A hybrid method for the butt-welding of metal sheets (2, 6) in a welding machine using the Joule effect, which method comprises: the placing of the sheets facing each other; the compression of the join line (18) between two conducting rollers (16, 17); the flow of a preheating current between the conducting rollers (16, 17); the displacement of the conducting rollers (16, 17) over the entire width of the sheets (2, 6) to be joined together; the emission, by a laser head, of a coherent light beam (20) capable of melting the abutted ends; and the concomitant displacement of the conducting rollers (16, 17) and of the coherent light beam (20).
Metal sheet butt-welding method and device for a continuous manufacturing process

Field of the Invention
The invention relates to the butt welding of metal sheets in continuous production processes.
The invention also relates to welding machines for applying the method in question and to an inexpensive device for converting machines existing on the market.

Prior Art
To keep up with current production rates in the steel industry, sheet metal treatment machines work continuously. For this purpose, the ends of two sheets coming for example from different coils are simultaneously sheared and then butt-welded to each other. During the very brief time needed for the operation, buffer devices absorb the excess sheet produced, so that the production progresses smoothly.
The butt-joining of sheets on continuous lines may be carried out in various ways, namely by the Joule effect (resistance welding), flash butt welding or laser welding.
Resistance welding, described in particular in EP 1 484 130 is one of the most common processes at the present time, its principle going back to the 1950s.
According to this process, after having been sheared, the ends of the two sheets are lightly superposed, compressed between planarizing rollers and then welded by the Joule effect, through the action of an intense current passing between two welding rollers that are applied to them on either side. The weld seam is then seized by passing over planarizing rollers.
Variation in steel grades poses problems in resistance welding and flash butt welding. It is possible
to weld most metal sheets, but in certain cases the weld is not always of sufficient quality for the run speed of the strip and there is a risk of tearing, an incident which is not only dangerous but also extremely expensive since it necessarily entails a production stoppage.

As for the laser welding system, this has been operated on an industrial scale for some ten years. The advantage of laser welding over the other welding processes is that it permits practically all types of steel to be welded.

However, it should be understood that the purchase of a laser machine requires substantial investment (between 4 and 5 million Euros), a long manufacturing lead time (12 to 15 months), new research on welding parameters for the materials to be welded, training of the personnel and a lengthy period of running in the new equipment.

EP 1 157 753 describes a laser welding method in which the metal sheets are preheated by high-frequency induction heating so as to cause annealing. Such a method obviously makes the design of laser welding machines even more complex. Moreover, the induction heating itself requires considerable energy, considerably greater than the energy needed for the actual welding. It should also be noted that the necessary energy greatly increases with certain high-alloy steels, especially manganese steels, because of their mediocre magnetic properties.

Attempts have already been made, but in an entirely different field, to combine the advantages of laser welding and resistance welding. EP 1 629 927 teaches a hybrid welding method used in the field of motor vehicle bodies, which is limited to juxtaposing passage of a laser beam with conventional resistance welding, with joining by superposition of the sheets, so as to avoid problems
resulting in particular from the surface finish of the body parts to be welded, which parts have, at the moment of welding, already undergone quite a series of forming operations. Here the working rates and energy levels are in no way comparable to those imposed by the production rates in the field of metal sheet production. Finally, it should be noted that the complementary laser welding has in particular the purpose of sealing the body parts produced. The system proposed is in no way capable of working alternately according to one process or the other.

EP-I 157 773 describes a method of butt-joining sheets in which the ends of the sheets, prior to their roller welding, are bevelled by compression.

JP-01196180 describes a resistance butt-joining method with superposition of two sheets of different thickness, in which the edge of the thicker sheet is irradiated by a laser so as to promote its melting.

EP-1-743-728 describes a laser band welding machine which includes a first device to cut and weld the band ends and a second device to treat the weld seam and/or the welded band ends. The first and second devices are used together for welding and treatment of the weld seam and/or the welded band ends and travel on a common guide device.

Summary of the Invention

One object of the invention is to develop 100% hybrid welding machines for both resistance welding AND laser welding.

Another object of the invention is to develop a welding process for welding together metal sheets of very different grades for a low investment cost.

Another object of the invention is to develop a welding process for easy back-conversion of resistance
welding machines.

Another object of the invention is to reduce the technical stoppage time caused by the prolonged shut-down of welding machines.

Another object of the invention is to reduce breakdowns.

