

LASER MACHINING APPARATUS

BACKGROUND

1. Technical Field

The present invention relates to a laser machining apparatus, and more particularly, to a laser machining apparatus for machining a workpiece with a laser beam introduced into a jet liquid column ejected from a nozzle.

2. Related Art

Examples of known laser machining apparatuses which machine a workpiece with a laser beam introduced into a jet liquid column ejected from a nozzle are disclosed in Japanese Published Unexamined Patent Application Nos. 2010-221265 and 2011-125870.

The laser machining apparatus disclosed in Japanese Published Unexamined Patent Application No. 2010-221265 machines a workpiece with a laser beam introduced into a water column while directing a jet of water at the workpiece, in which a protector for protecting the nozzle is provided between the nozzle and the workpiece to prevent water bouncing off the workpiece from adhering to the nozzle and disturbing the flow of the water column. The protector is constructed of a thin plate. After the protector is mounted to the laser machining apparatus at the start of machining, a hole for the passage of the water column and the laser beam is formed by the laser beam introduced into the water column. By machining the hole in this manner, the need to align the protector with the position through which the water column and the laser beam pass is eliminated, and the mounting operation of the protector is facilitated.

Furthermore, in the laser machining apparatus disclosed in Japanese Published Unexamined Patent Application No. 2011-125870, an air introduction housing is provided below a liquid chamber housing to introduce air into the air introduction housing through an air intake port. Air introduced into the air introduction housing passes through the inside of a pipe formed in the air introduction housing and surrounds a liquid column passing through the inside of the pipe to straighten the flow of the liquid column.

Unfortunately, in the laser machining apparatus disclosed in Japanese Published Unexamined Patent Application No. 2010-221265 described above, at the time of the first hole drilling in the protector, water is trapped inside the space in between the protector and the nozzle during the time until the hole is formed in the protector. The trapped water might disturb the flow of the water column ejected from the nozzle.

Furthermore, in the laser machining apparatus disclosed in Japanese Published Unexamined Patent Application No. 2011-125870, when the air flow rate is increased so that the liquid bouncing off the workpiece, dross generated at the time of machining, etc. are discharged, the large flow of air might cause disturbances in the liquid column, leading to a reduction in machining efficiency.

SUMMARY

Accordingly, an object of the present invention is to provide a laser machining apparatus with favorable liquid-column flow straightening properties.

In order to achieve the above-mentioned object, a first

aspect of the present invention provides a laser machining apparatus that includes a laser oscillator for generating a laser beam, a nozzle for directing a jet liquid at a workpiece, and a liquid supply unit for supplying the jet liquid to the nozzle, to machine the workpiece with the laser beam introduced into a jet liquid column ejected from the nozzle. The laser machining apparatus further includes: a protector cap disposed between the nozzle and the workpiece for protecting the nozzle; and an air supply unit for supplying air to a space formed between the nozzle and the protector cap. The protector cap has a flow passage permitting passage of the jet liquid column. The space between the nozzle and the protector cap has a surface toward the nozzle and a surface toward the protector cap, each of the surfaces of the space being at least partially bounded by a projection that protrudes inwardly of the space.

With this structure, the liquid supplied from the liquid supply unit is ejected from the nozzle to form the jet liquid column, and the laser beam introduced into the jet liquid column reaches the workpiece to machine it. The air supplied to the space by the air supply unit surrounds and straightens the flow of the jet liquid column while flowing through the space and the flow passage of the protector cap.

Because the protector cap is provided between the nozzle and the workpiece, liquid bouncing off the workpiece is prevented from adhering to the nozzle. Thus, disturbances in the jet liquid column ejected from the nozzle are prevented.

Also, the surface of the space between the protector cap and the nozzle, which is located toward the protector cap, is at

least partially bounded by the projection protruding inwardly of the space. Thus, the jet liquid column not passing through the flow passage flows outwardly of the space (toward the workpiece) along the projection located toward the protector cap even if, due to disturbances in the jet liquid column occurring in an early stage of machining, the jet liquid column remains in the space, rather than passing through the flow passage of the protector cap, or splashing liquid droplets pass through the flow passage and enter the space, and therefore blocking of the flow passage with the liquid is prevented. Consequently, disturbances in the jet liquid column due to the liquid entering the space are prevented.

