BILKENT UNIVERSITY
DEPARTMENT OF MECHANICAL ENGINEERING

INDUSTRIAL DESIGN PROJECTS

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CONTENT

PREFACE

The primary goal of university-industry collaboration is to provide future engineers with a broad understanding of industry and business. In support of this goal, we have a two-semester long design activity for the senior-level students. This year, thirteen groups, each consisting of six students, were provided with design projects from leading industrial organizations. Projects were selected such that students could leverage their undergraduate studies to design a product needed in today's world, but also bring out their creativity in both the design phase, completed in the first semester, and in the manufacturing phase in the second semester.

At the project fair, the students are provided with the unique opportunity to present detailed design specifications of their products alongside the manufactured prototypes. The fair and this booklet explain the design and manufacturing goals, constraints, challenges, and, of course, the students' efforts that led to their accomplishments. The continuous guidance and advice provided by their academic and industrial mentors, instructors, and teaching assistants are very much appreciated.

On behalf of the Mechanical Engineering Department, I would like to thank all those who have generously contributed their time and resources that enabled tomorrow's engineers to gain invaluable experience during this process and demonstrate their capabilities.

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Design and Manufacturing of Automated Fiber Placement Machine Head

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Abstract

With improving composite technology and increasing usage of composite materials, automation becomes more and more necessary in manufacturing of these products. Automated Fiber Placement Machines (AFP) are designed for this purpose increasing speed and quality for composite layup process. However these machines are expensive, hard to obtain and their design are quite new, thus open for improvement. Here we present a new design for an AFP machine head to be produced in Turkey. The design will be based on certain requirements for AFP machines and there is an objective defined considering common composite products. The requirements are originated by either material properties, layup procedure standards or by the sponsoring company. Our design will differentiate from current ones due to its modularity and size. The literature on AFP shows that these machines should be capable of doing many processes simultaneously to achieve automation. Therefore the design is separated to individual subsystems fulfilling different processes: gimbal, unwinding system, restart feeder, cutter, compaction roller and heaters. Each part is designed

individually with their own criteria and purpose to be assembled to a whole AFP design. At the end of the project a prototype which meets the requirements of a typical AFP machine is created.

PROJECT DESCRIPTION

Composite parts have been using in different areas such as defense and automotive industry because parts that are manufactured from composite materials are strong and light at the same time. Due to the fact that composite part manufacturing is one of the most trending technologies in industry. The problem for the use of these materials for manufacturing parts is their high cost and complex production methodology. A composite material is made from strong fibers placed within a resin structure resulting in a material called prepreg. Most common composites are carbon fiber prepregs. A material is produced from prepregs by placing multiple layers of the material on top of each other with different angles, then heat processing the multi layered semi product in autoclaves [1]. The most time consuming and expensive part of production is the layup process. Around the world most of the layup is done by hand layup whereas in Turkey, almost all layup is done by hand. Automation of this process increases production speed and quality as well as allowing more complex geometries to be produced from prepress. The automation in production is achieved by Automated Fiber Placement machines (AFP). Here we present an AFP machine head design to be produced in Turkey for national and international market.

Automated fiber placement enables the construction of complex composite structures having steered or fiber surface with curvature. This method of producing composite structures is more cost effective than manual methods. It provides an improved structural efficiency due to its ability to orient the fibers along local internal load paths, which potentially results in lighter structures and lower costs than in structures made by other production methods. By producing an AFP machine Turkey will also acquire easy reach to the technology of composite part manufacturing and this will make further applications of composites possible. In addition to this, Turkey's foreign dependency at composite part manufacturing industry will decrease. Moreover, due to the fact that composite production in Turkey will no longer be restricted with hand crafting, the quality of composite produced as well as rate of yield production will be increased. In 2014, 8 millions of tons composite produced around the world while Turkey produced 245 tons of composite [2]. This means Turkey only covered 3% of composite demand around the world. Thus it is required to increase mass production of composites. AFP machine that arises at the end of this project will work integrated with Cartesian linear robotic system. Resulting integrated system will be used to produce curved parts for automobile and defense industry. These are the reasons provided that makes the problem relevant.

Considering the common products made from composites there is defined a final objective such that an AFP machine should satisfy. The final objective of the project in technical approach is to design an Automated Fiber Placement machine head which is capable of laying-up 1/8 or 1/4 inch thermoset fiber prepreg tows to 1.2x2.4m^2 surface, in a maximum curvature of 12 cm with a 30/1000 inch gap tolerance.

To sum up, the problem is the automation of composite material production to achieve the final objective. There are several current solutions around the world to this problem; however, the solutions are ever improving.

There are several processes that an automated fiber placement machine should be capable of no matter how the machine is designed. These processes can be shown in the following chart:

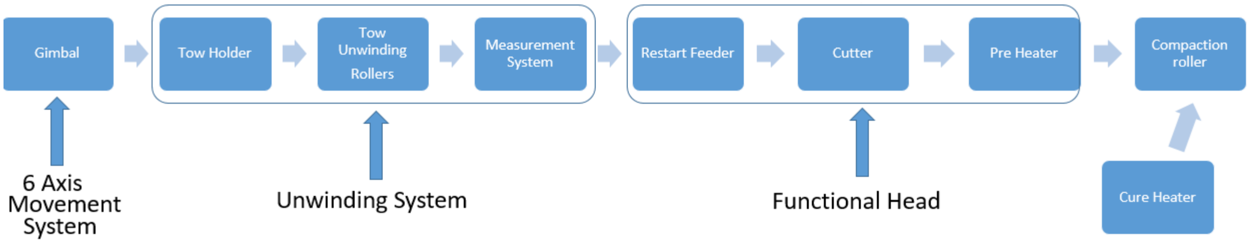

Figure 1: Flow Chart of the chosen concept

It should be able to hold the material that will be used for lay-up. Composite material should be unwinded to be used, this process should be done by applying tension to the composite in a certain range. Measurement system should be used to keep the tension in this acceptable region which will not harm the material. After unwinding operation, the material is entering the functional head. Functional head should be capable of four main functions: Restart Feed, Cut Mechanism, Heating and Compaction system. These functions are necessary for the lay-up process. As when the material cut to start a new ply (lay-up) due to tension material tries to go back to the tow holder, to prevent material leaving the functional head a mechanism should hold the material just after cut operation. Moreover, after cutting operation the material should be fed to the compaction roller for the next lay-up starting point which is done by restart feed mechanism. In addition, the material should be lay-up with a certain pressure to the surface. This pressure is obtained by compressing material between a roller, called compaction roller, and the surface area. Last but not least, heating system is used to cure thermoplastic material and is used to cure the thermoset material after the lay-up. [1][4]

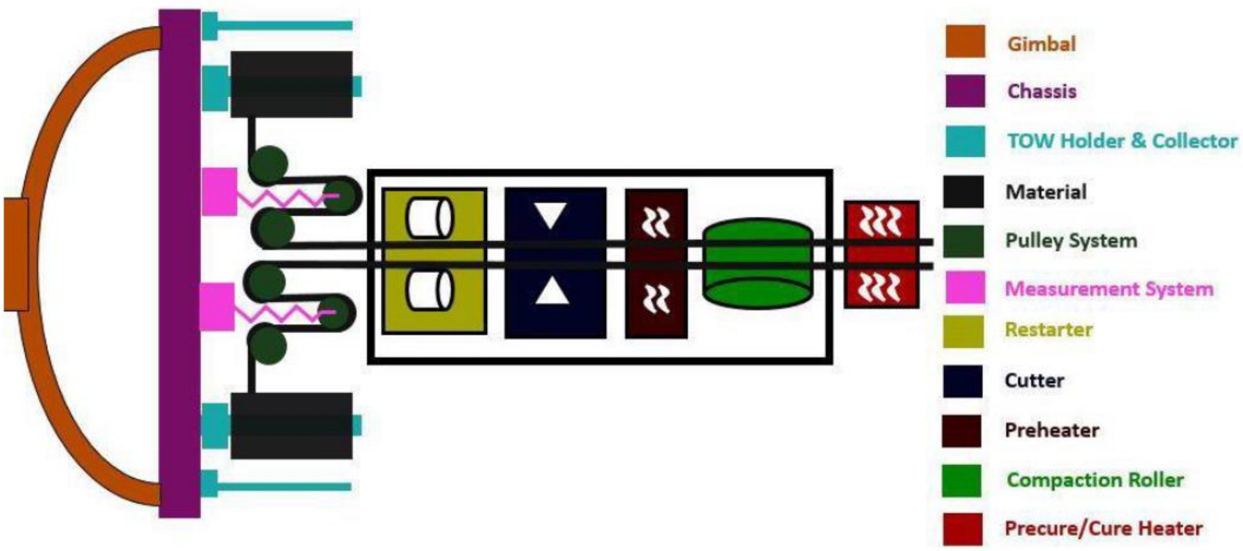

Figure 2: Conceptual Design Scheme showing separated parts of an AFP (Automated Fiber Placement) Machine

MILESTONES AND ACCOMPLISHMENTS

Although during such a complex structure design and manufacturing the some of the milestones are interbedded the milestones and accomplishments can be enumerable as like followings:

Material Specifications Search: The first thing that is done is making research about composite materials. Hence our main aim is to lay-up, thermoset carbon fiber reinforced epoxy resined single tow prepreg, we started to make research and understand the mechanical and thermal behavior of the material under different circumstances.

Design Selections: For design selection the essential parts of an AFP machine is examined and for which sub-part what type of and mechanism should be used is decided.

Conceptual Design: According to the design selections a basic conceptual design had been done.

Preliminary Design: According to the conceptual design rough but 3D modeling for our new machine has done.

Test Mechanism Design: To test the

Learning Machine Elements: After selecting parts and create preliminary design before starting detailed design of the machine we aim to start detailed 3D modeling. However for detailed design machine elements knowledge is essential. We started to make research and started to learn the literature of machine elements. Bearings, shaft design, snap rings, screws and bolts also belts and chain are examined. Machine elements assembly protocols were studied from their data sheets and taught by Akana engineers.

3D Modeling: After preliminary design a realistic 3D model is started to be created by SOLIDWORKS. Every sub-part that is divided to the work packets are modeled by themselves first, from their big main parts to their shafts and o rings. After that all packets are assembled and the 3D model of machine is created.

Simulations and Mathematical Modeling: A mathematical model is created for specify the gimbal power and torque requirements. According to the results of the mathematical model optimum design parameters were determined. Also for understanding deformation of compaction roller and restart feeder under force material behaviors of these materials modeled based on Hertz Model of contacting materials. For cutter cutting force and speed calculations are done and pneumatic piston system is designed and selected based on this calculations. Also stress analysis of specific self-design parts are done and they improved based on this analysis.

2D Drawings: Technical drawings of the sub-systems which 3D models are finished are done. During the 2D drawings tolerancing is done carefully to ensure mounting guarantee.

Manufacturing: Manufacturing process of the subsystems that 2D drawings are finalized have been started.

Assembly: At the end of the April the assembly would be finished.

Calibration and Test: During the May through the demo the test and calibration would done

MATERIALS AND METHODS

Hence this machine is a complex system which has complex subsystems lots of choices had to be done and lots of unique parts are designed. There are 218 parts, 55 of them are unique parts and will be manufactured. Chosen parts and systems are listed below, also the manufacturing of unique parts will be mentioned.

Motors and Drivers: According to the mathematical model and system requirements SMH 60 series of motors by PARKER are used.

Reductors: GM 45 dynabox 50-70 are used as redactors.

Pneumatic Pistons: According to the mathematical model and system requirements pneumatic piston systems by PARKER are used.

Bearings: Several types of bearing are used in the project. SKF deep grow ball bearings and drawn cup needle roller bearings are used.

Prepreg: ¼ inch single tow carbon fiber prepregs are composite materials which we aimed to lay-up. This material is coiled up to a bobbin. The material inside has carbon fibers and epoxy resin.

Screws and Bolts: DIN 912 standard screw and bolts are used.

Materials used in Production: For the chassis, gimbal and main body a manufacturing process needed. These parts are manufactured from aluminum alloys. Also the shafts, lids and other small parts are manufactured from AISI 1040, AISI 1020 or 4140. In order to satisfy the considerably critical tolerance values, computerized numerical control (CNC) machines are used in manufacturing.

CONCLUSION AND FUTURE DIRECTIONS

For the company this project would be a ten year project. The aim is after this ten year developing an AFP machine which can be released or used in their facility to produce composite parts with full performance. Besides manufacturing an AFP, one of the main challenges is developing the algorithm behind the scene. To be able to do that manufactured prototype will be used by Akana Engineering for developing sophisticated algorithms that are capable of identify lay-up surface and determine lay-up path for complex surface.

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Enhancing the Performance of the Grill Heating Systems and Obtain Homogeneous Heat Distribution at the Cooking Product

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Abstract

The scope of the project is to increase the grilling performance of the cooking grill. The performance test will be done after 8 minutes of cooking toast breads. After cooking, colors of breads will be determined and according to color distribution, performance parameter will be obtained. Our main goal is to estimate the resistance performance, including straight and curved parts of the resistance, and reach optimum shape which will provide more homogeneous heat distribution on the cooking surface.

PROJECT DESCRIPTION

The project is about enhancing “Grill Oven Heating Systems” which is used in built-in ovens of Arçelik A.Ş. Pişirici Cihazlar İşletmesi. Main problem is about homogeneous cooking of the products in the oven. Project goal is to design a system which achieves the desired success. By doing this we will be able to get accurate homogeneous cooking in regular uses of the built-in ovens. In this project, which is on the purpose of making improvements at the “Grill Oven Heating Systems”, mechanical design and material selection processes are our top priorities. Also, the performance of the design, its heating capacity and its heat distribution technique are going to be a part of thermodynamic concept. As a whole, this project holds different concepts of mechanical engineering and from these concepts, both practically and theoretically experience can be gained. Figure 1 shows the modeled oven by using software.

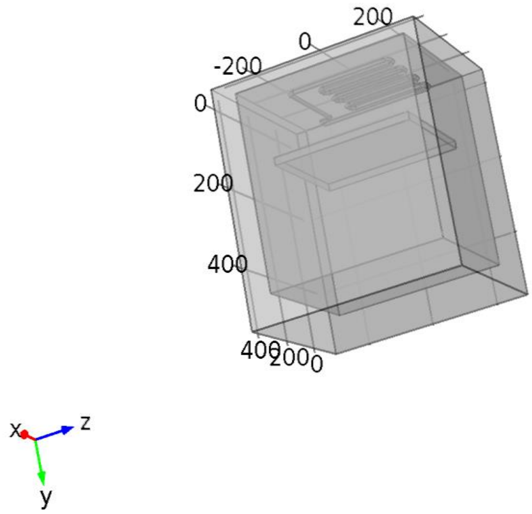

Figure 1: Geometry of oven

The systems, which is going to be used while production and development processes, and the solutions of the possible problems that may be seen while these processes can be used at the future for different products of supporting company. Our final product will provide more economical and more efficient usage for the customer in addition to features of homogeneous grilling and increments at the efficiency of grilling performance.

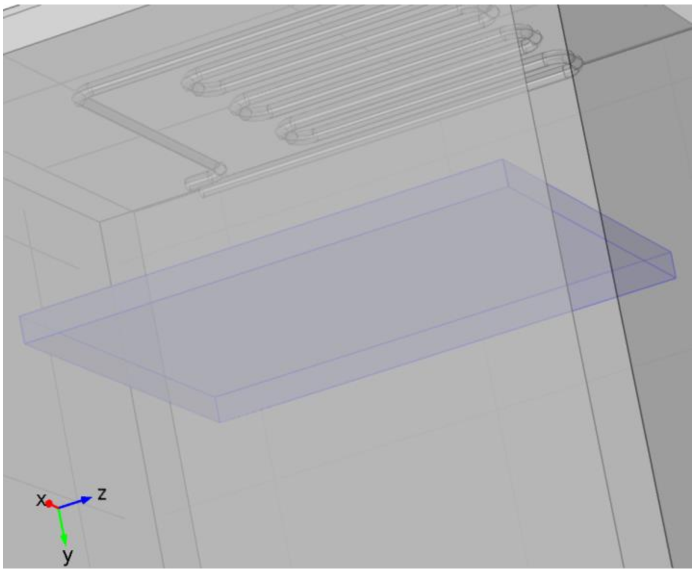

Figure 2: Cooking surface

In the existing ovens, homogeneity cannot be achieved mainly because of the resistance tubes. Observations showed that homogeneity in the ovens is lost because of the curving parts of tubes. Inside of tubes there are Nichrome wires. Figure 2 shows the cooking surface inside the oven and figure 3 shows the Nichrome resistance tubes. Roughly, supplied currents heat the wires inside the tubes and radiation occurs. But during the manufacturing process of existing tubes, wires per area get reduced because of the curves. Computer aided observations showed that heat of curved parts is so small compared to long and straight parts. That causes the heat distribution in the oven to be irregular.

MILESTONES AND ACCOMPLISHMENTS

Milestones for this project are determined in cooperation with Arçelik A.Ş, and satisfied throughout the process of design and production

- Toasting bread will be placed on the grill in order to determine the performance of the grill. The result of the color scaling analysis device should not exceed 14 in the BSI color scale.
- The power values of the inner and outer resistances of the top grill should not exceed the existing value.
- W/cm^2 value of the heater should not exceed 4.5.
- The grilling should be done in the specified rack which is stated in the user manual.
- In the toasting bread experiment, the total grilling time should not exceed 8 minutes with 5 minutes of pre-heating process.

MATERIAL AND METHODS

Using the features of COMSOL, current grill is modeled and temperature analysis is obtained. According to simulations in COMSOL, 4.4A is the current value in the resistance with a power supply of 220V.

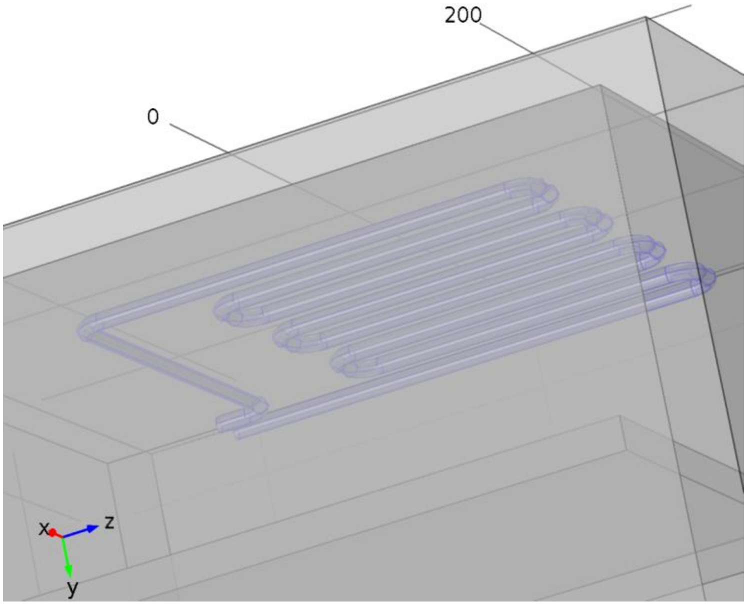

Figure 3: Nichrome resistance tube

RESULTS AND PERFORMANCE EVALUATIONS

Figure 4 represents the temperature distribution on the resistance tube. The uniform temperature across the straight parts in resistance gives us the opportunity to model the straight parts of the resistance with a single temperature value. Also it was proved that there is a temperature drop across the bending parts compared to the straight sections. Figure 4 shows the temperature distribution along the wall of the oven.

This conclusion made us to model the whole resistance as a composition of “straight” and “bending” parts. We defined two different uniform temperature values like a single point temperature, one of them for the straight section and the other one is for the bending parts. We defined 1500 Kelvin for straight sections of the resistance and 1300 Kelvin for the bending sections. This stationary analysis in the COMSOL model is convenient because in the actual experiment there is a 5 minutes pre-heating period before putting the breads into the oven and after this pre-heating period, the temperature values in the resistance become stationary, not transient. Figure 5 shows the cross-section of the resistance tubes.

