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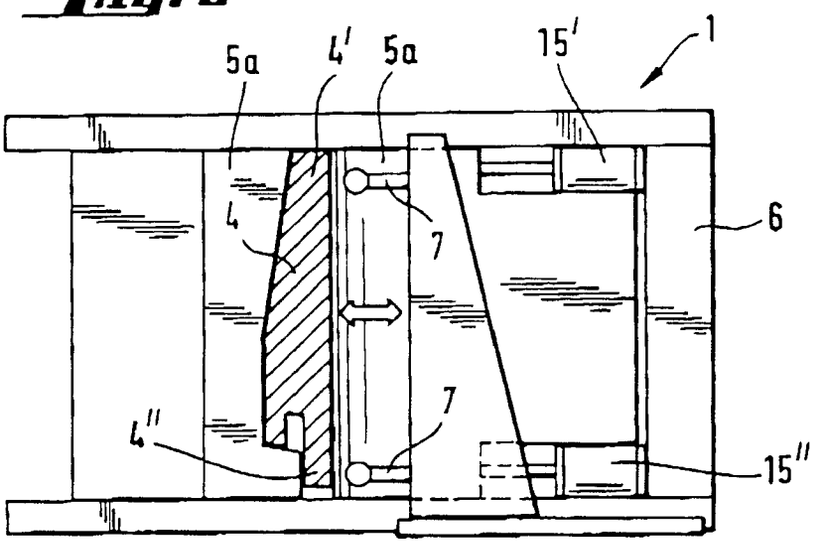
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(54) Bending arrangement for aluminium profile

(57) In a press bending arrangement for an aluminium profile having an asymmetric cross-section, especially for manufacturing the equator profile (4) for a LNG-tank, the press (1) is connected to control and measuring devices (3) in such a manner that the spring-back and twisting of the workpiece (4) is arranged to be taken into account both in bending the profile and in determining the bending control based on measurements being made.

Fig. 2



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Description

This invention relates to a bending arrangement according to the preamble of claim 1 and to a bending method for bending an aluminium profile in a press. In particular, but not exclusively, the invention is intended for manufacturing a so-called eqatorial profile for a LNG-tank.

Substantial spherical tanks used for the storage and transport of liquefied gas are generally large, typically being about 40 m in diameter. The equatorial region of such a large spherical tank is provided by a special profile which is formed to the desired curvature by press bending. A typical equatorial profile workpiece to be bent normally has a length of about 15 m, a width of about 1 m, a thickness of close to 200 mm and a weight in excess of 5000 kg. The completed workpiece must meet high demands with respect to dimensional accuracy. Because of the size of the workpiece and the bending and checking of the degree of bending of the workpiece, the final control of the bending is difficult to perform. In particular the springback of the workpiece after the release of an applied stress needs to be taken into account in the measuring and bending process. Also, accurate movement of the workpiece in the press is difficult because of the great weight of the workpiece. Furthermore the equatorial profile is asymmetric in cross-section relative to a central horizontal plane, typically being thicker at points below the central plane than at corresponding points above the central plane. Consequently, there is a tendency for the profile to twist during the bending process and so it is generally necessary either to take special steps to prevent twisting during the bending process or to carry out correction steps to remove the twisting after the bending process.

Prior art bending arrangements are disclosed, for example, in US-A-3,333,445 and Japanese Publications JP 61199517 and JP 61199518. These known arrangements relate to bending of generally symmetric workpieces which already take into account reflection or springback during the bending stage. Prior art measures for controlled movement of the workpiece are disclosed in Japanese Publication JP 5131330.

The object of the invention is to provide a bending arrangement by means of which the work phases of bending, measuring and adjustment bending, i.e. taking into account reflection or springback as well as twisting, of an equatorial profile may be accomplished in a particularly efficient manner in a single work station, preferably so that all work phases are carried out in one process. A further object of the invention is to enable easy and accurate workpiece movement in the bending press. Practice has shown that the use of an arrangement according to the invention in many cases more than doubles productivity. In addition, accurately measured workpieces are obtained which simplifies the assembly of a spherical tank. Space is spared, because a separate measuring station is not required.

The object of the invention is obtained in the manner stated in claim 1.

