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Design, Analysis and Empirical Researches for Solar Heat Collecting System based on Flat Mirrors Combination

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***Abstract*—There has been a dramatic increase of research on energy production using solar energy. This research aims to examine development of concentrating solar collector that is related to mid-high solar energy field. Although the use of dish type solar thermal system has been common in the existing high-efficiency collector technology, several problems have been raised. In order to solve these issues, the frame has been designed as flat plate type with Fresnel lens and the structural stability has been proved by analysis. Furthermore, the experiment that checks collector's temperature has been performed for the correct works of the stirling engine.**

***Index Terms*— Solar Collecting System, Heat water Generating, Flat Mirrors, Stirling Engine**

I. INTRODUCTION

Current trends in energy production in the world is a higher share of Renewable Energy than nuclear power. In addition, the Republic of Korea relies on foreign imports for more than 97% of the energy demand due to absolute lack of energy resources [1]. Among Renewable Energy, solar energy is considered as the most competitive sector that can substitute for fossil fuels. It is because only 1% of the annual solar energy reaching the earth from the sun can afford the world energy demand [2-4]. Concentrating solar collectors are used for mid-high temperature solar power system, and they are divided into Vacuum-Tube type, PTC (Parabolic Trough Concentrator) type, CPC (Compound Parabolic Concentrator) type, dish type, and Solar-Tower type in accordance with the geometry of the concentration form. The Dish type high-temperature solar thermal systems are the most representative technology of the high efficiency and concentration. It is generally designed in the form of parabolic shape with the curvature reflector for the dish type collecting systems. Collecting systems using the curvature reflector has a number of disadvantages, such as production cost, weight and maintenance. In this paper, we study the design of a solar collector system to solve these problems by using a Fresnel manner. The author also investigates and analyses experiments using the prototyped small products.

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II. THE DESIGN OF A SOLAR COLLECTOR SYSTEM

A. Reflector design using Fresnel method

The goal of this study is to drive the stirling engine so that the engine produces electrical energy. The absorber is in the stirling engine that has heat collecting area of 200mm*200mm. For the engine work, 150mm*150mm reflector is designed to collect the heat to the absorber. The number of reflectors is 182 and reflective area represents 4.41m^2. In addition, for the reflector material, the mirror PC (polycarbonate) is used as it has a less bending, the excellent strength, stability, elasticity, and light weight than acrylic material.

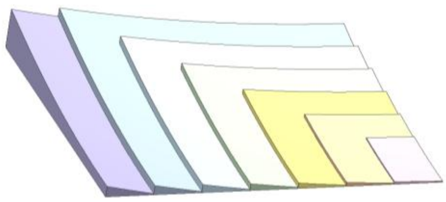

FIGURE I. THE DESIGN OF RECTANGULAR REFLECTOR USING FRESNEL METHOD

B. Structural design of the plate-type solar heat collection system

In order to implement light weight Dish type collecting device, prototype design and production is performed with turntable scheme. In this study, we implement the control of the Tracker that has two axes (azimuth, elevation) of a turntable system. It is also possible to determine the precise solar tracking system using GPS. Though the azimuth uses the same way of the angle of altitude, the collecting plane is designed not to be more than 90 degrees from the surface. Furthermore, the Prototype is designed and manufactured by calculating the appropriate reduction ratio, the rotation angle, and the control angle.

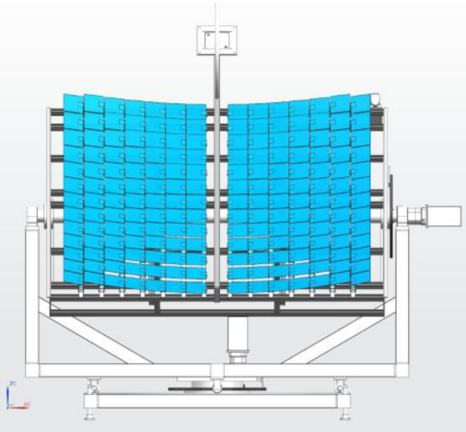

FIGURE II. PROTOTYE 3D MODELING ASEEMBLY

C. Flat plate solar thermal collector systems analysis

During the actual operation of the heat collection system, the structure is under the drag by the wind, and thus, the stress is generated in structurally weak points. Accordingly, when the drag force due to the wind acts on the flat plate heat collection system, the maximum ultimate tensile stress is generated on the reflector and this can lead to the deformation of the structure and so the loss of collector's function. And the analysis is conducted in order to verify the structural stability. ANSYS program is used for the structural analysis and the conditions are determined by considering the area over the drag co-efficient by the wind.

