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(54) Build-up Welding on Rotating Workpieces

(57) Apparatus for controlling the progress of build-up welding on rotating workpieces, in particular large diameter shafts, makes use of one or more welding heads 16 arranged to deposit one or more continuous weld beads on a rotatable workpiece 11. A drive motor M1 is used to produce rotation of the workpiece and a feed motor M2 to produce axial feed movement of the welding heads 16 relative to the workpiece 11. A sensor 15 measures a value corresponding to the prevailing diameter of the workpiece. The rotational speed of the drive motor M1 and thus of the workpiece 11, is controlled in accordance with the sensed diameter of the workpiece so as to hold the peripheral speed of the workpiece and thus the length of bead deposited per unit time, substantially constant. The rate of axial feed of the welding heads 16 relative to the workpiece 11 is controlled in dependence on the rotational speed of the workpiece so as to produce a continuous weld build-up over the length of the workpiece. Methods of controlling the progress of build-up welding are also disclosed.

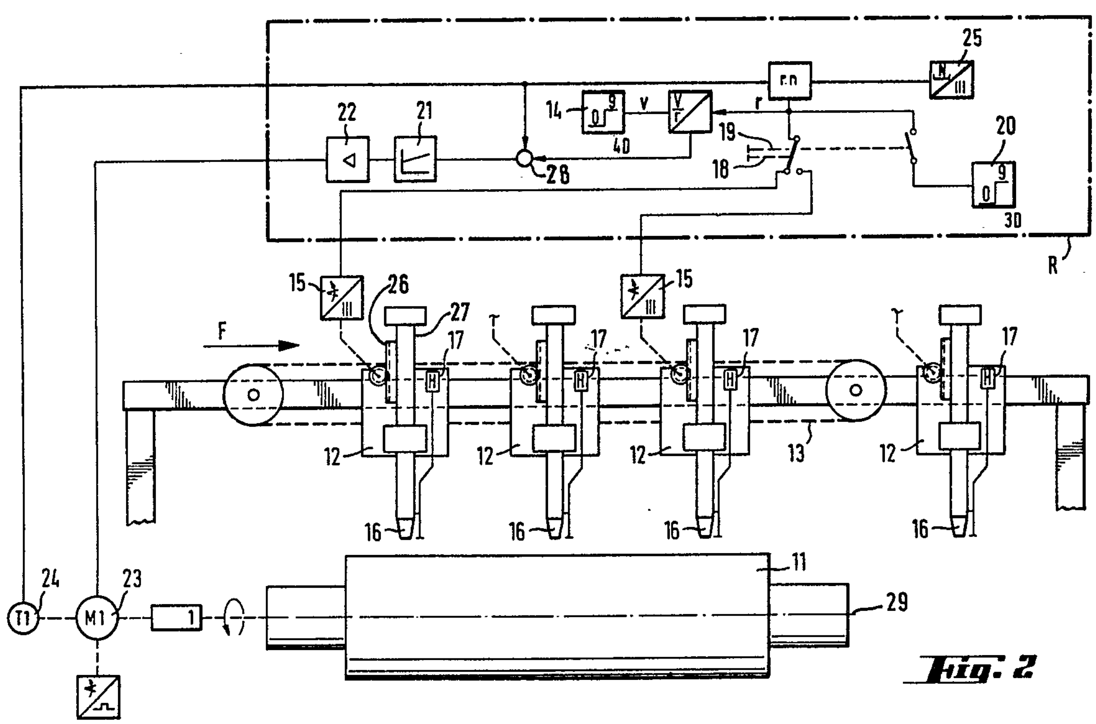

Fig. 2

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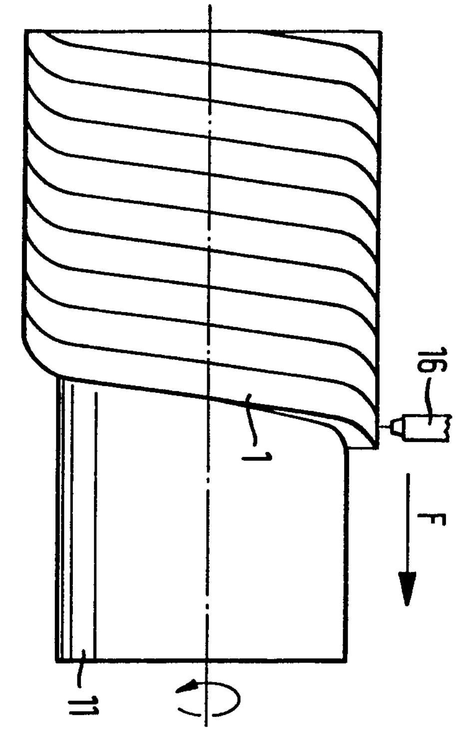

