

Description

Title of the invention: Method and corresponding device for welding a sealing membrane for a tank

Technical field

5 [0001] The present invention concerns the field of tanks intended to store and/or transport gas in the liquid state, for example liquefied natural gas (LNG), in particular for sea or river transport and terrestrial tanks. To be more precise, the invention concerns a method for welding a sealing membrane suitable for such a tank. The invention also concerns the associated welding device.

10 Technological background

[0002] Tanks for transporting gas in the liquid state each have a capacity of several thousand cubic metres of gas in the liquid state, even a plurality of tens of thousands of cubic metres of gas in the liquid state. Ships for transporting liquid gas have holds specifically adapted to contain these tanks, their holds often being partitioned to form a plurality of tanks. Such a tank can equally be produced for a ship or for terrestrial storage of natural gas in the liquid state. The gas therein is maintained in the liquid state, for example at -163°C (degrees Celsius) at atmospheric pressure in the case of LNG. The tank therefore has to be sealed and thermally insulated. Because of this the internal surface of such a tank is covered by a sealing membrane generally consisting of an assembly of metal (typically stainless steel) sealing plates welded together, each sealing plate being a part of the sealing membrane of the tank.

[0003] A welding machine is used to weld these metal plates to one another which an operator must cause to follow the edges of these sealing plates disposed two by two in a manner adjacent to one another (this is known as a fillet welding/assembly) using a guide rail. The operator starts a program on the machine and the latter, equipped with a welding torch, welds the edges of the sealing plates as it moves along those edges, continuously adjusting the distance between the welding torch and the parts to be welded using a positioning sensor mounted on the machine.

[0004] Known methods for assembling these metal plates to form a sealing membrane are plasma welding or TIG (tungsten insert gas) welding. TIG welding is an arc welding process using a tungsten electrode, if necessary with a filler metal. This welding process produces large quantities of metal oxides on the edges of the sealing plates, which can in the long term degrade the integrity of the membrane by corrosion. It is then necessary to brush the welds after the welding step. Such a step proves lengthy and tedious.

35 [0005] A solution for improving productivity is to employ laser welding. Laser welding consists in raising the temperature of the metal to a precise value so that the metal reaches its melting point and begins to melt. Laser welding is based on extremely concentrated light that causes the metal to begin to melt. This light is emitted at a certain wavelength. For example in fibre optic laser welding the wavelength can be 1064 nanometres.

- [0006] However, laser welding has a very small tolerance in respect of the assembly clearance. In other words, to weld two metal plates to each other in order to form a sealing membrane an edge of an upper metal plate is superposed on an edge of a lower metal plate to form a processing line. For optimal welding it is desirable for the height between the lower surface of the upper plate and the upper surface of the lower plate to be close to 0 mm. In other words, the clearance between the two metal plates must advantageously be close to 0 mm. This is generally not the case and this clearance can vary from one pair of metal plates to another along the line for processing a pair of metal plates. This clearance can be of the order of a few tenths of a millimetre. Such variability of the assembly clearance is unacceptable in laser welding because such clearances constitute an obstacle to the proper distribution of heat at the level of the welding point, thereby preventing the metal of the two plates being joined at this point.
- [0007] The invention aims to alleviate some or all of the aforementioned problems by proposing a new continuous laser welding method compatible with the variability of the assembly clearances of the metal plates without human intervention. Such a method makes it possible to profit from the good productivity of laser welding by accommodating the assembly clearances.
- [0008] To this end the invention has for object a method of welding an edge of a first plate extending in a first plane and an edge of a second plate superposed on the edge of the first plate along a processing line extending along a first axis in the first plane using a welding device mobile above the processing line including a welding torch adapted to emit a laser beam, the welding method including, for each point along the processing line:
- a first step of determining a height difference along a second axis perpendicular to the first plane between the upper surface of the edge of the first plate and the lower surface of the edge of the second plate;
 - a second step of modifying at least one welding parameter of the welding torch as a function of the height difference determined if the height difference determined is above a predefined threshold;
 - a third step of welding the edges of the first plate and the second plate;
 - a fourth step of moving the mobile welding device.
- [0009] The height difference along the second axis represents the assembly clearance between the two plate edges to be welded. Thanks to the method according to the invention the assembly clearance is determined at each point along the processing line. If this assembly clearance is greater than a predefined value, for example of the order of 0.1 or 0.2 millimetres, corresponding to a value for which optimal laser welding is not possible, at least one welding parameter is modified in order to enable welding of the two plate edges. In other words, as soon as an assembly clearance between the two plates is detected the welding method according to the invention enables adaptation of one or more welding parameters to guarantee correct melting of the metal of the plates necessary for the required welding quality.
- [0010] In one embodiment of the invention the welding method includes after the first step of

determining the height difference a step of storing the height difference. This storage step has the advantage that it enables determination of the height difference for all or part of the processing line before undertaking the successive welding steps.

