CONSTRUCTION DETAILS AND PERFORMANCE CHARACTERISTICS OF A PARABOLIC TROUGH SOLAR COLLECTOR SYSTEM

Soteris Kalogirou
Higher Technical Institute P.O.Box 2423 Nicosia, CYPRUS
Stephen Lloyd
The Polytechnic of Wales, Pontypridd CF37 1DL, U.K.

ABSTRACT

The construction details and the performance characteristics of a Parabolic Trough Solar Collector system are presented in this paper. Two main items of the system are presented namely; the collector and the tracking mechanism. From the results obtained the collector performance equation is given by:
$n = 0.642 - 0.441\ (\Delta T/I)$

The collector time constant is equal to 30 sec and its half-acceptance angle is 0.5°. The tracking mechanism proved to be very reliable and accurate. Its maximum error is 0.2°.

From all the above results it can be concluded that the Parabolic Trough Collector System is a viable means for harnessing solar energy.

INTRODUCTION

Because of the low density of solar radiation in order to obtain temperatures higher than about 100°C concentrating collectors are used. A particular type, the parabolic trough collector, is currently receiving considerable attention. The disadvantage of this type of collectors is the tracking requirement which has to be accurate and reliable. This disadvantage is apparently offset by the advantage associated with the high concentration ratios attainable with this collector. Typical applications of the Parabolic Trough Collectors (PTC) are hot water production for domestic and heating purposes and steam for sterilisation and electrical power generation.

The solar collector model developed as part of this research work [1] is $1m^2$ aperture area and is shown in Fig 1. Its specifications are tabulated in Table 1.

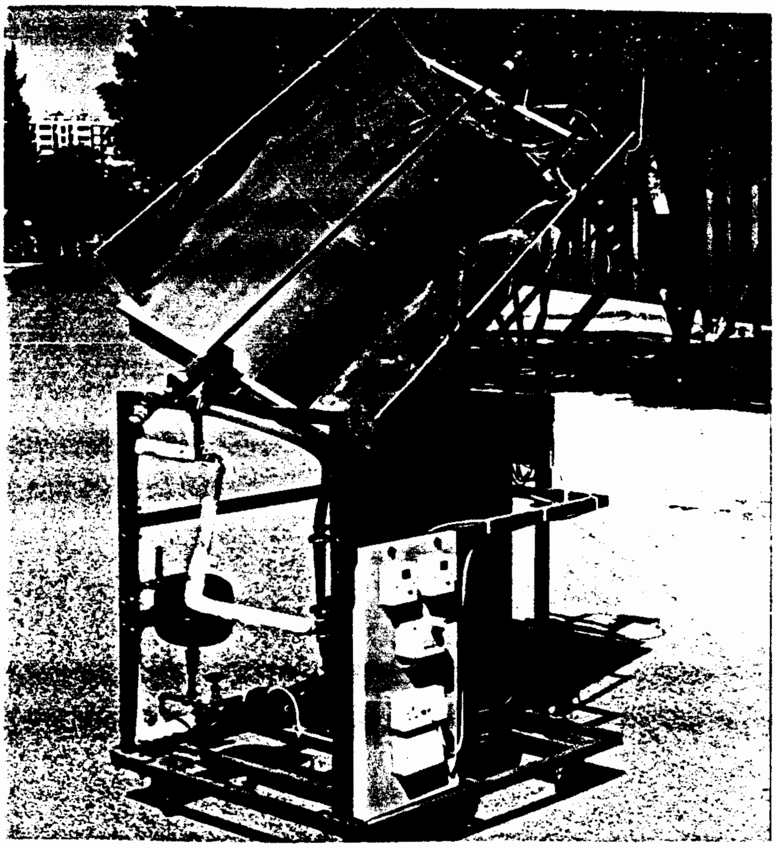


Fig 1 The Parabolic trough collector system

The solar collector model developed as part of this research work [1] is $1m^2$ aperture area and is shown in Fig 1. Its specifications are tabulated in Table 1.

