THE TRACKING SYSTEM FOR SOLAR COLLECTORS WITH REFLECTORS

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Abstract
In the report advantages of the sun tracking collectors in comparison with stationary collectors are expounded. The realization principle of equatorial mounting of the sun tracking system and structural performance of the sun tracking collector with reflectors is viewed. The solar collector was provided with reflectors at the collector's rear side. The experimentally obtained energetic parameters of the sun tracking collector are compared to those of the ordinary flat-plate solar collector, and the assessment of energetic parameters is given. The placement of the sun tracking system elements on the collector with reflectors, functional scheme, working principle and characteristics of the sun tracking system are shown. The possibilities for improvement for the solar collectors with reflectors and their meaning are discussed.
Key words: solar energy, solar collector, tracking system.

Introduction

As positive factors for introduction of the sun tracking collector should be noted the following: the collector has an optimal condition of solar energy tracking, because such a construction secures that the solar collector's surface is tracking the sun all day long and the solar rays are striking it perpendicularly. As a result, the solar radiation losses which are related to the energy reflection from the collector surface will be decreased, and in this case the efficiency of a solar device will be at its maximum. For the covering of a sun tracking collector's absorber, a transparent material (glass) with a smoother surface can be used, which has higher solar radiation transmittance than material with a textured layer, which is normally used for industrially manufactured collectors. Flat-plate, smooth-faced surfaces are cleaned easily from dust, snow and rain spots. The sun tracking collectors released from dew frost and snow earlier in the morning, because it is directed to the sun at that moment. In this case collector produces as much heat energy as possible, and efficiency of a solar device increases. In addition, equipping the sun tracking collector with effective energy reflectors (mirrors) it is possible to obtain higher temperature. Also such type of collectors can be rotated and placed (stored) on a position which is not influenced by unfavourable weather conditions.

Tracking systems can be classified by the mode of their motion. This can take place about a single axis or about two axes. In the case of a single-axis mode, the motion can be in various ways: east-west, north-south, or parallel to the earth's axis. For full tracking or two-axis tracking, the position of the frame has to be changed in two planes – horizontal and vertical. The full tracking configuration collects the maximum possible sunshine, but the system for automatic management of such a process is rather complicated and expensive.

The task of the tracking system is to rotate and orientate the equipment of the solar energy collector so that the collector's surface is placed perpendicular to the solar rays all day long to receive maximum solar energy. Complexity of the sun tracking system, wherewith the price are largely determined by the accuracy of tracking and orientation, which is dependent on the collector type which is used. For example, solar radiation incidence angle deviation from normal of 20° for flat-plate collector does not create even noticeable captured radiation capacity reduction.

The higher accuracy for solar tracking system by solar collector with reflective mirrors is necessary (Latvia patent) (Putans et al., 2006), because the deviation of solar radiation on mirrors deals with the reflected solar radiation from the mirrors on the work surface of the collector's absorber. Besides this deviation is horizontal for cited collector and diagonally for collector without heel (Latvia patent) (Kancevica et al., 2007).

A more precise tracking system is necessary for solar collectors with energy concentrators like those of a parabolic trough collector or a parabolic dish reflector, besides, parabolic dish reflector the accurate as vertical as well as a horizontal plane orientation needed.

Materials and methods

Using meteorological data recording device MD-4 (Latvia patent) (Putans et al., 2011), at the Agency 'Research Institute of Agricultural Machinery' of Latvia University of Agriculture, during three years (2005-2007) from 1st March till 1st November in every 12 minutes, the meteorological parameters were measured. This device was envisaged for data acquisition (measuring and registration) about the air temperature, its relative humidity and intensity of solar radiation for the stationary and the sun tracking thermo battery. Summarizing the experimental data, the average yearly values for each of the three years

Table 1

Average values of meteorological parameters obtained by device MD-4 in Ulbroka 2005-2007

Month	T_{ov}, °C	E_{cst}, kWh m^{-2}	E_{ctr}, kWh m^{-2}
March	2.6	111	139
April	8.1	136	185
May	14.3	159	231
June	18.6	180	272
July	21.1	176	267
August	19.7	146	204
September	15.5	120	158
October	9.5	69	81
	S*E*	1096	1538

Source: Ziemelis et al., 2009

were obtained (Ziemelis et al., 2009) (Table 1): T_{ov} – average daily temperature, E_{cst} – amount of solar insolation energy daily received by a static, in south direction oriented surface, and E_{ctr} – amount of solar insolation energy daily received by tracking the sun to sun beams normally oriented surface. Data in Table 1 show that during the season, the sun tracking collector received 1.4 times more energy than the south oriented stationary collector, but during the summer months, for example, in June and July – 1.5 times more.

