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A TRACKING MECHANISM FOR MEDIUM AND HIGH CONCENTRATION RATIO PARABOLIC TROUGH SOLAR COLLECTORS

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ABSTRACT

This paper describes a tracking system for use with solar parabolic trough collectors. The position and "status" of the Sun are detected by three Light Dependent Resistors (LDRs), one of which detects whether the collector is focused, whilst a second resistor determines if there is cloud cover, and the third senses whether it is day or night. The resultant signals are fed to an electronic control system which operates a low speed 12 V d.c. motor which rotates the collector via a speed reduction gearbox. The system provides a tracking accuracy of 0.2° with solar radiation of 100 W/m^2 and 0.05° for solar radiation of 600 W/m^2.

INTRODUCTION

Concentrating solar collectors can provide significant advantages over the usual flat plate collectors especially for medium to high temperature applications although the Sun must be very accurately tracked to ensure good thermal performance.

Although various forms of tracking mechanisms varying from the complex to the very simple, have been proposed they can be divided into two broad categories, namely mechanical [1,2], and electrical / electronic systems [3-8]. The electronic systems generally exhibit improved reliability and tracking accuracy and this can be further subdivided into:

1. Mechanisms employing motors controlled electronically via feedback from sensors which detect the magnitude of the solar illumination [3-6].
2. Mechanisms using computer controlled motors with feedback control provided from sensors measuring the solar flux along the receiver tube [7,8].

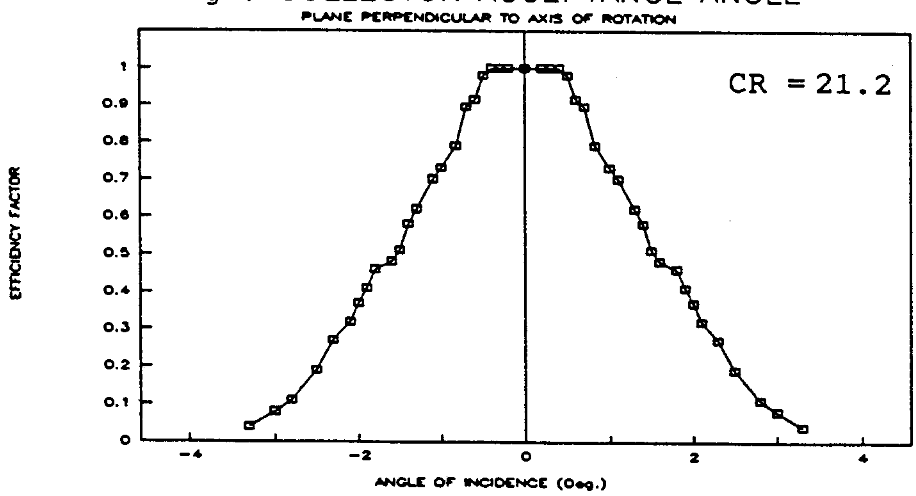
Inevitably these latter systems employing computer control are more expensive.

THE TRACKING SYSTEM

A tracking mechanism must be able to:
Follow the Sun with a certain degree of accuracy, and return the collector to its original position at the end of the day or at the beginning of the next day and also overcome the problem of intermitted cloud cover.

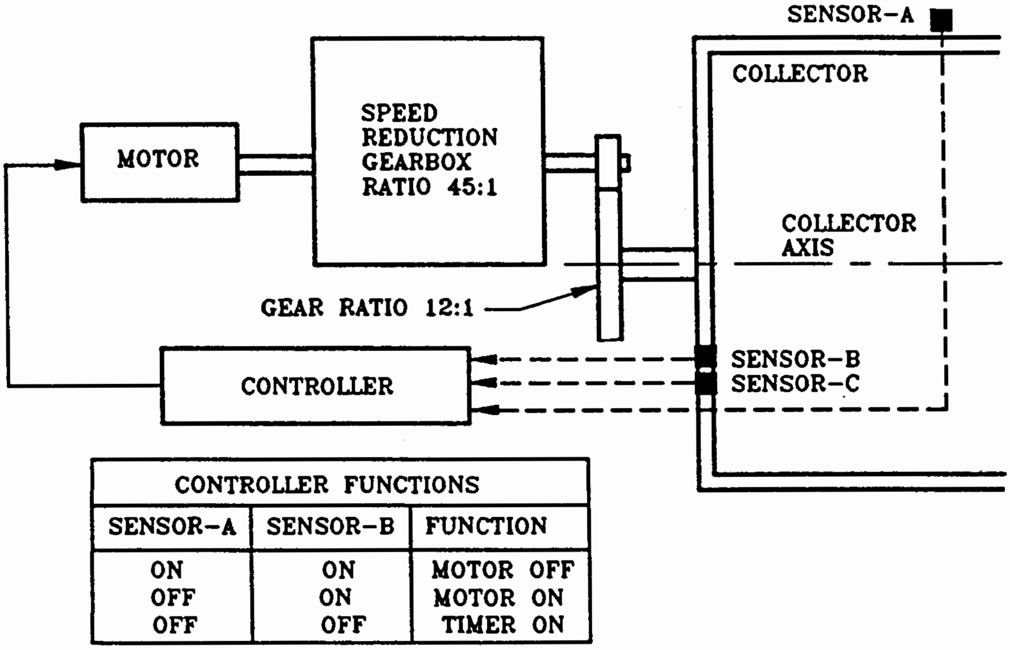
The required accuracy of the tracking mechanism depends on the collector acceptance angle. This angle is defined as the range of solar incidence angles measured relative to the normal to the tracking axis, over which the efficiency varies by less than 2% from that associated with normal incidence [9]. The results of tests carried out on the collector model constructed as part of this research, are presented in Fig 1 from which the acceptance angle of the collector is approximately 1° [10]. It thus appears that it is sufficient for the present mechanism to track the Sun with an accuracy of 0.5° (i.e. a value equal to half the acceptance angle). The employed mode of tracking is the polar i.e. the collector axis is tilted to an inclination equal to the local latitude and tracks the Sun in an E-W direction.

