ROBOT ASSISTED AUTO LASER WELDING MACHINE

FIELD OF THE INVENTION

BACKGROUND OF THE INVENTION

In one application, it is required to laser welding a stainless-steel capillary tube of OD0.29mm, ID0.09mm; onto another sleeve holder tube of OD 1.7 ID0.295mm at the two parts left end-surface with fully automatic processing, as shown in Fig 1. Hermetic sealing between the capillary inner cavity and the sleeve are required at high pressure environment, while the inner cavity edge must be kept clean from weldment or spatters. The objectives drive the development of the innovative customized laser micro welding machine with 6-axis robotic arm auto loading/unloading system, as there are no prior arts readily available to perform this task.

PRIOR ART

In the prior art 1 WO2022/182896 A3 (Refer fig 2.), the welding is carried out by the seam already present in the actual part (which acts as guiding line), through which the welding path continues. Our machine logic lies on the principle of precise auto alignment of part without any prior seam path, ensuring good and uniform weld quality with consistency.

In the prior art 2 US 8322591 B2 (refer fig 3), the mentioned automated system consist of pair of robots, one for pick and place and other for welding purpose. Also its capability is restricted only for cuboidal workpieces. Our invention trumps ahead in terms of capability to weld the circular weld of two workpieces together with precise alignment.

TECHNICAL FIELD

The invention discussed pertains primarily to laser material processing, a method widely adopted across industries for tasks such as marking, welding, cutting, ablating, and cleaning due to its speed, adaptability, and non-contact nature. The process involves directing a focused laser beam through a set of optical mirrors and focusing lens onto the object surface to remove or melting and resolidify the material to form the marks or weldment or ablate out material for different applications. The early models of laser processing machines with manual operation features do not meet the requirement of increased parts production quantity and the reduced parts dimension, especially with the advanced manufacturing environment of Industrial 4.0.

As shown in Fig 1, the capillary tube part (1) and the sleeve part (2) are in the dimensional scale of micro-meter level, manual operation of laser welding is not able to meet the required accurate alignment and processing speed. The proposed system setup consists the precision fiber laser welding system and granite-table based servo motor motion system and the automatic robotic arm loading unloading system, together with the automatic part holding and alignment fixture and machine vision system with high magnification vision lens. The full welding machine must be controlled by the PC software with user-friendly user interface (UI) for programming all the laser micro welding process parameters and processing sequence.

DESCRIPTION OF INVENTION

The invention is a precise automatic laser welding machine with automatic loading unloading robotic arm system. One embodiment of the invention consists of a customize designed automatic material micro welding system and a 6-axis robotic arm loading unloading system for the targeted stainless steel micro tubes (figure 1) welding. It aims to enhance functionality and streamline production time through compact or all-in-one system design. The embodiment overall isometric view is illustrated in Fig 4. Its internal

overall view is illustrated in Fig 5. The embodiment accommodates all necessary system and sub-modules and components to perform the automatic laser welding processing for the sample capillary tubes Part(1) and Part(2) showing in Fig 1. Content of present embodiment tool includes:

- A fully closed safety enclosure (1), refer to Figure 4, made of metal tube and panels assembled together with swinging doors, ventilation slots (3), laser safe eye protection window windows (2), and control PC and keyboard mouse set (KVM) (4). The enclosure is to protect the operator and all observant and the surroundings from potential high power laser radiation leakage and moving components inside the cabinet caused hazard.
- Fiber Laser source generator and laser welding head with optics
- Refer to Fig 5, an XYZ servo motor precision motion stage integrated onto granite table (5)
- Machine vision system to check the capillary tubes Part(1) and Part(2) end face alignment before welding processing and checking the weldment quality after the welding process
- Automatic robotic arm loading unloading system, and the parts holding trays (6)
- Automatic part holding and alignment fixture (item 26 of Figure 11) integrated to the XYZ stages
- Compact all-in-one PC with touch panel monitor Fig 4 item (4)
- Software with the integration of the XYZ motion control and laser welding process parameter setting, and robot motion control software, machine vision control software, and other IO modules as shown in Fig 17.

