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PRE-5941; No. of Pages 10

ARTICLE IN PRESS

Precision Engineering xxx (2012) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

Development of a maglev lens driving actuator for off-axis control and adjustment of the focal point in laser beam machining

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ARTICLE INFO

Article history:
Received 8 May 2012
Received in revised form 21 August 2012
Accepted 31 August 2012
Available online xxx

Keywords:
Electro-magnetic actuator
Laser beam machining
Off-axis control
Focal point
Air core coils

ABSTRACT

In laser beam machining, the machining speed and quality are very sensitive to the flow of the assist gas and the position of the focal point of the laser beam. In order to reduce the consumption of assist gas and improve the cutting speed and capability to remove molten material, and, in addition, enable the focal point to be adjusted in order to drill high aspect-ratio holes, a six-degree-of-freedom (6-DOF) controlled magnetic-levitated (maglev) lens driving actuator was proposed and fabricated. A novel air core coil type electro-magnetic driving unit was designed to actuate the lens holder. The driving unit can generate both repulsive and attractive forces by utilizing a modified Halbach array on the driven target and the air core coils. The air core coil windings allowed a spatial-cross-arrangement of the components, enabling the actuator to be sufficiently compact for it to be accommodated in the machining head of a laser beam machining tool. The proposed actuator can drive the lens to achieve real-time control of the axial position of the focal point and of the relative radial displacement between the lens axis and the assist gas jet nozzle axis (off-axis control). A range of ±5 mm with a tracking error of less than 12 μm and a bandwidth of more than 100 Hz was achieved in the axial direction, and a radial displacement up to ±1 mm with a tracking error of 1 μm and a bandwidth of more than 150 Hz was also obtained. Furthermore, under half sine wave pulse acceleration with a peak of 40 m/s^2 and duration of 10 ms in the radial direction, sufficient positional accuracy of the lens holder could be maintained.

1. Introduction

Laser beam machining is widely used in many industries because a high energy laser beam cannot only cut almost any material without contact with the workpiece, but can also machine complex geometrical profiles and make miniature holes in the material. The high energy laser beam is focused by a lens to melt and vaporize the workpiece material and the molten material is blown away by an assist gas jet acting at the cutting front [1,2].

Laser beam cutting is the most frequently performed material removal process in laser beam machining. In laser beam cutting, the capability with which the assist gas removes molten material from the cutting front is reduced as the workpiece becomes thicker. Insufficient gas flow to the cutting front decreases the cutting speed, and generates burr, dross and recast layers [3–5].

In order to improve cutting speed and the capability to remove molten material, as well as to save on the consumption of assist gas, a machining method that applies a suitable eccentricity between the axis of the laser beam and the axis of a convergent assist gas supply nozzle was proposed, as shown in Fig. 1(a). The eccentricity between the laser beam axis and the convergent nozzle axis was manually adjusted for each experiment [6].

The effect of the off-axis position was also verified using a supersonic nozzle in a straight laser beam cutting experiment. The nozzle angle and the distance between the injection point of the gas jet and the laser beam were changed manually for each experiment [7,8]. Furthermore, off-axis positioning has been tested in two-dimensional laser beam cutting, in which the lens followed the two-dimensional reference cutting trajectory shown in Fig. 1(b), and where a relative displacement between the nozzle and the laser beam was generated [9].

On the other hand, the focusing position, defined as the gap between the lens and the surface of the workpiece, is another of the more critical process parameters. The laser beam focal point, as shown in Fig. 2 ((a) focused above, (b) focused on and (c) focused below the surface of the workpiece), can be optimized according to the material and thickness of the workpiece to achieve the desired machining accuracy, speed and surface quality in various

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http://dx.doi.org/10.1016/j.precisioneng.2012.09.003

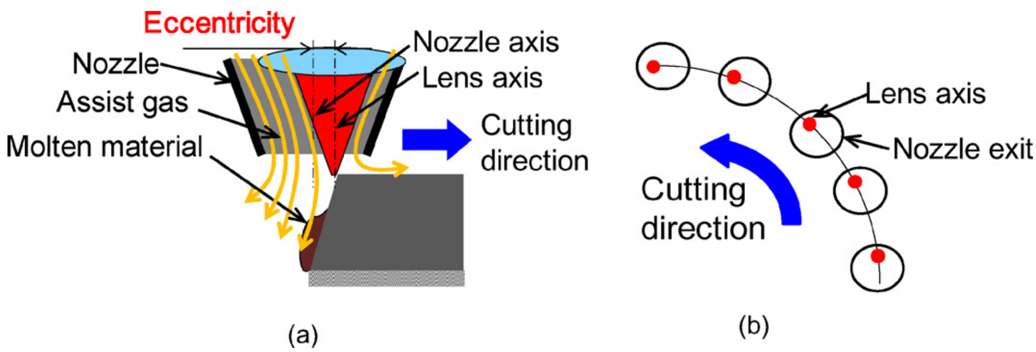

Fig. 1. Off-axis laser beam cutting realized by radial motion of the lens.