By incorporating the springback properties of a profile to be formed into a control program controlling the profile bending process, the desired profile curvature can normally be achieved in a single pass of the profile through the press. Typically each bending operation will involve more than one, preferably no more than two, bending phases, each bending phase involving bending the profile, by the application of a force in the press, from an initial position, through an intermediate position to a final position, relieving the applied press force to allow the profile to spring back from the final position to the intermediate position and subsequently measuring the position of the profile in the intermediate position. In a two phase bending operation, the first bending phase will provide a rough or approximate bending of the profile and the second bending phase will provide the final "adjustment" bending to the desired final desired curvature. If the control program is programmed to take account of measurements made by measuring transducers of the shape of the profile after every pressing operation, any deviation from the desired shape is immediately detected and remedial adjustment actions can be carried out immediately. The bending of the profile may be accomplished using two bending tools, a female tool acting on the convex surface of the bent profile and a male tool acting on the concave surface of the bent profile. In this case, the twisting of the asymmetric profile can be controlled during the bending procedure by using at least two power cylinders, one effective near one edge of the profile to be bent and the other near the opposite edge of the profile, to force the tools together. Automatic computer-governed calculations are suitably arranged to control the press and the various pressing operations and provide the required corrective actions.

It is of advantage to use a computer operating a so-called FEM-program, that is a Finite Element Method program or the like, by means of which calculating and shape determining work and additional corrective actions may be determined, as known in the art, precisely and quickly. The program can also take into account properties of the workpiece material as well as the asymmetric cross-section of the profile so that the correct bending is easily achieved. The bending process thus functions in a reliable manner and practically automatically.

There is a requirement for the workpiece, in spite of being large and heavy, to be moved accurately at the work station. It can be moved in the press by means of driven transport rolls arranged close to jaws of the press. In this case only one operator is required to operate the entire bending and measuring process. It is also important that the profile be smoothly curved to an accurate radius. This is achieved by moving the workpiece only a short distance, typically from 5 to 30 cm, preferably about 10 cm, from one bending position to another. The movement distance of the workpiece is

conveniently measured by a measuring wheel, positioned close to the bending point, and which is suitably in connection with computerized control devices of the transport rolls. This provides a precise and fast movement that is almost fully automatic.

The workpiece may be supported by air cushion devices reducing the friction forces to a minimum. If the press includes tools applicable for correction of an excess bending, corrective actions can be taken quickly in the same work station as the bending. Tools for "straightening" excess bending would correspond to the tools for initially bending the workpiece, except that their positions would be reversed relative to the bending plane of the workpiece and it would be necessary to take account of the asymmetry of the profile in the shape of the tools.

The invention also relates to a method of bending a profile, and to a bent profile, the bending of which has been carried out by a method, or in an arrangement according to the invention.

Embodiments of the invention will now be described, by way of example only, with particular reference to the accompanying drawing, in which:

Figure 1 is a schematic top view of a bending arrangement according to the invention; and

Figure 2 is a partly sectioned side view of the arrangement shown in Figure 1.

In the drawing, 1 indicates a measuring and bending station including a bending press 2, which is capable of exerting a press force of more than 5000 kN, measuring devices 3 for controlling the bending of an equatorial metallic, preferably aluminium, profile 4 of a spherical tank, and bending tools 5 adapted to the shape of the workpiece. The profile is of uniform cross-section over its length but is asymmetric relative to a central horizontal plane, i.e. a horizontal plane equidistant from the top and bottom edges of the profile. The press includes a rigid body 6 fixed to a firm base. The measuring devices 3 include measuring transducers 7 for measuring the workpiece. There are preferably two transducers 7 at each side of the bending position, their measurement values being supplied to a control unit (not shown) including a computer. As shown in Figure 2, at each measurement position there are two transducers 7, one near the top edge of the profile and one near the bottom edge of the profile.

The profile 4 may be moved in the directions shown by the arrows 8a and 8b and the measuring transducers 7 are adjustable in the direction of the arrows 9a and 9b. Movement of the profile 4 in the press 2 is achieved by motorized transport roll pairs 10a, 11a and 10b, 11b. These rolls receive control commands either automatically from a control unit of the measuring system (not shown) or by manual control. A secure function is obtained when there are transport rolls at both sides of the press. The rolls 11a and 11b are pressure rolls pressing the workpiece 4 steadily against the transport rolls 10a and 10b.

A measuring wheel 12 is provided for measuring the longitudinal movement of the profile 4. At each side of the press, workpiece supports 13a and 13b are arranged which are carried by air cushion bases and which include lateral support elements 14a and 14b. The supports 13a, 13b are easily movable over the floor so that they follow the workpiece and carry its weight.

The measuring transducers 7 may be mounted for movement in a vertical direction for measuring the profile 4 at different heights. Alternatively, it is possible to provide a sufficient number of transducers 7 at different heights so there is no need for them to be vertically movable.