Further, because both surfaces of the space which are located toward the protector cap and the nozzle are bounded by the projections protruding inwardly of the space, the air entering the space flows while being guided by both projections, so that the air becomes less likely to impinge directly on the jet liquid column ejected from the nozzle. Thus, the disturbances in the jet liquid column due to the air are prevented even when the air flow rate increases, thereby reducing deterioration of machining efficiency.

In accordance with a second aspect of the present invention, preferably, the air supply unit includes an air supply port and an air discharge port. The air supply port is located around an injection port of the nozzle and in communication with the space for supplying air into the space. The air discharge port is located around the flow passage and in communication with the space for discharging air from the space.

With this structure, because the air supply port of the air supply unit is located around the injection port of the nozzle and in communication with the space and the air discharge port is located around the flow passage and in communication with the space, the air supplied into the space through the air supply port flows toward the protector cap while being guided by the projection on the surface located toward the nozzle, and then is guided by the projection on the surface located toward the protector cap to be discharged from the air discharge port. The air supplied into the space can be prevented from impinging directly on the jet liquid column ejected from the nozzle and passing through the flow passage, thereby allowing an increase in air flow rate while preventing disturbances in the jet liquid column. The increase in air flow rate allows more reliable prevention of the entry of liquid droplets or dross into the space and more efficient elimination of liquid or dross on the workpiece.

Also, because the air discharge port is provided, even if liquid enters the space, the liquid can be discharged from the air discharge port together with air, and thus trapping of liquid inside the space can be prevented.

In accordance with a third aspect of the present invention, preferably, the air supply port is located toward the nozzle with respect to a most protruding position of the projection located toward the nozzle, and the air discharge port is located toward the protector cap with respect to a most protruding position of the projection located toward the protector cap.

With this structure, the air ejected from the air supply

port and the air before entering the air discharge port flow easily along the projections. Thus, the movement of air within the space can be effectively controlled.

In accordance with a fourth aspect of the present invention, preferably, the laser machining apparatus further includes a nozzle holder for supporting the nozzle, wherein the projection of the space located toward the nozzle is formed on a surface of the nozzle or the nozzle holder, the surface of the nozzle or the nozzle holder being exposed at the space.

Furthermore, in accordance with a fifth aspect of the present invention, preferably, the projections of the space located toward the nozzle and the protector cap each have a circular cylindrical shape or a truncated cone shape.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will be described in detail based on the following drawings, wherein:

FIG. 1 is a general schematic view of a laser machining apparatus according to a first embodiment of the present invention;

FIG. 2 is a partially enlarged view of the laser machining apparatus according to the first embodiment of the present invention;

FIG. 3 is a partially enlarged view of a laser machining apparatus according to a second embodiment of the present invention;

FIG. 4 is a partially enlarged view of a laser machining apparatus according to a third embodiment of the present

invention;

FIG. 5 is a partially enlarged view of a laser machining apparatus according to a fourth embodiment of the present invention;

FIG. 6 is a partially enlarged view of a laser machining apparatus according to a fifth embodiment of the present invention;

FIG. 7 is a partially enlarged view of a laser machining apparatus according to a sixth embodiment of the present invention; and

FIG. 8 is a partially enlarged view of a laser machining apparatus according to a seventh embodiment of the present invention.

DETAILED DESCRIPTION

Hereinafter, preferred embodiments of the present invention will be described with reference to the accompanying drawings. It should be noted that, in the second and subsequent embodiments, in the drawings, the same elements as those of the first embodiment are denoted by the same reference signs, and a description thereof will be simplified or not be repeated.

First Embodiment

FIG. 1 is a general schematic view of a laser machining apparatus 1 according to a first embodiment of the present invention. It should be noted that, in the following description, the vertical direction in FIG. 1 is assumed to be a vertical direction of the laser machining apparatus 1 according to this embodiment.

As shown in FIG. 1, the laser machining apparatus 1 according to this embodiment includes: a laser machining head 2; an optical device 4 that irradiates a workpiece W with a laser beam through the laser machining head 2; a liquid injector 6 for making a high-pressure water jet serving as a jet liquid injected into the workpiece; and a flow straightener 8 for straightening the flow of the ejected liquid column.

