more two steps for better cleaning there is three cleaning cycle dry, non-woven cloth with oil & lastly non-woven cloth stepwise.as shown in image brush and cotton cloth both are used as requirement.

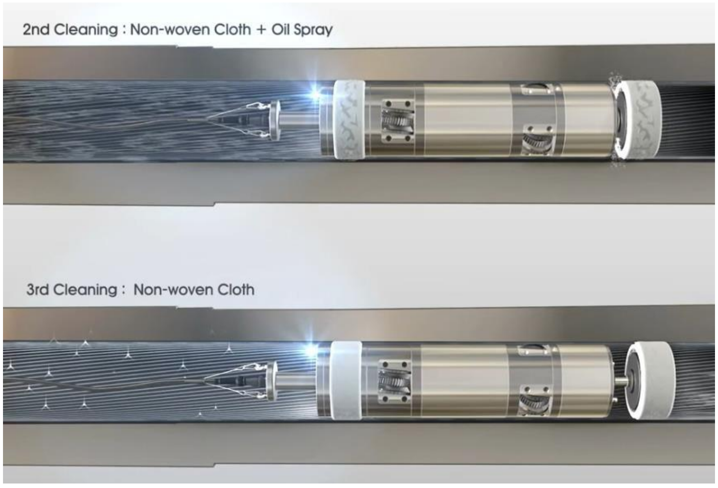

Figure 3. 8 stepwise cleaning process of SPM

Chapter 4 Design and Analysis of Automatic barrel cleaning SPM

4.1 Introduction

The automatic barrel cleaning spm will design and analyze in following steps:

- Worm gear Mechanism: the worm gear & worm shaft are designed for linear motion which provide the forward & backward motion inside the gun barrel.
- Spring Mechanism: the spring mechanism is used for to maintain the inside circumferential force to the wall of barrel to get proper grip contact of abrasive wheel on internal surface.
- Triangle plate: its provide support to the spring , whole worm assembly also lock the rotation of assembly in the casing.
- Bevel gear assembly: used for provide rotary motion the further spur gear train which are all connected to the bevel gear.
- Spur bevel gear assembly: the function of the gear one circular arrengment of gear train is only used for to connect the bevel gear to spur gear which also used for transfer power to the further individual spur gear.
- Spur gear assembly: the spur gear is connected to wire brush by the bolting and circlips and the arrangement of spur gear is designed as angle of spiral groove of barrel.
- Wire Brush assembly: the main function of wire brush is to remove the carbon and copper particle from the internal surface of gun barrel groove.

4.2 Design Procedure

Step 1: Development of scheme

Design scheme for particular purpose or need, reflect the ideas and logic used to prepare certain design which is going to be made.

Step 2: 3d Solid modelling

Once the scheme will be finalized, each part with assumed dimensions is modelled and assemble. The modelling is done on CAD software SOLID EDGE 22.

Step 3: Analytical Calculation

The model which are made may be over designed or under designed, to verify we need analytical calculation of each part. Then, further optimization of model is carried out on the basis of such calculation and update the model accordingly.

Step 4: Analysis of the model

Rigid dynamic analysis and static structural analysis are carried out using finite element analysis. For both analysis Ansys Workbench 19.2 and Siemen NX 12 is used.

4.3 Design of spur gear

1. Pitch Circle:

It is an imaginary circle which by pure rolling action would transmit the same motion as the actual gear.

2. Pitch Circle Diameter (d):

It is the diameter of the pitch circle. The size of the gear is usually specified by the pitch circle diameter. It is usually denoted by 'd'.

3. Pitch Point:

It is the common point of contact between two pitch circles.

4. Pressure Angle or Angle of Obliquity (ϕ):

It is the angle between the common normal to the two meshing teeth at the point of contact and common tangent to the two pitch circles at the pitch point. It is usually denoted by 'ϕ'.

The standard pressure angles are: 14.5", 20°, 22.5° and 25°. The most widely used pressure angle is 20.

5. Circular Pitch (p_c):

. It is the distance measured along the circumference of the pitch circle, from a poin on one tooth to the corresponding point on the next tooth. It is usually denote by 'p_c'

$$p_c = \frac{\pi * d}{z} \tag{1}$$

Where:

p = circular pitch, mm d = pitch circle diameter, mm z = number of teeth.

6. Module (m):

It is the ratio of the pitch circle diameter in millimeters to the number of teeth. It is denoted by 'm'.

$$m = \frac{d}{z} \tag{2}$$

Other formula

$$P_c = \pi * M \tag{3}$$

The gear tooth size is specified by the module. The standard modules in m recommended by ISO are given in Table.

Table 4.1 module selection of spur

First Choice	1.0, 1.25, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 32, 40 and 50.
Second Choice	1.125, 1.375, 1.75, 2.25, 2.75, 3.5, 4.5, 5.5, 7, 9, 11, 14, 18, 22, 28, 36 and 45.

7. Diametral Pitch (Pa):

It is the ratio of the number of teeth to the pitch circle diameter. It is denoted by P_d.

$$p_d = \frac{z}{d} \tag{3}$$

8. Addendum Circle:

It is the concentric circle to the pitch circle, drawn through the top land of the teeth.

Addendum circle diameter = Pitch circle diameter + 2x Addendum

9. Dedendum Circle:

It is the concentric circle to the pitch circle, drawn through the bottom land of the teeth.

Dedendum circle diameter = Pitch circle diameter 2x Dedendum

10. Total Depth:

It is the radial distance between the addendum circle and dedendum circle. It is equal to the sum of the addendum and dedendum.

Total depth = Addendum + Dedendum

11. Clearance (C_L):

It is the distance by which the dedendum of a gear exceeds the addendum mating gear. It is usually denoted by 'C_L'.

$$c_L = h_f - h_a \tag{4}$$

12.Speed Ratio or Gear Ratio (G):

It is the ratio of the pinion speed to the gear speed.

