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(**SOLAR TRACKING SYSTEM**)

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(**Burrell E. Hammons**) A

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Structural Phenomena in Solids Division 5132

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ABSTRACT

This report describes an automated solar tracking system which is adaptable to most solar collectors which require alignment with the sun's radiation. The system uses partially shaded photovoltaic solar cells to produce error signals for both elevation and azimuth tracking with a high degree of accuracy. An electrical circuit processes the error signals and controls gearmotors to direct the solar collector toward the sun.

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INTRODUCTION

Recent developments on solar concentrating collectors have emphasized the need for a solar tracking system capable of aligning the collector toward the sun's radiation and tracking with a fine degree of accuracy in both the elevation and azimuth axes.

Earlier automated solar alignment was accomplished basically by one of two methods:¹ either by an accurate variable speed motor coupled to a very high ratio gear train, or by a thermocouple device. The motor-gear combination did not sense the direction of solar radiation and therefore had no method for self-correction of misalignment. The thermocouple device used the differential output of two or more thermocouples to drive motor-gear combinations, thus providing a feedback loop to correct misalignment problems. There were a few shortcomings even with the thermocouple device, however. It had no means of coarse self-adjustment for severe misalignment. It therefore had to be manually placed within a few degrees of alignment for the self-aligning feature to be activated. It would not track on cloudy days and had to be adjusted for ambient temperature variations. This report describes a solar tracking system adaptable to most solar collecting systems which has some attractive features over the earlier methods of solar tracking.

MECHANICAL DESIGN

This system uses photovoltaic solar cells which are partly shaded from the sun's radiation to provide tracking error signals. These error signals are then electrically processed and used to turn on motors to drive the solar collector into alignment. Figure 1 shows the solar alignment device which uses silicon photovoltaic cells, and Fig. 2 shows how this device could be mounted on a concentrating solar collector. The silicon solar

cells have an active area 2 cm by 2 cm to provide sufficient signal to operate the tracking circuit with mild cloud cover. The circular plate below the shade horn is 10 cm in diameter and the shade horn is 10 cm tall. The mounting bar may be changed to any convenient size for mounting the alignment device to the collector.

For clarity refer to Fig. 1 and consider only cells BT1 and BT2. These cells are used to produce an error signal for the elevation circuitry. If this device is in direct alignment with the solar radiation, then cells BT1 and BT2 will each be half shaded by the shade horn. If the solar radiation is coming from a point higher in elevation, cell BT2 will be more shaded than cell BT1, thus producing an error signal to drive the alignment device upward toward perfect elevation alignment. Conversely, if the solar radiation is coming from a point lower than perfect alignment, cell BT1 will be more shaded than cell BT2, thus producing an error signal to drive the alignment device downward toward perfect alignment. With this same idea reproduced for the azimuth directions, one may visualize the same shading effect on cells BT3 and BT4, thus producing error signals to drive the alignment device toward perfect azimuth alignment. Note the other cells in Fig. 1 (BT5-BT8) which are mounted on the four sides of the shade horn and each covered with a light filter. These cells are added for rough alignment purposes; i.e., when the solar radiation is at some skew angle greater than 90 degrees from perfect alignment. During normal tracking time (perfect or near-perfect alignment) all four of these cells are shaded and have no net effect on alignment. However, if the solar radiation were from a skew angle greater than 90 degrees from perfect alignment, cells BT1, BT2, BT3 and BT4 would all be shaded. Thus, cells BT5, BT6, BT7, and BT8 would provide elevation and azimuth error signals

to drive the shade horn back toward alignment. Light filters of 1% transmission cover each of these cells to reduce reflections caused by buildings, windows, autos, etc. from producing erroneous tracking signals during normal tracking time.

Cell BT9 (on top of shade horn) is used to detect the amount of cloud cover present. If the cloud cover reaches a critical point where the alignment device is inclined to track toward the edge of the cloud or another bright spot in the sky, the signal from cell BT9 will decrease to a threshold level and turn off the elevation and azimuth tracking circuits. As soon as the cloud cover has lifted sufficiently for cell BT9 to again reach the threshold level, the elevation and azimuth circuits will be turned on.

ELECTRICAL CIRCUIT

Some precautions were taken in choosing electronic components such that ambient temperature variations would have little or no net effect on the operation of this system. It was also very important to choose silicon photovoltaic cells which have matched illumination-current characteristics over a wide temperature range to keep the electronic network balanced while tracking in adverse conditions.

The electrical circuit (Fig. 3) provides a method to change the electrical error signal obtained from the photovoltaic cells to a mechanical movement of the solar collector. The circuit is designed to operate from a 115 volt 60 Hz source. In normal tracking operation, solar cells BT1 and BT2 produce a d.c. error signal which is amplified by AR1. If the output of AR1 is negative, AR3 drives relay K1 on, which applies voltage to the elevation gearmotor and raises the solar collector. Conversely, if the output of AR1 is positive, AR 4 drives relay K2 on, which applies

voltage to the elevation gearmotor and lowers the solar collector.