The laser machining head 2 includes a housing 10 formed in a substantially cylindrical shape. The housing 10 houses, in its upper portion, a portion of the optical device 4 and is provided in its lower portion with a portion of the liquid injector 6. A nozzle 14 formed with a nozzle hole 12 for ejecting a jet liquid column F is provided in a lower portion within the housing 10. The nozzle 14 is supported and fixed by a nozzle holder 15 from below. The nozzle hole 12 goes vertically through the center of the nozzle 14. The nozzle hole 12 has an upper portion in the form of a circular cylinder and a lower portion in the form of a truncated cone widened toward the lower end.

The optical device 4 includes a laser optical system 16 that focuses a laser beam at a predetermined position, and a laser oscillator 18 that allows entry of the laser beam into the laser optical system 16.

The laser optical system 16 is configured to introduce the laser beam emitted from the laser oscillator 18 into the laser machining head 2 through optical fibers or the like and focus the laser beam at a position in the vicinity of an opening at an upper end of the nozzle hole 12 in the laser machining head 2. It should be noted that FIG. 1 illustrates, partly in schematic form,

the laser optical system 16 and shows only a single focusing lens 20 that finally focuses the laser beam.

The laser oscillator 18 is constructed to generate a laser beam having a predetermined intensity. In this embodiment, a green laser is used as the laser beam; however, any kind of laser beam may be arbitrarily selected as long as it is poorly absorbed by water.

The green laser is a second harmonic generation (SHG) YAG laser and has a wavelength of 532 nm. Unlike a YAG laser (with a wavelength of 1064 nm) and a CO₂ laser (with a wavelength of 10.6 μ m), the green laser has the property of more easily passing through water. Therefore, when water easily available at a cheaper cost is used as a jet liquid, the propagation efficiency of the laser beam can be increased. Further, because the green laser is poorly absorbed by water, the generation of a thermal lens is suppressed and thus the laser beam is more easily guided with high accuracy to the position in the vicinity of the opening of the nozzle hole 12 in the laser machining head 2. Consequently, the nozzle 14 can be prevented from being damaged and stable machining quality can be ensured.

The liquid injector 6 includes: a liquid supply source 22; a liquid processor 24 that executes processing such as deionizing the liquid delivered from the liquid supply source 22; a high-pressure pump 26 that sends the liquid delivered from the liquid supply source 22 to the laser machining head 2; a high-pressure filter 28 that is provided between the high-pressure pump 26 and the laser machining head 2 for removing impurities from the liquid; and a liquid flow path 30 that is formed within the laser

machining head 2 to introduce the high-pressure liquid delivered from the high-pressure pump 26 into the nozzle 14. In this embodiment, water is employed as the liquid.

FIG. 2 is a partially enlarged view of the laser machining apparatus 1 according to the first embodiment of the present invention. As shown in FIG. 2, the flow straightener 8 includes: a protector cap 32 that is fixed to the housing 10 below the nozzle 14 for protecting the nozzle 14 from water bouncing off the workpiece W or dross generated at the time of machining; and an air supply unit 36 that supplies air into a space 34 in between the nozzle holder 15 and the protector cap 32.

The protector cap 32 is formed in a substantially circular cylindrical shape and disposed and held inside a lower opening of the housing 10. An upwardly-protruding projection 40 in the form of a circular cylinder is formed on an upper surface 38 of the protector cap 32. The diameter of the projection 40 is smaller than that of the protector cap 32, and thus the upper surface 38 of the protector cap 32 has an annular plane formed around the projection 40, the annular plane being located below the projection 40. A flow passage 42 for the passage of the jet liquid column F and the laser beam along a vertical axis is formed in the center of the protector cap 32. A lower surface of the protector cap 32 is formed in a downwardly-protruding truncated cone shape. It should be noted that, preferably, the diameter of the flow passage 42 is in the range of 0.3 to 1 mm so that air can be discharged at a constant rate and thus the water or dross bouncing off the workpiece W can be prevented from entering the space 34.

A downwardly-protruding projection 46 in the form of a circular cylinder is formed on a lower surface 44 of the nozzle holder 15. The diameter of the projection 46 is smaller than that of the nozzle holder 15, and thus the lower surface 44 of the nozzle holder 15 has a shouldered shape with an annular plane formed around the projection 46, the annular plane being located above the projection 46. A through-hole 48 for the passage of the jet liquid column F and the laser beam along the vertical axis is formed in the center of the nozzle holder 15.

