DESIGN AND DEVELOPMENT OF SOLAR PANEL CLEANING SYSTEM

A project thesis for the fulfilment of the requirements for the award of the degree of

Bachelor of Technology

in

Mechanical Engineering

and

Master of Technology

in

Mechatronics and Automation

by

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DECLARATION

I hereby declare that to the best of my knowledge this submission is my own work and that it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text.

Date: 1st June, 2015 Shaikh Tariq Mobin

NIT Rourkela

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

CERTIFICATE

This is to certify that the project entitled "**Design and Development of Solar Panel Cleaning System**", being submitted by **Shaikh Tariq Mobin** bearing **Roll No – 710me4085**, has been carried out under my supervision for the purpose of fulfilment of the requirements for the degree of **Bachelor of Technology in Mechanical Engineering and Master of Technology in Mechatronics and Automation** during the session **2014-2015** in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

PLACE: ROURKELA
DATE: 30TH MAY, 2015

(PROF. SUBRATA KUMAR PANDA)
DEPARTMENT OF MECHANICAL ENGINEERING
NIT ROURKELA

ACKNOWLEDGEMENT

This report a result my efforts of my project work for the fulfilment of the requirements of Dual Degree : B.Tech in Mechanical Engineering and M.Tech in Mechatronics and Automation in the Department of Mechanical Engineering, NIT Rourkela. This project would not have been possible without the active support and help by various people, whome I wish to express my sincere gratitude.

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I am also very much thankful to my fellow classmates Ashish Singh, Chiranjibi Sahoo, Abyarth Kumar Behera and Sheak Aftab Ali for constant support and suggestion in the entire process.

Lastly, I would also like to thank my parents who were always behind me for the moral support I required in this project.

ABSTARCT

Solar energy is the most abundant source of energy for all the forms of life on the planet Earth. It is also the basic source for all the sources of energy except Nuclear Energy. But the solar technology has not matured to the extent of the conventional sources of energy. It faces lots of challenges such as high cost, erratic and unpredictable in nature, need for storage and low efficiency. This project aims at increasing the efficiency of solar power plants by solving the problem of accumulation of dust on the surface of solar panel which leads to reduction in plant output and overall plant efficiency. It proposes to develop a Solar Panel Cleaning System which could remove the accumulated dust on its surface on a regular basis and maintain the solar power plant output. The system is a robotic system which could move autonomously on the surface of solar panels by using pneumatic suction cups and use dry methods for cleaning such as rotating cylindrical brush and vacuum cleaning system keeping in mind the limited availability of water in areas where such plants are mainly located. This project also aims to reduce the human involvement in the process of solar panel cleaning as it is a very hazardous environment for them in scorching sun.

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INTRODUCTION

A robot is a machine equipped with the ability to carry out series of actions automatically on the basis of input from the environment and inbuilt program.

1.1 *Autonomous Robot*

An autonomous robot has the ability to carry out tasks and commands with high degree of accuracy autonomously according to the following rules.

- Has the ability to gain tangible inputs from the environment.
- Has the ability to perform task for long intervals without human interferences.
- Has the ability to move in its workspace without human help.
- Has the ability to avoid situations that are harmful to itself or humans unless it is programmed to do so.

1.2 *Cleaning Robot*

Cleaning is one of the necessary activity in the daily life of human beings, but in the same time regarded as one of the least preferred jobs. In some places cleaning also becomes hazardous for humans. So time and again machines have been invented to assist us in this necessary evil of cleaning. Robotic cleaning is the most recent trend which is being seen in the recent years. Robotic cleaner is an autonomous device that can move around and clean the surface using different techniques such as mopping, vacuum cleaning, or simply scrubbing the surface with a rotating brush.

The proposed solar panel cleaning system falls in the category of cleaning robots, but for industrial cleaning application in large scale solar power plants. It is an autonomous robot that moves on the slanted surface of the solar panels with the help of vacuum suction cups and cleans the surface of the panels with the help of a rotating cylindrical brush. In each cycle the robot first moves a certain distance in the direction parallel to the base of the solar panel and then the rotating brush moves in the direction perpendicular to the base from top to bottom. Depending upon the latidunial location of the solar power plants the solar panels are fixed at an angle to the ground, so as to receive maximum solar irradiance. But this advantage becomes a disadvantage for robotic cleaning system as they have to move on a slanted surface. Because of the slanted surface a normal wheel based robot cannot move on it as it will slip on its surface and fall on the ground. So we have used pneumatic system in which the suction cups are placed on its bottom. These suction cups when actuated using the vacuum pumps, create a suction force which helps the robot to get attached to its surface and move on it.

LITERATURE REVIEW

As accumulation of dust on the PV panel reduces its transmittance which results in the reduction of the power output, thus resulting in loss of power generation. This particular problem is also responsible for the short life span of many interplanetary exploration missions such as Mars Exploration Mission of Curiosity Rover as the power output from their solar panel reduces over time because of the accumulation of dust. At a point of time density of dust increases to level where power output declines to the extent which is not able to support its vital functions.

Further this problem has also resulted in huge losses for the solar power plant operators which suffer from reduced power output because of frequent dust storms. Most widely used method of cleaning the solar panels is through the manual labour. Apart from being time taking and cumbersome, there is also a risk of damage to the expensive solar panels by the unskilled labour which is involved in this method.

The purpose of this project is to develop a semi-automatic self-cleaning mechanism for cleaning the solar panel so that the process can become more reliable and fast, thus increasing the power output of the solar power plant.

Various technologies being developed around the world for self-cleaning of solar panels are discussed below:

2.1. Removal of dust using Mechanical Methods

There are different types of methods that are used to clean solar panel. Few of them are mechanical vibration, ultrasonic cleaning, scrubbing and mopping.

When brushing is used for cleaning, it is mainly done with the help of brush or scrubber. In these systems a brush is driven by using a machine, which are similar to automobile wipers. But this cleaning method is not that efficient because of the sticky nature and small size of the dust particle. It is also seen that difficult and harsh working condition of the solar power plant make the maintenance of these machines difficult. Also the solar power plant is present over a very large area which makes this cleaning method expensive and inefficient.

The process of blowing of air on the surface of the solar panel is an effective method but it has some negative features such as low efficiency, huge energy usage and difficulty in maintenance of blower arrangement.

Mechanical methods of cleaning also include ultrasonic and vibrating method. The factors that are considered in this process include driving methodologies, amplitude and frequency of vibration. Williams R. Brett [1] has used piezo electric and piezo ceramic actuation methods for making self-cleaning solar panel system. These system work on the above described vibrating method.

2.2 Removal of dust using Nano-Film.

When the solar panels have a layer of pellucid nano films capable of self-cleaning, it cleans itself automatically. The Self Cleaning Nano-Films method mainly use two strategies for cleaning the solar panel, namely Super-Hydrophilic Material or Super – Hydrophobic Materials. These two strategies are explained below.

