SOLINAS Product Design Challenge

Team 15

Abstract

This report proposes a novel design solution for a retractable and extendable shaft aimed at facilitating the homogenization of solid materials and liquids within deep tanks, specifically addressing depths of up to 5 meters. The challenge involves overcoming the limitations of a rigid and heavy solid shaft currently used in agitator mechanisms for creating pumpable slurries. The innovative design developed allows for the shaft's seamless extension to a length of 5 meters and retraction to 1 meter without compromising other components. Waterproofing and spark-proofing measures are integrated into the design, safeguarding the shaft's functionality in the intended environment. Moreover, user-friendliness is a central aspect of this design, necessitating a simple operation through a single switch or button for both expansion and retraction processes. The report details the structural elements, materials, mechanisms, and operational features of our design, providing a comprehensive solution to optimize the blending process for deep tank applications.

1. Introduction

In addressing the challenges encountered by the team of engineers tasked with blending waste in deep tanks, this report delves into the ideation and step-by-step processes involved in designing a revolutionary telescopic shaft. The primary hurdle faced is the inflexibility and considerable weight of conventional solid shafts, limiting their effectiveness in tanks with a depth of 5 meters. This report outlines the journey of developing a shaft capable of deployment up to 5 meters and retraction to 1 meter, with due consideration for the tank's diameter of 0.4 meters.

The envisaged telescopic shaft seeks to overcome stability issues during deployment into slurry material while ensuring ease of portability by human operators. The study aims to achieve a design that facilitates waste blending within deep tanks, enhancing operational efficiency. Furthermore, the report provides insights into the incorporation of waterproofing and spark-proofing measures for the shaft, crucial for its immersion in underwater or sludge storage tanks of 5 meters in depth. Through a meticulous examination of materials and methodologies, this study aims to offer a comprehensive solution to the challenges posed by conventional shaft designs in this specialized operational environment.

2. What is a Telescoping Mechanism

A telescoping mechanism is a design in which one part can slide over another part to adjust its length. Such a mechanism is utilized for reaching extended distances by pulling or pushing sections or tubes into each other. This kind of mechanism can be used in our case to design an extendable shaft that would be capable of deployment up to 5m.

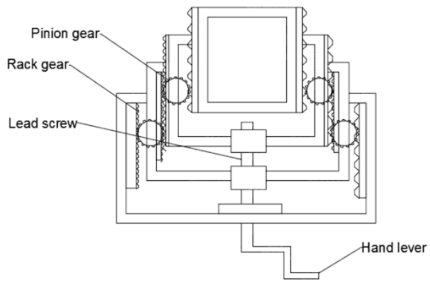


Figure 1: Rack and Pinion

3. Various Telescoping Mechanisms that can be utilized:

- Rack and pinion
- Cable-pulley
- Lead Screw Mechanism
- Spiral Lift Mechanism
- Zip Chain Actuator

3.1. *Rack and pinion*

The Rack refers to a linear gear or toothed rod with teeth along its length and the pinion is a small gear with teeth that engages the teeth of the rack. Figure 1 is the representation of a 3-stage Rack and Pinion Telescoping Mechanism[19].

3.1.1. *Advantages and Disadvantages of the Rack and Pinion Mechanism:*

- Rack and pinion systems are prone to backlash, which is the play or clearance between the teeth of the rack and pinion. External shocks or impacts can cause momentary separation of the mating teeth, leading to backlash error. This can result in imprecise motion and reduced accuracy, particularly in applications where tight tolerances are essential.

- Since we have a constraint that the diameter of the tank is expected to be 0.4m and for proper functioning in challenging conditions we must also expect the diameter of the tank to taper as the shaft moves in, achieving a rack and pinion telescopic mechanism which would need a high precision and accuracy would end up becoming challenging.

- Achieving high precision in a rack and pinion system often involves additional manufacturing processes and higher-quality materials. This can increase the overall cost of the system.

- The constant contact between the teeth of the rack and pinion can result in wear over time. This wear can lead to a decrease in the system's overall efficiency and may require regular maintenance or replacement of components. [15][19]

3.2. *Cable-Pulley Telescoping Mechanism*

A telescopic deployable boom consists of thin-walled tubes that are nested among each other. The telescopic boom has the following advantages: high stiffness, lightweight, high reliability, and it is foldable (it can be folded into a small volume for easy transportation).

3.2.1. *Functioning:*

The red wire deploys the mechanism and the blue one drives the mechanism to retract. Both ends of the deployment cable are wound onto the same winch, and it is routed along the tubes back and forth. One end of the retraction cable is fixed with the bottom of the nth tube, and the other is wound on the winch.

