B. TECH. PROJECT REPORT

On

Shape memory alloy actuated Solar tracker

BY

Abhishek Kumar
Ishan Meshram
Rohan Rathore

DISCIPLINE OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY INDORE

December 2017

Shape memory alloy actuated Solar tracker

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degrees

of
BACHELOR OF TECHNOLOGY
in

MECHANICAL ENGINEERING

Submitted by:
Abhishek Kumar (140003001)
Ishan Meshram (140003018)
Rohan Rathore (140003031)

Guided by:
Dr. I.A. Palani

INDIAN INSTITUTE OF TECHNOLOGY INDORE
December 2017

CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"Shape memory alloy actuated Solar tracker"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Mechanical Engineering' completed under the supervision of **Dr. I.A. Palani (Associate Professor, Mechanical Engineering),** IIT Indore is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

Signature and name of the student(s) with date

Abhishek Kumar   Ishan Meshram   Rohan Rathore

CERTIFICATE by BTP Guide

It is certified that the above statement made by the students is correct to the best of my/our knowledge.

Signature of BTP Guide with dates and their designation

Dr. I.A. Palani
Asso. Prof. Mechanical Engg.
IIT Indore

Preface

This report on “Shape memory alloy actuated Solar tracker" is prepared under the guidance of Dr. I.A. Palani.

Through this report we have tried to give a detailed design of a solar tracker actuated using shape memory alloy. We have tried to cover every aspect of the proposed design and its calculation. We fabricated the set-up and performed the experiments successfully which shows that the design is technically sound and feasible, and can have numerous applications.

We have tried to the best of our abilities and knowledge to explain the content in a pellucid manner. We have also added 3-D CAD models and figures to make it more illustrative.

Abhishek Kumar
Ishan Meshram
Rohan Rathore
B.Tech. IV Year
Discipline of Mechanical Engineering
IIT Indore

Acknowledgements

We wish to thank our guide **Dr. I.A.Palani** for his kind support and valuable guidance and giving us the opportunity to work for the B.Tech project under his supervision. We are thankful and fortunate enough to get constant encouragement from him. We owe profound gratitude to him who took keen interest in our project work and we are extremely fortunate to have his guidance. It is his help and support, due to which we were able to complete the design and technical report.

We would also like to thank Discipline of Mechanical Engineering and in total IIT Indore for providing us the necessary equipment for the fabrication process. We express our thanks to **Mr. A.Petare, Mr. Satish** and entire workshop staff for helping us in fabrication.

We would like to extend our sincere regards to **Mr. Ashish Shukla** and **Mr. Karthick.S** for helping in the lab activities. We are thankful to get constant encouragement, support and guidance from B.Tech project evaluation committee. It is their help and support, due to which we are able to complete the project.

Abhishek Kumar
Ishan Meshram
Rohan Rathore
B.Tech. IV Year
Discipline of Mechanical Engineering
IIT Indore

Abstract

This report deals with design and development of a shape memory alloy actuated solar tracker which is used to orient solar panel or any payload towards the sun. This project focuses on constructing a single axis solar tracker which tracks the sun only in azimuthal direction i.e. it tracks sun's daily east-west movement, not accounting for sun's seasonal motion. The tracker aims to incorporate the advantages of both active and passive solar trackers i.e. it focuses on constructing an accurate as well as efficient tracker. The design also dictates a way to actuate shape memory alloy springs directly through sunlight through the use of a high thermal conductive fluid. The design features a mechanical assembly connected to the shape memory alloy springs which are controlled using a control system consisting of ultrasonic sensor and Arduino. The panel rotates 120° in 8 hours (i.e. from 8:00 am to 4:00 pm), which implies the panel rotates 15° per hour. The net increase in output is recorded as 12.45% in an experiment conducted for 4 hours.

Table of Contents

List of Figures

CHAPTER 1: INTRODUCTION

Solar panel can convert direct sun rays to electricity. It is free from pollution and raw fuel cost. In order to get maximum energy converted from sun, an automated system is required which should be able to rotate the solar panel constantly. Solar trackers are devices which are used to orient the solar panels towards the sun. They do so by decreasing the incident angle of the incoming radiation which increases the net output. Generally, solar panels are in static mode due to which the power generated by them is less as compared to the panels in tracking mode. So the main challenge in getting the maximum benefit of solar panel is to ensure that it is correctly positioned with respect to the direct sunlight coming from the sun. To orient the solar panel in the direction of sun, we should know the trajectory or the path followed by sun.

1.1 Trajectory of Sun -

The position of sun in sky can be calculated by using two angles – altitude and azimuth.

Azimuth – It can be defined as the angle of the sun as it moves from east to west through the sky. Azimuth angle is zero at solar noon. By convention, azimuth is measured from north towards the east along the horizon.

Altitude – It is the angular height of sun in the sky measured from the horizontal. The sun elevation is 0° at sunrise and sunset while it is 90° when the sun is directly overhead. It varies throughout the day and also depends on the latitude of a particular location and the day of the year.

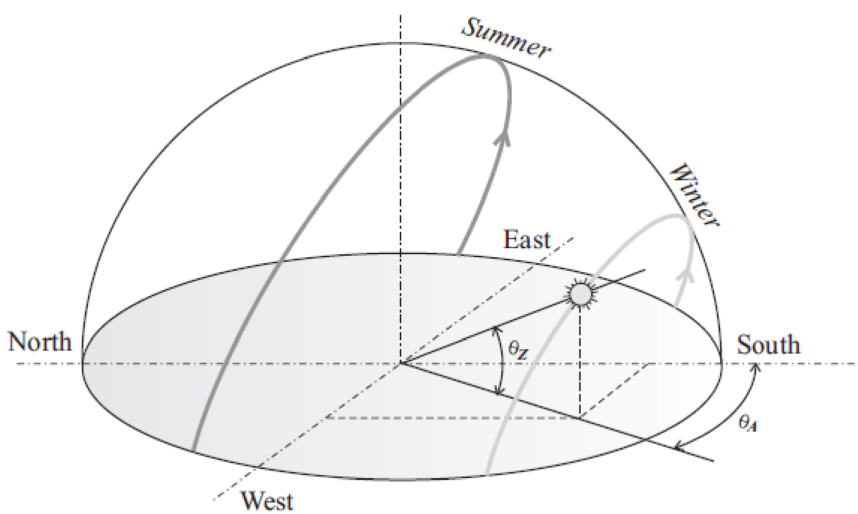


Figure 1: Sun's trajectory

Above figure shows behavior of sun's path in December (winter) and June (summer).The rotational angle of the orientation system in the vertical plane (θ_z) can be calculated from equation –

Sin θz = Sin φ * Sin δ + Cos φ * Cos δ * Cos ω

Where, θz is the altitude angle of the system (θz = 90° - zenith angle of the sun)

φ is the Latitude

ω is the hour angle mm

δ is the solar declination

The rotational angle of the system in the horizontal plane (θa) is calculated from the Equation –

Sin θa = Cos δ * Sin ω / Cos θz

Where, θa is the azimuth angle of the system.