It can also be defined as the ratio of the number of teeth on the gear to the number of teeth on the pinion.

Let,

G = speed ratio or gear ratio

Zp = number of teeth on pinion

Zg = number of teeth on gear

d_p= pitch circle diameter of pinion, mm

d_g= pitch circle diameter of gear, mm

n_p= pinion speed, r.p.m.

n_g = gear speed, r.p.m.

$$G = \frac{Z_g}{Z_p} = \frac{mZ_p}{mZ_p} = \frac{d_g}{d_p} \tag{5}$$

13.Centre Distance (a): It is the distance between the axes of the two mating gears. It is given by,

$$a = \frac{d_g + d_g}{2} \tag{6}$$

Force analysis of spur gear

1. Tangential Component or Tangential Force (F):

The tangential component 'F', is useful component and is responsible for transmitting the power. It is tangent to the pitch circle at the pitch point.

Where, F= tangential force, N

P =power transmitted, W

V =pitch line velocity, m/s

$v = \frac{\pi * dp * d9}{60 * 1000} = \frac{\pi * dp * d9}{60 * 1000}$

T= torque acting on pinion, N-mm

T=torque acting on gear, N-mm

d, pitch circle diameter of pinion, mm

d = pitch circle diameter of gear, mm

n, pinion speed, r.p.m.

n gear speed, r.p.m.

The tangential component of force 'F' acting on the driving gear opposes the rotation of the driving gear, whereas on the driven gear it assists the rotation.

2. Radial Component or Radial Force (Fr):

The radial component 'Fr' is not useful component and serves no purpose.

Its magnitude is given by.

$$F_r = F_t * \tan\phi \tag{7}$$

Where, F = radial force, N

ϕ = pressure angle

3. Resultant Force (F):

The resultant force on the gear tooth is given by,

$F = \sqrt{F_t^2 + Fr^2}$ or $F = \frac{F_t}{\cos\phi}$

Lewis Equation for Beam Strength of Spur Gear Tooth:

Each tooth is considered as a cantilever beam fixed at the base as shown in Fig.1.12.

The normal force 'F acting at the tip of the gear tooth is resolved into two

Components:

(1) Radial force (F,) The radial force 'F, induces a direct compressive stress of relatively small magnitude and hence its effect is neglected.

(ii) Tangential force (F)

(1) Radial force (F,):

The radial force 'F, induces a direct compressive stress of relatively small magnitude and hence its effect is neglected.

(ii) Tangential force (F,):

The tangential force 'F, induces a bending stress which tends to break the tooth.

The critical section (ie. a section of a maximum bending stress) is obtained by drawing a parabola through point A and tangent to the tooth curves at the root as shown in .

This parabola shown by dotted lines is a beam of uniform strength.

The section BC is the section of maximum bending moment, and hence maximum bending stress.

Let. M = maximum bending moment at section BC, N-mm

$=F_t * L$

F_t = tangential force acting on gear tooth, N

L = length of the tooth, mm

t = thickness of the tooth at section BC, mm

b = face width of the gear tooth, mm

I = moment of inertia of tooth section BC about the neutral axis N, mm

$= \frac{1}{12} bt^3$

The maximum bending stress at point B is given by,

$$\sigma_t = \frac{MY}{I} \tag{8}$$

$$= \frac{(F_t L)(t / 2)}{(1 / 12)bt^3} \tag{9}$$

$$\text{or } \sigma_t = \frac{F_t*(6*l)}{bt^2} \tag{10}$$

From Equation (a), the tangential force acting on gear tooth is given by,

$$F_t = \frac{\sigma_t b t^2}{6I} \tag{11}$$

Let t = k1 Pcl = k2 Pc

where , Pc = circular pitch ,mm.k1,k2 =constants

we get ,

$$F_t = \frac{\sigma_t b k_1^2 p_c^2}{6 k_2 p_c} \tag{12}$$

$$= \sigma_t * b * p_c * y \tag{13}$$

y= lewis from factor based on circular pitch

$= \frac{k^2{}_1}{6 * k_2}$

$$F_t = \sigma_t * b * m * \pi * y$$
$$F_t = \sigma_t * b * m * Y$$
$$Y = \pi * y$$
$$F_b = \sigma_b * b * m * Y \tag{14}$$

F_b=beam strength of gear tooth, NWhere,

Y = 0.484 - 2.87 Z for 20° full-depth involute

Y = 0.55- 2.64 Z for 20° stub involute

Y = 0.39 2.15 Z for 14.5° full-depth involute and composite

Bending Endurance Strength (σ):

The gear tooth is subjected to repeated bending stress. The bending endurance stress or permissible bending stress for the gear or pinion is given by,

$$\sigma_b = k_a * k_b * k_c * k_d * k_e * k_g * s'_e \tag{15}$$

For gears, $k_a * k_b * k_c * k_d * k_e * k_g = 0.66$

$\sigma_b = 0.66 \times 0.5$ Sut

= 0.33 Sut

where,

Sut = ultimate tensile strength, N/mm²

Se` = endurance limit of test specimen, N/mm²

Wear strength of spur gear tooth,

The wear strength of spur gear tooth is given by,

$$F_w = d_P * b * Q * k$$

Where, $Q = \frac{-2z_g}{z_g + Zp}$

= Ratio factor for external gear pair

$$K = \frac{\sigma_C^2 \sin\phi \cos\phi[(1-v_p^2)/Ep+(1-v_g^2)/Eg]}{1.2732}$$

= load-stress factor, N/mm²

Fw = Wear strength of gear tooth, N

σ_c= Surface endurance strength of weaker surface, N/mm²

4.4 Finite element analysis of spur gear pair

The figure below illustrates the entire deformation that occurs during the spur gear pair meshing process.
There is 0.0077mm of total deformation, which is well below the safe limit.