The deployment cable is wound on one winch, while the retraction cable is unwound from the other winch when the mechanism is in the deployment process, and vice versa. The velocity of the winding winch is given to drive the mechanism, while the velocity of the unwinding winch should be adjustable to ensure that the unwinding cable is not taut or slack. A cable-adjusting assembly is designed to realize the velocity adjustment of the unwinding winch, as shown in Fig. 2 [5]. Rocker 1 is installed at the center, and it can rotate around joint D. Rockers 2 and 3 are placed at the left and right sides. Angle sensors are placed at D, RL, and RR to measure the rotation angle of the rockers. Torsional springs are also installed at these joints to ensure the cables are under tension. Deployment has been taken as an example to describe the working process of the cable-adjusting assembly. First, the velocities of the deployment and retraction winches are set as ω_1 and $\omega_2(\omega_2{=}0.5{*}\omega_1)$, respectively. Rocker 1 rotates clockwise because the unwinding velocity is smaller than the winding velocity. Rocker 1 reaches its right extreme position where the angle is qmin measured by the angle sensor, which means the retraction cable is too tight, and

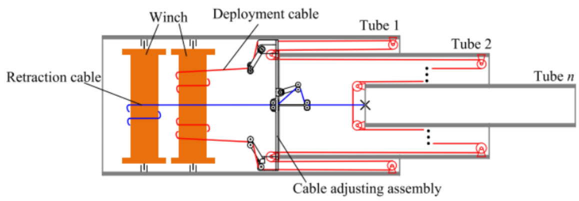


Figure 2: Cable-Pulley Telescoping Mechanism[5]

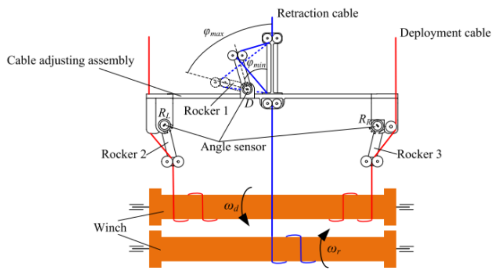


Figure 3: Rocker [5]

this may cause additional resistance to the deployment. The unwinding velocity ω_2 should be increased to $1.5{*}\omega_1$. When rocker 1 rotates anticlockwise under the action of the torsional spring at D. The unwinding winch stops rotating when the retraction cable becomes too slack and rocker 1 reaches its extreme left position where the angle is qmax Rocker 1 will rotate clockwise and repeat the above procedures. The angle of rocker 1 is controlled between qmax and qmin, which means the state of the retraction cable is appropriate. Similarly, rockers 2 and 3 are adjusted at the retraction process.[5]

3.2.2. *Advantages and Disadvantages of the Cable-Pulley Mechanism:*

- Compact Design: Cable pulley telescopic mechanisms can be designed to be compact and space-efficient when retracted, thus making them suitable for applications where space is limited.

- Design Complexity: Designing a cable and pulley system for motion in multiple directions or complex paths can be challenging. The system's complexity increases as the number of pulleys and cables grows, potentially leading to more points of failure and increased maintenance requirements.

- Wear and Tear(Maintenance): Cable pulley mechanisms may require regular maintenance to ensure smooth operation. Cables can wear over time and may need to be replaced periodically.

- Misalignment: External shocks can cause misalignment in pulley systems, affecting the proper engagement of belts or cables with the pulleys. Misalignment can lead to increased friction, wear, and reduced efficiency in the system. It can also cause derailment of ropes from the pulleys.

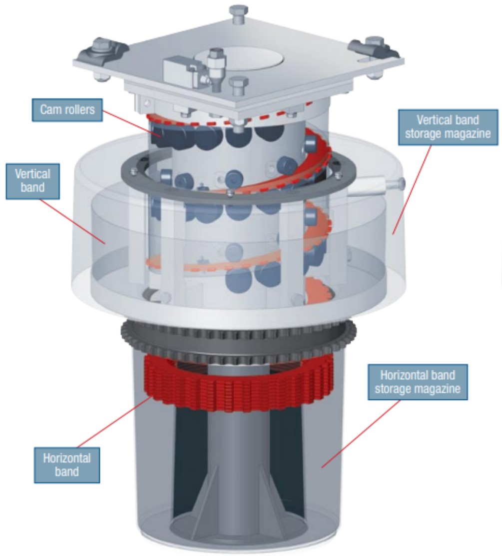


Figure 4: Spiral Lift Mechanism[7]

3.3. *Spiral Lift*

This technology uses two bands of intertwining stainless steel to form a strong and stable column. The telescoping column is formed by a pair of interlocking stainless steel bands. One band has a vertical rectangular profile and the other horizontal one. The vertical band spirals up on itself into a stacked helix, forming the wall of the column, while at the same time, the horizontal band interlocks the continuous spiral seam of the vertical band. When the column lowers, the bands separate and retract into two compact coils. The bands are combined, separated, and stored by an assembly located at the base of the column.[12][7]

3.3.1. *Advantages and Disadvantages of Spiral Lift Mechanism:*

- The Spiral lift requires relatively low-power electric motor drives due to its very high mechanical efficiency.

  The high speed of the column due to the large pitch of the helix Spiral lift mechanisms can be designed to be more compact compared to the other telescoping mechanisms since the spiral structure allows for a coiled configuration when retracted.[19]

- The spiral structure distributes the load evenly along the helix, contributing to stability and preventing issues like sagging or uneven weight distribution.

- Complex Design: The helical structure can introduce complexity to the design, potentially requiring a high level of precision and more intricate engineering processes. This complexity may result in higher production costs.

- Since we expect our shaft to be capable of traversing into the slurry, the particles present in the slurry could bind together and lead to jamming of the mechanism which is not preferred.