The two main parts of the collector system are; the collector itself (parabola and receiver), and the tracking mechanism. The construction details of both are given in this paper together with their performance characteristics.

THE COLLECTOR

Parabola Construction

The accuracy of the parabola plays an important role in the performance of the collector. The surface imperfections, (measured as the standard deviation of the surface errors), affect the intercept factor and consequently the efficiency of the collector. From this it can be realised that the parabolic surface must be constructed as accurately as possible.

Two types of parabolas were constructed as part of this research. The one, shown in Fig 1, is made of five wooden parabolic ribs. On the top of these ribs, a sheet of metal (0.5mm in thickness) was fixed by means of small screws. Over the sheet metal a self adhesive reflective material (Scothcal 5400, manufactured by the 3M company) was fixed.

ITEM	VALUE / TYPE
Collector aperture area	1 m^2
Collector aperture	0.8 m
Aperture to length ratio	0.64
Rim angle	90°
Glass to receiver diameter ratio	2.17
Concentration ratio	21.2
Focal point	0.2 m
Mode of tracking	Polar (axis at 35°)
Optimum water flow rate	0.012 Kg/s
Local latitude	35°

Table 1 Parabolic trough collector specifications

The five parabolic ribs were fixed on a Rigid Hollow Section (RHS) frame. The frame was located such that the point of rotation was at the centre of gravity of the collector in order to reduce the tracking mechanism torque. This is shown in Fig 2 together with the dimensions of the ribs.

The second method of parabola construction is oriented towards mass-production. In order to achieve cost-effectiveness in mass-production not only must the collector structure feature a high stiffness-to-weight ratio, so as to keep material content to a minimum, but also the collector structure must be amenable to low-labour manufacturing processes. A structure which offers all these is shown in Fig 3. The parabola in this case is made of fiberglass. The success of the manufacturing process is based on the production of a very accurate master-mould. One layer of fiberglass 2mm in thickness is first laid-up. Then, in order to increase rigidity both in the longitudinal and traverse directions, plastic conduits are glued on the surface as shown in Fig 3 and another 2mm of fiberglass is laid on top. The cavity thus produced provides the required reinforcement of the structure. On the inside surface of the parabola, which was made fair face, the reflective material is fixed as in the first case. The parabola is fixed on a similar RHS structure but in this case passing through the focal point as shown in Fig 3. This method of parabola construction proved both cheap and accurate.

Receiver Construction

The receiver is made from copper pipe. For the absorbing surface a foil made by INCO ALLOYS LTD (Maxorb) was used. The foil is specifically manufactured for solar energy applications and combines high absorptance (0.96) of solar energy and low emittance (0.08) of solar radiation. The foil is supplied in a strip form coated with a pressure sensitive adhesive suitable for high temperatures.