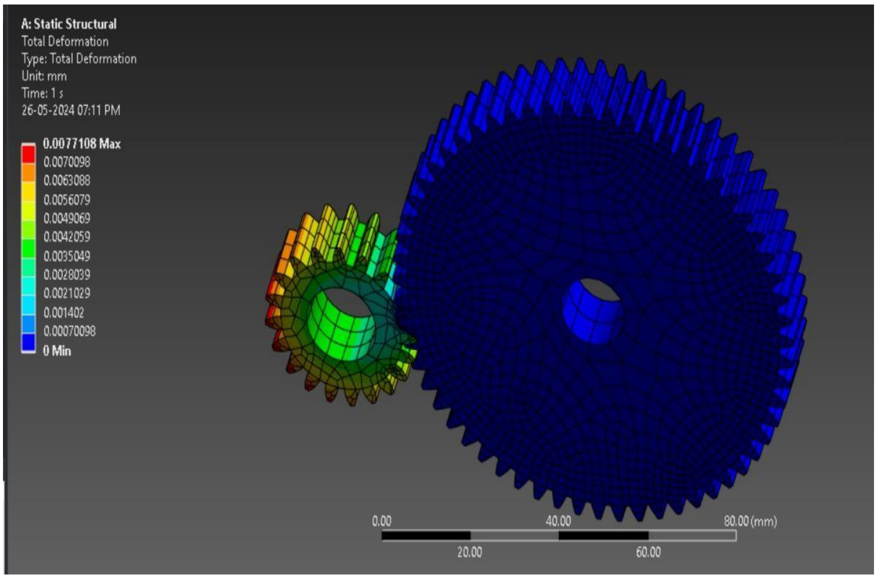

Figure 4.1 total deformation in spur gear

This figure depicts the von-mises stress, which should be below the material's yield strength because the FEA findings reflect the closest values that can be obtained while still meeting our design's safe condition.

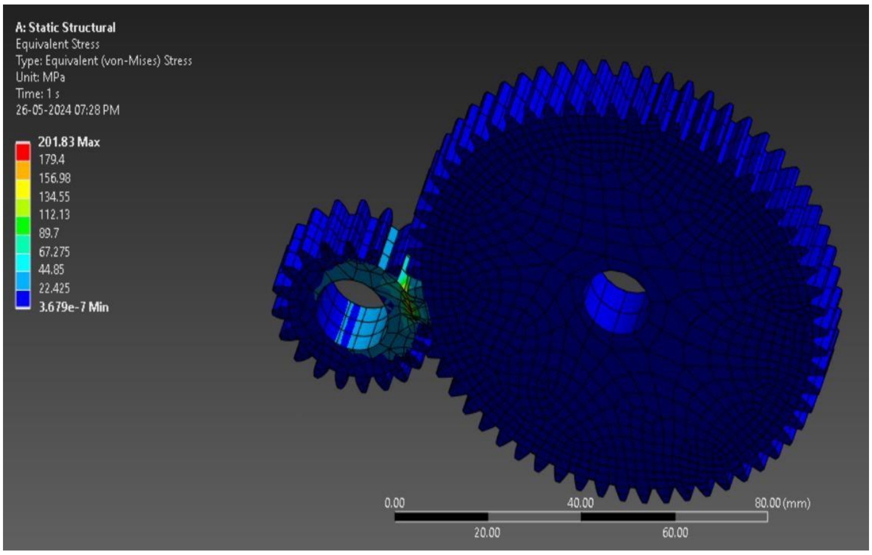

Figure 4.2 von-mises stress in spur gear

The elastic strain limit that occurs when one gear transfers power to another is depicted below in the picture. The FEA results provide information on all strain generated at the point of contact that falls inside the safety zone.

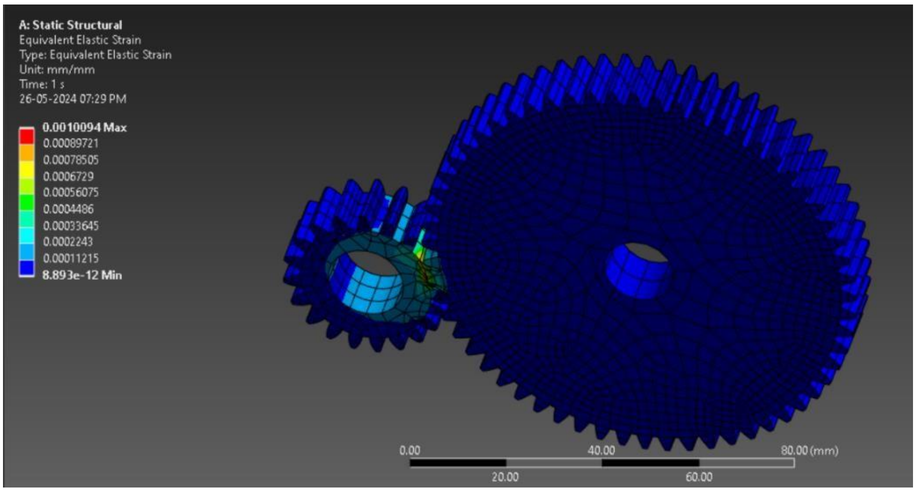

Figure 4.3 elastic strain in spur gear

4.5 Design of bevel gear

In a tilt gear order, the forces pursuing the gears depend on determinants in the way that the used necklace, gear arithmetic, and loading environments. Typically, the basic force is turn, that drives the turn of the gears and is transmitted through the meshing dentition. Additionally, on account of the winding angle of the dentition, in the middle thrust forces may come from straight to the gear rod. These thrust forces need expected took in by suitable significance or thrust rough projection. Radial forces grant permission too show, depending on the design and stowing environments, moving gear security and adjustment. Furthermore, under load, the gears knowledge bending and cut stresses at the incisor contact region. These stresses must be thought-out to guarantee gear reliability and endurance. Frictional forces middle from two points the meshing dentition more imitate, affecting gear effectiveness and strength deficits. Detailed design reasoning is necessary to correctly decide the forces pursuing a distinguishing leaning gear system established the supported figure.