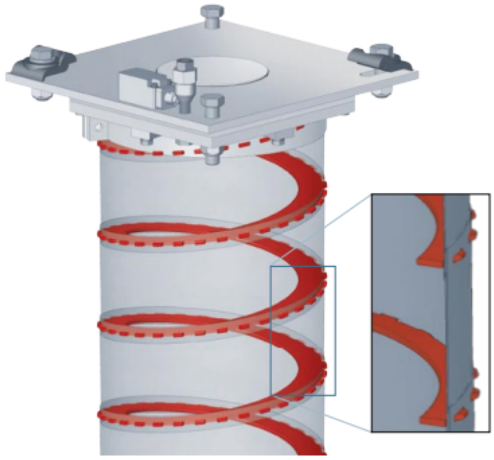


Figure 5: Spiral Lift[7]

3.4. *Zip Chain Actuator*

A Zip chain consists of two strands of chains that interlock in a zipper-like fashion to form a single, strong column that can be retracted and deployed as per our requirements.[10]

3.4.1. *Advantages and Disadvantages of Zip-Chain Actuator Mechanism:*

- It can be utilized to reach varying depths with high precision.

- It is extremely fast for deployment and retraction and the entire mechanism at its retracted state would be lightweight and easily portable.

- It wouldn't have any issues in being operated at challenging conditions such as tapering diameter of the tank and external impulses.

- Zip chains can achieve high-speed operation while maintaining stable telescoping speed, and the heat generation is also expected to be minimal.

- Not compact and violates our 0.4m diameter constraint.

- As in the case of the spiral lift, the mechanism is expected to traverse further into the slurry and the binding of particles could potentially jam the mechanism and so would require regular maintenance.

- Abrasive particles in the slurry can cause wear and tear on the components of the actuator, potentially leading to increased friction and the risk of binding.

- As the mechanism is expected to extend up to 5m, we can expect a considerable decrease in stability.

3.5. *Lead Screw Telescopic Mechanism:*

A lead screw telescoping mechanism consists of a long threaded screw and a nut that moves along the thread when the screw is rotated. In a multi-stage lead screw telescoping mechanism multiple screws are nested over each other creating a more complex design that can achieve a longer deployment range.

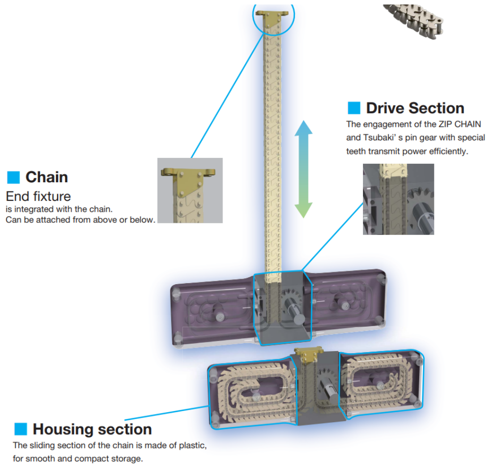


Figure 6: Zip Chain Mechanism[9]

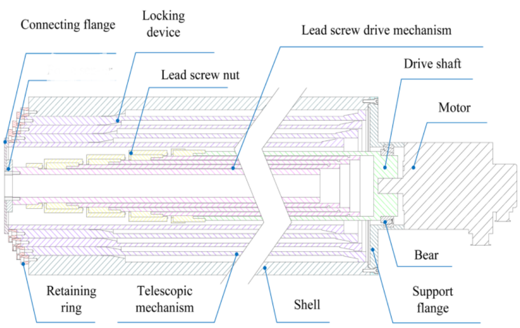


Figure 7: lead screw[8]

3.5.1. *Advantages:*

The speed and distance of deployment of the mechanism can be precisely calculated based on the pitch of the lead screw Compared to the other mechanisms mentioned above the lead screw is the most stable toward external impulses. It is expected to be the heaviest when compared to the other mechanisms, but however, that can be dodged by choosing an appropriate material. The friction between the sliding tubes can be reduced by bearings and suitable lubricants. It can also be made corrosion-resistant by choosing a suitable outer coating.

4. Choosing the appropriate mechanism for our specific application

- A suitable candidate must be compact, occupy less space in its retracted state, must be stable, portable, and completely controllable to the precise depth.
- In addition, manufacturing it must be of low cost, requiring less precise manufacturing and high-quality components.
- From Table 1 it can be inferred that the Lead screw telescoping mechanism would be the most suitable for our required application as it is the most stable among all of the other mechanisms and a failure proof model that can work in any challenging condition would be the requirement.

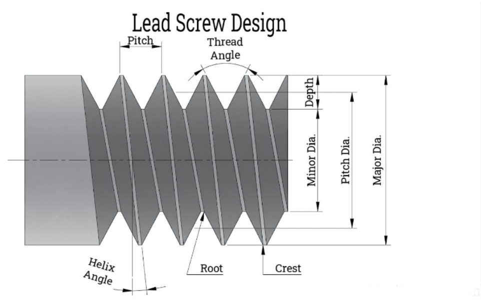


Figure 8: Lead Screw parts

- The major challenges in incorporating such a model would be to make it lighter for portability and this could be overcome by choosing appropriate light materials having the necessary spark-proof and water-resistant characteristics.
- Although the spiral-lift and Zip-chain mechanisms might seem innovative and easily portable the necessity that the mechanism would have to move through the slurry materials makes it impossible to choose such a mechanism for our application.
- Further sections in this report will look into the calculations involved in modeling the lead-screw mechanism and a detailed review of the materials that could be used for our shaft.