2.2.1. Super-Hydrophilic Material

TiO_2 is one of the most popular super – Hydrophilic material which has both hydrophilic as well as photocatalytic properties. This method has two stages in its cleaning process. In the first stage, which is a photocatalytic process, the ultraviolet light falls on the TiO_2 film and the film reacts with it splitting the organic matters in the dust. Now in the second stage, the hydrophilic nature of the TiO_2 diffuses the rainwater on to the surface of the solar panel and rinse the dust. But this method is not that popular because solar power plants are mainly located in the arid region where rainfall is very scarce and erratic in nature.

2.2.2 Super-hydrophobic Material

Super-hydrophobic are those materials which show high level of repulsion to the water molecules. For example leaves of lotus plant which are have very less wettability. In recent times lot of studies have been conducted to replicate the hydro-phobic nature by forming micro-structures or nano-structures. These structures are designed such that they create a contact angle of more than 150°. As a result of this, the water droplets that fall on these types of surface roll off the surface, carrying organic and inorganic dust particles with them. Thus cleaning the surface. But there is still a lot of scepticism in the application of super hydrophobic material in self cleaning application. It is suggested that future studies should be conducted to verify the feasibility of these types of materials in real world. [2-3]

2.3. Removal of dust using Electro-Static Methods

Technologies for removal of dust using electrostatic methods are mainly based on the "Electric Curtain Concept" by F.B. Tatom and NASA in 1967 and further developed by Masuda at the University of Tokyo in the 1970s [4]. In this technique electr-ostatic and dielectro-phoretic forces are used to raise and transport charged and uncharged particles [5]. In recent past a lot of research has been done to apply this method in space application especially in rovers that are being sent to moon and mars. Electric curtains technology uses a series of parallel conducting electrodes which are embedded in a dielectric surface. Across this surface an oscillation is transmitted between the electrode potentials.

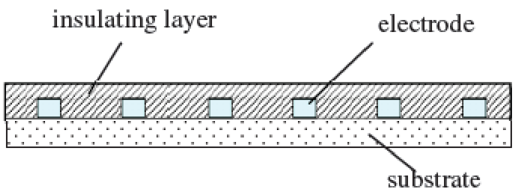


Figure 1 Basic Structure of Electric Curtain

When electrodes are connected to a single-phase AC voltage, a standing-wave field is generated as seen in figure 3. Earlier it was believed that standing-wave fields can levitate particles on the curtain, but not cause a net transport [6].

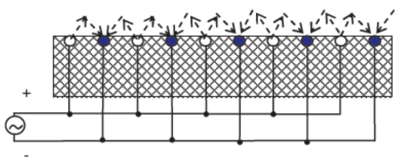


Figure 2 Single Phase Electric Curtain

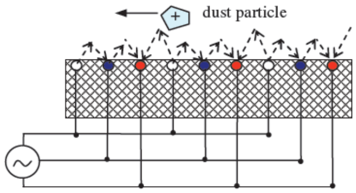


Figure 3 Three Phase Electric Curtain

But if the electrodes are connected to a multi-phase AC voltage, we can create a traveling-wave electric curtain as shown in fig 4. If right frequency and amplitude conditions are provided then the charged particle can move along the surface of the solar panel following the electric field. In this manner the surface of the solar panel gets cleaned.[7].

Mazumder[8] designed a flexible electrodynamic screen to protect the solar cell on Martian explorer based on travel-wave field technology.

Based on the study of feasibility, both technical and financial, I propose a robotic system that moves on the surface of the solar panel and cleans the surface with the help of a brush. Since the surface of the solar panel is not horizontal but tilted suction method is used for creating the grip on the panel.

In suction method, a vaccum pump and a suction cup is used. Vacuum pump sucks air out of the cup and suction cup grips the wall due to external pressure. A semi-independent Wall Climbing Robot with Scanning Type Suction Cup was created and tried by Tomoaki Yano, Tomohiro Suwa, Masato Muraxami and Takuji Yamamotq [9]. This robot used two vacuum pumps. The robot was connected with the gears on the ground through the electric power cables. Experimental results showed that the robot was able to walk on walls, clear steps, and stick on cracks and crevices with high effectiveness.

KEY PROBLEM

A number of environmental factors such as wind speed, humidity, ambient temperature, solar radiation, atmospheric dust and direction influences the power generation process using installed solar photovoltaic modules. Dust build-up on solar module surface is an issue of great worry, particularly in desert provinces where infrequent to regular dust storms do occur. The glass cover transmittance decreases because of accretion of dust on the surface of PV module, which ultimately decreases the amount of solar irradiation reaching the cells. The dust density of the surface, orientation, the tilt angle, exposure period, dominant wind direction, and site climatic conditions determines the reduction in glass transmittance [1,2]. The density of deposited dust, the composition of the dust and its particle distribution determines the effect of the effect of dust on the power output and current -voltage (I~V) characteristics of PV modules [3,4].

Surveys in Saudi Arabia to study the effect of dust amassing on power production of solar module have revealed that power provided by the modules declined constantly due to dust addition [6]. P_{max} which is the average of daily peak power output in a month, for the period of the investigation is shown in Fig. 1.

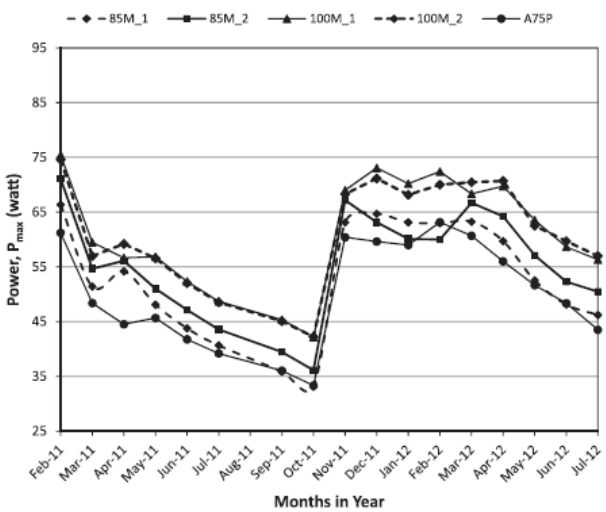


Figure 4: Monthly average maximum power output

The modules power outputs reduced by twenty percent due to a single dust storm in March irrespective of the technology and evaluation. In November, the power production for all the modules amplified to their uppermost values due to rainfall; however it did not recover fully to the original power output at the beginning of the examination. Nevertheless, in one cleaning routine (Dec-Mar) in which the modules were cleaned was in a week, the power outputs of the modules remained high. Without further cleaning from April, the power productions began to reduction again.

When PV modules are exposed to real outdoor condition for a long period, it was observed that the performance decreases gradually with dust build-up lest the modules are cleaned by rain or human action. The power output decreases by more than half if no cleaning is accomplished on modules that exceeds six months. Reduction in power output due to dust build-up does not depend only on the length of module exposure, but also on the occurrence and strength of dust.