A first subject of the invention is a hybrid method of butt-welding metal sheets in a welding machine, comprising an input clamp, an output clamp, shear means and preheating rollers, which comprises the following operations:

- the ends of two sheets to be welded together are gripped, between an input clamp and an output clamp respectively;
- these ends are sheared;
- the clamps are brought closer together in such a way that the sheared ends of the sheets are placed facing each other and come into contact with each other via their edges along a join line;
- the join line is compressed between two conducting rollers;
- a preheating current is passed between the conducting rollers and the sheets placed facing each other;
- the conducting rollers are moved over the entire width of the sheets to be joined;
- a coherent light beam capable of melting the facing butted ends is emitted by a laser head;
- the coherent light beam is positioned relative to the join line;
- the conducting rollers and the coherent light beam are moved concomitantly; and
- the join line is supported between two planarizing rollers.

One advantage of the method of the invention is that all the components used, with the exception of the laser head, are found in most resistance welding machines currently on the market and that, as a consequence, it is possible, at the cost of simple adjustment changes, to use such machines alternately either as purely resistance welding machines (with butt-joining by superposition of the sheets) or as machines carrying out the hybrid welding of the invention.

According to a first advantageous embodiment, the conducting rollers are placed in front of the point where the coherent light beam passes, so as to preheat the sheets.

One advantage of this method of proceeding is that the power needed for the welding may be greatly reduced, enabling a lower-power laser source to be employed.

According to another advantageous embodiment, the conducting rollers are placed behind the point where the coherent light beam passes, so as to relieve the tensile stresses induced during welding. This way of proceeding may be applied to sheets requiring a lower laser power, but it also enables a substantial energy saving to be made since it is no longer necessary to carry out localized annealing of the weld.

Optionally, the planarizing rollers compress the sheet in line with the weld so as to push back the fibres of the metal in the joint plane, avoiding any over-thickness when the sheet, after treatment, has to be recoiled.

The coherent light beam is, advantageously, conveyed from the laser head to its emission point by optical
fibres. It will be noted that the systems used at present, as described in particular in EP 1 157 753, use reflection of the coherent light beam through a set of tubes and mirrors, these requiring impeccable accurate positioning (and therefore constituting a source of potential error) and, especially, impeccable cleanliness. Now, it is known that these machines are stationed under extremely severe environmental conditions: dust, fumes and spatter are their common fate. The progressive and inevitable fouling of the mirrors reduces the power available and therefore makes regular shutdowns necessary.

It should be noted that YAG sources are currently limited in terms of power compared with CO2 sources. At the present time, the most powerful YAG sources have a power of about 8 kW. This limitation is in no way a drawback within the context of the present method, this power being greatly sufficient, precisely because the sheets are preheated.

Another subject of the invention is a device for converting a continuous Joule-effect sheet welding machine comprising an input clamp, an output clamp, means for shearing the sheets, means for positioning the sheets, rollers for conducting the heating current and planarizing rollers. This device comprises:

- a laser source;

- a fibre-optic system bringing a coherent light beam emitted by the laser source plumb with a join line between the sheets intended to be welded together;

- electronic and mechanical control means for positioning the sheets in such a way that their facing ends are butted together;

- means for modulating the energy dissipated in the rollers, so as to keep the temperature of the sheets clamped facing each other between these rollers below
the melting point;
- fine adjustment means for centring and decentring
the point where the coherent light beam encounters the
sheets relative to the join line of these sheets;
- means for fastening the end of the fibre-optic
system, designed to coordinate the movement of the
point of emission of the coherent light beam and the
movement of the rollers; and
- means for adjusting the planarizing rollers,
enabling the pressure exerted on the sheets by these
planarizing rollers to be varied, so that said
pressure can if necessary be reduced to a simple
holding pressure.

The laser source is preferably a YAG source and
is advantageously fastened to a carriage to which the
conducting rollers are also fastened.

**Brief Description of the Drawings**

These aspects and other aspects of the invention will
be clarified in the detailed description of particular
embodiments of the invention, reference being made to the
drawings of the figures, in which:
- Figures 1 to 8 are schematic side views, parallel
to the run direction of the sheets, of the various
phases of a resistance welding operation;
- Figures 9 to 14 are schematic side views of the
various phases of a welding operation using the
hybrid process according to the invention.
- The figures have not been drawn to scale. In
general, similar elements have been denoted by
similar references in the figures.
Figure 1 shows the first step of a conventional welding process, comprising resistance welding or laser welding: the end of an emerging sheet 2 is immobilized by an output clamp 4, while the end of the incoming sheet 6 is immobilized simultaneously by the output clamp 8. The two ends 2 and 6 are sheared by actuation of a lower shear 10 and an upper shear 12.