5. Design and modeling of the multi- stage lead screw mechanism

We have used SolidWorks for making the CAD model of the required Lead Screw Mechanism

5.1. *Length Calculation:*

5.1.1. *Assumptions:*

- The length of the outermost cylindrical enclosure is 1m.
- A 30mm space is provided in the outermost cylindrical enclosure to hold the first screw.
- Let us assume that the threaded length of the first nut is x mm.
- We gradually decrease the threaded lengths of successive nuts by 5mm i.e. for the second nut it will be (x-5)mm, for the third it will be (x-10)mm, and so on.
- In the extended version of each screw-nut system, the nut's threaded part end will be 20mm away from the respective screw's end on the inner side.
- With these assumptions and the knowledge that the length of the successive screw-nut system should decrease so that the retracted length is 1m, we realized that a 7 screw-nut system will be involved.

MECHANISM	SPEED AND ACCURACY	COMPACTNESS	DESIGN CONSIDERATION
Rack and Pinion	Comparatively slow and accurate	Designing a compact mechanism could lead to a higher risk of failure	Requires multiple stages, leading to a complex design
Cable Pulley	Comparatively faster with a trade-off in stability	Designing a compact mechanism could lead to a higher risk of failure	Requires multiple stages; 0.4 m Diameter constraint leads to a complex design
Spiral Pulley	Fast and accurate	Very complex design requirement	Traversing through slurry increases the chances of jamming
Zip Chain Mechanism	Fast and accurate	Easily portable	Issues with jamming and housing a retracted 5m long chain
Lead Screw Mechanism	Comparatively slow but can be very accurate	Can be designed compactly without much trade-off in stability	Feasible for the specified application with potential for improvement

Table 1: Summary of the mentioned mechanisms

5.1.2. *Formulas:*

Nut length:

- Let the length of nth nut be represented by N_n
- The length of first nut is N_1=970mm.
- Formula for other nuts:
  $N_n = N_{n-1} - (x + 15 - 5 \times (n - 2))$
  where n=2,3,4,5,6,7

Threaded screw length:

- Let the length of nth nut be represented by T_n
- The length of first Screw is T_1=970mm.
- Formula for the visible length of other nuts:
  $T_n = T_{n-1} - (x + 15 - 5 \times (n - 2))$
  where n=2,3,4,5,6,7.

Visible length of Nuts

- Let the visible length of nth nut be represented by L_n.
- Formula for other screws:
  $L_n = N_n - 20 - (x - 5 \times (n - 1))$
  where n=1,2,3,4,5,6,7
- $\sum_{i=1}^{7} L_n = 4000$.

With these assumption, we get the value of x=93mm.

5.2. *Pitch Calculation:*

5.2.1. *Assumption:*

- Since each screw will rotate with the same angular velocity, the ratio of pitch and the distance moved by the nut will be same for all the screw-nut system.
- We are assuming the pitch of first screw to be P_1=8mm and then calculating the pitch of other screw based on this.
- Pitch for second screw-nut system.
  Since the ratio is same we have
  $P_1/L_1 = P_2/L_2 \implies 8/857 = P_2/744 \implies P_2 = 6.95$
  In similar fashion, we can calculate the other values.
- Therefore, we are getting 8mm, 6.95mm, 6.13mm, 5.26mm, 4.44mm, 3.66mm and 2.93mm pitches respectively for each screw-nut system.

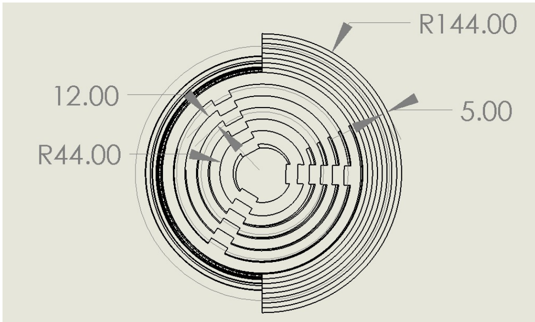


Figure 9: Diameter of concentric circles

5.3. *Diameter Calculation:*

- The radius of the first screw is 32mm.
- The width between the successive screws is 12mm.
- The width between the successive nuts is 5mm in order to increase the strength.
- The thickness of the outer cover is 5mm.

Final diameter of the system = $2 \times (32 + 12 \times 6 + 5 \times 7 + 5)$ = **288mm**.

5.3.1. *Major Diameter :*

From figure 9, we can see that the major diameters are 64mm, 88mm, 112mm, and so on.

