IMPROVING THERMAL CONTROL EFFICIENCY OF SOLAR ENERGY UTILIZATION BASED ON AT SERIES SINGLE-CHIP MICROCOMPUTER

by

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The thesis researched and designed a solar air heating automatic control system. The system is based on the AT89C52 single-chip microcomputer. The system has automatic tracking function control of the blade heat collector, winter and summer function conversion, and active and passive function conversion functions. The advantage of this system is that it can set the operating parameters of the system as required and can typically work following the set mode under complicated weather changes. Through experimental research, it is found that the solar air heating automatic control system can effectively improve the utilization efficiency of solar energy.

Key words*: solar air heating, blade-type heat-absorbing plate, Sun tracking, single-chip microcomputer control*

Introduction

Solar heating is divided into two categories from the operating mode: active and passive. Actively collect and obtain solar energy through high efficiency heat collectors and transport heat through equipment such as pipes, fans or pumps. All parts of the system can be controlled to reach the required room temperature. Passive is based on the local weather conditions, relying on the structure of the building and the material's thermal performance so that the house can absorb and store as much heat as possible to achieve heating purposes. It is divided into solar air heating and solar hot water heating from the different types of heated media. The solar air heating automatic control system is discussed in this article. The heat-collecting component used in the system is a solar-air heat collector. The heat-collecting plate is a blade-type rotatable tracking solar operation, which can absorb solar radiation the maximum extent. In summer, the heat-absorbing blades can be turned over to make the backside facing the Sun, reflecting sunlight radiation to insulate and cool down [1].

Solar thermal power generation tracking control system control scheme

The control of the tracking device is mainly to use PLC to program and control the operation of the groove profile. The entire control system includes PLC, stepper motor driver, stepper motor, and two reducers with reduction ratios of 300:1 and 62: 1. The control system

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uses PLC to output pulses to control the stepper motor driver to rotate. Simultaneously, the speed reducer drives the shaft under the groove to rotate to track the Sun's position [2].

Depending on the Sun trajectory control algorithm

The algorithm requires the following input data: UT is the fractional representation of 1 day; D/M/Y is the date (day/month/year), Δ is the difference between UT and TT. The TT (Earth time) is the time scale of the ephemeris and does not depend on the Earth's rotation. The difference Δ is $\Delta = TT - UT$. The θ/φ is the longitude/latitude (radian system), ρ/T – the pressure (standard atmospheric pressure)/temperature. The solar altitude angle, e_0, refers to the angle between the tangent plane of a point on the Earth and the line connecting the moment. The solar altitude angle calculation is:

$$e = a\sin\left(\sin\varphi\sin\delta_t + \cos\varphi\cos\delta_t\cosh_t\right) \tag{1}$$

where e is the solar altitude angle and φ – the local geographic latitude. The solar declination angle, δ_t, is the angle between the Sun's rays and the Earth's equator:

$$\delta_t = a\sin\left(\sin\varepsilon\sin\gamma\right) \tag{2}$$

and h_t is the solar hour:

$$h_t = 6.30038809903t_c + 4.8824623 + 0.9174\Delta\gamma + \theta - \alpha \tag{3}$$

where ε is the inclination of the Earth's axis, γ – the longitude of the Sun in the center of the Earth, and α – the ascension of the center of the world. The Julian day t_c is:

$$t_c = INT\left[365.25\left(Y - 2000\right)\right] + INT\left[30.6001\left(M + 1\right)\right] + D + \frac{UT}{24} - 1158.5 \tag{4}$$

The structure of the solar air heating automatic control system

In this paper, a solar air heating automatic control system is designed. The system includes a signal detection module, a parameter input module, a calculation control module, and a drive execution module. It is composed of four large modules, as shown in the four boxes in fig. 1. It shows the process of using solar energy to detect air, and in the process of the above four modules, the solar air heating system heats the air, and sets the corresponding temperature sensor in the system, and installs the corresponding temperature sensor in the heating system's inlet, outlet and heating area. Set temperature sensors in the outdoor environment and use the signals from these sensors to calculate the daily average temperature of the environment to determine the heating period. During the heating period, it will automatically detect the strong signal of sunlight and then detect the intensity of the sunlight. The temperature sensor of the heating system is equipped with a photosensitive sensor to monitor the intensity of sunlight, and through the detection signal, it is judged whether to activate the Sun direction tracking function of the system; in the non-heating period, the system will check the ambient temperature signal, and then control the interior and heat collection of the heat collection system. The board, through the ambient temperature detection signal, the control system drives the motor so that the side with the selective heat reflection coating faces the Sun, so as to realize reflection, heat dissipation, heat insulation and cooling.