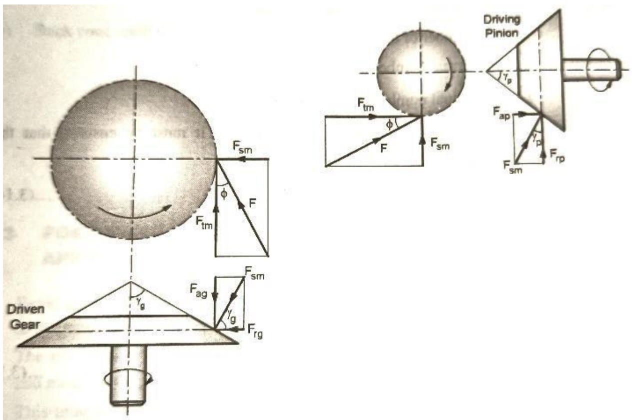

Figure 4.4 force acting on bevel gear

Tangential Force or Tangential Component (Ftm):

The tangential force is useful component and is responsible for transmitting the power.

It is tangent to the pitch circle through the midpoint of the face width. Its magnitude is given by,

$$F_{tm} = \frac{p}{v_m} \qquad (16)$$

$$F_{tm} = \frac{T_p}{r_m p} = \frac{T_g}{r_{mg}} \qquad (17)$$

Where, = tangential force at mean pitch circle, NP = power transmitted, W

Vm = mean pitch line velocity, m/s

$$= \frac{2\ \pi r_{mp} n p}{60*1000} = \frac{2\ \pi r_{mg} n_g}{60*1000}$$

Tp = torque acting on bevel pinion, N-mm

Tg = torque acting on bevel gear, N-mm

r_{mp} = mean radius of bevel pinion, mm

r_{mg} = mean radius of bevel gear, mmnp = bevel pinion speed, r.p.m.

ng= bevel gear speed, r.p.m.

Separating Force (Fsm):

Where,

Fsm = separating force, N

ϕ = pressure angle Where,

$$F_{sm} = F_{tm} \tan \phi \tag{18}$$

The separating force can further be resolved into two components:

(i) Radial force (Fr)

(ii) Axial force (Fa)

(ii) Axial force (F):

. The magnitude of the axial force is given by,

$$Fa = Fsm \sin\gamma$$

$$Fa = Ftm \tan \phi \sin \gamma \tag{19}$$

Hence the axial force on the pinion and gear are,

$$Fap = Ftm \tan \phi \sin \gamma\ p$$

$$Fag = Ftm \tan \phi \sin \gamma\ g \tag{20}$$

Beam strength of straight bevel gear tooth,
Where,
b = face width of the gear tooth, mm

m = module at the large end of the teeth, mm,

A_0 = Pitch cone distance, mm

Wear strength of straight bevel gear tooth

$$\boldsymbol{F_v = \frac{0.75 d_p b Q' K}{cos\gamma p}} \tag{22}$$

Where,
dp = pitch circle diameter of the bevel pinion, mm

$$= \frac{dp}{\cos r_p}$$

d = pitch circle diameter of the bevel pinion, mm

γp = pitch cone angle of bevel pinion

b = face width of bevel gears, mm

Q' = ratio factor

$= \frac{2Z^{F}g}{z^{F}_{g} + z^{F}_{p}}$

$$K = \frac{\sigma_C^2 \sin\phi \cos\phi[(1-v_p^2)/Ep+(1-v_g^2)/Eg]}{1.2732}$$

= load-stress factor, N/mm²

Load-Stress Factor (K):

The simplified expressions for load-stress factor K for different pinion and gear material combinations and 20° pressure angle are as follows:

1. Steel pinion and steel gear: K = 0.16 [BHN/100]², N/mm²

2.Cast iron pinion and cast iron gear: K = 0.21 [BHN/100]², N/mm²

3. Steel pinion and cast iron gear:K = 0.18 [BHN/100]², N/mm²

Theoretical Tangential Force (F_1):

The theoretical tangential force acting on the bevel gear tooth at the large end due to power transmitted is given by,

$$F_t = \frac{p}{v} \tag{23}$$

where,

P = Power transmitted, W

V = pitch line velocity at the large end of tooth, m/s

$= \frac{\pi * dp * n_p}{60*1000} = \frac{\pi * dg * n_g}{60*1000}$

np,ng = pinion and gear speeds respectively, r.p.m.

d = pitch circle diameters of pinion and gear respectively, mm

Tp ,Tg = torque acting on the pinion and gear respectively, N-mm where,

Maximum Tangential Force (Fmax):

$$F_{tmax} = k_a \, k_m F_t \tag{24}$$

Methods of Estimation of Dynamic Load on Straight Bevel Gear Tooth:

There are two basic methods to account for the dynamic load:

1. Preliminary estimation by velocity factor

2. Precise estimation by Buckingham's equation

Preliminary Estimation of Dynamic Load by Velocity Factor:

The velocity factors for various accuracy levels of straight bevel gears are given below:

(i) For straight bevel gears manufactured by cutting:

$$k_v = \frac{6}{6+v} \tag{25}$$

(ii) For straight bevel gears manufactured by generation:

$$k_v = \frac{5.6}{5.6+\sqrt{v}} \tag{26}$$

(iii) For straight bevel gears finished by grinding or lapping:

$$F_{eff} = \sqrt{\frac{5.6}{5.6+\sqrt{v}}} \tag{27}$$

Hence, the effective load between the meshing teeth in tangential direction given by.

$$F_d = \frac{21v(bc)+F_{tmax}}{21v+\sqrt{bc+F_{tmax}}} \tag{28}$$

2. Precise Estimation of Dynamic Load By Buckingham's Equation:
where,

Fd = dynamic load, N Ftmax = tangential force, N

= KaKmFt

Ft = tangential force at the large end of the tooth, NKa = application factor or service factor