[0011] In the welding method according to the invention the at least one welding parameter includes at least one of the following: the orientation of the laser beam relative to a normal to the first plane, the movement of the laser beam, the power of the laser beam and the frequency of the pulses of the laser beam. The modification step can therefore include modification of one or more of these parameters. The step of modifying the welding parameter or parameters makes it possible to control the input of the right quantity of energy per unit surface area to weld the two plates despite the presence of an assembly clearance. This energy input depends on the local height difference between the two plates to be welded. As a result of this the material is heated to the correct level for local melting of the material of the plates and compensation by this modification of the existence of the assembly clearance.

[0012] Furthermore, this modification of the welding parameter or parameters being carried out for each height difference detected, the welding method according to the invention allows permanent modification of the parameter or parameters and makes it possible to adapt locally the quantity of energy required to work continuously.

[0013] The aforementioned modification of the parameter or parameters also makes it possible to simplify the welding kinematic since it does not involve repositioning the welding head.

[0014] In the welding method according to the invention the at least one welding parameter includes at least one of the following: the height between the welding torch and the processing line and the orientation of the welding torch relative to the normal to the first plane. In this variant the orientation of the welding head and/or the distance to the processing line can vary. The advantage is being able to maintain an optimal welding angle, which is to say that the laser beam is situated in a circular cone the apex of which coincides with the point to be welded at an angle between 0° and 45° , preferably 15° to 30° , around the normal to the processing line at the point to be welded.

[0015] The welding method according to the invention advantageously includes before the first step of determining the height difference a step of determining a distance between a reference point of the position sensor and at least one point on the second plate. This determination step enables evaluation of the distance at which the welding torch is situated relative to the processing line. This distance evolves in particular when the plates to be welded include corrugations, also referred to as waves, as may be the case for sealing membranes for tanks intended to store and/or transport liquefied gas.

[0016] Thus the welding method according to the invention can include a step of modifying the power of the laser beam as a function of the distance determined if the distance determined differs from the distance determined for the previous point along the processing line, for example a sign of passing over a corrugation. Taking into account the distance to the processing line makes it possible to carry out the welding with a vertical welding head and at the same height by causing the focusing point and power of the beam to vary. This adaptation is necessary because the laser beam is not perpendicular to the surface to be

welded, resulting in a loss of energy coming from the laser. This results in a focal spot of more oval shape and the power provided by the laser is distributed over a larger spot. Modification of the power of the laser makes it possible to counter these effects.

[0017] Alternatively, the welding method according to the invention can include a step of orienting the laser beam as a function of the distance determined if the distance determined differs from the distance determined for the previous point along the processing line, also a sign of passing over a corrugation.

[0018] The steps of modification of the power of the laser beam as a function of the distance to the processing line are obviously cumulative with the step of modifying one or more welding parameters as a function of the locally determined height difference.

[0019] The invention also relates to a mobile welding device intended to weld an edge of a first plate extending in a first plane and an edge of a second plate superposed on the edge of the first plate along a processing line extending along a first axis in the first plane, the mobile welding device including a welding torch adapted to emit a laser beam and means for modifying at least one welding parameter of the welding torch as a function of a height difference along a second axis perpendicular to the first plane between the upper surface of the edge of the first plate and the lower surface of the edge of the second plate if the height difference is above a predefined threshold.

[0020] In the mobile welding device according to the invention the at least one welding parameter includes at least one of the following: the orientation of the laser beam relative to a normal to the first plane, the movement of the laser beam, the power of the laser beam and the frequency of the pulses of the laser beam.

[0021] The mobile welding device according to the invention advantageously further includes a position sensor adapted to measure the height difference along the second axis perpendicular to the first plane between the upper surface of the edge of the first plate and the lower surface of the edge of the second plate. The position sensor incorporated in the welding device has the advantage of measuring the height difference continuously and at all points along the processing line. This information is directly transmitted to the means for modifying the welding parameter or parameters, enabling them to be modified at the exact moment at which the welding torch welds at the point on the processing line exhibiting said height difference. This results in laser welding that adapts to the assembly clearances present between two plates to be welded.

