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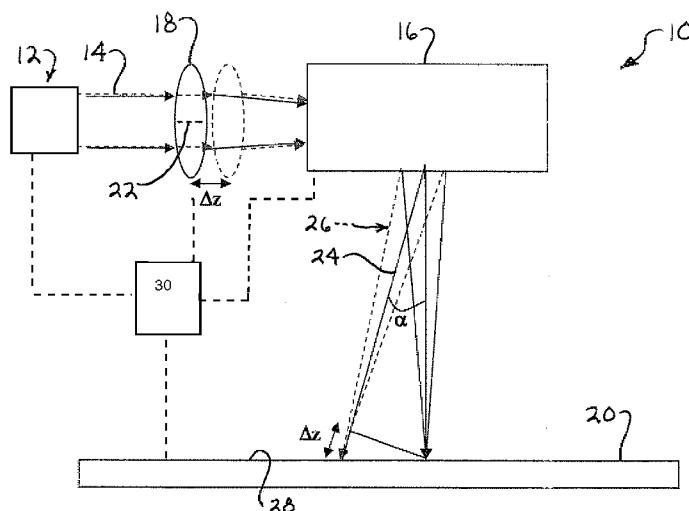


FIG 1

(57) Abstract: A laser micro-machining system includes a simple focusing lens located between a laser source and a beam steering mechanism along the path of a laser beam pulse. The focusing lens is a simple single-element spherical lens with an optical axis of the focusing lens located in line with a laser beam input from the laser source. The focusing lens is located further away from a work piece than the beam steering mechanism. An active beam path management system moves the simple focusing lens in concert with and relative to the beam steering mechanism to maintain a focal point coincident with a surface of the work piece at all deflection angles affected by the beam steering mechanism. The focusing lens is rapidly moveable in concert with the beam steering mechanism to maintain a constant beam path length from the lens output to the work piece.



POST-LENS STEERING OF A LASER BEAM FOR MICRO-MACHINING APPLICATIONS

FIELD OF THE INVENTION

[0001] The present invention relates to laser beams used for micro-machining applications.

BACKGROUND

[0002] Many laser micro-machining systems include fast beam-steering mechanisms (such as a pair of galvanometers) to deflect the laser beam in order to rapidly move the beam spot on the work surface. In a typical implementation, the angular deflection of the beam by the fast beam-steering mechanism is translated to planar motion on the work surface via an "f-theta" lens (also known as a "telecentric lens" or "scan lens"). When the beam steering mechanism is located at the front focal point of the lens and the input beam is collimated, the result is a converging (focusing) output beam that is also parallel to the optical axis. In most cases, this arrangement is coupled with a part chuck that presents a work surface perpendicular to the optical axis. As such, the (focusing) beams emanating from the f-theta lens impact the work piece at a 90-degree angle. A typical arrangement is illustrated in FIG. 2, where a laser micro-machining system 10a includes a laser source 12a positioned to direct a path 14a of a laser beam pulse through a beam steering mechanism 16a and an f-theta focusing lens 18a toward a work piece 20a.

SUMMARY

[0003] A laser micro-machining system includes a laser source positioned to direct a path of a laser beam pulse through a beam steering mechanism and a focusing lens toward a work piece. According to one embodiment of the invention, the focusing lens is a simple focusing lens located between the laser source and the beam steering mechanism along the path of the laser beam pulse. In another embodiment, the focusing lens is a simple single-element spherical lens with an optical axis of the focusing lens located inline with a laser beam input from the laser source. The focusing lens is located

further away from the work piece than the beam steering mechanism to reduce susceptibility of the focusing lens to contamination by debris generated during a machining operation with the laser source. In another embodiment, an active beam path management system moves the simple focusing lens in concert with and relative to the beam steering mechanism to maintain a focal point coincident with a surface of the work piece at all deflection angles affected by the beam steering mechanism. The focusing lens is rapidly moveable in concert with the beam steering mechanism to maintain a constant beam path length from the lens output to the work piece at all times.