CHAPTER 2: SHAPE MEMORY ALLOYS

A shape-memory alloy (SMA, smart alloy) is an alloy that "remembers" its original shape and that when deformed returns to its pre-deformed shape when heated. This material is a lightweight, solid-state alternative to conventional actuators such as hydraulic, motor-based systems and pneumatics. Shape-memory alloys have variety of applications in aerospace, biomedical industries, automotive and robotics.

2.1 How shape Memory Alloys work?

Shape memory alloys has two different crystal structures or phases. Austenite exists at higher temperatures and martensite exists at lower temperatures. When a SMA is in martensite form at lower temperatures, the metal can easily be deformed into any shape. When the alloy is heated, it goes through transformation from martensite to austenite. In the austenite phase, it remembers the shape it had before it was deformed.

The unique property that allows shape memory alloys to return to their original shape after heating is that

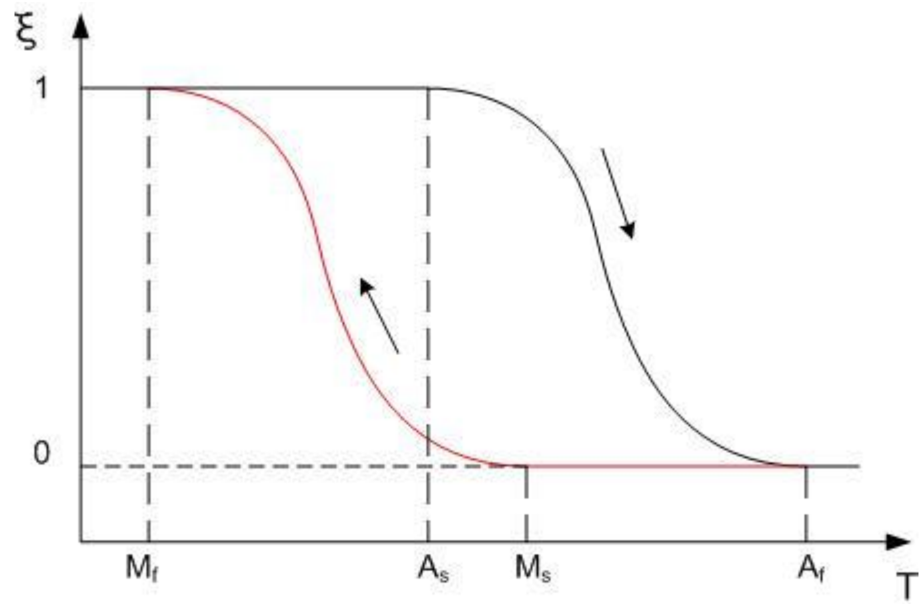


Figure2: ξ (T) represents the martensite fraction

their crystal transformation is fully reversible. In most of the crystal transformations, the atoms in the structure will travel through the metal by diffusion, changing the composition locally, even though the metal as a whole is made of the same atoms. A reversible transformation does not involve this diffusion of atoms, instead all the atoms shift at the same time to form a new structure, much in the way a parallelogram can be made out of a square by pushing on two opposing sides.

In this figure, ξ (T) represents the martensite fraction. The difference between the heating transition and the cooling transition gives rise to hysteresis where some of the mechanical energy is lost in the process.

One-way vs. two-way shape memory

One-way memory effect- When a shape-memory alloy is in the cold state (below As), it can be stretched or bent and it will hold those shapes until heated above the transition temperature. After heating, it regains its original shape. When the metal cools again it will remain in the hot shape, until deformed again. With the one-way effect, cooling from high temperatures does not cause a macroscopic shape change. A deformation is necessary to create the low-temperature shape.

Two-way memory effect- In two-way shape-memory effect the material remembers two different shapes: one at low temperatures and other at the high-temperature. A material that shows a shape-memory effect during both heating and cooling is said to have two-way shape memory. This can also be obtained without the application of an external force (intrinsic two-way effect). The reason the material behaves so differently in these situations lies in training.

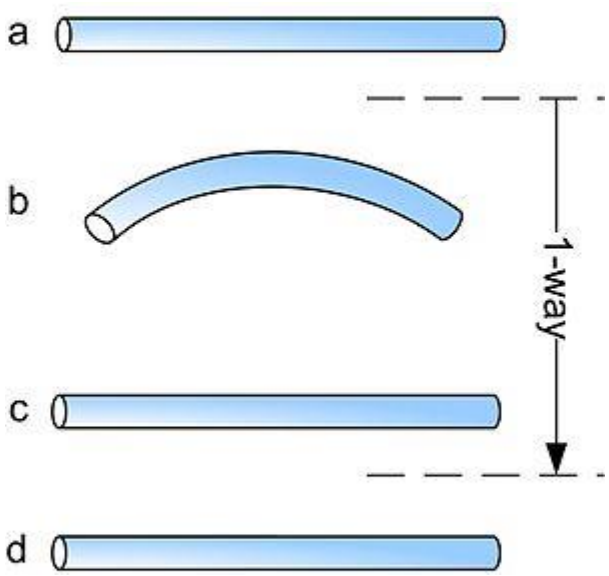


Figure 2: One-way shape memory effect

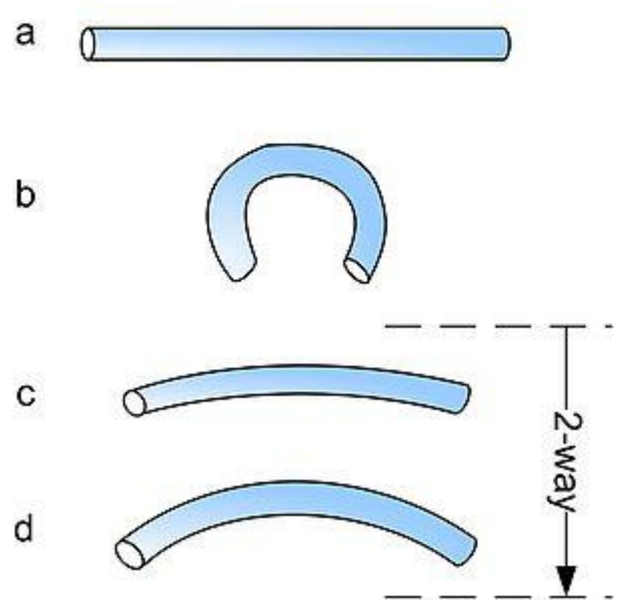


Figure 4: Two-way shape memory effect

Choice of SMA component –

SMA springs were used for obtaining the actuation in sheet. We conducted experiments on two of the available SMA products, namely SMA springs and SMA wires. Experiments were done on both and former came out as the preferred choice. Since the actuation in wire was too miniscule to have even a considerable effect, the SMA springs, on the other hand proved to be better alternative.

Property	SMA Wire	SMA springs
Actuation (Relative Displacement)	**Very Small**	**Adjustable(as per requirement)**
Restoring force Required	**Low**	**Very Low**
Implementation in Design	**Clumsy**	**Easy**

Table 1: Choice of SMA component

Hence the obvious choice was to work with the **SMA springs**.

CHAPTER 3: CLASSIFICATION OF SOLAR TRACKERS

Trackers can be broadly classified into two types –

- Single-axis trackers - They have only one degree of freedom that acts as an axis of rotation. They move only about a single axis, usually in the east-west direction.