The sheets now having a clean sharp edge are brought close together by a translational movement of the clamps 6, 8 (Figure 2). The output clamp is simultaneously actuated by pivoting (Figure 3) so as to superpose the edge of the sheet 2 on top of the edge of the sheet 6. The superposed sheets 2, 6 are then work-hardened by the passage of two preplanarizing rollers 14, 15 (Figure 4), after which the work-hardened edges are repositioned (Figure 5) before two conducting rollers 16, 17 pass (Figure 6). Since these rollers 16, 17 are connected to a welding transformer, an intense current passes through the sheets at the point of contact and, because of their resistivity, causes instantaneous melting. After optional passage of planarizing rollers (Figure 7), the sheets 2, 6, now intimately joined together, are released from the clamps and resume their run (Figure 8).

The various phases of the hybrid welding process according to the invention are shown in Figures 9 to 14.

Although the process is different, the same numbering has been adopted in the drawing in order to denote the components brought into action, so as to clearly show that the same base machine can be used in both processes.

The prior shearing of the sheets is identical in both processes. Consequently, Figure 8, identical to Figure 1, is repeated merely as a reminder.
After shearing, the straight ends of the sheets 2, 6 are brought edge to edge by the translational movement of the clamps 4, 8 (Figures 9 and 10). The join line 18 of the sheets is then clamped between the conducting rollers 16, 17 (Figure 12). However, the energy involved is intentionally limited (either by reducing the current or by increasing the rate of passage of the rollers) so that the temperature in the sheets remains below the temperature required for melting and the sheets merely undergo a simple preheating which is however sufficient to relieve the tensile stresses therein.

It should be pointed out that a very different result is obtained depending on whether the sheets are placed facing each other, as in the present process, or are superposed, as in a conventional welding process using rollers. This is because when the sheets are superposed (see Figure 4), the flow resistance, in an equivalent circuit diagram, is equal to the sum of the resistances of each sheet (2, 6), i.e. \( R_T = R_2 + R_6 \). However, when the sheets are juxtaposed with their ends facing each other, the flow resistance is the resultant of two resistances in parallel, i.e. \( 1/R_T = 1/R_2 + 1/R_6 \). The current must therefore be modulated differently and, in addition, it will be distributed unequally between the two sheets. Moreover, the area of contact between the sheets and the rollers is extremely small and irregular, whatever the quality of the prior shearing of the sheet ends may be. A person skilled in the art would there be obliged on principle to reject such a way of carrying out a welding process.

As soon as the rollers pass, a coherent light beam 20 is directed onto the join line 18 (see Figure 13), melting the two sheets 2, 6, after which the clamps 4, 8 are opened.
(Figure 14) and the sheets resume their path, as in a conventional process.

It has been found that, despite the somewhat unorthodox and paradoxical way in which the preheating is carried out, the heat supplied by the welding rollers as described greatly improves the quality of the laser welding (preheating, hence improvement in the mechanical properties before welding and reduction in the laser power to be used).

It is also possible to reverse the operations shown in Figures 12 and 13 when dealing with sheets not requiring welding energy greater than that which can be delivered by the laser source. In this case, the respective positions of the conducting rollers and the laser source are reversed. Here, the rollers no longer play a preheating roll but serve to anneal the sheet close to the weld line, so as to reduce the tensile stresses induced therein. This annealing, which is highly localized, dispenses with an additional annealing step, and therefore saves time and energy in the production process, while still guaranteeing optimum welding quality.

It goes without saying that it is possible, where appropriate, to combine the two embodiments and provide both laser irradiations for preheating and for annealing.

Comparison between Figures 1 to 8 and 9 to 14 clearly shows that, with the exception of the coherent light emitter and the adjustments for the different positioning of the sheets, an identical base machine can be used to carry out both welding processes.

Consequently, it is possible, thanks to a suitable fitting kit (the cost of which is out of all proportion with that of a new machine), to convert a welding machine
using the Joule effect into a hybrid (resistance welding + laser welding) machine.

It should be understood that the welding machines are placed at the head of the production line and that they therefore play a paramount role in ensuring continuity of the finished products.

Moreover, experience has shown that, despite its limitations, a well-maintained resistance welding machine is infinitely less subject to breakdowns than a laser welding machine. With an enormous advantage over the known technique, the machine converted into a hybrid machine, by the addition of the device of the invention, will practically never occasion a line stoppage since, in the case of a failure of the laser system (a situation which is by far the most probable), it is still possible, at the cost of simply changing parameters, in particular by positioning the sheets in such a way that their ends are superposed rather than placed facing each other, to make the hybrid machine function on its resistance welding system, which is still operational.