It should be noted that, preferably, distance L between a lower surface of the projection 46 of the nozzle holder 15 and an upper surface of the projection 40 of the protector cap 32 is set in the range of 1 to 3 mm.

The projection 40 on the upper surface 38 of the protector cap 32 and the projection 46 on the lower surface 44 of the nozzle holder 15 as described above form the space 34 in between the protector cap 32 and the nozzle holder 15 into a substantially H-section when viewed in a direction perpendicular to the direction of the vertical axis (direction perpendicular to the sheet of FIG. 1). An upper surface of the space 34, that is, the surface located toward the nozzle 14, and a lower surface of the space 34, that is, the surface located toward the protector cap 32, each have a shape recessed inwardly of the space 34.

The air supply unit 36 has: an air supply source 50; an air controller 52 that controls the pressure of compressed air delivered from the air supply source 50; an air supply passage 54 for supplying air into the space 34; and an air discharge passage 56 for discharging the air in the space 34 to the outside.

The air supply passage 54 has: a main passage 58 that is formed within the housing 10; a distribution passage 60 that is in communication with the main passage 58 and formed in an annular shape around the whole circumference of the nozzle 14; and plural (four in this embodiment) equally spaced communicating passages 62 that are provided in the distribution passage 60 for the communication between the distribution passage 60 and the space 34. Each of the communicating passages 62 extends parallel to the vertical axis of the nozzle machining head 2 to form an air supply port 64 that has an opening at a position of the lower surface 44 of the nozzle holder 15 outwardly of the projection 46. Therefore, the air supply port 64 is located outwardly of the through-hole 48 of the nozzle holder 15, above a lower end of the through-hole 48, that is, above a lower end of the projection 46.

The air discharge passage 56 is formed with plural (four in this embodiment) equally spaced circumferential grooves that go through outer peripheral portions of the protector cap 32 in a direction parallel to the vertical axis. Thus, one end of the air discharge passage 56 forms an air discharge port 66 that has an opening at a position of the upper surface 38 of the protector cap 32 outwardly of the projection 40. More specifically, the air discharge port 66 is located outwardly of the flow passage 42 of the protector cap 32, below an upper end of the flow passage 42, that is, below an upper end of the projection 40.

The other end of the air discharge passage 56 opens into a lower surface of the protector cap 32, and thus the air discharge passage 56 allows the space 34 and the outside of the laser machining head 2 to communicate with each other.

The laser machining apparatus 1 according to this embodiment as constructed in this manner operates as follows.

When a workpiece W is laser-machined, the workpiece W is mounted on a mounting table T located below the nozzle 14. Next, when a laser beam is emitted from the laser oscillator 18, the laser beam enters the laser optical system 16 to be introduced into the laser machining head 2. The laser beam is focused in the vicinity of the opening at the upper end of the nozzle hole 12 by the focusing lens 20 of the laser optical system 16, or the like.

On the other hand, the liquid injector 6 sends, with the high-pressure pump 26, water from the liquid supply source 22 through the liquid flow path 30 and causes a jet liquid column F to be ejected from the nozzle 14 and directed at the workpiece W. It should be noted that, at this time, the diameter of the ejected jet liquid column F is slightly larger than that of the nozzle hole 12. The jet liquid column F passes through the through-hole 48 of the nozzle holder 15 and the flow passage 42 of the protector cap 32 to the workpiece W. The laser beam focused in the vicinity of the opening at the upper end of the nozzle hole 12 by the laser optical system 16 is introduced into the jet liquid column F while repeating total reflection within the jet liquid column F and reaches the workpiece W to carry out a laser machining on the workpiece W.

The flow straightener 8 supplies air from the air supply source 50, and the air passes through the air supply passage 54 to be supplied to the space 34 through the air supply port 64. The air, after entering the space 34, flows downward while being guided by an external surface of the projection 46 of the lower

surface 44 of the nozzle holder 15 and an external surface of the projection 40 of the upper surface 38 of the protector cap 32 and surrounds the jet liquid column F ejected from the through-hole 48 of the nozzle holder 15 to straighten the flow of the jet liquid column F. Also, the air in the space 34 enters the flow passage 42 of the protector cap 32 to surround and straighten the flow of the jet liquid column F. And after being ejected from the protector cap 32, the air eliminates water bouncing off the workpiece W, dross generated at the time of machining, etc. from the surface of the workpiece W. A portion of the air in the space 34 which does not pass through the flow passage 42 is discharged to the outside from the air discharge port 66 through the air discharge passage 56.