- Dual-axis trackers - Dual axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. They move in both directions (i.e. east-west and north-south) simultaneously thus tracking the sun more accurately.

On the basis of energy consumption trackers can be classified as -

- Active solar tracker- Active Trackers uses external power for their operation. They use motors and gear trains to direct the tracker towards the sun. The Light-sensing trackers usually have two photo sensors, such as photodiodes, programmed such that they show zero output when they receive light of same intensity. Mechanically, tracker should be Omni directional (i.e. flat) and are aimed 90 degrees apart which will cause the steepest part of their cosine transfer functions to balance at the steepest part and thus translates into maximum sensitivity.

- Passive solar tracker-Passive trackers do not rely on external power supply for their operation. They directly use sunlight to orient any payload towards the sun. A simple passive solar tracker working on inertial imbalance. Two identical cylindrical tubes (each at either side of the panel and equal distances from the central pivot) are filled with a fluid under partial pressure. Using suitably placed shades, the sun heats the fluid causing evaporation and transfer from one cylinder to the other. This mass imbalance is used to move the solar panel. However, it begins each day pointing in the wrong direction, losing sight of the sun as it attempts to reposition itself.

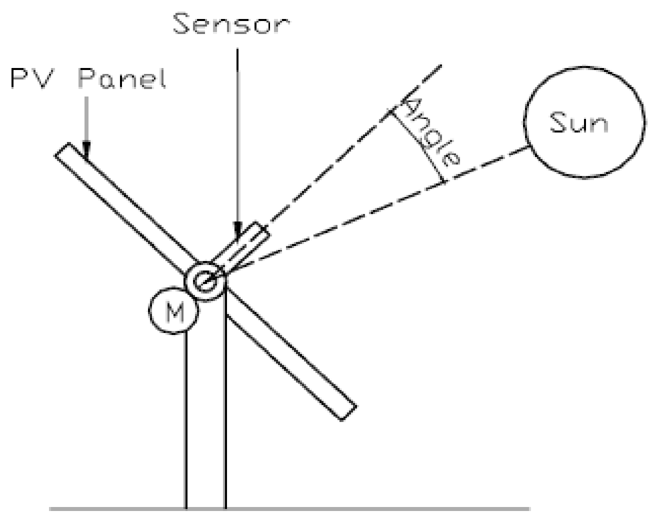


Figure 3: Active tracking system

Figure 6: Dual-axis tracker which uses induction motors

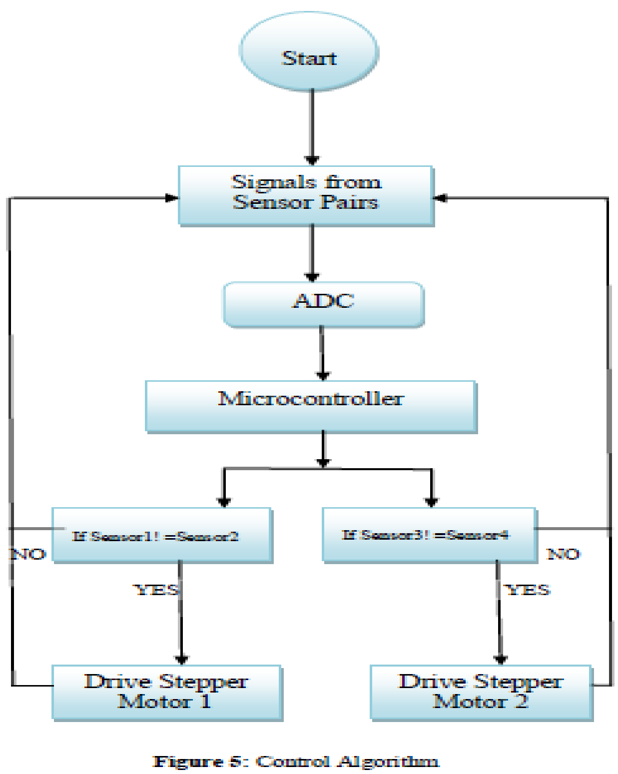


Figure 7: Algorithm for tracker which uses sensors

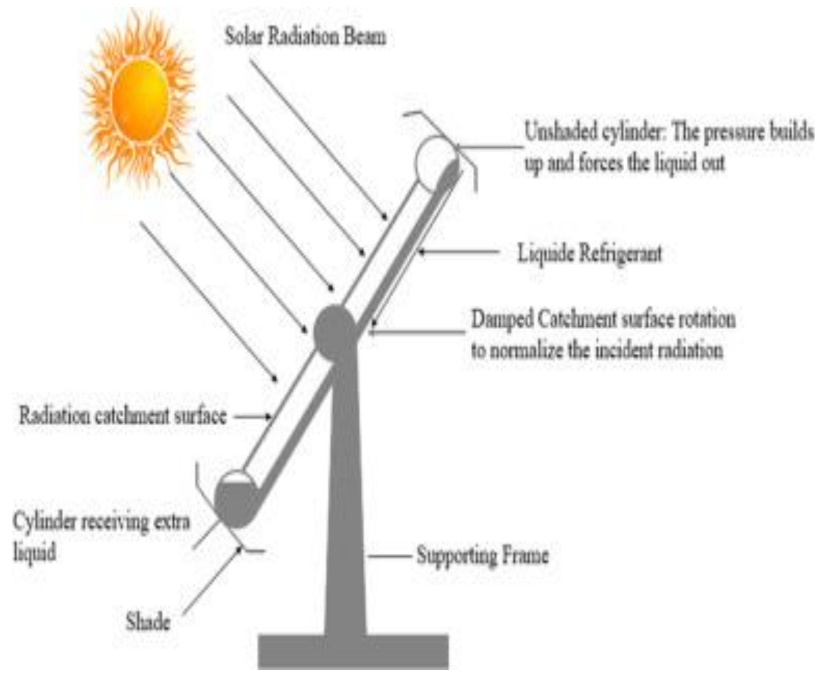


Figure 8: Passive tracker

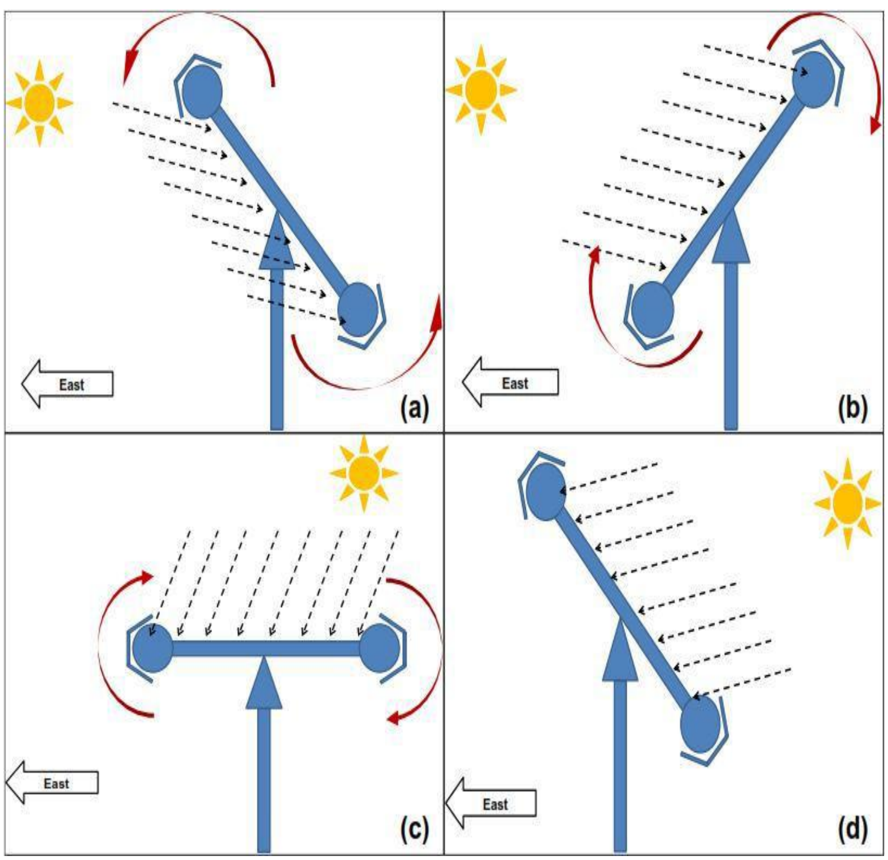


Figure 9: Working of a passive tracking system

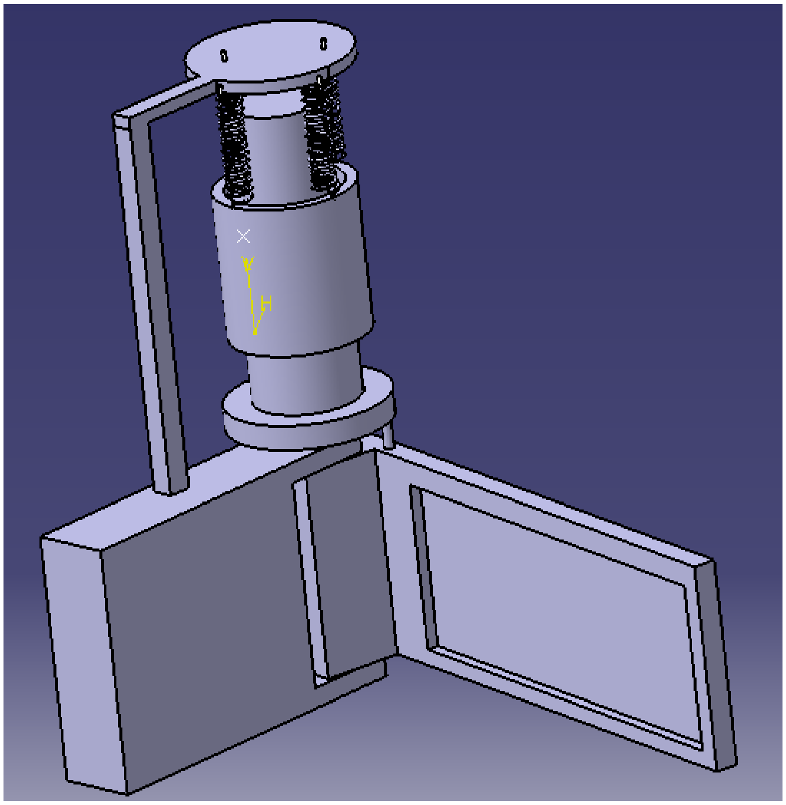


Figure 10: Proposed CAD model

The proposed design consists of three main subsystems –

- Panel and its carrier
- Mechanical Assembly
- Actuation subsystem

