A REVIEW OF AIMING STRATEGIES FOR CENTRAL RECEIVERS

Annemarie Grobler[1] and Paul Gauché[2]

[1] MEng Research Candidate, Mechanical and Mechatronic Engineering Department, Stellenbosch University. Address: Private Bag X1 Matieland 7602, Stellenbosch, South Africa. Phone: +27 (0)76 816 8916, E-Mail: 17667291@sun.ac.za

[2] Snr. Research Engineer and Director at the Solar Thermal Energy Research Group (STERG). E-Mail: paulgauche@sun.ac.za

Abstract

A review was performed on published experimental and commercial aiming strategies. Focus was placed on experimental and external receivers since a lack of publications exist on aiming strategies for commercial and cavity receivers. Aiming strategies on cylindrical and flat plate receivers were evaluated and compared. The review showed that aiming strategies for cylindrical receivers are mostly based on the vertical placement of aim points whereas flat plate receivers make use of 2D positioning of aim points. It was also found that mass flow rate manipulation can be used together with aiming strategies in order to optimise the efficiency of volumetric receivers. There is a great need for further development in aiming strategies as concentrated solar power tower technology becomes more advanced.

Keywords: Aiming strategy, optimisation, central receiver, heliostat, flux distribution.

1. Introduction

As the commercialisation of concentrated solar power towers becomes a reality, advancements in this field are necessary in order to keep lowering the costs and raising the efficiency of central receiver plants. The purpose of central receivers is to intercept the solar light concentrated by the heliostat field. Thousands of heliostats are arranged around a central receiver tower in different geometries and aim solar light at the receiver aperture.

Aiming all heliostats at a single aim point on the receiver creates a Gaussian-like flux distribution with a very high flux density at the centre of the aperture [1] (Figure 1). Thermal gradients and high temperatures exist on the receiver due to the uneven distribution of flux and can lead to deterioration of the receiver and lower the receiver thermal efficiency and lifetime [2].

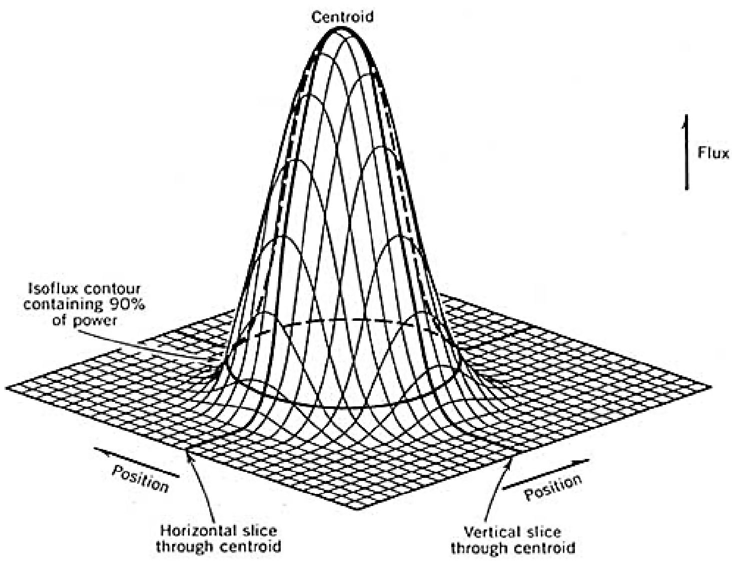

Figure 1: Flux distribution for a heliostat field with a single aim point in the centre of the receiver [3]

Aiming strategies are introduced to distribute flux more evenly on the receiver while obtaining maximum power within the temperature and flux limitations [1]. Various receiver designs exist each with distinctive limitations. Aiming strategies differ for each receiver due to the receiver geometry and heliostat field design.

This review paper gives an overview of the aiming strategies used mainly by cylindrical and flat plate external receivers. A summary of the reviewed aiming strategies is also provided.

