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A NOVEL HELIOSTAT FIELD CONCEPT FOR SOLAR THERMAL CONCENTRATING SYSTEMS

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Abstract

A new heliostat field concept "cross beam" is proposed for an effective utilization of solar field with minimum number of heliostats. Assuming one dimensional heliostat field with a given length, the amount of the solar energy collected by dual central towers has been calculated by continuum optical modeling. As a result 48% more energy is collected with 18% reduction of specific energy cost. It is also shown that with two kind of heliostats the novel heliostat field "cross beam" concept may be effectively realized.

Keywords: Heliostat field, blocking, plural towers, cross beam, mixed heliostat field

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Introduction

A large scale central tower system requires a circular solar field with a radius in proportion to a specified solar energy while solar trough or photovoltaic cell to its square root. This results from "blocking" of the beam reflected by the heliostat and thus may make the scale-up of the system necessitate larger area. To reduce this defect, multi-tower array concept was proposed[1] that distributes multiple towers in heliostat field in which heliostats directs beam to the nearest tower. In this concept, however, further improvement remains to be made in view of economy. In the present paper, optimal heliostat array is investigated to mitigate "blocking" and increase field efficiency with minimum number of heliostats.

Nomenclature

A : surface area of a heliostat (m^2)
C : merit(Eq.(1))(-)
E : solar energy collected(kW)
H : tower height (m)
i : sun beam incidence angle to a heliostat (rad)
L : length of shadow / blocking length (m)
l : field length (m)
N : total number of heliostat (-)
n : number of heliostats per unit field length (m^{-1})

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r : blocking length(m)
s : cosine factor(= $cos(i)$)
x : location of heliostat , shadow length(m)

Suffices
1: heliostat of the first kind
2: heliostat of the second kind
b: blocking
max: total solar energy

Greek letter
α : portion of heliostat cost(-)
ρ : solar energy collected(kW)
φ : altitude of the sun (rad)
η_f : field efficiency (Eq.(2))(-)

Characteristics and performance of cross beam heliostat array
Optical characteristics of a single tower system

Heliostat array design requires consideration of "blocking" appearing in a large scale central tower system. Figure 1. shows contour lines of blocking length in a central tower system in west half area of the field with 120m tall tower and heliostats 8m in diameter. It is seen there is longer blocking length in the area north to the tower.

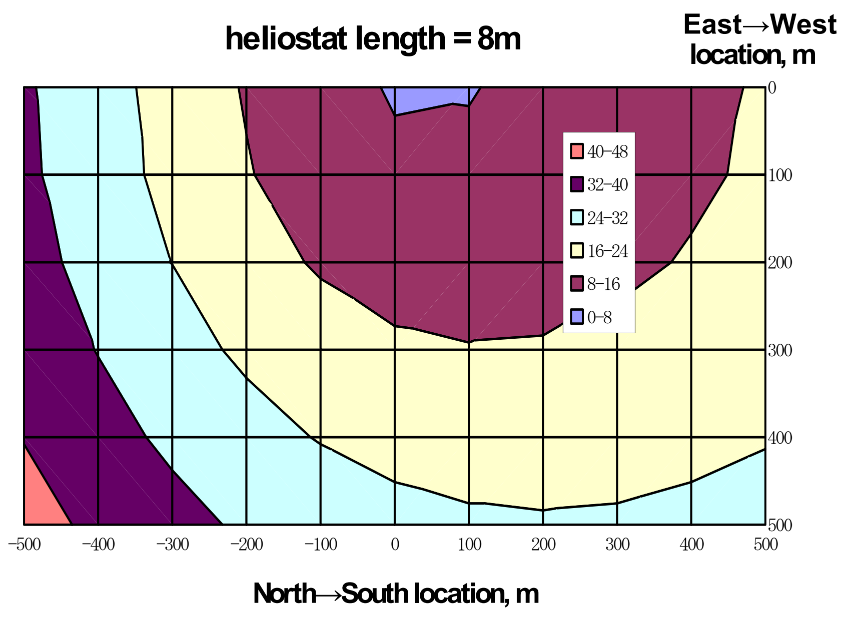

Figure 1. Two dimensional profile of blocking length

Optical characteristics of a single tower are analyzed. Figure 2 shows distribution of energy density and heliostat number density along direction with the sun and a tower in line. Black solid line shows energy collected by a single heliostat $A \times cos(i)$, blue solid maximum possible heliostat number per field length in case of no optical interference (shadowing and blocking) n and red solid energy collected per unit field length $A \times cos(i) \times n$. Clearly, a heliostat positioned north (in the north hemisphere) to the tower collects energy more than one positioned in south to the tower. It is interesting to note red solid is symmetric around the central tower.