Using given methodology (Харченко, 1991) and the computer program MS Excel, the forecasted amount of the produced heat energy for stationary and sun tracking selective coating collectors were calculated (Ziemelis et al., 2009). The obtained data in the form of histograms are shown in Fig. 1: during the season 1 m^2 of the selective solar collector is surface area can produce 405 kWh of energy, but that of the sun tracking collector – 569 kWh, which is 1.4 times more. In some of summer months the difference was higher. It should be noted that if the water heated with solar collector is used intensively, the collector will work at $(T_{in} - T_o) < 50\ °C$ for long periods, so that the collector efficiency and amount of generation heat energy will be even higher.

Basically the sun following collector's devices consists of two blocks, supports with the rotation mechanism and mounted solar collector with or without solar energy reflectors on it and automatic sun tracking systems.

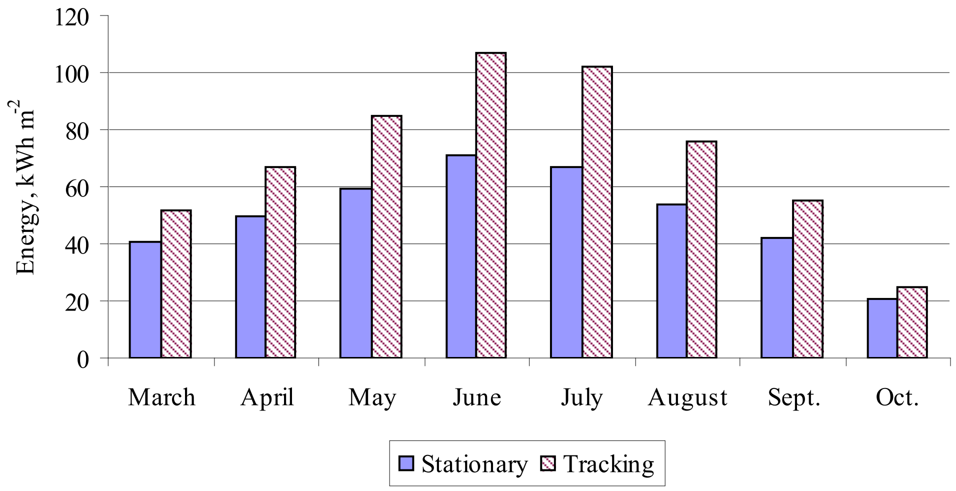
The sun tracking collector with reflectors

Due to the promotion work and for testing patented ideas, at the Agency 'Research Institute of Agricultural Machinery' of Latvia University of Agriculture tracking the sun solar energy collector with solar reflectors was constructed (Fig. 2). At solar collector with reflectors the rear surface of the absorber is receiving the solar radiation reflected from the two reflectors (mirrors). It is important that such a device works correctly. The collectors following the sun when secondary spindle of reducer turned. For example, for orientation to the sun on the true solar time, the reductor of device shall be fixed so that its secondary spindle symmetry axle with a vertical angle will be $(90° - \varphi)$, would be directed to the North and focused on the polar star (φ – the degree of the latitude of the place). To take full advantage of the absorber's and mirror's surface areas, the collector must be equipped with a sensitive automatic tracking system. As it is known, the earth makes one rotation about its axis every 24 h, which means that 1 h of rotation equivalent to 15°. On 10 minutes solar ray will deviate for 2.5°.

The solar energy collector with automatic tracking system elements is shown on Fig. 2, where: 1 – solar energy collector; 2 – frame; 3 – reducer; 4 – screw mechanism for change the zenith angle of collector; 5 – support; 6 – chain belt; 7 – electric motor; 8 – reflectors (mirrors); 9 – slip contact of the potentiometer; 10 – slip ring of the potentiometer; 11 – resistor of the potentiometer; 12 – potentiometer axle; and 13 – electronics block of automatic tracking system. The collector comprises the frame (2), where between the side balks the flat-plate collector (1) is fixed (absorber is placed in the collector box and both sides of the box are covered by planes of glass). Two mirrors (8) are fastened to the frame (2). The collector and mirrors are secured symmetrically and perpendicular to the frame plane.

