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(54) **Improvements in or relating to the heating of substances**

(57) The surface of a substance (19) is heated by locating it at one focal point (6) of an elliptical reflector (3) and subjecting it to radiation from a source (4) located at the other focal point (4A). Relative movement between the reflector and the surface may be effected to heat successive portions of the surface. The substance to be heated may be a metal which is subsequently welded. The heating prepares the metal for welding and subsequently stress relieves the weld area.

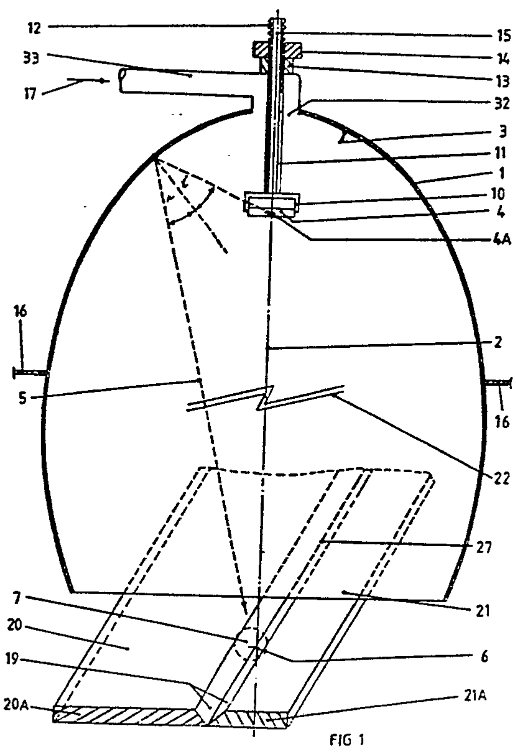

FIG 1

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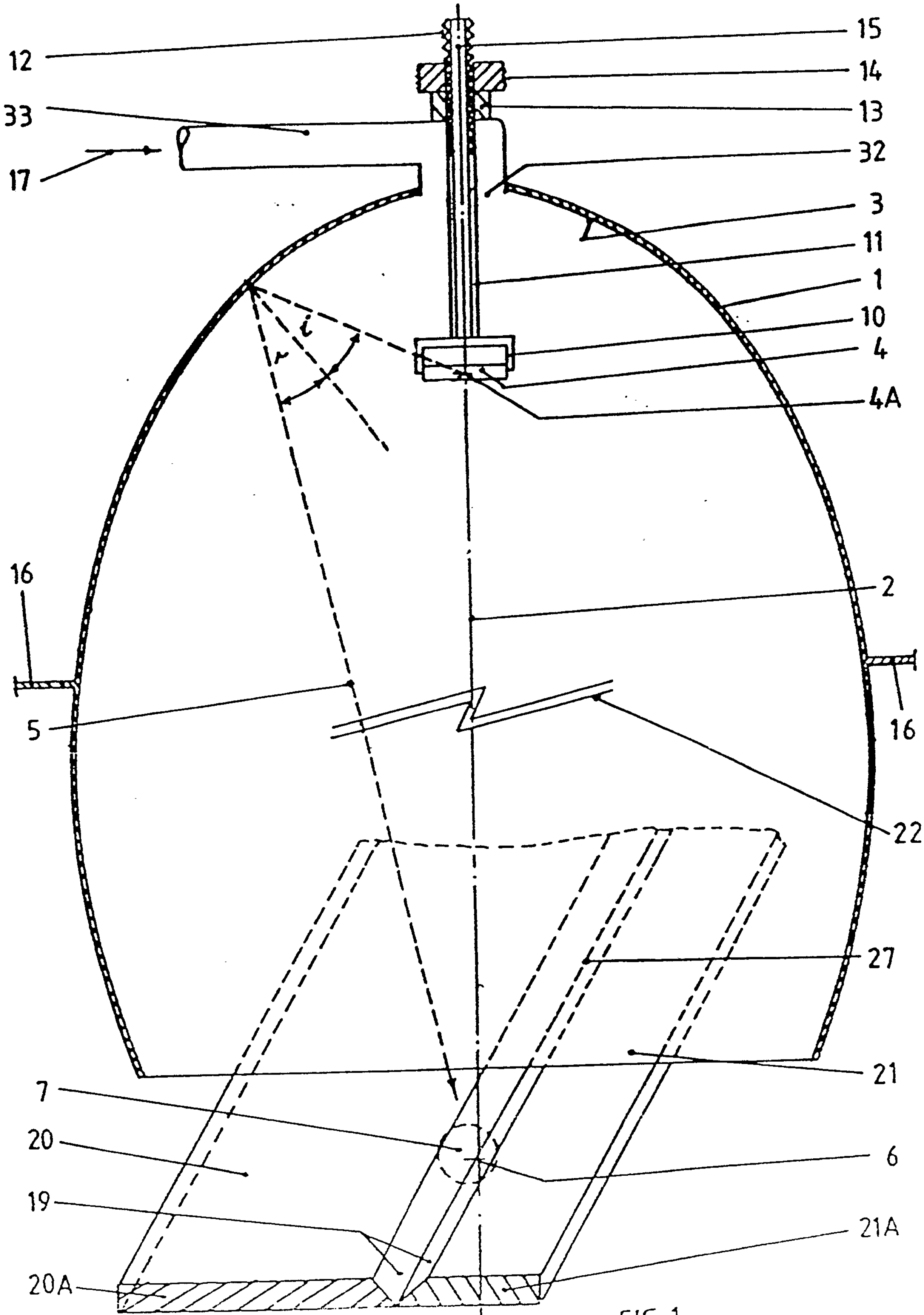

FIG. 1.