The full working sequence is described as below:

When the production starts, the integrated robotic arm and end effectors will automatically scan and register the work pieces pre-loaded into the loading trays, then the robot will load the work piece to the laser welder jig fixture one by one for the welding process. Once a workpiece is loaded onto the laser welder, the welder will in sequence to check the parts alignment in the jig fixture, correct the position according to the vision checking result, and laser welding the loaded parts together with the

integrated XYZ motion stages. After the welding, the machine vision system comes in again to check the weldment quality and indicate the welded parts are good part or no-Good (NG) part. Then the checking result will be passed to the robot arm to do the unloading process. The robot arm then collects the welded part and place it to the good part tray or the NG part tray accordingly. After the whole loading trays of the work pieces finished welding and unloading, the machine control program will send the alarm signal to operator for processing the next batch production.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is made more apparent with reference to a preferred embodiment with the aid of the drawings. The drawings are listed below:

Figure 1	Is the illustration for one sample capillary tubes to be welded
Figure 2	Is the illustration for prior art 1 control diagram
Figure 3	Is the illustration for prior art 2 overall system
Figure 4	Is the overall view of the embodiment auto laser micro welding machine for the sample capillary tubes as shown in Fig 1.
Figure 5	Is the internal view of the embodiment auto laser micro welding machine after removing the safety enclosure
Figure 6	Is the front view of the embodiment auto laser micro welding machine
Figure 7	Is the left side view of the embodiment auto laser micro welding machine
Figure 8	Is the embodiment overall view of the laser welding system integrated onto the solid granite XYZ stages
Figure 9	Is the laser welding head and machine vision systems of the embodiment
Figure 10	Is the illustration of the linear motion stages X, Y, Z and the rotational A and B positioner of the embodiment auto laser welding machine
Figure 11	Is the sample capillary tube parts grippers components of the embodiment auto welder
Figure 12	Is another rotary positioner stage integrated onto the embodiment laser welder for another type of tube part welding

Figure 13	The touch panel control PC and keyboard and mouse assembly of the embodiment
Figure 14	Is a 6-axis robotic arm auto loader/unloader of the embodiment
Figure 15	Is a sample parts loading tray of the embodiment
Figure 16	Shows the platform to holding the parts loading tray, which spaces up the tray from the robot mounting table, so the parts inside the tray are within the robot arm reach
Figure 17	Shows the PC software UI for the operation of the embodiment auto laser welder
Figure 18	Shows the visual effect of the integrated machine vision system on the sample part before and after the auto laser welding by the embodiment

DETAILED DESCRIPTION OF THE INVENTION

Figure 4 and 5 serve as a general overview of the embodiment auto laser micro welding machine. The embodiment machine depicted in Figure 6 measures 1580mm in length, 1110mm in width, and 1902mm in height. It features ten safety swinging doors (1), and three laser safe eye protection windows (2) in the upper block, and nine doors with ventilation slots (3) for air circulation in the lower cabinet which houses the machine control components like the circuit breaker, and IO modules, and the fiber laser generator module. The installed semi-transparent laser safety windows(2) filtered out the high power laser wavelength about 1070nm, and give visible light spectrum transmission about 40-60%, thus enables safe operation of the machine without the need for laser safety goggles and facilitates easy monitoring of the auto laser welding processing from outside. The integrated touch panel PC and KVM (4) at the front left corner of the machine enable operators to control the machine setting via the software interface as shown in Fig 17.

Figure 5 illustrates the machine without its upper enclosure. To prevent laser micro welding inaccuracies caused by vibrations caused by the robotic arm motion, the embodiment laser welding machine is divided into two portions: the left side one (5) for laser welding system integrated onto solid granite base and the bottom cabinet rest onto the production floor via the four sets antivibration foot-mounts (7); and the right side portion (6) for robot transportation of the work pieces which are rest on the floor via another 4 sets of antivibration foot-mounts (7). The antivibration foot-mount (7) also serve as the machines levelling adjusting tools. These foot-mounts (7) are equipped with rubber pads at bottom to absorb vibrations during production, with their size determined by the machine's dimensions and weight. The machine can be easily switched on and off by the main roller switch (8) installed on the bottom cabinet panel under the control PC.