1) Selection of the analysis conditions from the wind load

Among the analysis conditions by the wind load, the drag co-efficient is determined by the shape of the structure subjected to drag forces. The drag co-efficient is applied to 1.9. For the Reynolds number and the density, the non-compressive fluid, that is a standard air state, are applied to the basic conditions. As the reflector has only small impacts by the surface roughness that influences drag coefficient, it is ignored. For the wind speed, 20m/s is selected based on the largest domestic wind speed.

Collector system achieves a maximum angle of approximately 30 degrees at the noon time looking at the sun. As the collecting system works under the maximum degree of 30, this condition should be considered to the drag force. Consequently, the load condition is applied to the modelling which is tilted 30 degrees. As the collecting system works under the maximum degree of 30, this condition should be considered to the drag force. As a result, the load condition is applied to the modelling which is tilted 30 degrees. The loads are applied to each of the reflecting plate rather than the drag force to the entire area. The equation (2.1) shows how to calculate the load.

$$\mathfrak{D} = \frac{1}{2} \times \rho \times V^2 \times A \times C_d$$

From the above equation, the calculated load to each of reflector is 10.26N, and physical properties of each material for the structural analysis is shown in Table 1 below.

TABLE I. PHYSICAL PROPERTIES OF EACH MATERIAL FOR THE STRUCTURAL ANALYSIS

Material	Density (kg/m^3)	Young's Modulus (GPa)	Poisson's Ratio
Structural Steel	7850	200	0.3
Aluminum Alloy	2770	71	0.33
ABS	1338	2.8	0.42
Polycarbonate	1170	9.65	0.42

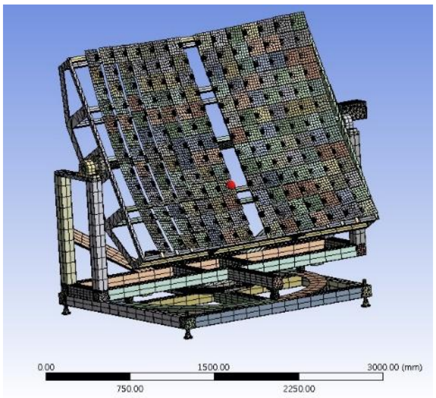

FIGURE III. MESH OF SOLAR HEAT COLLECTING SYSTEM MODELING

The total number of Nodes and Elements are generated from the mesh set of structures which are 413,838 and 139,936 respectively. Figure 3 shows the mesh of solar heat collecting system modelling and figure 4 shows the modelling of structural analysis.

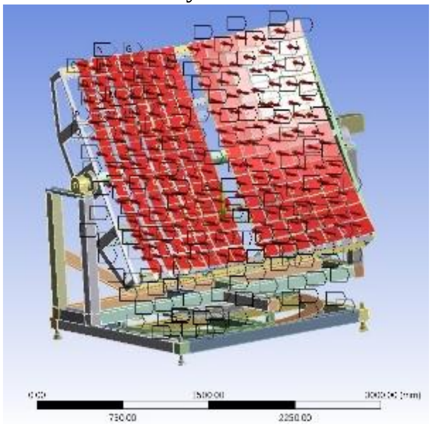

FIGURE IV. MODELING OF STRUCTURAL ANALYSIS

2) Analysis results by the wind load

The total amount of deformation and the equivalent stress by the wind load are obtained from the analysis results, and so we could determine the system stability. When the wind speed is at 20m/s, the stress of 44.7Mpa is concentrated between the caster and the structure which are rotating for the azimuth. As the yield tensile strength of this area is about 500Mpa, it is considered to be at structurally stable state. Figure 5 is a result of an equivalent stress at the heat collection system according to the wind speed.

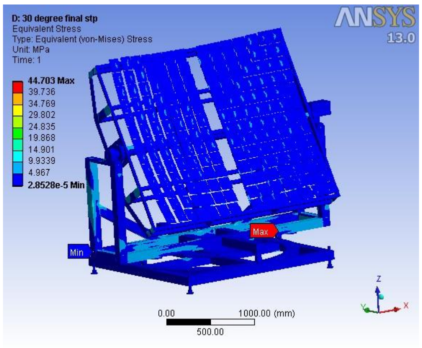

FIGURE V. RESULT OF ANALYSIS ABOUT EQUIVALENT STRESS

The deformation is occurred in the attached reflector and the result of this is 6.6mm. Fig. 6 is a total deformation amount results in collecting system.