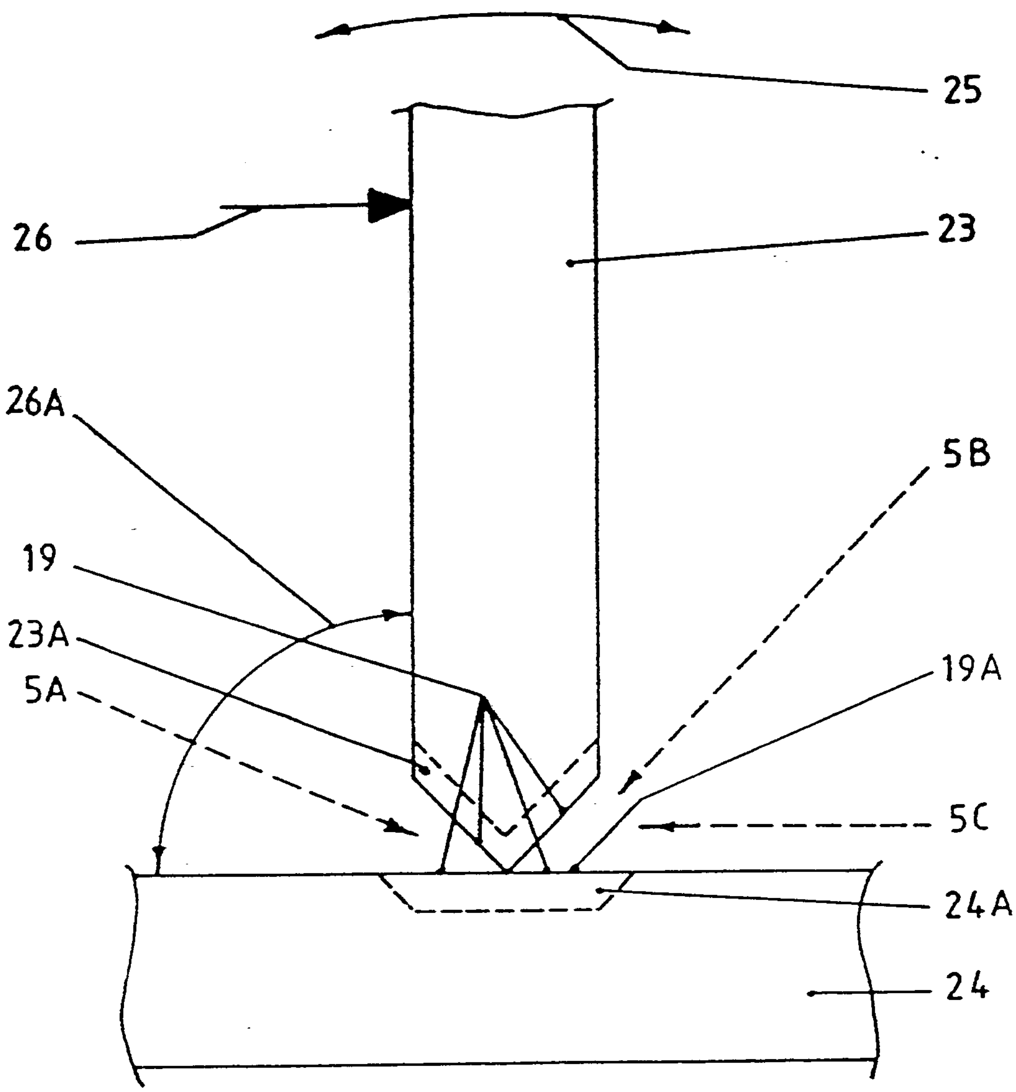

FIG. 2

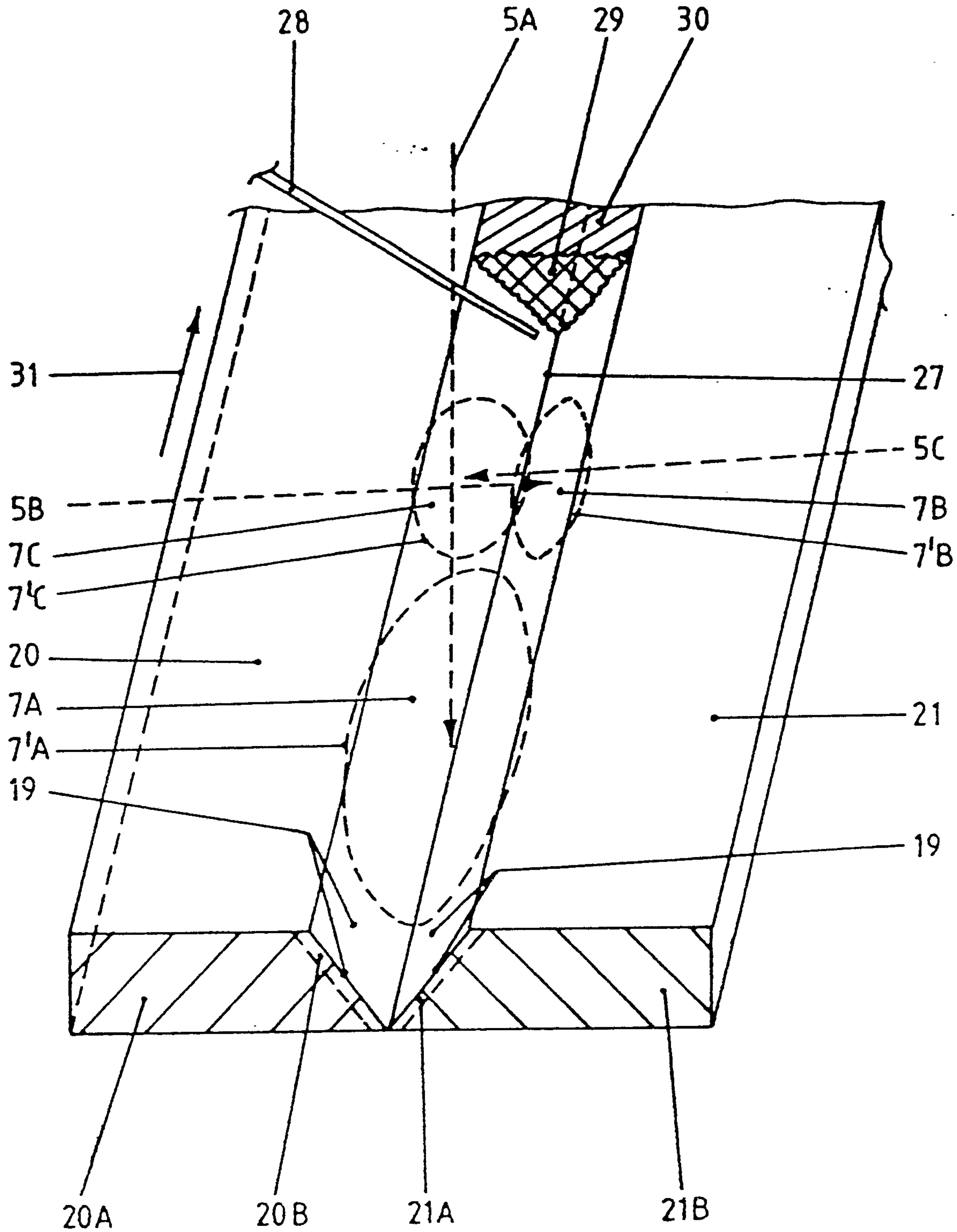

FIG. 3

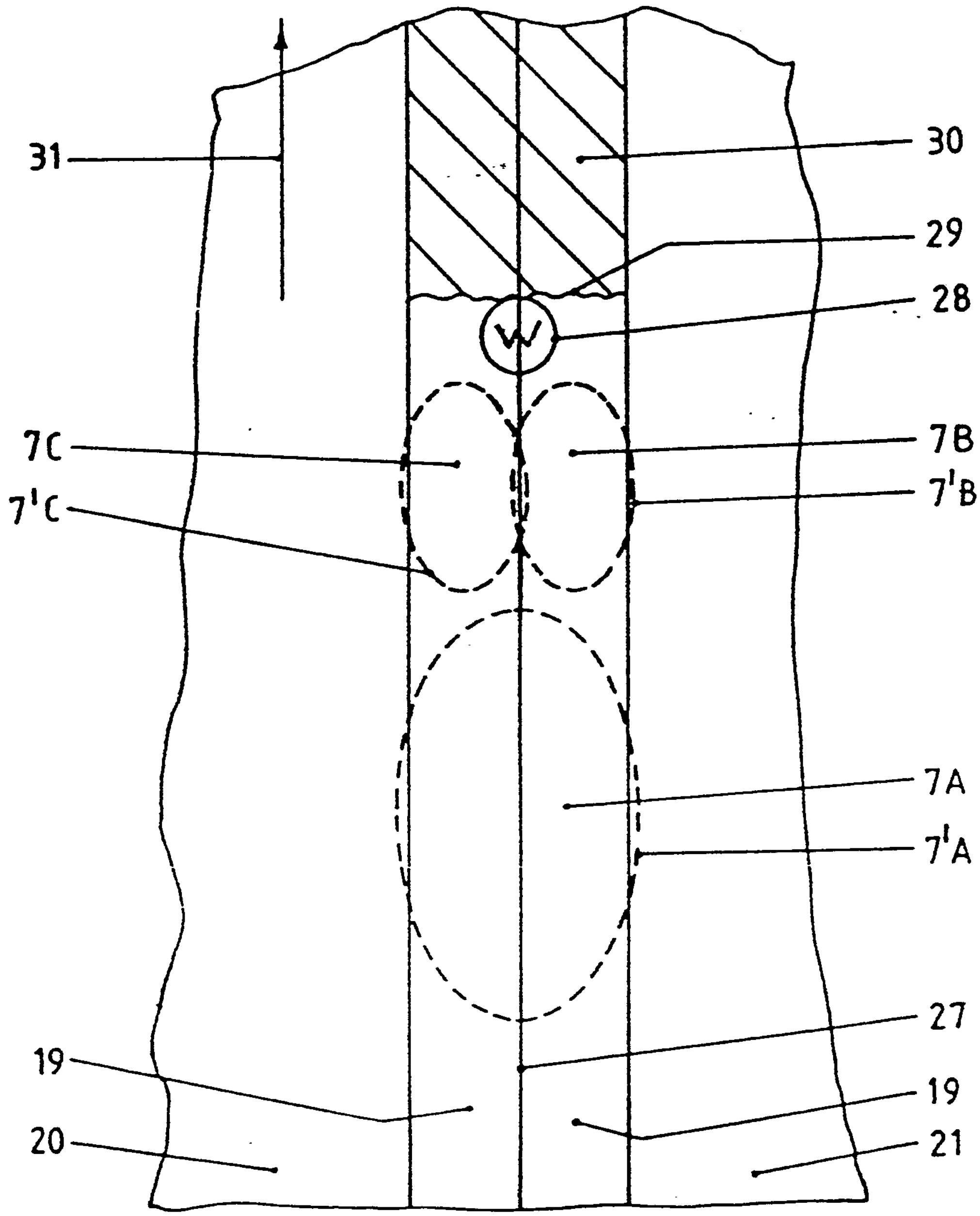

FIG. 4

5/5

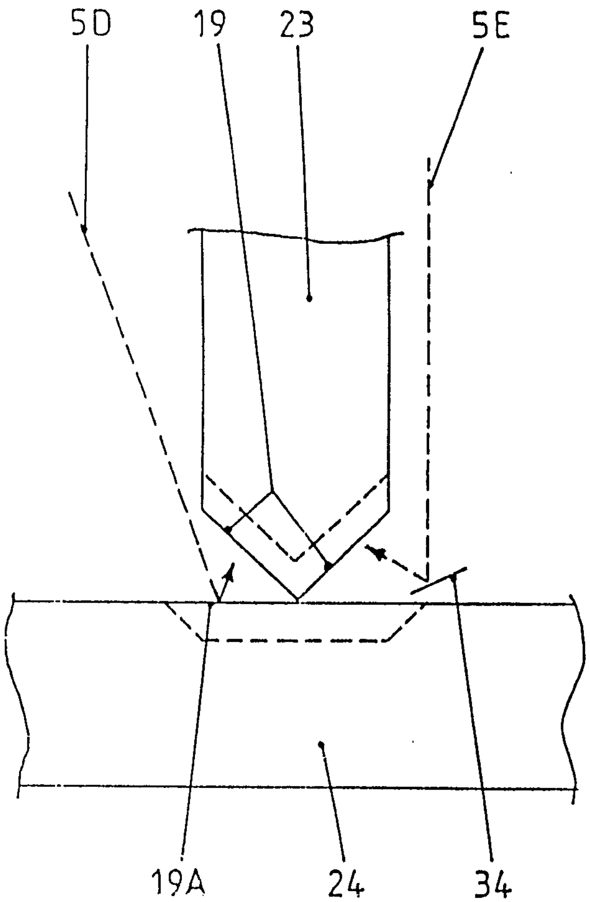