Subsequently, it is suggested that installed PV modules should be cleaned at least once in two weeks. Nevertheless, in the time when sandstorm occurs, immediate cleaning of the solar modules should be performed. It was observed that rainfall improved the power production of dusty solar modules, yet it cannot be trusted upon for cleaning since it is not foreseeable.

METHODOLOGY

The solar panel cleaning system consists of two basic system unit depending on their functioning, namely **Locomotion Unit and Cleaning Unit**.

4.1. Locomotion Unit

Locomotion Unit is responsible for the movement of robot on the surface of the solar panel. Since the solar panels are mounted at an angle to ground level so as to capture maximum solar irradiance, the robot cannot rely entirely on the conventional wheel based system for its movement. The inclined surface of the solar panel demands for a movement mechanism that can stick to the surface of the panel and prevent the robot from sliding on the surface. So the pneumatic suction system was used along with a double rack and pinion mechanism.

The design consists of two legs present at the top and bottom of the robot. Each leg has two moving platform which move parallel to each other with the help of a double rack and pinion mechanism. On the base of each moving platform a Pair of Suction Cups are mounted which are attached to a vacuum pump. The working of the legs is demonstrated in figure 2.

The suction cups get actuated alternatively on each of the moving platform in individual legs. A rack is attached to each moving platform. When the suction cup in Platform 1 is actuated, it becomes stationary. The motor attached to the pinion moves in the clockwise direction and

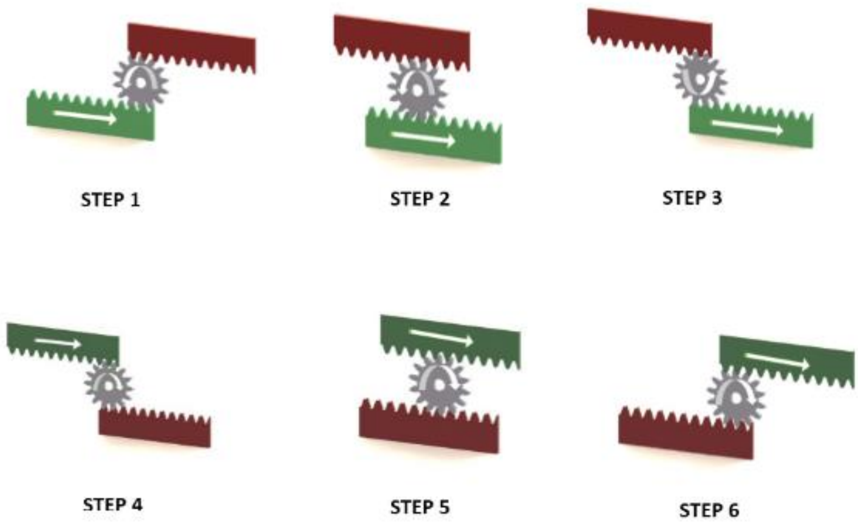


Figure 5 Working of Doube Rack and Pinion System

the pinion moves on platform 1. As a result the rack attached to platform 2 also moves in the forward direction. Once the pinion reaches to the end of the first rack the motor stops and the suction cups on platform 2 actuates making it stationary. In the same time the suction cups attached to platform 1 gets disengaged making it mobile. Now the pinion moves in the anticlockwise direction on the rack attached to the platform 2. So the platform 1 now moves in the forward direction. This cycle repeats itself for moving the robot in the forward direction.

Step	Rack 1	Rack 2	Pinion	Motion	Remark
1	Fixed	Mobile	Anti-Clockwise	Rack 2 Moves in forward Direction	Pinion at extreme end
2	Fixed	Mobile	Anti-Clockwise	Rack 2 Moves in forward Direction	Pinion in Middle
3	Fixed	Mobile	Anti-Clockwise	Rack 2 reach extreme end	Pinion In extreme end
4	Mobile	Fixed	Clockwise	Rack 1 Moves in forward Direction	Pinion at extreme end
5	Mobile	Fixed	Clockwise	Rack 1 Moves in forward Direction	Pinion in Middle
6	Mobile	Fixed	Clockwise	Rack 1 reach extreme end	Pinion In extreme end

Table 1 Working of Double Rack and Pinion

4.2. Cleaning Unit

Cleaning Unit is responsible for taking care of the cleaning action of the robot. It is placed perpendicular to both the legs. Both the legs are present in at the opposite end of the cleaning unit. Cleaning unit consists of two main parts, namely, Linear Actuator and the Rotating Brush.

4.2.1 Linear Actuator

Linear actuator is an actuator that creates motion in a straight line, in contrast to the circular motion of a conventional electric motor. Linear actuator is used in machine tools and industrial machinery, in computer peripherals, in valve and dam and dampers. There are various categories of linear actuators depending upon the mechanism used and power source, namely, mechanical actuators, hydraulic actuators, pneumatic actuators, piezoelectric actuators, electro-mechanical actuators, linear motor and telescopic linear actuators.

In this project we propose to use electro-mechanical linear actuator, which works on the principle of conversion of rotary motion of the electric motor into the linear motion. This actuator consists of a stepper motor mounted at one end of the aluminium rail. A platform moves on the rail with the help of v-wheels and idler pulley. A timing belt is attached to the platform and is run by the stepper motor. Thus the circular motion of the motor is converted in the linear motion.

The linear actuator also acts as the central spine which connects both the legs. The platform also carries the cylindrical brush with it. So as the platform does a "to and fro" linear motion on the rails so does the brush attached to it.

4.2.2. Brush

The brush is responsible for scrubbing and dusting away of the dust accumulated on the surface of the solar panel. It is attached to the v-slot gantry plate platform which moves in the linear actuator. The brush is mounted on radial bearing which is rotated with the help of a 12 volt DC motor.

WORKING

The cleaning unit moves on the central spline in a back and forth motion. The cylindrical Brush mounted on the cleaning unit rotates in the clockwise direction. The cleaning unit along with the rotating brush moves along the central spline towards the bottom of the panel. Along the entire path, it forces the dust to move in the direction of the motion of the cleaning unit and finally blows it away at the edge of the panel. Once the cleaning unit reaches the lower end of it, it again returns back. Once it reaches the top of the spline, the cleaning unit stops there. Then the locomotion units come into action and release the suction cup which keeps the system in rest. Then the wheels move in the direction parallel to the edge of the solar panel until it reaches the part of the panel that is not cleaned. Then the suction cups are again engaged to make the system still. After this the cleaning unit again come into action and the process keeps on going until the entire array is cleaned. Once one array of the solar panel is cleaned, it is moves to another array.