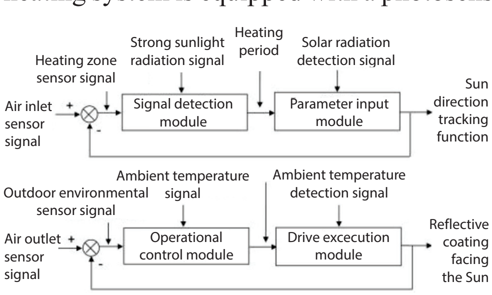

Figure 1. Schematic diagram of system structure

Realization of the control system

The control system uses PLC to output pulses to control the stepper motor driver to rotate. Simultaneously, the speed reducer drives the shaft under the groove to rotate to track the Sun's position. The realization of the program is mainly divided into three parts:
- Write the calculation as aforementioned equation of the Sun position realize the Sun position corresponding to a particular moment every time you input.
- Synchronize the current time to recognize that the data read by the PLC at each moment is the same as the present time. The system realizes the automatic determination of the real-time Sun position. The PLC has a built-in clock, which can synchronize the current time by reading the value of the built-in clock.
- Calculate the direction and speed of the motor by calculating the position of the Sun at each moment. The system can set the pulse number and frequency value output by PLC [4].

Active and passive operation heating conversion control

The control system is equipped with active and passive transfer switches, which can choose active or passive operation according to heating requirements. At the beginning of the heating period, the ambient temperature has not dropped a lot. At this time, the system can be set to passive heating. When the room temperature is low, it can be set as active heating.

Active heating temperature difference cycle operation control

We set temperature sensors at the inlet and outlet of the heating collection system to monitor the channel and outlet temperature. When the difference, ΔT, between the air outlet temperature, T_0, and the air inlet temperature, T_i, reaches the upper limit of the temperature difference setting, ΔT_{01}, the control system automatically starts the fan. At this time, the hot air is sent into the room for heating through the air duct. When the temperature difference is less than the lower limit of the temperature difference setting ΔT_{02}, the fan will stop running. The temperature difference cycle operation control subroutine is shown in fig. 2.

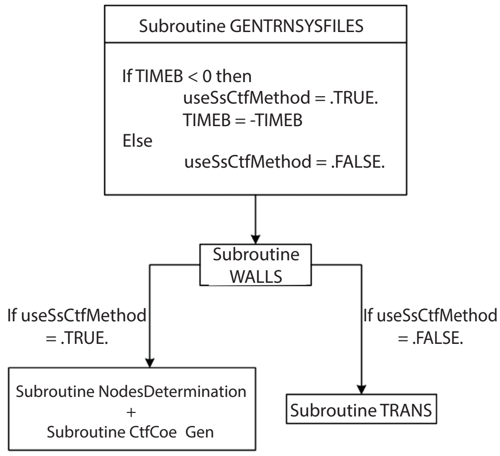

Figure 2. Temperature difference cycle subroutine

Automatic tracking control of collector plate

After system analysis and comparison, a control method combining sensor system and program control system is adopted. Every one hour, the sensor is used to monitor and locate the intensity of sunlight in real-time to eliminate the accumulation caused by factors such as mechanical structure error. Make the collector plate receive the maximum solar radiation in real-time. The 1-D tracking of the solar heating system heat collector plate can have three methods. *Method A*. The rotation axis of the heat collection sheet is set vertically, and the heat collection blades rotate around the axis from east to west to track the Sun, that is, the vertical axis orientation tracking. *Method B*. The rotation axis of the heat collector is set horizontally from east to west. According to the change of the height angle of the Sun, the heat collection blades are pitched and rotated around the east and west horizontal axis to track the Sun, that is, the flat axis elevation angle tracking. *Method C*. The rotation axis of the heat collector is horizontal north and south placed. According to the change of the Sun's azimuth angle, the heat-collecting blades rotate around the axis of rotation from east to west to track the Sun, that is, horizontal axis azimuth tracking [5].

