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Ring transformation with a new axicon lens and its laser welding of copper

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Abstract

We developed a 'New Axicon Lens' to convert from Gaussian beam profile to ring beam profile. This new axicon lens integrates a condenser lens and an axicon lens and does not have cone-point in center. New Axicon lens uses characteristics formulas which have a very small conic constant and a quadratic term that is not usually used in aspherical lens. At the same time, we also developed a tilt mechanism and the profiler to correct the deflection of the laser from the delivery fiber. In addition, we confirmed that the ring bias can be adjusted. Finally, we customized to a ring to a ring with center. By using them, we tried pure copper welding and studied welding characteristics, such as amount of sputtering.

Keywords: NIR Laser; Axicon Lens; Cupper welding; Profiler; Tilt correction mechanism

1. Introduction

With the development of laser, laser processing has come to be utilized in various fields. The welding field of copper is one of them. Although Copper is known as a difficult laser welding material, because of high reflectance in the 1 µm wavelength band (near-infrared) and its high thermal conductivity. Therefore, some

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research uses blue or green wavelength bands laser (400-500nm) which has low reflectance and high absorption. Other research uses both blue and near infrared lasers. Moreover, other research uses welding that changes the profile to a ring shape or a ring shape with a center by utilizing doble-core fiber laser instead of near infrared laser.

In this study, we developed a new axicon lens and a mechanism the tilted laser emitted from the delivery fiber. In addition, the effects on welding characteristics such as stability were investigated.

2. Development of new axicon lens and tilt correction mechanism

2.1. Optical design of the new axicon lens

It is well known that a conical axicon lens can form a ring-shape. The axicon has an apex in center and we thought apex is vulnerable to damage from high power lasers. In addition, when using an axicon lens, a condenser lens is required. We tried to optically design a new axicon lens that integrates the axicon lens and the condenser lens. Zemax OpticStudio was used for this optical design. The focal length of the collimating lens and the focal length of the condensing lens were both 200 mm, and the optical magnification was 1. Fig.1 shows the optical paths, ring profiles and cross-sectional shapes of the axicon lens with condenser lens, and new axicon lens, respectively.

The aspheric surface design formula for the new axicon lens is shown in (1). It is made of quartz and has a plano-convex shape.

$$f(x) = \frac{x^2}{r(1+\sqrt{1-(1+\kappa)x^2/r^2}} + A_2x^2 + A_4x^4 \quad (1)$$

r	200
κ	-400000
A_2	5×10^{-3}
A_4	2.5×10^{-8}

f(x) is the amount of sag, r is the radius of curvature, κ is the conic constant, A_2 is the 2nd order terms, and A_4 is the 4th order terms. The conic constant κ expresses spheres, ellipses, paraboloids, and hyperboloids.

In this new axicon lens, we succeeded in integrating an axicon lens and a condenser lens. And this lens does not have an apex in center. New axicon lens using an extremely small conic constant κ. In addition, the 2nd order terms A_2 is used to this new axicon lens which is not usually used in optical lens. The focal length is controlled by r and A_2. Like the axicon lens, it has a ring profile.

Incidentally, the conical axicon lens does not use κ, r, A_2, A_4, but uses only the 1st order term of A_1, which is not use in the equation (1).

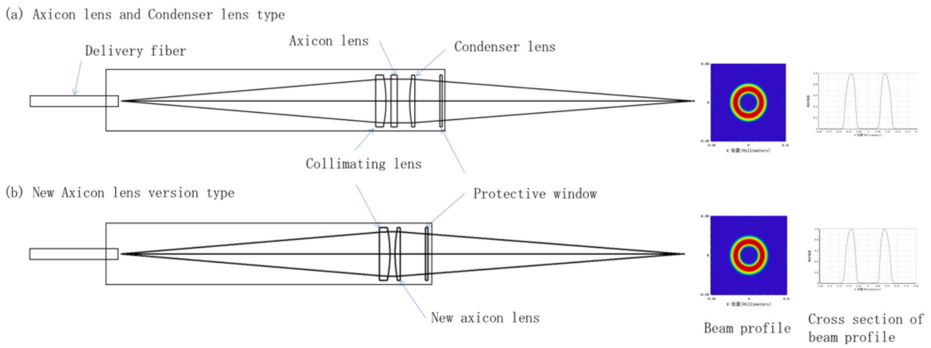

Fig. 1. Optical paths and ring profile of axicon and condenser lens, and new axicon lens

The use of such a small value for the conic constant κ is innovative to optical designers. Fig.2 shows diagram of spherical, axicon, and new axicon lens shapes.

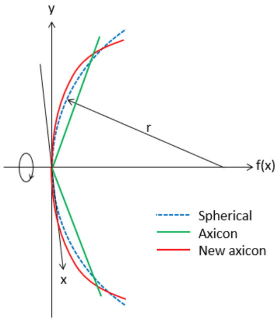

Fig. 2. Schematic diagram of spherical, axicon, new axicon

2.2. Tilt correction mechanism

The laser emitted from the delivery fiber may be tilts depending on the situation, and the maximum tilt is said to be 20 [mrad]. When this tilted laser is incident to the axicon lens, the ring intensity is biased. Fig.3 shows the calculated results for the relationship between tilted laser and the unbalanced ring intensity. Therefore, we developed a mechanism for correcting the collimator lens and new axicon lens, and a profiler for correcting the laser emitted from the delivery fiber.