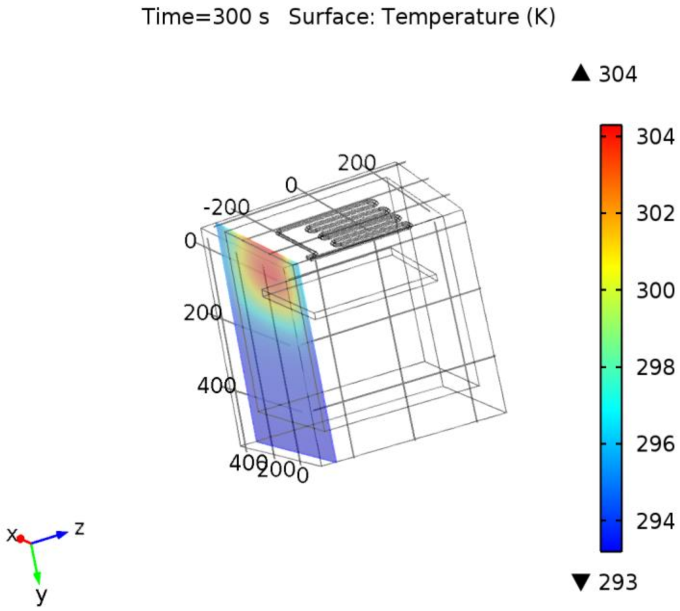

Figure 4: Temperature distribution

Joule Heating module in COMSOL was used in order to obtain the temperature distribution in the resistance. The total resistance in the NiCr tube was designated as 50 ohms. According to our simulations in COMSOL, 4.4 Amps is the current value in the resistance with a power supply of 220 Volts.

Figure 5: Cross-section of the resistance

CONCLUSION

Project goal is to design a grilling system which achieves the desired performance (85%). This performance percentage is obtained from the BSI color scale that Arçelik A.Ş. Pişirici Cihazlar İşletmesi uses. The scale is unique for the machine that they use, so we found a relation between the BSI color scale and temperature. By using our new temperature parameter, the performance of the grilling is enhanced.

At the first stage, patent and literature researches are done to investigate the grilling principles of ovens. After that, in order to obtain constant parameters of the problem, such as, dimensions of oven, given power input or desired temperatures, briefings are taken from Arçelik A.Ş. Pişirici Cihazlar İşletmesi and our industrial and academic mentors. Also, software analysis of the current grills are done by using COMSOL in order to understand the behaviors of grills, such as what happens at the rapid bending or what happens at the long straight grills, and temperature distribution on the cooking surface.

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Mechanical Design of a "Clam Shell" Type Dome for TUBITAK National Observatory

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Abstract

Clam-shell dome project aims to design and manufacture a clam-shell dome with a diameter of 1.5 meters made up of fiberglass with integrated controller mechanisms. As a group, our motivation is to design and manufacture a clam-shell dome which coincides with the standards of TÜBİTAK National Observatory, and represent the name of Turkey with a delicately innovated design. Design process of the clam-shell dome has been dealt step by step. First step consisted of distinguished technical perspective and conceptual design. Other steps followed the predetermined technical perspective and the design has achieved its up to date form. Following such distinguished technical perspective allowed us to succeed in finalizing the project, and perform practical and experimental tests to prove our claims such as isolating the scientific instruments placed inside the dome from outer effects.

PROJECT DESCRIPTION

Clamshell domes are used to protect the telescope from the environmental conditions. That is needed, because telescopes are immobilized at the observatories and they need to stay there in all weather conditions. That is why there should be a protection for telescopes. Clamshell domes meet this demand. They are in shape of domes because the spherical structure is the best against weather conditions, especially drag force due to the wind.

Clamshell domes have four slices and two of them are on the one side of dome and the other two are on the other side. Motor turns and slices open with a belt from the top of the dome. So the telescope will be outside totally and ready to observe the space.

Figure 1: Standard Clamshell dome

We, as a group, were willing to design a clam-shell dome for TÜBİTAK National Observatory. They asked us to build up a clamshell dome with the diameter of 1.5 meters because they were in need of it which is not produced in Turkey.

The main goal of the project is to increase the isolation of clamshell, mostly around the end of the slices. To achieve this goal, we designed our clam-shell's slices to reduce the gaps among them. So, the telescope would be more isolated from the weather conditions and well protected.

Additionally, the main body of the clamshell should be resistant against the wind with the velocity of 300 km/h at most. Therefore, clamshell should be strong. Also, since slices move around the pivot tube with motor power, they need to be light. These requirements are satisfied with the fiberglass. Also, it is low cost material and easy to produce. These all features of fiberglass shaped our mind for the material of the main body. That is why we choose fiberglass to produce our clamshell dome.

MILESTONES AND ACCOMPLISHMENTS

Milestones for this project are determined in cooperation with TUG, and satisfied throughout the process of design and production

1. Acquisition of our own project through personal attempts and network capabilities

2. Satisfying the needs for initial documents and requirements of the project and obtaining BIDEB fund

3. Complete literature search for intended clam-shell dome type and establishing a final concept suited for all units and individuals involved

4. Successful design of components of the desired end-product and adequate solutions to the problems given in the definition

5. Scaled down, 3D printed version for a visual aid and mechanical analysis of the system

6. Proper mechanisms, motors, gears are selected suited for the conditions and requirements for the design

7. Recognition of the design to build a full-scale product by our mentor

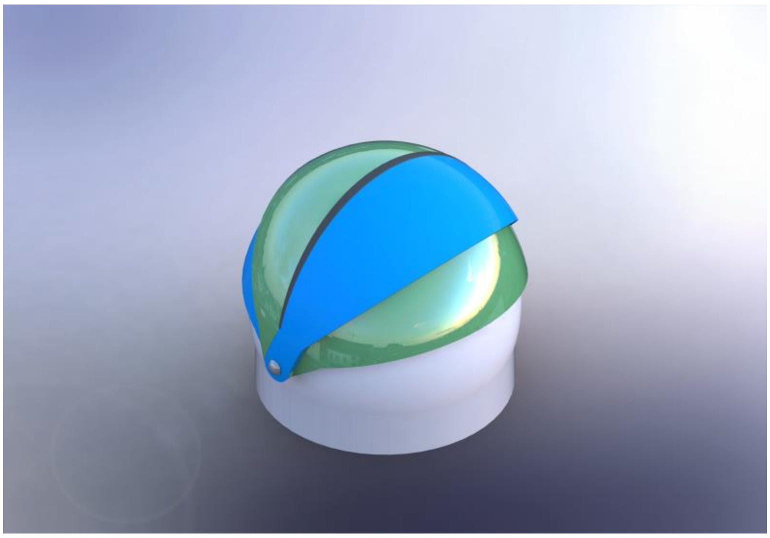

Figure 2: Final Design

MATERIALS AND METHODS

The materials used to produce such an integrated clam-shell dome can be listed as follows:

- 4 Specifically Designed, Identical Fiberglass Dome Slices
- 2 Fiberglass Cylindrical Dome Base
- 2 Pivot Tubes
- 150 W Brake Motors (2 pieces)
- 1/15 Ratio Worm Gearbox (2 pieces)
- Motor Drivers
- Hall Effect Sensors
- Power Distribution Board
- Safety Belts
- Pulleys
- Gaskets
- Bolts and Nuts

The fiberglass parts of the dome are manufactured in Antalya by using conventional fiberglass manufacturing techniques. Short fiber glass is chosen intentionally for this project in order to have material strength in all directions equally. The power required to supply to the system by motors is determined as 150 Watts. The thickness of the pivot tubes is calculated through basic beam deflection calculations.

RESULTS AND PERFORMANCE EVALUATION

First, multiple number of designs were investigated and engineering calculations were made with taking the desired mechanical problem into account. The main problem was to prevent external factors such as dust, snow, water etc. from infiltrating inside of the dome and resultant interfering with the proper operation of the telescopes and the dome itself.

Figure 3 show the drag force on the dome when closed and half open in which case parachute like effect is observed which increases the drag force.

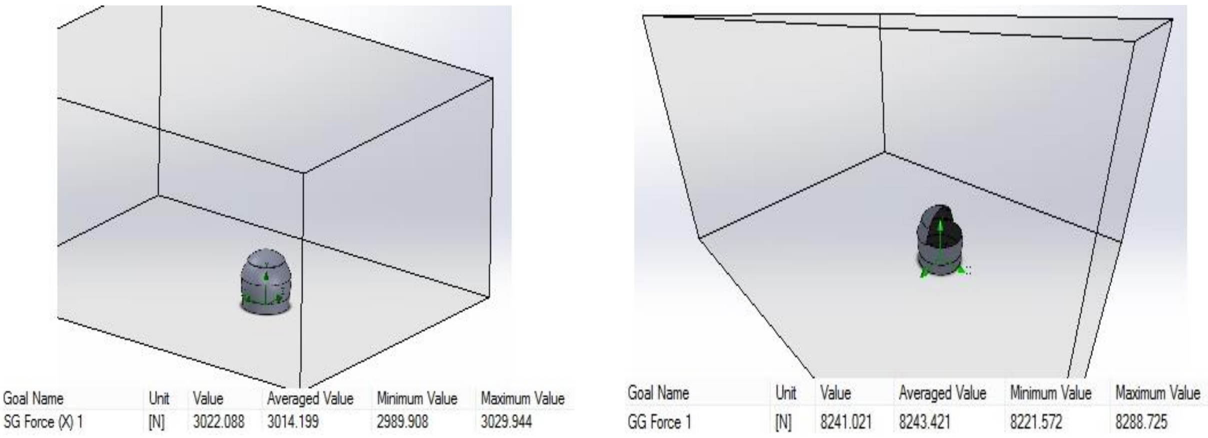

Figure 3: Drag force

The stress analysis of one slice of the dome satisfies the requirements as can be seen in figure 4. The stress analysis of the pivot tube, which carries the load of the slices and holds them stable, is also proved to be safe as can be seen in figure 5.

To test and evaluate the functionality and competence of the dome, a prototype was manufactured via 3D printer (figure 6). The prototype didn’t satisfy the desired mechanical and surface properties because of poor quality manufacturing, however it allowed us to confirm that the design solves the main problem of preventing external factors with satisfying functionality.

After manufacturing the first prototype, several tests were performed on the joint area where slices meet around the pivot tube. It was seen that the prototype succeeded and withstood the effects of wind, dust and low temperature. Several design changes such as thickness and orientation were made to improve the strength of the design.

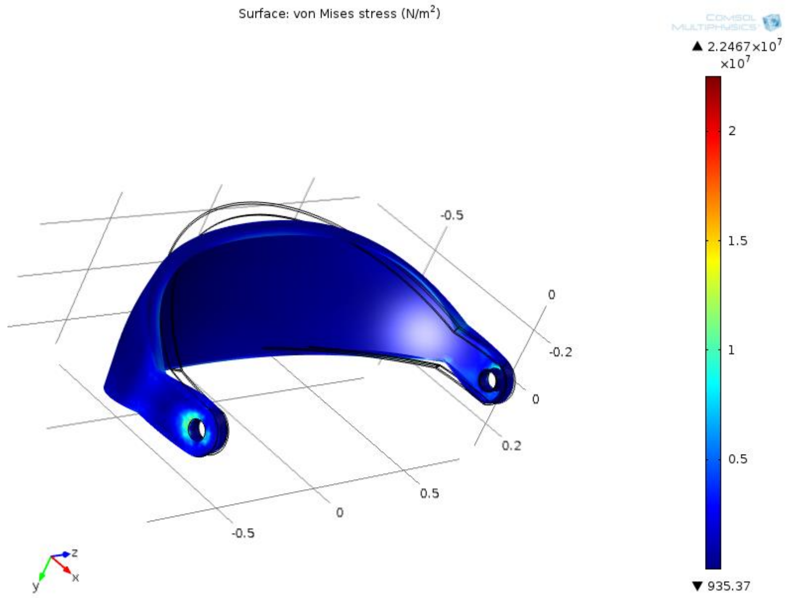

Figure 4: stress analysis of dome

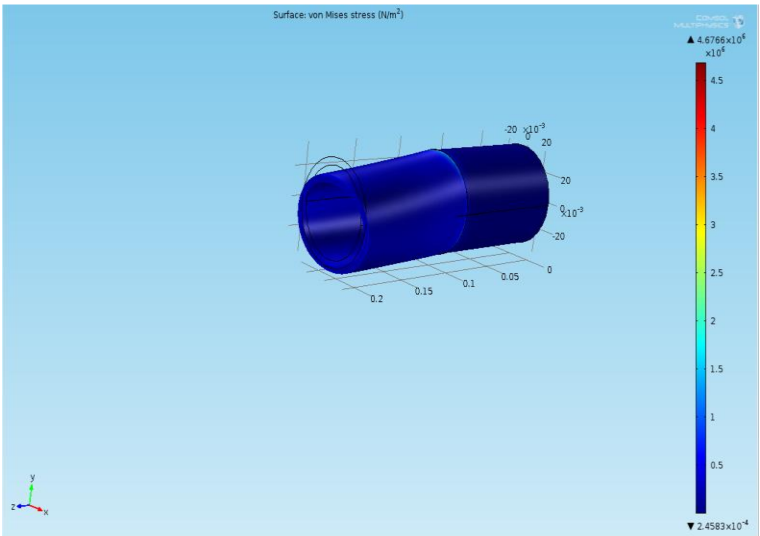

Figure 5: Stress analysis of pivot

As a group, we are satisfied with the final design of the dome. The common design problem in the existing Clamshell domes found in the industry is solved by our design. Moreover, installing the dome and investigating the operation of it in its real life conditions would help to enhance the design.

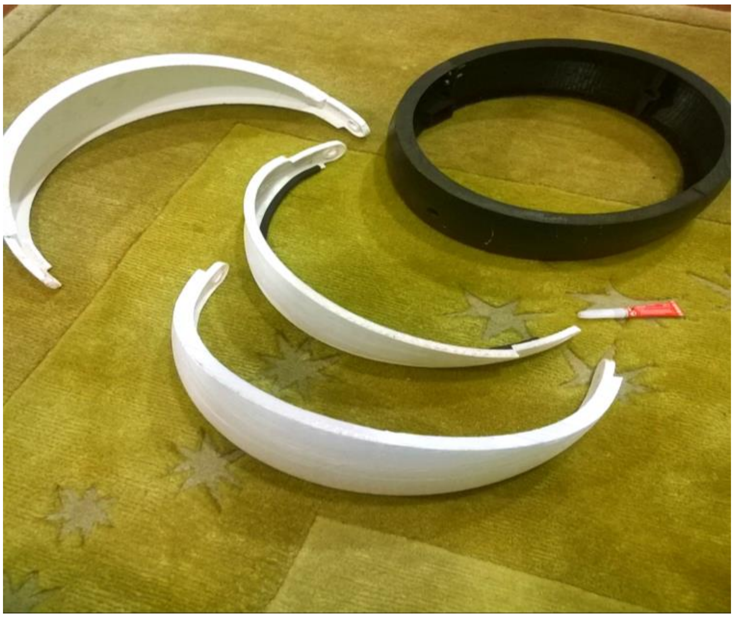

Figure 6: Components of prototype

CONCLUSION AND FUTURE DIRECTIONS

The produced clam-shell dome is capable of preserving a small telescope to be used for S-Dimm observations on the site of TÜBİTAK National Observatory (TNO), at top of the Saklıkent Mountain-Antalya. Alternatively, it can also be applicable for military cases. It is the first domestic clam-shell dome ever designed and produced in Turkey, with much less production costs than its foreign counterparts. Domestication will also eliminate the possible communication and transportation problems with foreign dome companies, where most of them are located in U.S.A. or Canada. Moreover, if the case of dome export trade may arise in future, it will provide revenue to national economy and recognition in markets. The research and development (R&D) in this area is currently inactive. This project assures know-how accumulation and will lead possible future R&D projects with the assistance of TNO.

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Design and Manufacturing of the Prototype of a Liquid Piston Compressor

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Abstract

The compressed air produced by compressors are used in many different industries, and the efficiency of a compressor is important regarding the both the economic and environmental aspects. In a conventional compressor, a solid piston compresses the air. During this compression process, an air leak occurs which diminishes the performance of a compressor. The leakage becomes even greater as the operation time increases. Moreover, the compression process of the solid piston performed at a relatively high speed to minimize the air leakage. Since the gas does not have enough time to realize heat transfer, compression at high frequencies increases temperature of the gas, which leads to an inefficient compression process. One alternative to overcome this issue is to use liquid piston in which the solid piston is replaced by the liquid rising in a column. This way, both the air leakage can be avoided and the compression process can be performed slower. Moreover, due to the circulating nature of the water, and the superior heat transfer characteristic of the flowing water, a better heat transfer can take place which leads to a lower temperature rise of the gas, and hence more efficient compression process. With a more efficient compression process, the environmental foot print of the process can be minimized. Moreover, Liquid piston is more silent than conventional compressor, because there is no mechanical friction and crank shaft which increase vibration and disturbing noise.

PROBLEM DESCRIPTION

Pressurized air is commonly used in industry. Compressors with reciprocating pistons are preferred to increase pressure of air. These compressors are using mechanical power to move the metal piston in a cylinder in which the pressure of air is increased. To accomplish this task, the piston, which increase the pressure of the air, gives work to closed system of air described by dashed line in the Figure 1.

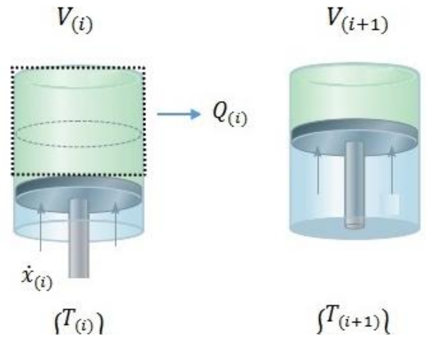

Figure 3: Closed control volume for liquid pistons

In conventional compressors, during the compression process, an air leak occurs. To minimize the amount of air leak, the compression process should be performed at a relatively high speed. Although increased piston velocity prevents gas leakage up to some extent, it also restricts the amount of heat transfer from the pressurized gas to the environment. Hence, temperature of gas is increased. This situation hinders to obtain pressurized air with high efficiency, because some amount of work delivered by the motor is used to increase temperature of the gas. Therefore, total efficiency of conventional compressors which use reciprocating pistons cannot exceed 70% [1]. In addition to this, when gas is cooled to room temperature in storage tank, its pressure decreases significantly.

In a liquid piston compressor, water, oil or some another appropriate liquid can be pumped into a cylinder to pressurize the air. There are major improvements coming with liquid piston compressor. The most significant advantage of this new concept is to prevent gas leakage inherently by the nature of the liquid. Since the air is not allowed to leak, the cycle can be operated slower than conventional compressors which allow the heat transfer to take place which will decrease the temperature rise during the compression process. Hence, the efficiency of compressor is increased by using the power delivered by the pump almost only to increase the pressure of air. Therefore, liquid piston compressors serves as a more environmentally friendly alternative compared to conventional compressors by supplying the same amount of air with desired pressure with a less power. In this study, a mathematical model to predict the performance of a liquid piston is developed. The liquid piston considered in this study includes also small metal tubing inside the main cylinder to enhance the heat transfer between the liquid and the compressed gas. The performance of the liquid piston compression is presented as a function of number of tubes packed in the main cylinder. The polytrophic constant, compression efficiency, total efficiency and the total work per stroke of the compression process is determined as a function of number of tubes inserted in the main cylinder.

Accordingly, the design of the liquid piston is considered with three design models for different pressure options: 4 bar, 10 bar and 15 bar. Therefore, based on air compressors of Dalgakıran Company, requirements and constraints are determined as in Table 1.

Model	Requirements				Constraints			
	Pressure (bar)	Flow Rate (lt/min)	Engine Power (hp)	Efficiency (%)	Dimension (m)			Weight (kg)
					Width	Length	Height	
Prototype 1	4	0.5	1	75	1.5	0.9	2	150
Prototype 2	10	0.75	5	75	1.5	0.9	2	165
Prototype 3	15	0.75	8	75	1.5	0.9	2	180

Table 1: Requirements/Constraints for liquid piston

Prototype 1 is selected for the system as its engine power requirement is more suitable for our project. This is important since more expensive motors with high engine powers are required.

WORKING PRINCIPLE OF LIQUID PISTON COMPRESSOR

At the basic level, the liquid piston gas compression concept utilizes a column of liquid to directly compress a gas in a fixed volume chamber. Figure 2 shows the schematic representation of the liquid piston air compressor.

