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Large-Scale Production of Heliostats

Determination and Reduction of Fabrication Cost

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Abstract. Heliostats are the main cost factor of solar tower plants. To optimize them in terms of cost, it is mandatory to estimate the fabrication cost. A method to do so is presented and applied to a sample heliostat. The sample heliostat that is optimized for low production cost is of 2 m² size. The design already provides a low part-count, an efficient material usage and low-cost purchased parts but is also of high accuracy. A part list of the heliostat is created and every part is analyzed. For production cost optimization, the optimal manufacturing process both from a technical and an economical view has to be determined. Furthermore, the material cost has to be estimated based on the weight and material of the heliostat components. Also cost for control and energy supply has to be considered. Optimizing their cost depends significantly on unit quantities. Higher volumes generally translate to lower development costs, yet component and manufacturing expenses become predominant. The circuit board design proves to be a central point here. Selecting easily accessible, interchangeable components suited for function and longevity, optimizes component and manufacturing costs.

Keywords: Central Receiver, Concentrator, Heliostat, Manufacturing, Cost

1. Introduction

Solar tower systems are a promising technology for generating renewable electricity and process heat and could make an important contribution to reducing CO_2 emissions. An important advantage of solar thermal systems is the possibility of cost-effective energy storage as heat. With solar thermal systems, the biggest cost factor (about 40% of the investment cost) are the mirrors that track the sun and concentrate the sunlight, the so-called heliostats. DLR has developed a heliostat design of extraordinary low cost [1] which shall be brought to market maturity. A first prototype of 2 m² has been built (Figure 1). The design already provides a low part-count, an efficient material usage and low-cost purchased parts but is also of high accuracy. With the breakdown of the production cost, the heliostat can be further cost optimized.

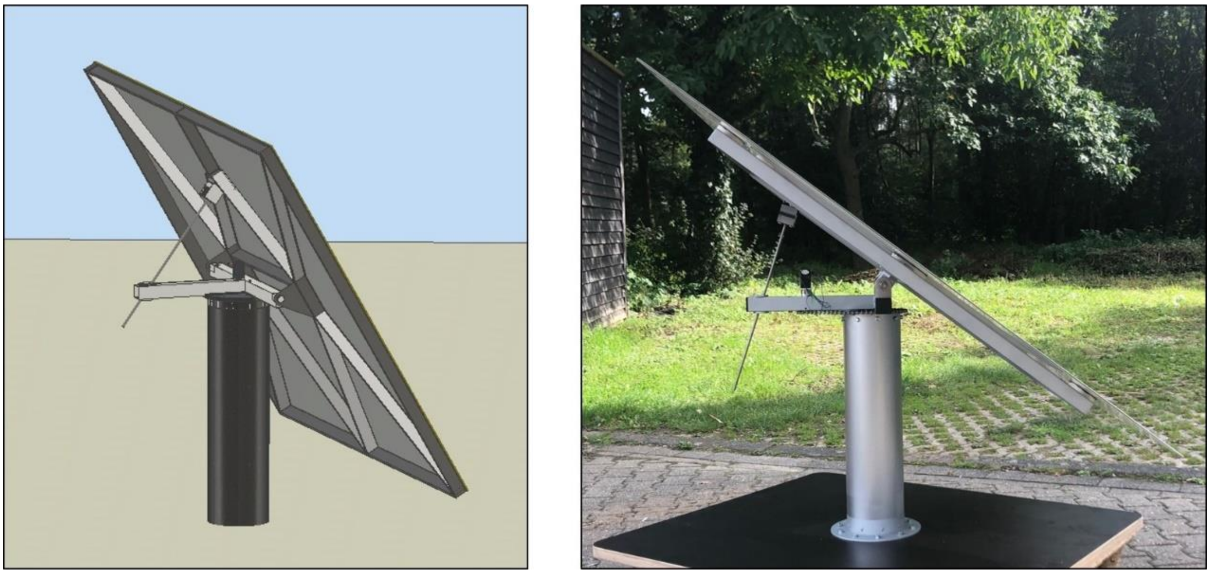

***Figure 1.** Heliostat design, CAD (left) and first prototype (right)*

Fabrication cost is the biggest cost factor. However, after fabrication, the pylon, the tracking device, and the concentrator have to be shipped to the site, assembled and installed (Figure 2). In this paper, only fabrication cost for high-volume production (> 100 000 units) is investigated. Installation of this heliostat is treated in an extra paper [2].