Brief description of the figures

[0022] These and other features and advantages of the present invention will become more clearly apparent from the following description given with reference to the appended drawings, which are provided by way of non-limiting example and in which:

[0023] Figure 1 represent a view in section of a first metal plate and an adjacent second metal plate intended to be assembled by welding them together;

[0024] Figure 2 represents a device according to one embodiment of the invention for welding a sealing membrane employing a step of welding a sealing plate to an adjacent sealing plate;

[0025] Figure 3 is a diagram representing the steps of the method according to the invention for

welding two metal plates;

[0026] Figure 4 is a representation in section of the step of determining the height difference between the two plates to be welded in one embodiment of the present invention;

[0027] Figure 5 is a representation in section of the step of determining the height difference between the two plates to be welded in accordance with another embodiment of the present invention;

[0028] Figure 6 is a diagram representing a welding torch using a laser beam and including a reflection module;

[0029] Figure 7 represents one embodiment of the step of welding plates by the method according to the invention;

[0030] Figure 8 represents another embodiment of the step of welding plates by the method according to the invention;

[0031] Figure 9 is a diagram representing welding two plates with no assembly clearance by the method according to the invention;

[0032] Figure 10 is a diagram representing welding two plates with an assembly clearance by the method according to the invention.

Description of embodiments

[0033] For clarity, the same elements bear the same references in the various figures.

[0034] The features, variants and embodiments of the invention as described or to be described in the following detailed description can be associated with one another in various combinations provided that they are not incompatible or mutually exclusive. Variants of the invention can in particular be conceived of having only a selection of the features described hereinafter separately from the other features described if that selection of features is sufficient to procure a technical advantage and/or to differentiate the invention from the prior art.

[0035] Figure 1 represents a view in section of a first metal plate 11 and an adjacent second metal plate 21 intended to be assembled together by welding. The first plate 11 extends in a first plane P1. An edge 22 of the second plate 21 is superposed on an edge 12 of the first plate 11 along a processing line 30 extending along a first axis Y in the first plane P1. As can be seen in figure 1 the first metal plate 11 and the adjacent second metal plate 21 intended to be assembled together have an area 15 of overlap. In this overlap area the first plate includes a plane edge 12. To enable such an overlap the second plate 21 includes a joggle 23, that is to say a raised portion of a lateral edge of the second plate 21 so that the raised portion of the lateral edge of the second plate 21 is superposed on the lateral edge 12 of the first plate 11 at the level of the overlap area 15. The welding step produces a weld line at the level of the processing line 30 so as to assemble the second plate 21 and the first plate 11 in a sealed manner.

[0036] For optimal welding it is desirable for the height difference 31 between the lower surface 24 of the upper plate 21 and the upper surface 14 of the lower plate 11 to be close to 0 mm. In other words, the clearance between the two metal plates 11, 21 must ideally be zero, that is to say equal to 0 mm. As mentioned above, this is generally not the case. Not only can

this clearance vary from one metal plate to another but this clearance can also vary along the processing line 30 for a given pair of plates.

[0037] Figure 2 represents a device 7 according to the invention for welding a sealing membrane employing the method according to the invention of welding a sealing plate to an adjacent sealing plate. This representation is highly diagrammatic with the aim of disclosing the invention. The distance between the position sensor 73 and the welding torch 72, that is to say the distance between the points A and B, is generally of the order of 2 cm to 15 cm.

[0038] The welding method according to the invention employs a welding device 7 that is mobile above the processing line 30. The welding device 7 includes a welding torch 72 adapted to emit a laser beam. The welding device 7 further includes means 74 for modifying at least one welding parameter of the welding torch 72 as a function of a height difference 31 along a second axis Z perpendicular to the first plane P1 between the upper surface 14 of the edge 12 of the first plate 11 and the lower surface 24 of the edge 22 of the second plate 21 if the height difference 31 determined is above a predefined threshold.

[0039] The welding device 7 can further include a position sensor 73 adapted to measure the height difference along the second axis Z perpendicular to the first plane between the upper surface 14 of the edge 12 of the first plate 11 and the lower surface 24 of the edge 22 of the second plate 21.

[0040] Alternatively, the welding device 7 may not be provided with a position sensor. In this variant the successive height differences 31 along the processing line are predetermined and stored on a storage medium in the welding device or on a remote server. The height difference 31 associated with each point on the processing line is accessible to the modification means 74 to enable the method according to the invention to be used.

[0041] The welding device 7 can be moved along a rail 3 that follows the edge of the second plate 21 above the processing line 30.

[0042] Figure 3 is a diagram representing the steps of the method according to the invention of welding two metal plates. The welding method according to the invention includes for each point along the processing line 30:

- a first step 110 of determining a height difference 31 along a second axis Z perpendicular to the first plane P1 between the upper surface 14 of the edge 12 of the first plate 11 and the lower surface 24 of the edge 22 of the second plate 21;
- a second step 120 of modifying at least one welding parameter of the welding torch 72 as a function of the height difference 31 determined if the height difference 31 determined is above a predefined threshold;
- a third step 130 of welding the edges 12, 22 of the first plate 11 and the second plate 21. The step 130 is a step of fillet welding the edges of the plates 11, 21 using the welding torch 72. During this welding step, the plates 11, 21 are welded by melting the material of the edge of the plate 21 onto the edge of the plate 11.
- a fourth step 140 of moving the mobile welding device 7.