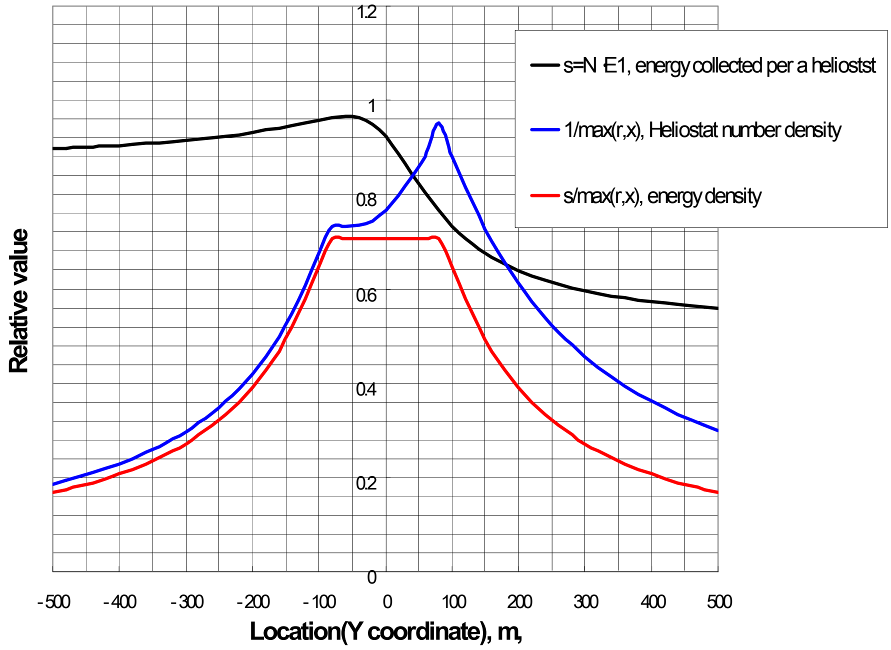

Figure 2. Energy and heliostat number densities along direction with the sun and tower in line

Optimal heliostat array concept

To obtain an optimal layout in the present problem the object function C to be maximized is

$$C = \frac{\eta_f}{N} \qquad (1)$$

where

$$\eta_f \equiv \frac{\rho}{\rho_{\max}} = \frac{\int_0^l cos(i)n(x)dx}{lsin(\varphi)} \qquad (2)$$

$$N = \int_0^l n(x)dx \qquad (3)$$

Here, $lsin(\varphi)$ expresses a total solar energy on a given field where heliostats are distributed. Then, strategic layout to maximize C using two towers is as follows: first to distribute heliostats of the first kind which redirect beam to the first tower as dense as possible and third to add heliostats of the second kind in bright space among heliostats of the first kind so that the beam be redirected to the second tower placed on the north side of the field.

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To mitigate influence of "blocking" and increase field efficiency with minimum number of heliostats, new heliostat array concept "cross beam" is proposed.

Figure 3 shows how solar field required could be made narrower by use of "cross beam" concept. Incorporating plural towers and two types of heliostats, what is called T-bone type redirecting ray to the first tower and the second one shorter than the T-bone to the second tower located north to the first tower in north hemisphere would collect the rest of the solar energy uncollected by a single tower. Figure 4 illustrates two kinds of heliostats. Heliostats of the second kind (black) featured in being short[2], would be placed on a shining ground in between the T-bone heliostats (red). Then reflected beams by mixed heliostat field would cross in the air and show no optical interference.