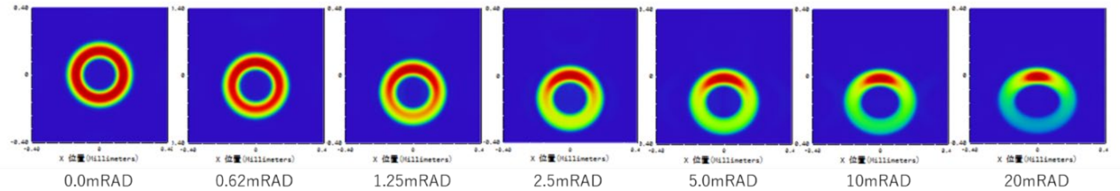

Fig. 3. Calculated results for the unbalanced ring with the tilted laser emitted from the delivery fiber

2.2.1. Tilt correction mechanism

Considering that the laser is tiltly emitted from the center of the end of the delivery fiber, we added tilt mechanism in the processing head to correct the tilt laser emitted from the delivery fiber.

2.2.2. Detachable profiler

A profiler was also developed to check and correct the unbalanced ring intensity shape. Profiler is attached to the tip of the laser processing head, it is equipped with beam splitters, ND filters and a camera. It can also be detached from the laser processing head. Laser safety is considered to ensure that the processing laser beam does not leak. While checking the unbalanced ring on the camera, the tilt mechanism adjusts the bias of the laser emitted from the delivery fiber. The correction is completed when the intensity balanced. A schematic diagram of this mechanism is shown in Fig.4. Of course, this profiler is detachable and can be removed from the laser processing head when you want use to laser processing.Fig.5 shows the PRIMES FM+ measurement results before and after ring alignment of this method. The laser is YLS-2000 made by IPG

PHOTONICS, and the delivery fiber diameter is 200 µm. We also confirmed that there are cases where the laser is not tilted, and tilt correction is unnecessary.

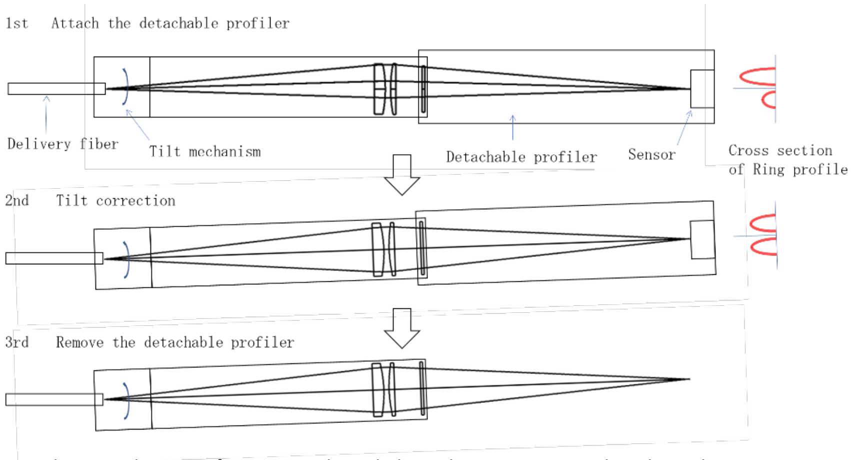

Fig. 4. Schematic diagram of correcting the unbalanced ring intensity with a tilt mechanism

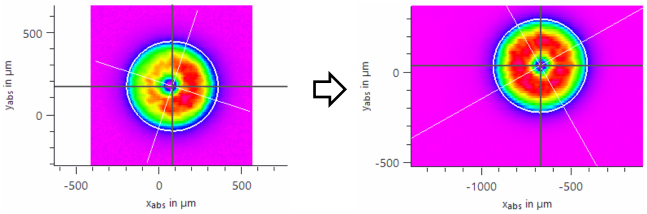

Fig. 5. PRIMES FM+ measurement results before and after about unbalanced ring correction

3. Pure copper laser welding

We created ring with center lens adding a center part to the new axicon lens. Fig.6 shows the optical design of ring with center mode calculation result. Central part of the condenser lens is a normal aspherical condenser lens, and the outer part is a new axicon lens. Moreover, studied the pure copper (C1100) welding about spatter amount and welding stability with gaussian mode and ring with center mode. Laser was used IPG PHOTONICS YLS-6000, and delivery fiber diameter is 100 µm. Gaussian and ring with center profile were measured with PRIMES FM+ by defocusing (DF) range of 0, 3 and 5 mm. The results are shown in Fig.7.