[0004] In one embodiment of the invention, a process for laser micro-machining includes a laser source positioned to direct a path of a laser beam pulse through a beam steering mechanism and a focusing lens toward a work piece. The process includes locating a simple focusing lens between the laser source and the beam steering mechanism along the path of the laser beam pulse. In another embodiment, the process includes locating a simple single-element spherical focusing lens with an optical axis inline with a laser beam input from the laser source. The process includes locating the focusing lens further away from the work piece than the beam steering mechanism to reduce susceptibility of the focusing lens to contamination by debris generated during a machining operation with the laser source. In another embodiment, the process includes moving the simple focusing lens in concert with and relative to the beam steering mechanism to maintain a focal point coincident with a surface of the work piece at all deflection angles affected by the beam steering mechanism with an active beam path management system. The focusing lens is rapidly moveable in concert with the beam steering mechanism to maintain a constant beam path length from the lens output to the work piece at all times.

[0005] Other applications of the present invention will become apparent to those skilled in the art when the following description is read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The description herein makes reference to the accompanying drawings wherein like reference numerals refer to like parts throughout the several views, and wherein:

[0007] FIG. 1 is a schematic view of a beam-steering arrangement preceded by simple focusing lens according to one embodiment of the invention including an "active beam-path management" concept for maintaining focus on a work surface at different deflection angles affected by the beam-steering mechanism; and

[0008] FIG. 2 is a schematic view of a typical beam-steering arrangement followed by an f-theta lens.

DETAILED DESCRIPTION

[0009] Referring now to FIG. 1, a laser micro-machining system 10 includes a laser source 12 positioned to direct a path 14 of a laser beam pulse through a beam steering mechanism 16 and a focusing lens 18 toward a work piece 20. The focusing lens according to one embodiment of the invention can be a simple focusing lens 18 located between laser source 12 and beam steering mechanism 16 along the path 14 of the laser beam pulse toward work piece 20. Beam steering mechanism 16 is, for example, a so-called "fast" beam steering mechanism comprising beam steering optics controlled by galvanometers as is known in the art. Work piece 20 is conventionally supported on a part chuck of a one- or multi-axis linear stage for movement therewith. Alternatively, work piece 20 can be static, that is, mounted in a fixed position on a part chuck.

[0010] In one embodiment of the invention, the focusing lens can be a simple single-element spherical lens 18. The laser beam input or path 14 to focusing lens 18 from laser source 12 at least immediately adjacent to focusing lens 18 is in line with an optical axis 22 of focusing lens 18 at all times. It should be recognized that the path 14 of the laser beam pulse can be redirected between laser source 12 and focusing lens 18 by devices known to those skilled in the art before being coaxially aligned with optical axis 22 for entry into focusing lens 18.

[0011] According to an embodiment of the invention, focusing lens 18 is located further away from work piece 20 than beam steering mechanism 16, both in the direction of the optical path from laser source 12 to work piece 20 and as measured by a direct line from each of focusing lens 18 and beam steering mechanism 16 to work piece 20. This reduces the susceptibility of focusing lens 18 to contamination by debris generated during a machining operation with laser source 12 on work piece 20. A path 24 of an output

beam 26 from beam steering mechanism 16 can hit a surface 28 of work piece 20 at an angle α including angles other than a right angle as discussed in more detail below.

[0012] An embodiment of the invention can also include an active beam management system 30. Generally, beam management systems are comprised of a computer with knowledge of target locations on a work piece and that control galvanometers and laser firing to achieve a focused laser spot at the target location and trigger firing of the laser when the position is achieved. Here, active beam management system 30 is a microprocessor-based controller, preferably incorporated into a stand-alone computer that receives inputs from beam steering mechanism and position indicators of work piece 18 when work piece 18 is movable and provides outputs to laser source 12, beam steering mechanism 17, the movable stage supporting work piece 18 when provided, and optionally focusing lens 18. More specifically, programmed instructions are implemented by active beam management system 30 to control the galvanometers of beam steering system 16 and, in some cases, the position of focusing lens 18 to achieve a focused laser spot at target locations and to control and fire laser source 12 when each position is achieved.