[0043] For a given point on the processing line 30, if the height difference 31 is 0 mm the edges 12, 22 are welded at this point. However, if at this point the height difference 31 is non-

zero the step 120 of modifying at least one welding parameter of the welding torch is carried out. The modification of the welding parameter or parameters depends on the height difference 31 determined. The modification of the welding parameter or parameters is described in detail hereinafter.

5 [0044] The welding method according to the invention is based on determining an assembly clearance between the two plate edges to be welded and adapting the welding parameter or parameters as a function of the assembly clearance determined. This results in permanent adaptation at each point to be welded along the processing line of the welding parameters as a function of the height difference 31 between the two plates at that point. This
10 adaptation carried out continuously as a function of the environment encountered enables correct welding together of the two plate edges to be guaranteed whatever the local height difference. The two plates 11, 21 are welded by melting the material of the edges of the two plates as the welding device 7 advances along the rail 3.

[0045] In a variant of the invention the welding method may include a step 115 of storing the
15 height difference 31 after the first step 110 of determining the height difference 31 on a storage medium in the welding device or a server external to the welding device. Storing the height differences 31 along the processing line produces the profile of the assembly clearances over all of the processing line. This variant is of benefit if the welding device does not have a sensor and recovers the value of the height differences 31 before the
20 modification step 120.

[0046] In other words, the welding method according to the invention necessitates at one point at least on the processing line determination of the height difference 31 at that point. This can be determined beforehand for this point or for all of the points on the processing line, for example by passing a position sensor beforehand above the processing line and storing the
25 plurality of height differences 31. Now this determination of the height difference can be carried out point by point. This is the case with a welding device provided with a position sensor 73. In this configuration, as represented diagrammatically in figure 2, the position sensor 73 and the welding torch 72 are spaced by a fixed distance 76, typically between 2 cm and 15 cm. At a time t1 the position sensor 73 measures the height difference 31 at
30 the point A. At this time t1 the welding torch 72 is welding at the point B. The modification means 74 are connected by a wired connection 75 or by a wireless connection to the position sensor 73 and to the welding torch 72. The height difference 31 can be stored on the storage medium or transmitted directly to the modification means 74 to modify at least one welding parameter as a function of the height difference 31 determined at the point A. The speed of movement of the welding device 7 being known and following
35 determination of the height difference 31 at the point A the modification means 74 are configured to modify the at least one welding parameter at the time t2 corresponding to the time at which the welding torch 72 is above the point A. Thanks to this configuration only one passage of the welding device over the processing line is needed to carry out the determination step and the welding step.
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[0047] Figure 4 is a representation in section of the step of determining the height difference between the two plates to be welded in one embodiment of the present invention.

- [0048] In this embodiment the position sensor 73 is a contactless sensor, for example a laser profilometer, also known as a laser scanner. This is a profile sensor that can detect, measure and evaluate a two-dimensional profile in the section plane with no physical contact with the two plates 11, 21.
- 5 [0049] In this embodiment the position sensor 73 carries out the following substeps:
- [0050] - sending an initial optical signal to a point on the surface of the edge 22 of the plate, this initial optical signal being a laser pulse for example,
- receiving a return optical signal corresponding to the initial optical signal, this return optical signal being for example a reflection of the laser pulse initially impacting the
- 10 surface of the edge 22 of the plate, and
- measuring a distance between the reference point of the position sensor 73 and the point on the surface of the edge 22 of the plate as a function of the initial optical signal and the return optical signal. This measurement typically uses the time between emitting the laser pulse and receiving the reflected laser pulse.
- 15 [0051] The position sensor 73 therefore determines a first distance 33 between a reference height of the sensor along the axis Z and the upper surface of the edge 22. It also determines a second distance 32 between the reference height of the sensor and the upper surface of the edge 12. Knowing the thickness e of the edge 22 (which is typically of the order of 1.2 mm), it is thus possible to determine the height difference 31. To this end, the position
- 20 sensor 73 can include a device able to calculate the height difference 31 on the basis of the distances 32, 33 and the thickness e . Alternatively, the calculator device can be remote from the position sensor 73 and incorporated in the welding device 7 or a remote server.
- [0052] Figure 5 is a representation in section of the step of determining the height difference between the two plates to be welded in another embodiment of the present invention.
- 25 [0053] In this embodiment the position sensor 73 is a physical contact sensor. It may be an LVDT (linear variable differential transducer), an electromechanical device converting a mechanical movement (here a rectilinear movement) into a varying electrical current indicating the length of the movement carried out and therefore the height 32, respectively the height 33. As in the figure 4 example knowing the thickness e of the edge 22 and the
- 30 heights 32, 33 it is therefore possible to determine the height difference 31. If this height difference 31 is above the predefined threshold, typically a few tenths of a millimetre, for example 0.1 mm or 0.2 mm, at least one welding parameter is modified to guarantee that the welding step is executed correctly.
- [0054] In the welding method according to the invention the at least one welding parameter that
- 35 can be modified in the step 120 is at least one of the following: the orientation of the laser beam relative to a normal to the first plane, the movement of the laser beam, the power of the laser beam and the frequency of the pulses of the laser beam.
- [0055] Figure 6 is a diagram representing a welding torch 72 producing a laser beam and including a reflection module 57.
- 40 [0056] The welding torch includes a laser beam generator 56 projecting the laser beam 6 onto a reflection module 57 at the free end of the welding torch 72. The welding torch 72 is represented in a highly-simplified manner in figure 6 in order to lighten its depiction. In