Fig. 1a

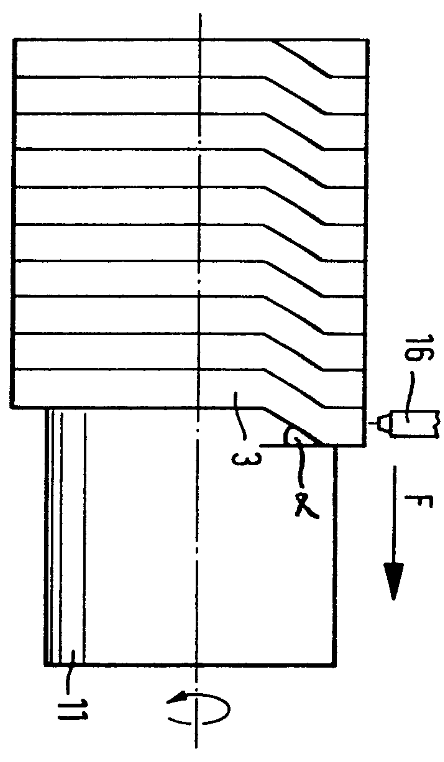

Fig. 1b

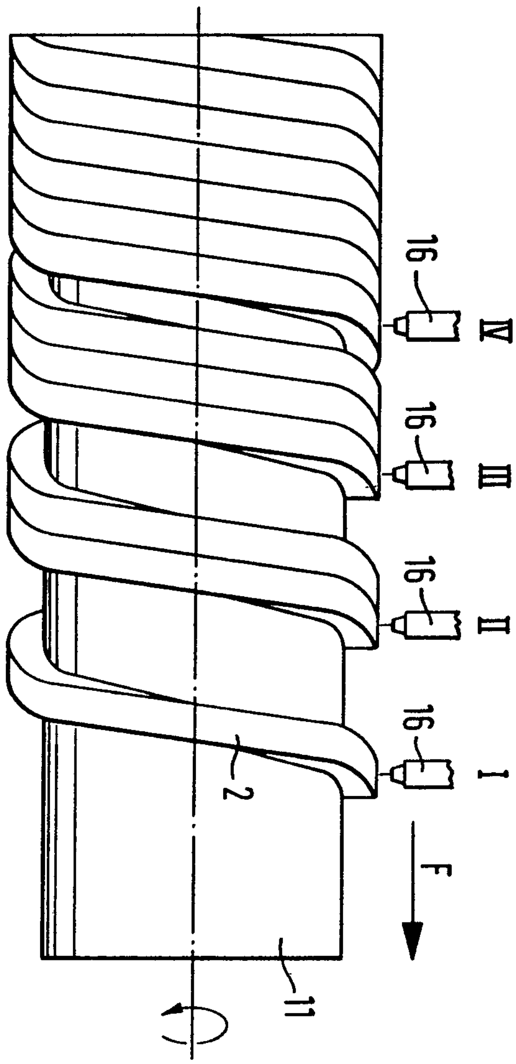