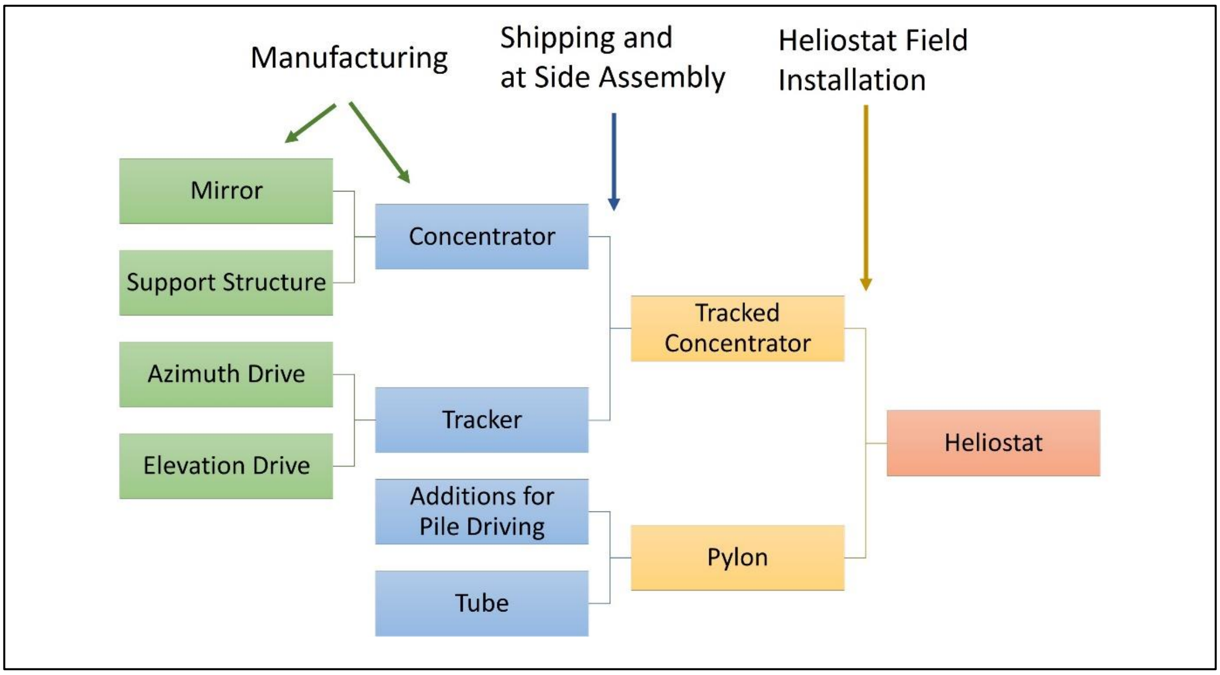

***Figure 2.** Process steps for building heliostat fields*

2. Method

In principle, fabrication cost can be determined by specific costing software. But, many software tools are only affordable for large companies while the lower cost versions are not sufficient to determine the fabrication cost entirely. Simus systems^{TM} offers the low-cost tool costing 24. With it, material cost, manufacturing methods, and machine hourly rates could be determined for part of the components while for the remaining components this information had to be determined by means of literature and internet research. Furthermore, additional cost besides material and machining like joining cannot be considered with this tool and also had to be estimated by other means.

The material costs are calculated using a material price/kg (Table 1) and the weight of the components. By calculating the processing time with the machine hourly rate, the production costs can be calculated. With the production costs added to the material costs, the manufacturing costs are obtained. Thus, the impact of each component on the production process and cost can be analysed in detail and the design can be modified and optimized for lowest cost. Besides the mechanical structure, also the cost of the control unit must be considered.

Table 1. *Material cost/kg*

Material	Cost €/kg or €/m²
Non-alloy pure steel [3]	0.78
Galvanized steel [3]	0.82
Polymers [4]	0.84
4 mm solar mirror	14.00

The manufacturing costs are calculated by adding the material costs and the production costs. Material costs are calculated as direct material costs and material overheads, while production costs are calculated as direct production costs, production overheads and other direct production costs [5]. For highly automated production, machine hours are allocated directly to the cost item as direct production costs using the machine hourly rate calculation. The following costs can be allocated to each machine [6].