The integrated touch panel PC and KVM (4) at the front left corner of the machine allows users to control the system, set laser working parameters, XYZAB motion parameters, the robotic arm settings,

the IO modules etc, and monitor welding results visually. It provides control over the entire machine and production process. A few E-Stop buttons are installed at the machine enclosure outer surface and the touch panel PC bottom panel. In case of emergence situation, the machines moving components, both the XYZAB motion stage (9) and robot movement (10), and the laser firing can be immediately disabled by press down any of the E-Stop buttons. A few USB ports and network ports are linked out from the PC to the bottom panel of the PC housing to facilitate file import/export and communication with external machines or devices. The tower light (11) integrated to the machine IO modules can indicate machine status: green for normal operation, orange during initialization, and red for errors.

From Figure 6, it illustrates that the left cabinet (9) houses the laser welding XYZ linear stages, and another two rotational positioner AB, and the parts grippers (details in Fig 11). The right cabinet (10) houses the 6-axis robotic arm auto loader unloader and the parts loading trays for the capillary tubes. Safety curtains sensors are installed in between the robot movement path at the junction of the left and right portion top cabinet. The Safety curtains sensors works as safety interlock to prevent the XYZAB stages movement while the robot arm entering the left side cabinet for loading unloading or position teaching tasks.

This embodiment adopted the ABB robot model IRB1200-5/0.9, with 5kg load carrying capacity and 900mm arm reach. Inside the enclosure bottom cabinet (12), there are the laser fiber source, power supply for the controller, for the laser, and electrical components like the MCB switch and safety relays, sensor amplifiers, etc..

There are ten sets swinging doors (1) mounted on the upper portion of the machine enclosure. All doors can be closed and locked easily with a door knob (13) and key switch indicated in Figure 7. There are nine sets swinging doors (12) mounted on the lower portion of the embodiment machine. The lower door panels have many through slots, which is designed to let the warm air inside the cabinet to flow to the outside, and fresh air enters the inside to cooling the control devices inside the bottom cabinet. Safety interlocks are installed for all the top enclosure swinging doors. If any of the doors are not properly

closed, the door interlocks will trigger the safety relay to disable the XYZAB stages movement and the laser firing.

Figure 8 illustration shows that embodiment machine consists several other key components on the XYZ linear stages: a rotary workpiece jig (Jig 14) facilitates the 3-dimensional welding by rotating and securely holding another sample tube parts. A shielding gas flow meter (15) regulates and displays the flow of argon gas to safeguard the weld area from oxidization during the laser welding processing. A coaxial camera and lens system (16), situated at the top of the laser welding head(17), transfers the parts top surface images of the laser welding process to the software interface (49 in Figure 17), providing operators with visual feedback and the ability to adjust parameters, and adjusting laser focusing position.

A second machine vision system with CCD camera and lens and lighting system (18) is installed on the right side of the coaxial camera lens and the laser welding head (17). To ensure the parts alignment with higher accuracy, high magnification lens (0.7X~ 4.5X zoom lens) is installed for this off-axis vision system. The off-axis high resolution vision system works for both parts alignment before welding, and the weldment quality checking after the laser welding. To get the good image quality for the imaging processing with the same machine vision system under the different object condition, the different exposure time setting are used for the alignment process and the QC checking process. For each parts welding, the high resolution off-axis vision system captures at least 3 images of the work piece top end surfaces: one before welding (55) and two after welding (56) (57) of Figure 18, with different exposure times ranging from micro-seconds(us) to mili-seconds (ms). The first image (55) shows the initial setup after the robot positions a work pieced onto the welding jig (26) with a longer exposure time, like 15ms or 15000us. The subsequent images depict the situation after software auto adjusted the concentricity alignment stage movements to have repeating alignment adjusting. The second image is taken after the laser welding with an exposure time, like 8ms or 8000us, for the trained software to determine weldment quality, marking "true" for good welds and "false" for bad ones. After the QC checking, the third image is taken with a further shorter exposure time, like 4ms or 4000us. The third image is only for manual

inspection reference as production traceability purpose, in case the auto QC part are found NG during the double checking period by the QC auditors. Furthermore, users have the flexibility to manually capture images and adjust exposures to reach the best weldment feature via the software interface (Figure 17). During machine system setup, users can manually adjust the focus of each camera using the lenses (19) and (20). The robot places the two capillary tube part (1) and part(2) (in Figure 1) concurrently into workpiece jigs (21), The jig (21) consists two sets of grippers which designed to hold the two capillary tube parts concentrically, with the top gripper to hold the bigger diameter sleeve part(2) of Figure 1, and the bottom gripper to hold the smaller diameter capillary tube part(1) of Figure 1.