Research on parameters of the solar collector irradiated from both sides

Usually solar energy flat-plate collectors are constructed so that the sun heats the one to sun oriented solar energy collector's absorber side. In the box (other side of collector) the layer of heat insulation and heat absorber with a heat exchanger are placed. Due to the fact that from the heat insulation coated collector side there are less heat losses than from the side covered with glass, it is expected that by heating two glass-covered collector sides



Source: Ziemelis et al., 2009

Figure 1. **Calculated amount of heat energy produced by solar collectors at Δ$T = T_{in} - T_o$ = 50 °C**
where: T_{in} – heat carrier inlet temperature into collector, °C; T_o – surrounding air temperature, °C.

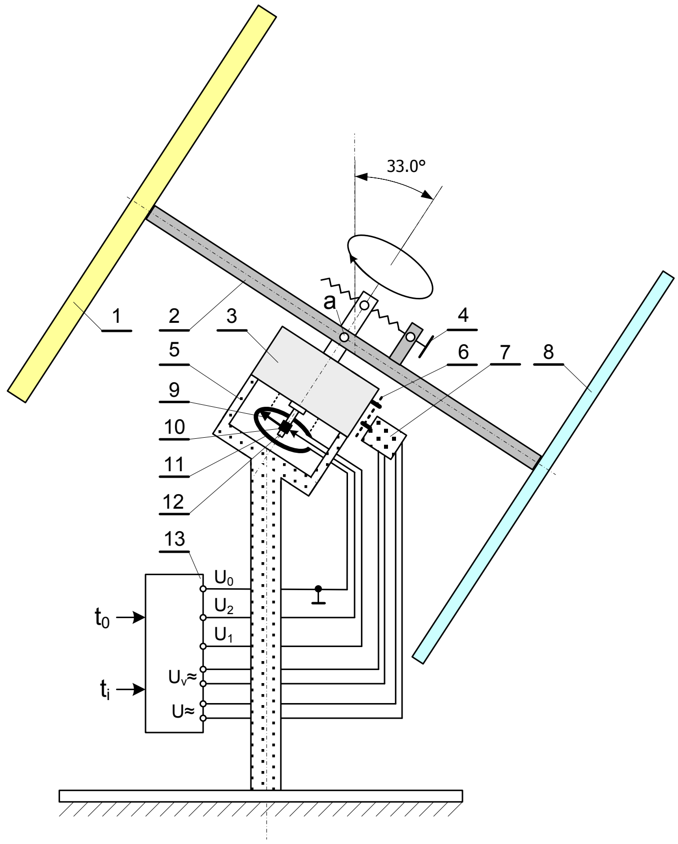


Figure 2. **Solar energy collector with elements of sun tracking system**

of the same intensity of radiation, it will be not produced twice as much energy in comparison with the standard flat-plate collector. Therefore to determine the energetic parameters of the collector irradiated from both sides, experimental investigations have been carried out.

In order to evaluate the produced amount of heat energy, in Table 2 as the reference point irradiation of the absorber only from one side with power 1000 W and 2000 W respectively is taken. From Table 2 it follows that when only one surface of the absorber with two times higher power is irradiated, 2.05 times higher amount of heat energy is produced. But when both surfaces of the absorber with power equal to the reference power are irradiated, 1.77 times more heat energy is produced.

Table 2

Energetic parameters at irradiation of the absorber surface with power of 1000 and 2000 W m^{-2}

No.	Parameters	Absorber irradiated by power		
		1000 W m^{-2}		2000 W m^{-2}
		75 min		
		One surface irradiated, another insulated	Both surfaces irradiated	One surface irradiated, another insulated
1	T_{in}-T_o *max*, °C	36.7	65.3	75.9
2	Power consumed, kJ	450	900	900
3	Power produced, kJ	185	328	379
4	Efficiency average	0.41	0.36	0.42
5	Gain	1	1.77	2.05