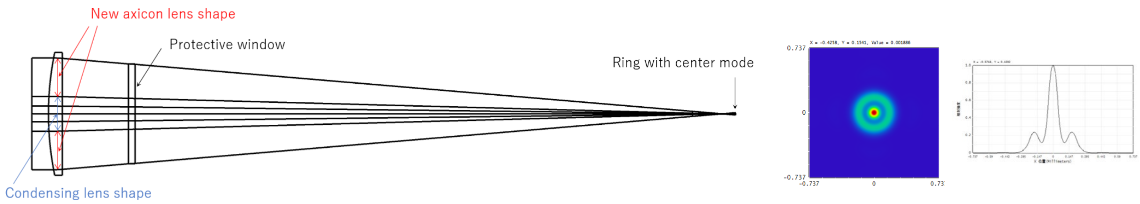

Fig. 6. Optical design of ring with center mode and calculation result

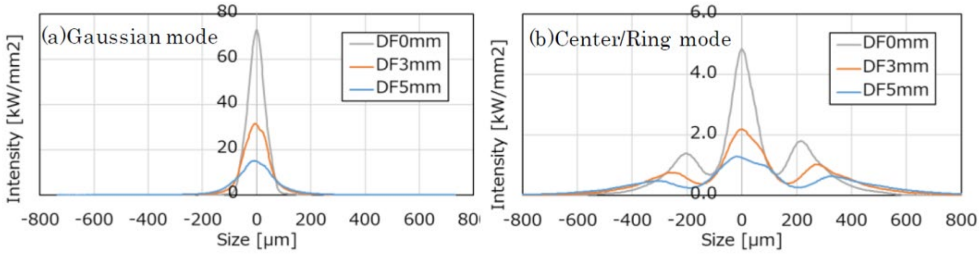

Fig. 7. Beam profile of gaussian mode and ring with center mode

3.1. Comparison of spatter generation amount

Bead-on-plate welding with a plate thickness of 1.0 mm and a sweep speed of 2 m/min was compared. Recorded the welding scene with a video camera and counted the amount of spatter during welding. Fig. 8 shows the number of spatters at a weld length of 30 mm. Spatter were decreased as the bead width widened for Gaussian and ring with center. With the same DF, the amount of spatter was smaller in the ring with center mode.

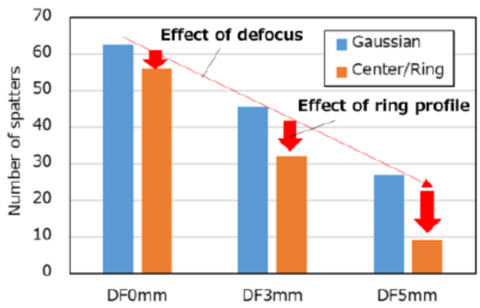

Fig. 8. Effect of beam mode on the number of spatters

3.2. Comparison of penetration stability

Lap welding with a plate thickness of 0.15 mm was compared. Fig.9 shows the results of categorized according to the penetration conditions at sweep speeds of 5 to 20 m/min. The Gaussian shape had a narrow output width of penetration welding and the penetration was unstable. The ring with center shape has a wide output range for penetration welding and stabilizes the penetration.

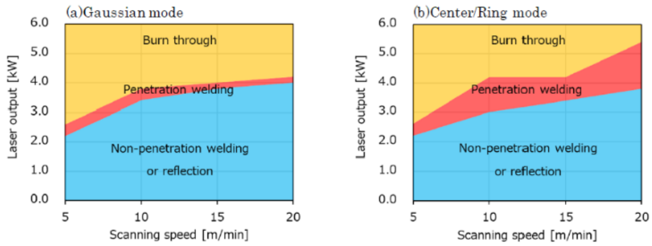

Fig. 9. Relationship between welding conditions and penetration form of 0.15mm lap welding

4. Conclusion

We have designed and developed a new axicon lens with no apex in center that integrates a condenser lens and an axicon lens. At the same time, we developed a profiler, a mechanism that corrects the tilt of the laser emitted from the delivery fiber. From them, the laser emitted from a single core was converted into a clean ring shape.

Furthermore, we made a ring with a center mode and studied the pure copper welding. The ring with center mode is effective for reducing spatter and stabilizing the penetration of thin plate welding.

Acknowledgments

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References

Andreas Heider., Peter Stritt., Axel Hess., Rudolf Weber., Thomas Graf., 2011, Process Stabilization at welding Copper by Laser Power Modulation, Physics Procedia, Volume 12, Part A, p. 81-87.

Seiji Katayama., 2020. Present State and Trend of Laser Materials Processing, Journal of the welding society, Volume 89, Number 1, p. 5-15.

Tomari Keiichiro, Maeda Kyohei, Komori Kazunori, Takemoto Masaki., 2022. Effect of beam profile in lase weldability of copper sheet, Preprints of the National Meeting of JWS, Volume 111, 304-305.

Tsuyoshi Nakamura., 2020. Green Laser Materials Processing Technology That Contributes to Carbon Neutrality, Journal of Smart Processing, Volume 9, Number 2, p. 63-68.