5.3.2. *Minor Diameter:*[6]

From figure 10 we can see that Helix angle = 30 degree
Minor diameter = Major diameter - 2 $\times pitch \times 0.866$
Therefore,
Minor diameter of first screw = $64 - 2 \times 8 \times 0.866$ = 50.144mm
Minor diameter of second screw = $88 - 2 \times 6.95 \times 0.866$ = 75.963mm , and so on.

5.3.3. *Root diameter:*

Root diameter = (Major Diameter + Minor Diameter)/2
Root diameter of first screw = (64+50.144)/2 = 57.072mm
The root diameter of the second screw = 81.9815mm, and so on.

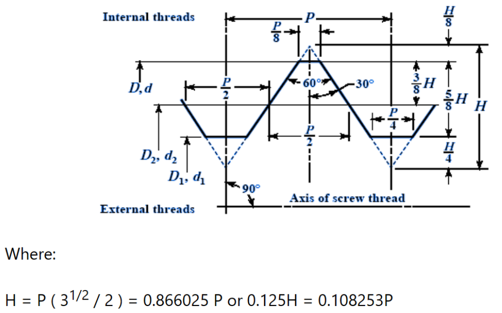


Figure 10: Relation between pitch and height

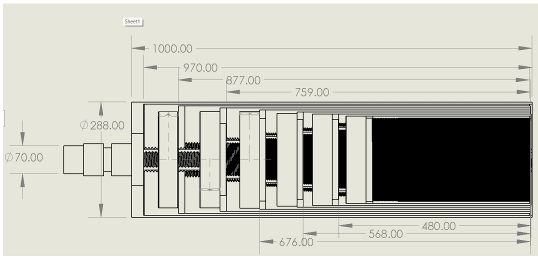


Figure 11: Cross-Section Dimensioning of Lead Screw

6. Materials

Material selection for the telescopic shaft would be very crucial and must involve research and comparison. Key parameters include shock absorption, spark resistance, water resistance, abrasion resistance, corrosion resistance, weight considerations, and structural integrity for optimal performance, durability, and safety in operational environments. Through meticulous research, the following materials have been listed with respect to their use.

6.1. Spark-Proofing Materials

- **Purpose:** The goal is to eliminate the risk of spark generation during operation, particularly in environments where flammable or explosive substances may be present.
- An explosion occurs when a fuel mixed with air (i.e. a sufficient amount of oxygen) reaches the explosive limits in the presence of an ignition source.
- In many incidents in industry, the main problem was the appearance and evolving of sparks through friction.
- There are a few factors to be considered like the degree of friction of two or more materials in contact, impact intensity, and shock-absorption characteristics while analyzing the spark-proofing nature of any mechanism.
- It can be considered that gears, especially those with a high load present high risks to start and spread sparks.
- For a spark to be dangerous must have a high temperature and exist for a certain period of time in order to start the combustion of a flammable compound.
- In some cases, equipment may generate *cold sparks*. In this case, based on a **reduced quantity of heat**, they are not capable of starting a fire through CS_2 ignition.[3]
- Cu and Cu-based alloys have good chemical composition and structure distribution and most of the time single-phase materials. Usually, these materials are not transformed through heat treatments, and the main properties can be modified through cold or hot plastic deformation. Anyway using Be (beryllium) as accompanying elements between 0.6 to 3%, Cu-alloys present a hardening of the materials by formation of precipitates.
- Table 2 presents a summary of the potential spark-proof materials that can be utilized in our mechanism.
- Recent research has led to the identification of a new possible alloy system of bronze with aluminum and beryllium to reduce the possibility of spark production.
- Use of Aluminium and Carbon Fibre in a composite fashion as our building material provides us with the required spark-proofing behavior. [3]

6.2. Waterproofing Material:

- **Purpose:** This aspect aims to safeguard internal components from water ingress during immersion, ensuring the reliability of the telescopic shaft in wet or underwater conditions.
- Waterproofing is a protective measure aimed at preventing the infiltration of water or moisture into structures, surfaces, or materials to shield them from potential damage. In electrical systems, it is vital to avert short circuits and corrosion, mitigating the risk of failures due to water exposure. Similarly, in mechanical systems, it protects moving parts and components from water-induced corrosion, ensuring longevity and preventing premature failure.
- Waterproofing methods, such as coatings, membranes, sealants, and drainage systems, are employed to preserve structural integrity by preventing water ingress. In both electrical and mechanical applications, the use of seals, gaskets, and coatings establishes a protective barrier against water, enhancing system durability and minimizing the risk of malfunctions, downtime, and costly repairs due to water-related damage.
- Hydrophobic nano-TiO_2 can be used to produce a TiO2 coating spray over the shaft as it repels the moisture for corrosion protection of metals. In addition, it has Anti-foul and heat-stable characteristics.
- Laser carving on metal surfaces can be used to create patterns that repel water enhancing anti-corrosive nature.
- We are using collapsible tubes, coated with TiO2 spray, in our design for waterproofing purposes.