2. Aiming Strategies

The purpose of aiming strategies is to have good receiver reliability and durability while keeping costs low and efficiency high [4]. A single point aiming strategy involves computing the sun vector and determining how the individual heliostats should move in order to reflect the concentrated solar light of each heliostat onto the centre of the receiver. This strategy does however have the possibility of causing an overheating of the receiver components. It can also produce stresses due to thermal gradients which cause elastic and plastic deformation and lower the life of the receiver materials [5].

As cost is a major issue with concentrated solar power systems, the size of the receiver should be kept to a minimum. This could be done by increasing the amount of flux intercepted by the receiver [4]. Aiming strategies will allow the reduction of the receiver size while obtaining an appropriate amount of total flux on the receiver without overheating the receiver components.

Several aiming strategies have been developed, tested and implemented. The following sections focus on various aiming strategies and the corresponding receivers they pertain to.

2.1. Abengoa Solar and Gemasolar: Flux Distribution on Vertical Plates

In a study done by Abengoa Solar evaluating six different central receiver plant designs, a simple flux distribution profile was introduced. The receiver design consisted of 24 panels of tubes arranged in a cylinder and made use of parallel flow of the heat transfer fluid. An even flux profile is created on the central 75 percent of each panel (Figure 2) [6]. The aim points of each heliostat initially associated with a specific panel is moved vertically up or down the panel until the desired flux distribution is created.

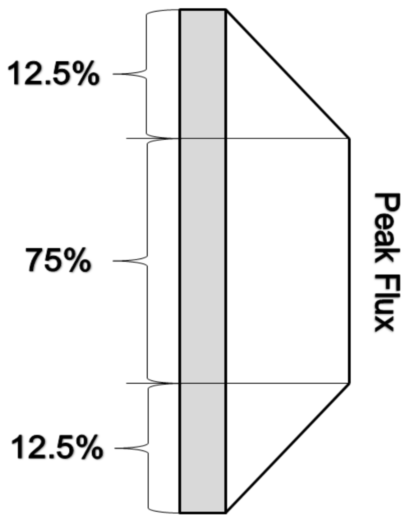

Figure 2: Side view of panel with flux profile

The distance method can be used to determine the position of an aim point of a heliostat along the vertical axis. The position of the aim point is directly related to the distance between the heliostat and the tower base. In this method closest heliostats are aimed at the lower aim points while furthest heliostats aim at the top aim points [7]. This method is implemented at Gemasolar; the first commercial sized solar tower technology using molten salt storage [7] [8].

A similar method as the distance method uses the standard deviation of the flux distribution as reference. In this method the heliostats with small images aim at the lower and upper aim points while heliostats with larger images aim at the central aim points. The deviation strategy is better than the distance method since it lowers peak flux as well as temperature gradients [7].

2.2. Solar Two: Static and Dynamic Aim Processing Systems

The receiver of the experimental plant, Solar Two, comprised of 24 panels with 32 tubes each, configured as an external cylinder [9]. Flux on the receiver was controlled by two software systems. The static aim processing system determined the initial aim point for each heliostat according to the orientation and errors related to the respective heliostat. The dynamic aim processing system estimated the flux density on the receiver aperture for 21 nodes on each panel. When the flux of a node surpassed the allowable flux density, the heliostat aimed at the node responsible for the high flux density was removed from operation [10].

As this process is considered an open loop control system, various errors occurred during operation. The existence of these problems produced a need for the development of automatic closed loop control systems [10].

2.3. Plataforma Solar de Almería (PSA) CESA-1 Plant: Temperature Optimisation

A closed loop automated system was developed by García-Martín et al for the open cycle volumetric receiver at the PSA solar plant. Thin wire packages in the form of hexagonal cells make up the profile of the receiver (Figure 3).