Fig. 1c

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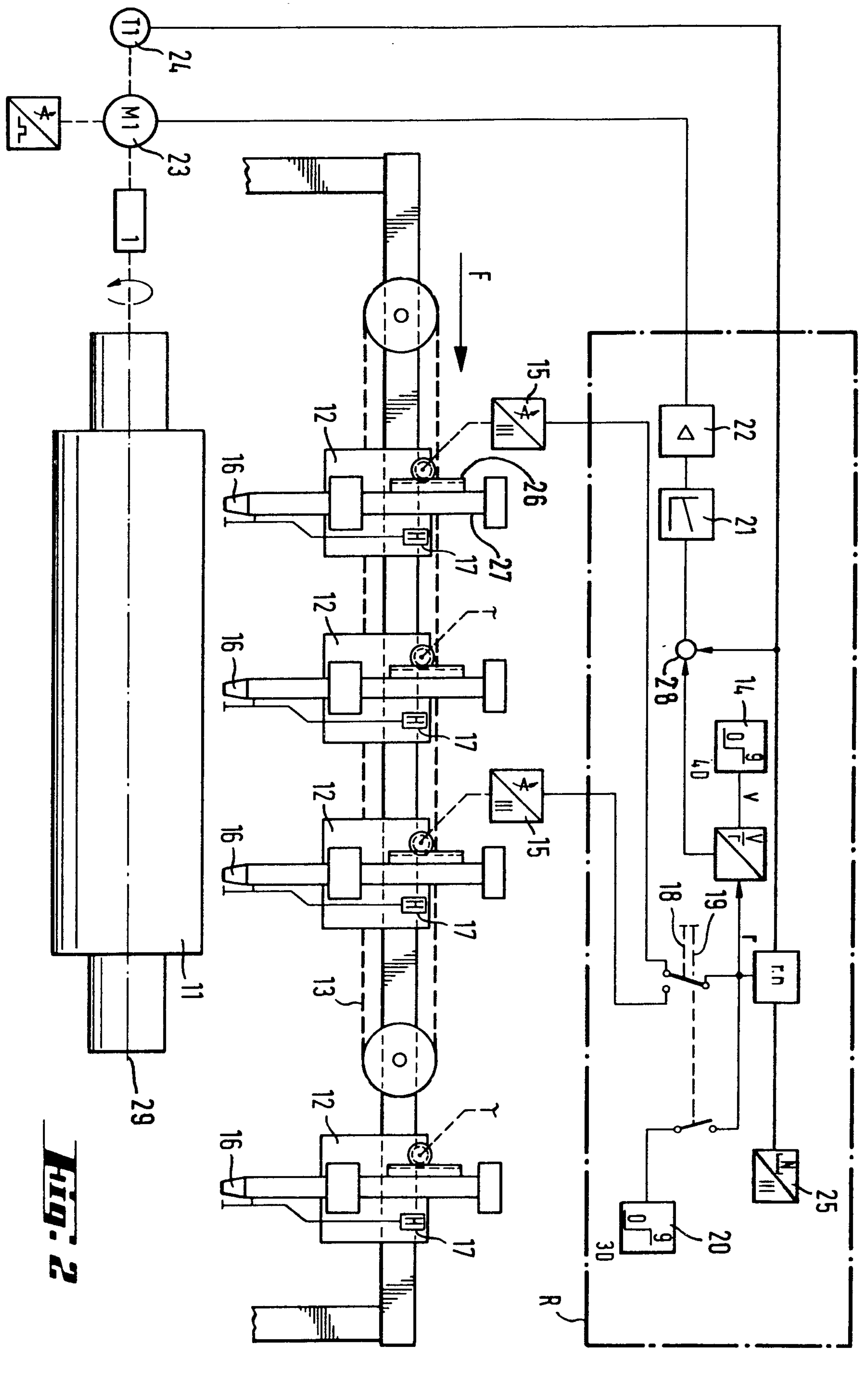