This embodiment constructed in this manner can provide the following advantages.

Since the protector cap 32 is provided below the nozzle 14, adhesion of water droplets to the nozzle 14 can be prevented even if the jet liquid column F bounces off the workpiece W. Thus, disturbances in the jet liquid column F ejected from the nozzle 14 can be prevented.

Because air is supplied to the space 34 in between the nozzle 14 and the protector cap 32 by the air supply unit 36 to straighten the flow of the jet liquid column F ejected from the nozzle 14, a more stable jet liquid column F is provided. Thus, the propagation efficiency of the laser beam introduced into the jet liquid column F is increased, and consequently the machining ability of the laser machining apparatus 1 can be improved.

The space 34 between the nozzle 14 and the protector cap 32

is bounded by the projection 46 of the lower surface 44 of the nozzle holder 15 and the projection 40 of the upper surface 38 of the protector cap 32, and thus the upper and lower surfaces of the space 34 are formed in inwardly-recessed shapes. Thus, the air supplied through the air supply port 64 flows downward while being guided by the projections 46 and 40 and is prevented from impinging directly on the jet liquid column F.

Furthermore, because the projections 46 and 40 can prevent air from impinging directly on the jet liquid column F and disturbing the jet liquid column F, the flow rate of air supplied to the space 34 can be increased relative to the related art. Thus, the air ejected from the flow passage 42 together with the jet liquid column F allows water or dross on the workpiece W to be more effectively eliminated.

Further, even in the event of entrance of water into the space 34, the projection 40 of the protector cap 32 makes it less likely that water is trapped in the vicinity of the flow passage 42.

Because the air supply port 64 is located around the projection 46 of the nozzle holder 15 and the air discharge port 66 is located around the projection 40 of the protector cap 32, a vertical air flow around the jet liquid column F within the space 34 is likely to occur, thereby allowing flow straightening of the jet liquid column F without causing disturbances in the jet liquid column F.

Furthermore, because the air discharge port 66 is located around the projection 40 of the protector cap 32, even in the event of entrance of water into the space 34, the water can be

discharged from the air discharge port 66 together with air.

Second Embodiment

Next, a laser machining apparatus 70 according to a second embodiment of the present invention will be described. The laser machining apparatus 70 according to the second embodiment has the same construction as the laser machining apparatus 1 according to the first embodiment except for a difference in construction of the air discharge passage.

FIG. 3 is a partially enlarged view of the laser machining apparatus 70 according to the second embodiment of the present invention. As shown in FIG. 3, plural (four in this embodiment) air discharge passages 72 of the laser machining apparatus 70 are formed in lower ends of the space 34 within the housing 10. Therefore, air discharge ports 74 open into an inner surface of the housing 10. Each of the air discharge passages 72 is inclined radially and downwardly toward the outside from the central axis of the nozzle 14 and has an opening toward an external surface of the housing 10.

With this structure of the laser machining apparatus 70 according to the second embodiment, the same advantages as those of the first embodiment are obtained. In addition, the air discharge passage 72 is formed in the housing 10 and has the opening toward the outer surface of the housing 10, thereby preventing air discharged from the air discharge passage 72 from impinging on the workpiece W. Thus, even if water or the like entering the space 34 is discharged from the air discharge passage 72 together with air, the influence of emission matter on machining of the workpiece W can be limited.

Third Embodiment

Next, a laser machining apparatus 80 according to a third embodiment of the present invention will be described. The laser machining apparatus 80 according to the third embodiment has the same construction as the laser machining apparatus 1 according to the first embodiment except for a difference in shape of the projections.

FIG. 4 is a partially enlarged view of the laser machining apparatus 80 according to the third embodiment of the present invention. As shown in FIG. 4, a downwardly-protruding projection 86 in the form of a truncated cone is formed at the center of a lower surface 84 of a nozzle holder 82 of the laser machining apparatus 80. The projection 86 is formed peripherally with an annular planar portion that is located above the projection 86. Here, an angle α of an isosceles triangular section of the truncated cone shape of the projection 86 taken along the central axis is 120° in this embodiment. It should be noted that, preferably, the angle α is set in the range of 0° (that is, a circular cylindrical shape) to 150° , and more preferably, in the range of 90° to 150° .