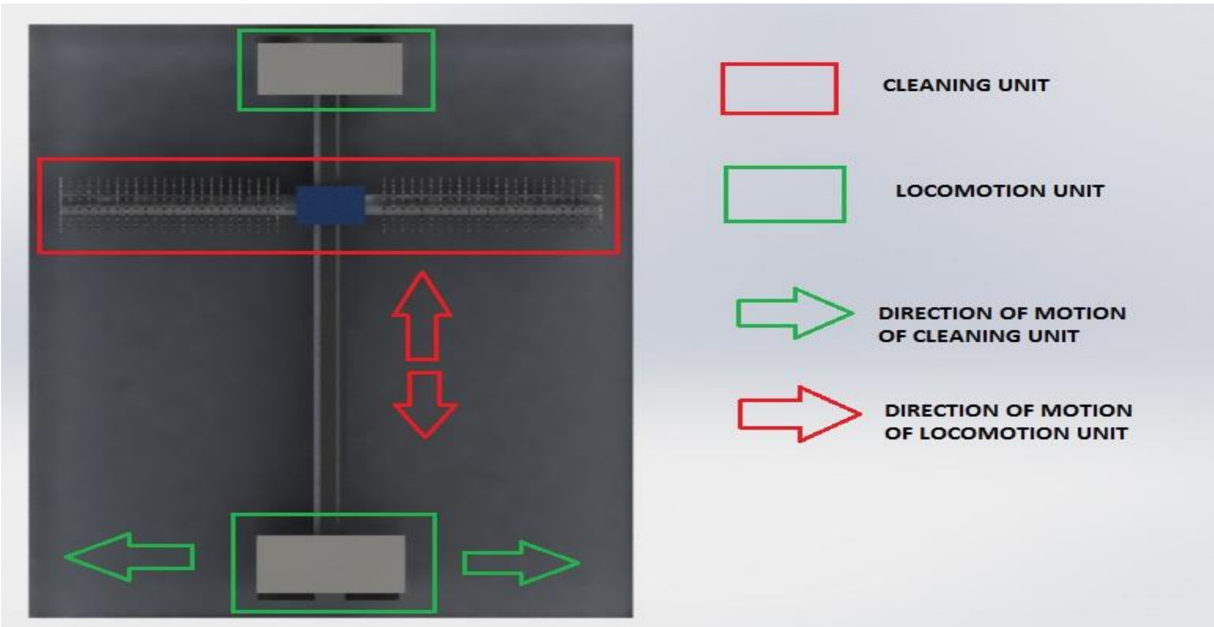
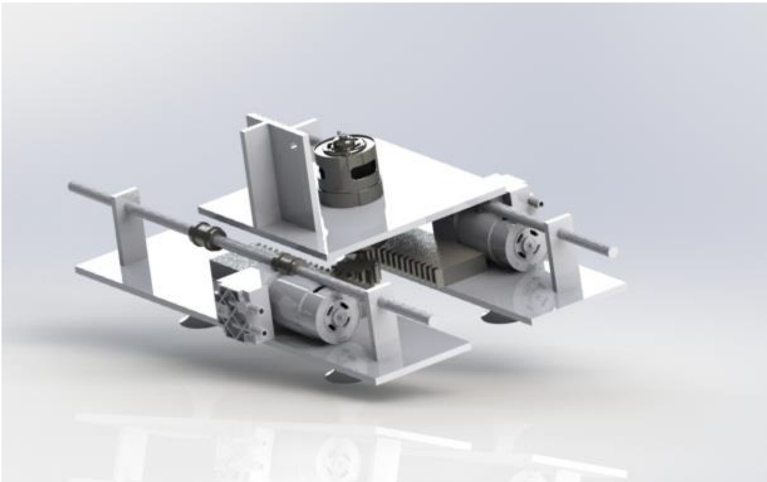


Figure 6 Working of Prototype

DESIGN AND COMPONENT SPECIFICATION

6.1 LOCOMOTION UNIT

The Locomotion Unit is responsible for the movement of the robot on the solar panel. It consists of two legs which are placed parallel to it. The locomotion unit consists of a structure, pneumatic system and the Double Rack and Pinion System.



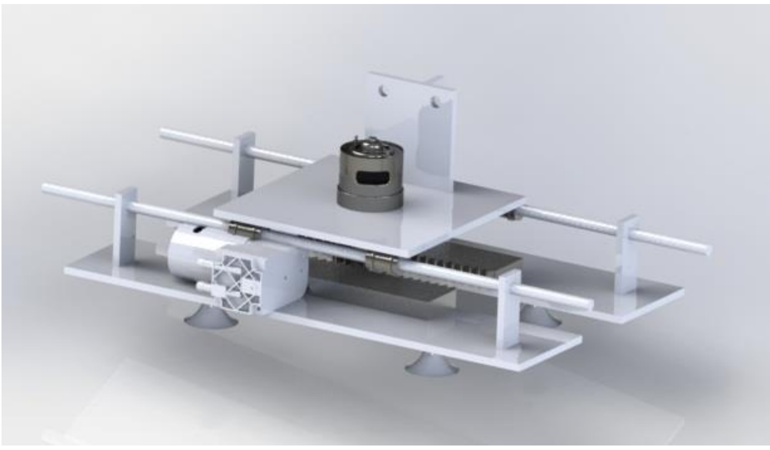


Figure 7 Locomotion Unit

The locomotion unit consist of three basic Components:

6.1.1 Double Rack and Pinion

Double Rack and Pinion system consists of two parallel racks with a pinion in between them. The racks are attached to the structures whereas the pinion is fixed to the DC Motor. The DC Motor is attached to the movable platform which are then attached to the rods with the help of linear bearings.

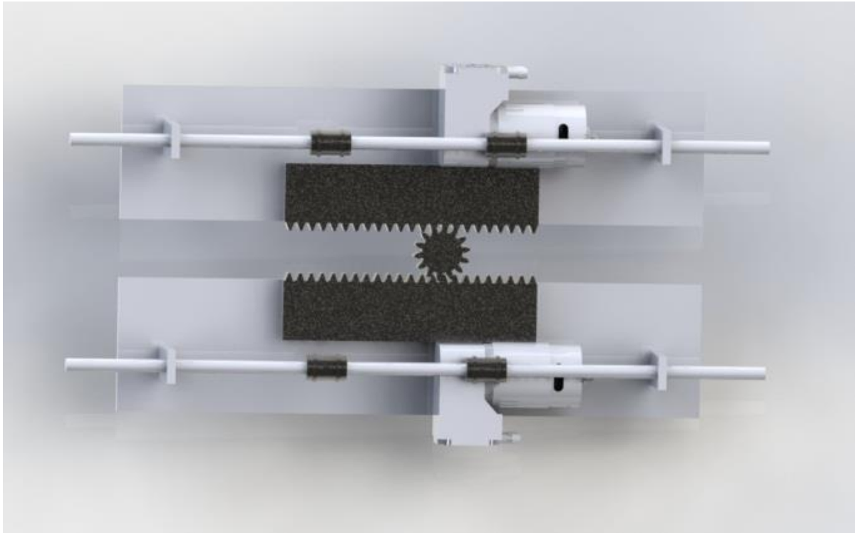


Figure 8 Double Rack and Pinion Arrangement

6.1.2 Pneumatic System

The pneumatic system is responsible for sticking the robot to the surface of the solar panel. It consist of the suction cup, the vacuum pump and the pneumatic pipes.