The panel carrier is made from stainless steel. The rotating system consists of two concentric cylinders. Both the cylinders are made from ABS (Acrylonitrile Butadiene Styrene) to reduce weight and friction. The inner cylinder consists of a helical groove with a suitable helix angle and the outer cylinder consists of a button which moves along the groove. The inner cylinder is attached to the solar panel on one side and can only rotate about its own axis. The outer cylinder is attached to SMA springs and can only translate along its axis.

The actuation subsystem consists of SMA springs which are connected to the outer cylinder as shown in Fig 6. The springs when actuated pull the outer cylinder of the mechanical assembly which leads to the rotation of the inner cylinder and hence the solar panel. The panel can be made to rotate fixed angle in a particular time interval by actuating the SMA springs directly using sunlight. For uniform heating of shape memory alloy springs, they are surrounded by a fluid contained in a cylinder. The material of the cylinder should have high thermal conductivity and hence Copper is used in its fabrication. The fluid used should also have high thermal conductivity and less specific heat so that the temperature of the springs dipped in it will be as high as possible and the actuation temperature of the springs is reached easily. If the contraction is less than required, then external power supply will suffice the contraction.

Control Strategy -

- A control system has been designed that ensures that the panel accurately tracks the sun and also accounts for weather fluctuations (9). It monitors how much the SMA springs have contracted using Ultrasonic sensor. The length of the helical groove is 100 mm. So the outer cylinder will travel the same distance in 8 hours. This implies that the outer cylinder should move 12.5 mm in 1 hour. Energy (both actively and passively) is supplied till the springs contract 1.25cm in an hour which is equivalent to 15° rotation of the panel in an hour). In this way, the panel can accurately track the sun.

Design of cylinders-

- Inner cylinder-

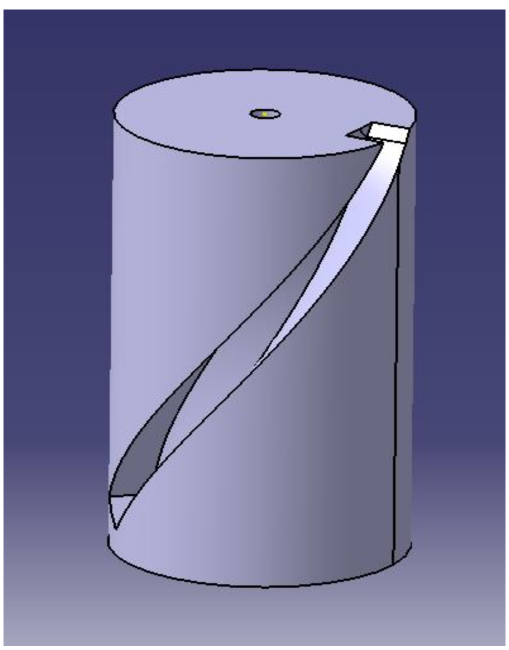


Figure 11: CAD design of inner cylinder

Figure 12: 3-D printed model of inner cylinder

- Outer Cylinder-

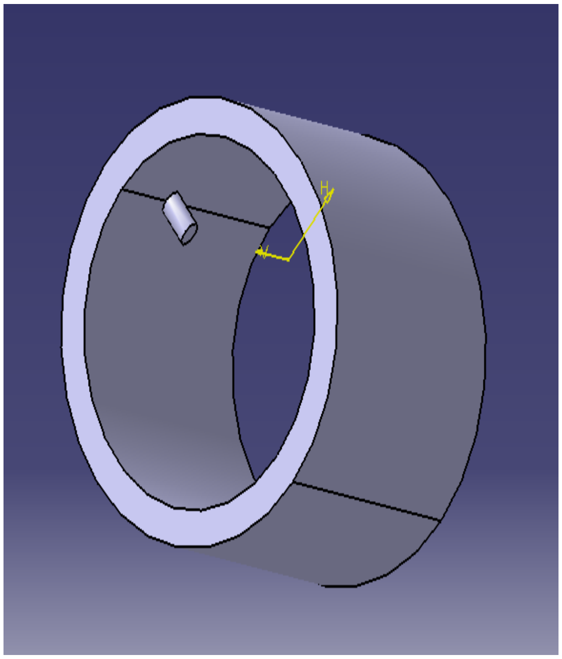


Figure 13: CAD design of outer cylinder

Figure 14: 3-D printed model of outer cylinder

Dimensions-

- **Inner cylinder-**

  Material – Acrylonitrile Butadiene Styrene (ABS)