The automatic tracking control program design should be applied to any method to meet the different installation methods of the collector. The light sensor detects the intensity of sunlight. When the light intensity, I, is less than the set value, I_0, the heat collecting plate is reset. When the light intensity value is greater than the set value I_0, first rotate the heat collecting plate 1° counterclockwise to judge the fair intensity value. If the current light intensity value I_2 is greater than the light intensity value I_1 before the rotation (*i.e.* $I_2 \geq I_1$), continue to move forward. Until $I_2 < I_1$ stops advancing. Then turn it clockwise by 1°, and then compare the light intensity. If $I_2 \geq I_1$, continue to grow 1°, and stop at $I_2 < I_1$, which corresponds to the best light intensity. The program is delayed for 15 minutes, and the loop is executed again to find the corresponding position of the best light at that moment. This tracking method is suitable for 1-D tracking of azimuth angle and 1-D search of elevation angle. The control system can capture the maximum solar radiation regardless of the horizontal or vertical setting of the rotation axis of the collector. The flow of the automatic tracking control subroutine is shown in fig. 3 [6].

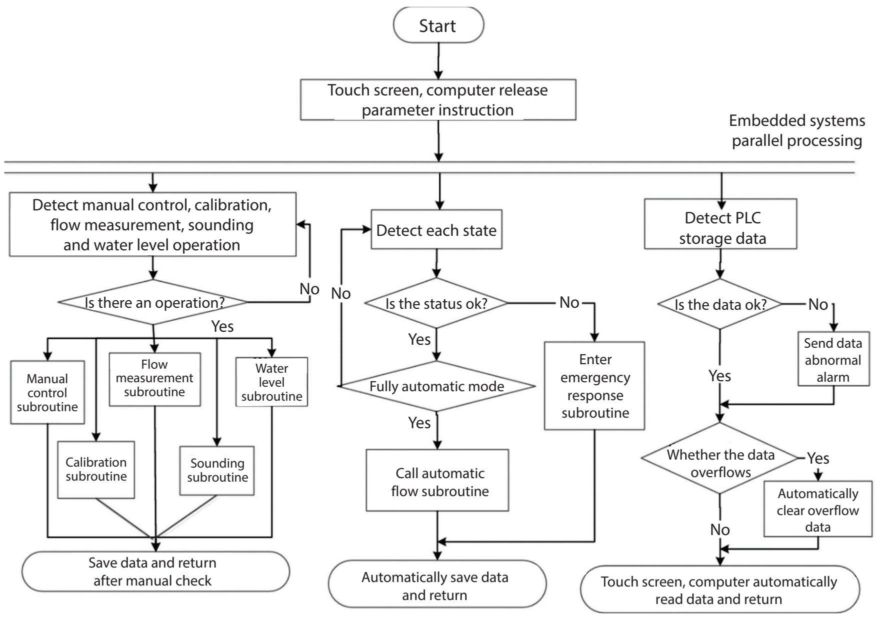

Figure 3. Automatic tracking control subroutine flow

Control system hardware design

This paper presents a solar air heating automatic control system based on DS1302 and AT89C52 single-chip microcomputer. The system hardware comprises a signal acquisition unit, LED display unit, a parameter input keyboard, single-chip microcomputer, timing chip, drive module, DC servo motor, servo controller, and axial fan.

Signal acquisition unit

The system control signal acquisition unit is composed of a temperature sensor and a light intensity sensor. This design uses the digital temperature sensor DS18B20, which has the characteristics of a simple circuit, small size, and high measurement accuracy. The light intensity sensor uses photo resistive elements to obtain different analog voltage values by sensing light intensity. An amplifier circuit amplifies the signal. The processed analog signal is converted into a digital signal by the analog-to-digital conversion circuit and input into the single-chip microcomputer [7].

Parameter input keyboard

The parameter input keyboard is used to set the system operating state parameters and operating process parameters.

The MCU

The single-chip microcomputer is the core component of the solar air heating automatic control system, which performs data calculation and operation control. This design uses an AT89C52 single-chip microprocessor produced by ATMEL Company of the United States. The display unit adopts an LED display module to display the temperature of each part of the heating system and the operating status of the system. The actuator of the control system consists of an automatic tracking servo motor and an active heating axial fan.

Analysis of control system application effect

Automatic tracking control

On February 11th, 2019, the solar radiation intensity test of the three tracking methods of the solar tracking device was conducted. The solar radiation obtained by the three tracking methods is shown in fig. 4.