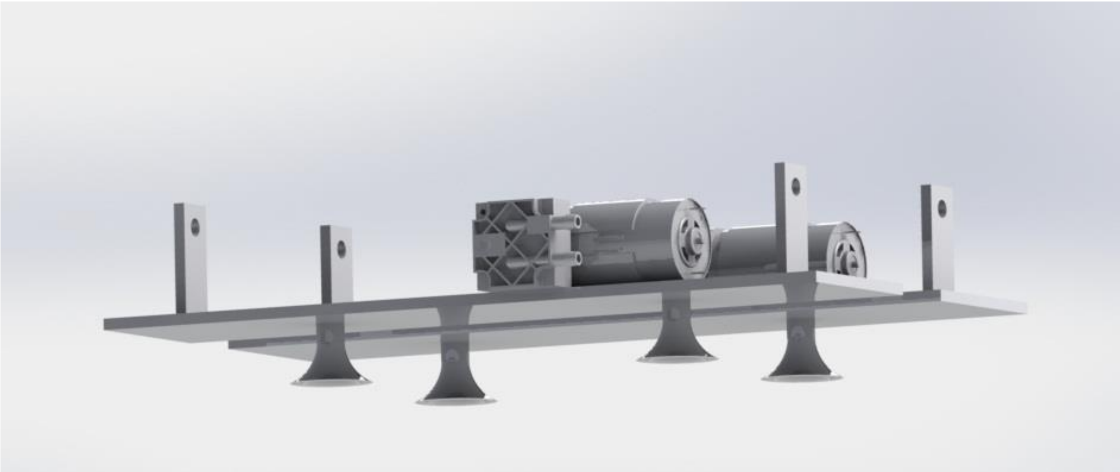


Figure 9 Pneu8matic System

6.1.3 Structure

The structure is the basic part of the locomotion unit on which all other parts are fixed. It is mainly made up of acrylic sheets and the rods are made of stainless steel. The rods are fitted with linear bearing which help in the linear motion of the platform on the rods.

Figure 10 Structure of the Legs

6.2 Cleaning Unit

6.2.1 Linear Actuator

Linear actuator converts the rotatory motion of the stepper motor into the linear motion. It consist of a central bar with a stepper motor attached to it. On the top of it a V-Slot Gantry plate is placed which moves on it with the help of v-wheels. The platform is attached to a timing belt which is run with the help of a stepper motor.

Figure 11 Linear Actuator System

6.2.2. Linear Actuator Platform

It is the main platform that moves on the V-Slot rail. On this plate the brush controller is mounted.

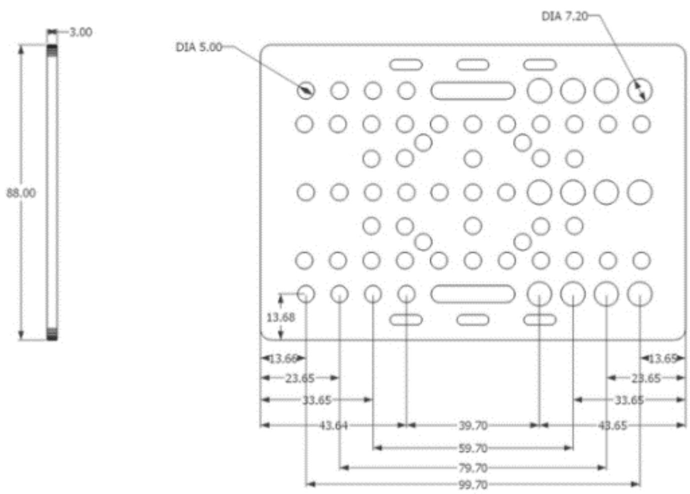


Figure 12 V - Gantry Plate

6.2.3 V- Wheel Assembly

It is the main functioning unit of the cleaning system which allows the gantry plate to move on the v rail in a smooth manner reducing the vibration in the process.

Figure 13 V - Wheel Assembly

6.2.4 DC Motor

A DC Motor is a class of electrical machine that convert direct current electrical power into mechanical power. The most common type rely on the forces produced by the magnetic field. DC motors speed can be controlled over a wide range by using a variable supply voltage or by changing the strength of current in the field winding.

Specification:

Voltage: 12 V
Speed: 200 rpm
Current: 0.5- 1 A

Figure 14 DC Motor

6.2.5. Vacuum Pump

Vacuum Pump is a device that removes gas molecules from a sealed volume in order to leave behind a partial vacuum. Vacuum pump is connected to the suction cups which helps the robot to move on the surface of the solar panel.

Specification:

Vacuum Range: 0-16” of Hg

Voltage: 12 V DC

Pressure Range: 0-32 psi

Power: 12W

Figure 15 Vacuum Pump

6.3 Electronics

3 DC motor, 4 vacuum pump and one stepper motor were used in this project. To provide power supply a SMPS (3.5 amps @ 6V) is used. The controlling is done using an Arduino Mega microcontroller. The power is distributed via a circuit designed on a general purpose PCB. Schematic Diagram and Layout of Electronics Component are shown in figure 9 and figure 10.