Now consider a more detailed description of the circuit. Solar cell array BT1, BT2, BT5 and BT6 produces an error signal which is amplified by AR1. This signal may be a positive d.c. error voltage, a negative d.c. error voltage, or no error voltage, depending upon alignment with the sun's radiation. For solar cell output stability, power supply PS3 provides a reverse bias which forces the cells into a stable operating range. R1 acts as a load resistor across which the error voltage is produced, and also serves as a balance control to balance out any differences in solar cell performance. R4 is the gain control for AR1; and R7 limits the output current of AR1 to a safe value. Zener diodes CR1 and CR2 limit the voltage applied to the input of AR3 and AR4 to a safe value. AR3 and AR4 are voltage comparators working also as drivers to turn on relays K1 and K2. R9 and R13 produce a bias voltage of -2 volts which is used as a threshold turn-on level for AR3. Likewise, R10 and R15 produce a threshold bias of +2 volts for AR4. A time constant is produced by C1 and R14 for minimum collector overshoot due to gearmotor combinations. If this time constant is too short, the collector may oscillate across the area of proper alignment or relays K1 and K2 may chatter. If the time constant is too long, the collector response may be sluggish, or once turned on, the motor may "lock-on" for an unnecessary period of time. R14 also produces some regenerative feedback across AR3 which has the effect of changing the turn on threshold level and widening the "dead band" turn-on level between AR3 and AR4. Relays K1 and K2 reverse the a.c. voltage connections to the elevation gearmotor, causing the gearmotor to drive the solar collector in either an upward or downward motion, thus producing the desired elevation for perfect collector alignment. If no correction in alignment is needed,

neither relay is turned on. Switch S4 provides two modes of operation, either automatic tracking or manual control. In the manual position the amplifiers and comparators are turned off, and S1 manually controls relays K1 and K2 for elevation adjustment.

The elevation and azimuth circuits are identical except for the time constant produced by C2 and R17. Therefore a detailed electrical description of the azimuth circuitry is not included.

The output from solar cell BT9 is used to drive AR7 "on" when the cloud cover reaches a threshold level determined by R20. Thus when cloud cover is heavy, the elevation and azimuth relays (K1-K4) are disabled. The cloud detector should be disabled (S3) if the collector is more than 90° from perfect alignment. This is necessary for the coarse alignment cells BT5-BT8 to rotate the collector until the cloud detector cell (BT9) is no longer shaded. A timer might be used to disable the cloud detector at night in order for the collector to swing from the westerly position back to the easterly position for early morning tracking, or a timer might be used during the nighttime hours to manually drive the collector back to the easterly position. Connections H, J, K, L, M, N and G at J2 provide a means for controlling the collector from a timer or any other remote device capable of switch closure.

Table 1 is a parts list for the electrical components. Note C1, R14, C2, and R17 need to be installed with the proper time constants to fit the exact gearmotor combinations for a given application.

DISCUSSION AND CONCLUSION

This solar tracking device has been field tested on the Sandia 1 KW photovoltaic test bed shown in Fig. 2. The bi-axial yoke assembly used to rotate the collector was a military surplus search light tracker which

was modified (with extra gearing) to move very slowly in response to an error signal. Thus, small gearmotors were able to drive a fairly massive collector at a slow speed in either the elevation or the azimuth direction. The effect of wind loading on a system such as shown in Fig. 2 has been a very important consideration too, especially on the driving gears in both elevation and azimuth directions. Sufficiently strong gears have to be chosen for the loading conditions encountered. It has also been found desirable not to locate the tracking system close to reflective surfaces such as large white buildings, windows, or other glazed surfaces. The solar reflections in such cases produce errors in tracking signals especially on days where a few white clouds are present. Wind, rain, dust, etc. seemed to have little effect on the reproducibility of the exposed solar cells. Although no specific data were collected to determine the power consumption of this tracking device, it was estimated at an average of 60 watts during tracking time. This figure includes the power consumed by the electric motors on each axis. Tests were conducted at various ambient temperatures, with differing amounts of cloud cover, and under severe misalignment start-up conditions. Results show alignment and tracking resolution better than 0.1 degree on a clear day, with resolution decreased on cloudy days depending upon the amount of cloud cover. The tracking device may be adapted to most types of solar collectors which require biaxial tracking, and a simplified version could be used for single axis tracking.

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REFERENCE

1. Proceedings of the World Symposium on Applied Solar Energy, Stanford Research Institute, Menlo Park, California, 1956.

Table 1.
Electrical Components

Part Number	Description
BT1-BT9	Silicon photovoltaic solar cell 2 cm by 2 cm, 10 ohm-cm single crystal from OCLI (formerly Centralab)
FL1-FL4	Neutral density light filter, 1% transmission from ORIEL Corp. of America
AR1, AR2	Operational Amp. LM741DM from National Semiconductor Corp.
AR3-AR7	Voltage Comparator/Buffer LM206H from National Semiconductor Corp.
R1, R2	Potentiometer, 10 turn, 5 watt, 1 K
R3-R6	Potentiometer, dual, 1 turn, 2 watt, linear, 5 K
R7-R19	Resistors, 1/8 watt
R20	Potentiometer, $\frac{1}{4}$ watt, 1 K
R21	Resistor, 1 watt, 62 ohm
R22	Resistor, 2 watt, 31 ohm
CR1-CR4	Diode, Zener, IN748A
C1	Capacitor (see text)
C2	Capacitor (see text)
C3, C4	910 pf
K1-K5	Relay, Armature, 10 Amp. resistive, 5 Amp. inductive, Babcock No. BR19-5178
PS1	Power Supply + and - 12 volt, .100 Amp.
PS2	Power Supply + 15 volt, .100 Amp.
PS3	Power Supply + 5 volt, .100 Amp.
DS1, DS2	Lamp, Neon
S1, S2	Switch, DPDT, open circuit in center position
S3	Switch, SPST
S4	Switch, 4 PDT, open circuit in center position
F1	Fuse, 5 Amp. Slow Blow
B1, B2	Gearmotor, 1/15 HP, Dayton No. 2Z797
J1, J2	Jack, 15 pin
J3	Jack, 3 pin

Fig. 1

SOLAR ALIGNMENT DEVICE

Fig. 2
1 KW PHOTOVOLTAIC TEST BED

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