effect, the laser beam generator 56 is in fact external to the welding torch 72 and it is the fibre 9 that feeds the beam generated into the welding torch 72. The reflection device 57 is for example a set of mirrors that deviate the trajectory of the laser beam 6 leaving the beam generator in a direction D1 in a plane parallel to the longitudinal direction L and the vertical direction V or a direction D2 in a plane parallel to the transverse direction T and the vertical direction V. The modification means 74, which are depicted diagrammatically here, are connected by the wired or wireless connection 75 to the laser beam generator 56 in order to adapt the power or the frequency of the pulses thereof. Similarly, the modification means 74 can act on the reflection module 57 in order to adapt the orientation of the laser beam relative to the normal to the first plane P1. Such adaptation of the orientation of the laser beam toward the upper plate enables the energy delivered by the laser beam to impinge on the material of the upper plate and/or the lower plate in order to heat the material at the edge of the plates and compensate the height difference 31. It is equally possible to modify the path of the beam in the module 57 by altering the inclination of the mirrors; this modifies the height of the focal point which enables the optimum focal point to be obtained without modifying the power. Alternatively, it is equally possible to modify the power of the beam according to the clearance detected and the height at which the torch is located. Similarly, the modification means 74 can move the laser beam to create a scanning movement at the level of the processing line. Scanning enables heating of both sides of the processing line to melt the material in order to bond the two plates together.

[0057] In another embodiment of the welding method the at least one welding parameter includes at least one of the following: the height between the welding torch 72 and the processing line and the orientation of the welding torch 72 relative to the normal to the first plane P1. Figures 7 and 8 show examples of this method.

[0058] Figure 7 represents an embodiment of the step 130 of welding the plates of the welding method according to the invention.

[0059] In this embodiment the plates to be welded include corrugations extending over a surface of each plate. These corrugations aim to impart flexibility to the membrane formed after welding the plates to accommodate thermal contraction of the steel when the tank is cooled down. It is therefore possible to define the surface of the plate by plane zones 51 and waves 52 as represented in figure 7. As it moves above the processing line 30 the welding device 7 is therefore caused to pass over the plane zones 51 and the waves 52.

[0060] In the embodiment represented in figure 7 the welding device 7 remains in a rectilinear position as it moves along the axis Y. Thanks to this configuration the welding kinematic is simplified since the welding head remains vertical and at the same height. However, the welding device 7 encounters two situations. The first situation concerns the plane zone 51 represented by the position (a). The distance between the welding torch and the plates to be welded does not vary. The height difference 31 between the two plate edges can vary, however. At every point on a plane zone along the processing line at least one welding parameter is adapted as a function of the height difference 31 determined at that point.

[0061] In the second situation the wave is represented by the positions (b) and (c). The distance

between the welding torch and the plates to be welded varies during passage over the wave. The height difference 31 between the two plate edges can also vary, however. To this end the welding method according to the invention may include before the first step 110 of determining the height difference 31 a step 105 of determining a distance between a reference point of the position sensor 73 and at least one point on the second plate. This distance indicates the presence of a wave. Alternatively, a profile of the plates to be welded that is generated beforehand, for example by laser profilometry, can be made available to the calculator device which can then determine the adaptation of at least one welding parameter on the one hand on the basis of the distance between the plates and the welding torch and on the other hand on the basis of the height difference. For example, as can be seen at the positions (b) and (c) the power of the laser beam 6 can be adapted at two different distances between the plates and the welding torch.

[0062] Figure 8 represents another embodiment of the step of the welding method according to the invention of welding the plates.