  Length of the cylinder = 11 cm

  Length of helical groove = 10 cm

  Diameter of the cylinder = 7 cm

- **Outer cylinder-**

  Material – Acrylonitrile Butadiene Styrene (ABS)

  Length of the cylinder = 11 cm

  Inner diameter of cylinder = 7 cm

  Outer diameter of cylinder = 8 cm

  Diameter of the button = 0.9 cm

  Length of the button = 0.9 cm

- **Panel carrier-**

  Material – Stainless steel

  Cross-section of rectangular pipe used = 2cm*2cm

  Height at which the panel is mounted = 29 cm

Schematic Diagram of complete system-

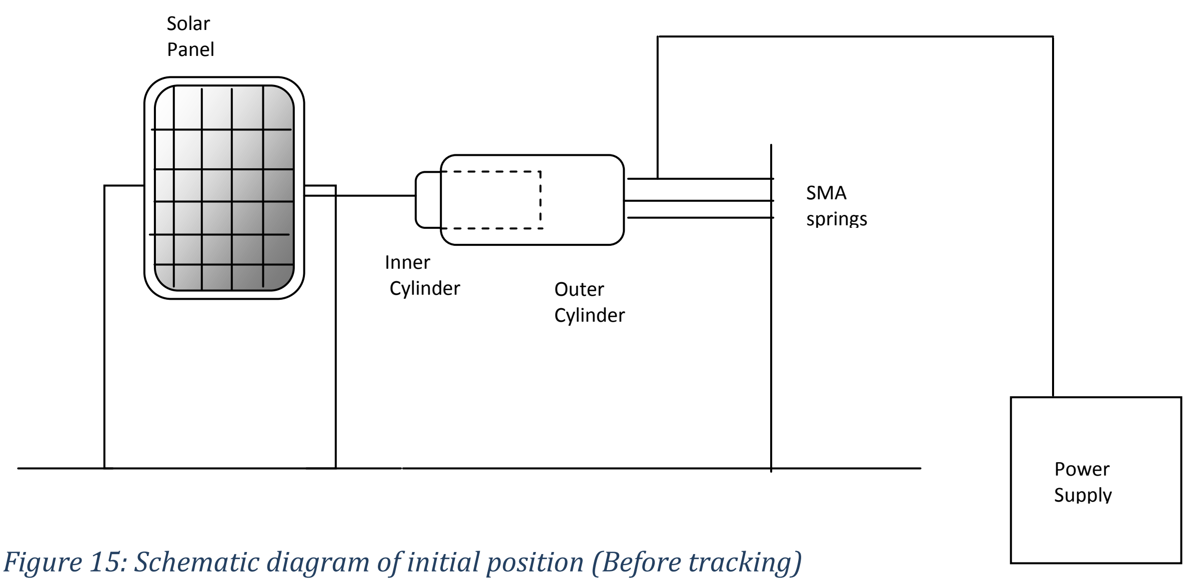


Figure 15: Schematic diagram of initial position (Before tracking)

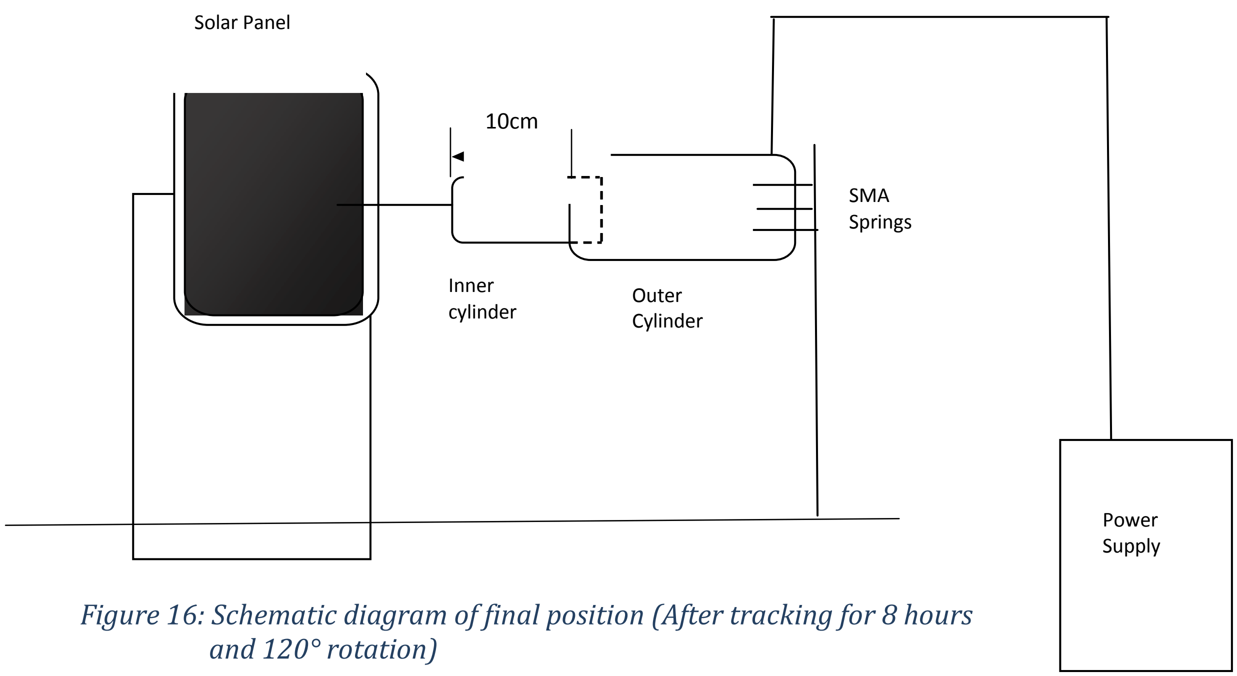


Figure 16: Schematic diagram of final position (After tracking for 8 hours and 120° rotation)