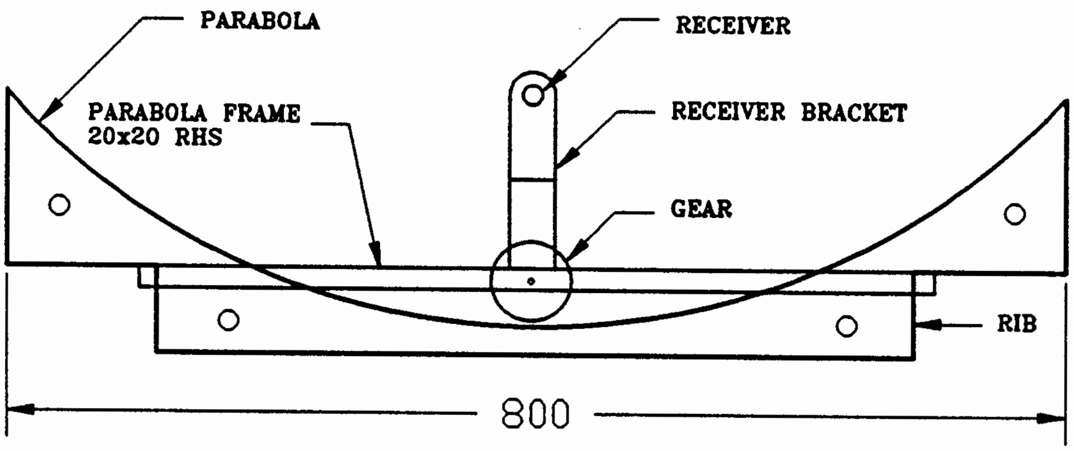


Fig 2 Parabolic rib detail

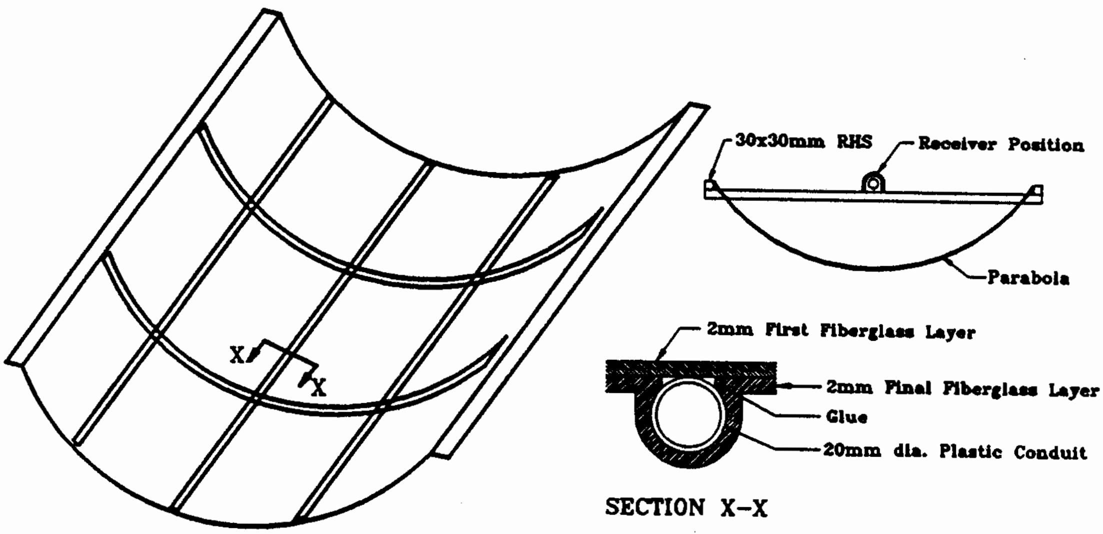


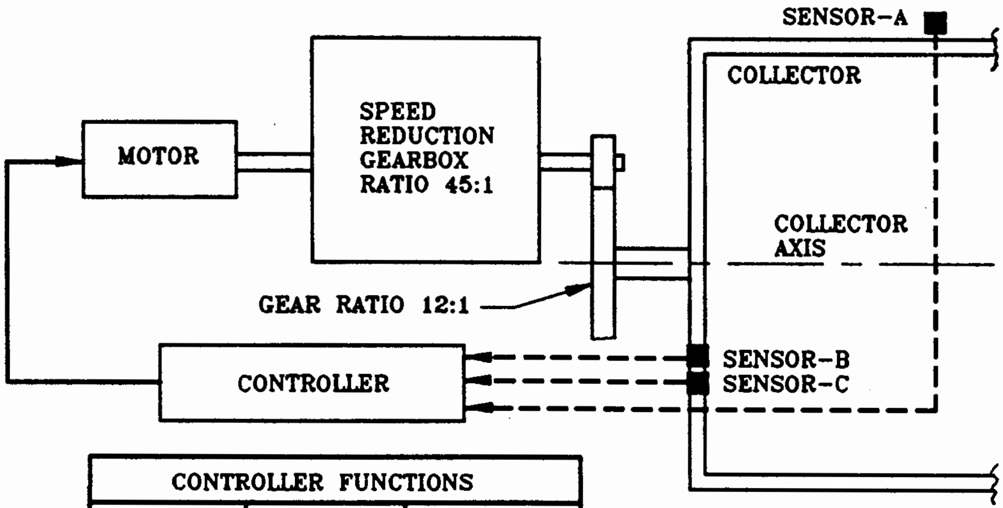
Fig 3 Fiberglass parabola detail

THE TRACKING MECHANISM

Description of the Mechanism

Many types of tracking mechanisms have been designed by various researchers [2-7]. The system developed by the author consists of a small direct current (d.c.) motor which rotates the collector through a speed reduction gearbox. A control system is used to detect the Sun's position and through an electronic circuit, controls the operation of the motor.

A diagram of the system together with a table showing the functions of the control system are shown in Fig 4. The system employs three sensors,(A,B and C). One is installed on the east side of the collector shaded by its frame, (A), whereas the other two are installed on the collector's frame, (B and C). Sensor A is the "direction" sensor i.e. this sensor will receive direct sunlight when the collector is focused (in practice is half-shaded). Sensor B is the "cloud" sensor determining cloud cover when illumination falls below a certain level. Sensor C is the "daylight" sensor. Therefore the function of the control system is to ensure that the three sensors receive sunlight at all times (i.e. the collector is continuously focused). The functions shown in the table of Fig 4 are followed provided that sensor C is ON i.e. it is daytime.



CONTROLLER FUNCTIONS		
SENSOR-A	SENSOR-B	FUNCTION
ON	ON	MOTOR OFF
OFF	ON	MOTOR ON
OFF	OFF	TIMER ON

Fig 4 Tracking mechanism - System diagram

The Control System

The sensors used in the tracking mechanism are Light Dependent Resistors (LDR). The signal of the three LDRs is fed to a number of nund gates in the control system which thus determines the condition of each sensor and switches the motor (according to the functions shown in Fig 4) so as to correct the collector position. When the three LDRs receive direct sunlight the motor is stopped. The LDRs used are the ORP 12 supplied by RS. Their resistance is about 300 Ohms in the shade (penumbra) and 15 Ohms in direct sunlight. The system also