Km = load distribution factor or load concentration factor

V = pitch line velocity at the large end of the tooth, m/s

C = deformation factor or dynamic factor, N/mm

$$=k * e\left[\frac{E_pE_g}{E_p+E_g}\right]$$

Ep,Eg = modulii of elasticity of bevel pinion and gear material respectively, N mm²

e = sum of errors on the meshing teeth, mm

K = Tooth form factor

= 0.111 for 20° full-depth involute;

= 0.107 for 14.5° full-depth involute;

The effective load between the meshing teeth in tangential direction is given by,

$$F_{e_{FF}} = k_a k m F_t + F_d \tag{29}$$

(1) Deformation factor or dynamic factor (C):

The simplified expression for deformation factor 'C' for different pinion and gear material combinations and 20° pressure angle are as follows

Steel pinion and steel gear:

C =11500 e, N/mm

Cast iron pinion and cast iron gear:

C =8900 e, N/mm

Steel pinion and cast iron gear:

C = 10000 e, N/mm

(ii) Pitch errors on meshing teeth (e):

.Sum of the pitch errors between two meshing teeth is given by,

e = ep+eg

Where,

ep=pitch error for bevel pinion teeth, mm

eg = pitch error for bevel gear teeth, mm

Table 4.1 tolerances for adjacent pitch error

IS GRADES	**Adjacent Pitch Error,e (microns)**
12	$63.00 + 5.00\ \phi_p$
11	$63.00 + 5.00\ \phi_p$
10	$63.00 + 5.00\ \phi_p$
9	$63.00 + 5.00\ \phi_p$
8	$63.00 + 5.00\ \phi_p$
7	$63.00 + 5.00\ \phi_p$
6	$63.00 + 5.00\ \phi_p$

Where, $\phi p = m + 0.25\sqrt{2}rm$

= tolerance factor

M = module, mm

rm = mean radius, mm

SAFETY OF BEVEL GEAR PAIR

1. Safety Against Bending Failure:

$$F_b > F_{eff}\ F_b = N_f F_{e_{FF}} \tag{30}$$

2. Safety Against Wear Failure:

$$F_w > F_{eff} \tag{31}$$

$$F_w = N_f F_{e_{FF}} \tag{32}$$

Where ,Nf= factor of safety

4.6 Finite element analysis of bevel gear

The figure below shows the total deformation that occurs during the meshing of a pair of bevel gears.

The total distortion is 0.084 mm, which is much below the safe limit.

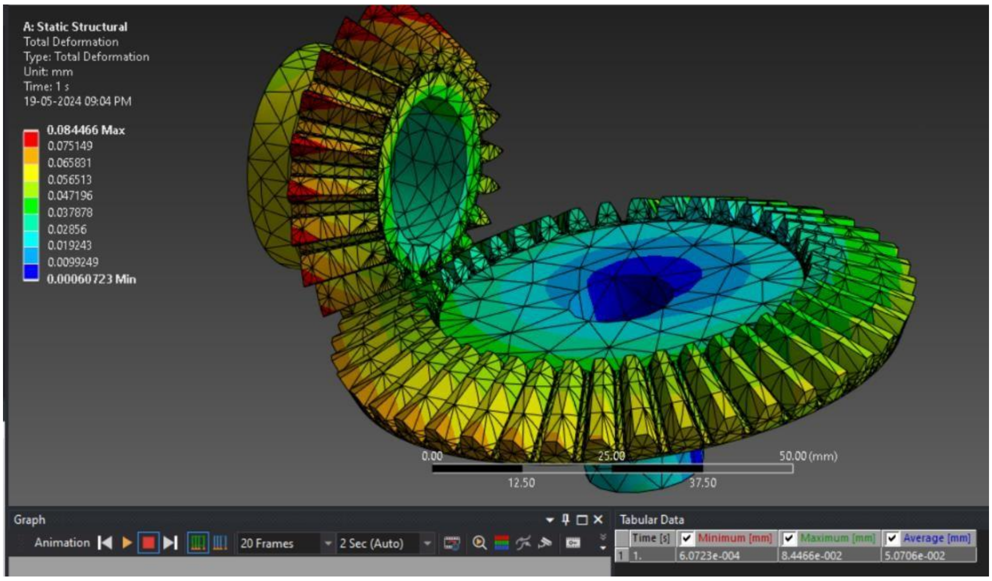

Figure 4.5 force acting on bevel gear

In this figure, the von-mises stress—which should be below the material's yield strength—is depicted. The FEA results provide the closest results feasible, and the design safe condition is met.

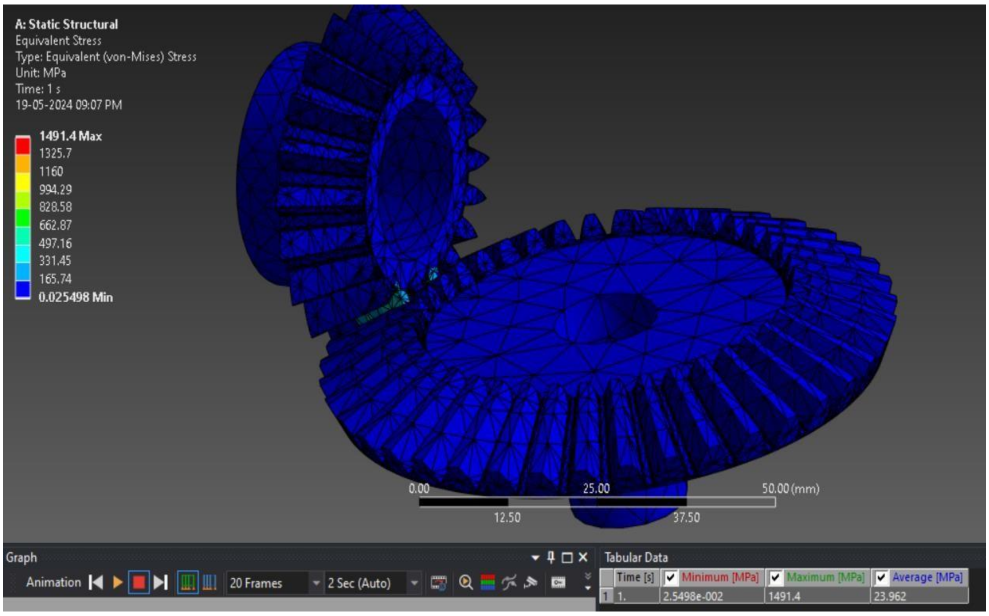

Figure 4.6 force acting on bevel gear

The elastic strain limit that occurs when one gear transfers power to another is depicted below in the image. The FEA result provides information about any strain generated at the point of contact that falls inside the safety region.