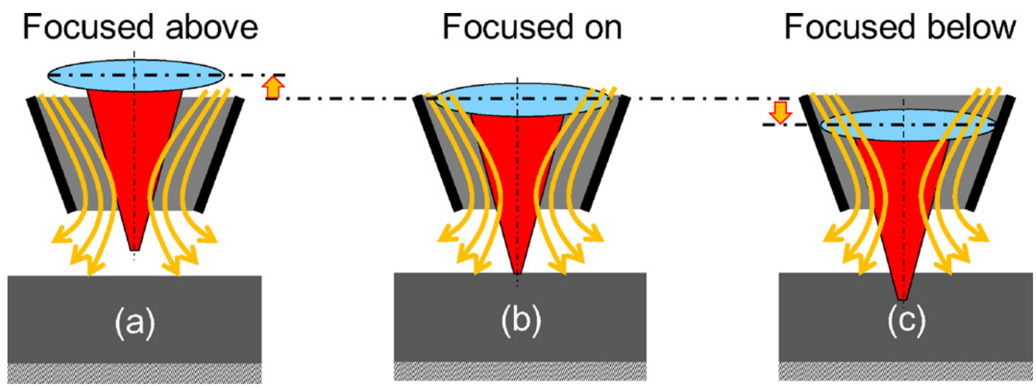

Fig. 2. Focal position adjustment realized by axial motion of the lens.

laser beam machining processes [10–14]. In previous research, the focal point was manually adjusted and fixed during the machining process; however, high speed real-time adjustment of the focal point responding to changes in the thickness and material of the workpiece has not, so far, been reported.

In order to realize two-dimensional off-axis cutting and adjust the focal point correctly during laser machining processes, a supplementary actuator which can drive the lens in three orthogonal directions is needed. The objective of study is the realization of a compact lens driving actuator which can drive the lens in both the

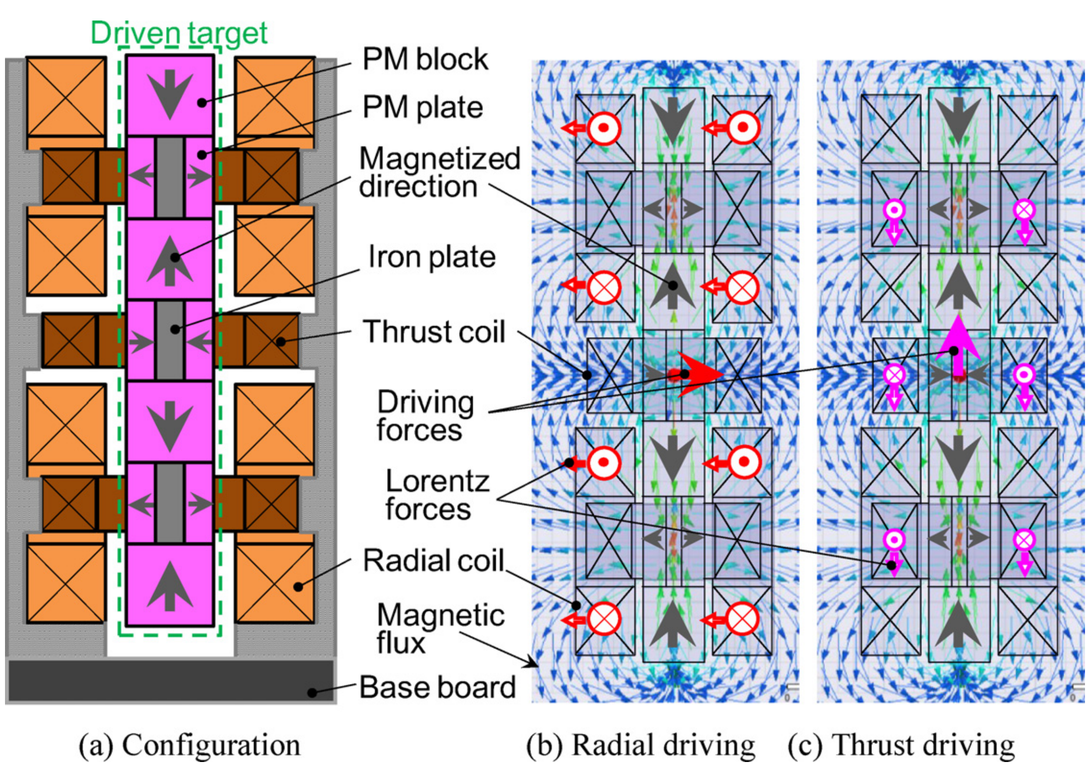

Fig. 3. Operating schematic of electro-magnet driving unit.

Please cite this article in press as: He D, et al. Development of a maglev lens driving actuator for off-axis control and adjustment of the focal point in laser beam machining. Precis Eng (2012), http://dx.doi.org/10.1016/j.precisioneng.2012.09.003