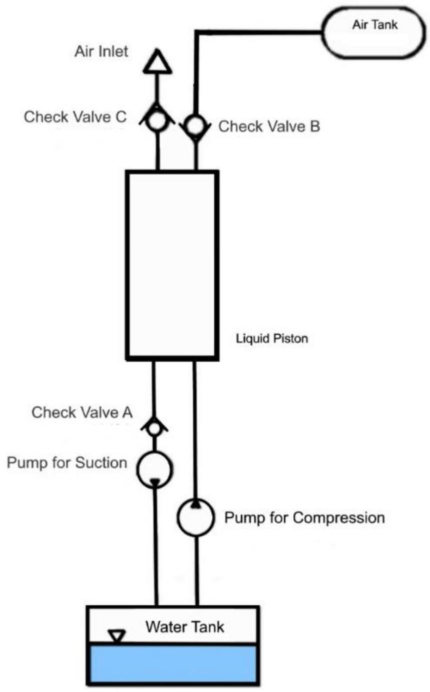

Figure 4: Schematic representation of the liquid piston air compressor

Working principle of the system is described as follows:

- At the beginning, the pump for compression starts the cycle of the system with compressing gas in the liquid piston chamber.
- When the gas pressure reaches higher value than pressure in the air tank, check valve B is automatically opened and pressurized air is transferred the air tank. After all gas in the chamber transferred, check valve B is closed; check valve A and check valve C (i.e. for taking the air from environment to the chamber) are opened. Then the suction pump starts to work in order to evacuate the water inside the piston.
- When the liquid is pumped out of the piston, first cycle of the system is completed successfully.

- The process is initiated for the next cycle by closing check valve A and C and pumping the water inside the piston.
- The system stops to work when the pressure of the air in the tank reaches desired value.

MILESTONES AND ACCOMPLISHMENTS

The project which realizes the operations described in previous section is conducted according to a schedule. There are steps followed throughout the project:

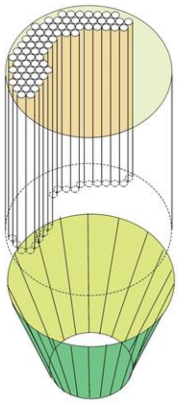

Figure 7: Tubes inside the piston

Developing Mathematical Model: At the beginning of the project, one-dimensional model of the system is investigated and mathematical model is developed. To increase the rate of heat transfer, number of tubes with small diameter are introduces into the piston. They are modeled to be densely packed inside the piston as it is demonstrated in Figure 3. The calculations are performed according to number of these pistons. When this number is changed, temperature of the gas after compression process decreases in most cases. Apart from the number of tubes, flow rate has also significant influence on efficiency of the compressor. The variation of total efficiency with respect to number of tubes and flow rates is depicted in Figure 4.

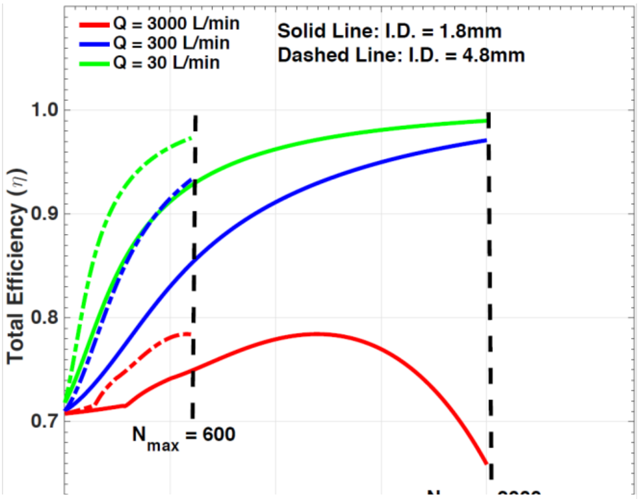

Figure 5: Variation of efficiency with respect to number tubes and flow rates

As Figure 4 suggests that, except the case with 3000 L/min flow rate, increase of number of tubes inside the piston contributes to gain efficiency. In addition to that, since when flow rate decreases, the process occurs slowly and the heat transfer rate increases. Hence the efficiency of the system increases. If the diameter of tubes are decreased to 1.8 mm and flow rate is increased to 3000 L/min, frictional forces dominate the process and efficiency start to decrease. It is obvious that manufacturing and packaging of 2000 tubes with 1.8 mm diameter is almost impossible, it is reasonable to proceed with 600 tubes with 4.8 mm diameter tubes to compare the efficiencies of conventional compressors and liquid piston compressor. The results state that the total efficiency of liquid piston compressor with declared configuration is almost 95%, while it is 70% for conventional compressors.

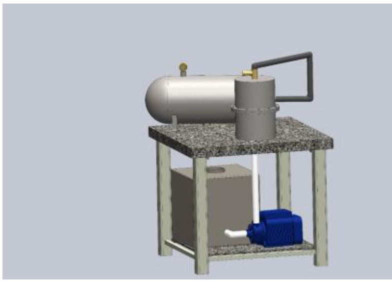

Figure 6: Experimental Setup

Establishing Experimental Setup: After concept is selected for liquid piston, experimental setup is built to validate claims. Figure 5 shows the representation of setup which is composed of 2 pumps (one of them is behind the appearing one), air tank, liquid piston and water tank. Together with these main components, there are several components like hose, valves and sensors etc. which are used to complete the system and regulate the flow. Once the compression process is successfully performed, the cycle requires evacuation of water from the piston to fill it with air at atmospheric pressure once more. This is a crucial step in the cycle because the pump for evacuation should start as soon as the pressurized air is delivered to storage tank. Electronic valve is connected to suction pump and they are linked to Arduino controller together. When the compression is completed, they work simultaneously to remove the water from the piston.

MATERIALS AND METHODS

In this step, alternative materials for piston are investigated for their strength at high pressure. This is accomplished by fracture analysis and results of this analysis are shown in following table:

Table 2: Fracture analysis of Plexiglas and Stainless Steel

Fracture Analysis		
Properties	Designs	
	Initial Design (Plexiglas)	Current Design (Stainless Steel)
Yield Strength	70 MPa	540 GPa
Modulus of Elasticity	3 GPa	200 GPa
Fracture Toughness	1.8 MPa$\sqrt{m}$	60 MPa$\sqrt{m}$
Ultimate Strength	72 MPa	840 MPa
Thickness	3 mm	4.7 mm
Maximum Principle Stress (for 4 bar)	13.33 MPa	20.62 MPa
Maximum Allowable Pressure	5.58 bar	95.6 bar

The analyses are carried out for Plexiglas and stainless steel. Since fracture toughness of stainless steel is much hıgher than Plexiglas, the outer casing of liquid piston is made out of stainless steel.

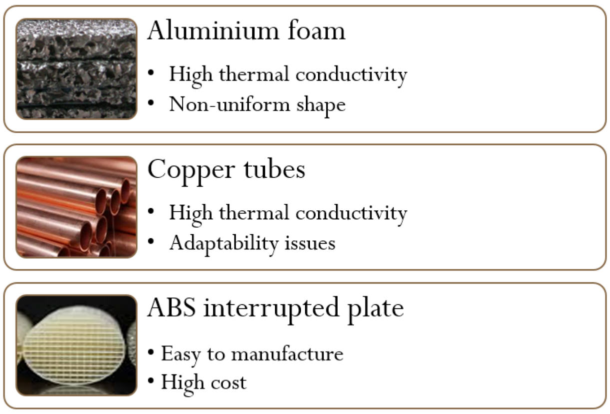

Figure 8: Selection of concept of liquid piston

Concept Selection for liquid piston: Since the most significant component of the compressor is the piston itself, special attention is paid to develop a concept for it. This concept involves the material of the piston and the insertion for increasing heat transfer rate [2]. The alternatives are depicted in Figure 6. The initial selection was copper tubes, because the mathematical model gives superior improvement. However, manufacturing of these tubes wasn't as easy as it is thought to be. Hence Aluminum foam was selected to put inside the piston in order to increase the heat transfer.

Evacuation of water: After compression process, air at atmospheric pressure should be replaced with water inside the piston. This problem is solved by electronic discharge valve which operates simultaneously with suction pump. During water removal, the pump and the valve work together. When the valve is open water is discharged, while it closes whenever it is obliged to hold water during compression.

Monitoring Water Level: The level water at bottom of the piston after evacuation period should be neither too high to prevent air intake, nor too low to lead air suction in the pump. Therefore it is essential to monitor what is happening inside the piston. The water level sensor is responsible for sending signals which is converted into level information afterwards. When it is possible to know where the water is exactly, the pump and electronic discharge valve can be closed immediately after all the water is removed. This prevents pump to suck the air.

RESULTS AND PERFORMANCE EVALUATION

After experimental setup is built, several experiments are conducted to optimize the parameters that have influence on efficiency. Since the level of water cannot be seen during compression and evacuation, sometimes air can be sucked by the pump which is responsible for removing the water. This situation inhibits the way of working of the pump because it cannot deliver the water due to air bubbles and time delay between compression and evacuation may occur. If Arduino controls the system, pumps and valves cannot be synchronized because of these delays. In order to prevent this handicap, level sensor for monitoring the position water is tried to be adapted and experiments are conducted for maintaining full automation.

CONCLUSION AND FUTURE WORK

Liquid piston compressor is an alternative technology which aims to increase efficiency by preventing gas leakages and high heat transfer rates. Heat transfer is favorable since it allows to keep temperature of air constant at a certain level, hence power delivered by the pump is consumed almost only to pressurize the air. Correspondingly, our project aims to present this technology as a prototype at the end of the work. However, the system needs to be developed further in order to come into the market. For instance, we use two centrifugal pumps but it is possible to manufacture a single pump which can work in two directions and can be implemented into the body of the liquid piston. Moreover, liquid piston can be submerged into a water tank in order to transfer heat more efficiently on the surface of the liquid piston. Inserting metal tubes into the piston and submerged the piston into a water tank can help the process to become closer to being an isothermal one. One limiting case for the cylinder with the metal inserts is the total process time. Depending on the nature of the process, the design parameters can be optimized to obtain the desired performance within the certain limit of process time. In this study, only the compression process and the discharge of the compressed gas is modeled. The modeling of the expansion step and the inclusion of the heat transfer occurring at the metal tube walls can be future research direction.

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Automatic Cable Winder Reel

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Abstract

The project executed with ASELSAN aims to wind the cables in a short time interval. Because the cables are used for the test operations, they are capable to interlace easily and connectors that are placed on tips may be damaged. Our primary focus is minimize the idle time as well as distinguish any condition can harm the cables.

Several designs were proposed as a solution of the problem till the detailed design process. In accordance with the previously determined project requirements and constraints, the final version of design was determined as spring loaded winder with a path following locking mechanism. From

preliminary to detailed design process, although proposed designs are same in terms of their working principle, they always have been revised in order to get optimal results. When design were manufactured, it is experienced that obtained product would not always match up with the theoretical expectations. These experienced flaws results with using more suitable materials and manufacturing techniques during the improvement process.

After some manufacturing experiences are gained, progress stage of the project accelerates and better results are obtained. In the light of the meetings with ASELSAN, product receives approval about its design and functionality; however it is still ongoing process to make it more optimal in terms of size and weight.

PROBLEM DESCRIPTION

ASELSAN utilizes Integrated Circuit Piezoelectric Sensors in their mechanical test operations, especially in vibration tests, and cables belonging to these sensors interlace seriously. Eliminating this interlacing problem and picking up all cables take plenty of time (approximately 120 hours per year). Picking up of these cables is an exhausting process both physically and psychologically. In addition to these, deformations occur in connector connections and wiring of cables which are not picked up properly due to the time limitation in field tests. Therefore, the main purposes of this project are to extinguish the idle time and provide using cables in longer duration by preventing them from any damage by designing and producing a functional, active or passive cable winder system which will pick up these cables in a short time interval regarding to the project requirements which are given throughout this report.

Problem Requirements

Problem requirements can be listed as below:

- **Regarding to size, dimensions and materials:** It needs to be storable size and transportable safely and without giving any damage to cables. The maximum weight of the system should be 1 kilogram. Finally the dimensions of system should be indicated as;

  Width ≤ 100 mm

  Length ≤ 150 mm

  Height ≤ 100 mm

- **Regarding to Durability:** After many uses, there is a strong possibility for string to wear down due to the constant tension of pulling and rewinding. Corrosion protection for the automatic cable winding drums must be provided. It should be resistive to any kind of environmental effect, such as humidity or temperature. Operation temperature range should be between -20C^o and 40C^o. It should be resistive to any impacts resulted from 3 meter falls. Its load capacity should be maximum 30 kilograms. The occurrence of any kind of expansion and constriction should be eliminated.
- **Regarding to Safety:** The project should be designed as harmless for its user.
- **Regarding to Ergonomics:** Regarding to observations, overlapping of cables during picking up process causes problems for also unwinding operations.

- **Regarding to Cost:** There are 300 cables in total, so they are needed to be produced with a reasonable cost. Unit manufacturing cost should be maximum 100 TL.

Problem Constraints

Problem constraints can be listed as below:

- It should be a compact and lightweight tool.
- Materials will be chosen should be corrosion resistant, should not shrink or expand no matter how long and where it is used, should be able to protect its inner mechanism and should not be expensive.
- Spring should not malfunction no matter how many times it is used. Even if it is broken down, there must be an alternative solution in mechanism for winding cables.
- Edges may be smooth rather than sharp for people to hold it safely.
- Single or multi-layer drum reel may be used to prevent disorder and congestion of cables.

MILESTONE AND ACCOMPLISHMENTS

At the statements of needs stage, after the meeting with ASELSAN, the requirements and constraints were determined, several concepts were proposed by group members. Spring loaded winder with a manual alternative was chosen. Suitable spring types were researched. The power spring (see Figure 1) was chosen because of its functionality for the small size products. The mathematical model of the design was established in order to calculate torque values corresponding to number of turns.

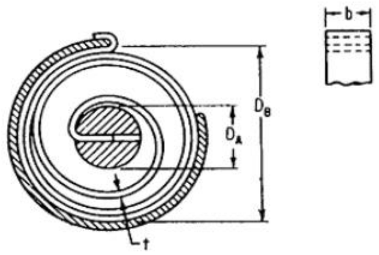

Figure 9: Illustration of power spring

As a result of the literature researches about the power spring, some calculations have been done to get optimal torque. Theoretically, to be able to get the maximum torque from the spring, it should be occupy the 50 % of the area between the pulley and the arbor.

Working principle of the power spring originates from bending of a rectangular beam. Therefore main mechanism working inside is bending stress examination. Maximum moment is calculated by combining maximum bending stress and moment of inertia for a rectangular beam expression. The outputs obtained from the calculations are as follows:

$$L = \frac{\pi}{8}\frac{\left(D_b^2 - D_a^2\right)}{t}$$

Where;
L: Length of metal strip

D_A: Diameter of arbor

$$N = \frac{\sqrt{2(D_b^2 - D_a^2)} - (D_b - D_a)}{2.55\ t}$$

$$M_{max} = \frac{\theta\, w\, E\, t^3}{12\, L},\ \ \theta = N * 2\pi$$

$$S_{max} = \frac{6\, M_{max}}{w\, t^2}$$

D_B: Diameter of housing

t: Thickness of spring

b: Width of spring

θ : Number of turns in radian

M: Maximum moment

S_{max} : Maximum stress

E: Young's modulus of spring

After modeling, in the detailed design process, depending on the values that comes from the modeling, our design has been created and arranged.

The parts for the designed products are searched on the Internet, company's catalogs, by the help of experts' opinions. According to obtained information, determined parts are easily manufactured at various types of industrial centers.

In the progress of the project process, first purpose was to check whether mathematical model applies to the real cases or not and would the dimensions of the case be enough to wind the 15 meter cable. Therefore, the first prototype which was very basic and had no locking mechanism was decided to manufacture just to observe the behavior of the spring. The first trial ended up in failure. It had so many drawbacks and even did not work. First problem with it was that the spring was too small so not strong enough to make the pulley turn. Additionally, there were friction between arbor and pulley which also made turning operation harder. Also, dimensions of the pulley were too big that made it heavy. Poor dimensioning was due to that it could not be predicted the real product from the SolidWorks drawings. Furthermore, dimensions of the design were reviewed and went to another spring manufacturer for a bigger spring production. The second prototype was far better than the first one.

After the manufacturing of second prototype, the results of mathematical model and prototype compared. The outcome was satisfactorily acceptable. The difference was very small and caused by frictional effects which was expected because it is not considered any frictional effect in model. With this second trial our mathematical model was verified.

The first trial of locking mechanism works with a push button which depends on the friction principle. At that process, another modification that is done on the design was integration of cable to the pulley. In the previous design, cable had to be taken out from the pulley at every use. However, now it is integrated to the pulley so usage became easier.

Thereafter, the design has been improved in the direction of requirements and constraints of size and weight; however, the working principle remained the same. Addition to the modifications, it has become more elegant. The final design consists of a power spring which supplies the power in order for winding operation, two washers which reduces the friction between spring and its case significantly, a pulley on which cables will be winded, a cover which not only protects cables from any external damage, but also guides cables to pulley by the small window in front of it, and a locking mechanism that locks the pulley

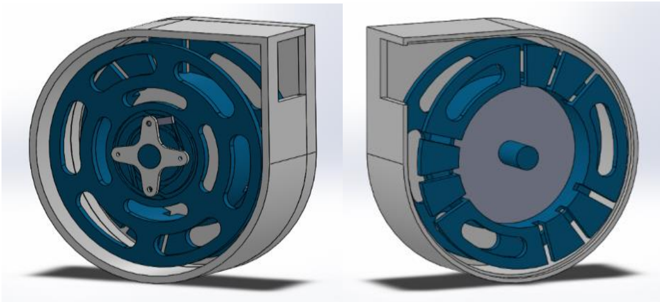

Figure 10: CAD model of proposed final product

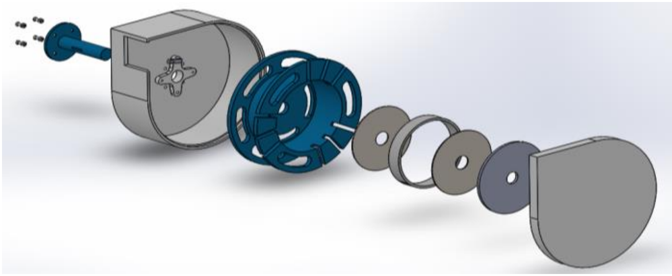

Figure 11: Exploded view of final product

Furthermore, it can be seen from the Figure 2, plenty of material is subtracted from the pulley, so that the whole mechanism can be lightweight.

MATERIALS AND METHODS

At the same time, the materials of the parts except spring have been searched. After the plastics are compared with the metals, they are considered as proper for usage area. Polyamide and Kestamid were the focus; however, finally, material has chosen as polyamide for the prototype material which is very lightweight and cheap compared with Kestamid.

At the progress process, polyamide turned out to be that it is not a good material for CNC operations, so Delrin is adopted in the next stage which increased the weight of material because of its high density. Therefore, in the next cycle 3D printer will be tried with the material PLA.

RESULTS AND PERFORMANCE EVALUATION

Until this period which we were obligated to change our dimensions and materials and modify the design, it is experienced that the manufacturing is time-consuming and toilsome process. When polyamide is selected as a material, it is considered the manufacturing process differ than the injection molding. In same way, when it is decided to modify and adopt locking mechanism to the product, choosing the best version of design become difficulty. Because it was hard to get manufactured it in desired and cheap way. Therefore, it is also observed that the selected materials, chosen design and appropriate manufacturing techniques should be accommodated themselves. Finally, the importance of the time schedule is experienced but hard to stick to. That is the reason project time schedule and risk management are important especially for manufacturing stage.

CONCLUSION AND FUTURE DIRECTIONS

From the start to the final stage, the design as a solution of project has been revised in many times. Although the design has been improved in every stage, the working principle remains same. However, the additional modifications have always been made to get more elegant and functional product in terms of requirements and constraints.

Because it seems as the most difficult one, all prototypes were concluded to try to wind 15 meter cable. At the final product, the successful results were gained and the 15 meters cable was winded. This obtained final product receives approval about its design and functionality in the light of the meetings with ASELSAN; however it is still ongoing process to make it more optimal in terms of size and weight. The prototype is capable to wind/unwind the cables and to arrange the desired length to use by means of locking mechanism. In addition to these, it is decided to make it smaller and lighter helps the users at the usage stage. Finally, the design needs to be revised for different length of cables and become optimal for them.

Although it is not required and desired by ASELSAN, another modification could be done for further enhancements. Usage areas of the product can be considered as problematic. The tests are concluded at the areas with mud and dust. Because cleaning the whole cables before winding them might not be worthwhile, the cables could be winded with its dirt and damaged in that process. In order to solve this problem, a sub-mechanism could be added to the case which would be able to clean roughly the cables.