Fig. 2

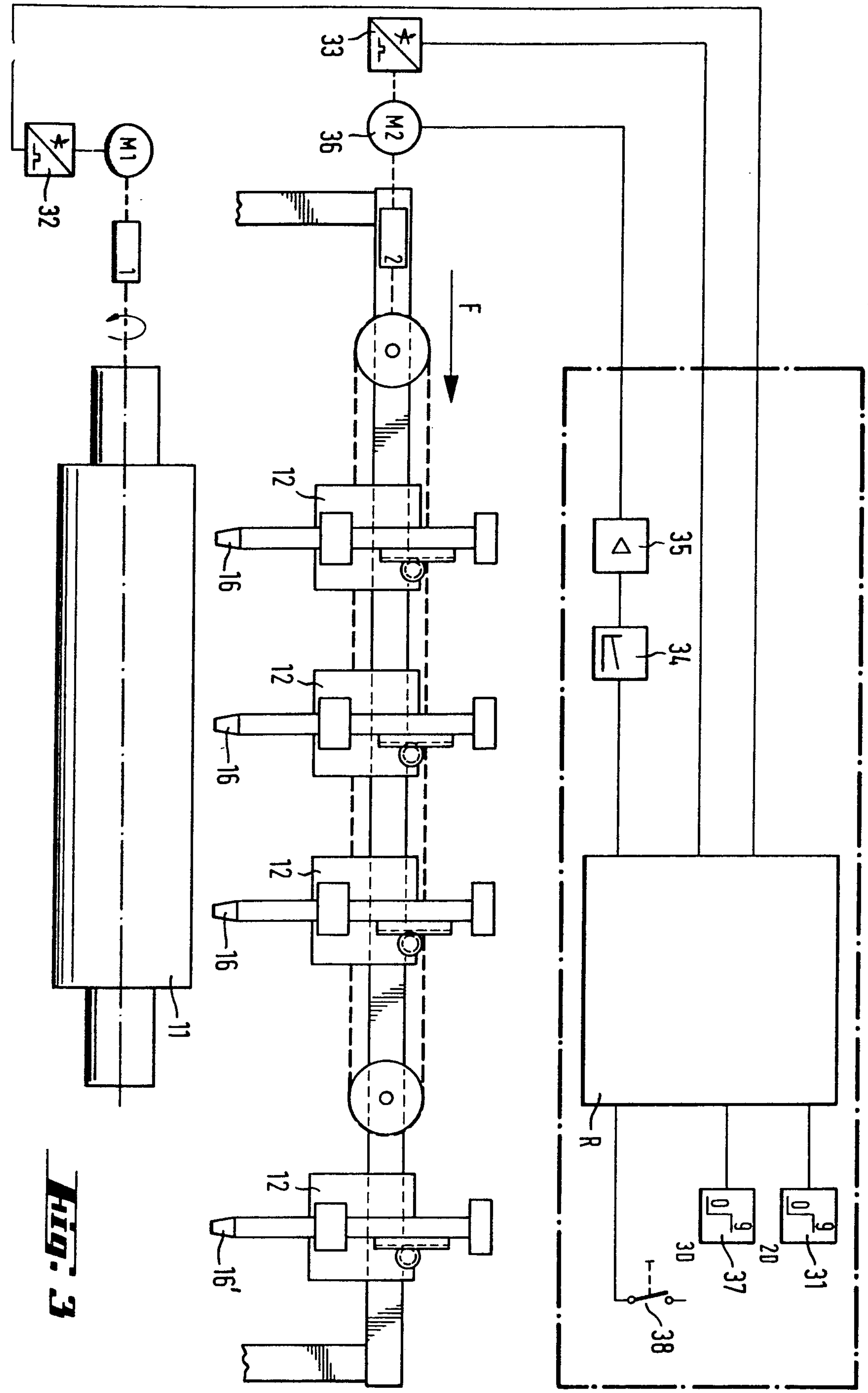

Fig. 3

SPECIFICATION

A Method of Controlling the Progress of Build-up Welding on Rotating Workpieces

The invention relates to a method of controlling the progress of build-up welding on rotating workpieces, in particular on large diameter shafts, and to apparatus for carrying out this method.

Large shafts and ring structures with diameters of the order of several meters can be manufactured by build-up welding processes. In general one or more welding heads are used to deposit one or more continuous weld beads on a rotating work-piece with the welding head or heads being fed axially along the workpiece so as to produce a continuous weld build-up over the length of the workpiece. The diameter of the workpiece is increased in stages by repeatedly passing the welding head or heads over the workpiece. As the finished workpieces are invariably highly stressed components it is essential that the weld beads are all properly fused one with another. It will be appreciated that significant problems arise in controlling the progress of the welding process. It will also be appreciated that the individual welding passes should follow one another in quick succession and indeed preferably continuously, so as to minimize the duration of the total welding process.

The principal object underlying the present invention is to provide methods and apparatus for controlling the progress of build-up welding on rotating workpieces, in particular shafts of large diameter, which allow the welding process to be extensively automated without restricting the versatility of the equipment.

A further object underlying the present invention is to minimize the time required for carrying out build-up welding on rotating workpieces.