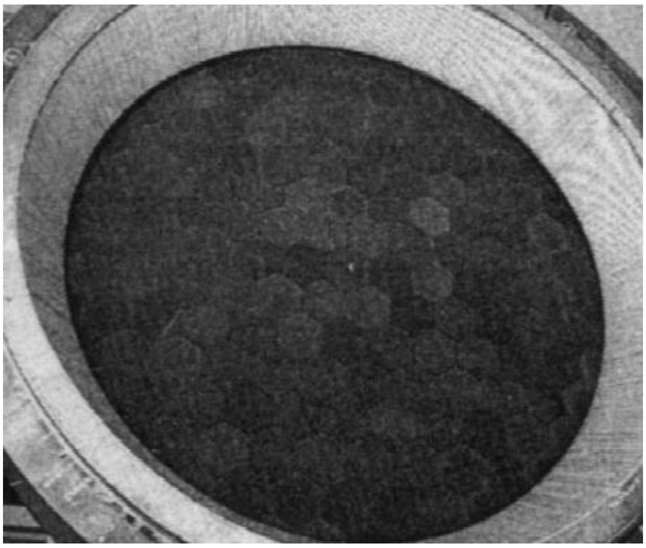

Figure 3: PSA receiver profile [10]

Biggs and Vittoe determined that only five aim points were necessary in this aiming strategy in order to optimise the flux distribution [11]. Therefore, the PSA aiming strategy utilises five aim points (aim point 6 in the centre and aim points 1-4 around the centre) located on the receiver and four standby points located off the receiver as illustrated in Figure 4.

The standby points are used to aim the heliostats away from the receiver before aiming at aim points, after defocusing and during emergencies. Initially each heliostat is assigned to one of the five aim points in such a manner as to distribute the irradiance more evenly over the receiver aperture [10]. An optimisation code called HELIOS is used to determine the initial aim points for each heliostat [12].

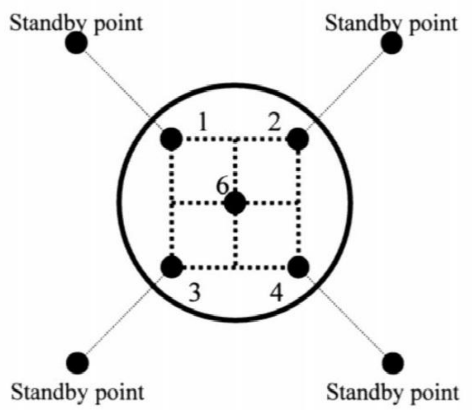

Figure 4: The receiver aim point and standby point positions [10]

To optimise the flux distribution during operation a temperature dependant system is put in place. Four thermocouples measure the temperature of the receiver surface, while another 36 thermocouples are placed at the back of the absorber to determine the temperature of the air at the specific points [10].

The temperature measurements are grouped into 5 zones with an aim point in each zone and the average temperatures for these zones are determined. The first part of the control process searches for aim points where the difference between the average temperature of a specific aim point and the rest of the aim points are beyond the set limitations. Some of the heliostats aimed at an aim point with an eccentrically high average temperature are then moved to another aim point with a lower temperature than average until the temperature between them is balanced. The second part of the control process allows the movement of aim points to raise the temperature of a cooler zone or to lower the temperature of a hotter zone [10].

The objective of this real-time system is to keep the difference between the maximum and minimum temperatures less than 100 ºC as proposed by the receiver manufacturer (L&C Steinmüller) [10].

2.4. THEMIS Solar Tower: Control of Flux Distribution

The method described in section 2.3 makes use of real time temperatures in order to manipulate the temperatures on the receiver. However, it does not optimise the flux distribution on the receiver aperture. An open loop control process which requires no temperature or flux measurements has been developed by Salomé et al. and was validated using the THEMIS research platform in Targasonne, France. The main purpose of this method is to uniformly distribute the flux density on flat plate receivers within the limits of the system [2].

This method uses the HFCAL model for estimating the flux density distribution of each heliostat in the field [13]. Aiming points are pre-defined according to the dimensions of the receiver and the heliostats are initially assigned an aim point each. The TABU meta-heuristic algorithm is used in conjunction with the maximum receiver efficiency as main criteria, to optimise the flux distribution over the aperture by reallocation of aim points to heliostats. This process works by arbitrarily moving a pair of heliostats to a different aim point and comparing the flux profile until the best profile is found [2].

An additional development in this process is the means by which aim points are chosen for specific heliostats. Heliostats producing a large image on the aperture are favoured to aim at the central aim points to reduce spillage, while heliostats producing small images are aimed at the outer aim points [2].