FIG.5

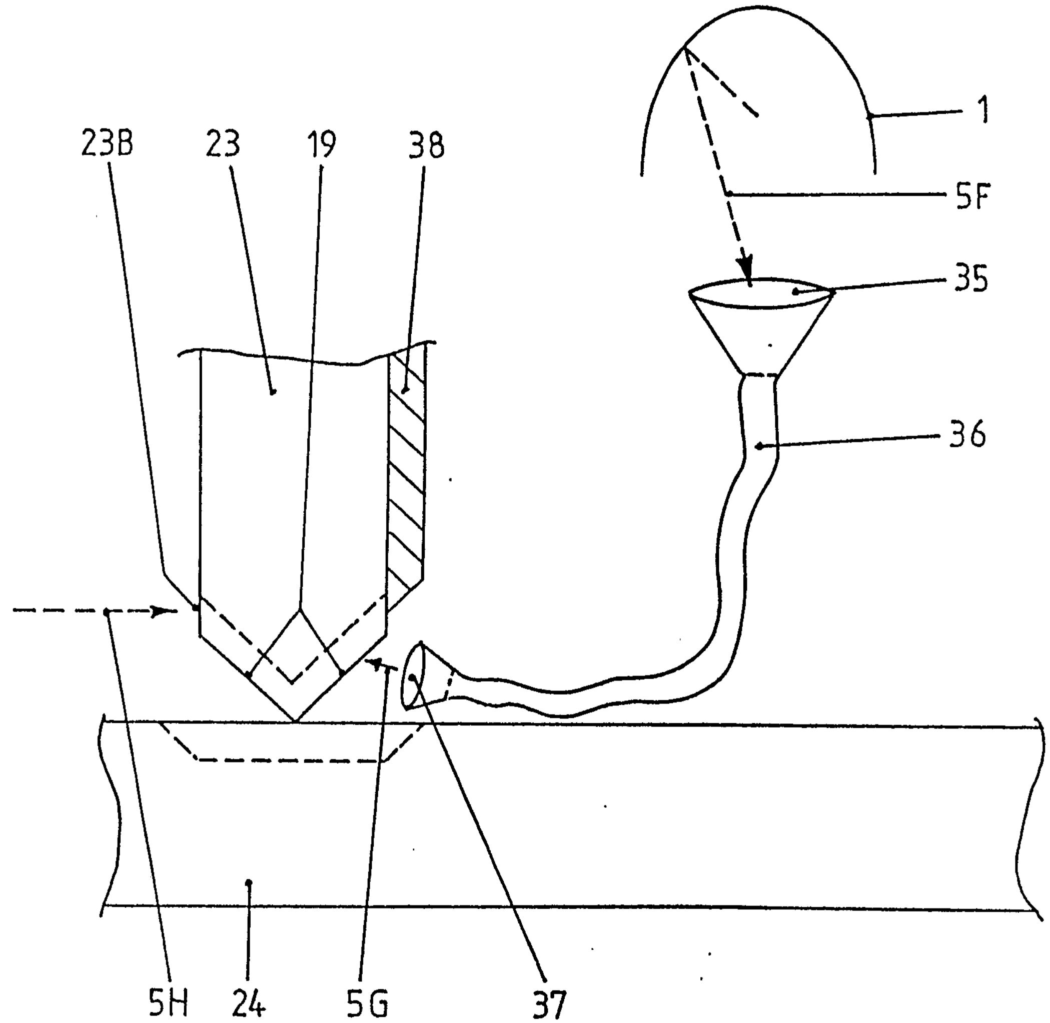

FIG. 6

IMPROVEMENTS IN OR RELATING TO THE HEATING OF SUBSTANCES

This invention relates to the heating of substances and is concerned with the use of thermal imaging techniques to provide a concentrated source of heat which may be directed onto the portion of the substance to be heated.