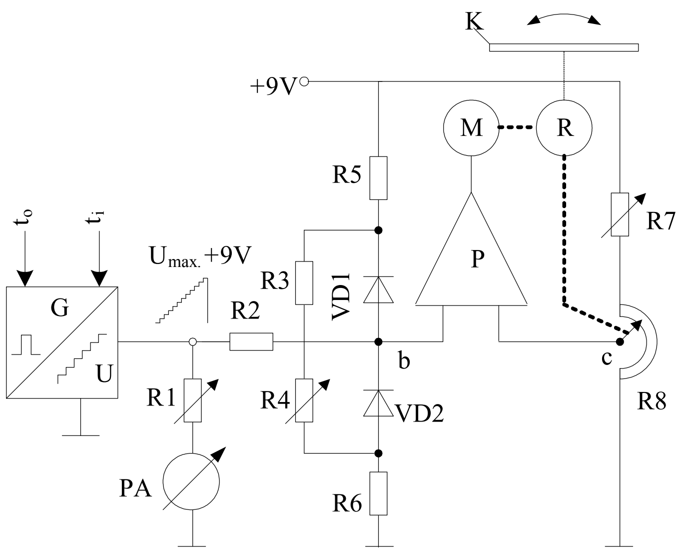


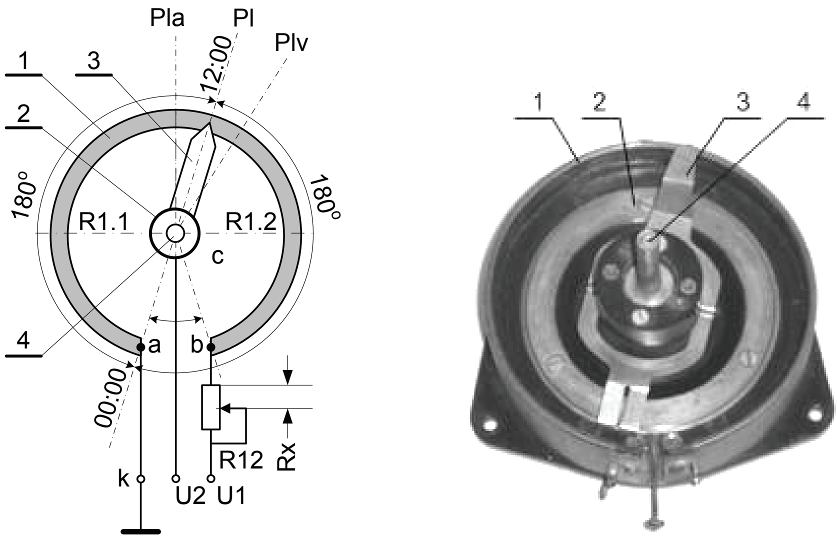
Figure 3. **Functional scheme of the automatic tracking system of solar energy collector with reflectors**

The functional scheme and working principle of the automatic sun tracking system for solar collector with reflectors

Different schemes of automatic control of the tracking system's work can be used. The scheme used in the present research for self-acting management of the device is presented in Fig. 3, where: *G* – voltage generator of real time; *PA* – real-time indicator; *R1*, *R2*, *R3*, *R4*, *R5*, *R6*, *VD1*, *VD2* – limiting devices for the turning angle of the collector; *P* – amplifier of the voltage and power; *M* – electric motor; *R* – reducer; *K* – solar energy collector; *R8* – potentiometer (alter-resistance) (see also Fig. 5), position sensor of solar energy collector (voltage divider); *R7* – turning speed range adjustment of the solar energy collector (variable resistors). The electronics block of solar automatic tracking system is shown in Fig. 4.

The automatic tracking system of solar collector with reflectors works as following. When real time voltage generator works, gradually increases the voltage on the generator output circuit. Each growth of the voltage impulse increases the current on indicator *PA*, that causes lead of indicator clockwise by showing the time, because the scale of the instrument graduated h. Similarly voltage on generator output circuit point *b* increases, which is connected to one of amplifier *P* inputs circuits. This increase of voltage upsets the balance of potentials on amplifier inputs (balance of voltage between points *b* and *c*) and leads tracking system reaction – on amplifier *P* output circuit appears voltage, start to turn the electric motor and reducer with on its axis fixed collector and potentiometer (voltage divider) *R8* slip contact. During rotation on the potentiometer slip contact (point *c*) increases the voltage, so the rotation will continue until the voltage difference on amplifier inputs

Figure 4. **The electronic block of automatic tracking system**



a b

Figure 5. **Potentiometer (alter-resistance) R8**:
a – schematic illustration; *b* – overview; 1 – potentiometer resistor (electrical resistance); 2 - slip ring of the potentiometer; 3 – slip contact of the potentiometer, 4 – axis; *U1* – the supply voltage to the potentiometer; *U2* – circuit output voltage of the potentiometer

disappear (between point's *b* and *c*). Then disappears the voltage on amplifier output circuit and the electric motor stops working. When next voltage impulse arrives, the process repeats. For the real time voltage generator with t_0 set up day start (zero-voltage on output circuit of the generator), but to t_i – for running time of an appropriate voltage.