1. Imputed depreciation: Imputed depreciation is determined based on the current replacement value (including installation and start-up costs) and the estimated service life.

2. Imputed interest: Imputed interest is usually determined according to the prevailing interest rates for long-term debt. To simplify the calculation and ensure comparability between different periods, the interest is calculated on the basis of half the replacement value of the machine.

3. Occupancy costs: The occupancy costs relate to the space occupied by the machine. These costs include depreciation and interest on buildings and plant, maintenance costs for the building, as well as lighting, heating, insurance and cleaning

4. Energy costs: Energy costs include electricity, gas, water and similar costs.

The machine hourly rate results from the sum of these cost types divided by the utilization time of the machine [6]. As the cost of production does not cover all operating costs, the net cost is also defined. Here, operating overheads and administrative overheads are added to the cost of production [5]. Since for this study all these detailed cost factors are not known, published typical general values are used.

A part list of the heliostat is created and every part is analyzed. For production cost optimization, the optimal manufacturing process both from a technical and an economical view has to be determined. Besides cost, also accuracy and lifetime have to be considered when optimizing the heliostat design.

3. Results

3.1 Mechanics

The components of biggest size are the pylon and the mirror support structure. A thin wall thickness is therefore particularly important for these components. To enable that, a comparably larger diameter for the pylon and a C-profile of comparably large height is chosen. As the most cost-effective manufacturing method for the pylon, roll forming with a subsequent HF-welding process [7] was determined (Figure 3). For the C-profiles, also roll forming [8] shall be used (Figure 4).

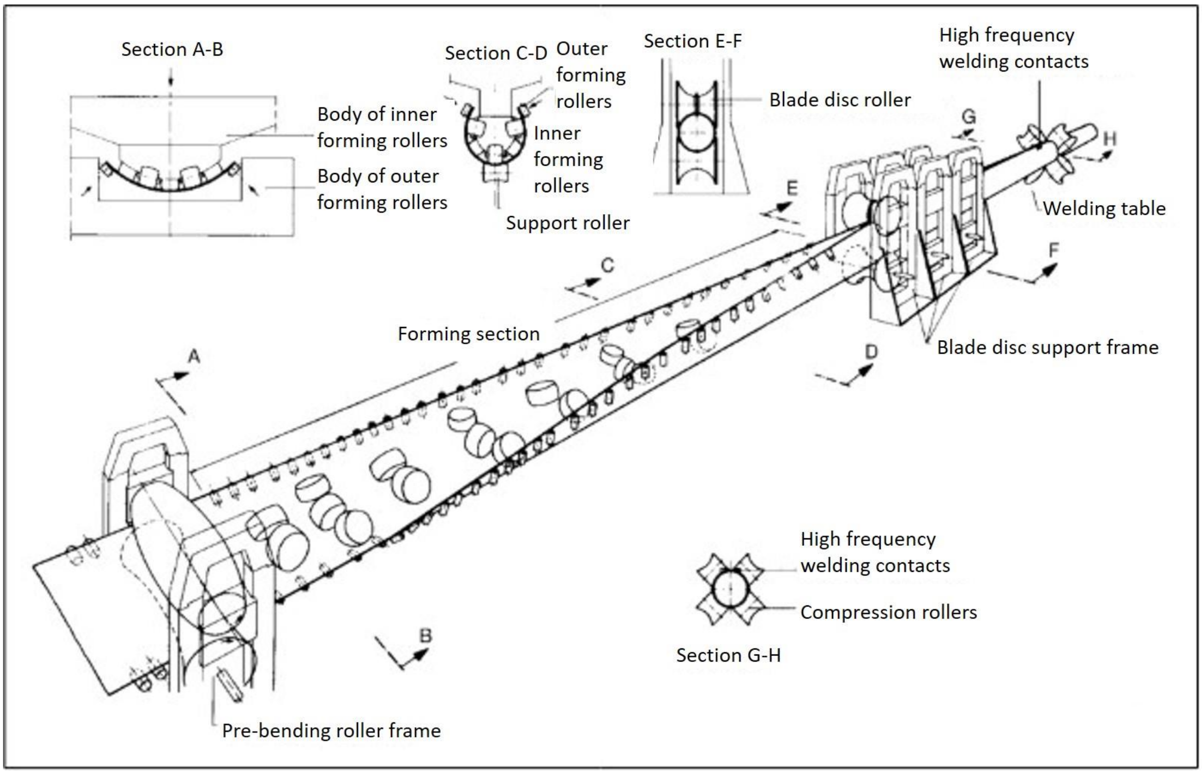

Figure 3. *Roll forming with subsequent high frequency welding process [7] for pylon production*