The press 2 includes tools 5a, shown in solid lines, for bending the workpiece. The tools 5a include a female tool at the exterior of the bend in the workpiece, i.e. for acting on the convex surface of the profile, and a male tool at the interior of the bend, i.e. for acting on the concave surface of the profile. The tools 5a are mounted in outer and inner tool carriers 5.

At the beginning of the bending process one end of the profile 4 is placed in the press 2 in a first bending position and the other end of the profile is supported by two of the supports 13a and 13b at one side of the press. The measuring system including the transducers 7 is trimmed for action to monitor the bending and the springback of the workpiece after each bending operation. In particular the bending process is based on the assumption that the profile is plastically deformable and can be bent to a desired curve, or approximation to a curve, by bending the profile at spaced apart bending positions along the length of the profile. In practice this is achieved by moving the profile in a stepwise manner through the press 2 in a single pass (although bending could occur in more than one pass if required) and subjecting the profile to bending operations at spaced apart intervals along the length of the profile during dwell periods of the stepwise movement. During each bending operation, the profile is bent from an initial position, through an intermediate position to a "final" position. On relieving the applied bending force, the elasticity or resilience of the profile causes it to spring back or "reflect" from the final position to the intermediate position. Thus the profile is deliberately overbent to compensate for springback of the profile after the release of the applied force of the press 2. The position of the profile is measured by the transducers. The degree of bending applied by the press is controlled by a computerised control system which is programmed to take account of the springback properties of the workpiece profile, which is assumed to have the same cross-section throughout its length. It may be necessary or desired to perform the bending of the profile in each bending operation in more than one bending phase. In this case the bending and measuring steps described above are repeated. The

control system is supplied with information on the desired final bending radius and, if the bending is made in several phases, the desired bending radius of the first or next phase in turn is fed to the control system. The required degree of bending at each bending operation along the length of the profile is calculated on the basis of a theoretical springback and, after each bending operation, the actual result is compared by the control system with the theoretical calculations and springback value corrections are made on the basis of the actual bending measurements. If the bending needs to be corrected, the transducers 7 provide the required data to enable corrective bending, i.e. further bending or straightening action, to be effected in subsequent bending phases or operations. Any deviation between the theoretical "springback" and the actual "springback" can be compensated for in subsequent bending phases or operations. The profile 4 is then moved to the next following bending position, which is typically at a distance of approximately 10 cm from the preceding bending position. The various stages of each bending operation are repeated at each bending position along the whole length of the profile 4. During the progress of the work the air cushion-carried supports 13a and 13b must from time to time be adjusted or increased or decreased in number as the workpiece progresses through the press. They may also be arranged to follow the workpiece automatically.

Figure 2 shows two cylinders 15' and 15" which are arranged to drive the inner tool carrier, which carries the male bending tool 5a. The cylinders are spaced apart vertically so that the cylinder 15' acts on the male bending tool 5a in the vicinity of the upper edge 4' of the asymmetric profile 4 whereas the cylinder 15" acts on the male bending tool 5a in the vicinity of the lower edge 4" of the asymmetric profile 4. The tool carriers 5, and hence the bending tools 5a, are able to tilt about a horizontal axis perpendicular to the axes of the cylinders 15' and 15". Due to this arrangement it is possible to exert more pressure on one edge of the profile than on the other edge of the profile in order to prevent the profile from twisting during the bending operation. By taking measurements using the transducers 7 during the bending procedure, the control unit is able to supply the cylinders of the male bending tool with control signals for correcting the bending result and for preventing or correcting twisting of the profile.

Since the two transducers 7 at each measurement position are spaced apart vertically, the control unit can determine from the measurement values provided by the transducers whether the profile has twisted during the bending operation. In the event that the bending tools 5a are operated to prevent twisting, the measurement values can be used to verify that the profile has not twisted during the bending operation to an unacceptable extent.

As described above, it is of advantage in each bending operation first to achieve a rough or approximate bending close to the final profile shape in a first bending phase before finishing the bending in preferably one, or more than one, second bending phase. In this manner particularly good bending results are achieved. By selecting the bending positions so as to be closely spaced apart the profile will be particularly accurately bent. Means may be provided to bend the profile back in the opposite direction to that provided by the press if the profile is overbent in the initial bending phase.