takes care of the condition that there is no Sun i.e. sensor B is not receiving direct sunlight. When this happens a timer is automatically connected into the system which will start the motor every 2 minutes for about 7 seconds. In this way the collector follows roughly the Sun and when the Sun reappears the collector moves though a small angle in order to focus itself.

Two limit switches are installed on two stoppers at the ends of the run of the collector in both directions. Their function is to stop the motor (when they are pressed) irrespective of the condition of the sensors.

The collector remains at the west position as long as it is daytime. When the Sun goes down and sensor C determines that it is night, the reverse relay is activated to change the motor's polarity and turn the collector until the east limit switch is pressed.

If during the morning there is no Sun the timer is used to follow the Sun as in the normal cloudy condition.

The Power Drive System

The main concern on the selection of the type of input voltage is safety. For this reason a d.c. voltage is selected which has two additional advantages:
A. The drive system can be powered by a battery or by a number of photocell panels which makes the system independent of the mains power supply.
B. By changing the polarity of the motor connection the motor rotation changes which is very useful in turning the collector back from the west to the east position.

The power drive system consists of a small d.c. motor and a reduction gearbox. The motor selected operates on 12 V and turns at 6 rpm. The reduction gearbox has a ratio of 45:1, therefore the output speed is 0.13 rpm.

For the speed reduction gearbox the worm and gear assembly of an automobile wiper unit was used. This provides the speed reduction required and a minimum of backlash. In the case of mass production of the system, speed reduction gearboxes off the shelf would be used, at low cost.

COLLECTOR PERFORMANCE EVALUATION

The collector testing was carried out in order to determine its performance characteristics. All tests were performed according to ASHRAE Standard 93-1986 [8].