The bottom jig gripper is integrated onto a fine adjustment XY stages with travel range of about 1mm, in case the self-centering of the two tube parts is not meet the concentricity tolerance, the system will automatically adjusting based on off-axis vision system measured offset value of ΔX and ΔY. This alignment can also be visually confirmed after a second snap.

Figure 9 illustrates the vision and laser head module setup in a close-up view. The fiber laser beam collimator module(22) passes the laser beam through two internal mirrors (23) and (24) then reaches the focusing tube (19). On top of the focusing tube (19), there is the coaxial vision camera and lens module (16). The internal mirror 24 works as a beam splitter to deflect the IR laser beam down to the work piece, and transmit the visible light to the top side coaxial camera and lens system. With this coaxial vision system, the work piece real-time welding image can be captured and displayed on the machine control software UI sub-display window (49) as shown in Figure 17.

The second machine vision system (18) with CCD camera and high magnification lens (0.7X~ 4.5X zoom lens) module is installed to the right side of the coaxial camera lens and the laser welding head (17). It is functioning as the pre-alignment checking and after welding weldment quality checking off-axis vision system. With the lens high magnification function, the optical resolution can achieve about 1 micro-meter.

Figure 10 illustrates that the granite-based motion system. It consists of X, Y, and Z linear axes, also consists the rotary A-axis and B-axis on the jig for other types of welding applications. All the 5-axis movement parameters can be controlled via the customized software UI as shown in Figure 17 item (54).

Figure 11 illustrates jig fixture for welding the sample capillary tube part (1) and sleeve part (2) (refer to Figure 1). The jig fixture assembly (26) comprises top (27) and bottom (28) grippers for holding the larger sleeve part(2) and smaller capillary tube part (1) respectively. The two parts (1) and (2) are pre-assembled with the capillary part (1) protruding out from the top surface of the sleeve part(2), and the robot arm grippers carry them together to position them into the welding jig fixture (26). After the top (27) and bottom (28) grippers activated and holding the two parts, then the robot arm grippers release, and the robot returns to the standby position. Then the alignment swinging bar (25) activated to rotate for 90degree and press the capillary tube part (1) move down against the sleeve part(2), and finally stops at the top surface of the sleeve part(2). This ensures both tubes top end-surfaces are levelled and flat. Next, the off-axis vision system is called in and align to the tubes top end-surfaces, and capture the image and calculate the two tubes concentricity offset ΔX and ΔY. Further next, the fine tuning XY stage (30) automatically adjusts smaller capillary tube move half of the ΔX and ΔY value to get the two tubes to be concentrically aligned.

Figure 12 depicts another set of rotary jig fixture for other types of tube welding, which is an optional feature for future parts of the machine. This rotary jig fixture has been covered in another PCT application: "AN APPARATUS FOR LASER WELDING TWO FREE RUNNING TUBES AND METHOD OF USING THE SAME", with the application filing No: PCT/SG2024/050187.

Figure 13 illustrates the all-in-one control PC for the machine. It is integrated to the machine body via a swinging arm, for easy access the working area during position teaching or trouble-shooting. The PC is hold by a metal cabinet. There are control buttons and switches installed below the PC. The key switch (36) is to on/off the controller and the PC. A green LED (37) indicates readiness of the software and machine, while a red LED (38) signals laser firing, prompting caution are required despite safety windows. Item (39) is the E-Stop button, under emergencies, pressing down the E-Stop (39) will shut down all stage, robot movements, and laser firing. To reset errors, operators press the reset button (40), stop cycles with the red button (41), and initiate a production cycles with the green button (42).

Figure 14 illustrates the Robot (ABB IRB1200-5/0.9) used in the system. It consists the double gripper(43) to pick up the pre-arranged two parts together from the two parts trays (44). Then it will place the two parts (the smaller capillary tube part(1) and the larger tube sleeve part(2)) onto the welding jig fixture (26).