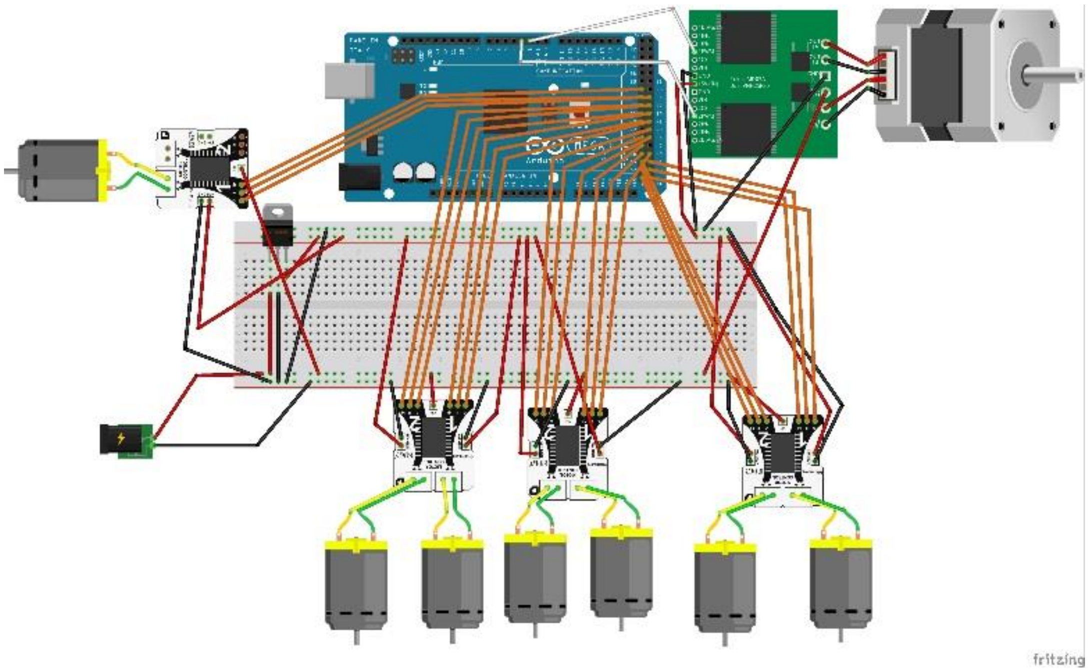


Figure 16 Electronic Component Layout

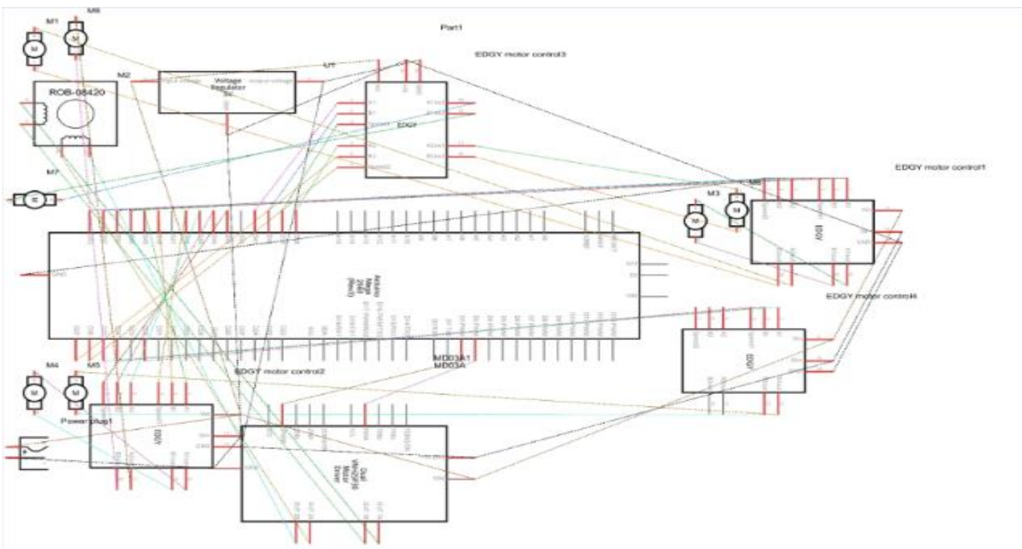


Figure 17 Schematic Diagram of Electronic Circuit

6.4 Weight Estimation

Sl. No.	Name of the Component	Number of Components	Weight of each Component	Total Weight
1	Linear Actuator	1	300g	300g
2	Stepper Motor	1	80g	80g
3	DC Motor	3	90g	270g
4	Vacuum Pump	4	85g	340g
5	Cylindrical Brush	1	200g	200g
6	Linear Bearing	10	23	230g
7	Cylindrical Bearing	1	24g	24g
8	Structural Component		300g	300g
9	Machine Screws, Standoffs and Wirings (Estimation)		200g	200g
			Total	1944g

Table 2 Weight Estimation

ANALYSIS AND CALCULATION

7.1 Static Analysis Of Gear

7.1.1 Model Information

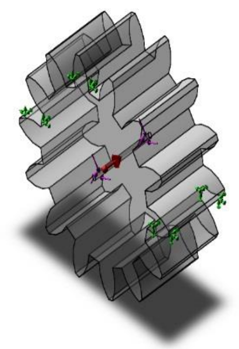
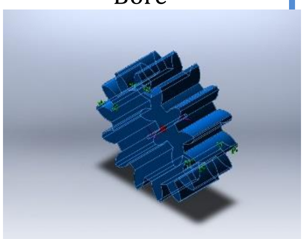


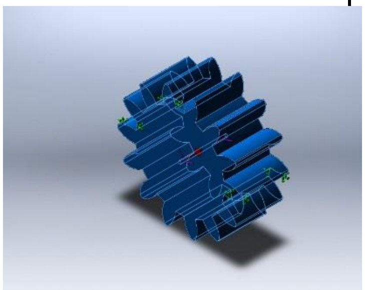
Figure 18 Model Information

Model name: spur gear_ai
Current Configuration: Inch - Spur gear 12DP 14T 20PA 0.5FW ---S14N3.0H2.0L0.03125N

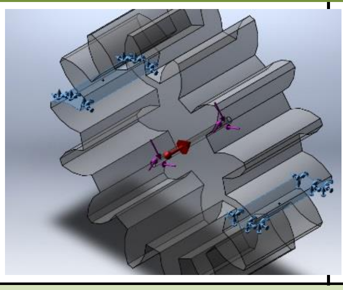
Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Bore 	Solid Body	Mass:0.00883245 kg Volume:8.25462e-006 m^3 Density:1070 kg/m^3 Weight:0.086558 N	c:\solidworks data\browser\ansi inch\power transmission\gears\spur gear_ai.sldprt May 19 23:33:34 2015

7.1.2 MATERIAL PROPERTIES

Model Reference	Properties		Components
	Name:	**ABS PC**	**SolidBody 1(Bore)(spur gear_ai)**
	Model type:	**Linear Elastic Isotropic**	
	Default failure criterion:	**Unknown**	
	Tensile strength:	**4e+007 N/m^2**	
	Elastic modulus:	**2.41e+009 N/m^2**	
	Poisson's ratio:	**0.3897**	
	Mass density:	**1070 kg/m^3**	
	Shear modulus:	**8.622e+008 N/m^2**	
Curve Data:N/A			

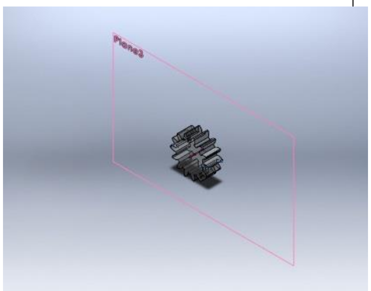
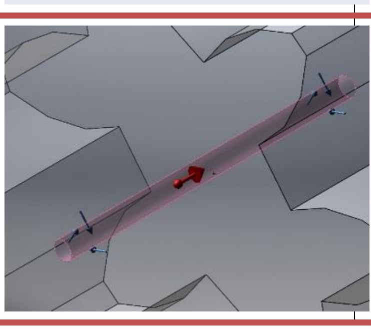
7.1.3 LOADS AND FIXTURES