Another object underlying the present invention is to allow the progress of build-up welding on rotating workpieces to be controlled in such a way that a high quality welded structure results.

The above objects are accomplished, in accordance with first and second aspects of the invention, by the methods set forth in claims 1 and 5. The above objects are also satisfied, in accordance with the invention, by apparatus in accordance with claim 10.

A further development of the method of the invention makes it possible to select either a welding process in which the rate of axial feed of the, or each, welding head is controlled to produce one, or a number, of continuous helical weld beads, or, a welding process in which the rate of axial feed of the, or each, welding head is controlled to produce a series of interconnected ring-like weld beads with a single axial stagger per revolution of the workpiece.

Furthermore, for carrying out the method of the invention in an apparatus, there is usefully provided a four stage decade switch for manual selection of the desired peripheral speed of the workpiece, a two stage decade switch for selecting the cyclical feed length and pulse generators for detecting movements of the workpiece and welding head, or heads, with the consecutive pulses from these pulse generators being detected as actual values by counting devices.

A key (or encoding) switch can be provided for selecting either the continuous helix or ring-like welding processes with the key switch helping to regulate the feed drive during the stagger interval. A three stage decade switch can be provided for selection of the stagger angle.

The invention will now be described in more detail by way of example only and with reference to the accompanying drawings which show:

Figs. 1a to 1c the principle of various operating modes for carrying out the deposition welding,

Fig. 2 an apparatus in accordance with the invention showing details of the arrangement used to control the welding speed, and

Fig. 3 a further view of the apparatus of Fig. 2 showing details of the arrangement used to control the movement of the welding heads along ths workpiece.

Referring firstly to Figs. 1a to 1c there can be seen a number of different operating modes for carrying out build-up welding. As seen in Fig. 1a a single helical bead 1 is formed by a single welding head 16 on a workpiece 11 using a submerged arc welding process. For this purpose a wire is continuously fed in the usual manner through the welding head 16 and is shielded from the atmosphere by a gas such as carbon-dioxide. In Fig. 1b the same welding head 16 is used to produce a series of ring-like welds along the workpiece 11. As each ring is completed the welding head 16 is moved at a stagger angle α along the workpiece to commence the next ring. It will be seen that the stagger between one ring and the next always takes place at a constant angular position of the workpiece so that a continuous sheath of weld is formed on the surface of the workpiece.

Fig. 1c shows a modification of the arrangement of Fig. 1a in which a number of welding heads I—IV are used to produce a number of helical weld beads 2 on the surface of the workpiece 11. These weld beads are arranged on the workpiece in the form of a multiple start thread in contrast to the arrangement of Fig. 1a where the weld bead 1 can be likened to a single start helical thread.

Referring now also to Figs. 2 and 3 there can be seen details of apparatus which is suitable for carrying out the welding processes shown in Figs. 1a to 1c. The workpiece 11 is mounted between centres in a support apparatus (not shown) and can be rotated via a variable speed drive motor M1 through a gear box G1. A gantry 13 extends above the workpiece and supports a number of welding heads 16. The welding heads 16 are mounted on carriages 14 which can be moved along the length of the workpiece via a chain drive 13 which is driven by a feed motor M2 through a gear box G2. When a welding head, for example the welding head 16′ in Figs. 2 and 3 reaches the end of the workpiece it is lifted by a crane (not shown) and returned to the other end of the chain drive where it is hitched back onto the chain and starts to lay a new weld bead on the workpiece. This bead will in fact be at a slightly larger diameter than the other weld beads but this difference in diameter is not critical having regard to the overall diameter of the workpiece. The operating ends of the welding heads 16 can be moved on respective lifting pillars 18 to and away from the axis 29 of the workpiece. The chain drive 13 is common to all the welding carriages 12 so that these carriages are all fed at the same rate along the workpiece. It will be apparent that a maximum exists for the length of bead which can be deposited by any one welding head per unit time. This rate of deposition of the weld bead is referred to as the welding speed and it will be appreciated that this welding speed is practically identical to the peripheral speed of the workpiece. As the diameter of the workpiece grows the peripheral speed must be kept constant in order to hold the welding speed substantially constant at or near its maximum value. Thus, as the diameter of the workpiece grows, the rotational speed of the workpiece must be reduced so as to hold the welding speed constant.