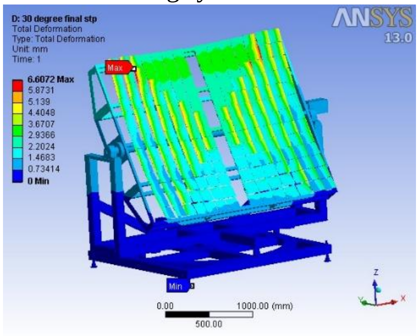

FIGURE VI. RESULT OF ANALYSIS ABOUT TOTAL STRESS

III. Experiment Result

In order to drive stirling engine by using the solar heat, the heat should be collected at the amount of the proper work of the engine. For the collection of the solar heat, the amount of solar direct gain is significant. In this experiment, thermal imaging cameras and temperature sensors are used to measures and analyses the temperature of the collected solar energy compared to the amount of solar direct gain.

FIGURE VII. PROTOTYPE OF THE SOLAR COLLECTOR SYSTEM

A. Temperature result using thermal imaging camera

The thermal imaging camera is used to observe whether the solar heat is collected at the center point of absorber. The result appears that the maximum temperature is at around 470 ℃ and the focus is spread to the center and the left part. The reason for this is that as it is flat plate reflector, the focus is collected into the one line rather than the points. And the temperature is measured through the sensor by adjusting the zero point.

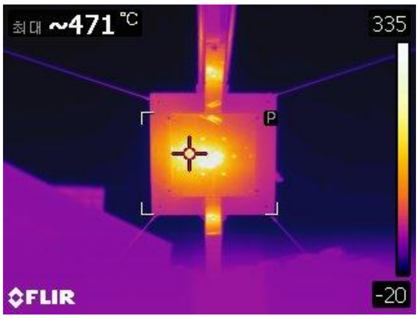

FIGURE VIII. TEMPERATURE MEASUREMENT RESULT FROM THE THERMAL IMAGING CAMERA

B. Temperature measurement results with an temperature sensor

This experiment is conducted at the time between 11:30am and 4pm which has a high amount of solar direct gain. This is an average of more than 800DNI (W/m^2). The below figure shows hourly temperature and the amount of radiance. From the result, it is confirmed that it is able to obtain high temperature of 500 degrees after about 15 minutes.

Furthermore, between 12pm and 14pm, the maximum temperature which has the highest radiance is measured at 580℃. It can be seen that the radiance is dramatically decreased after 16.000sec, this is because of the installation location. Due to the location, the solar heat cannot reach to the measuring instrument.

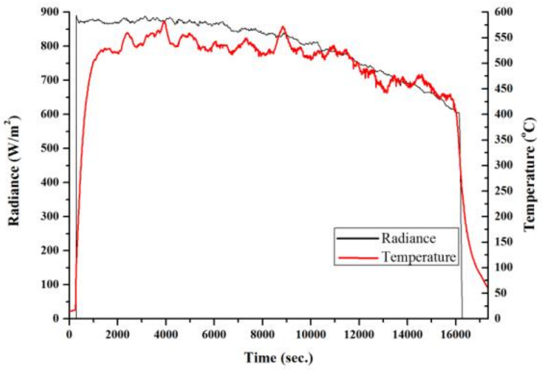

FIGURE IX. TEMPERATURE MEASUREMENT RESULT FROM THE TEMPARUTRE SENSOR

C. Worm water result

This experiment is also performed at the same condition of sensor case. It is shown that there are a fluctuated points between 3,000 and 8,000sec. This is because hidden solar radiation is measured by the cloud. In addition, the radiance decreases after 16,000sec. The reason for this is also same to the sensor case that is because of the location. From this experiment, it is found that the input temperature and the output temperature rise to maximum of 59℃.

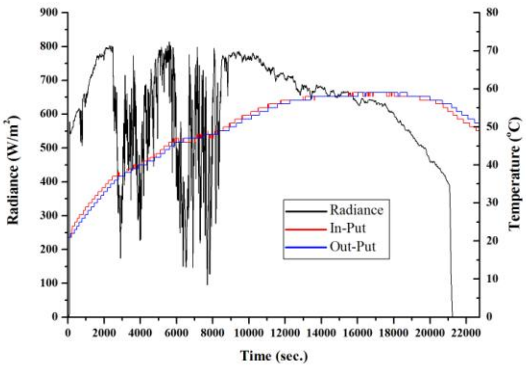

FIGURE X. DATA OF THE WORM WATER RESULT

IV. CONCLUSION

In this study, polycarbonate and 1.5T are selected for the reflector material and thickness, respectively. The design and analysis of the solar heat collector system have been conducted with the selected features. The results show that approximately 6.6mm of deformation is occurred in the reflector and the maximum stress represents 44Mpa at the wheel. As it is allowable stress, it is considered to be at proper stability. However, there is a need for more research to hold the reflector from the deformation view.

From the temperature measurement experiment, it is confirmed that the minimum driving temperature of 600℃ for the stirling engine work is collected and ongoing research which uses solar heat to drive stirling engine for the energy production, the warm water production and etc. is required.

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