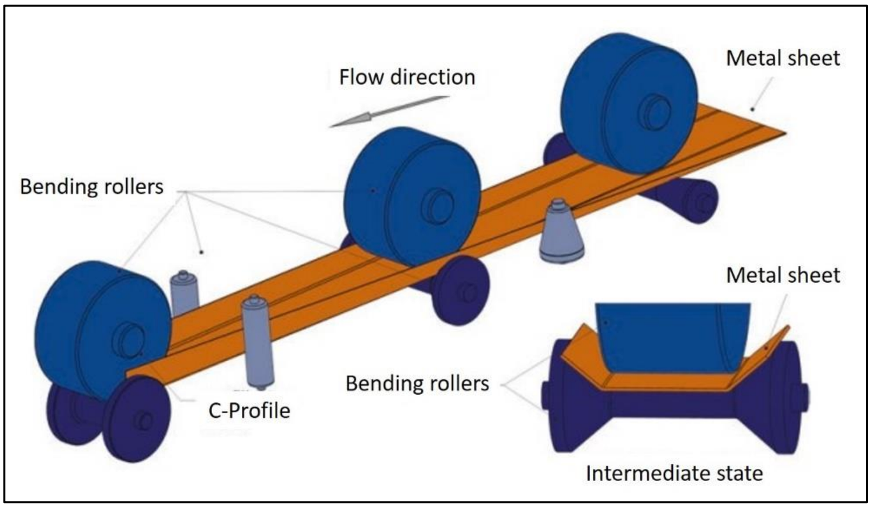

Figure 4. *Roll forming [8] for manufacturing of the C-profiles of the mirror support structure*

Purchased parts were identified by searching suppliers on the Internet. With the favorable production methods found, manufacturing costs of €116/piece or €58/m² could be achieved. This represents an initial cost estimate for the heliostat and comes very close to the cost target. In addition to the manufacturing costs, costs for the energy supply, control, transport and installation have to be considered.

3.2 Energy supply and control

Optimizing the costs of the control unit depends significantly on unit quantities. Higher volumes generally translate to lower development costs, yet component and manufacturing expenses become predominant. The circuit board design proves to be a central point here (Figure 5). Selecting easily accessible, interchangeable components suited for function and longevity, optimizes component and manufacturing costs. Moreover, resizing the circuit board positively impacts manufacturing expenses. Adhering to the KISS principle [9], simplicity is prioritized, enhancing maintainability and robustness while retaining adaptability to changes.

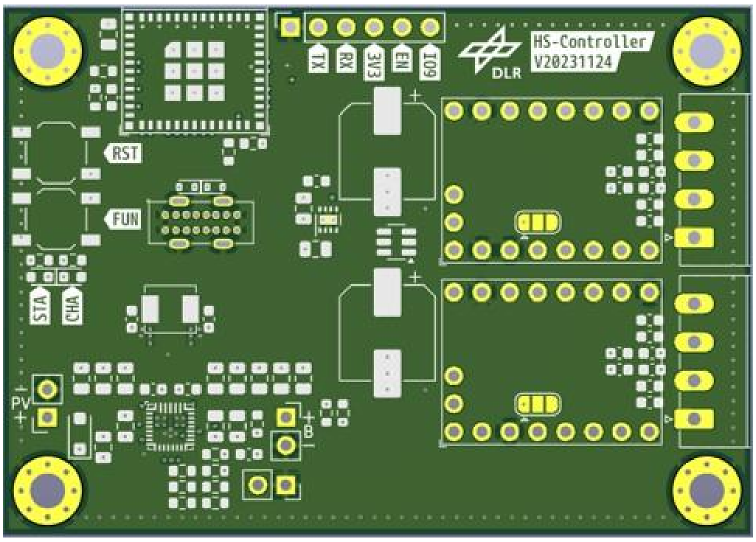

Figure 5. *First circuit board prototype for DLR's heliostat prototype*

In any design process, particularly in control units, trade-offs must be made between performance, cost, and scalability. For instance, adopting advanced energy-saving technologies can enhance system efficiency but may increase initial costs. Conversely, opting for simpler, less expensive components can reduce upfront costs but may lead to higher maintenance or energy consumption costs over the system's lifetime. Conducting a detailed trade-off analysis is essential to optimize both the short-term and long-term costs of the system.