Fig 1 COLLECTOR ACCEPTANCE ANGLE



System Description

The final system which was designed to operate with the required high tracking accuracy consist of a small direct current (d.c.) motor which rotates the collector via a speed reduction gearbox. A control system is used to detect the Sun's position and operate the motor.
A diagram of the system together with a table showing the functions of the control system are presented in Fig 2. The system employs three sensors of which A is installed on the east side of the collector shaded by the frame, whereas the other two (B,C) are installed on the collector frame. Sensor A acts as the "focus" sensor i.e. it will only receive direct sunlight when the collector is focused. Sensor B is the "cloud" sensor and cloud cover is assumed when illumination falls below a certain level. Sensor C is the "daylight" sensor. The function of the control system is to make sure that at all times the three sensors receive sunlight (i.e. the collector is continuously focused). The functions shown in the table of Fig 2 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 2 Electrical tracking mechanism - System Diagram

The Control System

In the preliminary stages of the design of the control system a number of sensor types were considered including photocells, bimetallic strips, fluid mechanical devices and light dependent resistors (LDRs).

These all have certain disadvantages, e.g. the performance of sensors which depend upon heat differences is affected by other ambient conditions such as wind and temperature. Photocells were rejected because they require a large area in order to supply the power required for the operation of the relays. Moreover there are operating problems when they are half shaded and half exposed to sunlight.

The main disadvantage of LDRs is that they cannot distinguish between direct and diffuse sunlight. However this can be overcome by adding an adjustable resistor to the system which can be set for direct sunlight (i.e. the threshold value) so that this type of sensor was adopted. The present LDRs are type ORP 12 supplied by RS components Ltd. Their resistance is normally 300 Ohms in the shade (penumbra) and 15 Ohms in direct sunlight.

As mentioned previously the motor in the present system is switched off when all three LDRs receive direct sunlight. The system also accommodates cloud cover i.e. when sensor B is not receiving direct sunlight a timer is automatically connected to the system and this powers the motor every 2 minutes for about 7 seconds. As a result the collector follows approximately the Sun's path, and when the Sun reappears the collector is re-focused. Figure 3 is a block diagram of the control system showing the three sensors together with the timer chip, forward