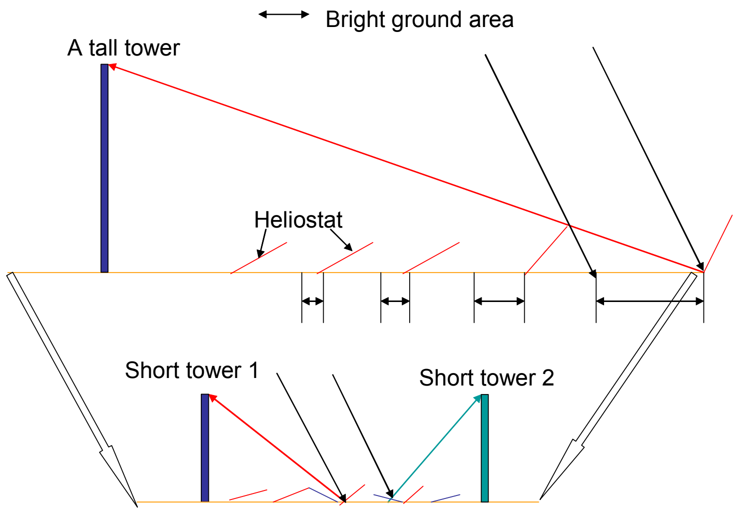

Figure 3. Cross beam heliostat array concept

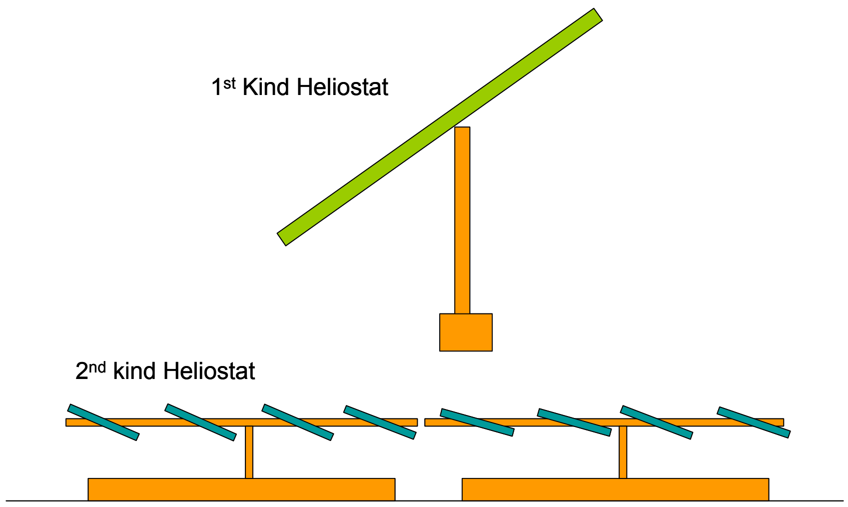

Figure 4. Two kinds of heliostat

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The present concept is different from multi-tower solar array proposed by Schramek and Mills[1] where beam from heliostat is redirected to the nearest tower to the heliostat. Using continuum optical model, an optimum layout of the cross beam array has been investigated.

Figure 5 illustrates how the second kind can be placed and the maximum number of heliostats implanted ideally. From the figure, it is seen that practically heliostat of the second kind should be shorter than the first kind in order to avoid optical interference and increase field efficiency.

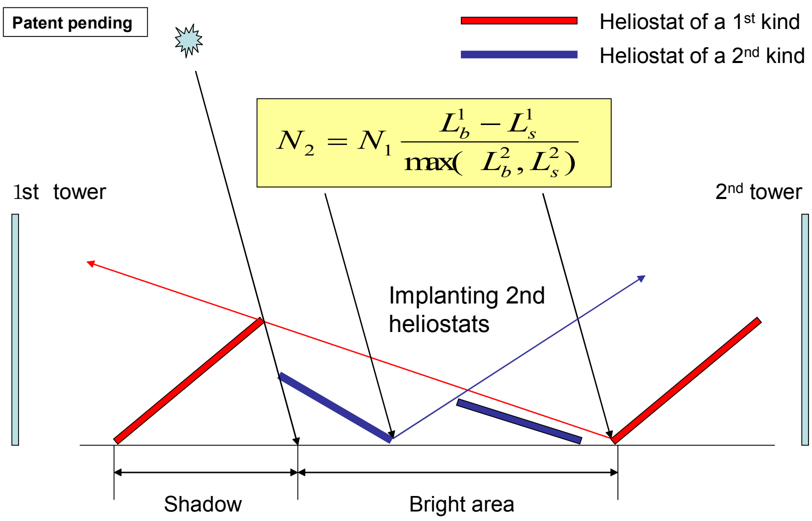

Figure 5. Concept of mixed heliostat field

Results and discussion

Next, optimum location of the two towers has been sought.

Figure 6 compares field efficiency theoretically attainable between single tower and double tower for the field length $l = 480$m and the tower height $H = 60$m with tower location as variable. It is seen that at the optimal location 92% of all the solar energy could be captured in the cross beam concept while a single tower optimized in the same manner could reach 67%. Figure 7 shows the value of C with tower cost included. Assuming the portion of an initial cost of heliostats is 50%, then the optimal C would supreme the case of optimized single tower by 13%. Reference value (zero) shows when a single tower is located at the center of the field. Table 1 shows details.