[0063] In this other embodiment the welding device 7 also encounters the two situations in respect of the plane zone 51 (position (a) and passage over the wave at positions (b), (c) and (d)). In this variant embodiment the welding head remains vertical and the welding angle remains optimal, that is to say the laser beam is situated in a circular cone the apex of which coincides with the point to be welded, forming an angle between 0° and 45° , preferably 15° to 30° , around the normal to the processing line at the point to be welded. It is then the laser beam 6 that is oriented. This configuration makes it possible to hold the welding head straight in order to limit movement and to simplify the welding kinematic.

[0064] To this is added the possible variation of the height difference 31 between the two plate edges. As before, the welding method according to the invention can include before the first step 110 of determining the height difference 31 a step 105 of determining a distance between a reference point of the position sensor 73 and at least one point on the second plate. This distance is an indication of the position of the welding torch relative to the wave. Alternatively, a profile of the plates to be welded that is generated beforehand can be made available to the calculator device. The calculator device can then determine the adaptation of at least one welding parameter on the one hand on the basis of the distance between the plates and the welding torch and on the other hand on the basis of the height difference determined. For example, as can be seen for the positions (b), (c) and (d), at different orientations of the welding torch relative to the processing line 30 the orientation of the laser beam 6 is adapted for the positions (b) and (d) while the laser beam 6 is vertical in position (c). In a similar way to what has been explained above, in addition to the adaptation of the beam because of the presence of the wave on the processing line the welding method applies a modification of at least one welding parameter for each of the points on the processing line at which the height difference 31 is greater than the predefined value.

[0065] In the welding method according to the invention the second step 120 of modifying at least one welding parameter of the welding torch 72 is executed if the height difference 31 determined is above a predefined threshold. This predefined threshold can be 0 mm. In

other words the step 120 is initiated as soon as an assembly clearance is detected.

[0066] In a variant of the invention the predefined threshold is 0.01 mm. This threshold corresponds to the sensitivity of the position sensor 73 measuring the height difference 31.

[0067] In another variant of the invention the predefined threshold is 0.1 mm. This threshold corresponds to a height difference from which optimal laser welding can no longer be achieved without modifying at least one welding parameter.

[0068] In a further variant of the invention the second step 120 of modifying at least one welding parameter of the welding torch 72 is executed by applying a predefined modification of a set of welding parameters according to the height difference determined, the predefined modification of this clearance varying in accordance with a predefined increment of the height difference, for example 0.05 mm or 0.1 mm. In other words the step 120 is executed as soon as the height difference determined crosses the predefined threshold (for example a threshold of 0.1 mm). In the execution of the step 120 for a predefined increment of 0.1 mm and for a height difference between 0.1 mm and 0.2 mm the welding method of the invention applies a modification in a first range to a set of welding parameters. For a height difference between 0.2 mm and 0.3 mm the welding method of the invention applies a modification in a second range to the same set of welding parameters. However, the invention also covers the situation of modification of another set of welding parameters for a greater height difference increment.

[0069] An application example is described later with reference to figure 10.

[0070] The welding parameter or parameters of the welding torch is/are then modified as a function of the height difference 31 determined. In other words, for each of the points on the processing line a first test evaluates if the predefined threshold has been reached. If the predefined threshold has been reached at least one welding parameter of the welding torch is modified to compensate this assembly clearance and to guarantee correct welding at said welding point.

[0071] In an advantageous embodiment of the welding method according to the invention the step 120 of modifying the welding parameter or parameters of the welding torch depends on the height difference 31. This means that depending on the height difference determined at a point the welding correction applied, that is to say the modification of the welding parameter or parameters, could differ from one welding point to another. This makes it possible to adapt the quantity of energy delivered at each welding point depending on the level of the assembly clearance to obtain the required melting of the metal for welding the two plates.

[0072] Possible embodiments of the step 120 of modifying welding parameters are described in a non-limiting manner hereinafter with reference to figures 9 and 10, in which dz corresponds to the height difference determined (also referenced 31). In these examples it is considered that the following welding parameters enable welding of two plates with no assembly clearance: laser beam power 1750 W, orientation of the laser beam relative to a normal Z' to the first plane by angle α_0 (for example between 0° and 30°). The predefined threshold for triggering the modification step 120 is 0.01 mm.

[0073] Figure 9 is a diagram representing the welding of two plates 11, 21 with no assembly

clearance using the method according to the invention. In this configuration the welding device 7 moves above the processing line 30 and the steps of the method are executed at each point on the processing line as the welding device 7 advances. During the first step 110 the height difference 31 between the upper surface 14 of the edge 12 of the first plate 11 and the lower surface 24 of the edge 22 of the second plate 21 is determined at each point on the processing line 30. In the example depicted in figure 9 this height difference is equal to 0 mm and there is no assembly clearance. The height difference determined is therefore not above the predefined threshold. There is no step to be carried out to modify at least one welding parameter of the welding torch.