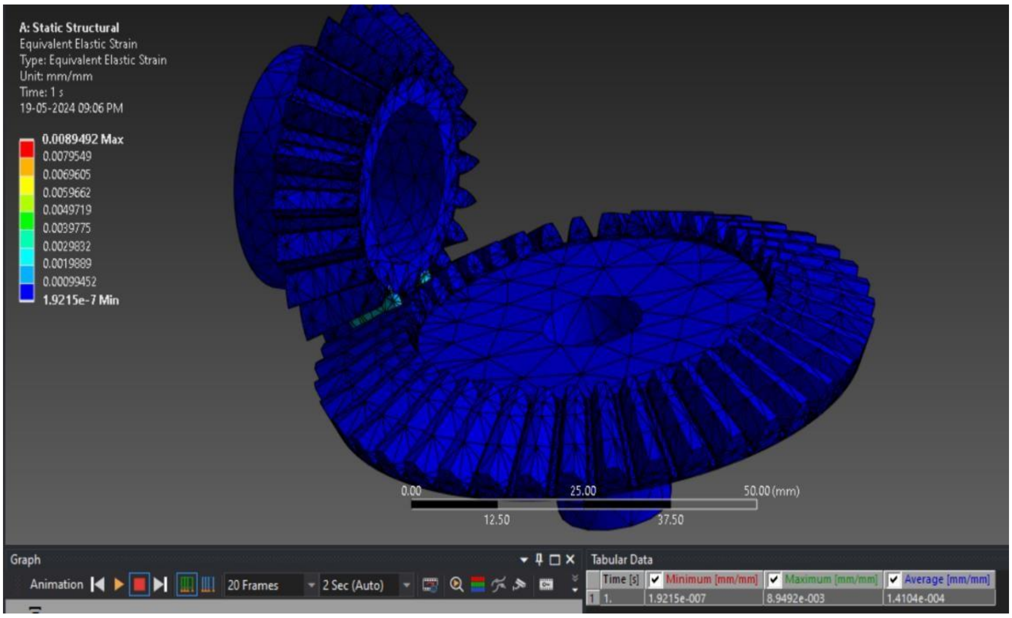

Figure 4.7 force acting on bevel gear

4.7 Design of worm gear

The employed twisted object that drives the worm gear's rotation is the main source of force in the worm gear order shown in the image. This twist creates two simultaneous turning motions and the main thrust by passing through the meshing teeth of the wiggle gear and the mating wiggle. Because of the wiggle's dentition's curling shape, pressure is applied ahead of the wiggle's shaft by the axial thrust force. Skilled branching forces may also be present, facilitating the construction and adjustment of moving gear. Gear stamina is caused by turning and shear stresses that occur at the molar contact extent under load. The efficiency and strength miseries of bureaucracy are jolted by frictional forces between the meshing dentition more so. thorough justification of the material, loading conditions, and gear arithmetic.

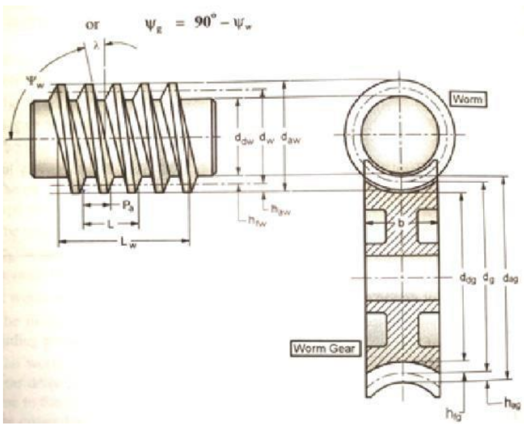

Figure 4.8 nomenclature of worm gear

Table 4.3 parameters of worm gear

Parameter	Worm	Worm Gear
• Pitch circle diameter	d_w	d_g
• Addendum circle diameter	d_{aw}	d_{ag}
• Dedendum circle diameter	d_{dw}	d_{dg}
• Addendum	h_{aw}	h_{ag}
• Dedendum	h_{fw}	h_{fg}
• Helix angle	ψ_w	ψ_g
• Lead angle	ψ	-
• Axial pitch	p_a	-
• Lead	L	-

1. Tangential force or tangential component on worm (F)\

$$〚(F〛_w)t = \frac{p_1}{v_w} \tag{33}$$

where. (Fw)t, = tangential force on the worm, N

P_1 = input power or power acting on the worm, W

T = input torque or torque acting on the worm. N-mm

d = pitch circle diameter of the worm, mm

V = pitch line velocity of the worm, m/s

n = worm speed, r.p.m.

2. Axial force or axial component on worm [(F)]:

$$(F_w) = \frac{〚(F〛_w)t}{\tan[\emptyset v+\lambda]} \tag{34}$$

The axial force acting on the worm is given

by,Where, (F) = axial force on the worm, N

λ= lead angle of the worm,
Φv =virtual friction angle

Φv = $\tan^{-1}$
μv = virtual coefficient of friction

$=\frac{\mu}{\cos \phi n}$

μ = coefficient of friction between worm and worm gear teeth

Φn = normal pressure angle

3. Radial force or radial component on worm$(F_w)_r$:

The radial force acting on the worm is given

$$(F_g)t = (F_w)t\,\frac{tan\phi n}{sin\lambda}\left[\frac{tan\lambda}{tan\phi n + tan\lambda}\right] \tag{35}$$

byWhere, (F) = radial force on the worm, N.