Material	Spark Formation	Thermal Conductivity (W/mK)	Corrosion Resistance	Mechanical Strength (MPa)	Ductility	Applicability
Cu-Al	Cold sparks	High (150-400)	Good	Higher than steel (590-760)	High	Explosive environments, periodic inspections
Stainless Steel	Cold sparks	High (15-20)	Excellent	Higher than Cu-Al (505-580)	Moderate	Various applications, corrosion resistance
Ag-base Materials	Cold sparks	Moderate to High	Good	Moderate (200-300)	High	Various applications, corrosion resistance
Al (Aluminum)	Not confirmed	High (205)	Good	Lower than steel (240-310)	High	Possible non-sparking material, needs confirmation
Cu-Zn	Not clearly highlighted	Moderate to High (96-121)	Good	Lower than steel (290-490)	Moderate	Potential non-sparking material, unclear spark ability
Cu-Sn	Not clearly highlighted	Moderate to High (43-72)	Good	Lower than steel (300-600)	Moderate	Potential non-sparking material, unclear spark ability
Cu-Ni	Not clearly highlighted	Moderate to High (30-50)	Good	Lower than steel (290-520)	Moderate	Potential non-sparking material, unclear spark ability
Cu-Be	Potential risk, safety concerns	Moderate to High (150-200)	Good	Higher than steel (860-1380)	Moderate	Hardening through Be alloying, safety concerns with Be exposure
Ti-based Alloys (Ti6Al4V has burning-resistant mechanism)	Spark risk	Low (6-10)	Good	Higher than steel (620-1150)	Moderate	Potential non-sparking material, but sparks in tests
Cu-Zn Alloys	Spark ability not clearly highlighted	Moderate to High	Good	Lower than steel (290-400)	Moderate	Potential non-sparking material, unclear spark ability

Table 2: Summary on Spark-proof Materials [3]

6.2.1. *Specialized Coatings:*

- **Hydrophobic nano-TiO2 coating:** Enhancing corrosion protection for metals, especially 316L stainless steel, involves the deposition of hydrophobic nano-TiO2 composite coatings. This process utilizes a sol–gel method and hydrothermal post-treatment to optimize the coating's structure and properties, effectively addressing cracks and defects. By employing FAS-13 self-assembly, high hydrophobicity is achieved in both organic and inorganic nano coatings. This then repels moisture for corrosion protection of metals and provides antifouling, heat stability, and corrosion resistance.[13]

- The material is expensive and Synthesis of TiO2-based nanomaterials is a complicated process that requires a lot of time and effort.

- Multifunctional surfaces produced by femtosecond laser pulses modify optical and wetting properties. The resulting superhydrophobic surfaces, achieved through laser-induced nanostructures and chemical coating, offer self-cleaning effects, repelling water and dust. These surfaces also provide multifunctionality, including anti-corrosion, anti-icing, anti-biofouling, and self-sanitation. The combination of large water contact angles (>150), low sliding angles (<10), and reduced adhesion between surfaces and dust particles contributes to the enhanced performance of these laser-generated structures.[17]

- Laser carving on the metal surface is required to create a pattern that repels water by broadband absorption, superhydrophobicity, and self-cleaning which is highly costly and complicated to achieve.

6.2.2. *Gaskets and Seals:*

Waterproofing materials used in machines are designed to protect sensitive components and ensure the equipment's functionality even in wet conditions.

- **Silicone sealant** is a simple type of adhesive that's commonly used to create a water or airtight seal between two surfaces. It typically has a gel-like consistency when you first apply it, making it easy to fit into gaps. It then cures to a robust, rubber-like texture that's very durable.[16]

- **PTFE** is virtually inert to all chemicals, including highly corrosive acids, making it an ideal material for applications where harsh chemicals are present. It can operate continuously at temperatures as high as 260°C (500°F), making it suitable for high-temperature applications. Additionally, PTFE has one of the lowest friction coefficients among solids, often used in applications where sliding action of parts is needed 1.[18]

- PTFE exhibits outstanding corrosion resistance in most aggressive environments, remaining stable except for exposure to liquid alkali metals, fluorine, and potent oxidizers. PTFE coatings provide exceptional chemical and corrosion tolerance, non-adhesive properties, and high-temperature resistance up to 260°C. Despite its challenging fabrication due to limited flow, molded parts can be produced through compression and heating of fine powders with lubricants. Alternatively, metallic surfaces can be coated by spraying or dipping in aqueous PTFE dispersion.

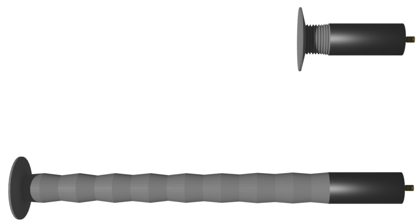


Figure 12: Collapsible Tubes Waterproofing

6.2.3. *Collapsible Tubes:*

- Collapsible tubes are typically made from materials that can be formed into a tube shape and then collapsed into a two-dimensional state when not in use. This is often achieved by using a two-dimensional element, such as a sheet or a strip, and folding it into a tube shape. The tube can then be expanded by adding two surfaces at the ends, creating a watertight surface that encloses a certain volume.

- The material used for the tube can significantly affect its properties and uses. For example, Nitrile Rubber (NBR) is known for its excellent water resistance, making it suitable for use in environments where the tube may be exposed to water. Chloroprene Rubber (Neoprene Rubber) is known for its flexibility and durability, which can be beneficial in applications where the tube may need to be stretched or bent.