Figure 15 illustrates parts tray alignment method. Three toggle clamps (45) secure the parts tray on the platform. Operators can conveniently remove trays by loosening the clamps and carrying them away from the platform. After placing the parts tray onto the racks (46), users must ensure the tray present sensors (47) are activated upon placing the trays on the platform. Each tray can hold 20 tube parts, with a total of 40 tubes for a complete production cycle using two trays.

Figure 16 illustrates the spacer platform under the parts tray. The spacer platform function to lift up the parts trays from the robot mounting base plate, so the robot can pick the tube parts without crossing its dead angles.

Figure 17 is the illustration of the embodiment machine control Software user interface (UI). The software UI consists a few sub-display windows on the same PC screen, including the high magnification alignment and QC vision camera view (48), the coaxial vision camera view (49), the system log display (50), error messages display (51), program buffer status (52), and the weldment QC verification box (53). Operators can view before and after welding images (48) and check tube tolerances and locations in the

QC verification box (53). Additionally, users can manually control tube location verification and camera image capturing and saving to the PC or USB storage device. The QC camera view(48) and coaxial camera view (49) can be activated, allowing operators to align the laser beam onto the desired reference position on the object center. The buffer display (52) enables troubleshooting of stage movement errors. The system log display (50) records all process steps for trouble shooting in case any welding defects happens. Upon completion of a production cycle, the buzzer signals up, to remind the operators to come in and replace the empty trays onto the platform (figure 15), and restart production by initializing the software and pressing the start button (42).

Although the present invention has been described with reference to presented embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

CLAIMS

What is claimed is:

1. A motorized auto welding machine for welding two circular tubes at the end surface with the multi-axis robotic arm auto loader system, comprising a laser and beam guiding and focus welding head, a multi-axis linear or rotary stages to move the laser beam or the work piece at pre-programed trace while focusing the laser spot to the joining area of the work pieces to form the weldment, a multi-axis robotic arm loading system to auto loading the work pieces to the jig fixture, and unload the welded part, an auto jig fixture system to auto align and hold the work pieces, and a programable controller to set all process parameters and the machine working sequence.

2. The auto welding machine according to claim 1, further comprising a coaxial machine vision system (16) providing real-time visual feedback of the welding process to operators.

3. The auto welding machine according to claim 1, further comprising an off-axis machine vision system (18) providing further magnified view of the registered fiducial marks or the work piece feature for auto alignment of the work pieces before the laser .

4. The off-axis machine vision system (18) according to claim 3, further comprising the QC checking functions for the weldment and workpiece dimensions.

5. The off-axis machine vision system (18) according to claim 3, has the programming capability of adjusting the exposure parameters to capture the images with different settings to checking different features inside the same workpiece for different usage.

6. The two circular tubes to be welded according to claim 1, further comprising one smaller tube and bigger tube whereas the smaller tube can be inserted into the bigger tube's inner cavity.

7. The two circular tubes welded according to claim 1, further comprising a full sealed weldment with or without hermetic sealing requirement, or just consists some spot welding or partial weldment.

8. The multi-axis robotic arm auto loader system according to claim 1, At least one loading tray with customized holding spots for at least 2 sets of workpieces for welding.

9. The multi-axis robotic arm according to claim 1, further comprising programable workpiece grippers at the end effector to be able to pick up the two tube parts concurrently with self centering capability

10. The auto jig fixture system according to claim 1, further comprising two sets of programable workpiece grippers separately mounted with self centering capability, with which at least one set of the grippers can be auto adjusted along at least one direction with the machine vision calculated offset values or from other devices with wired communication method or wireless communication method.

11. The welding head according to claim 1, further comprising a shielding gas flow meter or flow regulator (15) to program the require welding protection gas flow to the welding area.

12. The multi-axis linear or rotary stages according to claim 1, further comprising granite table based motion stages with at least one linear motion stage or rotary stage for precision motion and laser synchronize control to form the required welding seam or welding spots via the programable controller.

13. The auto welding machine according to claim 1, further comprising an integration Software system with user friendly windows interface allows for manual control of various parameters, image capture, exposure adjustments, and monitoring of system status.

14. The auto welding machine according to claim 1, further comprising a laser safety enclosure and at least one set of laser safe viewing windows

15. The laser safety enclosure according to claim 14, further comprising emergency stop buttons, error reset mechanisms, and safety interlocks, status indicators to ensure operation safety.