A thorough cost estimation process is essential when designing the control unit, as it directly influences both the initial development budget and the long-term operational expenses. Cost estimation in the context of energy supply and control units involves evaluating both fixed and variable costs. Fixed costs include design, prototyping, and tooling, while variable costs encompass component procurement, manufacturing, assembly, and testing.

Component costs are particularly sensitive to market fluctuations, making it necessary to balance the selection of high-performance components with budget constraints that are readily available. While choosing high-quality, long-lifespan components can increase the initial outlay, this can ultimately result in cost savings by reducing maintenance, downtime, and replacement needs over the system's operational life. Therefore, the cost-benefit analysis must account for both upfront expenditures and long-term savings in areas such as energy efficiency and reduced operational failures.

Moreover, manufacturing scale is a key factor in determining cost. As production volumes increase, unit costs typically decrease due to economies of scale, particularly in printed circuit board (PCB) manufacturing, assembly, and component sourcing. However, it is crucial to optimize the circuit design early on, as redesigns or adjustments to the PCB layout in later stages can incur substantial costs. Techniques such as Design for Manufacturability (DFM) and Design for Assembly (DFA) can help reduce these risks by ensuring that the control unit design is optimized for mass production, minimizing waste and assembly time.

Implementing a modular PCB design can significantly reduce maintenance costs by enabling easy replacement of faulty or worn-out components in the field. By dividing the control unit into removable modules, technicians can quickly swap out specific parts that are prone to wear, such as motor controllers or components subjected to high workloads. This approach not only streamlines repairs, reducing system downtime, but also lowers long-term maintenance costs as only individual modules need replacing rather than the entire control unit. Furthermore, modularity contributes to environmental sustainability by reducing e-waste; instead of discarding whole PCBs, only damaged sections are replaced, extending the lifespan of the overall system.

A modular PCB design also benefits research and development by allowing interchangeable modules to be tested with different designs, such as evaluating various motor drivers or components in the field. By maintaining the same pinout on the main control unit, performance can be easily compared, enabling rapid prototyping and real-world testing without extensive redesign.

Another aspect of cost estimation involves considering the impact of energy efficiency on the overall system. While the integration of more efficient power supplies or advanced power management circuits might elevate the initial component cost, these additions can yield significant savings over time through reduced energy consumption. The balance between upfront investment and long-term operational savings is a crucial part of the total cost of ownership (TCO) analysis.

Our first assembled prototype, built in a small run of five units, incurred costs of around €22 for components, €9 for the PCB and stencil, €18 for a 10W solar panel, and €20 for super capacitors per control unit totaling €69. However, extrapolating the manufacturers' volume price scales for a production run of 1,000 units demonstrates significant reductions. The component costs drop to around €10 per unit, with PCB costs at just €0.59 per unit. While we do not have exact figures for the solar panels and super capacitors at this scale, preliminary research on Alibaba suggests vendors offering 10 W solar panels for as low as €3.80, indicating that the overall unit cost would decrease substantially with larger production volumes to around €20.

4. Conclusions and outlook

With a bottom-up cost analysis, manufacturing cost of a new heliostat design of 2 m² size was estimated assuming high volume production. The cost for fabrication resulted in 58 €/m² and the cost for autonomous energy supply and control in 20 €/m². Shipping and installation were not considered in this study. Installation is investigated in a separate study [2]. With a rough estimation of the missing cost, total cost of the installed heliostat field of below 90 €/m² is estimated.

So far, the heliostat is not optimized in terms of size yet. For that, the heliostat design shall be upscaled to several sizes. For each size the fabrication cost will be determined as well as the optical efficiency of the heliostat field for several applications to find the in total most efficient solution for each application. With such a size optimization, a further significant cost reduction is expected.

Author contributions

Daniel Lenski: Data curation, formal analysis, investigation, methodology, visualization, writing – original draft of all besides paragraph 3.2.

Moritz Wirger: Investigation and writing – original draft of paragraph 3.2.

Andreas Pfahl: Conceptualization, methodology, supervision, writing – review & editing.

Competing interests

The authors declare that they have no competing interests.

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