It should be understood that in continuous manufacture, manufacturing stoppage resulting in particular from a sheet breaking (typically lasting 24 hours) incurs losses of around €500 000.

Furthermore, it is possible to optimize the production according to the nature of the sheets treated. The laser source will thus be mainly used in the production of sheets made of alloys that are difficult to weld together. In contrast, the resistance welding system will remain applicable for other alloys that do not pose compatibility problems. This means that all the parameters already acquired by the producer remain perfectly operational.
It will be obviously apparent to a person skilled in the art that the present invention is not limited to the examples illustrated and described above. The invention comprises each of the novel features and any combination thereof. The presence of reference numerals cannot be considered to be limiting. The use of the definite article "a" or "an" to introduce an element does not exclude the presence of a plurality of these elements. The present invention has been described in relation to specific embodiments, which are purely illustrative and must not be considered to be limiting.
1. Method of butt-welding metal sheets (2, 6) in a welding machine, comprising an input clamp (8), an output clamp (4), shear means (10, 12) and at least one set of conducting rollers (16, 17), characterized in that it comprises the following operations:

- the ends of two sheets (2, 6) to be welded together are gripped, between an input clamp (8) and an output clamp (4) respectively;
- these ends are sheared;
- the clamps are brought closer together in such a way that the sheared ends of the sheets are placed facing each other and come into contact with each other via their edges along a join line (18);
- the join line (18) is compressed between at least two conducting rollers (16, 17);
- an electric current is passed between the conducting rollers (16, 17) and the sheets placed facing each other, causing Joule heating in the sheets;
- the conducting rollers (16, 17) are moved over the entire width of the sheets (2, 6) to be joined;
- a coherent light beam (20) capable of melting the facing butted ends is emitted by a laser head;
- the coherent light beam (20) is positioned relative to the join line (18);
- the conducting rollers (16, 17) and the coherent light beam (20) are moved concomitantly; and
- the join line (18) is supported between two planarizing rollers (14, 15).
2. Method according to Claim 1, characterized in that at least two conducting rollers (16, 17) are placed in front of the point where the coherent light beam (20) passes and preheat the sheets.

3. Method according to either one of claims 1 or 2, characterized in that at least two conducting rollers (16, 17) are placed behind the point where the coherent light beam (20) passes, so as to relieve the tensile stresses induced during welding.

4. Method according to any one of the preceding claims, characterized in that the planarizing rollers (14, 15) compress the sheets (2, 6) in line with the weld so as to push back the fibres of the metal in the joint plane.

5. Method according to any one of the preceding claims, characterized in that the coherent light beam (20) is conveyed from the laser head to its emission point by optical fibres.

6. Method according to any one of the preceding claims, characterized in that the laser source is a YAG source.

7. Device for converting a continuous Joule-effect sheet welding machine comprising an input clamp (8), an output clamp (4), means for shearing the sheets (10, 12), rollers (16, 17) for conducting the heating current, means for positioning the sheets and planarizing rollers (14, 15), characterized in that it comprises:
   - a laser source;
   - a fibre-optic system bringing a coherent light beam
emitted by the laser source plumb with a join line (18) between the sheets (2, 6) placed facing each other and intended to be welded together;
- electronic and mechanical control means for positioning the sheets (2, 6) in such a way that their facing ends are butted together;
- means for modulating the electrical power dissipated in the rollers (16, 17) so as to keep the temperature of the sheets clamped between these rollers below the melting point;
- fine adjustment means for centring the point where the coherent light beam (20) encounters the sheets (2, 6) relative to the join line (18) of these sheets (2, 6);
- means for fastening the end of the fibre-optic system, designed to coordinate the movement of the point of emission of the coherent light beam (20) and the movement of the rollers (16, 17); and
- means for adjusting planarizing rollers (14, 15), enabling the pressure exerted on the sheets by these planarizing rollers (14, 15) to be varied.

8. Conversion device according to Claim 7, characterized in that the laser source is a YAG source.

9. Conversion device according to either of Claims 7 and 8, characterized in that the laser source is fastened to a carriage to which the conducting rollers (16, 17) are also fastened.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. B23K11/02 B23K11/06 B23K11/34 B23K26/26 B23K26/24
ADD. B23K101/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B23K B21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and where practical search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C

See patent family annex

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Date of the actual completion of the international search 5 December 2008

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Name and mailing address of the ISA/
European Patent Office, P B 5818 Patentlaan 2 NL-2280 HV RIJSWIJK
Tel (+31-70) 340-2040,
Fax (+31-70) 340-3016
Authorized officer
Jaeger, Hein

Form PCT/ISA/210 (second sheet) (April 2005)
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