The invention is of particular value for directing heat onto a metallic member to be welded immediately prior to the welding operation. However, it may also be used to provide controlled thermal cycles to relieve local stresses generated due to welding, cold working, etc., and for other metallurgical processes, eg. hardening.

Many industrial operations involve the welding together of heavy metal sections, eg. vessels are often fabricated from rolled plate welded to sections of other shapes. In such an example, the plates may be butt welded to each other and the sections may be T-butt welded to the plates.

It is known to pre-heat metal sections prior to (and after) welding. However, as metals have good thermal conductivities, much of the heat applied is conducted away to the adjacent substrate; this is a particular problem with heavy metal sections, and tends to mean that the whole structure has to be heated up to near the pre-heat temperature. Some fabrications can have a mass of, for example 50 Tonnes and the pre-heating time may thus take several days, due both to the heat input required and to the level of heat loss.

When metals are welded, it is necessary only to pre-heat the substrate immediately adjacent to the weld pool, i.e. the heat affected zone, e.g. that volume of metal within a few millimetres surrounding the solid/liquid interface of the molten weld pool. Clearly, as the welding progresses, the pre-heated zone must also move. However, it is very expensive and time consuming if the whole, or a large part of a 50Te section has to be pre-heated even though the mass of the metal adjacent to the welding arc never exceeds a few kilograms. There is thus a need to provide a heat source, movable with respect to the metal to be heated and welded, and able to heat the area of metal to be welded, and its immediate substrate, prior to welding in a manner such that only the minimum required volume/mass of metal reaches the pre-heat temperature as the welding operation commences at any point.

According to one aspect of the present invention there is provided a thermal imaging apparatus for heating the surface of a substance comprising

(i) a source of radiation;

(ii) a reflector of part-elliptical section;

(iii) mounting means for supporting said source of radiation at a first focal point of said reflector; and

(iv) means for supporting said apparatus such that said surface to be heated is at a second focal point of said reflector.

According to a second aspect of the present invention there is provided a method for preheating a surface of a substance which method comprises:-

(i) placing a source of radiation at a first focal point of a reflector having a part elliptical section;

(ii) placing said surface at or near a second focal point of said reflector, and

(iii) energising said source of radiation to cause the radiation thus emitted to be focussed onto said surface.

Generally said second focal point will be the focal point which is the more remote from the reflector.

Preferably the wavelength of the radiation emitted by said source is in the range of 0.4-1.4 μm, i.e. it is infra red radiation and the inner concave surface of the reflector is highly polished so that it is a good reflector of radiation at these wavelengths. Suitable sources are discharge lamps and conventional coiled filament lamps but a coiled filament tungsten iodide lamp is preferred.

The mounting means for the source of radiation is preferably adjustable with respect to the reflector so that it can be aligned as closely with the first focal point as practicable. As the powerful sources of radiation intended to be used in the invention will also generate considerable heat, cooling of the source and reflector is desirable.

The radiation produced by the source at the first focal point is focussed at the second focal point and thus the surface to be heated, located at or close to the second focal point, is subject to intense energy transfer whereby its temperature rises rapidly.

In a first embodiment of the invention the reflector essentially has the shape of the surface of revolution of an elliptical arc when said arc is rotated about the major axis of said ellipse.

In accordance with a second embodiment of the invention, said reflector is of an elongate form whilst having a section which is essentially part-elliptical, the reflector being essentially symmetrical about the major axis of the elliptical. In this case the source of radiation may be either a plurality of point sources or one or more elongated sources, the or each source being located at said first focal point of the reflector.

Where a considerable quantity of heat must be input to a surface on a continuous basis, it is preferable that the reflector is elongated in this way i.e. so that it is in the form of an elongated "trough" with an essentially symmetrical elliptical section. In this case, the first focal point forms an axial line along the trough, at right angles to the major axis of the elliptical shell of the reflector. A number of sources of radiation, e.g. point sources or those of extended axial length, can then be positioned along the axial line through the first focal point. Thus an elongated narrow "strip" of radiation is focussed along an axial line passing through the second focal point.

In the case where the surface to be heated is the surface of an elongated object, by causing relative movement between the reflector and the object so that successive portions of the surface move through the second focal point, the surface of the object will be progressively heated by the focussed radiation.

The surface to be heated in accordance with the present invention may be a weld preparation. In this case, the reason for heating would be for pre-heating prior to welding so that the surface and immediate substrate reach an appropriate temperature for welding. As the heat input is very much greater than the heat losses due to conductivity, etc., the metal to be welded gains heat very rapidly. Preferably the apparatus and the weld preparation are movable relative to each other so that the zone of heating can be moved along the whole length of the weld preparation, immediately prior to the actual welding operation.