2.5. Jülich Solar Tower Test and Research Plant: Ant Colony Optimisation

An optimisation method for implementation and testing at the Jülich solar tower test and research plant was developed using the ant colony optimisation algorithm introduced by Dorigo [14]. The optimisation method is similar to that developed by Salomé et al., but uses STRAL ray-tracing software [15] instead of flux estimation. The optimization criterion for this method is to maximize the receiver output instead of the efficiency. Therefore, a thermal model is developed to aid in this form of optimisation [1].

Ant colony optimisation uses the natural behaviour of ants in order to determine the optimal aim point for each heliostat [14] [16]. When a good resource in found, the ants will excrete pheromones to guide other ants to the resource. Ants will follow the highest concentration of pheromones in order to find the resource. However, when the resource is close by the ants will rely on their myopic optical perception. The same logic could be applied to heliostats. Each heliostat and aim point combination has its own concentration of pheromones proportionate to the receiver power (quality value). The higher the receiver power when a heliostat is aiming at a specific aim point, the most likely that heliostat will choose to aim at that aim point in the future. If the temperature or flux limits are exceeded the quality value is reset to the upper or lower bound value. This method results in shorter computational time for each iteration since the heliostats have a better chance of finding the optimum solution [1] (Figure 5).

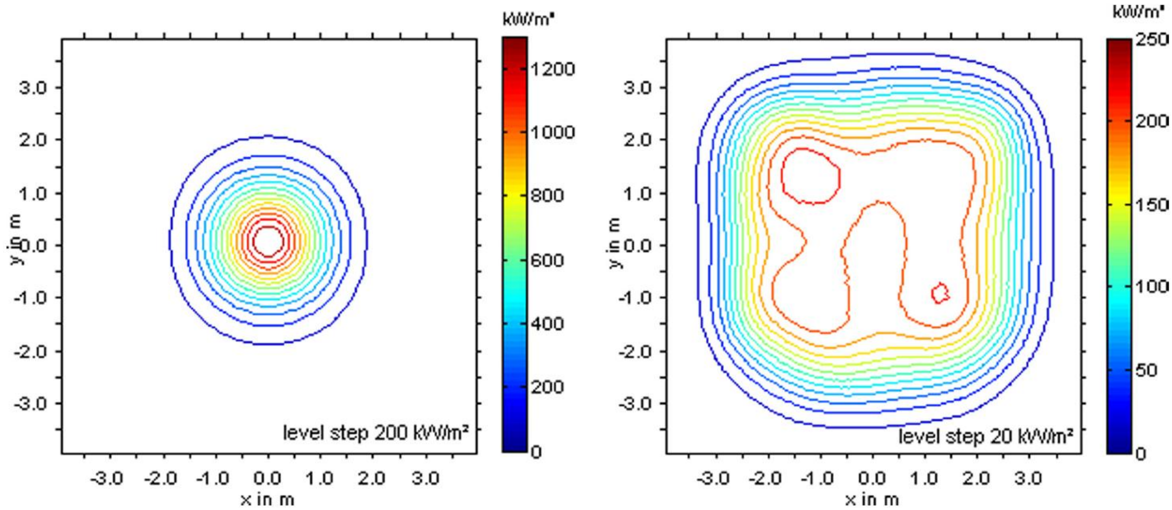

Figure 5: Single aim point flux distribution (left) compared to multiple aim point flux distribution using ant colony optimisation (right) [1]

2.6. Combination of aim point and thermodynamic optimization

Specifically pertaining to open volumetric receivers, this optimisation method does not only make use of aiming strategies, but of mass flow manipulation as well. After the optimal flux distribution is found through genetic algorithms, such as the above mentioned ant colony optimisation, the maximum mass flow rate is determined for an outlet temperature as required by the storage or generation system. After the calculation of the optimal mass flow rate, the aiming strategy is run again considering the new mass flow rate (Figure 6) [17].

The purpose of this optimisation is to make use of the available power in the most optimal way possible during receiver operation [17].