In contrast the feed rate of the welding heads along the workpiece must be reduced in accordance with the growing diameter in order to ensure an invariable position of the weld beads.

As previously mentioned the build-up welding process can be carried out by two different methods namely either with a continuous helix-like weld bead or with a series of ring-like weld beads. During welding using continuous helical weld beads the advance movement of the welding heads is continuously regulated. The reference values for this control are the rotational speed of the workpiece and the predetermined cyclical feed length, i.e. the pitch of the weld bead on the periphery of the workpiece during one rotation of the workpiece.

For single start helical welding in accordance with Fig. 1a the cyclical feed length is so selected that the single welding head lays one bead alongside the next. For multiple start helical welding as shown in Fig. 1c the cyclical feed length is increased. The cyclical feed length is then selected so that it equals the product of the cyclical feed length for a single welding head multiplied by the number of welding heads that are in use.

When using the ring welding method with stagger as shown in Fig. 1b no feed movement of the welding head 16 occurs until the beginning of the stagger is reached as can be seen from the path of the weld bead 3.

During the stagger interval the advance motor is so regulated that the selected cyclical feed length is achieved over the stagger path. In order to ensure that the stagger path is always positioned at the same location on the periphery over the whole length of the workpiece an electrically marked null point is specified at a desired angular position of the workpiece. A transducer (not shown) senses the periodic return of this null point which forms a zero datum. The stagger is then commenced sufficiently far in front of the passage of the rotating workpiece through the zero datum that the stagger movement finishes at the zero datum. The angle of stagger is selected at a three stage decade switch 37.

The change-over between the helical and ring welding methods can be effected by operating the key or encoding switch 38 (Fig. 3). The coded signals from the switch are then used to advise the control system, in this case a computer R (microprocessor), of the type of control that is required. The computer R is used to maintain an invariable exact position of the weld beads 1, 2 or 3 within a tolerance of ± 1 mm over the whole length of the workpiece. The desired, preselected, control values for the welding speed (rotational speed of the workpiece) and for the cyclical feed length of the carriages 13, and thus of the welding heads, are derived by the computer R from initial key data fed in to the decade switches 14 and 31 respectively.

Fig. 2 shows the operation of the computer R with respect to the welding speed. The desired welding speed is manually set at the four stage decade switch 14 and a value for the workpiece diameter is obtained, by means which will later be described in more detail, from the position of the welding head(s). The role of the computer is now to calculate and output the desired welding speed, to calculate and display the actual welding speed and to output the calculated desired rotational speed of the workpiece.

The workpiece diameter is continuously and automatically detected by a positional encoder in the form of an angle encoder 15 which continuously passes the measured value of the position of the welding head relative to the axis of the workpiece to the computer R. A toothed rack 26 which moves the toothed wheel of the angle encoder 15 on change of the vertical position of the welding head 16 is located on the pillar 27 for raising and lowering the welding head 16.

A contactless capacitive vertical control 17 monitors the spacing between the welding head and the surface of the workpiece. When changes in this distance of more than 2 mm occur a signal brings about a displacement of the motor driven pillar and raises or lowers the welding head 16 until the old and desired distance is re-established. This control system can be a separate closed loop control system or can be effected by the computer R as desired. This arrangement ensures, in addition to the fact that the displacement maintains the welding head stand off which is important for the welding procedure, that the new workpiece diameter is also transmitted to the angle encoder 15. If several welding heads 16 are in use (Fig. 1c) the angle encoder 15 of the last welding head 16 to be operated is activated by means of the change-over switch 18.

In addition to the automatic measurement of diameter the workpiece diameter can also be input manually be adjusting a three stage decade switch 20 after changing over to the "manual" setting 19.

The desired speed of rotation which is output by the computer R is passed to the controller 21 and to the current rectifier 22 of the DC motor MI for the rotational drive.

The actual welding speed is calculated from the actual speed of rotation (n) as determined by a tachogenerator 24 and from the input, or measured, diameter (r) and is output as an actual value on a digital display 25.

The desired rotational speed V is divided by the computer, in a block illustrated schematically at 25, by the diameter (or radius) R of the workpiece and the signal resulting from this division is compared at 28 with the actual speed of rotation n as determined by the tachogenerator 24. The result of this comparison is used via a function forming stage 21 and a rectifier 22 to produce a control signal for regulating the motor M1 so as to hold the actual speed substantially constant at the desired speed.