[0074] The third step 130 of welding the edges 12, 22 of the first plate 11 and the second plate 21 is executed by means of a laser beam set to a power of 1750 W for example and followed by the fourth step 140 of moving the mobile welding device 7 to execute the first step 110 again at the next point on the processing line.

[0075] Figure 10 is a diagram representing the welding of two plates with an assembly clearance using the method of the invention. In this configuration, and in a similar manner to that explained in the case of the figure 9 example, the welding device 7 is moved above the processing line 30 and the steps of the method are executed at each point on the processing line as the welding device 7 advances. During the first step 110 the height difference 31 between the upper surface 14 of the edge 12 of the first plate 11 and the lower surface 24 of the edge 22 of the second plate 21 is determined at each point on the processing line 30. In the example depicted in figure 10 this height difference 31 (denoted dz hereinafter) is non-zero. To illustrate the invention the situation is considered of a height difference greater than 0.01 mm, that is to say above the predefined threshold.

[0076] The height difference being above the predefined threshold, the step 120 of modifying at least one welding parameter is initiated. The welding parameter or parameters modified can for example be as follows, depending on the height difference.

[0077] For $0 \text{ mm} < dz \leq 0.1 \text{ mm}$ the welding parameter modified is the power of the laser beam, which is increased from 1750 W to 2000 W. The orientation of the laser beam relative to the normal Z' to the first plane remains at the angle a_0 . The offset between the processing line and the intersection with the surface 14 of the straight line of the laser beam is 0 mm. In other words, the laser beam is pointed at the processing line.

[0078] For $0.1 \text{ mm} < dz \leq 0.2 \text{ mm}$ the welding parameter modified is the power of the laser beam, which is increased from 1875 W to 2125 W. Furthermore, the orientation of the laser beam relative to the normal Z' to the first plane is modified from the angle a_0 to the angle a_1 (as represented to a larger scale in the top right-hand corner of figure 10). The offset (denoted d) between the processing line and the intersection with the surface 14 of the straight line of the laser beam is of the order of 0.5 mm. In other words, the laser beam is no longer pointed at the processing line. The laser beam is pointed at the edge of the upper plate. This offset enables the laser beam to access a metal zone of the upper plate in order to raise its temperature locally and to cause a part of it to melt to contribute to forming the weld bead. The angle can be modified by modifying the inclination of the mirrors of the module 57.

[0079] For $0.2 \text{ mm} < dz \leq 0.3 \text{ mm}$ the welding parameter modified is the power of the laser beam, which is increase from 2000 W to 2250 W. As when dz is between 0.1 mm and 0.2 mm, the orientation of the laser beam relative to the normal Z' to the first plane is modified. The height difference between the two plates being greater, the angle α_1 becomes greater than in the previous case so as to obtain an offset d between the processing line and the intersection with the surface 14 of the straight line of the laser beam of the order of 1 mm. The offset d is larger compared to the previous example of a height difference between 0.1 and 0.2 mm. The height difference is greater than that of the previous case and the assembly clearance to be compensated is greater. It is then necessary to obtain more metal. Proceeding in this way, the laser beam of higher power can guarantee melting of sufficient material to form the weld between the two plates.

[0080] The numerical values of the welding parameters are given here by way of example to explain the invention. The method of the invention is in no way limited to them, however. In particular, the beam power can vary by $\pm 10\%$ to take account of the height difference 31 to which can be added the height variation between the zone to be welded and the welding torch at the level of passing over a wave. Furthermore, depending on the height 33 detected and the fact that the thickness of the assembly in vertical section in the plane ZX at the level of the wave is locally greater (due to the curvature), the power of the laser beam is advantageously increased. In other words, the welding parameter or parameters to be modified can vary by a certain percentage depending on the height difference 31 encountered and a potential greater or lesser variation of the zone to be welded on passing over the waves.

[0081] Other welding parameters can be modified, such as the movement of the laser beam in the plane perpendicular to the processing line, constituting scanning of the laser beam. The scanning speed can also be modified. This movement enables the laser beam to come into contact with the edge of the upper plate so as to constitute a local and localised input of energy at the edge of the upper plate, near the processing line. As a result, the metal of this plate edge reaches its melting point and melts to form the weld bead.

[0082] Based on the description of the invention, the person skilled in the art will understand that the welding method according to the invention relies on the continuous detection of an assembly clearance and continuous adaptation of the welding parameter or parameters according to the assembly clearance encountered by the mobile welding device at each welding point along the processing line. The values of the welding parameter or parameters to be applied during the modification step 120 depending on the height differences encountered can advantageously be tabulated and saved on a medium accessible to the modification means 74 to ensure correct control of the welding device.