Actual photo of complete setup -

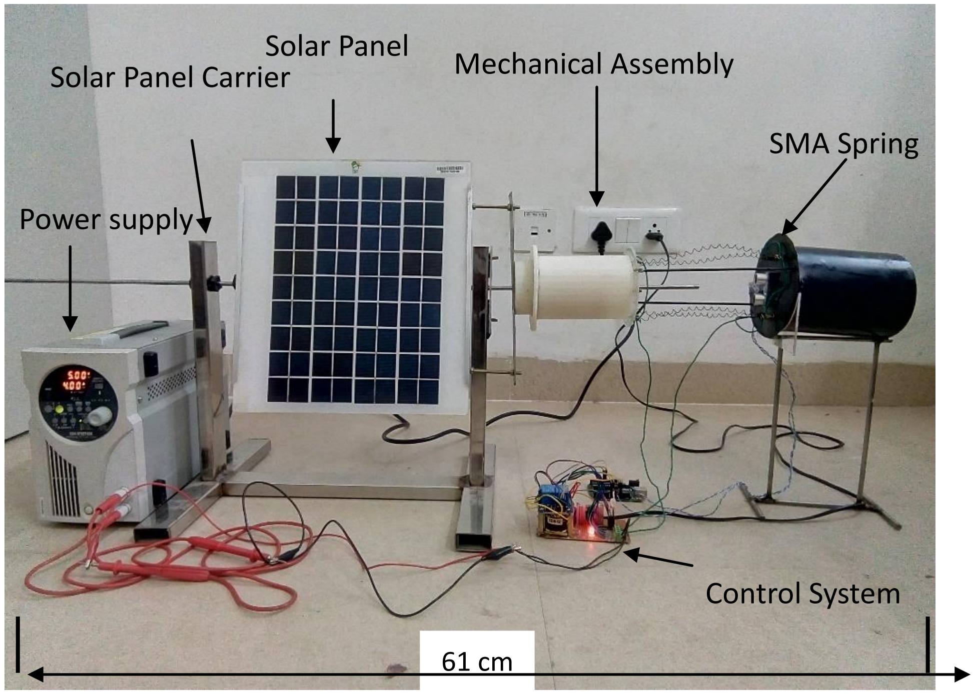


Figure 17: Actual system when the springs are elongated (initial position)

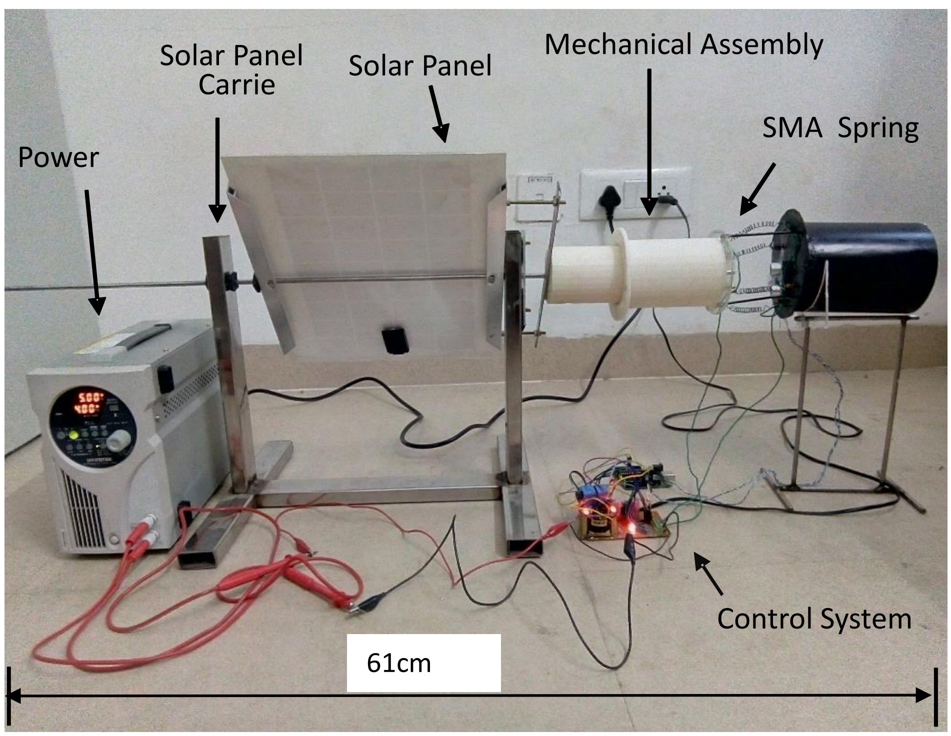


Figure 18: Actual system when the springs are contracted (final position)

CHAPTER 4: RESULTS AND DISCUSSION

Experiments were conducted to determine the increase in output of the solar panel through the use of solar tracker. In this experiment, a solar panel was kept during the day in both static mode and tracking mode and the output in both the modes were compared.