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Bearing Friction Test System with Software Support

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Abstract

Friction measurement of the bearings is crucial for the scanning camera in gimbal stabilization systems in front of missiles. The purpose of this project is to design and manufacture a bearing friction test system which can measure the friction torque, both static and dynamic, exerted on the outer race of the ultra slim thin film coated angular contact ball bearing, so that the measured friction can be eliminated as much as possible and the scanning camera to respond even to the slightest alteration in the direction of the missile. In the system, the driven shaft, connected to the motor shaft, rotates in the vertical direction; since the bearing is close fitted, the inner ring rotates in conjunction with the shaft. Outer race of the bearing rotates due to friction torque. This friction torque is measured with strain gauges which are adhered on the force transmitting rod. The force transmitting rod is integrated to the system from the side and it holds the outer race of the bearing.

The control of the motor and the data gathering from the strain gauges are both visually performed with the control panels of the software LabVIEW and the connection to the software is achieved by EPOS2 and QuantumX for motor and strain gauges, respectively.

PROJECT DESCRIPTION

In gimbal stabilization systems the friction needs to be eliminated as much as possible to make sure that the scanning camera responds even to the slightest alteration in the direction of the missile. Otherwise, a missile might miss the concerted target, which may cause catastrophic incidents. For this purpose, measuring the friction in between inner and outer races of a bearing carries an utmost importance by means of properly including the amount of energy that is lost and the time delay in between the actual direction change and the direction change of the scanning camera, in the calculations. In this project, friction force occurring between inner and outer races of the bearing which is being used in the gimbal stabilization systems is measured by using strain gauges which have a quarter-bridge configuration.

The bearings used in gimbal stabilization systems are thin-film coated which have very small friction values. Available bearing test systems could not be used due to the lack of sufficient measurement precision for a thin-film coated angular contact bearing - in the order of mNm's. An example of a bearing friction test system can be seen below but it uses a much larger bearing with higher friction values.

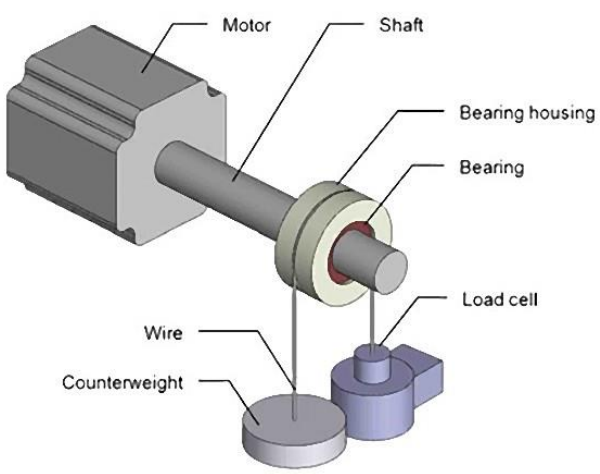

Figure 1: Schematic representing one of the systems that is being used in the industry [1]

In addition to the test subject bearing described above, other bearings can be tested by just using a different shaft with proper dimensions. Another aspect that is lacking in most of the current systems is that there is a housing on bearings which applies an external load on the bearing. In this project, the design is constructed in a way that there is no radial or axial load that acts as a source of external force on the bearing to be tested.

In order to measure friction, the first step is to rotate the bearing because rotation of the inner ring will cause the outer ring to rotate due to the friction force between the rings. The strain gauges are adhered to the force transmitter rod. The friction occurring in the outer ring of the bearing is measured by strain gauges which are configured in the bending measurement configuration. HBM

QuantumX is used to obtain the strain gauge data. Motor speed and the measurements by the strain gauges are both controlled by LabVIEW on a user friendly interface. An incremental magnetic encoder is used to obtain the rotational speed values. By measuring the rotational speed on the shaft, it is aimed to change the motor input voltage by a controller in a closed loop system between the encoder and motor.

To sum up, the motivation of this project is to measure the friction between the inner and outer races of a bearing, as accurate and precise as possible. According to Kaydon's datasheet, 3mNm is the expected value to be obtained as the starting torque value for the bearing to be tested.

The constraints and requirements of the project are given on the tables below:

Table 1: Requirements of the project

Bearing type to be tested	Kaydon ultra slim angular contact ball bearing Thin film coating
Bearing dimension	Inner diameter: 60 mm Outer diameter: 66 mm Thickness: 2.5 mm
Friction torque	3 mNm starting torque (Given)

Table 2: Constraints of the Project

Functional	Velocity: 100 - 1000 rpm No radial and axial load on bearing
Timing	Design Matrix due - October 2015 Preliminary Design due - November 2015 Detailed Design due - December 2015 Project due - May 2016
Economic	Cost: 11000 TL+ VAT
Manufacturability	Proper material and shape
Safety	Component fixation to prevent any damage

MILESTONES AND ACCOMPLISHMENTS

1. **3D Prototype Design and Manufacturing**

Firstly the design was manufactured as a prototype with a 3D printer in order to accurately manufacture the system with the selected materials for the shaft, base, and motor holder discussed in "*Materials and Methods*" section. 3D printer technology is an emerging concept, and with 3D printers and with almost any type of materials, desired shapes and sizes of products can be manufactured [2].

All of the components of the prototype were manufactured using ABS plastic. The prototype was used in order to demonstrate the actual system and to find the weak points to enhance later on.

2. Software Development

The first plan was to use EPOS Studio to drive the DC Motor through EPOS2. Its modules are enough to drive the DC Motor in both position target and velocity target applications. Then, MATLAB was chosen over EPOS Studio as the software, since its interface was much easier to communicate. The MATLAB functions for motor driving were found to be complying with what can be achieved by using EPOS Studio software. However, this software, again, had to be changed because it was not able to collect data from the strain gauges by itself; the output from the strain gauges had to be collected simultaneously with the motor control part. Eventually the LabVIEW was decided to be used, for it has features to drive the motor, take measurements from the strain gauges, process and plot these data, simultaneously.

3. Data Gathering and System Debugging

After prototyping, the components were manufactured and assembled, the trials on the actual systems were given a start, so as to improve the system's overall work. The main problem was to measure the strain at the rod with an error as low as possible, and to transform the collected strain data to their force equivalent. When the configuration of the measurement system was prepared with the bending principle, our first data showed that, the order of measurements in terms of force found as expected, in the order of millinewtons. Then the measurements were continued and the final results are gathered as expected.

4. Test and Final Hardware Assembly

Final hardware is made out of ABS plastic by 3D printing. Quarter Bridge bending configuration is used in order to take measurements from strain gauge. When taking the measurements, for certain rpm values certain amounts of data were taken and they were examined statistically so that the results would be more reliable. Also, in the final assembly, a low-pass filter was used in order to avoid the potential noise within the system. After these operations, the gathered data were presented as mean results. Attention must be given to the real time measurement that was done by using the motor and sensor parts simultaneously.

MATERIALS AND METHODS

The mechanical and electrical parts of the system were placed on the base. The motor was fixed to the whole system by the motor holder component. The shaft, on which the bearing is close fitted, was connected to the motor shaft, in addition to the encoder disk. The encoder read head was placed approximately 0.4 mm apart from the encoder disk, as specified in the datasheet of the encoder.

The outer ring was fixed to the force transmitting rod; the inner ring was made to rotate together with the shaft. The cross-section, where strain gauge was adhered to, was made thinner compared to the rest of the force transmitting rod. Thus, measuring low strain values became less demanding. The material of the force transmitting rod was chosen as ABS plastic due to its low elastic modulus (∼ 2.25 GPa).

The measurements taken from the strain gauge were visualized using the LabVIEW software. With this, the static and dynamic friction torques were tested and observed in user-friendlier fashion. Strain gauge configuration was connected to the QuantumX to amplify the data. The DAQ device was, then, connected to the PC with an ethernet cable, and the measurements were processed in LabVIEW. Also, motor was driven through EPOS2 controller of Maxon. The communication between EPOS2 and LabVIEW was provided with an RS232 cable. Again, the controlling was issued using LabVIEW with the same interface as discussed before.

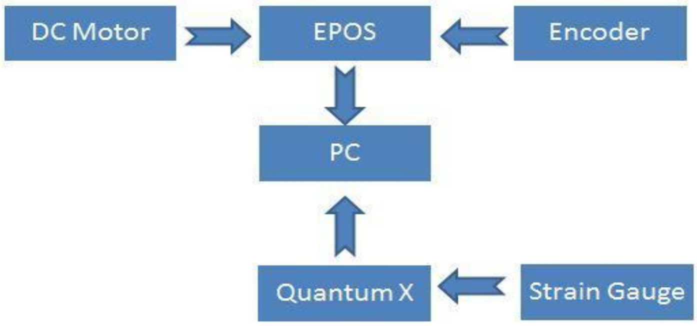

Figure2 : System Communication Schematic

RESULTS AND PERFORMANCE EVALUATION

In this test system, due to rotation of the inner ring of the bearing, the friction torque exerted on the outer ring is measured, using strain gauges in quarter bridge bending configuration. The output data were gathered by using LabVIEW and all the system control can be done by using the same user friendly interface as shown below.

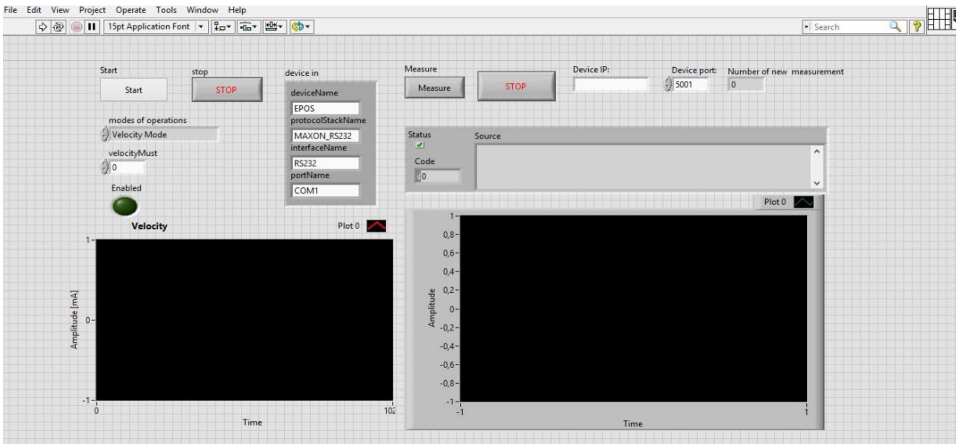

Figure 3: Single Interface-control panel of EPOS and HBM QuantumX

The strain gauge quarter bridge configuration was attached on the so-called force transmitter rod. As a result of calibration of this configuration, using reference masses in order to bend the force transmitter rod, a constant, to neutralize the sensing unit in reference to some specific point, was determined. Measured micro strain was, then, processed with this constant to obtain friction force in terms of millinewtons. The calibration results showed that a linear relationship with masses and measurements were realized and also it was found that the measured friction forces comply with the data obtained from Kaydon for corresponding rotational velocity values.

CONCLUSIONS AND FUTURE DIRECTION

Estimating friction torque is an important aspect of the gimbal stabilization systems. Available bearing friction measurement systems in the industry were found to be not capable of measuring low friction torques, in the order of mNm, and have relatively higher costs.

This system is designed in order to measure very low frictions on the bearings that are used in gimbal stabilization systems. The velocity range is in between 100-1000 rpm for this system. The results are visually presented by the same interface, LabVIEW, which are obtained from strain gauges and the motor. This test system can be used both for military and industrial purposes. In the future, it can be modified to measure several types of friction torques such as bearing friction torque when axial or/and radial load is/are applied, or for different bearing types.

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Design of a Moving Roof Utensil Basket for Adjustable Use

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Abstract

The problem with the available dishwashers is that, it is hard to locate long glasses due to the space that roof utensil basket occupies. There is a dead space between the upper basket and the roof of the dishwasher. It is proposed to increase the usage capacity of the dishwasher using this dead space. This will be done with changing the structure of the roof utensil basket for flexible purposes which actually provides us an opportunity to use the dishwasher with higher capacity.

PROJECT DESCRIPTION

Figure 1 represents the inner scheme of available dishwashers. As it can be seen from figure 1, there is a dead space between the upper basket and the roof. The proposed design provides a flexible design of the upper basket with using this dead space to increase the using capacity of the dishwasher.

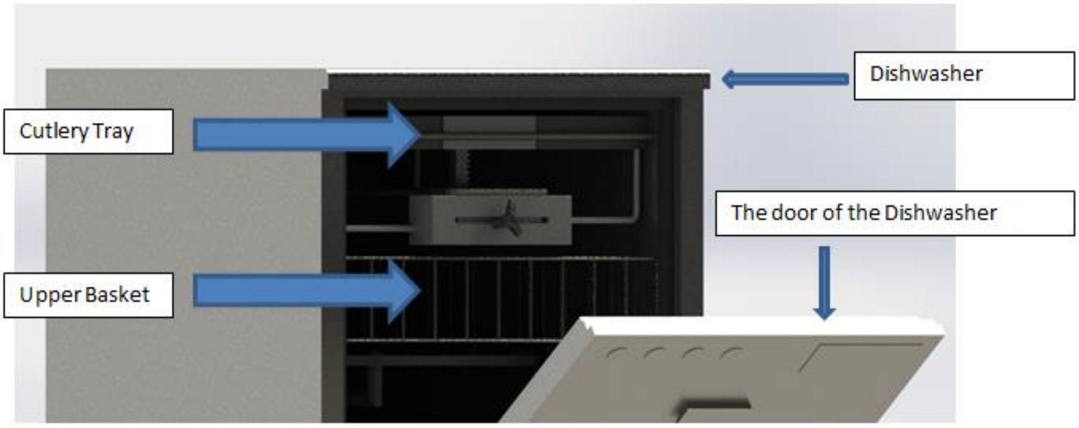
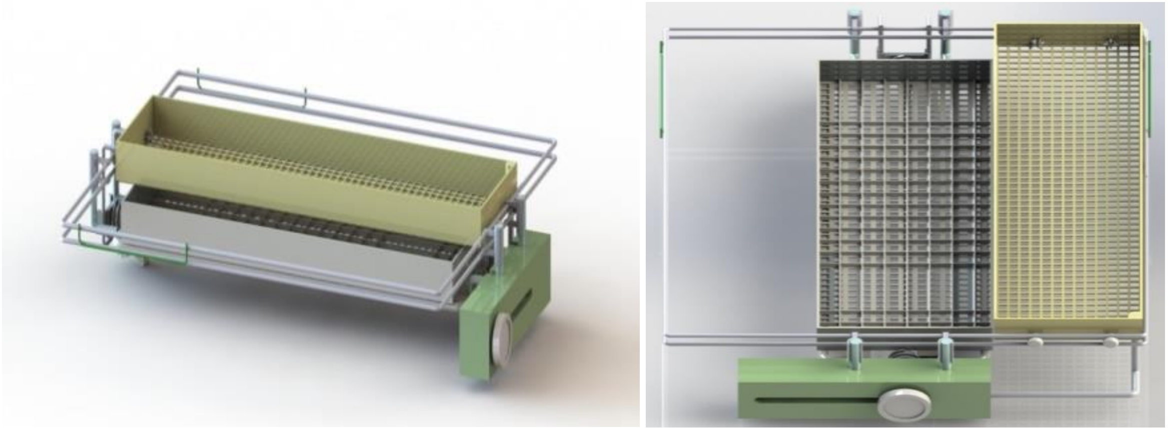


Figure 1: The Dishwasher and the dead space on the roof

The proposed roof utensil basket is composed of three parts that have the capacity of carrying 16 sets of spoons, knives and forks. These three parts are: the upper basket, middle basket and the knob. Figure 2 depicts the two different views of the design. Position of the middle basket shown in figure 2a enables customers to locate the large dishes in terms of height in the lower basket. Besides the position of the middle basket shown in figure 2b enables the costumer to use the middle basket.

Figure 3 shows the knob position and its structure. Knob is connected to set of gears. Gear set converts the rotational motion to the reciprocal motion. Once the knob is turned in the clockwise direction (counter clockwise), the middle basket moves left (right).

Using two the upper basket can be manipulated simply; user would pull the knob a bit and slide it to left in a particular way (Figure 4). The right basket can also be moved to its initial place by using the knob just sliding it to right. Figure 5 shows the technical drawing of the upper basket.



(a) (b)

Figure 2: Utensil Basket, (a) position proper for washing large dishes, (b) position proper for using middle basket

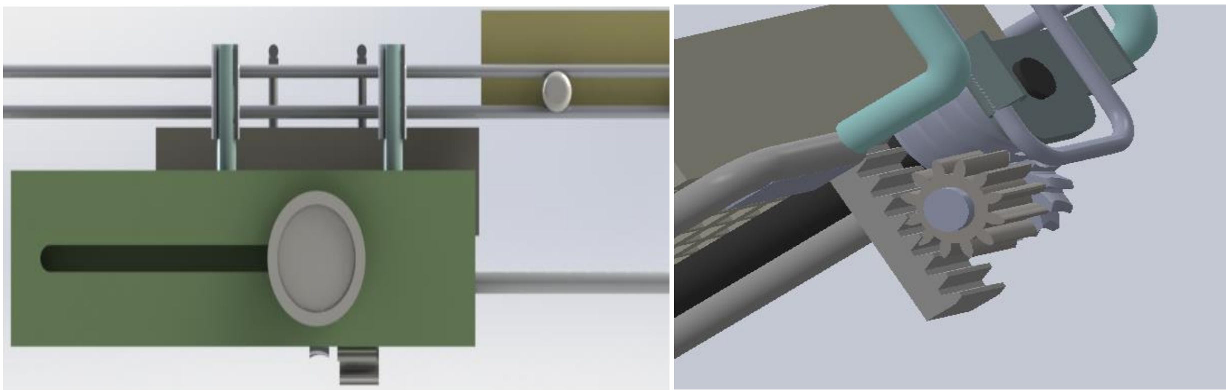


Figure 3: (a) Initial position of knob, (b) Gearset

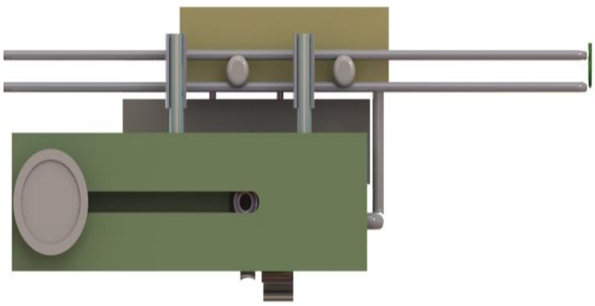


Figure 4: Moved tray position

MILESTONES AND ACCOMPLISHMENTS

Milestones can be listed as following:

- Bench marking
- Patent Research
- Conceptual Design
- Creating the design matrix and selecting the best one.
- Mechanical Design
- Identifying Forces and Loads
- Mechanical Analysis
- Preparing parts for the production
- Production
- Tests

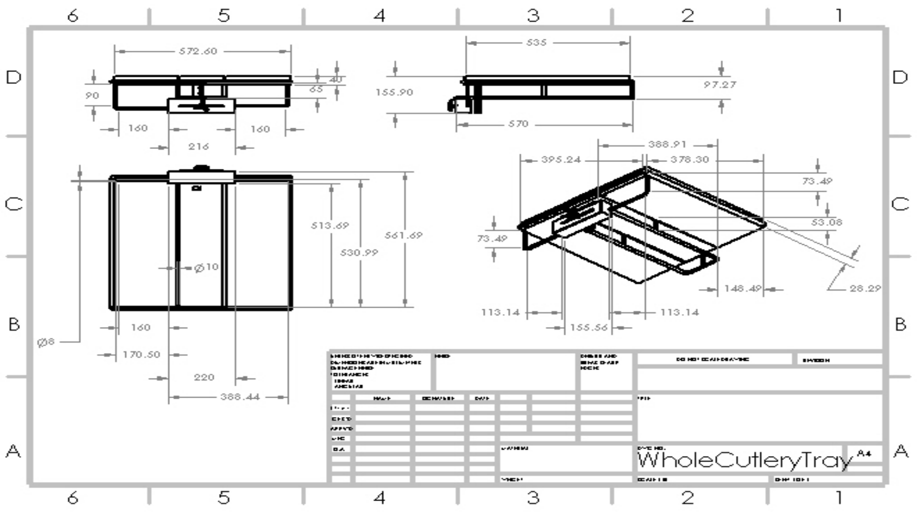


Figure 5: Technical drawing

MATERIAL AND METHODS

In this section components of the design are described in detail.

1- **Knob, Wheels, Box and Trays:** Knob, wheels, box and trays are depicted in figure 6. They were all manufactured by additive manufacturing method (3D printing) in Arçelik Sincan Compound. Their material is hydrophobic polypropylene.

2- **Frame:** Frame is manufactured by bending method in Ostim. The material of frame is chosen to be stainless steel.