The performance curve of the prototype model as derived from a total of five tests is shown in Fig 5. By using the ordinary least squares method, the line that best fits the data points can be obtained with a slope equal to 0.441 and an intercept of 0.642. Therefore the collector equation can be written as:

$$n = 0.642 - 0.441\ (\Delta T/I) \quad \text{(1)}$$

where: n = thermal efficiency
ΔT = temperature difference (collector inlet minus ambient temperature)
I = Beam Radiation (W/m^2)

The time constant of a collector is the time required for the fluid leaving the collector to reach 63% of its ultimate steady value after a step change in incident radiation [8,9]. For the PTC constructed this was found to be 30 sec which indicates that the collector has a fast response.

The incidence angle modifier determines the drop of optical efficiency due to the change in incidence angle. This is shown in Fig 6 where for the maximum of 23.5° incidence angle, possible with the polar mount, the loss is 17%. The test results obtained are denoted by the small squares. By using a curve fitting method (second order polynomial fit), the curve that best fits the points can be obtained. The curve shown in Fig 6 can be represented by the following equations:

For θ in radians: $K\alpha\tau = 1 - 0.22\theta - 0.47\theta^2$ ....(2)

For θ in degrees: $K\alpha\tau = 1 - 3.8*10^{-3}\theta - 1.4*10^{-4}\theta^2$ ....(3)

where: θ = the angle of incidence
$K\alpha\tau$ = the incidence angle modifier

Another test performed with the prototype model was the collector acceptance angle, which also characterised the effect of tracking mechanism angle error. A definition of collector acceptance angle can be the range of incidence angles measured from the normal to the tracking axis in which the efficiency factor varies by no more than 2% from the normal incidence