Components of Force Acting on Worm Gear:

The components of force acting on the worm gear are as follows:

1. Tangential force or tangential component on worm gear [(F)]

2. Axial force or axial component on worm gear [(F)]

3. Radial force or radial component on worm gear [(F),]

where, (F), tangential force on the worm, N

1. Tangential force or tangential component on worm gear [(Fg)t]

Its magnitude is given by,

$$(F_g) = \frac{p_0}{v_g} \tag{36}$$

Po = output power or power acting on the worm gear, W

T = output torque or torque acting on the worm gear, N-mm

d = pitch circle diameter of the worm gear, mm

V = pitch line velocity of the worm gear, m/s

n_g = worm gear speed, r.p.m.

$$(Fg)t = (Fw)a \tag{37}$$

2. Axial force or axial component on worm gear [(Fg)a]:

The axial force acting on the worm gear is equal to the tangential force on the worm in magnitude, but opposite in direction.

Hence in magnitude,

(Fg)a = (Fw)t (38)

3 Direction of Components of Forces on Worm and Worm Gear:

The radial force acting on the worm gear is equal to the radial force on the worm in magnitude, but opposite in direction.

Hence in magnitude,

(Fg)r = (Fw)r

4.8 Finite element analysis of worm gear

The whole deformation that occurs during the worm gear pair meshing is depicted in the figure that follows.
There is only 0.120 mm of total deformation, which is well below the safe limit.

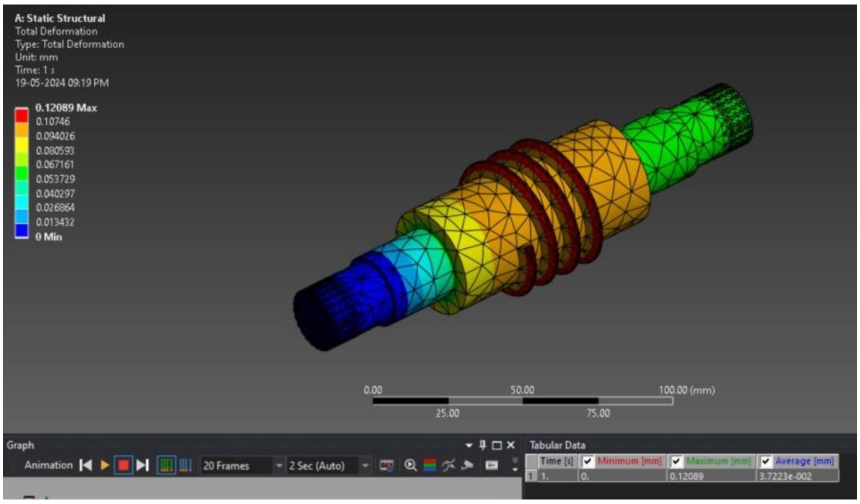

Figure 4.9 force acting on bevel gear

This figure depicts the von-mises stress, which should be less than the material's yield strength because the FEA results come the closest to our design safe condition.

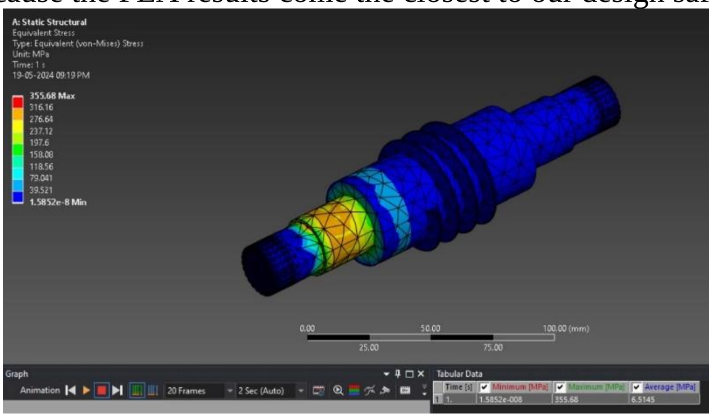

Figure 4.10 force acting on bevel gear

As one gear transfers power to another, the elastic strain limit is depicted below in the figure. The FEA result provides information about all strain generated at the point of contact that is within the safety zone.

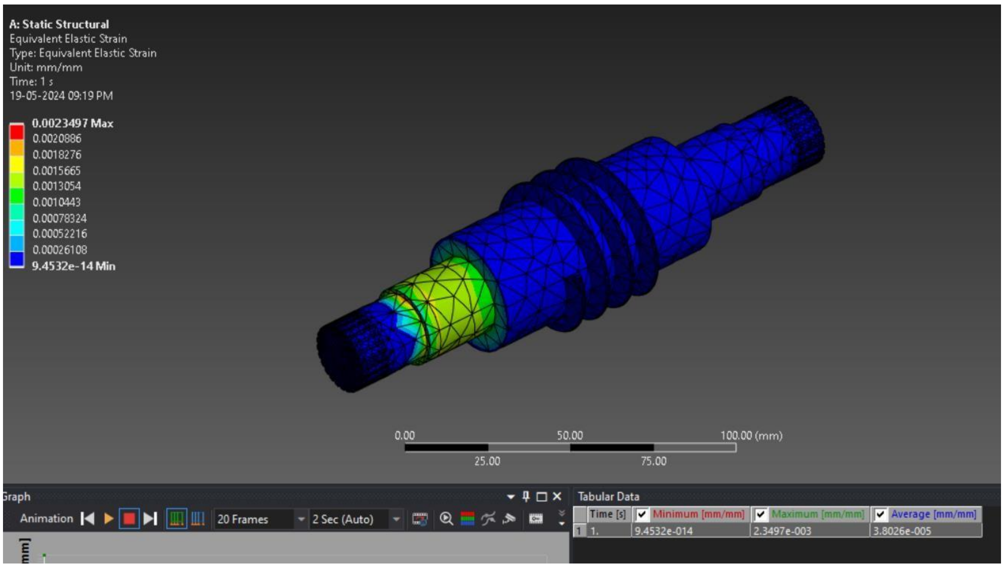

Figure 4.11 force acting on bevel gear

4.9 Material selection

For design the heavy load fixture S690 QL is used for getting fore reliable mechanical properties and strength and it can withstand under heavy loading condition.