The control of the feed of the welding heads is illustrated in Fig. 3. The desired value for the cyclical feed length is firstly selected at the decade switch 31. Alternatively this value can be stored in a memory bank of the computer and called up as required. The computer than carries out the following steps:

Calculation and output of the desired feed speed,

Calculation of the actual feed speed,

Calculation of the control deviation and its processing and output of the calculated desired rotational speed of the feed drive.

The desired speed of feed is dependent on the selected cyclical feed length (i.e. the distance of advance after rotation of the workpiece through 360°), on the speed of rotation of the workpiece and on the mode of operation (i.e. helical or ring-like welding).

The cyclical feed length can be selected manually at a two stage decade switch 31. The cyclical feed length can be reproduced as often as required within a tolerance of ±1 mm.

The tolerance of the seam position of one layer relative to the previous deposited layer is likewise within ±1 mm.

Pulse transducers are used to detect the rotational movement of the workpiece and of the feed drive for the welding head(s). The pulse transducer 32 is attached to the rotational drive and transmits pulses in dependence on the rotational speed of the drive motor M1.

The pulse transducer 33 is attached to the feed drive and transmits pulses in dependence on the rotational speed of the feed motor M2. The pulses that are gathered from the pulse transducers 32 and 33 are detected by counting devices as actual values.

Depending on the preselected mode of operation and the selected cyclical feed length a pulse rate (number of the desired pulses for one revolution) is associated with the pulse inputs and determines a desired pulse ratio. The desired pulse ratio is the quotient of the pulse rates of the rotational drive and of the feed drive.

(Desired pulse ratio=desired pulses from 32/desired pulses from 33).

The control deviation is obtained by subsequently comparing the counts registered by the counters and taking account of the desired pulse ratio.

The control deviations which occur must be balanced out in order to keep to the above named tolerances over the whole length of the workpiece. Each control deviation is processed in the next following computer cycle and is passed as a correction value to the regulator for the feed motor. This procedure is repeated after intervals of 100 ms.

It will be appreciated that in the illustrated embodiment the computer carries out the function of two cascaded first and second control means adapted to effect feed back control of both the welding speed and the feed of the welding head (s) along the workpiece. The microprocessor, when suitably programmed, can simply be regarded as a convenient means for carrying out these control functions. The first and second control means could however just as easily take the form of normal hard wired control devices set out in accordance with the control schemes illustrated in Figs. 2 and 3.

It will be appreciated by those skilled in the art that variations can be made to the above disclosed arrangements without departing from the scope of the present teaching as set forth in the accompanying claims.

Claims

1. A method of controlling the progress of build-up welding on rotating work pieces, in particular on large diameter shafts, characterized in that, with an adjustable and preselectable desired value for the peripheral speed of the workpiece, i.e. a value which can be calculated in dependence on the nature and size of the workpiece and selected by hand, and with a likewise adjustable and preselectable value for the desired cyclical feed length (pitch of the helix-like weld bead), i.e. a value which can be calculated and selected by hand, a computer automatically ensures, with a continuously growing diameter of the workpiece, the regulation of the rotational speed of the rotational drive for the workpiece, and of the feed drive for advancing the welding carriage chain, by correcting deviations on the basis of cyclically determined measurements of the cyclical feed length and of the workpiece diameter.

2. A method in accordance with claim 1 and characterized in that the computer makes it possible to select a ring-like welding process with

a single axial stagger per revolution in place of the helix-like welding process.

3. Apparatus for carrying out the method of claim 1 and characterized in that there is provided a four stage decade switch (14) for manual selection of the desired peripheral speed, a two stage decade switch (31) for selection of the cyclical feed length and pulse generators (32, 33) for detecting workpiece and welding head movements with the consecutive pulses being detected as actual values by counting devices.

4. Apparatus according to claim 3 for carrying out the method of claims 1 and 2 and characterized in that a key (or encoding) switch (38) is provided for selecting helix-like or ring-like welding processes, with the key switch (38) helping to regulate the feed drive during the stagger interval and wherein the stagger angle is selected at a three stage decade switch (37).