[0083] In a preferred embodiment, the welding method according to the invention relies on modifying a judicious combination of welding parameters. The choice of the parameters to be modified and the range in which they are modified depend on the height difference determined. At a given point the greater the height difference determined, that is to say the greater the assembly clearance, the more difficult it is to guarantee good welding of the two plates. The invention makes it possible, without human intervention, automatically and

continuously to obtain a weld bead having a good geometry and conforming to the conformity criteria required in order to guarantee the welding of two plates and the durability thereof over time. This effect is obtained thanks to a variation of the input of energy per unit surface area along the processing line according to the evolution of the height difference determined.

[0084] Although the invention has been described in connection with particular embodiments it is obvious that it is in no way limited to them and includes all technical equivalents of the means described and combinations thereof if they fall within the scope of the invention.

[0085] Use of the verbs "include", "comprise" and conjugate forms thereof does not exclude the presence of elements or steps other than those stated in a claim.

[0086] In the claims any reference sign between parentheses should not be interpreted as a limitation of the claim.

[0087] It will more generally be apparent to the person skilled in the art that diverse modifications can be made to the embodiments described hereinabove in the light of the teaching that has been disclosed to them. Terms used in the claims must not be interpreted as limiting claims to the embodiments disclosed in the present description but must be interpreted to include all the equivalents that the claims are intended to cover because of their formulation and forecasting which is evident to the person skilled in the art on the basis of their background knowledge.

Claims

[Claim 1] Method of welding an edge (12) of a first plate (11) extending in a first plane (P1) and an edge (22) of a second plate (21) superposed on the edge (12) of the first plate (11) along a processing line (30) extending along a first axis (Y) in the first plane (P1) using a welding device (7) mobile above the processing line (30) including a welding torch (72) adapted to emit a laser beam, the welding method being characterised in that it includes, for each point along the processing line (30):

- a first step (110) of determining a height difference (31) along a second axis (Z) perpendicular to the first plane (P1) between the upper surface (14) of the edge (12) of the first plate (11) and the lower surface (24) of the edge (22) of the second plate (21);
- a second step (120) of modifying at least one welding parameter of the welding torch (72) as a function of the height difference (31) determined if the height difference (31) determined is above a predefined threshold;
- a third step (130) of welding the edges (12, 22) of the first plate (11) and the second plate (21);
- a fourth step (140) of moving the mobile welding device (7).

[Claim 2] Welding method according to claim 1 including a step (115) of storing the height difference (31) after the first step (110) of determining the height difference (31).

[Claim 3] Welding method according to either one of claims 1 or 2 in which the at least one welding parameter includes at least one of the following: the orientation of the laser beam relative to a normal to the first plane, the movement of the laser beam, the power of the laser beam and the frequency of the pulses of the laser beam.

[Claim 4] Welding method according to any one of claims 1 to 3 in which the at least one welding parameter includes at least one of the following: the height between the welding torch (72) and the processing line and the orientation of the welding torch (72) relative to a normal to the first plane.

[Claim 5] Welding method according to any one of claims 1 to 4 including before the first step (110) of determining the height difference (31) a step (105) of determining a distance between a reference point of the position sensor and at least one point on the second plate.

[Claim 6] Welding method according to claim 5 including a step (150) of modifying the power of the laser beam as a function of the distance determined if the distance determined differs from the distance determined for the previous point along the processing line.

[Claim 7] Welding method according to claim 5 or 6 including a step (160) of orienting the laser beam as a function of the distance determined if the distance determined differs from the distance determined for the previous point along the processing line.

[Claim 8] Mobile welding device (7) intended to weld an edge (12) of a first plate (11) extending in a first plane (P1) and an edge (22) of a second plate (21) superposed on the edge (12) of the first

plate (11) along a processing line (30) extending along a first axis (Y) in a first plane (P1), the mobile welding device including:

- a welding torch (72) adapted to emit a laser beam;
- means (74) for modifying at least one welding parameter of the welding torch (72) as a function of a height difference (31) along a second axis (Z) perpendicular to the first plane (P1) between the upper surface (14) of the edge (12) of the first plate (11) and the lower surface (24) of the edge (22) of the second plate (21) if the height difference (31) is above a predefined threshold.

[Claim 9] Mobile welding device (7) according to claim 8 in which the at least one welding parameter includes at least one of the following: the orientation of the laser beam relative to a normal to the first plane, the movement of the laser beam, the power of the laser beam and the frequency of the pulses of the laser beam.

[Claim 10] Mobile welding device (7) according to claim 8 or 9 further including a position sensor (73) adapted to measure the height difference (31) along the second axis (Z) perpendicular to the first plane (P1) between the upper surface (14) of the edge (12) of the first plate (11) and the lower surface (24) of the edge (22) of the second plate (21).