3- **Shaft:** Shaft's material is also stainless steel and is manufactured by CNC machining.

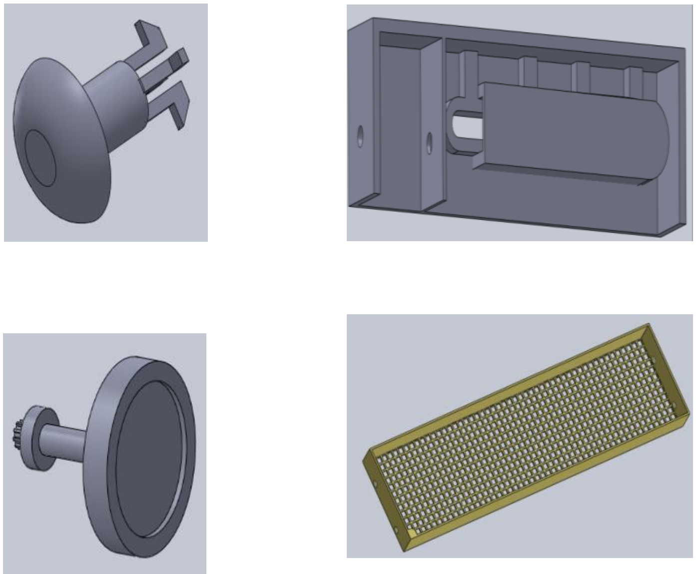


Figure 6: Knob, Wheels, Box and Trays

RESULTS AND PERFORMANCE EVALUATION

The main requirement for this project is that the design has to be adjustable and flexible. Our design ensures both of them. Other important advantage of our design is that the moving mechanism is unique which will obtain a patent. The second requirement given by Arçelik was the capacity of the basket. It has to wash 16 sets of cutlery which we also provide in our design.

CONCLUSION

To summarize, our design fully provides the requirements that has given by Arçelik. The prototype is manufactured by 3D printing. The mass production can be through injection molding. With this project we are experienced about the process of technical designing and industrial manufacturing of our technical design. For the further enhancements, molds required for mass production of the design can be designed. In addition some visual developments can be made.

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Fabrication of the 3D Printer Filament Machine, Which Is Capable of Recycling of Different Materials

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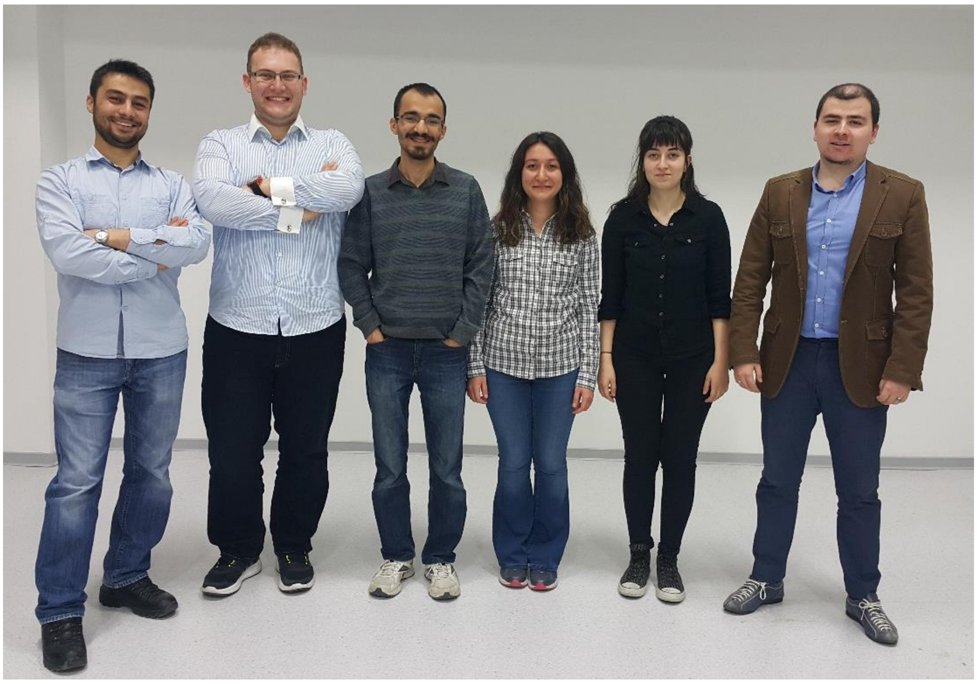

Abstract

3D printing is a highly popular additive type of manufacturing. With increasing popularity of 3D printing, the filament extrusion machines also come into prominence. Many people have tried to produce extrusion machines but there are many deficiencies in their systems and most of the machines do not include whole filament production processes. This project aims at building a bench top 3D printing filament extruder, which will be capable of recycling waste material of 3D printers.

PROJECT DESCRIPTION

The aim of the project is to manufacture a benchtop filament extruder machine being appropriate for office and home usage. A simple schematic of a filament extruder is given in Figure 1. Stages of the process:

- User puts wasted plastics in shredder to tear them.
- Raw thermoplastic materials with appropriate sizes are poured into the hopper.
- Raw materials are then passed to the screw part shown, where particles are transported to the nozzle while being heated.
- Melt thermoplastic takes the demanded shape for the filament, which is usually in the cylinder form, while passing through the nozzle.
- Extruded filament is transported automatically from the die towards the spooling system.
- Shape, dimension and chemical structure of the filament are controlled through cooling and puller system.
- The filament arrives at the spooling mechanism to be winded.

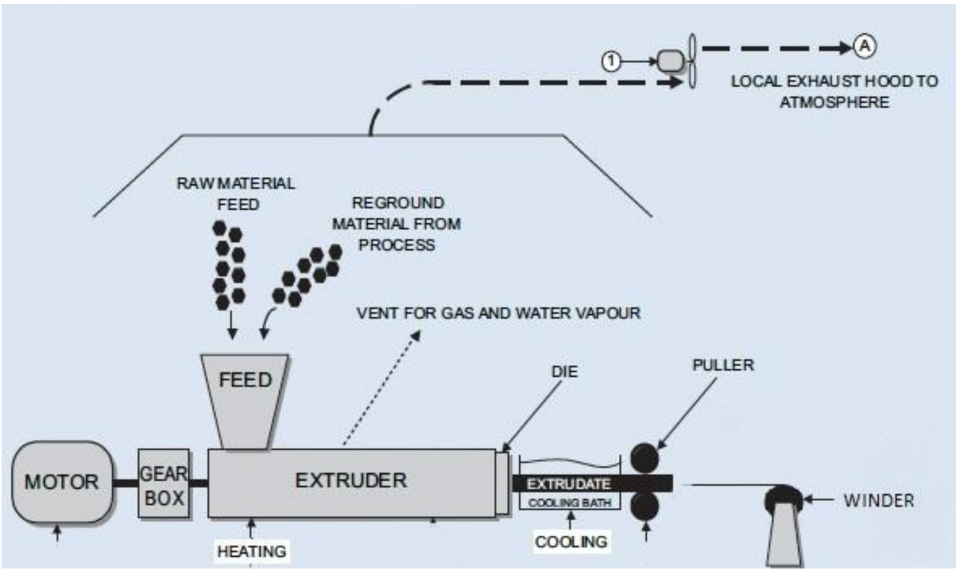

Figure 1: A schematic of Filament Extruder [1]

Subsystems of the project can be organized as follows:

- **Shredding Mechanism:** The aim of this mechanism is providing filament pieces via crumbling. This method is used for recycling of wasted filaments. This part is composed of a rotating circular knife. When wasted filament is put inside of this machine, it tears the filament apart. It is not possible to use big filament materials to be used in extrusion system so, this part is significant.

- **Extrusion Mechanism:** Torn filament pieces are thrown to the hopper of the filament extrusion system. The system composes of barrel and rotating screw. When the screw rotates via motor and it transports filament to the heater section. In heater section, filaments are melted and reshaped by the die of the extrusion mechanism.
- **Spooling Mechanism:** Extruded filament goes through cooling section and pulleys. In cooling section, the filament's appropriate chemical structure is gathered and in pulleys, the diameter is getting uniform. After cooling and pulleys, the filament is winded up to produce filament spool.

Requirements and Constraints

Functional Requirements/ Constraints	Safety Requirements/ Constraints	Economic Constraints	Environmental Constraints	Quality Constraints
- Bench top filament extruder is needed to be gathered. - Waste filament is needed to be reused via shredding mechanism - Fully-automated system is needed. - Stability of filament diameter should be provided and continuous flow through extrusion system should be achieved.	- The system contains knives, heating parts and electrical components so, the system should be isolated such that user intervention to these dangerous parts should be prevented. - Precautions should be taken against toxic chemicals spreading during melting of thermoplastic materials.	- Cost of the whole system should be below 5000 TL.	- The system should be capable of recycling of waste filament materials. User should be able to tear the waste filament of 3D printing and new filament spool should be made.	- The diameter of the filament should be 1.75 ± 0.05mm. - Filament produced by the system should be tested in terms of its mechanical/ thermal performance.

MILESTONES AND ACCOMPLISHMENT

<u>**Construction of the system**</u>

- For the extrusion system, geometry of the extruder is determined by MATLAB. In the extruder mass flow is highly dependent on channel depth and diameter of the extruder which is specified based on MATLAB code as well as the manufacturing related constraints.
- All extrusion system including heating, cooling based on manufactured screw is analyzed by COMSOL Multiphysics.
- In shredding mechanism, grater system is preferred because of its accessibility and comparing with other systems it can tear the materials into tinier pieces. This system had a torque control unit which gets activated when there are hard materials inside, this unit was deactivated since polymers have hard structure.

Experiments with the constructed system

- Experimental results are analyzed by "Design of Experiment (DOE)" method. This method enables one to identify the influence of different parameters on the results through a statistical approach. In the system, this method is used to determine motor torque and temperature effects.
- For DOE, a software MiniTab is used to interpret the results.

MANUFACTURING METHODS AND MATERIALS

The extrusion part of the system is manufactured and first experiments have been done. During experiments, there are many problems encountered. The screw mechanism, which provides transportation of filament, does not apply continuous flow and after some time, the filament finishes to go out of the nozzle. It is realized that the screw that is used in the system is not appropriate so, the screw mechanism is changed. Second significant problem is that there is toxic smell coming from molten filament. To prevent this, an aspirator system with filter is built. Another problem is that the thermistors used to measure temperature indicate results with errors so, the suitable temperature scale couldn't be achieved. This problem is solved with thermocouples working at higher temperatures.

Upon first experiments, the system design is changed and 2D technical drawings of the components are prepared for manufacturing process and proposed final design is finished. Figure 2 shows 3D drawing of the whole system.

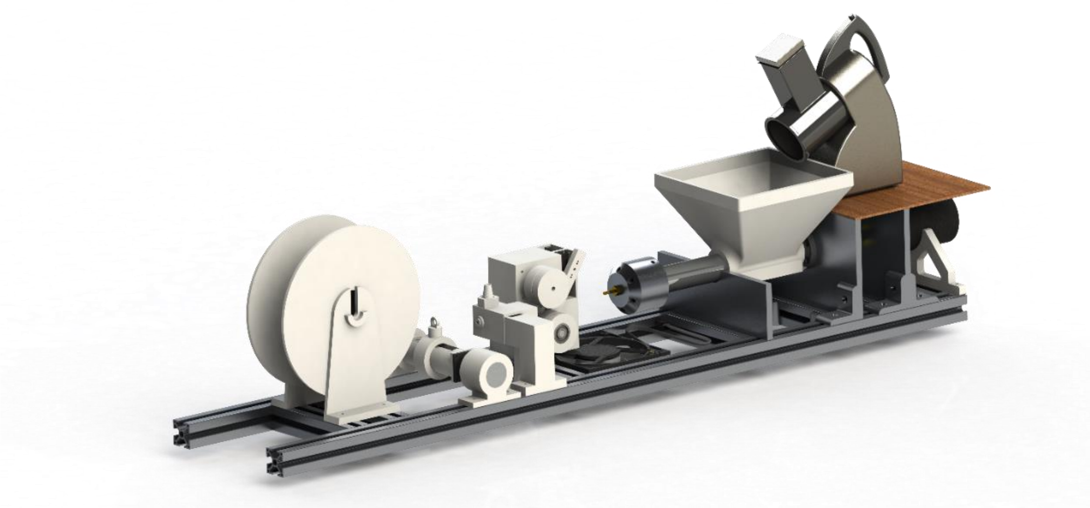

Figure 2: 3D drawing of the system

Manufacturing techniques and materials of the some parts are as follows;

- Screw and barrel: The screw mechanism is designed according to the suggestions of screw manufacturers and the screw and its barrel are manufactured from steel.
- Extrusion head: This part is used to give correct shape and diameter of the filament. This part also contains heating zones. For design of this part, the dimension of screw and its barrel and also minimum weight constraints are taken into consideration. This part is manufactured

from Aluminum (Al) 6063 because it is needed to dissipate heat very well. There are holes for placing heaters on the extrusion head and these holes are manufactured by CNC turning process.

- Heater band: This part is used to heat the barrel before the extrusion head because it is not easy to melt filament just at the extrusion head but some early heating is necessary. This part is manufactured from Al 6063 by CNC turning process.
- Spooling system: This system contains reverse screw mechanism and reverse screw is attached to the spool with the help of rollers. The reverse screw and spool rotates with motor and reverse screw gives the direction to the filament. The reverse screw and legs needed to keep the screw and spool are produced by 3D printing manufacturing. Also, there is a shaft, which is needed to transfer the energy and torque to the spool, is produced by CNC turning process.

RESULTS AND DISCUSSION

New experiments with last design are conducted. As a material, recycled High Density Polyethylene is used, comparing with the initial experiments better quality filament is gathered and uniform diameter in tolerance range is acquired. Cooling system worked well as expected. According to the constraints, continuous flow with uniform diameter of filament in tolerance range and recycling are accomplished.

CONCLUSION AND FUTURE DIRECTIONS

Data coming from experiments provide basis for company’s future designs and this product will be initial prototype of the company. Most important contribution of this project to the supporting company is to enhance the data pool since it is a developing company. Extrusion speed could be increased, diameter tolerance interval could be narrowed so, better quality product could be acquired. Material diversity could be enlarged and chemical structure of materials could be analyzed in more detail.

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Air Bearing Design Project for a Missile Seeker

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Abstract

This project focuses on the problem of designing an appropriate bearing system that provides the rotational motion for the gimbal seeker mechanism. Air bearing couple provide the stabilization of the shaft in the gimbal mechanism. Type of the missile which the air bearings will be inserted is a barrel fired missile so, huge amount of force applies on the system at the ammunition. In this project instead of conventional ball bearings air bearings are planned to be used in order to prevent jamming under high loading conditions. In order to prevent the damage due to high impact force at the beginning we tried to design an air bearing couple which eliminates the contact between the shaft and the bearing therefore causes no friction and no damage in the bearings. Flow and force equations were implemented to decide the design parameters like number of nozzles, nozzle and shaft diameter, allowed clearance with respect to force capacity of the bearing. Air flow simulations and structural simulations were done as well. After deciding the necessary parameters prototypes

were manufactured and necessary improvements were done as a result of the trials with initial product. By looking at these problems design was improved for the final product.

PROJECT DESCRIPTION

Supporting shafts or other components with air bearings is a widely used technique in industry. Axis movement stabilization of CNC machines with high rpms and low feed rates, some medical instruments drills are the fields that use air bearings [1]. Air bearings that are manufactured by the companies in market are most commonly designed for industrial usage such as in coordinate measuring machines, precision machine tools, semiconductor wafer processing machines which requires high speed and precision positioning [2].

In conventional missile applications, ball bearings are used to provide smooth rotational motion by decreasing friction but they are not durable and strong enough to be used in missiles. When the missile is fired from the barrel of a tank, they experience extremely high accelerations which cause an impact force of approximately 50,000N on the missile. Ball bearings cannot withstand such forces and gets damaged. Replacing ball bearings with air bearings is the proposed solution to this problem. Besides being strong, air bearings can also provide high precision of rotational motion for the gimbal seeker mechanisms by reducing the friction to almost zero. In theory, air bearings are excellent for these applications. Nevertheless, their size should be small enough to apply in a small missile. Minimizing the size of the bearings causes some difficulties such as manufacturing the system since they require small clearances between the gimbal shaft and the bearing housing, in the order of 10µm's.

In this project the size requirements are that outer and inner diameters of the bearing are 20mm and 8mm, respectively. Width of the bearing should not exceed 10mm. In addition to size requirements, the bearing should withstand the impact force about 50,000N and prevent axial movement larger than 0.1mm. Lastly, it should be operational for 60s.

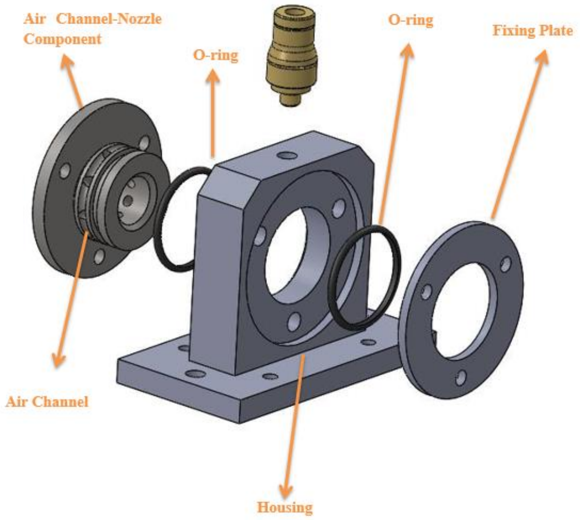


Figure 12: Dismantled view of the air bearing

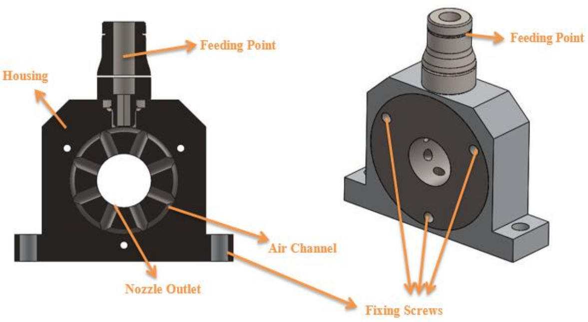


Figure 13: Half and complete views of the air bearing

MILESTONES AND ACCOMPLISHMENTS

Completing mathematical model: A mathematical model is created based on the article in [1]. According to the results of the mathematical model, optimum design parameters were determined. Determination of the parameters was done by checking the force capacity of the system.

Flow simulation and structural simulations: Behavior of compressed air coming from a gas supply and getting out of the nozzle was simulated in COMSOL Multiphysics. Also a structural analysis was done in the bearing, shaft couple in order to see whether our system can remain undeformed under 50,000N impact force at the firing of the missile.