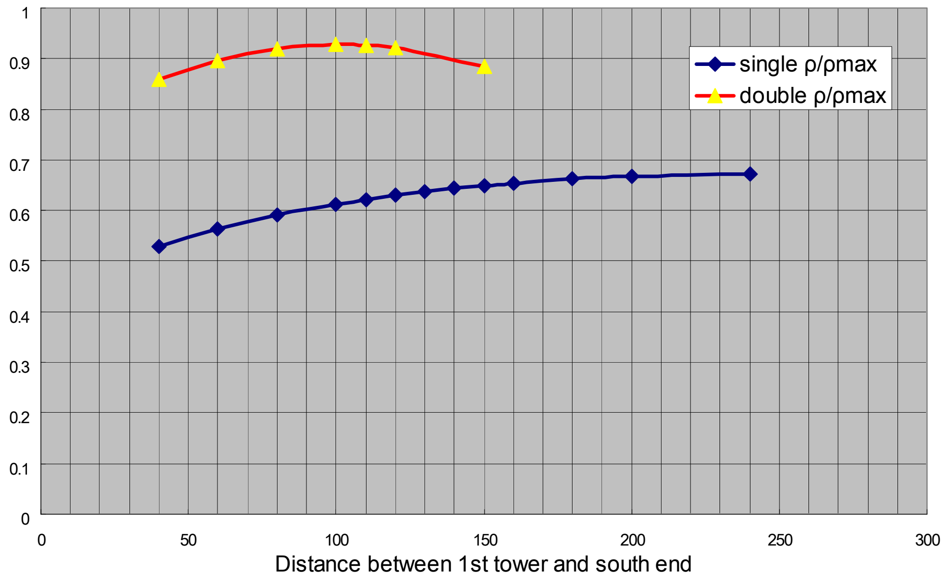

Figure 6. Field efficiency with tower location

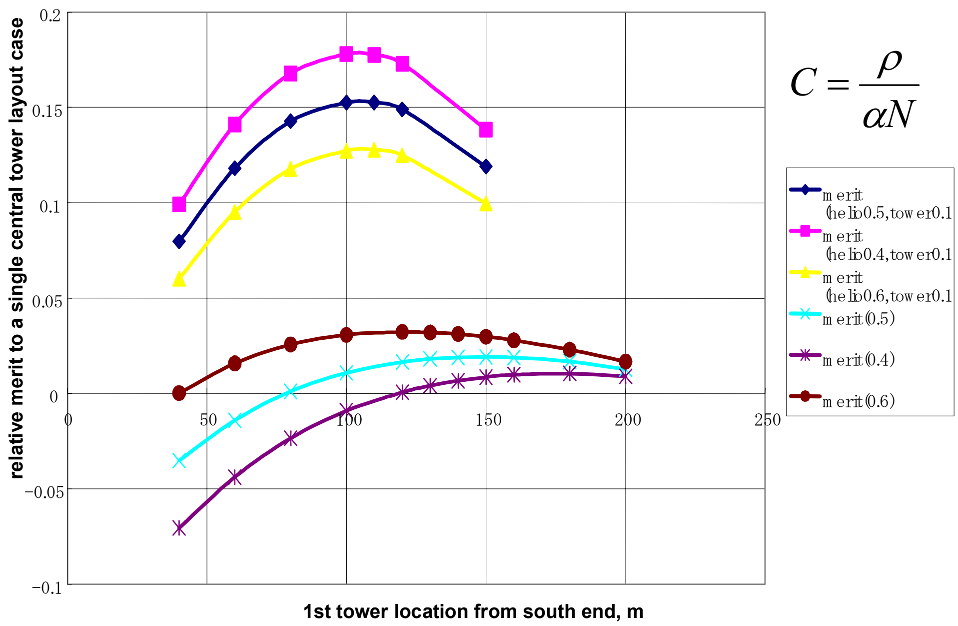

Figure 7. Optimal tower location in terms of economy

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Table 1 Result of merit calculation

	Sun altitude=45deg, Field length=480m, Tower height=60m					
	Helio portion of initial investment α =0.5					
		tower position from South/North end, m	Increased heliostat number N,%	Increased energy collected E,%	Merit C,%	Fraction of energy collected from field, %
Single optimized		150			2	40
double optimized		105	25	38	15.5	92.5
		Energy,%				
1st tower		60				
2nd tower		40				

Note: reference layout, a single central tower at 240m from South

Merit calculation $\frac{\delta C}{C_0} = \frac{\delta E}{E_0} - \alpha \frac{\delta N}{N_0}$

Conclusion

A new heliostat field concept “cross beam” is proposed for an effective utilization of solar field with minimum number of heliostats. Assuming one dimensional heliostat field with a given length, the amount of the solar energy collected by dual central towers was calculated by continuum optical modeling. Results showed that 48% more energy is collected with 18% reduction of specific energy cost. It was also shown that mixed heliostat field with two kind of heliostats could effectively realize the “cross beam” concept.

References

[1] Phillipp Schramek, David R. Mills, 2003,Multi-Tower Solar Array, Solar Energy 75(2003) 249-260

[2] Suzuki, A., et al., 2003, Optimization of a Cassegrainian Tower Concentrator with Innovative Horizontal Heliostats, Journal of Japan Solar Energy Society 29, 41-47.

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