Furthermore, an upwardly-protruding projection 92 in the form of a truncated cone is formed at the center of an upper surface 90 of a protector cap 88. The projection 92 is formed so as to extend to the vicinity of the outer periphery of the protector cap 88, the outer periphery of the projection 92 extending to an outer edge of the air discharge port 66. Therefore, the projection 92 is formed peripherally with an annular plane that has almost the same width as the diameter of

the air discharge port 66. Here, an angle β of an isosceles triangular section of the truncated cone shape of the projection 92 taken along the central axis is 120° in this embodiment. It should be noted that, preferably, the angle β is set in the range of 0° (that is, a circular cylindrical shape) to 150° , and more preferably, in the range of 90° to 150° .

A space 94 is bounded by the shapes of the lower surface 84 of the nozzle holder 82 and the upper surface 90 of the protector cap 88, and thus the upper and lower surfaces of the space 94 are formed in inwardly-recessed shapes by the projections 86 and 92, respectively.

In the laser machining apparatus 80 according to the third embodiment with this structure, since air from the air supply port 64 moves along the projection 86 of the nozzle holder 82, it is possible to straighten the flow of the jet liquid column F while preventing the air from the air supply port 64 from impinging directly on the jet liquid column F ejected from the through-hole 48.

Fourth Embodiment

Next, a laser machining apparatus 100 according to a fourth embodiment of the present invention will be described. The laser machining apparatus 100 according to the fourth embodiment has the same construction as the laser machining apparatus 1 according to the first embodiment except for a difference in shape of the projections.

FIG. 5 is a partially enlarged view of the laser machining apparatus 100 according to the fourth embodiment of the present invention. As shown in FIG. 5, a downwardly-protruding projection

106 in the form of a truncated cone is formed at the center of a lower surface 104 of a nozzle holder 102 of the laser machining apparatus 100. The projection 106 is formed peripherally with an annular planar portion that is located above the projection 106. Here, an angle α of an isosceles triangular section of the truncated cone shape of the projection 106 taken along the central axis is 40° in this embodiment.

Furthermore, an upwardly-protruding projection 112 in the form of a circular cylinder is formed at the center of an upper surface 110 of a protector cap 108. The projection 112 is about twice the diameter of the flow passage 42 and formed peripherally with an annular plane that is located below the projection 112.

A space 114 is bounded by the shapes of the lower surface 104 of the nozzle holder 102 and the upper surface 110 of the protector cap 108, and thus the upper and lower surfaces of the space 114 are formed in inwardly-recessed shapes by the projections 106 and 112, respectively.

In the laser machining apparatus 100 according to the fourth embodiment with this structure, the shape of the space 114 as described above offers the same advantages as the foregoing.

Fifth Embodiment

Next, a laser machining apparatus 120 according to a fifth embodiment of the present invention will be described. The laser machining apparatus 120 according to the fifth embodiment has the same construction as the laser machining apparatus 1 according to the first embodiment except for a difference in shape of the projections.

FIG. 6 is a partially enlarged view of the laser machining

apparatus 120 according to the fifth embodiment of the present invention. As shown in FIG. 6, a nozzle holder 122 of the laser machining apparatus 120 has a projection 124 in the form of a truncated cone in the same manner as the nozzle holder 82 of the laser machining apparatus 80 according to the third embodiment.

Furthermore, an upwardly-protruding projection 130 in the form of a truncated cone is formed at the center of an upper surface 128 of a protector cap 126. The projection 130 is formed peripherally with an annular plane that is located below the projection 130. Here, an angle β of an isosceles triangular section of the truncated cone shape of the projection 130 taken along the central axis is 90° in this embodiment.

A space 132 is bounded by the shapes of a lower surface 123 of the nozzle holder 122 and the upper surface 128 of the protector cap 126, and thus the upper and lower surfaces of the space 132 are formed in inwardly-recessed shapes by the projections 124 and 130, respectively.

In the laser machining apparatus 120 according to the fifth embodiment with this structure, the shape of the space 132 as described above offers the same advantages as the foregoing.

Sixth Embodiment

Next, a laser machining apparatus 140 according to a sixth embodiment of the present invention will be described. The laser machining apparatus 140 according to the sixth embodiment has the same construction as the laser machining apparatus 1 according to the first embodiment except for a difference in shape of the projection of the protector cap.