Fig 5 COLLECTOR PERFORMANCE CURVE

PROTOTYPE MODEL

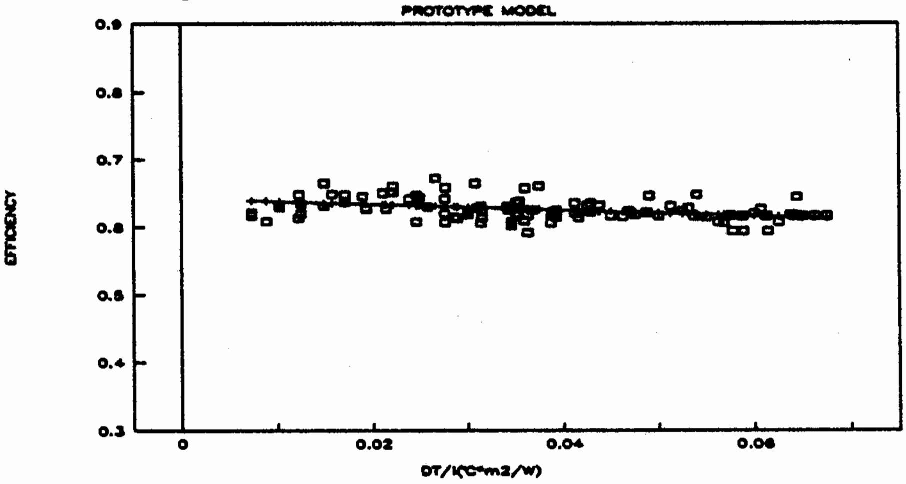


Fig 6 INCIDENCE ANGLE MODIFIER

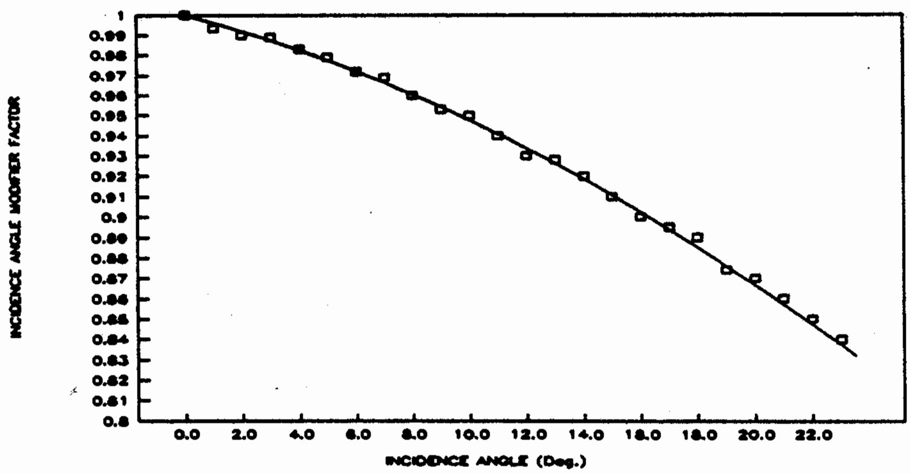
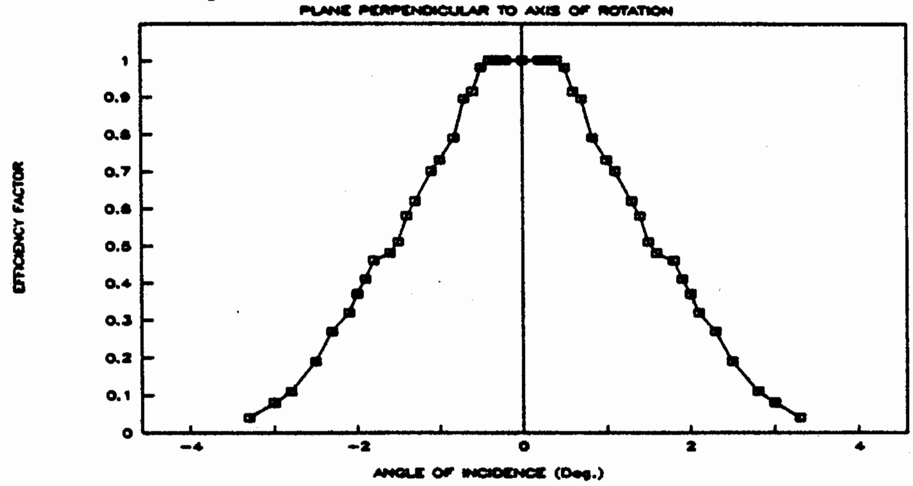


Fig 7 COLLECTOR ACCEPTANCE ANGLE

PLANE PERPENDICULAR TO AXIS OF ROTATION



angle [8]. Therefore from Fig 7 the collector half acceptance angle is 0.5°.

PERFORMANCE OF THE TRACKING MECHANISM

Following extensive testing during experimentation on the solar collector model, the tracking mechanism proved to be very effective and accurate. The accuracy of the system depends on the intensity of the Sun's illumination. In the worst case, with radiation of the order of 100 W/m^2, the accuracy of the mechanism was 0.2°. This variation was reduced to 0.05° at radiation levels in the order of 600 W/m^2. These readings suggest that the mechanism is able to provide sufficient accuracy throughout the year. Additionally they indicate an accuracy much lower than the 1° determined by the collector acceptance angle test (see Fig 7), therefore it is implied that the collector is operating at maximum efficiency at all times. No dependence of the tracking accuracy on the azimuthal position of the sun was detected as it is observed with other tracking system designs [3].

The accuracy of the mechanism was determined by measuring the time between two successive starts of the motor. By knowing that the Sun travels with constant speed of 0.25° in one minute the tracking accuracy (out of focus angle required to initialise system), can be determined.

The tracking mechanism proved to be very reliable during the testing period (about ten months). All the functions of the control system were found to be in good working order. The function of the mechanism to approximately follow the Sun when shaded behind a cloud was very effective as the mechanism requires less than 30 sec to focus after the Sun is about to reappear.

CONCLUSION

The parabolic trough collector system proved to be a feasible means for harnessing the Sun's energy. This is a result of the good characteristics of the collector and the good accuracy and reliability of the tracking mechanism. The use of PTC's against flat-plate collectors is investigated in [10] for two types of applications, namely; hot water production for a house and for a hotel. In both cases, because of their superior characteristics, the PTC's were found to be more viable than the flat-plate ones.

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