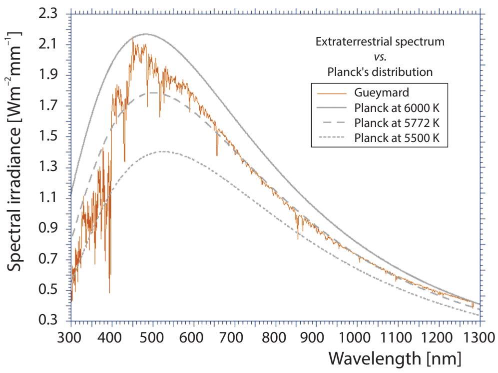

Figure 4. Solar radiation intensity on the collector surface with different tracking methods

It can be seen from fig. 4 that the solar radiation obtained by tracking the vertical axis azimuth angle is the largest. The total solar radiation from the vertical plane is more than the total solar radiation obtained from the horizontal plane. The amount of solar radiation is second. The amount of solar radiation received by the elevation angle tracking inclined plane in a day varies greatly. The total solar radiation obtained from the 11:00-14:00 inclined plane is much; the horizontal axis azimuth tracking receives the smallest amount of solar radiation. Because the solar altitude angle is negligible in winter, the solar radiation obtained by the horizontal plane is minimal, and the tracking effect of the horizontal axis azimuth angle is poor.

In summary, during the heating period in winter, the vertical and inclined surfaces have total solar radiation. The south façade wall heat collection system uses vertical axis azimuth tracking, and the roof heat collection system uses horizontal axis elevation angle tracking. Conducive to heat collection and heating.

Control analysis of heating system

The test was conducted on a sunny day from December 1st to 17th, 2019, and the active and passive operation heating tests were carried out, respectively. The automatic control system controls the heating process. The indoor temperature, air inlet and outlet temperature, wind speed, solar radiation intensity, and cumulative radiation of the test room were tested in different operating modes. The test data is calculated and analyzed, and the average heat collection efficiency of the heating system in various operational ways is obtained. The calculation method is shown in [7]. The test data processing results are shown in tab. 1.

Table 1. Control test results of heating system in winter

Date	12-1	12-3	12-4	12-5	12-17	1-2	1-6
Operating mode	Active operation without tracking		Actively run automatic tracking			Passive operation	
Average ambient temperature [°C]	9.1	7.8	9.2	7.8	4.5	8.2	7.5
Radiation amount [MJm^{-2}]	8.66	10.65	11.32	12.8	16.28	10.65	7.2
Average indoor temperature [°C]	18.8	21.5	21.5	22.3	24.2	16.8	16.2
Average temperature difference between test room and environment [°C]	9.7	13.7	12.3	14.5	19.7	8.6	8.7
Daily average heat collection efficiency of the system [%]	60.7	61.2	75	76.7	75.6	32.8	30.6
Average heat collection efficiency [%]	61		75.8			31.7	

It can be seen from tab. 1 that the automatic tracking control heating effect of the system is the best in active operation. The average heat collection efficiency of the heating system can reach 75.8%. The system actively runs without tracking control, the average heat collection efficiency reaches 61.0%, and the passive operation system is 31.7%. The average indoor temperature in active operation is 9.7-19.7 °C higher than the ambient temperature. The moderate indoor climate in the experimental room of passive process on sunny days is 8.7 °C higher than the ambient temperature. Regardless of whether the ambient temperature is high or low, the room temperature rises with increased radiation. In winter, sunny days rely on solar heat for heating, which dramatically improves the indoor thermal environment.

System debugging and results

Debug the tracking device for solar thermal power generation. Use a compass to adjust the tracking device so that the rotary shaft that drives the groove surface to rotate is in the north-south direction. Use a level gauge to change the upper surface of the bearing seat supporting the rotary shaft to a horizontal position. After debugging the tracking device, carrying out the Sun tracking experiment, and using the compiled PLC program to control the motor to run according to a certain law, the groove profile can track the Sun's position. Figure 5 is a physical diagram of the experimental device.

Figure 5. Physical image of the experimental device

After the design is completed, testing and debugging under a variety of environments are also carried out. During the debugging process, the upper computer is used to receive the data transmitted by the inclinometer, and the data is compared and analyzed. Error compensation is performed based on a large number of analyses to improve the system performance.