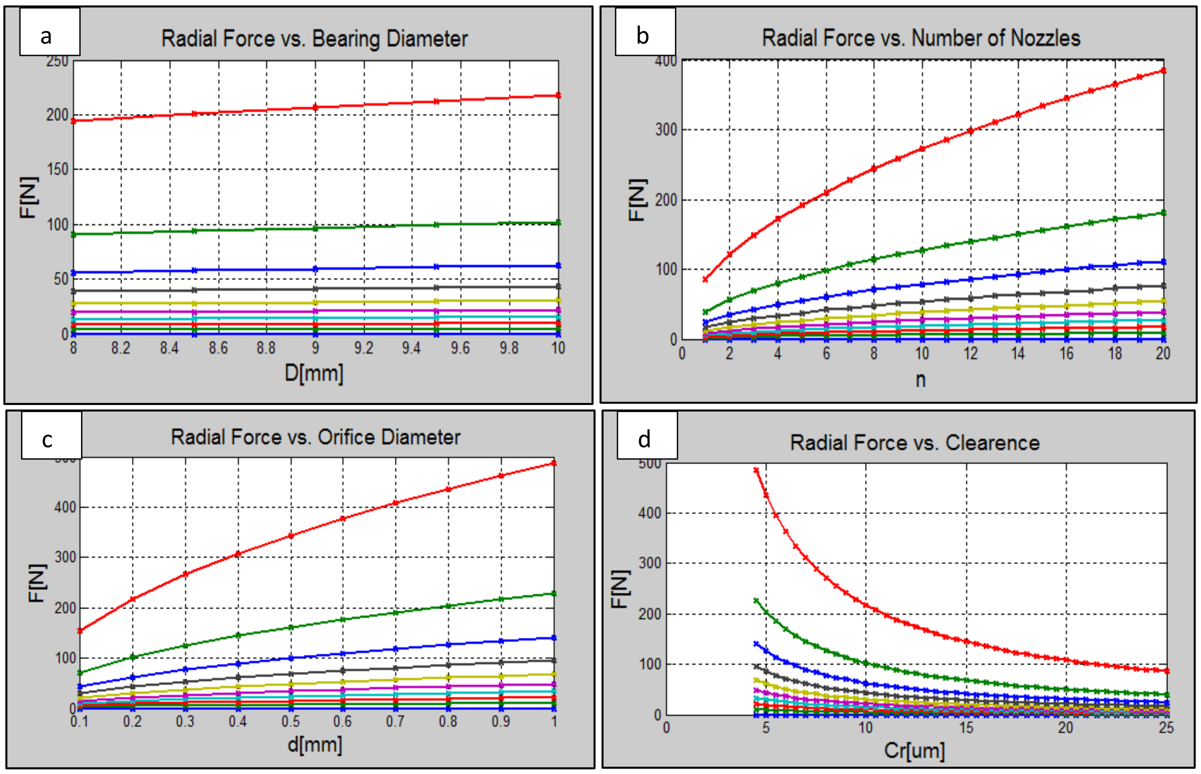
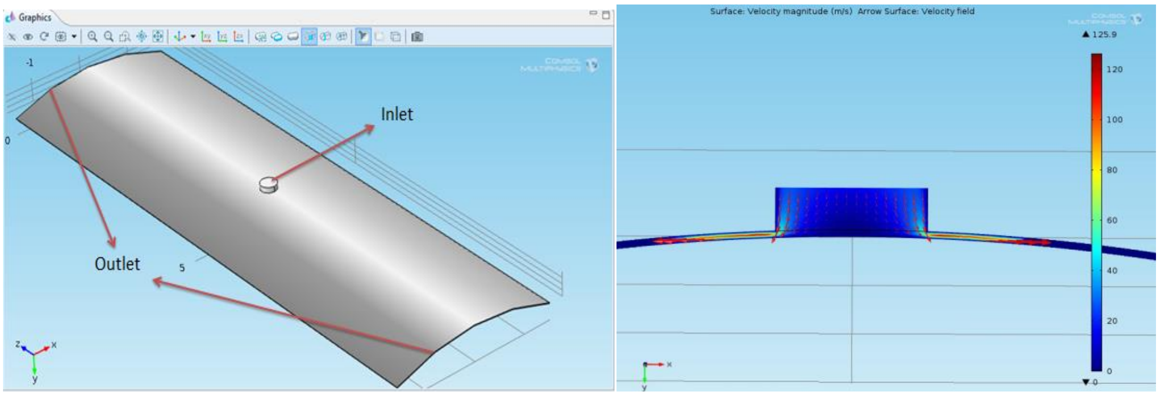


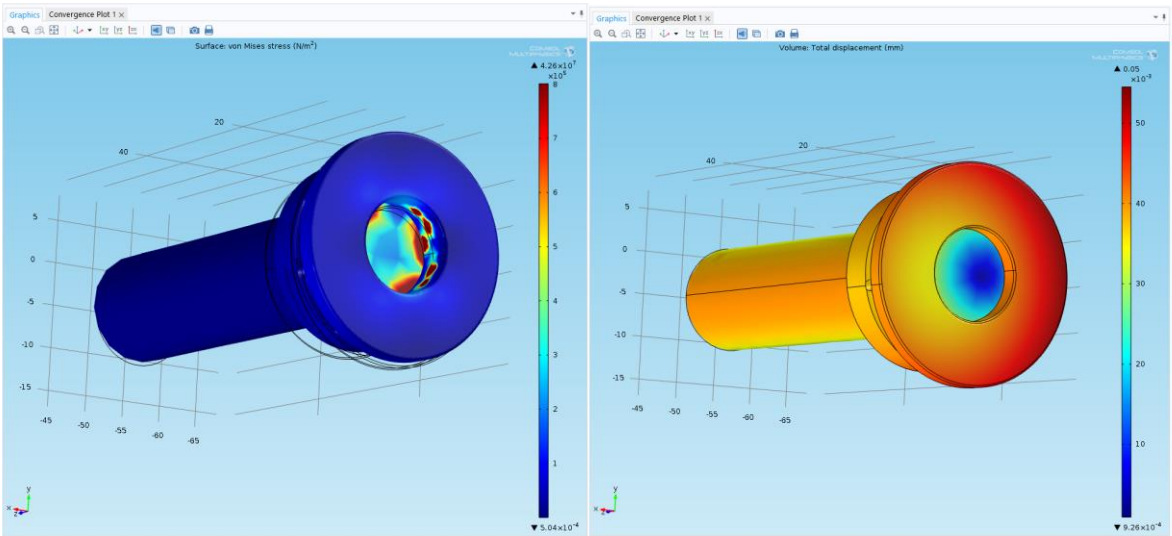
Figure 14: a. Inner diameter of the air bearing vs. load capacity graph, b. Nozzle diameter vs. load capacity graph, c. Nozzle number vs. load capacity graph, d. Clearance vs. load capacity graph

Manufacturing of first prototype: During the first prototype trials it was realized that there is a need for air bed on the inner surface of the bearing. Also the importance of nozzle alignment was realized. The final product was designed accordingly to get a finely working air bearing system.



a. **b.**

Figure 15: a. 1/8 of the geometry of the inlet and clearance with specified boundaries, b. Velocity and velocity arrows on the center plane including inlet and clearance



a. **b.**

Figure 16: a. Stress distribution on the shaft-bearing assmebly, b. Total displacement on the shaft and bearing assembly

MATERIALS AND METHODS

The complete system contains bearings, housings, nozzles, O-rings, fittings, air hoses and shaft. So, the system has three main parts which are manufactured from scratch: bearings, housings and nozzles. Housing is made from Al 6000. Bearings are made from brass and nozzles are made from brass set screws. Brass is preferred for its high machinability, 6000 series Al is selected for again high machinability and abundance in the market.

In order to manufacture the bearings CNC milling cutter is used. At first manual turning machine is used in order to manufacture the housing. The details and screw holes were manufactured with a CNC milling cutter. Nozzles were manufactured from setscrews. Nozzle openings were opened by CNC milling machine and manufactured nozzles were inserted to their holes on the bearing by allen wrench. A ready-made pin sleeve within the desired tolerance (h6) is used as a shaft.

The critical points in the manufacturing are concentricity, cylindricality of the two bearings, parallelism of the housing to the test ground and the alignments of the nozzle holes along the surface of the bearing. Micron level tolerances were assigned in datum features in order to get these above mentioned points as we desired. Manufacturing of the parts within given tolerances were achieved in Bilkent University Mechanical Engineering department manufacturing facilities.

RESULTS AND PERFORMANCE EVALUATION

Several trials with different nozzle numbers and shaft diameters were conducted. Supply pressure from 2 bars to 8 bars was used in the trials[1]. From the experiments it was learnt that the clearance and supply pressure is the most important parameter. Experiments with shaft diameter changes together with additional weights were also conducted. Pressure determines the rotation rate and the smoothness of the shaft. We designed this mechanical system such that it can be easily assembled and controlled. Modularity of the system is the most positive point in our design. Although we could not test a 50,000N impact force, the structural simulation results show that our design can withstand 50,000N of load statically.

CONCLUSIONS AND FUTURE DIRECTIONS

In this project we produced an air bearing couple to use in missile gimbal seeker mechanism for stabilization. Some prominent advantages of the air bearings over ball bearings like reducing the friction, increasing the smoothness, decreasing the heat generation are tried to be emphasized with this project.

Although there are different types of air bearings in the market the unique part of our project is the small dimensions. The main goal of this project is whether such a system can be used in a missile or not. In other words, this is a feasibility project given by ROKETSAN. With mathematical calculations, simulations and experimental trials we provide a complete feasibility study within the given constraints. This air bearing couple can be used in stabilization of systems on a shaft and can be combined with a motor in order to get a rotation with high rpm and zero friction. As future studies design and manufacturing of bearings from porous media materials can be done.

[1] For more information about the results please send an e-mail to eceozelci@gmail.com

REFERENCES

[1] D. G. Lee and J. K. Choi, "Design and Manufactur of an Aerostatic Spindle Bearing System with Carbon Fiber-Epoxy Composites," *Journal of Composite Materials,* vol. 34, no. 14, pp. 1150-1175, 2000.

[2] "Air Bearings," IBS Precision Engineering, [Online]. Available: http://www.ibspe.com/category/air-bearings.htm. [Accessed 07 October 2015].

Development of Stabilized Stretcher Support

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Abstract

Patients carried in the ambulance are exposed to vibrations caused by obstacles on the road (speed bumps, holes or any other structural imperfections). In certain frequency regions, those vibrations may present health and safety risks for patients. Literature research and studies show that there is not a system isolating vibration amplitudes in ambulances in Turkey. The purpose of the project is to

develop a stabilized stretcher support system to provide a safe and comfortable drive to the people in the ambulance. The system is also aimed at being developed by using local opportunities and decreasing foreign source dependency as much as possible.

PROJECT DESCRIPTION

In this project, the level of transmitted acceleration on the base plate is tried to be decreased which occurs when a disturbance comes to the ambulance ground. If there is no such isolation system or if presumably there is a solid link between ambulance ground and the base plate, the acceleration is directly transmitted to the base plate.

Firstly, the disturbance that comes to an ambulance ground is modeled. Then, active system is created and improvements have been made accordingly. In this system, with two linear telescopic arms (slider arm) which are controlled by two different servo motors, position of the base plate is adjusted. There is a bar connected to the servo motor shaft which translates angular motion of motors to the linear motion on the telescopic arm. When acceleration is detected on the base plate by IMU sensor which is capable to work on 9 axes, the information is sent to controller (Arduino), and then the controller determines the position of the servo motor by regulating the current.

Throughout this project, the mechanism is manufactured, assembled and control model is constructed. By testing prototype, a comparison between theoretical and experimental results is done. When there is a mismatch between results, modeling of the system is revised and required corrections are made.

The design and performance specifications of this project are as the following:

• Attenuating the level of transmitted acceleration to patient in vertical direction and so decreasing vibration amplitude.

• Use of local opportunities and easy access of parts

MILLESTONE AND ACCOMPLISHMENT

Modeling the Disturbance

In order to simulate real cases on ambulances as much as possible, development of disturbance model coming from ambulance ground is done as the first step. Model is generated on SIMULINK software.

Preliminary design

The literature research is done in order to find an optimal solution that satisfies determined requirements. By the inspiration from the current solutions which are mainly active, semi active and passive solutions, totally six solutions are developed.

Concept selection

In this step, in order to choose a design from the previously proposed solutions, a Gantt Chart (Table I) is developed by using the criteria which are determined amongst the team members and advisors. Then, proposed solutions are compared accordingly.

CRITERIA	WEIGHT	CONCEPTS											
		CONCEPT - 1		CONCEPT - 2		CONCEPT - 3		CONCEPT - 4		CONCEPT - 5		CONCEPT - 6	
		Average Rating	Weighted Score	Average Rating	Weighted Score	Average Rating	Weighted Score	Average Rating	Weighted Score	Average Rating	Weighted Score	Average Rating	Weighted Score
Required Power	0,11	8,13	0,91	9,63	1,08	6,50	0,73	6,75	0,76	3,00	0,34	5,13	0,58
Ability to Isolate Vibration	0,17	5,13	0,89	3,00	0,52	6,75	1,17	7,13	1,24	7,00	1,22	8,50	1,48
Time	0,11	7,25	0,82	7,88	0,89	5,63	0,63	5,50	0,62	4,75	0,53	6,88	0,77
Cost	0,15	7,00	1,06	7,38	1,12	4,13	0,62	3,75	0,57	4,00	0,61	6,13	0,93
Easy Access of Parts	0,11	6,75	0,74	7,88	0,87	3,63	0,40	3,63	0,40	5,25	0,58	7,50	0,83
Physical Dimensions	0,11	6,00	0,63	7,13	0,75	6,38	0,67	6,38	0,67	4,38	0,46	7,38	0,77
Maintenance and Reliability	0,11	5,50	0,61	6,38	0,70	4,50	0,50	4,50	0,50	4,13	0,45	8,00	0,88
Complexity	0,13	7,25	0,91	8,00	1,00	3,75	0,47	3,63	0,45	3,38	0,42	6,13	0,77
TOTAL		6,56		6,92		5,19		5,20		4,61		7,00	
RANK		*3*		*2*		*5*		*4*		*6*		*1*	
CONTINUE ?		No		No		No		No		No		Yes	

Table I: Concept Ratings

Detailed Design

The final choice amongst all solutions is decided to be an actively controlled mechanism. Movement is provided by two servo motors which are linked to left and right slider arms. Then, the design is modified according to required specifications.

Controlling Model

In order to understand the working principle of the mechanism, the system is modeled on SIMULINK. Then, by using the acquired data gathered from the control model, the power requirements, which are essential for choosing servo motors accurately, are calculated.

Production of mechanism

After power requirements are determined and dynamic model is developed, the mechanism is manufactured and assembled based on the technical drawings done on SolidWorks.

Programming of Controller

In this stage, the controller is programmed and the mechanism is tested to determine whether it satisfies the requirements of the project or not.

Development Process and Test

This stage is vital since it is hard to foresee the imperfections and impending miscalculations without revision. Accordingly, improvements on both controller and mechanical calculations are done in order to increase the accuracy.

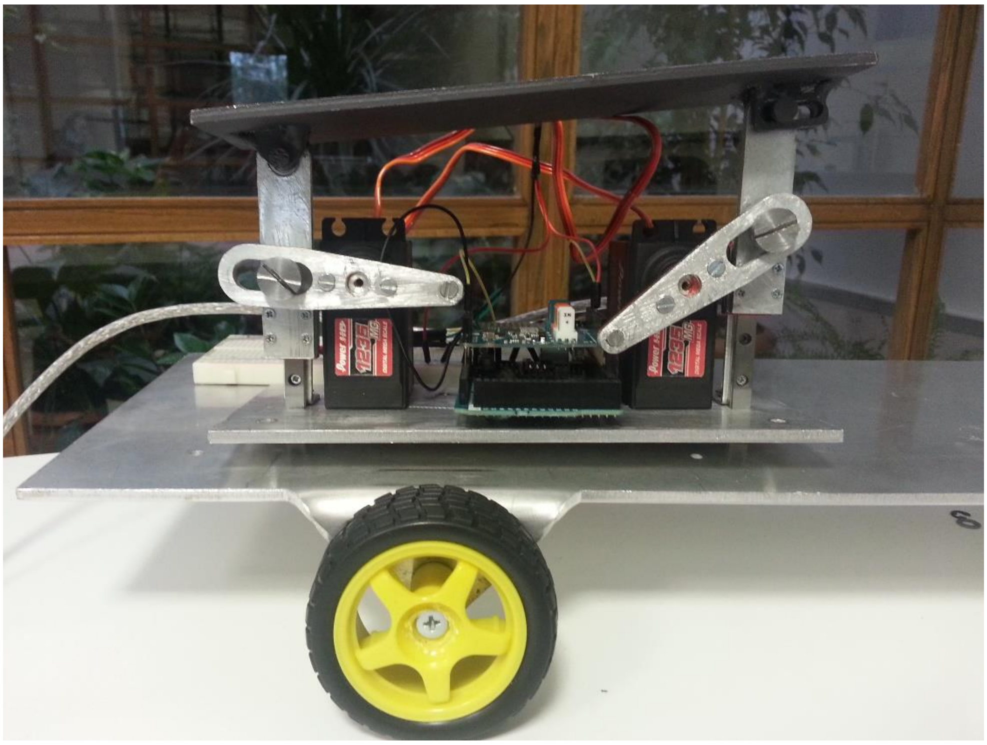

Figure 1 Front View of the Prototype Mechanism

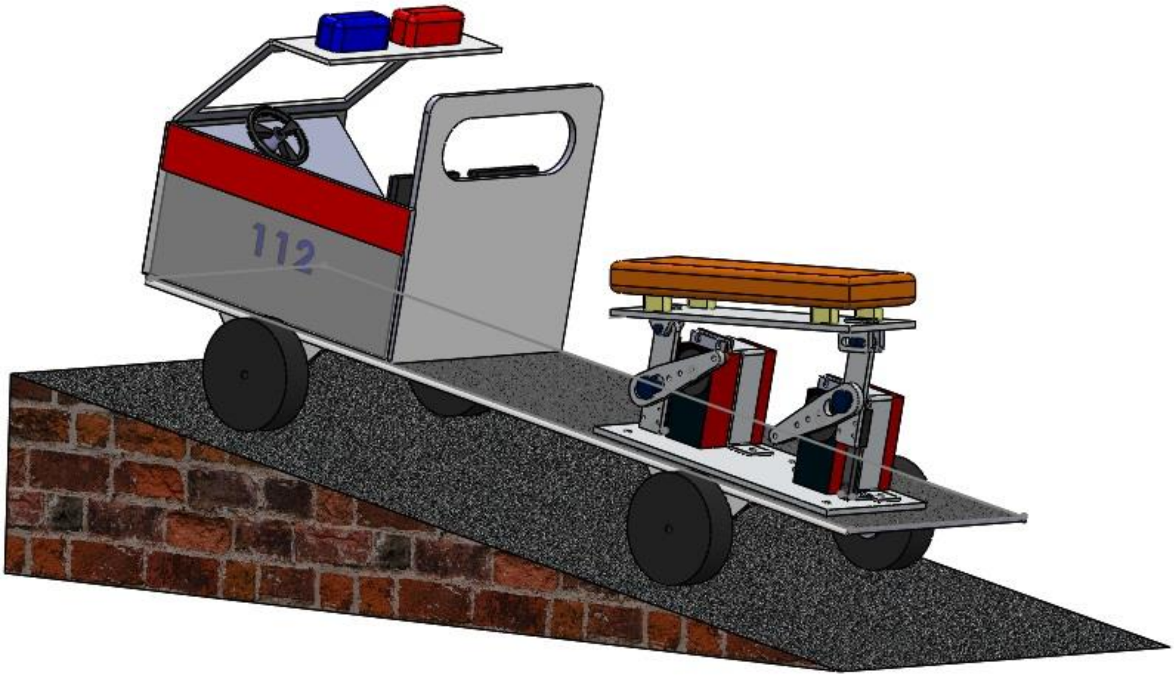

Figure 2 Appearance of the Mechanism in More Realistic View

MATERIAL SELECTION

Servo motors (Power HD 1235 MG):

Power HD 1235 MG has ultra-high torque and is very effective when system is exposed to high loads. It provides at 7.4V, 40 kg-cm torque, at 6V 35 kg-cm torque.

Arduino Mega:

The control of the servo motors are provided by the use of micro-controller. User friendliness and practicability of Arduino which provides access to open sources and libraries has proved Arduino to be the best choice among its alternatives. By considering the features that Arduino Mega provides, the use of this micro-controller seems to be appropriate under the consideration of the technical specifications it possesses with a purpose to control the servo-motors.

Arduino IMU-9 axis Motion Shield Sensor:

The reason behind the selection of the IMU as the sensor of the project is due to fact that gyroscopes and accelerometers do not provide quite enough information to comfortably calculate things like orientation, position, and velocity. Therefore, in order to measure those and other variables, inertial measurement unit (IMU) is decided to be used rather than gyroscopes and accelerometers in the project.

Linear Sliders (Schneeberger MNN 7):

For constructing the small prototype of the system, miniature linear sliders are required to sustain frictionless environment where Schneeberger MNN 7 fulfills technical requirements. In overall, these linear sliders have the task of transferring angular motion to linear motion to control the position of the stretcher.

METHODOLOGY

The system which is the combination of servomotors and linear transmission elements is based on an actively controlled system provided by the use of a control system.

This system gathers required data from sensors located on different places of the system and provides a harmonic motion between servomotors and the base plate of the stretcher. Inertial measurement unit (IMU) is used rather than accelerometers in order to make changes available in system considering possible problems due to acceleration measurement of sensor. IMU's are combination of three accelerometers, three gyroscopes and optionally three magnetometers, which provides current position, velocity and acceleration to reference point in three axes. They are able to provide fast data collection in small time intervals.

Servo motors are positioned according to obtained data from IMU. Liner arms are moved with servo motors and position of base plate is adjusted according to the amplitude of vibrations coming from road disturbances.