FIG. 7 is a partially enlarged view of the laser machining

apparatus 140 according to the sixth embodiment of the present invention. As shown in FIG. 7, an upwardly-protruding projection 146 in the form of a truncated cone, which is the same as that of the protector cap 88 according to the third embodiment, is formed at the center of an upper surface 144 of a protector cap 142 of the laser machining apparatus 140.

Therefore, a space 148 is bounded by the shapes of the lower surface 44 of the nozzle holder 15 and the upper surface 144 of the protector cap 142, and thus the upper and lower surfaces of the space 148 are formed in inwardly-recessed shapes by the projections 46 and 146, respectively.

In the laser machining apparatus 140 according to the sixth embodiment with this structure, the shape of the space 148 as described above offers the same advantages as the foregoing.

Seventh Embodiment

Next, a laser machining apparatus 150 according to a seventh embodiment of the present invention will be described. The laser machining apparatus 150 according to the seventh embodiment has the same construction as the laser machining apparatus 1 according to the first embodiment except for differences in shapes of the nozzle and the nozzle holder.

FIG. 8 is a partially enlarged view of the laser machining apparatus 150 according to the seventh embodiment of the present invention. As shown in FIG. 8, a downwardly-protruding projection 156 in the form of a circular cylinder is formed at the center of a lower surface of a nozzle 152 of the laser machining apparatus 150. The projection 156 is disposed inside a mounting hole 160 formed in a nozzle holder 158 and protrudes from a lower surface

164 of the nozzle holder 158. Therefore, the upper surface of a space 162 is bounded by the lower surface 164 of the nozzle holder 158 and the projection 156 of the nozzle 152, and thus the upper and lower surfaces of the space 162 are formed in inwardly-recessed shapes by the projections 156 and 40, respectively.

In the laser machining apparatus 150 according to the seventh embodiment with this structure, the shape of the space 162 as described above offers the same advantages as the foregoing.

The present invention is not limited to the above-described embodiments. While in the above-described embodiments, for example, various shapes are used for the projection located above the space (toward the nozzle) and the projection on the protector cap, a combination of these shapes may be arbitrarily set. Alternatively, the shape of the projections is not limited to the circular cylindrical shape or the truncated cone shape, and any shape such as a hemisphere shape may be used if it protrudes into the space.

While in the above-described embodiments, the projections are formed in such a manner as to protrude into the space partially from the lower surface of the nozzle or the nozzle holder and the upper surface of the protector cap, the present invention is not limited thereto, and the projections may be formed such that the lower surface of the nozzle or the nozzle holder and the upper surface of the protector cap protrude fully into the space. In short, the projection only needs to be formed on at least one portion of each of the upper and lower surfaces of the space.

While in the above-described embodiments, the air supply port is formed in the lower surface of the nozzle holder, the present invention is not limited thereto, and the air supply port may be formed in any place, such as an inner surface of the housing which is exposed at the space, if it is located above the position where the jet liquid column is injected into the space or above the most protruding position of the projection into the space, that is, above the through-hole of the nozzle holder or above the lower surface of the nozzle in the above-described embodiments. Furthermore, if the air supply port is located in the position where air supplied to the space is prevented from impinging directly on the injected jet liquid column, the air supply port does not always have to be located above the position where the jet liquid column is injected into the space or above the most protruding position of the projection into the space.

Also similarly, while in the first embodiment or the like, the air discharge port is formed in the upper surface of the protector cap, the present invention is limited thereto, and the air discharge port may be formed in an inner surface of the housing in the same manner as, for example, the protector cap in the second embodiment, if it is located below the position of the protector cap where the flow passage opens into the space or below the most protruding position of the projection into the space. Furthermore, if the air discharge port is located in the position to allow air supplied through the air supply port to be guided to the air discharge port without impinging directly on the jet liquid column, the air discharge port does not always have to be located below the opening of the flow passage into the

space or below the most protruding position of the projection into the space.

EXAMPLE 1

In the laser machining apparatus 80 with the structure of the third embodiment, a glass sheet was disposed below the laser machining head 2 and a jet liquid column F was ejected. The distance between the lowermost position of the laser machining head 2, i.e. the lower surface of the protector cap 88, and the glass sheet, was set to 25 mm, that is, the distance such that splashing of the jet liquid column F could be prevented. Furthermore, the diameter of the nozzle hole 12 was set to 60 μ m and the pressure of the jet liquid was set to 25 MPa.