- Output in static mode -

  41.6 Watt hour energy was stored in the battery in duration of 4 hours

- Output in tracking mode –

  48.4 Watt hour energy was stored in the battery in duration of 4 hours

- Energy consumption for tracking –

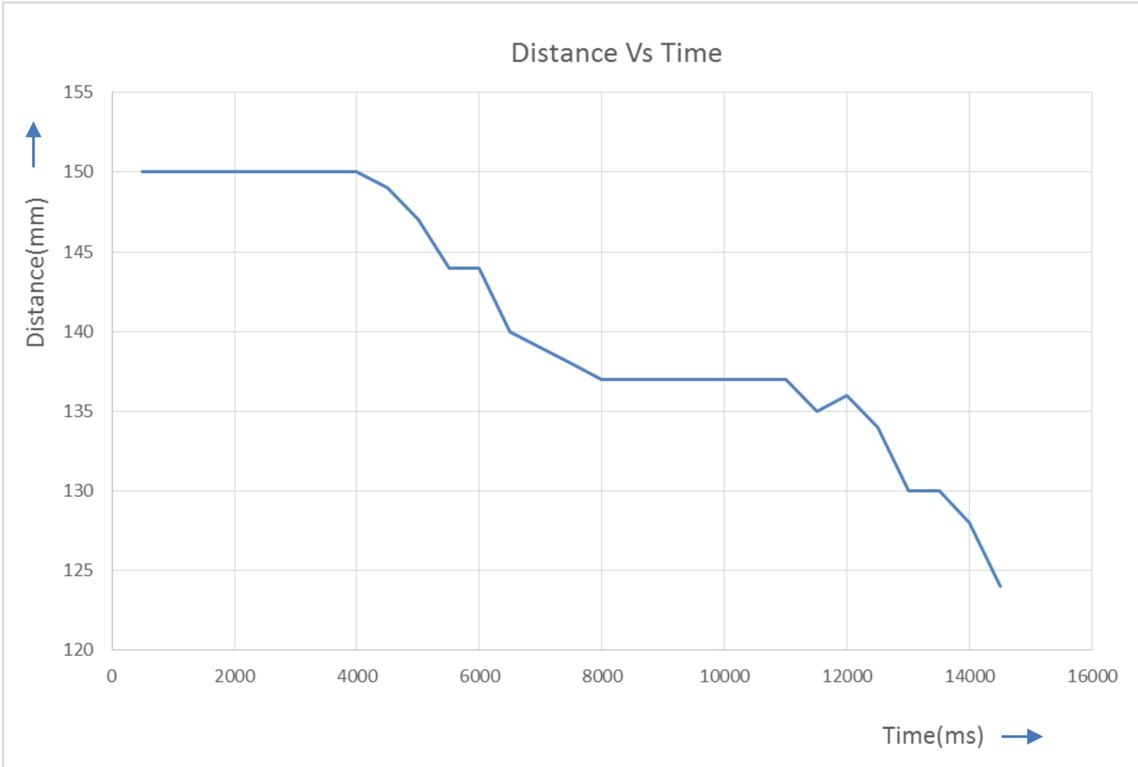
  For 1 actuation – 0.04 Watt hour

  For 4 actuations – 0.04*4 = 0.16 Watt hour

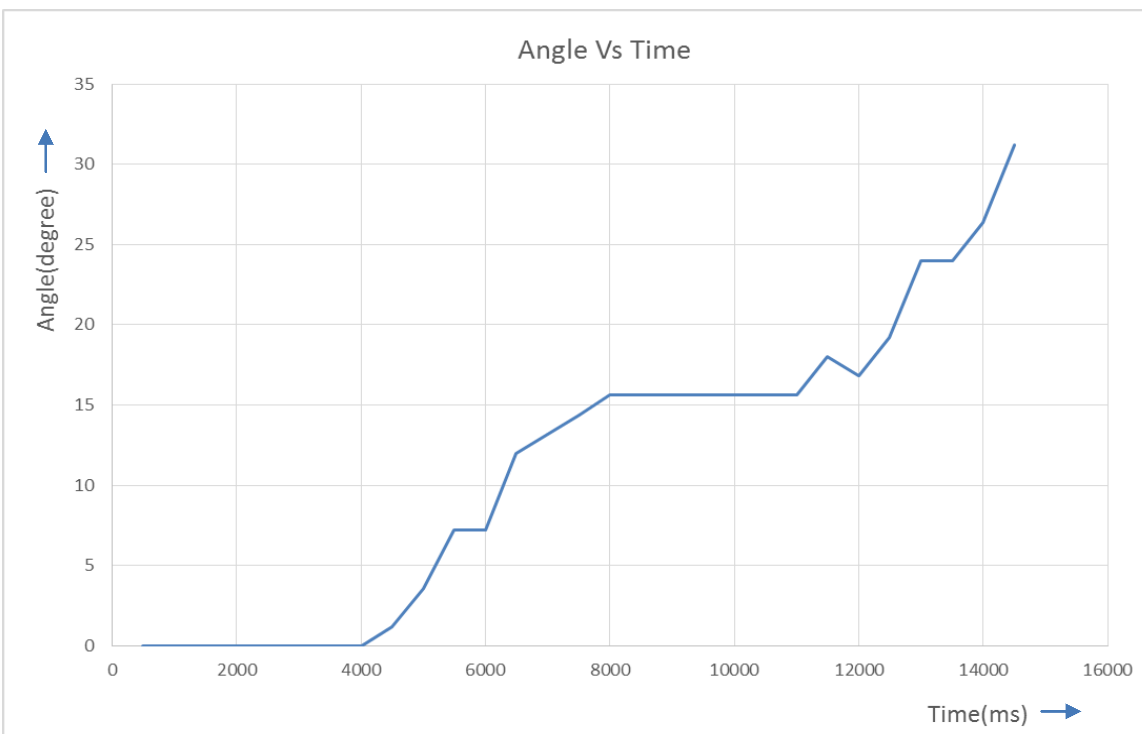
- Energy consumed by control system = 1.46 Watt hour
- Total energy consumption – 0.16+1.46= 1.62 Watt hour
- Increase in output = 48.4-1.62-41.6=5.18 Watt hour
- Increase in output=12.45%

This implies by using solar tracker the output of the solar panel increased by 12.45%.

- **Motion of cylinder with respect to time-**



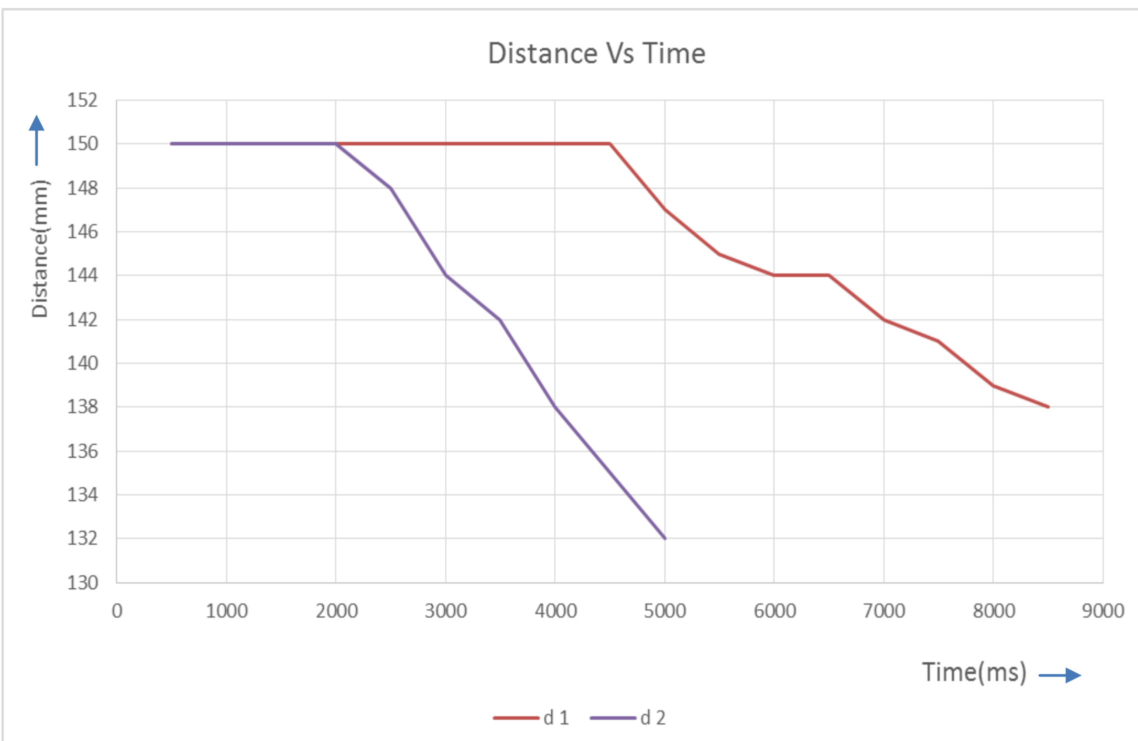
Graph 1: Showing variation of distance travelled by cylinder versus time taken