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **2 face(s)** **Type:** **Fixed Geometry**

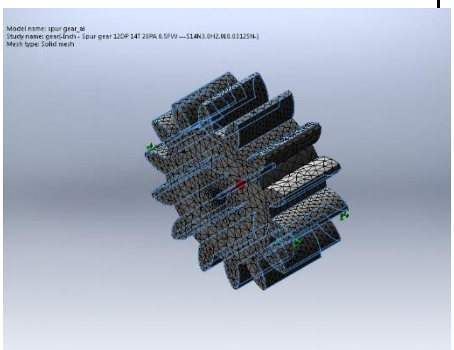
Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	0.0864813	0.00033262	-0.0654499	0.108457
Reaction Moment(N.m)	0	0	0	0

LOADS AND FIXTURES

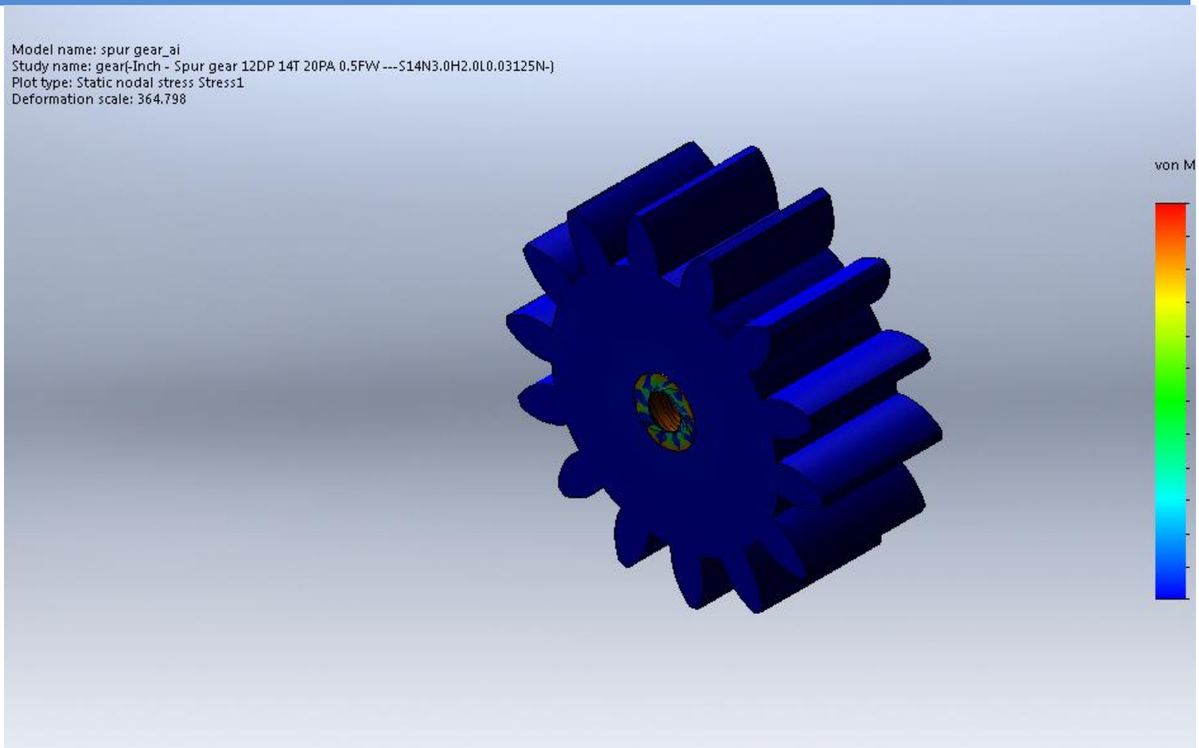
Load name	Load Image	Load Details
Gravity-1		**Reference:** Plane3 **Values:** 0 0 -9.81 **Units:** SI
Torque-1		**Reference:** Face< 1 > **Type:** Apply torque **Value:** 0.5 N.m **Phase Angle:** 0 **Units:** deg

7.1.4 MESH

Mesh Control Name	Mesh Control Image	Mesh Control Details
Control-1		**Entities:** 26 face(s) **Units:** in **Size:** 0.036814 **Ratio:** 1.5

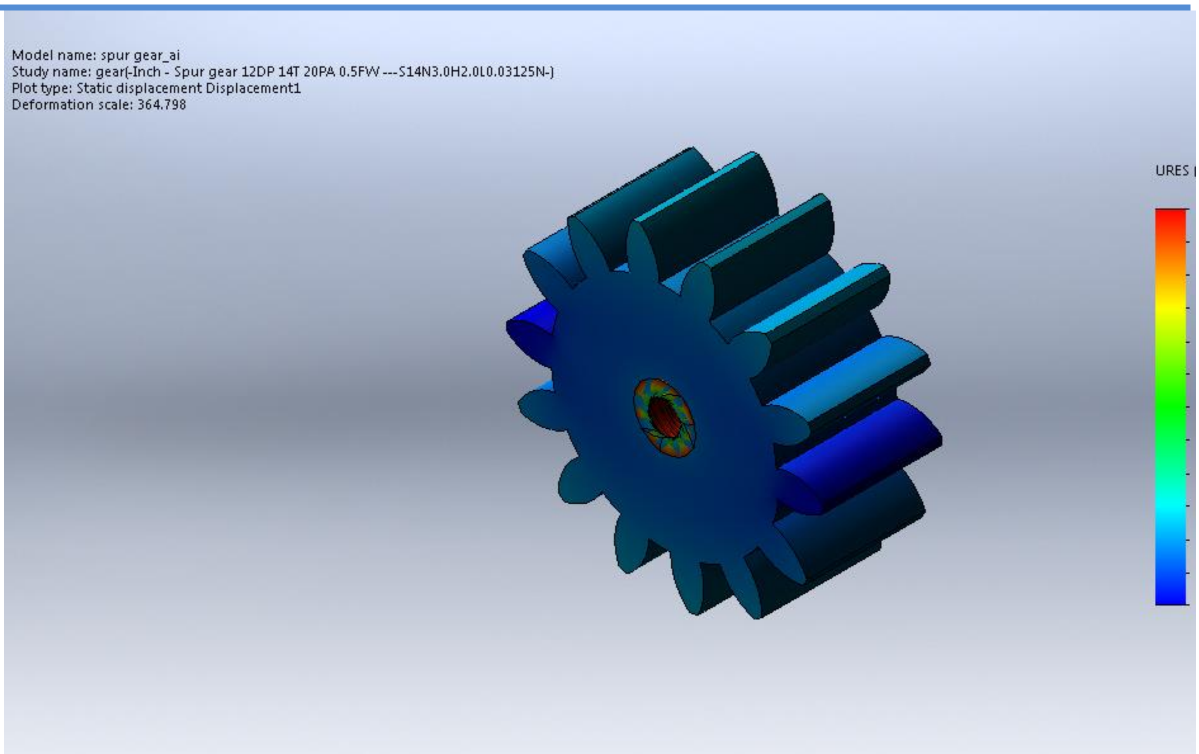
7.1.5 STUDY RESULTS

Name	Type	Min	Max
Stress1	VON: von Mises Stress	38.43 N/m^2 Node: 13217	6.94185e+007 N/m^2 Node: 26339