Alternatively, the surface to be heated may be all, or part of, a metallic component on which a metallurgical process is to be performed. In this case, the metallurgical process may be, for example, stress relieving, tempering, hardening, bending, etc. Alternatively, it may be a process such as soldering, brazing, or causing particulate material to fuse with, or onto, said surface to be heated.

In one form of the invention, the surface to be heated is in contact with a reactive gas. In this case, the hot surface can react with the gas; for example, if the gas is oxygen and the surface is made of aluminium, a thick protective oxide can be formed on the metal surface.

If desired, more than one thermal imaging apparatus may be used in series or succession and the surface may be traversed through the plane of the second focal points of the plurality of apparatus so that heating occurs progressively. Alternatively the plurality of thermal imaging apparatus may be moved relative to said surface.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings in which:-

Figure 1 is a schematic view of a thermal imaging apparatus of the invention being used to focus a spot of intense radiation onto weld preparations,

Figure 2 diagrammatically illustrates a T-butt weld being produced in accordance with the present invention,

Figure 3 is a schematic perspective view of a plate-plate butt weld being produced in accordance with the invention,

Figure 4 is a schematic plan view of the plate-plate butt weld of Figure 3.

Figure 5 diagrammatically illustrates another technique of producing a T-butt weld in accordance with the present invention, and

Figure 6 diagrammatically illustrates a further technique of producing a T-butt weld in accordance with the present invention.

In the drawings, corresponding or equivalent components are denoted by the same reference numerals.

Referring to Fig. 1, there is shown a thermal imaging apparatus comprising an outer metal case 1 formed as a solid surface of revolution of the arc of part of an ellipse. The axis of rotation is the line through the two focal points 4A and 6, i.e. the major axis of the ellipse; Fig. 1, this line corresponds to centreline 2. Outer case 1 is a light rigid member having an inner concave surface 3 formed of a substance which is highly polished to give a highly reflective surface. Suitable materials for the concave surface 3 are aluminium, etc. or gold plate.

A small but powerful source of radiation 4 is mounted at the first focal point 4A. This source 4 emits radiation at any suitable wavelength, though the range 0.4-1.4 µm is preferred. This is in the infra red wavelength band. Radiation emitted from the source 4 at the focal point 4A will be reflected from surface 3 and pass through the second focal point 6. In this context, the term reflected is used in the optical sense to mean that:-

angle of incidence (i) = angle of reflection (r).

This is shown in Fig. 1 where a typical ray of radiation 5 from source 4 at the first focal point 4A is reflected from surface 3 and passes through second focal point 6. If source 4 was a point source located exactly at first focal point 4A and surface 3 was perfectly ellipsoidal, then all rays 5 would be concentrated at second focal point 6. In practice it is preferred for a small circular or ellipsoidal area 7 of radiation to be directed on the surface and this can be achieved by 'defocussing', i.e. by moving weld preparations 19 slightly away from the second focal point 6. As shown, reflector 3 is generally "pear" shaped to minimise loss of stray radiation and to maximise efficiency as a thermal imaging device.

Source 4 is mounted in a holder 10 on a hollow member 11. The upper part of member 11 carries an external screw thread 12 which mates with an internal thread in boss 13. A lock nut 14 is used to lock member 11 at the desired position, i.e. with source 4 at first focal point 4A. The outer surface of locknut 14 is knurled for easy adjustment by hand. The adjustment just described is in the axial direction 2 only. Separate adjustment (not shown) in the other two directions may be provided, if required.

The electrical connection to source 4 is via wiring (not shown) running down bore 15 of hollow member 11. Outer metal case 1 is strong enough to maintain its shape after forming and is supported at its outer surface by members 16.

When source 4 is very powerful, a large quantity of heat will be generated so that cooling is required. One method of achieving this is to blow filtered air through duct 33 in the direction shown by arrow 17. The air enters outer case 1 via annular axial hole 32 to remove heat conducted along member 11 and source 4 and then flows radially outwards (from axis 2) to cool reflector 3.

The apparatus is supported from one, or more, of members 16 or 33 by external supports (not shown) which are adjustable to allow the apparatus to be moved in all three planes, as well as to be rotated angularly.

The purpose of the apparatus shown is to provide a concentrated source of heating and apply it, in particular, to weld preparations 19. The apparatus is thus mounted close to the workpiece 20,21 to be welded. Though the words 'close to' are used, it will be understood that ellipses can be constructed with considerable distance between the two focal points 4A, 6. Consequently symbol 22 is used to indicate a reasonable distance between these two points 4A, 6. As welding is an energetic process, fumes are evolved and weld metal droplets are sometimes ejected from the arc or weld pool. To protect the thermal imaging apparatus, it is advisable to use an ellipse with 0.5-1.0m between the focal points 4A, 6. Cooling air 17 will blow away weld fumes and reduce the tendency of weld spatter to enter or settle on reflector 3. Alternatively a protective screen, transparent to radiation at the particular wavelengths being used, could be provided.

The apparatus is first adjusted via members 11, 13 and 14 so that source 4 is at first focal point 4A. Then it is mounted from the adjustable external supports by members 16 and 1 or 33 and then moved, by adjusting the supports, relative to work pieces 20,21 so that the area 7 is essentially focused on weld preparations 19, i.e. so that weld preparations 19 are at, or approximately at, the second focal point 6. This may conveniently be done by running source 4 at partial power, and observing the size of area 7 through protective glasses. Having appropriately positioned the apparatus, the proper power is then fed to the source 4. Then the thermal imaging apparatus is moved past the workpiece, or vice versa, at a pre-determined rate and the welding process is commenced as soon as each successive region of the weld preparation has passed through area 7.