6.3. *Abrasion-Resistant Material:*

- Abrasive wear has been defined as the displacement of material caused by hard particles or hard protuberances where these hard particles or protuberances are forced against and moving along a solid surface.

- Aluminium-silicon alloys and aluminum-based metal-matrix composites (MMCs) containing hard particles offer superior operating performance and resistance to wear. In industrial processes where abrasive slurries are transported by rotating paddles or impellers, elements fabricated from MMC materials provide higher abrasive resistance and therefore a longer service life compared to those made from iron or nickel-based alloys.

- Aluminum alloys are the most commonly utilized materials in composite fabrication (e.g. 2000, 5000, 6000, and 7000 series). The reinforcement phase is generally one of the following, continuous boron or graphite fibres, or ”hard particles” such as SiC and Al_2O_3 in discontinuous particulate or whisker morphology. [4]

- The fabrication of composites containing so-called ”soft particles” (graphite or boron) favors a reduction in the coefficient of friction in dry sliding wear in bearings.[4]

- **Nitrided Titanium:** A nitrided layer of titanium with a thickness of 2μm shows a Vickers hardness of about 1300, about 10 times higher than that of pure titanium, and was strongly bonded with the pure titanium base metal.[14]

- **Iron Carbide Alloy** with Austenite-Carbide Eutectic micro-structure shows the highest resistance to abrasion among any Iron-based alloys. The particular alloy is composed of Carbon (>4% by weight) and Chromium (>16% by weight) which develops the Austenite-Carbide Eutectic hard-facing micro-structure.[11]

- We are using Iron Carbide Alloy to provide resistance against abrasion. Thin layers of this material are provided wherever displacement of material is expected due to hard particles or hard protuberances.

6.4. *Lubrication Material:*

- Silicone grease, also known as dielectric grease, is a waterproof lubricant created by blending silicone oil with a thickener, typically polydimethylsiloxane (PDMS) and amorphous fumed silica. Specialized variants may use fluorinated silicones or PDMS with phenyl substituents for low temperatures, with alternative thickeners like stearates and powdered polytetrafluoroethylene (PTFE).[1]

- This grease dissolves in organic solvents such as toluene, xylene, mineral spirits, and chlorinated hydrocarbons but remains insoluble in methanol, ethanol, and water.

- When it comes to coating leadscrew material, PTFE Teflon is the chosen option. In terms of compatibility with silicone grease, it’s described as very compatible, earning an excellent Grade A rating for compatibility.[2]

- For optimal lubrication, the preferred choice is a Dry PTFE Silicone spray. It’s emphasized that no grease or oil-type lubricant should be used to prevent the entrapment of colloidal particles which could jam the whole system.

7. Final Working Model Design and Specifications:

The working model of the finalized Lead-Screw mechanism was done in Solid-Works and a step file with the assembly, parts, and a README file for opening the assembly has been attached along with this report.

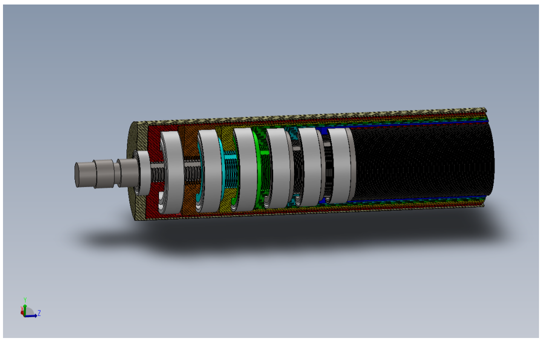


Figure 13: Ideal Retracted state of the mechanism

8. Ansys Structural Analysis:

To make our model stable, intact, and at the same time lightweight, we came across many materials, the ones that caught our eyes were titanium alloy and Aluminium alloy. Keeping our structural strength requirements in mind and the weight of the two alloys, we have selected **Aluminum alloy Al7075** for screws and **Reinforced Carbon fiber** for nut of the lead screw mechanism.

8.1. *Properties Of Aluminum alloy AL7075*

- Density: $2.81 g/cm^3$
- tensile strength: $525 MPa$
- Elasticity: $71.7 GPa$

8.2. *Properties Of Carbon Fiber*

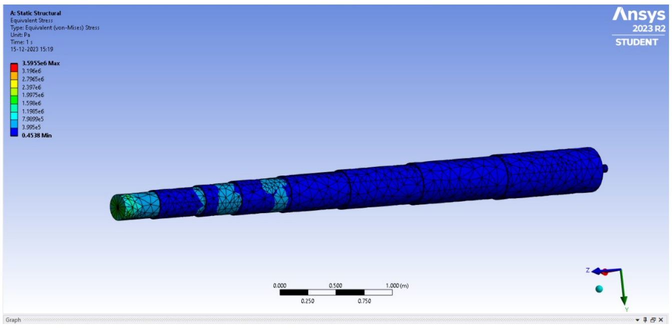
- Density: $1.9 g/cm^3$
- tensile strength: $3.5 GPa$
- Elasticity: $228 GPa$

The weight of the system with aluminum alloy AL7075 as screw and carbon fiber as nut is 151.47 kg. So the self load of the system is 1485.921 N. The model of the motor at the end of the shaft is **TMS160** and weighs 109 kg. So the imposed load of the motor is 1068.2 N. Therefore the total load on the topmost screw is 2554.12 N. Multiplying it with the **FOS** of 1.5, the resulting load is 3831.3 N. To check the structural integrity of our Screws, we have performed simulations in Ansys - Static Structural under the weight of the motor + self-weight multiplied by a factor of safety.