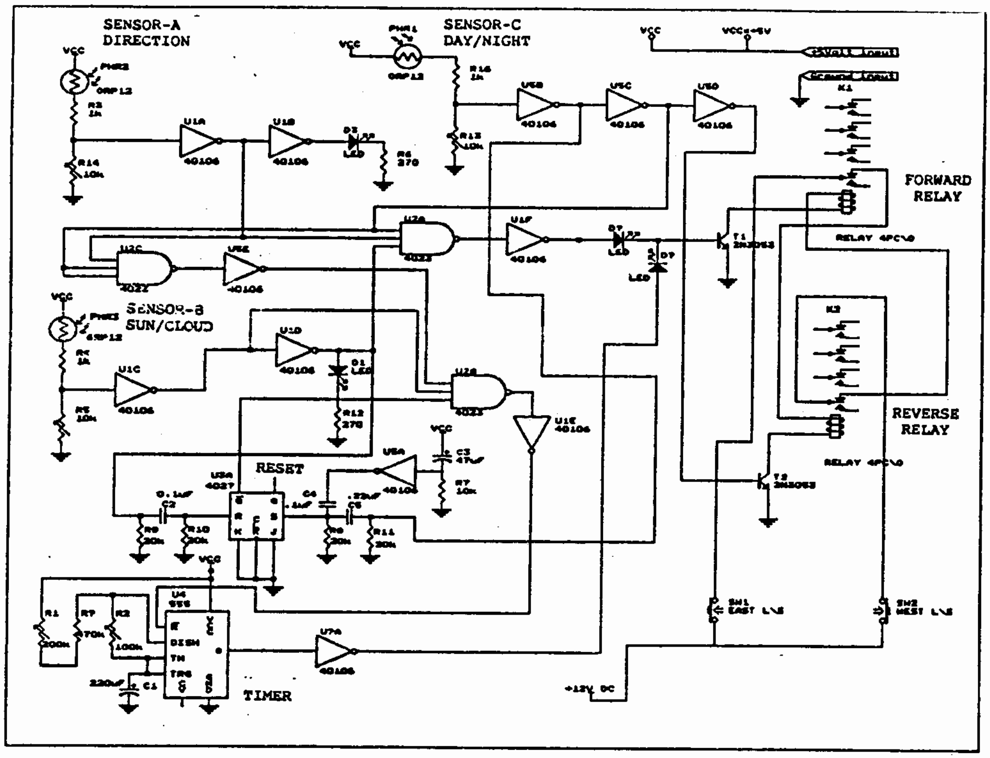


Fig 3 Control system circuit diagram

and reverse relays and limit switches (denoted as east and west L/S).

The function of the limit switches is to stop the motor irrespective of the condition of the sensors and they are installed on two stops which restrict the overall rotation of the collector in both directions. The collector remains in the west position as long as it is daytime. When the Sun goes down and sensor C determines that it is night, power is connected to the reverse relay which changes the motor's polarity and rotates the collector until its motion is restricted by the east limit switch. If there is no Sun during the following morning the timer is used to follow the Sun as under normal cloudy conditions.

The Power Drive System

Safety considerations were the paramount concern in the selection of the input voltage. Moreover the choice of a d.c. supply has advantages in that this can be supplied by a battery or photocell panels so that the system is independent of the mains supply. Furthermore the direction of rotation of the motor can be reversed by simply changing the polarity of the connections, and this is very useful when driving the collector from west to east position.

The drive system consists of a small d.c. motor and a reduction gearbox. The motor operates on 12 V and rotates at 6 rpm, whilst the reduction gearbox has a ratio of 45:1, so that the output speed from the gearbox is 0.13 rpm. This output is fed to a small gear (25mm in diameter) which drives a large gear (300mm in diameter) installed on the collector (see Fig 2). Thus the final rotational speed of the collector is 0.011 rpm i.e. 38 minutes are required to re-position collector from full east to full west.

In the prototype collector the worm and gear assembly of an automobile windscreen wiper unit was used as the reduction gearbox. This provided the required speed reduction with a minimum of backlash. For a mass produced system "off the shelf" gearboxes could be used to reduce cost.

PERFORMANCE OF THE TRACKING MECHANISM

The Sun "travels" at a constant speed of 0.25° per minute so that tracking accuracy (i.e. the out of focus angle required to initialise system), can be determined by measuring the period between successive operation of the motor.

The tracking mechanism proved to be very reliable during the testing period of about one year. All the functions of the control system as described previously performed reliably. The function which allowed the mechanism to follow the approximate path of the Sun when shaded behind a cloud was very effective as less than 30 sec were needed to re-focus the collector after the Sun reappeared.

Extensive testing of the solar collector, established that the tracking mechanism was 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° with radiation levels of about 600 W/m^2. Thus the mechanism performs satisfactorily throughout the year in the present parabolic trough collector application. The accuracy was much greater than the suggested 0.5° which was derived by the collector acceptance angle test (Fig 1).

CONCLUSIONS / RECOMMENDATIONS

The electronic tracking mechanism which was designed and constructed has proved to be sufficiently accurate for the present solar energy application. The accuracy is such that the mechanism can be used for "tracking" solar parabolic trough collectors of medium to high concentration ratios under any weather conditions. No dependence of the tracking accuracy on the azimuthal position of the Sun was detected as it is observed with other tracking system designs [2].

The mechanism may also find application to other systems which are required to follow the path of the Sun e.g. equipment used for measuring solar beam radiation. In this case the pointing error must be smaller than the instrument's angular field of view which is typically 10° and the instrument is usually mounted on a platform which tracks the Sun. The accuracy obtained from the proposed tracking mechanism is well within these limits. Tracking in the altitude direction could be achieved by manual periodic adjustment.

Beam radiation measurement is also required in cloudy conditions so that the ability to follow the Sun in these conditions is particularly important for automatic data collection.

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