[0013] As discussed in more detail below, active beam management system 30 can move simple focusing lens 18 in concert with and relative to beam steering mechanism 16 to maintain a focal point coincident with a surface 28 of work piece 20 at all deflection angles α affected by beam steering mechanism 16. Focusing lens 18 can be rapidly moved in concert with beam steering mechanism 16 to maintain a constant length beam path between focusing lens 18 and work piece 20 at all times.

[0014] A process for laser micro-machining including a laser source 12 positioned to direct a path 14 of a laser beam pulse through a beam steering mechanism 16 and a focusing lens 18 toward a work piece 20 according to an embodiment of the invention includes locating a simple focusing lens 18 between the laser source 12 and beam steering mechanism 16 along the path 14 of the laser beam pulse. In a typical configuration, focusing lens 18a is located downstream from, or after beam steering mechanism 16a, as best seen in FIG. 2. This arrangement requires an f-theta lens 18a. The configuration illustrated in FIG. 1 allows simple focusing lens 18 to be a simple single-element spherical lens 18. This configuration reduces the cost of the focusing lens substantially when compared to the typical configuration. Locating focusing lens 18 further away from

the work piece than beam steering mechanism 16, as illustrated in FIG. 1, reduces the susceptibility of focusing lens 18 to contamination by debris as mentioned above.

[0015] The process generally includes aligning the path 14 of the laser beam pulse input to focusing lens 18 from laser source 12 to be in line with an optical axis 22 of focusing lens 18 at all times. It should be recognized that the path 14 of the laser beam pulse can be redirected between laser source 12 and focusing lens 18 by devices known to those skilled in the art before being coaxially aligned with optical axis 22 before entry into focusing lens 18.

[0016] The process can include hitting a surface 28 of a work piece 20 with a path 24 of the output beam 26 from the beam steering mechanism 16 at an angle α including an angle other than a right angle (that is, a 90 degree angle). That is, in the system 10a of FIG. 2, the provision of f-theta lens 18a between beam steering mechanism 16a and work piece 20a allows a beam substantially parallel to the optical axis 22a to contact the surface of work piece 20a at substantially a right angle. In the system 10 of FIG. 1, however, movement of the galvanometers of beam steering mechanism 16 to target locations on work piece 18 by active beam management system 30 will result in output beams 26 having paths 24 offset from a right angle (departing beam steering mechanism 16 and contacting surface 28) by angle α .

[0017] As a result, and without any additional adjustments, the entire beam path from focusing lens 18 to surface 28 would lengthen by Δz . Simple focusing lens 18 can be moved in concert with and relative to beam steering mechanism 16 to maintain a focal point coincident with surface 28 of work piece 20 at all deflection angles α affected by beam steering mechanism 16 with active beam path management system 30. The process can include rapidly moving focusing lens 18 in concert with beam steering mechanism 16 to maintain a constant length beam path between focusing lens 18 and work piece 20 at all times. As the angle α increases, Δz increases, and focusing lens 18 is moved closer to beam steering mechanism 16 by a similar amount so as to maintain the constant length beam path.

[0018] In embodiments of the invention, a beam focusing/steering arrangement for a laser micro-machining system 10 is used in which focusing lens 18 precedes beam-steering mechanism 16. Such an approach provides benefits compared to a standard configuration. First, the input beam to focusing lens 18 can be aligned with optical axis

22 of focusing lens 18 at all times. Consequently, a simple single-element spherical lens 18 is sufficient in this arrangement. This is a much more favorable arrangement than the arrangement illustrated in FIG. 2 where focusing lens 18a has to be an f-theta lens 18a, which is significantly more complex (i.e. a multi-lens element) and hence more expensive. Second, the arrangement illustrated in FIG. 1 also leaves focusing lens 18 further away from work piece 20, reducing susceptibility of focusing lens 18 to contamination by the debris generated during a machine operation.