Referring to Fig. 2, there is shown the application of the invention to a T-butt weld. Here a first member 23 in the form of a web, with a suitable weld preparation 19, is mounted at right angles against a second member 24, with a suitable weld preparation 19A, prior to welding. Before welding commences, the metal substrate must be heated to a pre-determined temperature and to a pre-determined depth. These parameters will vary with the alloy, metal scantling and type of welding being used but typical values would be 100-150^{o}C and 5-15mm respectively. The heating is achieved by focussed radiation 5A from a single thermal imaging apparatus (or by focussed radiation 5B, 5C from additional thermal imaging apparatus directed at greater angles of incidence onto the respective surfaces of members 23 and 24.) The angles of incidence of the radiation, e.g. 5B, can be chosen so that, where possible, any reflection from weld preparation 19A, would impinge on the surface heated by radiation 5C.

The heating parameters are:-

i) Power being fed to source 4.
ii) Angle of incidence on weld preparation 19.
iii) Reflectivity/emissivity of weld preparation 19.
iv) Area of surface to be heated.
v) Depth of pre-heating required.
vi) Thermal conductivity of metal.
vii) Temperature required for pre-heated zones 23A, 24A.
viii) Wavelength of radiation used.

An analysis of these parameters will determine for how long the heating must be maintained, prior to welding. Clearly, if the rate of heat input is very, very much greater than the rate of heat loss, then the temperature in the substrate layers will rise rapidly. Within practical constraints, the sooner the required temperature can be attained, the lower will be the cost as less heat will be lost by conduction and convection.

Figs. 3 and 4 show the principle of the disclosure as applied to a conventional plate-plate butt weld. Two plates 20, 21 are butted along line 27, with their weld preparations 19 adjacent. The metal sections 20A, 21A respectively are shown to make Fig. 3 clearer.

In this example, plates 20, 21 are moved in the direction shown by arrow 31 at a constant, pre-determined rate, e.g. 150mm per minute i.e. the speed of welding is 150mm per minute. As plates 20, 21 move, any point on the weld preparations 19 will firstly enter the area bounded by curve 7'A and so commence to be heated by radiation 7A. After a period of time, this point will leave the area bounded by 7'A and enter a second area either 7'B or 7'C where further heating will take place. On leaving area 7'B (or 7'C), the temperature will have reached that required for pre-heating throughout substrates layers 20B, 21B and welding can be effected at position W denoted by reference numeral 28 in Fig. 4. Numeral 29 indicates the moving front of the completed weld 30.

In the example given, the heat is applied in two stages 7A and 7B or 7C. Depending upon the particular requirements one, two or more stages of heating may be used. Furthermore, the areas 7A, 7B and 7C are shown as circles or ellipses. This indicates that the beam is slightly defocussed. The heat input is at a slightly lower level over a larger area and for a longer time as plates 20, 21 move through area 7A in the direction shown by reference numeral 31. The radiation on areas 7B, and 7C is concentrated on the weld preparation 19 of plates 20, and 21 respectively to give greater heating at an improved angle of incidence e.g. as shown (5B,5C) in Fig. 2. The greatest heat input occurs when the major axis 2 is normal to the surface 19 so that the heated area is circular (Fig. 1).

In practice, there are several variables which can be used to optimise a particular welding process, e.g.:-

i) Number of thermal imagers used.

ii) Power rating of radiation sources.

iii) Angle of incidence of radiation 5 on weld preparation 19.

iv) Whether heated areas 7A and 7B (or 7C) overlap or are sequential.

v) Speed of movement of plates 20, 21.

As the rate of heat input from thermal imaging is very, very great, there may be the need for a brief dwell period between the final heating zone 7B/7C and the welding position 28 to allow time for any unacceptable heat distributions to be modified by the normal conductive processes.

If desired, weld pre-heating may be effected by means of thermal imaging apparatus located on the opposite sides of the plates to where the welding is to be performed in order to produce a more even distribution of heat in the substrate layers.

Although, as above described, the plates 20,21 are moved past the thermal imaging apparatus and the weld head (not shown) at position W, it is equally possible for the plates to be fixed and for the thermal imaging apparatus and weld head to move. In this case, the thermal imaging apparatus and the weld head can be mounted on a moveable trolley or frame to ensure alignment. Alternatively, both plates 20/21 and the weld head, at position W, may move together in opposite directions.

The thermal imaging apparatus of the invention may be used to provide local heating for stress relief in the welds following the welding operation.

The same principles as disclosed in Fig. 3 may equally well be applied to the arrangement of the T-butt weld shown in Fig. 2. In this case, two welding heads would be required. In the past, it has been common to use two welding heads which are staggered, i.e. one precedes the other. Welding is a highly energetic process and usually causes distortion of the joint. Thus, conventional staggered welding of a right angle butt will cause web member 23 firstly to cant in one direction 25 and then back to the vertical (see Fig. 2). Unfortunately, some net angular misalignment 25 may result.

By using two welding heads in line and on opposite sides of member 23 in accordance with the invention, it is possible to avoid misalignment of member 23 relative to member 24. As welding proceeds, a probe 26 can be provided to monitor angle 26A between member 23 and member 24. If the angle 26A moves out of its tolerance band, corrective action to the welding head(s) can be taken to rectify the discrepancy. Alternatively, a restoring force can be applied to member 23 to hold it at the correct angle.

