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# Analyzing the Impact of Incidence Angle and Focal Plane Distance on Laser Beam Spot Shape and Size

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**Introduction.** In recent years, laser-processing technology has seen significant advancements aimed at addressing diverse needs, particularly in surface material processing and micromachining [1]. Surface material processing demands a high level of accuracy, often termed high precision machining. In laser processing, achieving this precision is heavily influenced by factors such as the incidence angle and focal plane distance of the laser beam on the material's surface [2]. Building upon this understanding, this article aims to analyze how the incident angle and focal plane distance impact the shape and size of the laser beam spot using a simulation-based approach.

**Main part.** The simulation is designed to investigate the impact of laser beam positioning errors on material or workpiece surfaces, particularly on those with irregularities. The underlying mathematical model, elucidated in [3,4], serves as the foundation for the simulation's development. The simulation is executed using the PDE solver within the MATLAB software, employing the finite element (FE) method. This methodology ensures a swift and efficient solution to the surface heat treatment problem. The exploration of laser beam spot characteristics through surface heat treatment simulations is geared towards understanding the impact of material surface processing on the laser beam spot's size and shape. In developing the simulation, two pivotal variables — namely, the incidence angle of the laser beam ($\alpha$) and the distance from the focus beam or beam waist to the material surface ($h$) — contribute to the creation of 10 distinct conditions.

Condition 1 serves as a reference, situating the laser beam spot precisely at the beam waist or focus beam on the material surface, with $\alpha = 0$ rad and $h = 0$ mm. This baseline condition facilitates a comparative analysis, enabling a clearer evaluation of changes in size and shape across other laser beam spots.

Conditions 2 to 4 involve scenarios where the laser beam position is perpendicular to the material surface, yet the focus beam or beam waist is positioned above, creating a positive defocus situation. Positive defocus leads to an enlarged laser beam spot, with the size increasing proportionally to the distance between the beam waist and the material surface. For conditions 2 to 4, inclination angle ($\alpha$) is set at 0 rad and distance ($h$) is set at 25, 50, and 75 mm, respectively.

Moving to Conditions 5 through 7, the laser beam position on the material surface becomes uneven or inclined. This inclination induces an angle altering the beam's perpendicularity to the material surface, consequently changing the shape of the laser beam spot. The shape transforms into an ellipse with increasing inclination angles ($\alpha$) set at 0.436, 0.873, and 1.309 rad and distance ($h$) is set at 0 mm.

Conditions 8 to 10 represent a combination of conditions 2 to 7, introducing positive defocus and an uneven or inclined material surface. This amalgamation results in size and shape variations compared to condition 1, with the laser beam spot enlarging and adopting a more ellipse shape as the distance and inclination angle increase. In these conditions, the distance from the beam waist or focus beam to the material surface ($h$) is set at 25, 50, and 75 mm, while the inclination angles ($\alpha$) are 0.436, 0.873, and 1.309 rad, respectively.

**Conclusion.** In the ongoing research stage, a simulation has been devised to identify and validate the characteristics of laser beam positioning errors on material surfaces. Simulation results affirm that deviations in the laser beam spot's shape and size are directly influenced by the non-perpendicular alignment of the laser to the workpiece surface and the defocused beam waist or focus. Additionally, it was observed that an increased distance between the focus beam or beam waist and the material surface correlates with a larger laser beam spot. Moreover, greater inclination angles introduced by the laser beam against the workpiece surface lead to an increasingly ellipse-shaped laser beam spot.

**List of sources used:**


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