FOCAL LENGTH AND FIELD OPTIMISATION FOR TORIODAL HELIOSTATS IN HIGH ACCURACY SOLAR CONCENTRATORS

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A toroidal heliostat including mount and tracking system has been engineered for cheap large scale production. The heliostats are supported by a toolbox of complex simulation and optimisation interfaces used for the implementation of the heliostats in solar concentrator fields. The interfaces are required for optimisation of the heliostat focal lengths right through to generation and simulation of full solar fields for any given set of thermal receiver parameters. Full heliostat field simulation results have shown that toroidal heliostats perform significantly better than spherical heliostats, and empirical relationships have been developed to help the rapid identification of optimal field, heliostat and aperture configurations.

1. Toroidal Heliostats for High Accuracy Solar Concentrators

Heliostats are generally the most expensive component of a solar concentrator installation. This makes the development of an efficient and cost effective solution heliostat an important step towards the implementation of solar thermal energy production on a large scale. It has long been demonstrated that the effects of astigmatism off reflective surfaces can be minimised for extended periods of time during the day by using non-imaging optics [1]. Growing interest in the field has seen the development of the toroidal heliostat using a spinning elevation tracking method, and its application for high accuracy concentration of solar radiation in a number of different fields [2]. We have built upon these techniques to produce a highly adaptable toroidal heliostat for easy implementation in high accuracy solar concentrator fields.

A Toroidal heliostat has been designed from the ground up to be robust and economical for large scale production. The product has been modularised to allow quick and easy assembly onsite, with all necessary calibrations of encoders and actuators made in the factory. The mechanisms for tracking the sun have been developed to give any heliostat the capability of tracking the sun from sunrise to sunset for any position in a solar field, without modifications to the design.

2. Optimisation of Toroidal Heliostat Focal Lengths

Toroidal heliostats are different to spherical heliostats because they have different focal lengths for different axes of the heliostat surface (tangential and sagittal directions). The ability to optimise these focal lengths separately is the key to what makes a toroidal heliostat more effective than a spherical heliostat. It also means that toroidal heliostats cannot be simply deployed in a solar concentrator installation with assumptions for example that the radius of curvature should be just twice the distance to the receiver. To achieve the high concentration of light from a toroidal heliostat over the course of a day, the focal lengths must be optimised. To meet these requirements, a reliable simulation and optimisation code has been developed to make sure that the focal lengths are such that power collected from the field is maximised over the course of the year.

An optimisation of the tangential and sagittal focal lengths of a random toroidal heliostat has been approached by simulating the concentrated beam from the heliostat and calculating the affects of astigmatism throughout the day. By then taking into account the receiver height, aperture diameter, angle and the depth of the aperture shield, it is possible to create a collection / spillage criteria according to the apparent aperture at the position of the heliostat. These criteria are then used to calculate the power collected from the heliostat per day, and optimisation is achieved by selecting the combination of sagittal and tangential focal lengths that cause the least beam spillage on average. The flexibility of the toroidal heliostat focal lengths means that the shape of the beam can actually be tailored to best match any irregular aperture shape. For example, in positions in the field where the angle to the receiver is highly oblique, and the depth of the shield further reduces the aperture entry, the focal lengths can be tailored to best suit the apparent aperture.

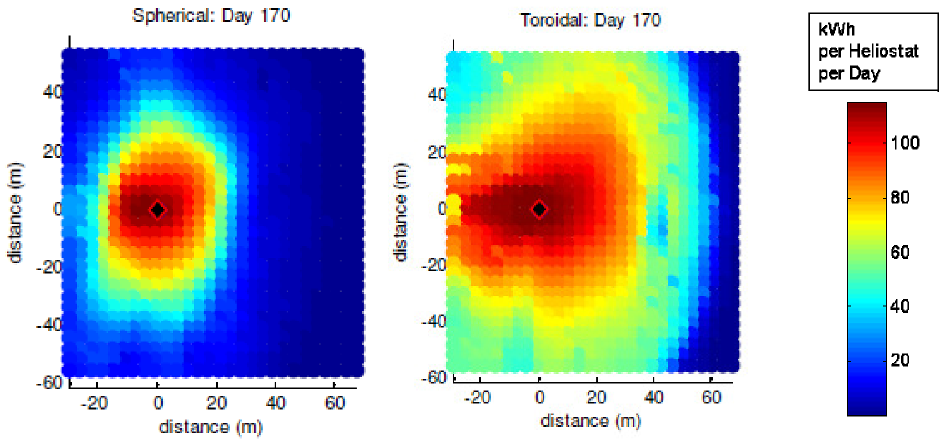

Fig. 1. Results from Simulation showing the performance of spherical and toroidal heliostats as a function of position in a solar field. The aperture (the black diamond) is situated 18m above the heliostat centres.

3. Toroidal Heliostat Field Layouts; Generation and Simulation

The focal length optimisation routines have been built upon to create a simulation environment for designing and testing full field layouts. The extension has required the design of efficient algorithms for checking the shading and blocking for any configuration of heliostats, receiver and sun. Optimised focal length contours are used to create rows of heliostats of similar properties for the simplification of manufacturing. Rows of heliostats are sequentially created and tested for collisions and for blocking and a technique called radial offset optimisation, where starting point of each row is tested in order to obtain a configuration with the most 'staggered' heliostats. Finally, the complete field can be simulated using full calculations for shading and blocking for all times of the day, and measuring the total power collected.

As the number of fields that have been simulated increase, empirical relationships are being developed between the total number of heliostat required in a field (and their dimensions), the total collected power, and the receiver aperture parameters. This is extremely useful as it allows optimised fields to be quickly selected for any power generation requirement. An example is shown in Figure 2. where fields of different sizes of heliostat have been simulated for a northern latitude. For a given power requirement, the number of heliostats required their size and the aperture diameter can be calculated by solving two simple simultaneous equations.

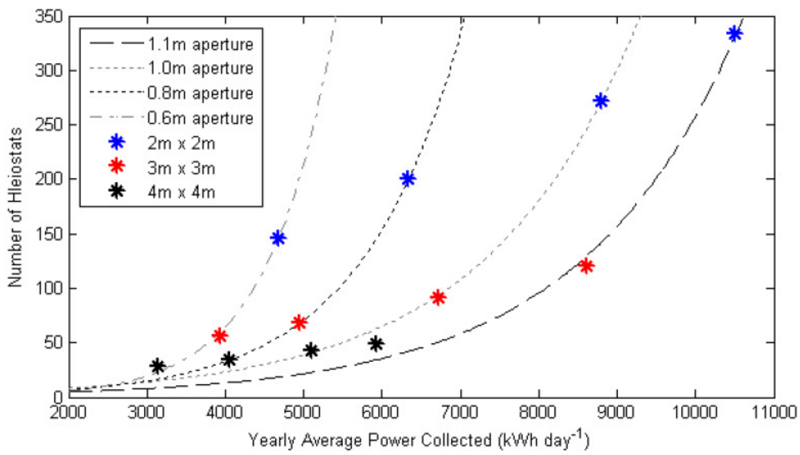

Fig.2. Number of toroidal heliostats in solar field required per Yearly Average Power Collection. Fields from different size heliostats are shown as different colour stars showing linear dependency with Power Collection. Approximate lines of constant aperture diameter are shown and are of exponential form.

4. References

[1] Igel EA, Hughes RL,. 1979, Solar Energy, Vol. 22, pp. 283 - 295.

[2] Chen YT, Chong KK, et al,. 3, 2001, Solar Energy , Vol. 71, pp. 155 - 164