RESULT AND PERFORMANCE EVALUATION

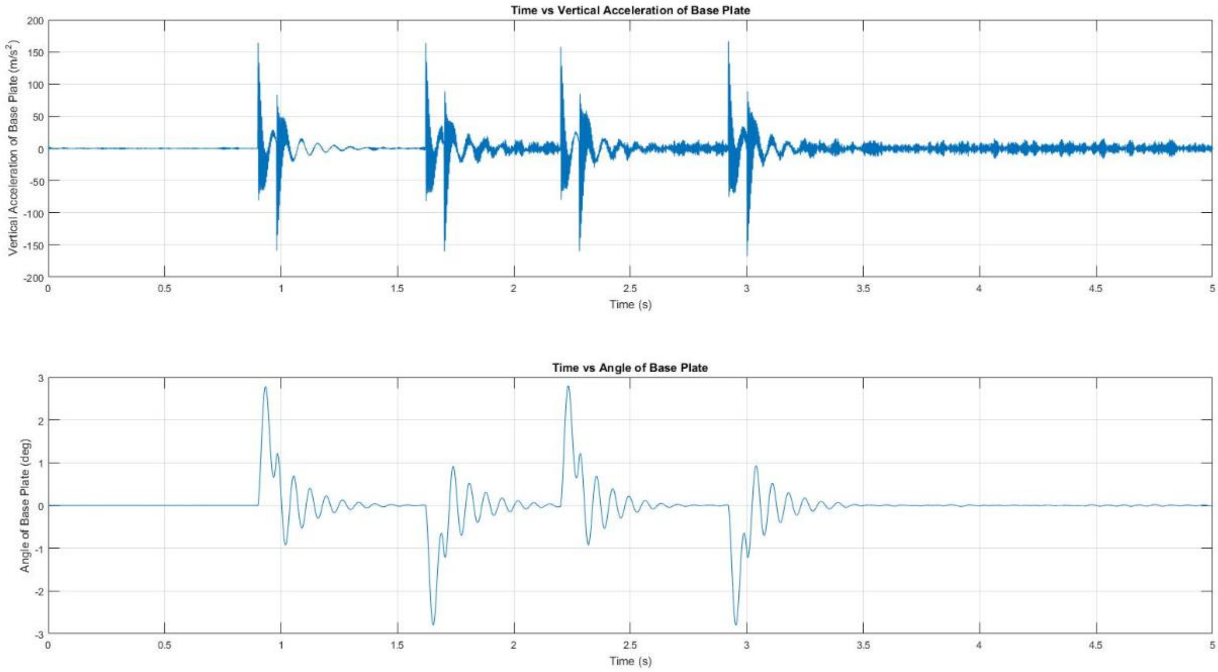

Figure 3 Mid-point Acceleration and Angle of Base Plate Caused by Disturbance

The figure above shows that how disturbance coming from road affects base plate. Namely, by looking at the above figure, acceleration and angle of the mid-point of base plate can be observed. The values of angle of base plate's mid-point ranges from approximately -3^{o} to 3^{o} (This range is valid for only prototype, not for the real scenario). As can be shown, there is a natural attenuation in both acceleration and angle values. This is mainly due to the fact that the system is modeled as if there is a suspension system. Although there will be no such a suspension system in the prototype, there will be a controller system which is expected to give faster responses and better results.

CONCLUSION AND FUTURE DIRECTIONS

If it is observed that power supply by servomotors lacks, currently used ones may be changed with their alternatives having superior features. While doing so, the main purpose will be to stay within especially physical constraints. However, before changing motors, the first aim is determined to decrease the friction in between mechanical components as much as possible.

It is expected that this prototype system will be a transition step for the real ambulance system with real physical dimensions if testing results are convincing. Since all the mathematical models and calculations are constructed parametrically, these can be implemented for the real scenario with subtle changes in values. However, it is expected that the current mechanical system cannot be used for the real systems directly.

Design of an Anti-Backlash Missile Control Actuation Mechanism

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Abstract

Backlash is the one of the most important problems that can be encountered during the design of high precision systems. Although many solutions are offered to solve the backlash problem, the mechanic backlash is not fully solved. In this project, we are asked by Roketsan to try to solve this problem in a gearbox which will be used as a missile control actuation mechanism. We are given a limited space to design our anti backlash system and the input and output shafts' places are determined beforehand. After many design trials and literature research, we offered two systems that aim to solve backlash problem in a missile control actuation mechanism. These two designs are compared with the reference boxes which don't have any anti-backlash mechanism with high resolution encoders placed at both input and output shafts. Then results are presented.

PROJECT DESCRIPTION

In the control system of the missile, wings are used as actuators and controller is the DC motor and the gearbox which transmits power and rotation from DC motor to the wings. Input is given to the system from the sensors according to the missile type, for example, for the laser guided missiles, laser seeker detects the laser aimed point and commands to the DC motor to rotate in specified degree. Gearbox is tasked to transmit this rotation to the wings. In this way, guided missile can change its direction to hit the aimed point precisely. However, a problem occurs due to the mechanical backlash in gearbox, the wings don't align themselves precisely due to backlash, thus this may cause missile to miss the target. Backlash not only causes steady state error but also creates a time delay when the rotation direction is changed. Thus, it can be said that backlash is a potential cause for instability in closed control systems. This project aims to design a gearbox that has minimal backlash for the control mechanism of the missile and the precise operation of the missile. One should also note that this anti-backlash system can also be used in other applications where gears are used to transmit power and rotation such as CNC lathe machines to improve precision.

Backlash can be defined as the lost motion caused by gap between the teeth of the mating gears illustrated in *Figure-1*. To illustrate, when the DC motor of the missile tries to turn the wing 20 degrees, the wings will not turn exactly 20 degrees, the exact number will differ 0.5 or sometimes 1 degree according to the severity of the backlash. This inaccuracy can misguide the missile and it may result in unwanted situations. Commercial solutions to backlash problem include pre-loaded gears, in which gears cut in half and force applied by help of springs. However this solution could not be applied to helical gears, which is used in the design.

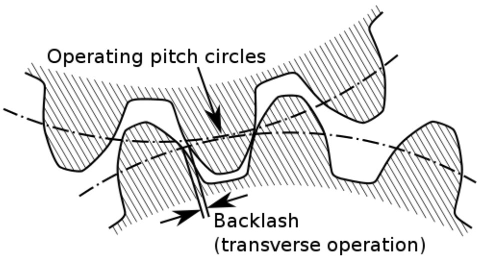

Figure-1: Backlash

There is a considerably small space inside the missile for controller mechanism. Therefore, gearbox should occupy as small space as possible. *Figure-2* shows the basic design and dimensions of the box; $64\,mm$ along x, $32\,mm$ along y and $32\,mm$ along z with non-parallel and non- intersecting input and output shafts. A $8\,mm$ in diameter input shaft is located at $16\vec{\imath} + 32\vec{\jmath} + 16\vec{k}\,mm$ and $8\,mm$ diameter output shaft is located at $48\vec{\imath} + 16\vec{\jmath} + 32\vec{k}\,mm$. The gearbox also has to be able to transmit input torque with minimal loss and the gears and shafts inside the box have to resist this torque.

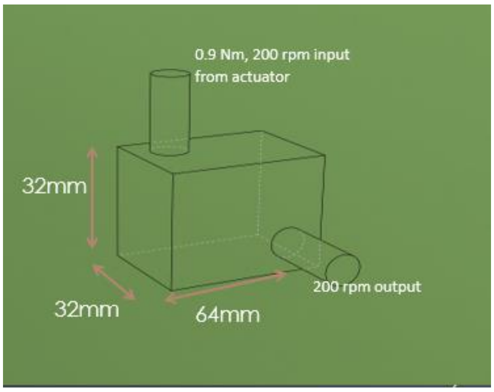

Figure-2: Project Requirements

The design and performance requirements of this project are summarized as below;

- Geometry requirements of the box are given in *Figure-2* above. Transmission system inside the box has to fit in a space with $64\ mm$ along x, $32\ mm$ along y and $32\ mm$ along z. The thickness of the box is not specified in the requirements, however, considering the limited space inside the missile, minimum space usage is always preferable for the gearbox.
- Rotation and power coming from the input shaft has to be transferred between *nonintersecting* and *nonparallel* shafts.
- $0.9\ Nm$ Torque is coming from the DC motor via input shaft to the system. Gears and shafts have to be strong enough to meet the input Torque. Stress analysis must be done.
- Input shaft and output shaft must rotate with 1:1 ratio meaning that 200 rpm input rotation must be transmitted to output shaft without any rotation loss and output shaft should rotate with 200 rpm as well.
- Output shaft must be able to rotate $\pm 30°$.
- Anti-backlash motion transmission system must be sufficient with tolerance $\pm 0.3°$.

MILESTONES AND ACCOMPLISHMENTS

- A number of preliminary designs are offered and 2 of the preliminary designs are selected according to criteria determined by requirements and constraints.
- Mathematical modeling and finite element analysis are done to select appropriate material and geometry for the designs.
- Designs are changed and modified according to the problems encountered and feedback received.
- First prototype helical gear set is manufactured.
- Designs are modified and improved again according to the feedback received.
- Both designs plus the reference boxes of these designs are manufactured successfully.
- Manufactured parts are treated with surface finish, and assembly is successfully done.
- Test setups are proposed to measure the backlash amount in the systems.

- The setups are improved and test setups are installed successfully.

MATERIALS AND METHODS

1. Proposed Systems & Their Working Principle

a. Cut Box

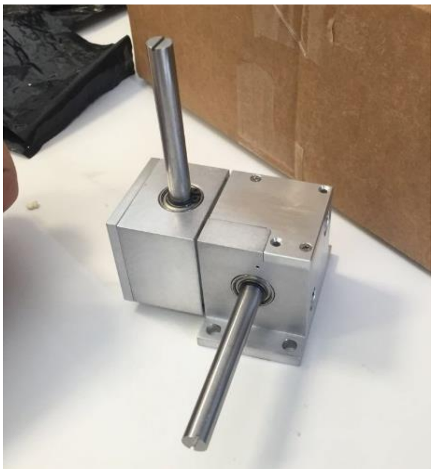

Figure 3. Manufactured Cut Box

This model is composed of two boxes which are assembled to each other via two springs connected to cross edges of them. Helical gears with $45°$ helix angle are connected to both shafts with 90° angle in order to transmit rotation and power between non-parallel and non-intersecting shafts. Since one of the project requirements is maximum $\pm 30°$ rotation for the output shaft, helical gears are trimmed from the edges to fit in limited space inside the box.

The main idea to minimize the backlash is to push two helical gears to each other with springs in order to prevent the backlash between mating teeth. If one pushes two gears to each other, it can decrease the clearance and also the backlash, so pressing the helical gears toward each other is expected to minimize the backlash.

b. Bevel Gear

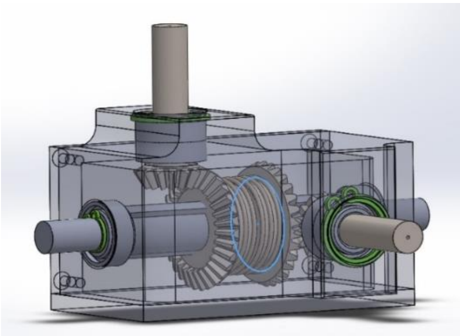

Figure 4. Bevel Gear Box

This design doesn't have two distinct boxes, instead it has one box. As it can be seen from the Figure 4, there are 2 big bevel gears and 2 small bevel gears, they are placed in a way that the ratio is still 1:1.

In order to minimize the backlash present, it is thought to place a compression spring between the two big bevel gears that are located at the middle shaft. This compression spring will be placed pre-loaded such that it will push the bevel gears to the input and output bevel gears. One should note that the middle shaft is a splined shaft thus it enables gears to slide axially, in the meantime make them rotate in harmony as well. By this way, the backlash is expected to be minimized by minimizing the clearance as it was in the Cut Box design.

2. Manufacturing & Assembly Processes

In order to ease the process of assembly and manufacturing both designs are carefully designed and their complexity is minimized. To illustrate, both designs have lids in proper places that will allow the assembly process without disturbing the precision of the box and the shafts' locations. The manufacturing of these designs, not including the bought parts such as bearings, is done by a single company. It is thought that, it would be wise to manufacture all of the parts in one place to reduce any manufacturing errors that might occur and any misunderstanding between manufacturing companies.

Gears produced by using gear hobbing machines. The boxes of designs are manufactured in milling and drilling machine. Springs are manufactured by using spring winding machine at necessary thickness and spin numbers.

RESULTS AND PERFORMANCE EVALUATION

In order to see whether our proposed designs can accomplish what they claim, a reference point was needed so for each design, a reference box is manufactured without any anti-backlash solution. In that way at the same scale and same working conditions it will be seen how much improvement is done by our proposed designs with anti-backlash solutions.

To measure both the reference boxes backlash and proposed designs' backlash, it is thought to use DC motors with encoders as it is given in below *Figure 5.* This DC motor including encoder will be placed onto the input shaft and only encoder will be placed onto the output shaft. In that way it is expected to read encoder data by a data acquisition device and to plot the read data in a graph to visualize the results better (i.e. a sinusoidal graph having both readings). Since it is required to minimize the backlash to 0.3 degrees, the resolution of the encoder should be at least 4000 counts per revolution to sense changes as low as 0.1 degrees.

Figure 5. DC Motor with Encoder

CONCLUSIONS AND FUTURE CONSIDERATIONS

We are aiming to decrease the backlash, so if readings that will be gathered from encoder and DC motor setup suggest that our anti-backlash solutions decrease the backlash, this decrease in backlash will be very effective to improve the precision of the missile. Also as mentioned before, in other applications such as CNC lathe machines, proposed designs can be modified to use in them, thus improving precision of the application.

To conclude, these anti-backlash solutions offered in this project are expected to minimize the backlash efficiently, thus they can be improved further and modified further to mass produce, and to fit other applications. In that way, not only missile precision will be improved but also other applications' precision will be improved too. The project improves our vision about backlash and its solutions. We became familiar to production process and manufacturing techniques. The project in general improved our perspective in working as a team. We made several connections in industry during manufacturing process. On the whole, the project taught us how to conduct a project.

Height Adjustment Mechanism for a Dishwasher

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Abstract

The problem with the dishwashers in today's world is that the only bottom basket can be used to wash the plates and other large dishes. This causes efficiency problems such as starting the machine without fully loading the top basket. Upper basket height adjustment mechanism provides convenience with such problem.

The design of upper basket height adjustment mechanism introduced in this report works by pushing handles towards the outside of the basket, freeing the arm from the holding box, and allowing height adjustment. Reversely, the arm will be locked to the box when it is pushed towards the inside of the basket. The handle rotates from the holding clamp and it does not stretch. The holding clamp is attached to an extra layer of pipe on the basket. The position of clamp here brings out some

concerns about carrying the load which is analyzed with Finite Element Analysis method using COMSOL Multiphysics®**.**

There are four main elements, which are critical for the process: the molder, the material, the injection machine and the mold.

Our mechanism will be made of POM (polyoxymethylene), which is suitable for plastic injection molding method. One of the main issues is that cost of the product. The cost data is taken from Arçelik for material and calculated for mass production.

PROJECT DESCRIPTION

The problem with the dishwashers in today's world is that the only bottom basket can be used to wash the plates and other large dishes. This causes efficiency problems such as starting the machine without fully loading the top basket, which is a waste of water and electricity. To prevent this waste, upper basket height adjustment mechanism is introduced. This mechanism, which will be put on the side of the upper basket, will allow the user to change the height of the upper basket. Therefore, allowing larger dishes to be put on the top basket so that the dishwasher can operate more fully, saving energy, water and time.

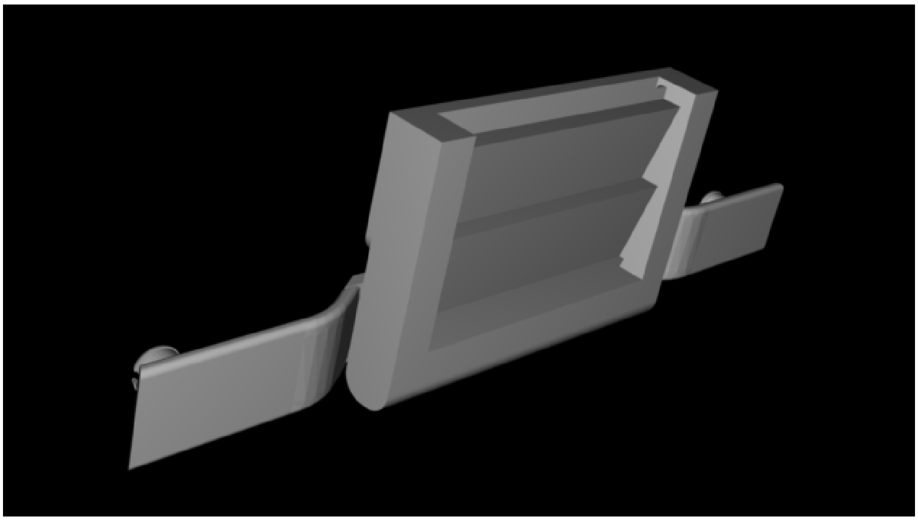

Figure 1: Leveler

Figure 2: Arm

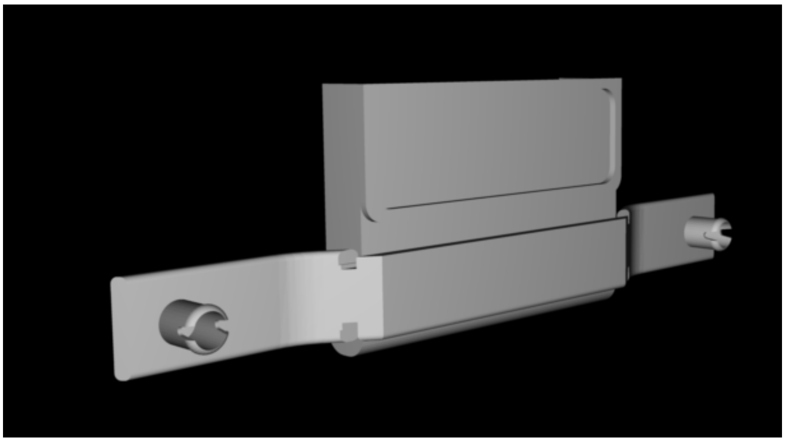

Figure 3: Leveler (Back View)

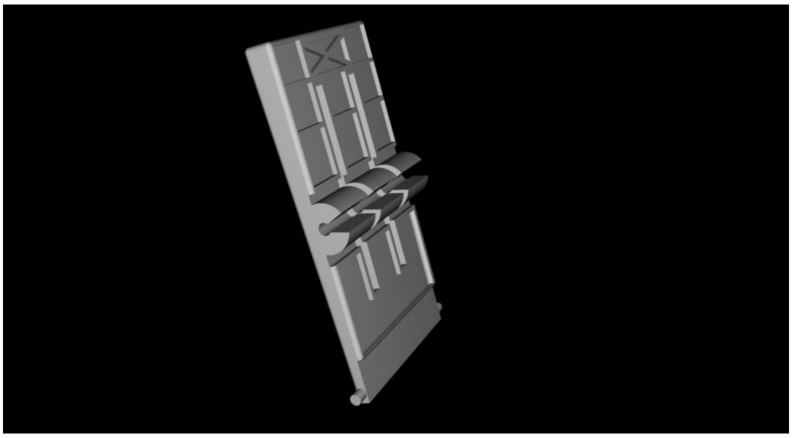

Figure 4: Arm (Back View)

Requirements

- Fully Mechanical Design
- Maximum Cost limit 4000 TL
- 3D Printer for Prototypes
- Durable for 50.000 cycle
- Patented design

Constraints

- Part able to carry 23 kg.
- Each step size should be 22,5 mm
- It has to be polymer used in injection molding to produce huge amount of it.
- Unique Design

MILESTONE AND ACCOMPLISHMENTS:

The main obstacle for the design section was coming up with a patentable design.