[0019] The optical configuration in FIG. 1 illustrates beam steering/focusing optics in a laser micro-machining system (beam steering mechanism preceded by a simple focusing lens). FIG. 1 also shows that focusing lens 18 can be repositioned Δz to maintain a focal point coincident with work piece surface 28 at all deflection angles α affected by beam steering mechanism 16. Depending on application requirements and how much the beam path 24 changes Δz as a result of beam deflection α , active beam path management system 30 may or may not be necessary. That is, adjusting the position of focusing beam 18 may or may not be necessary depending on the application and the angle α . Small values for angle α make it less likely that Δz will be large enough to adversely affect the machining operation at the target point. Especially in systems where work piece 20 is fixed, however, angle α can become large enough to adversely affect the machining operation at the target point without adjustment of the position of focusing lens 18.

[0020] As can be discerned, this design has some drawbacks. First, in the design illustrated in FIG. 1, output beam 26 from beam steering mechanism 16 will not always hit work surface 28 at a right angle. Depending on the application requirements, this may or may not be tolerable. In those cases where a distance between beam steering mechanism 16 and work piece 20 is fairly long when compared to the desired spot size movement on work piece 20 as a result of beam-steering, the change (from vertical) in this angle of attack will be fairly small. Second, the mismatch between the curved focal surface of focusing lens 18 versus flat surface 28 of work piece 20 is a problem in this particular case as well. The design as illustrated in FIG. 1 provides that focusing lens 18 can be moved Δz in concert with beam-steering optics of beam steering mechanism 16 to maintain a constant beam path length from focusing lens 18 to work piece 20 at all times. Note that such active management of beam path 24 requires the ability to rapidly move

focusing lens 18. This becomes possible in this design as the element being moved is a small single-element focusing lens 18 as opposed to a large multi-element f-theta lens 18a as illustrated in FIG. 2.

[0021] The standard optical configuration that calls for beam steering mechanism 16a followed by an f-theta lens 18a as illustrated in FIG. 2 is an expensive and, in some cases, difficult-to-implement solution due to the complexity of f-theta lens 18a itself. This complexity arises from two primary reasons. First, the presence of beam steering mechanism 16a before lens 18a indicates that input beam 32a to lens 18a is not necessarily along optical axis 22a. The angle of attack for input beam 32a to lens 18a is likely to vary in real-time during machine operation. Second, more often than not, work piece 20 is relatively flat, whereas the back focal surface of a standard spherical focusing lens would be curved. The need to accommodate input beams 32a that are not parallel to optical axis 22a and to maintain focus on essentially flat work pieces 20 (or sub-regions thereof) typically requires complicated multi-lens designs. As such, an f-theta lens 18a typically includes multiple lenses whose optical properties and physical placement (within the multi-element structure) are very carefully optimized to reduce the aberrations that would otherwise result from the two issues listed above.

[0022] As a consequence of the fundamental design challenges outlined above, f-theta lenses 18a are usually complicated, relatively large, difficult to manufacture and expensive. The cost issue becomes even more important when one realizes that these lenses 18a, more often than not, are the very last component in the optical train, i.e., the lenses 18a are in physical proximity to work piece 20a and thus are more susceptible to contamination from the debris generated during machine operation. Needless to say, having to replace such expensive elements on a regular basis has a big impact on the cost of ownership of the system 10a.

[0023] Replacing post beam-steering f-theta lens 18a with a pre beam-steering standard lens 18 immediately resolves the first issue. The input beam path 14 to such a lens 18 is fixed and can always be made to align with optical axis 22 of lens 18. Furthermore, such a lens 18 will be typically positioned much further away from work piece 20 and hence will not be as susceptible to contamination problems. Even if lens 18 were subject to contamination, regular replacement of such a part would be an acceptable

maintenance strategy as the part itself would be an order of magnitude cheaper than an f-theta lens 18a, if not more.

[0024] As for the issue of maintaining focus on a flat work piece 20, the following applies. If the work piece 20 area that needs to be scanned via beam-steering motion is small enough compared to the focal length of lens 18, the resulting spot size change might very well be negligible and/or insignificant for the application in question. Otherwise, the active beam management system 30 outlined above can be used to mitigate the effects of this problem.

[0025] While the invention has been described in connection with certain embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures as is permitted under the law.

What is claimed is:

1. A laser micro-machining system including a laser source positioned to direct a path of a laser beam pulse through a beam steering mechanism toward a work piece, characterized by:

a simple focusing lens located between the laser source and the beam steering mechanism along the path of the laser beam pulse.