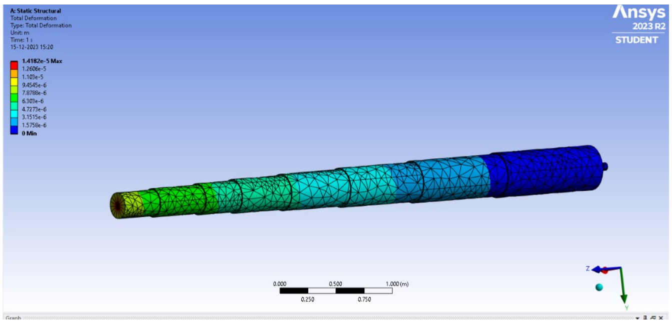
9. Calculations for Von-Mises Stress

Von Mises stress is a critical parameter used to assess the yield or fracture potential of materials, particularly ductile ones like metals. The von Mises yield criterion posits that if the von Mises stress of a material under load equals or exceeds its yield limit under simple tension, the material will yield.

We are calculating the von-Mises Stress to evaluate the strength of the lead screw in our mechanism. Von-Mises Stress



(a) Equivalent Stress Distribution



(b) Total Stress Distribution

Figure 14: Static Structural Analysis

is a combination of axial loading, bending stress, pure stress, and torsion:

$$\text{Axial Loading: } \sigma_y = \frac{4F}{\pi d_r^2}$$

$$\text{Bending Stress: } \sigma_x = \frac{6F}{\pi d_r P}$$

$$\text{Pure Stress: } \tau_{zx} = \frac{4T}{\pi d_r^2 P}$$

$$\text{Torsion: } \tau_{yz} = \frac{16T}{\pi d_r^3}$$

Here, F is the downward force due to the pre-load, T is the torque on the root of the screw, d_r is the root diameter of the screw, and P is the pitch of the screw.

The torque T is calculated using the Nut Factor K:

$$T = \frac{KFd_r}{1000}$$

Now, the Von Mises stress (σ') is determined as follows:

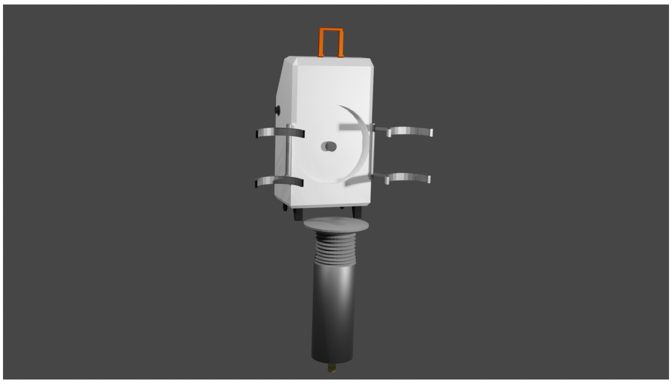
$$\sigma' = \frac{1}{\sqrt{2}}\Big[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x) + 6\left((\tau_{xy})^2 + (\tau_{yz})^2 + (\tau_{zx})^2\right)\Big]^{\frac{1}{2}}$$

Given a Nut Factor of 0.4, the calculated Von Mises stress is 4.8 **MPa**, which is significantly below the yield strength of AL7075.

10. User Experience and Portability

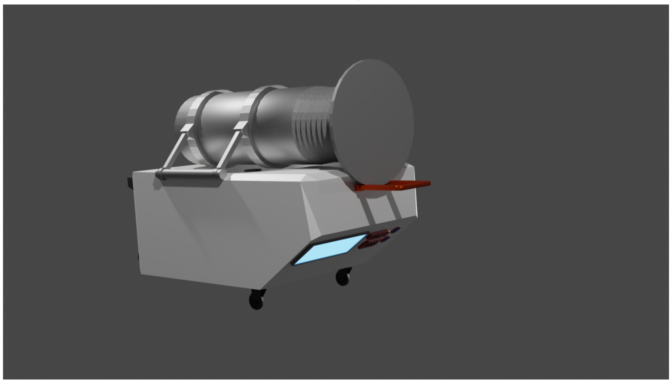
- The Figures 19,20 and 21 depict how the final manufactured model is expected to look in its retracted state.
- The mechanism would require a single switch for the retraction/deployment process as depicted in Figure 14(ON/OFF).
- The design can be further tweaked to control the agitator mechanism, deployment speed and depth of deployment which would completely depend upon the manufacturer.
- As far as portability is considered a handle along with wheels can be designed for moving around the shaft easily.

(a) Single ON/OFF switch for User-Friendliness



(b) Arms for Balancing the equipment

(c) Handles for portability



(d) Wheels for transportation

Figure 15: Representation of the User-friendliness and Portability of the mechanism

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