Under the above-described conditions, the flow straightener 8 was operated and it was confirmed to what extent the air flow rate could be increased without causing disturbances in the jet liquid column F.

EXAMPLE 2

In the laser machining apparatus of EXAMPLE 1, the same experiment as EXAMPLE 1 was conducted using the laser machining apparatus with the angle β of the projection 92 on the protector cap 88 set to 90°.

EXAMPLE 3

In the laser machining apparatus of EXAMPLE 1, the same experiment as EXAMPLE 1 was conducted using the laser machining apparatus with the projection 92 on the protector cap 88 in the form of a circular cylinder.

EXAMPLE 4

The same experiment as EXAMPLE 1 was conducted using the

laser machining apparatus 140 with the structure of the sixth embodiment.

EXAMPLE 5

In the laser machining apparatus 140 of EXAMPLE 4, the same experiment as EXAMPLE 1 was conducted using the laser machining apparatus with the angle β of the projection 146 on the protector cap 142 set to 90° .

EXAMPLE 6

In the laser machining apparatus 140 of EXAMPLE 4, the same experiment as EXAMPLE 1 was conducted using the laser machining apparatus with the projection 146 on the protector cap 142 in the form of a circular cylinder.

Comparative Example 1

In the laser machining apparatus 80 of the third embodiment, the same experiment as EXAMPLE 1 was conducted using the laser machining apparatus having a flat lower surface 84 with the projection 86 of the nozzle holder 82 removed.

Comparative Example 2

In the laser machining apparatus of Comparative Example 1, the same experiment as EXAMPLE 1 was conducted using the laser machining apparatus with the angle β of the projection 92 on the protector cap 88 set to 90° .

Comparative Example 3

In the laser machining apparatus of Comparative Example 1, the same experiment as EXAMPLE 1 was conducted using the laser machining apparatus with the projection 92 on the protector cap 88 in the form of a circular cylinder.

Results of EXAMPLES and Comparative Examples

In EXAMPLES 1 to 6, the maximum flow of air capable of being supplied to the space without causing disturbances in the jet liquid column F was 5 L/min.

In Comparative Examples 1 to 3, on the other hand, the maximum flows of air capable of being supplied to the space without causing disturbances in the jet liquid column F were 1.5 L/min, 2.3 L/min, and 2.2 L/min, respectively.

As described above, it could be confirmed that, with the laser machining apparatus according to an aspect of the present invention, the maximum flow of air capable of being supplied to the space without causing disturbances in the jet liquid column could be increased relative to the related art.

WHAT IS CLAIMED IS:

1. A laser machining apparatus comprising a laser oscillator for generating a laser beam, a nozzle for directing a jet liquid at a workpiece, and a liquid supply unit for supplying the jet liquid to the nozzle, to machine the workpiece with the laser beam introduced into a jet liquid column ejected from the nozzle, the laser machining apparatus further comprising:

a protector cap disposed between the nozzle and the workpiece for protecting the nozzle; and

an air supply unit for supplying air to a space formed between the nozzle and the protector cap,

the protector cap having a flow passage permitting passage of the jet liquid column,

the space between the nozzle and the protector cap having a surface toward the nozzle and a surface toward the protector cap, each of the surfaces of the space being at least partially bounded by a projection that protrudes inwardly of the space.

2. The laser machining apparatus according to Claim 1, wherein the air supply unit includes an air supply port and an air discharge port, the air supply port being located around an injection port of the nozzle and in communication with the space for supplying air into the space, the air discharge port being located around the flow passage and in communication with the space for discharging air from the space.

3. The laser machining apparatus according to Claim 2,

wherein the air supply port is located toward the nozzle with respect to a most protruding position of the projection located toward the nozzle, and

the air discharge port is located toward the protector cap with respect to a most protruding position of the projection located toward the protector cap.

4. The laser machining apparatus according to any one of Claims 1 to 3, further comprising a nozzle holder for supporting the nozzle, wherein the projection of the space located toward the nozzle is formed on a surface of the nozzle or the nozzle holder, the surface of the nozzle or the nozzle holder being exposed at the space.

5. The laser machining apparatus according to any one of Claims 1 to 4, wherein the projections of the space located toward the nozzle and the protector cap each have a circular cylindrical shape or a truncated cone shape.