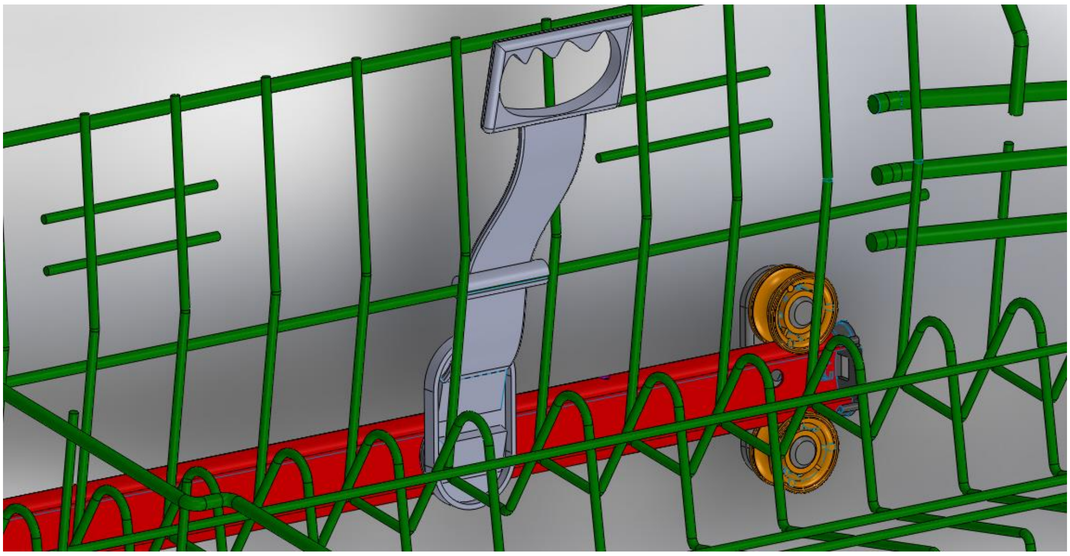

Figure 5: A finalized design

The figure above depicts a finalized design. A very simple and complete design was made in the first semester. After the change we have completely upgraded the design.

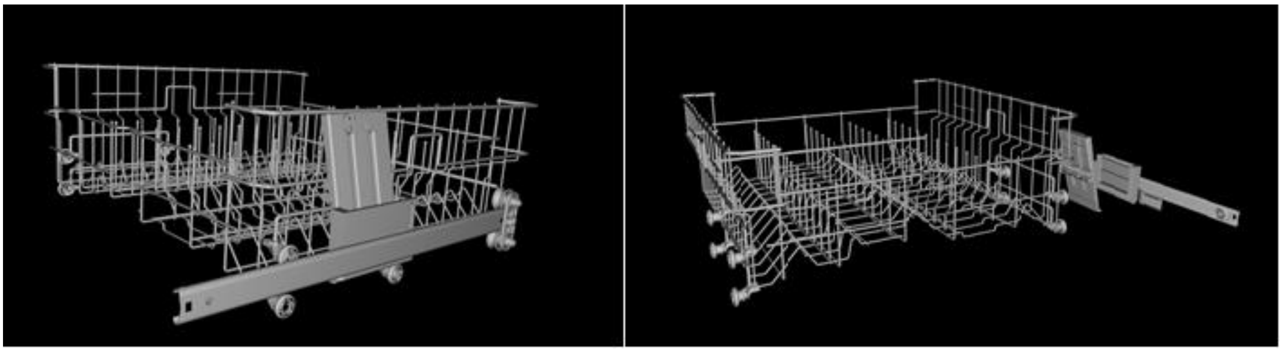

Figure 6 : Rendered image of Finalized Design

MATERIALS AND METHODS:

Fatigue and the life cycle of the main part of the system is calculated by using an online software. By calculating the stresses applied to the cross sectional area of our part. Maximum stress loaded is assumed as the 23 kg of the dishes and the minimum stress is 10 kg of the dishes as the average Daily use of the dishwasher upper basket.

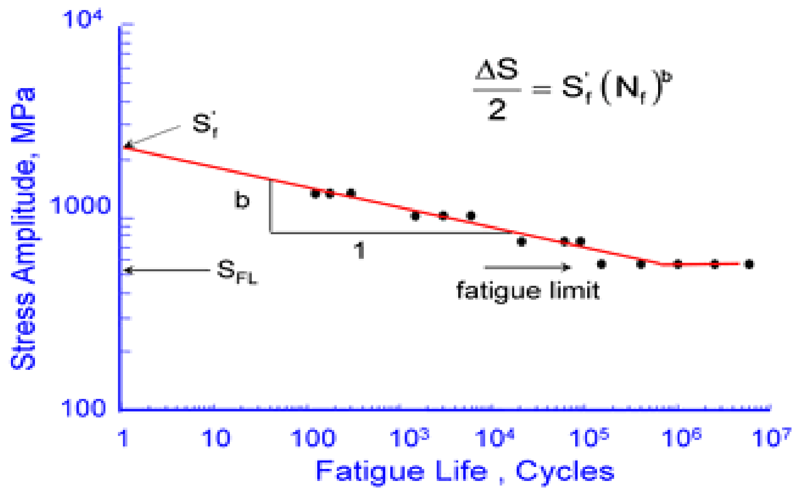

Figure 7: Fatigue analysis result

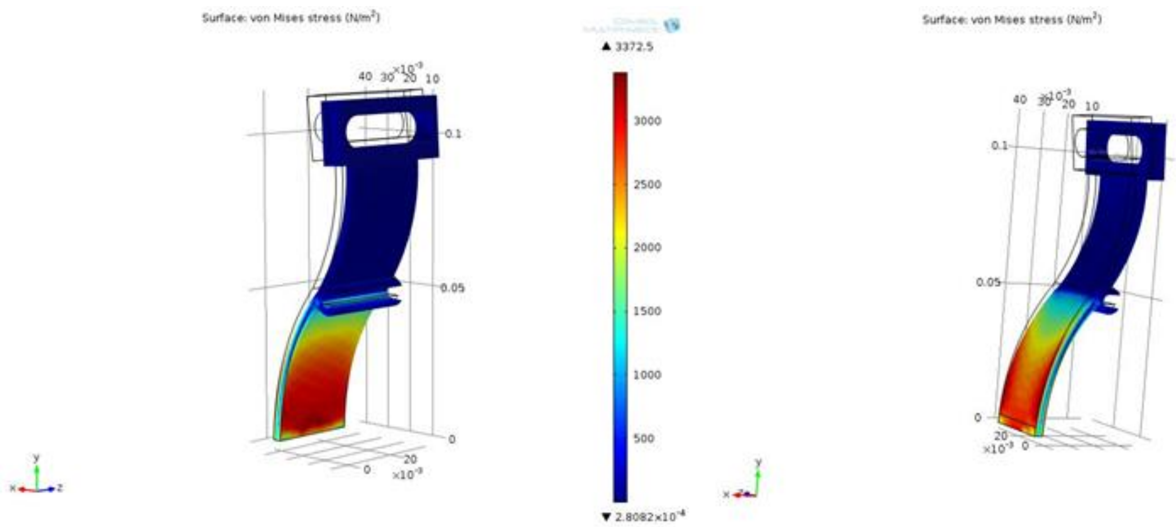

Figure 8: Finite Element Analysis Results

After obtaining the computer aided design of our system, we conducted a finite element analysis in order to see the stress distribution for corresponding loading forces. Maximum stress was obtained as 3372.5 N/m^2. It is within our maximum limits and safety factors.

RESULTS AND PERFORMANCE EVALUATION:

The leveler and the arm are both resilient enough to carry this procedure, for the necessary 50.000 cycles. With our material selection (POM) the pieces will endure and work properly for the given cycle requirement.

CONCLUSION

In this project, upgraded design has been sketched and analyzed based on manufacturing process needs. All the tests are done or are upon concluding in order to obtain perfect results. In addition, risk analysis of this design is also made and it is also another ongoing process. The major issue was to achieve compatibility with the original dimensions and solid model dimensions. A minor issue is the reliability of used material. The result is that dimensions are not ideally engaged; however, reliability of the material is satisfying.

Further step for the group is to make small rearrangements, and set the design up on dishwasher without any flaws in working conditions.

Compliant Mechanism Smart Wing with Shape Memory Alloy Spring Actuator for Missiles

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Abstract

An optimized lift-drag relationship of a cruise missile or UAV wing can be achieved when the camber can be varied according to the different operating conditions. Conventionally, these wings are controlled via electric motors or hydraulic actuators. Actuators made of smart materials have the advantage of higher power-to-weight ratio as compared to conventional electric or hydraulic actuators. The purpose of the presented project is to develop a wing which employs smart materials as actuators and has a compliant mechanism for motion instead of conventional actuators and hinges respectively. Thanks to these improvements, missile's wing adopts to different flight regimes, thus reducing the fuel consumption and increasing the range with a small added weight.

PROJECT DESCRIPTION

Smart wing is a concept that consists of new smart materials and pioneering structure. Smart wings project is focused on the actuator design with the use of smart technologies. Therefore, actuator selection is significant in terms of progress in the project.

In aerodynamics, one of the major goals for airframe is related to its weight, delivering the required lift with lowered drag leads directly to better fuel economy and range performance. To provide these conditions, lift-to-drag ratio which is defined as the amount of lift generated by a wing or vehicle, divided by the aerodynamic drag, is intended to be optimized for the whole flight conditions.

For different flight states, there exist different optimum wing designs. With the smart wings the need for different wing designs can be eliminated, as the smart wing can be adapted to different flight regimes. This technology although being investigated deeply in the recent years is generally applied on aircrafts and applications on missiles are very limited.

Requirements:

Wing geometry selection is selected as NACA 0012 air foil section since it is an open source, generic profile,

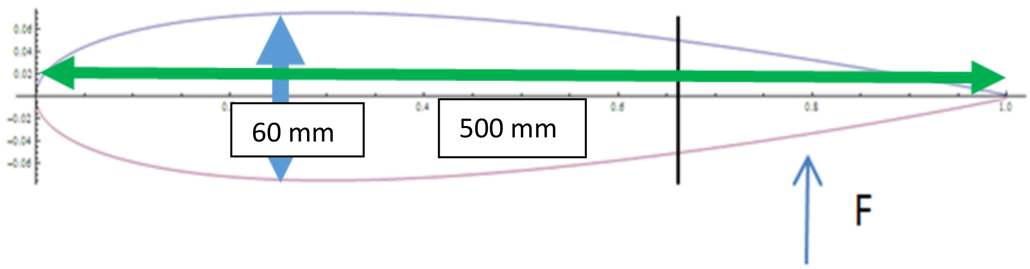

Figure 17: NACA 0012 air foil wing section

The tip of the wing should rotate minimum in the range of [-5 ^{o}, +5 ^{o}] with a target range of [-10^{o}, +10^{o}] degrees.

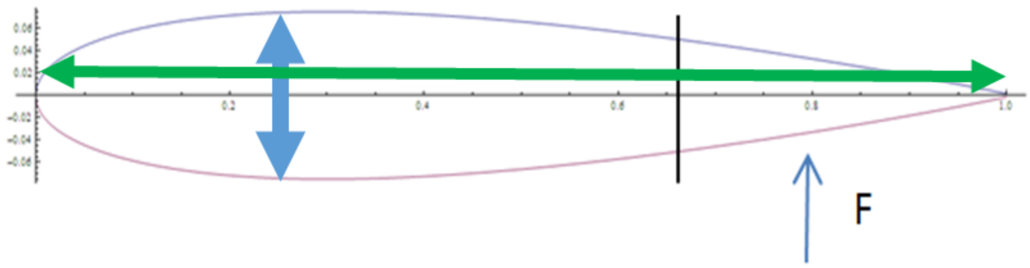

Figure 2: NACA 0012 air foil wing section

Bandwidth should be at least 1 Hz.

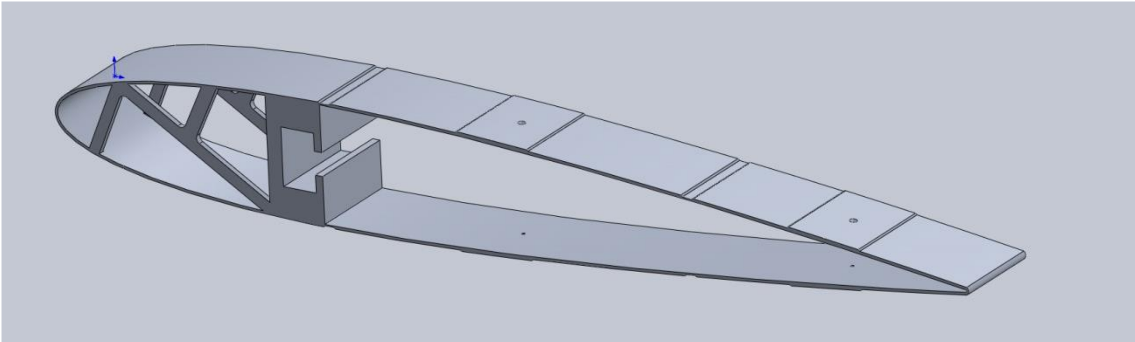

Figure 3: SolidWorks drawing of the wing

MILESTONES AND ACCOMPLISHMENTS

1. **Literature research:** At first, literature research was made. Three materials (aluminum, titanium and composite), two mechanisms (hinged and compliant), three sensor types (linear, magnetic and rotary) and three types of actuators (shape memory alloy, shape memory polymer and piezoelectrics) were considered. For each section of the matrix, best option was needed to be determined. At the end of the literature research, design was selected with aluminum as a material, compliant as a mechanism, rotary sensor as a sensor and shape memory alloy as an actuator.

2. **Design Process:** At this stage, placement of the SMAs (Shape Memory Alloys) was important. For wide-angle range, SMA springs are hinged from middle of the head section of the wing to the bottoms of the airfoils. First group was for movement of the upper wing side and the other group was for lower side.

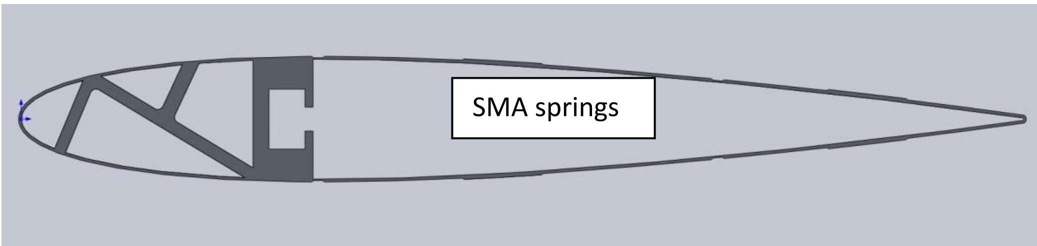

Figure 5: SMA spring locations

3. **SMA wires vs. SMA springs:** After the first testing of SMA wires, the required strain couldn't be observed. The cause of this failure was investigated and it was understood that the required deformation in the martensitic phase to cause the needed strain cannot be created without large loads. So, SMA springs were tested and the results were very remarkable, required strain levels were observed.

4. **SMA Spring Design:** After deciding to use SMA springs, design process had to be revised. Antagonistic working principle was thought and implemented in the design for push and pull movements.

Accomplishments

Hinge-less Mechanism

Hinges are used for rotation in the mechanical systems. Conventional hinges make the mechanical systems heavier and also they have to be lubricated. For overcoming these problems, compliant mechanism is used for the rotary motion. The compliant mechanism provides lightness and smooth surface while providing an easier motion for the smart wing system.

Smart Materials for Actuator

Nowadays, flaps are used on the missile wings for adjusting the angle of attack. In order to make *smart* wing, smart materials are used. Ni-Ti springs are selected as an actuator for the wings motion. These Ni-Ti springs have shape memory features.

MATERIALS AND METHODS

After conducting the design system, a model made from plastics is provided by ROKETSAN with the use of a 3D Printer. Using the model, the dimensions of the wing are enlarged to see the angle change better in the wing. The material of the wing procured as aluminum and the uniform wing body is produced with the material by wire erosion manufacturing technique. The SMA springs to actuate the wing will be placed in the wing and will be tested with the applied current.

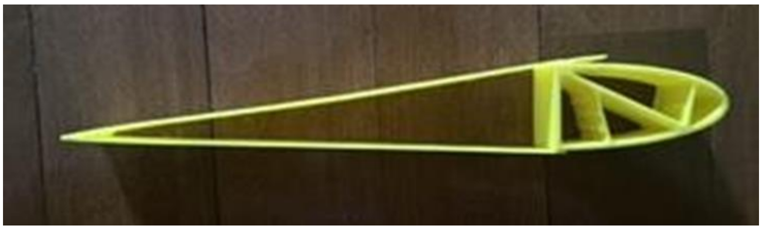

Figure 6: 3D Model of the wing

At the same time, in order to perceive and observe the wing angle change in the model, an electronic design system consisting of *PIC16F88 microcontroller* programmed with MPLAB IDE, used to deliver larger currents to the actuators, and an incremental *rotary sensor* for the feedback are used. The actuator movements are expected to rotate the tip of the wing segment; this angular displacement is expected to be fed into the control system through the rotary sensor. The read out data from the sensor is expected to be distributed to the PIC microcontroller and this will create a controlled environment for the electrical distribution.

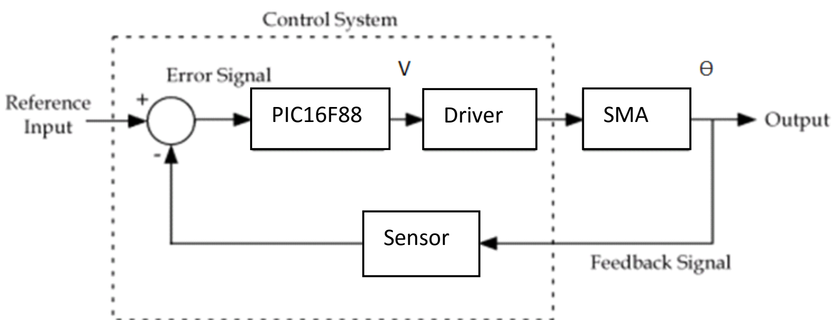

Figure 7: Feedback control system

RESULTS AND PERFORMANCE EVALUATION

Shape Memory Alloy springs was purchased and initial tests were performed in a test set-up in order to obtain and observe the phase changes. After deforming the SMA springs easily by a small amount of pull force by hand such as 80 grams. Since our aim is to control the actuators by a feedback control system, SMA springs have to be actuated by electrical current, using Joule heating. In order to investigate this phenomenon a SMA spring is attached on the flat surface by both of its ends which one end was attached to a clasp and the other was attached to a normal (not smart) stiff spring in order to see the pulling force by applying different voltages. The resistance of the SMA spring is measured by a potentiometer as between 3 to 4 ohms. Then, the alligators of the power supply (+ and -) are fixed to both ends of the SMA spring. The power supply at 4 Volts in the beginning is slightly increased to 9 Volts. SMA spring was actuated with electrical current and it was pulling the normal spring by a pulling force, which is directly proportional with the applied voltage.

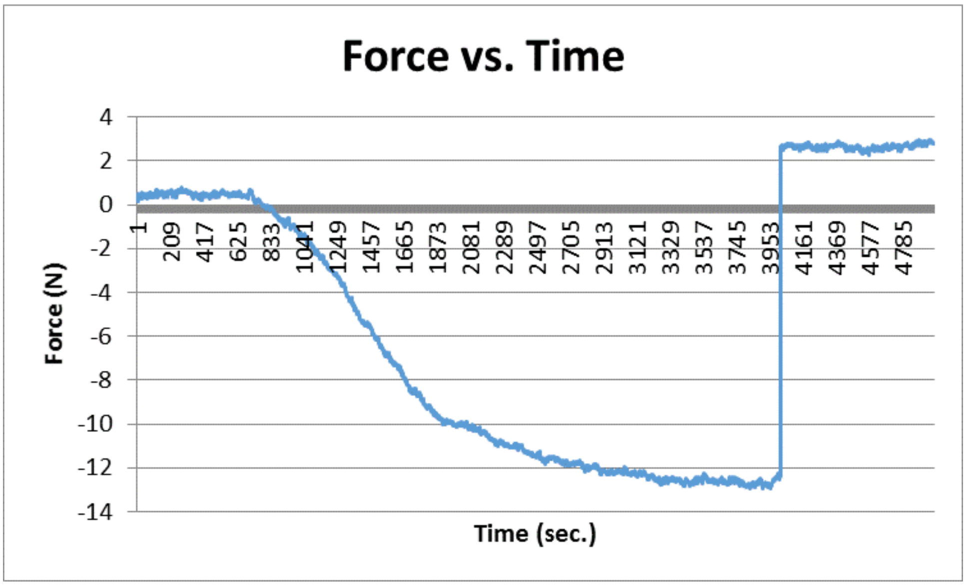

Figure 18: Force vs. Time graph of SMA Springs

In Figure 3, constant voltage that was 1.4 V was given to SMA springs. Less than 1 minute, SMA springs can generate approximately 12 N. These results showed that, SMA springs can generate large forces as expected.

CONCLUSION AND FUTURE DIRECTIONS

Controlling the angle of attack of the smart wing with the high accuracy is important because in military systems, especially for missiles, accuracy is very important. This project is a technology demonstration for employing smart actuators in missiles and UAVs.

For the future study a rescaling should be performed for actual wing profiles and environmental and performance tests should be performed for the implementation on real missiles.

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