2. The laser micro-machining system of claim 1, further comprising:
an active beam path management system moving the simple focusing lens in concert with and relative to the beam steering mechanism to maintain a focal point coincident with a surface of the work piece at all deflection angles affected by the beam steering mechanism.

3. The laser micro-machining system of claim 1 or claim 2 wherein the simple focusing lens is a simple single-element spherical lens.

4. The laser micro-machining system of claim 1 or claim 2 wherein the path of the laser beam pulse input to the simple focusing lens from the laser source is in line with an optical axis of the simple focusing lens at all times.

5. The laser micro-machining system of claim 1 or claim 2 wherein the simple focusing lens is located further away from the work piece than the beam steering mechanism, thereby reducing susceptibility of the simple focusing lens to contamination by debris generated during a machining operation with the laser source.

6. The laser micro-machining system of claim 1 or claim 2 wherein a path of an output laser beam pulse from the beam steering mechanism hits a surface of the work piece at an angle including angles other than a right angle.

7. The laser micro-machining system of claim 1 or claim 2 wherein the simple focusing lens is rapidly moveable in concert with the beam steering mechanism

to maintain a constant length of a path of the laser beam pulse output from the simple focusing lens to the work piece at all times.

8. A method for laser micro-machining a work piece including a laser source positioned to direct a path of a laser beam pulse through a beam steering mechanism toward the work piece, the method comprising:

directing the laser beam pulse through a simple focusing lens positioned between the laser source and the beam steering mechanism.

9. The method of claim 8, further comprising:

moving the simple focusing lens in concert with and relative to the beam steering mechanism to maintain a focal point coincident with a surface of the work piece at all deflection angles affected by the beam steering mechanism with an active beam path management system.

10. The method of claim 8 or claim 9 wherein the focusing lens is a simple single-element spherical lens.

11. The method of claim 8 or claim 9, further comprising:

aligning a path of the laser beam pulse input to the simple focusing lens from the laser source to be in line with an optical axis of the simple focusing lens at all times.

12. The method of claim 8 or claim 9, further comprising:

hitting a surface of the work piece with a path of an output beam from the beam steering mechanism at an angle including angles other than a right angle.

13. The method of claim 8 or claim 9, further comprising:

rapidly moving the simple focusing lens in concert with the beam steering mechanism to maintain a constant length of the path of the laser beam pulse output from the simple focusing lens to the work piece at all times.