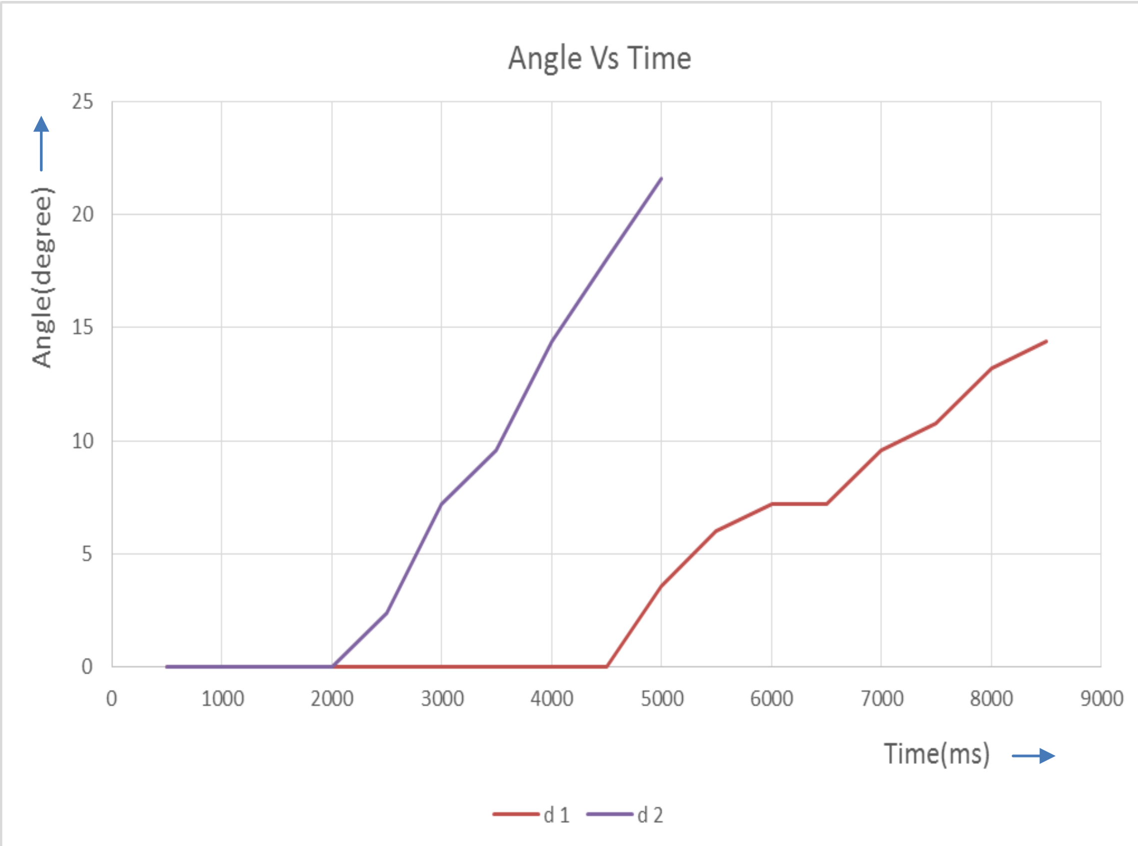
Graph 2: Showing variation of angle rotated by panel versus time taken

Graph 1 shows the variation of the distance between the outer cylinder and the fixed support with time while graph 2 shows the variation of angle rotated by the solar panel with time. The above experiment is conducted at 6 volts and 6 amperes. Current is supplied at time t=0 but the outer cylinder moves about 4 seconds later. This initial lag in graph 1 occurs because the springs are initially bent and when the current flows through them, they adjust and become taut. In graph 2, panel doesn't rotate till 4 seconds because of this initial delay. The idle time of 1 hour is set as 3 seconds in the graph to make it easy to demonstrate. Average time for each actuation is around 3 seconds at 6V and 6Amp.

- **Effect of different parameters on actuation-**



Graph 3: Showing variation of distance travelled versus time taken at different parameters



Graph 4: Showing variation of angle rotated by panel versus time taken at different parameters

Graphs 3 and 4 shows the motion of the cylinder and the panel with respect to time at different values of current and voltage. Curve “d1” represents 5V and 5A while curve “d2” represents 10V and 10A. When the power supplied was high, the springs contract at a faster rate. This lead to a smaller initial delay period as the springs get taut in lesser time. Due to high actuation rate the distance travelled by the cylinder was more than required as the cylinder was not able to stop after travelling 1.25 cm because of the significant kinetic energy acquired by it as a result of fast actuation and hence the angle rotated by panel was slightly more than required.

CHAPTER 4: CONCLUSION AND FUTURE SCOPE

Through the use of proposed solar tracker, the net output obtained from the solar panel can be increased. When the sun moves to a less optimal angle. The solar panels in stationary mode have their productivity compromised. But this doesn't happen in case of panels connected to solar trackers i.e. for a given space, the panels in tracking mode generate more electricity than their static counterpart. The solar tracker fabricated in this project is able to increase the net output of the solar panel by about 12%. Also this increment in the output of the panel can be increased further by manufacturing the main components of the tracking system (inner and outer cylinder) precisely and by reducing friction between them. The initial lag or delay in the rotation of the solar panels can be reduced by loading the springs which will force them to remain taut all the time. This will lead to reduction in the time for which power is supplied to the springs and thereby increasing the net output further.

In general, active trackers are more efficient while passive tracker require lesser energy input for their operation. The use of shape memory alloy springs in the tracking system enables us to combine the benefits of both active and passive solar trackers. This implies that the tracker fabricated is accurate as well as efficient i.e. the energy consumption in the operation of tracker is significantly less as compared to the net increase in the output.

The designed solar tracking system can be used in various areas both in small (domestic) and large scale (commercial). For large scale utilization, a solar array can be created by connecting large number of solar panels adjacent to each other and the tracking system can be connected to the solar panel at the last and hence all the solar panels can be put to tracking mode by using only one solar tracker. A small increase in efficiency in the large scale is equivalent to increase in the output in megawatts.

Also the solar tracking system built here is a single axis tracking system. This design can further be extended in future to build a dual axis tracking system based on shape memory alloys which will track the sun's daily east-west movement as well as seasonal north-south movement and hence the energy output from the solar panels can be increased to a greater extent.

REFERENCES

- Barsoum, Nader. "Fabrication of dual-axis solar tracking controller project." *Intelligent Control and Automation* 2.02 (2011): 57.
- Oner, Yusuf, et al. "Design of a new three-degree of freedom spherical motor for photovoltaic-tracking systems." *Renewable Energy* 34.12 (2009): 2751-2756.
- Choudhary, Nitin, and Davinder Kaur. "Shape memory alloy thin films and heterostructures for MEMS applications: a review." *Sensors and Actuators A: Physical* 242 (2016): 162-181.
- Abdallah, Salah, and Salem Nijmeh. "Two axes sun tracking system with PLC control." *Energy conversion and management* 45.11 (2004): 1931-1939.
- Suman, Siddharth, Mohd Kaleem Khan, and Manabendra Pathak. "Performance enhancement of solar collectors—A review." *Renewable and Sustainable Energy Reviews* 49 (2015): 192-210.
- Sinha, Sunanda, and S. S. Chandel. "Analysis of fixed tilt and sun tracking photovoltaic–micro wind based hybrid power systems." *Energy Conversion and Management* 115 (2016): 265-275.
- Mousazadeh, Hossein, et al. "A review of principle and sun-tracking methods for maximizing solar systems output." *Renewable and sustainable energy reviews* 13.8 (2009): 1800-1818.
- Clifford, M. J., and D. Eastwood. "Design of a novel passive solar tracker." *Solar Energy* 77.3 (2004): 269-280.
- Fathabadi, Hassan. "Novel high accurate sensorless dual-axis solar tracking system controlled by maximum power point tracking unit of photovoltaic systems." *Applied Energy* 173 (2016): 448-459.
- Poulek, Vladislav, and Martin Libra. "New solar tracker." *Solar energy materials and solar cells* 51.2 (1998): 113-120.
- Abu Hanieh, Ahmed. (2017). Automatic Orientation of Solar Photovoltaic Panels.