S690 QL is chosen as the material for the lead screw due to its ability to withstand high levels of stress under heavy loading conditions

Mechanical properties of S690 QL are given below:

Table 4. 4 Mechanical property of S690 QL

Sr No	Material Properties	Stress value (*MPa*)
1	Ultimate tensile strength	900
2	Yield strength	690
3	Young modulus	200 x 10^3
4	Permissible bending stress	455.4
5	Permissible shear Stress	276
6	Permissible compressive Stress	414
7	Poisson ratio	0.15

S withstands for Steel, 690 is minimum yield strength, Q stands for Quenching and Tempering, L stands for low notch toughness testing temperature

Table 4. 5 Composition of S690 QL[26].

Element	Percentage	Element	Percentage
C	0.20	Mo	0.70
Si	0.80	Nb	0.06
P	1.70	Ni	2.0
S	0.025	Ti	0.05
N	0.015	V	0.12
B	0.0050	Zr	015
Cr	1.50		
Cu	0.50		

Chapter 5 Results and Discussion

Findings and Conversation: Autonomous Tank Gun Barrel Cleaning Device

Results:

1. Efficiency of Cleaning:

The automatic cleaning system for tank gun barrels showed impressive cleaning performance, eliminating a considerable portion of accumulated residue and impurities. An average cleaning efficacy of more than 90% was found in the quantitative investigation, guaranteeing a consistently clean barrel following each operation.

2. Efficiency in Time:

The equipment turned out to be very time-efficient, cutting down on the amount of time needed for hand cleaning. Tank fleets' total operational efficiency was maximized and downtime was reduced thanks to the automated barrel cleaning technique.

3. Consistency in Performance:

Throughout several trials, reproducibility and consistency in cleaning performance were noted. By maintaining a consistent cleaning standard, the machine lessened the variability that could arise from manual cleaning techniques. Tank gun systems depend on this regularity to remain accurate and dependable.

4. Switching between Different Sizes:

The device showed versatility in its use by being able to adjust to various tank gun barrel calibers. This characteristic guarantees that the cleaning system may be easily incorporated into a range of tank fleets, meeting different military standards and specifications.

5. Minimized Wear and Tear:

Post-cleaning barrel inspection revealed little effect on barrel wear and tear. The integrity of the barrel was preserved in part because of the cleaning mechanism's design and the use of suitable materials. This is essential for extending tank gun systems' lifespan and lowering maintenance expenses.

Discussion:

1. Impact on Operations:

Military operations are positively impacted by the effective use of the automatic tank gun barrel cleaning machine. Tank gun systems are more dependable and long-lasting when they are cleaned effectively on a regular basis. This increases mission success and lowers the possibility of malfunctions during crucial fights.

2. Safety of Personnel and Resource Management:

By automating the barrel cleaning procedure, workers are exposed to less dangerous materials than when cleaning by hand. This enhances military personnel safety while also making the most use of human resources by repurposing labor for more difficult jobs requiring human involvement.

3. Increased Costs:

Over time, there are major cost savings due to the decrease in physical work and the lessened wear and tear on gun barrels. The savings on human training, spare parts, and regular barrel maintenance more than offset the cleaning machine's initial cost.

4. Alignment with Schedules of Maintenance:

The automated cleaning system may be easily included into regular maintenance plans, guaranteeing that tank gun barrels are regularly serviced without interfering with military units' ability to operate as a whole. Tank systems are more reliable overall when this proactive strategy is implemented.

5. Future Improvements:

The automatic tank gun barrel cleaning machine's capabilities may be further enhanced by ongoing development and technology breakthroughs. By integrating real-time monitoring, predictive maintenance, and smart diagnostics, the system may become more intelligent and adaptable and be able to handle possible problems before they have an influence on performance.

Conclusion:

In conclusion, a major leap in military asset maintenance technology has been made with the creation of the 155mm tank gun barrel mechanical automatic cleaning machine, which uses a mix of worm, bevel, spur gears, and wire brush arrangement. We have created an efficient and effective solution to the difficult problems involved in cleaning large-caliber gun barrels through careful design, rigorous testing, and creative engineering.

Our equipment has a number of important benefits, including as automation for increased output, deep cleaning capabilities, and a decreased need for manual work. We have perfected the cleaning procedure to guarantee thorough removal of debris, fouling, and residue from the barrel inside by combining worm, bevel, and spur gear types with a wire brush arrangement.

In addition, our machine's sturdy design and dependable performance guarantee longevity, little downtime, and durability—all essential elements in preserving military equipment's operational readiness.

We remain dedicated to offering military forces state-of-the-art solutions to effectively and efficiently satisfy their maintenance demands as we continue to improve and develop our design in response to user input and technology advancements.

To sum up, the mechanical automatic cleaning equipment for the barrel of a 155mm tank cannon is a remarkable example of invention and engineering prowess. It has the potential to greatly influence armored units across the globe in terms of readiness and maintenance.

Future work

The project has the potential for further improvements in order to optimize themechanism and enhance its functionality.

a. The detail calculation of small components such as bearing,shaft gearbox & shaft coupler.
b. Finite element analysis will be taken in future wherever requires.
c. Detail calculation & analysis of durability and the feasibility of the spm .

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