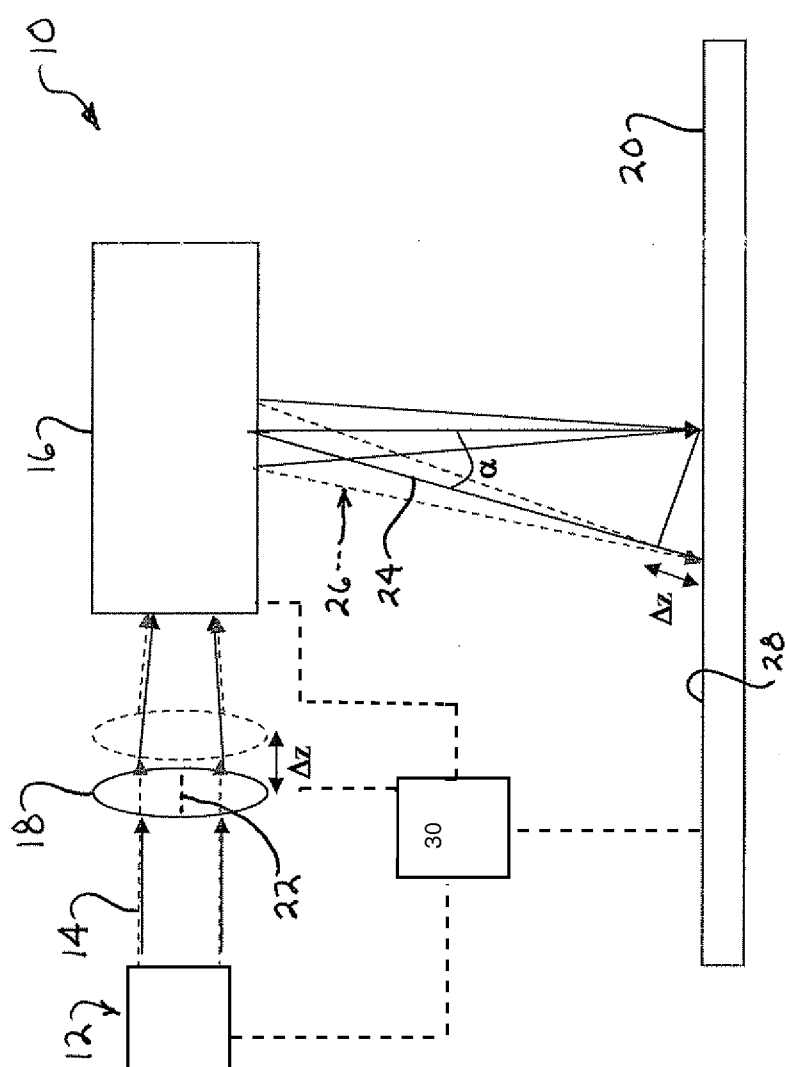


FIG 1

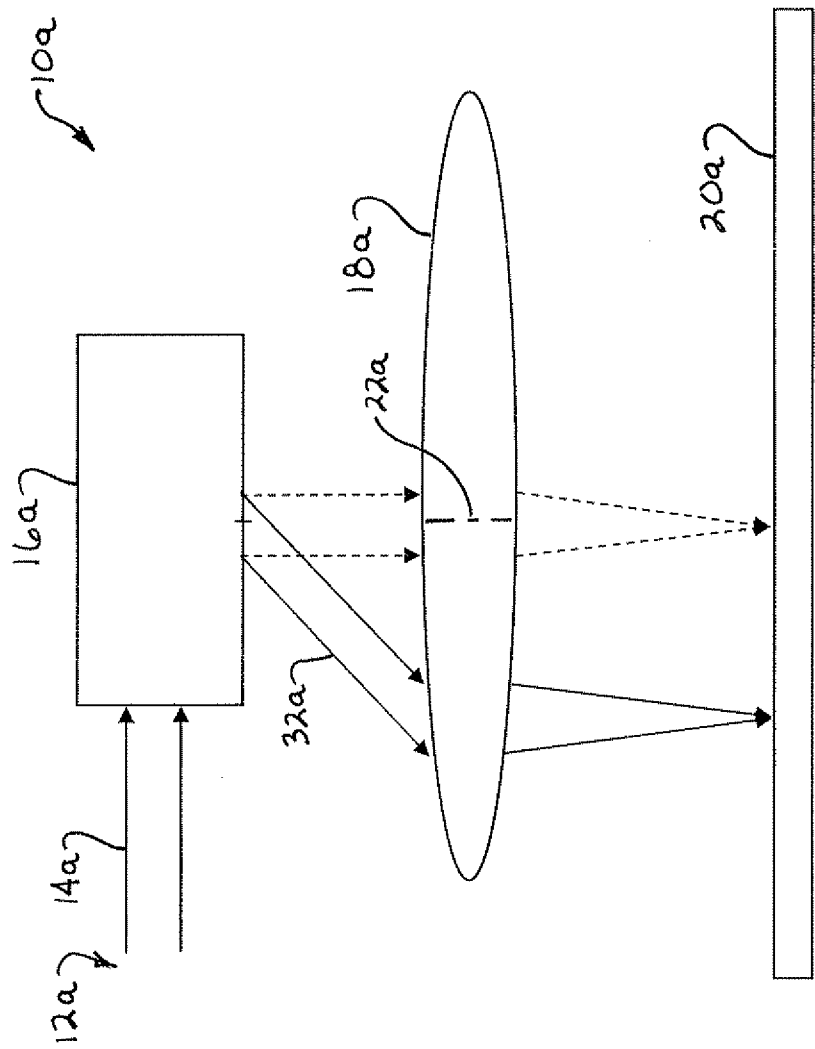


FIG 2