When applying heat to relatively inaccessible areas, a range of indirect measures may be employed. For example, radiation 5D (Fig. 5) may be reflected off one weld preparation 19A to heat another 19 or a reflective surface 34 may be used to reflect radiation 5E directly onto the weld preparation 19 to be heated. In this latter case, reflector 34 may be planar or concave and is preferably metallic in nature or is formed of a material which will not absorb radiation of the wavelength in question. If necessary, reflector 34 may be provided with some form of cooling.

By using an optical system comprising a lens 35 of a material transparent to the wavelength of the radiation being used, e.g. certain types of quartz, radiation 5F (Fig. 6) reflected by the reflector 3 can be focussed either directly onto the weld preparations 19, 19A, or into a flexible bundle of optical fibres 36 (again made of transparent material) forming a further part of the optical system. In the latter case, the radiation is transmitted through the fibres to emerge as radiation 5G, via a focussing lens 37 (if required) forming another part of the optical system, and is then directed onto weld preparation 19. In this case, a cooling means is preferably provided for lenses 35, 37 and fibre bundle 36.

In some cases, it may be convenient to direct radiation 5H (Fig. 6) onto surfaces 23B adjacent to weld preparation 19 and to allow thermal conduction to transmit the required heat to the weld preparation 19. This is, of course, less efficient, but could be the most practical means of applying the heat in certain cases. In such cases, the use of heat insulation 38 may be beneficial to prevent heat loss.

Though only conventional T-butt and plate-plate butt welds have been exemplified, the principle of applying heating by thermal imaging apparatus can be applied to all forms of weld pre-heating. The principle is equally applicable to stress relieving, hardening, tempering and casting and forging operations etc. For example, when metal is hardened, it is usually heated to a high temperature and quenched and in order to control the hardness (and brittleness) the metal is often subsequently tempered by heating to a lower temperature and allowing it to cool naturally. Such heating can be effected in accordance with the present invention. The invention can also be used to apply surface heating in an oxygen-rich atmosphere to generate a thick oxide-rich protective surface coating or for applying other forms of surface protection, e.g. enamelling, sputtering etc. When used to produce a finely focussed beam, in conjunction with cooling sprays, it can be used for rectifying distortion or producing desired shape changes in suitable metal components. Hardening or tempering of metallic components is also possible. Non-metallic components may also be heated and softened for bending, forming or joining etc.

Though reflector 3 has hitherto been described as a surface of revolution i.e. essentially circular as seen looking along major axis 2, if desired reflector 3 can be in the form of an elongated elliptical "trough", i.e. as though the view in Fig. 1 was a section at right angles to the longitudinal axis of the trough. In this variation, several sources 4 can be mounted at first focal point 4A which, in this case, is an axial line along the trough. Alternatively, sources 4 could be elongated filaments. With such a trough reflector, a strip of focussed radiation is produced rather than a circular or elliptical area (7) of radiation. The components to be welded are moved relative to the reflector so that the weld preparation and adjacent substrate are progressively pre-heated. A second thermal imaging apparatus, following the first could be used for stress relief after welding.

Though the elongated reflector will normally be straight in the elongated direction, curved troughs are also possible. These may be used for welding curved sections e.g. for the butt welding of drums or circular discs.

The radiation 5 generated by source 4 is very powerful and, when focussed, will readily burn any delicate objects accidently put at or near second focal point 6. The emission of stray rays as a possible cause of eye damage is largely eliminated by the pear shape of the reflector 3 and by its proximity to the work surface. Additionally, however, it is preferred for shields to be used round the thermal imaging apparatus.

CLAIMS:

1. A thermal imaging apparatus for heating the surface of a substance comprising

(i) a source of radiation;

(ii) a reflector of part-elliptical section;

(iii) mounting means for supporting said source of radiation at a first focal point of said reflector, and

(iv) means for supporting said apparatus such that said surface to be heated is at a second focal point of said reflector.

2. An apparatus as claimed in claim 1 wherein the second focal point is more remote from the reflector than the first focal point.

3. An apparatus as claimed in claim 1 or 2 wherein the location of the mounting means is adjustable with respect to the reflector.

4. An apparatus as claimed in claim 1, 2 or 3 wherein the reflector has the shape of part of the surface of revolution of an ellipse when the ellipse is rotated about its major axis.

5. An apparatus as claimed in claim 1, 2 or 3 wherein the reflector is of elongate form, has a cross section which is part of an ellipse and is symmetrical about the major axis of the ellipse.

6. A method for preheating a surface of a substance which method comprises:-

(i) placing a source of radiation at a first focal point of a reflector having a part elliptical section,

(ii) placing said surface at or near a second focal point of said reflector, and

(iii) energising said source of radiation to cause the radiation thus emitted to be focussed onto said surface.

7. A method according to claim 6 wherein the reflector and the surface are subject to relative

movement so that successive portions of the surface are progressively heated.

8. A method according to claim 6 or 7 and comprising the step of cooling the source and the reflector.

9. A method according to claim 6, 7 or 8 and comprising the additional step of effecting a welding operation on the heated substance.

10. A method according to claim 6, 7 or 8 wherein said substance is a metal and the method is effected to relieve stresses in the metal.

11. A thermal imaging apparatus for heating the surface of a substance comprising

(i) a source of radiation,

(ii) a reflector of part-elliptical section,

(iii) mounting means for supporting said source of radiation at a first focal point of said reflector,

(iv) an optical system for guiding radiation reflected from said reflector to said surface to be heated.

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