Since the potentiometer electrical circuit is interconnected, that is the currents in all its elements are equal then:

$$\frac{U_2}{R_{1.1}} = \frac{U_1 - U_2}{R_{1.2} + R_X}, \qquad (1)$$

where:

$$U_2 = U_1 \frac{R_{1.1}}{R_{1.1} + (R_{1.2} + R_X)}. \qquad (2)$$

For the resistance slip contact of the potentiometer (3) located on the solar noon (*Pl)* time axis ($U2 = 0.5 \cdot U1$), the sum of resistance ($R1.2 + Rx$) must be equal to *R1.1*. If resistances $Rx = 0$, then solar noon time axis *Pl* ($U2 = 0.5 \cdot U1$) will move to the *Plv* and collector will take the noon time position earlier than if ($R1.2 + Rx) = R1.1$. But when increasing the resistance *Rx*, if ($R1.2 + Rx) > R1.1$, then on noon time (*Pla*) the collector will turn later. So, if the value of resistance *Rx* is changed, on the constant voltage increase of the automatic tracking system the electronics unit output circuit time of the day, it is possible to accelerate and slow down the turning speed of the solar energy collector and to match it to real movement of the sun, i.e., to adjust the turning speed of the collector at the time of equation (alignment).

Results and discussion

Summarizing the experimental data, the average yearly values (Table 1) and calculations of it show that during the season, the sun tracking collector receives 1.4 times more energy than the south oriented stationary collector, but during the summer months, for example, in June and July – 1.5 times more.

Due to the fact that heat insulation coated collector side has less heat losses than from the side covered with glass, it is expected that by heating two glass-covered collector sides of the same intensity of radiation it will not be produced twice as much energy in comparison with the standard flat-plate collector. Technical performance for solar collector with reflectors (solar collector irradiated from both sides) can be improved by using selective coating for the absorber and selective glassing, which generally decreases the losses of radiation energy.

The tracking solar energy collector with reflectors with 1 m^2 surface area can get 3 times more energy than the stationary, provided that the total surface area of the mirrors is 2 times greater than the absorber's surface area. It is possible to increase the amount of energy received by the tracking the sun collector by increasing the number of mirrors (Latvia patent) (Putans et al., 2008; Kancevica et al., 2007). For solar energy collector oriented all year exactly to the sun, it should be turned around the polar axis on the true solar time.

Fig. 1 demonstrates that during the season 1 m^2 surface area of the selective solar collector can produce 405 kWh of energy, but of the sun tracking collector – 569 kWh, which is 1.4 times more. In some of summer months the difference was higher. From Table 2 it follows that when only one surface of the absorber with two times higher power is irradiated, 2.05 times higher amount of heat energy is produced. But when both surfaces of the absorber with power equal to the reference power are irradiates, 1.77 times more heat energy is produced.

Conclusions

The tracking the sun collector without reflectors had an optimal condition of solar energy tracking, because such a construction secures that the solar collector's surface is tracking the sun all day long and the solar rays are striking it perpendicularly. As a result, it produced 1.4 times more heat energy in comparison with stationary operating flat-plate collector of the same size.

The sun tracking collectors released from dew frost and snow earlier in the morning, because it is directed to the sun at that moment. In this case the collector produced as much heat energy as possible, and efficiency of the solar device increased. Also this type of collectors can be rotated and placed (stored) on position, which is not influenced by unfavourable weather.

In addition, equipping the sun tracking collector with effective energy reflectors (mirrors) it is possible to obtain higher temperature. When the absorber of a collector is irradiated from both sides with equal radiation intensity, it produces 1.77 times more heat energy than in case it is irradiated only from one side, the other one having a heat barrier.

The design of the sun tracking solar collector with reflectors is simpler, if the absorber is irradiated from both sides, therefore this variant can be recommended for practical use.

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