On October 11th, 2019, the Sun's azimuth angle was tested using the tracking system at (126.63° longitude, 45.75° latitude). The specific test results can be transmitted through the inclinometer and directly displayed in the host computer. The content involved here is fig. 4. By analyzing the test results, it is verified that the control error of the platform is ±0.13°, and the tracking error is ±1°. According to the error law of the data obtained from multiple experiments, the system is compensated for the error. The content involved here is fig. 5. A simple program compensation method is to cancel –0.5° per hour before 10 o'clock and 0.5° per hour after 10 o'clock. After error compensation, MATLAB is used for data analysis. Figure 4 shows the relationship between the experimental value and the theoretical value calculated by the Sun position tracking formula. It can be seen that the tracking error of the platform is ±0.5°, indicating that the solar thermal power generation monitoring the control system can accurately track the Sun's position. The content involved here, fig. 6, shows the relationship between the experimental value and the PLC control output value. It can be seen that the error between the two is less than ±0.2°, indicating that the control system can accurately control the movement of the tracking device. It is shown in fig. 7.

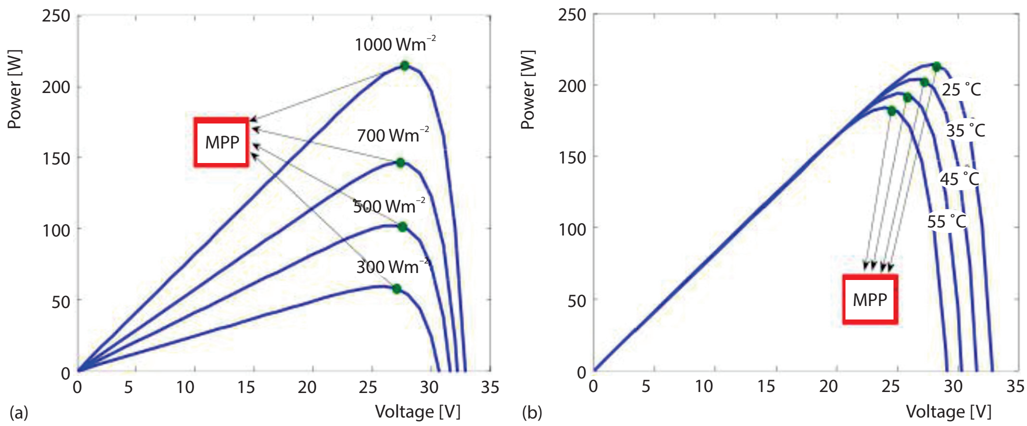

Figure 6. Experimental value-theoretical value

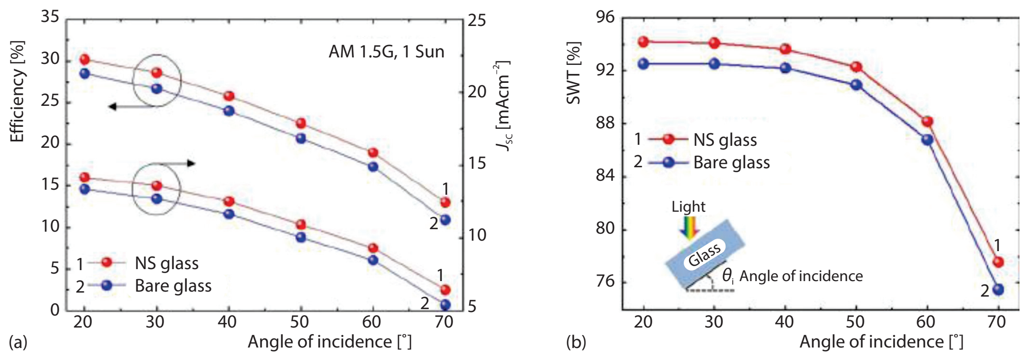

Figure 7. Experimental value-control value

Conclusion

The solar heating automatic control system can monitor the light intensity and the temperature of each part of the heating system and start the active operation temperature difference cycle function and automatic tracking function at the right time. It can set the operating parameters and operating status as required. The automatic tracking control uses the cycle to compare the solar radiation intensity value, making the computerized tracking system highly accurate and reliable. It can track the maximum solar radiation in real-time during the sunny day detection process. It can automatically reset to the initial position when cloudy, or the solar radiation is weak and stops the tracking operation improve the energy efficiency ratio of the system operation. The system can generally work even when the weather changes are more complicated. The heat collection efficiency of the system in active operation is increased by more than 30% than in passive process, which effectively improves the utilization efficiency of solar energy.

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