2.7. BrightSource's Ivanpah solar thermal power plant: Heliostat field management

This 377 MW central receiver power plant, to be completed in December 2013, will be the largest plant of its kind in the world [18]. This plant consists of three units, each with its own tower and heliostat field. Ivanpah makes use of the BrightSource developed SFINCS (Solar field integrated control) system as a method of heliostat field management. Optimisation of heliostat aim points are done by means of a closed-loop control system. Weather measurements in conjunction with cameras are used to provide references by which advanced algorithms can optimise the heliostat aim points in real-time [19]. The control system is proprietary and no further published information is known about this system.

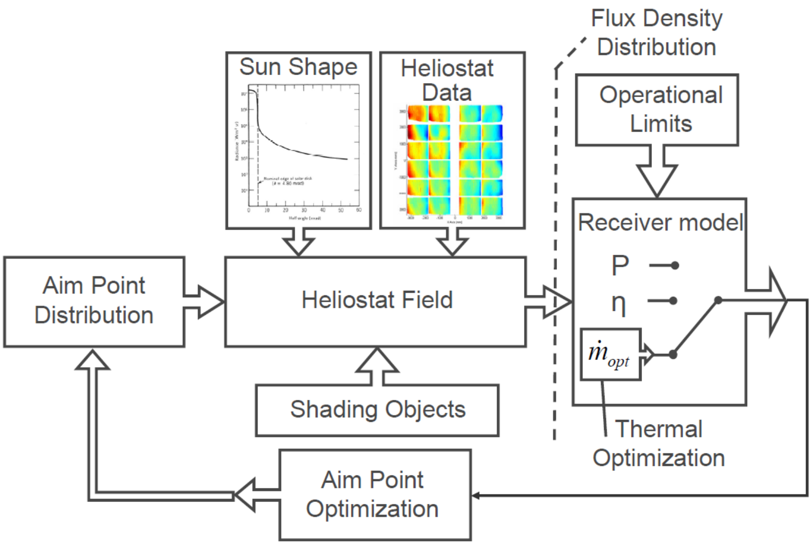

Figure 6: The combined optimization strategy [17]

3. Summary

The following table summarizes the reviewed aiming strategies and their functions.

Table 1: Summary of aiming strategies and their functions

Aiming Strategy	Function	Experimental/ Commercial	Receiver Type/s	Ref
Abengoa Solar	Distribute flux evenly over central 75% of plate	Experimental	Tubular external cylinder	[6]
GemaSolar	Lower peak flux and temperature gradients	Commercial	Tubular external cylinder	[8]
Solar Two	Remove heliostats causing flux density to surpass limit	Experimental	Tubular external cylinder	[10]
Plataforma Solar de Almería	Keep temperature between the allowable limits	Experimental	Flat plate volumetric	[10]
THEMIS	Real-time flux distribution optimisation through flux estimation and TABU meta-heuristic algorithm	Experimental	Flat plate tubular/volumetric	[2]
Jülich	Real-time flux distribution through ray-tracing and ant colony optimisation	Experimental	Flat plate tubular/volumetric	[1]
Combined strategy	Flux distribution and mass flow rate optimisation	Experimental	Volumetric	[17]
Ivanpah	Flux and temperature optimisation through weather measurements and visual and infra-red photography	Commercial	Tubular external flat	[19]

4. Conclusion

A review was done of all published work on aiming strategies. Since the simple vertical aiming strategy method there has been many new developments. It was found that cylindrical receivers were most likely to use the vertical aim point distribution whereas flat plate receivers used 2D aim point distribution. These aiming strategies were found to have different purposes. Some were used to evaluate the surface temperature or flux, while others were used to evaluate the output temperature of the heat transfer fluid. Combining aiming strategies with mass flow rate control was found to be a good strategy for volumetric receivers. The review determined that there exists a lack of published information on the aiming strategies used in commercial plants and cavity receivers. Due to the novelty of aiming strategies, numerous opportunities for research in this field are created. In order to research and develop aiming strategies, an understanding of all other components of the concentration and collection system is necessary. Even though aiming strategies could become very complex, advancements in this field will lead to many benefits for solar towers at a low expense.

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