5. A method of controlling the progress of build-up welding on rotating workpieces, in particular large diameter shafts, using one or more welding heads arranged to deposit one or more continuous weld beads on a rotatable workpiece, there being provision for relative axial feed movement between the or each welding head and the workpiece, the method comprising the steps of:

a) supplying a value corresponding to the prevailing diameter of the workpiece,

b) controlling the rotational speed of the workpiece in accordance with the prevailing diameter to hold the peripheral speed of the workpiece, and thus the length of the weld bead deposited per unit time, substantially constant,

c) controlling the rate of axial feed of the or each welding head relative to the workpiece in dependence on the rotational speed of the workpiece to produce a continuous weld build-up over the length of the workpiece.

6. A method in accordance with claim 5 and wherein the step of supplying a value corresponding to the prevailing diameter of the workpiece is effected by sensing the distance of the or each welding head from the axis of rotation of the workpiece and by the further substep of controlling the stand-off of the welding head from the workpiece to lie at a substantially constant value.

7. A method in accordance with either of claims 5 and 6 and wherein the rate of axial feed of the, or each, welding head is controlled to produce one, or a number, of continuous helical weld beads.

8. A method in accordance with either of claims 5 and 6 and wherein the rate of axial feed of the, or each, welding head is controlled to produce a series of interconnected ring-like weld beads with a single axial stagger per revolution of the workpiece.

9. A method in accordance with claim 8 and comprising the further step of triggering the axial stagger at a constant angular position of the workpiece.

10. Apparatus for controlling the progress of build-up welding on rotating workpieces, in particular on large diameter shafts, using one or more welding heads arranged to deposit one or more continuous weld beads on a rotatable workpiece, the apparatus further comprising a drive motor for producing rotation of the workpiece and a feed motor for producing axial feed movement between the or each welding head and the workpiece, means for supplying a value corresponding to the prevailing diameter of the workpiece, first control means for controlling the rotational speed of said drive motor and thus of said workpiece in accordance with the prevailing diameter of the workpiece, whereby to hold the peripheral speed of the workpiece, and thus the length of bead deposited per unit time, substantially constant and second control means for controlling the rate of axial feed of the or each welding head relative to the workpiece in dependence on the rotational speed of the workpiece to produce a continuous weld build-up over the length of the workpiece.

11. Apparatus in accordance with claim 10 and wherein said value is supplied by a position encoder mounted to detect the position of the or each welding head relative to the rotational axis of the workpiece.

12. Apparatus in accordance with claim 11 and wherein said positional encoder is an angular encoder.

13. Apparatus in accordance with any one of claims 10 to 13 and wherein further control means is provided for holding the stand-off of the welding head from the workpiece substantially constant.

14. Apparatus in accordance with any one of the preceding claims 10 to 13 and wherein said first control means has an input for selecting a desired peripheral speed corresponding to a desired speed of welding, a second input for receiving a signal from a tachometer giving the actual speed of rotation of the workpiece, a third input for receiving said value corresponding to the prevailing diameter of the workpiece, means for comparing the actual speed of the workpiece with the desired speed of the workpiece and means for correcting the speed of said drive motor.

15. Apparatus in accordance with any one of the preceding claims 10 to 14 and in which said second control means comprises a first input for a desired value equal to the desired feed length per revolution of the workpiece, an input for receiving a value proportional to the actual speed of rotation of the workpiece, an input for receiving a value proportional to the actual speed of the feed drive, means for forming the quotient of the actual feed rate of the feed motor divided by the actual speed of rotation of said drive motor, means for comparing this quotient with said desired value and means for controlling the speed of said feed motor in dependence on the outcome of this comparison.

16. Apparatus in accordance with any of the claims 10 to 15 and wherein the speeds of said

feed motor and said drive motor are detected by pulse transducers.

17. Apparatus in accordance with any one of the preceding claims 10 to 16 and wherein the control functions of said first and second control circuits are carried out by a computer, in particular a microprocessor.

18. A method of controlling the progress of build-up welding on rotating workpieces substantially as herein described and illustrated with reference to the accompanying drawings.

19. Apparatus for controlling progress of build-up welding on rotating workpieces substantially as herein described and illustrated with reference to the acompanying drawings.

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