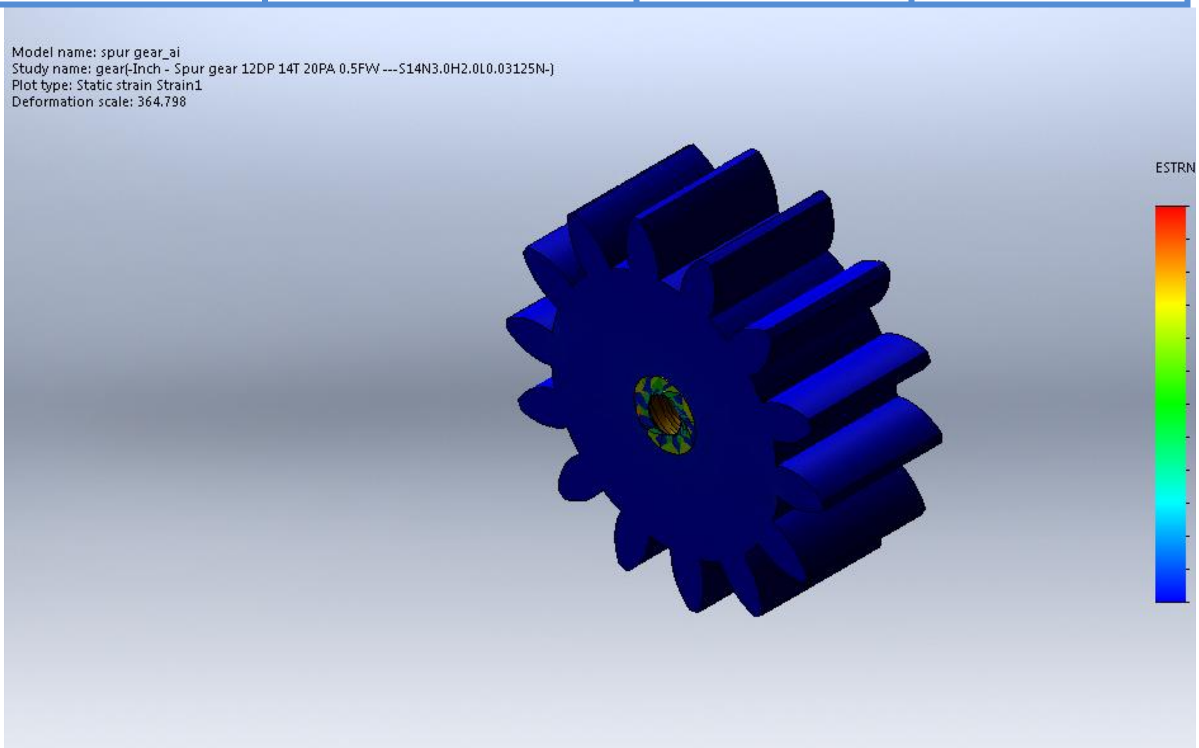
spur gear_ai-gear-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 38	0.00931607 mm Node: 26038



spur gear_ai-gear-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	4.34806e-008 Element: 18584	0.0233717 Element: 7332



spur gear_ai-gear-Strain-Strain1

CONCLUSION

The solar panel cleaning system was first designed taking into consideration the design parameters. At first the CAD model was made using Solidworks. The cad model was simulated to check the validity of the design.

The cad model was then fabricated using according to the CAD design.

The prototype was tested and the following observations were made:

1. The Double Rack and Pinion Mechanism worked as it was designed to do.
2. The suction cups were able to stick to the surface of the panel, but they were not able to stick longer.
3. The entire design was unstable in nature which created lots of disturbances while in operation.
4. The linear actuator system worked very nicely and was able to achieve the required design parameter.
5. The cleaning action of the brush was good but it failed to scrub the dust which was sticky in nature.
6. The sticky dusts need to be removes using hard brush or through mopping action.

REFERENCES

[1] Williams R B, Tanimoto R, Simonyan A, et al. Vibration characterization of self-cleaning solar panels with piezoceramic actuation. *Collection of Technical Papers - 48th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference* , 2007; pp. 512-520.

[2] Park Y B, Im H, Im M, et al. Self-cleaning effect of highly water-repellent microshell structures for solar cell applications. *Journal of Materials Chemistry*, 2011; 21:633–636.

[3]Zhu Jia, Hsu Ching Mei, Yu Zongfu, et al. Nanodome solar cells with efficient light management and self-cleaning. *Nano Letter*, 2010; 10:1979–1984.

[4] Masuda S, Aoyoma M. Characteristics of electric dust collector based on electric curtain. *Proceedings of the General Conference of the Institute of Electronic Engineers*. Japan, 1971, No. 821 Proc. of Albany Conference on Electrostatics (1971).

[5] Calle C I, McFall J L, Buhler C R, et al. Dust particle removal by electrostatic and dielectrophoretic forces with applications to NASA exploration missions. *Proc. ESA Annual Meeting on Electrostatics*, 2008; Paper O1.

[6] Liu G, Marshall J S. Particle transport by standing waves on an electric curtain. *Journal of Electrostatics*, 2010; 68: 289-
298.

[7] Liu G Q, Marshall J S. Effect of particle adhesion and interactions on motion by traveling waves on an electric curtain. *Journal of Electrostatics*, 2010; 68:179-189.

[8] Sharma R, Wyatt C A, Zhang Jing, et al. Experimental evaluation and analysis of electrodynamic screen as dust mitigation technology for future Mars missions. *IEEE Transactions on Industry Applications*, 2009; 45(2):591-596.

[9] Tomoaki Yano, Tomohiro Suwa, Masato Muraxami And Takuji Yamamotq Development of a Semi Self-contained Wall Climbing Robot with Scanning Type Suction Cups *Intelligent Robots and Systems, 1997. IROS '97., Proceedings of the 1997 IEEE/RSJ International Conference*

[10] Hegazy AA. Effect of dust accumulation on solar transmittance through glass covers of plate-type collectors. J Renew Energy 2001;22:525e40.

[11] El-Shobokshy MS, Mujahid A, Zakzouk AKM. Effects of on the performance of concentrator photovoltaic cells, IEE Proc Feb. 1985;132(1). Pt. I.

[12] El-Shobokshy MS, Hussein FM. Degradation of photovoltaic cell performance due to dust deposition on to its surface. J Renew Energy 1993;3(6/7):585e90.