The press 2 may include tools 5b, shown in broken lines in Figure 1, for "straightening" excess bending, i.e. for reducing the curvature of an "overbent" workpiece. The male and female tools 5b are similar to the male and female tools 5a used for bending the workpiece, except that the relative locations thereof are reversed with respect to the bending plane of the workpiece. Thus, whereas for bending the workpiece, the female tool 5a is at the exterior of the bend and the male tool 5a is at the interior of the bend, for straightening excess bending, the female tool 5b is at the interior of the bend and the male tool 5b is at the exterior of the bend. Naturally, the surface configuration of each tool should conform to the side of the profile engaged by that tool.

The invention is not limited to the embodiments disclosed, but several variations thereof are feasible, including variations which have features equivalent to, but not literally within the meaning of, features in any of the ensuing claims.

Claims

1. A bending arrangement for bending an aluminium profile (4,4',4") in a press (2), the profile being of asymmetric cross-section and having upper and lower edges, the bending arrangement comprising means (10a, 11a, 10b, 11b) for moving the profile through the press, bending means (5,5a,5b) for bending the profile (4,4',4") in separate bending operations at spaced apart bending positions along its length, said bending means including at least a first power cylinder (15') positioned to act on the profile adjacent an upper edge (4') thereof and a second power cylinder (15") positioned to act on the profile adjacent a lower edge (4") thereof, and control and measuring devices (7) associated with the press in such a manner that the springback and twisting of the profile is arranged to be taken into account both in bending the profile and in determining the bending control based on measurements being made.

2. An arrangement according to claim 1, characterised in that control means are arranged to control the bending process and its correction, so that a measuring inspection of the bent profile is performed in the press following every bending operation whilst the profile is in a stationary position.

3. An arrangement according to claim 2, characterised in that the arrangement includes measurement transducers (7) measuring the shape of the profile (4,4',4") close to the bending position for each bending operation, the measuring transducers (7) being connected to the control means for comparison of the actual bending with the desired bending result, the control means being arranged to control the press to carry out any required additional bending, or rebending, thereby taking into account the springback and twisting of the profile.

4. An arrangement according to claim 1, 2 or 3, including at least first and second transducers (7) for engaging the workpiece (4,4',4",) at vertically spaced positions.

5. An arrangement according to any of the preceding claims, characterised in that calculations for taking into account springback and twisting of the profile are based on a Finite Element Method program or the like.

6. An arrangement according to any of the preceding claims, characterised in that said moving means comprisetransport rolls (10a, 11a, 10b, 11b) in the vicinity of the bending means (5,5a,5b).

7. An arrangement according to any of the preceding claims, characterised in that said bending positions are spaced apart from 5 to 30 cm, preferably from 10 to 20 cm.

8. An arrangement according to any of the preceding claims, characterised in that a measuring wheel (12) for contacting the profile is provided for measuring the movement of the profile from one bending position to another.

9. An arrangement according to any of the preceding claims, characterised in that air cushion support devices (13) are provided for movably supporting the profile.

10. An arrangement according to any of the preceding claims, characterised in that the press includes means (5,5b) for straightening excess bending.

11. A method of bending a metallic, e.g. aluminium or aluminium alloy, profile (4,4',4") of asymmetric cross-section in a press (2) to a desired final profile shape, comprising moving the profile in a stepwise manner in at least one pass through the press and, in the or each pass, subjecting the profile (4) to separate bending operations at spaced apart bending positions along the length of the profile during dwell periods of the stepwise movement, each bending operation comprising applying force to the profile to bend it from an initial position, the bending force being non-uniform perpendicular to the length of the profile in order to correct for a tendency of the profile to twist during the bending, relieving the force applied to the profile so that it springs back, due to its resilience, from the final position to said intermediate position and measuring the deviation of the profile when in its intermediate position from an optimum position for achieving said desired final profile shape, any subsequent bending operations being modified in dependence on the measured deviation.

12. A method according to claim 11, characterised in that, for each bending operation, the steps of applying force to bend the profile, relieving the applied force and measuring the deviation of the profile are repeated one or more times so that bending and measuring of the profile occurs in two or more phases.

13. A method according to claim 11 or 12, characterised in that, in each bending operation, the bending of the profile from said initial to said intermediate positions is automatically controlled.

14. A method according to claim 13, characterised in that said bending is controlled by computer control means programmed to take account of the desired final profile shape, the springback properties of the profile and said measured deviations.

15. A method according to claim 11, 12 or 13, characterised in that the stepwise movement of the profile through the press into the different bending positions is also automatically controlled.

16. A method according to any one of claims 11 to 15, characterised in that the profile is supported by movable air-cushion means on opposite sides of the press.

17. A method according to any one of claims 11 to 16, characterised in that the bending positions are spaced apart from 5 to 30 cm, preferably from 10 to 20 cm.

Fig. 1

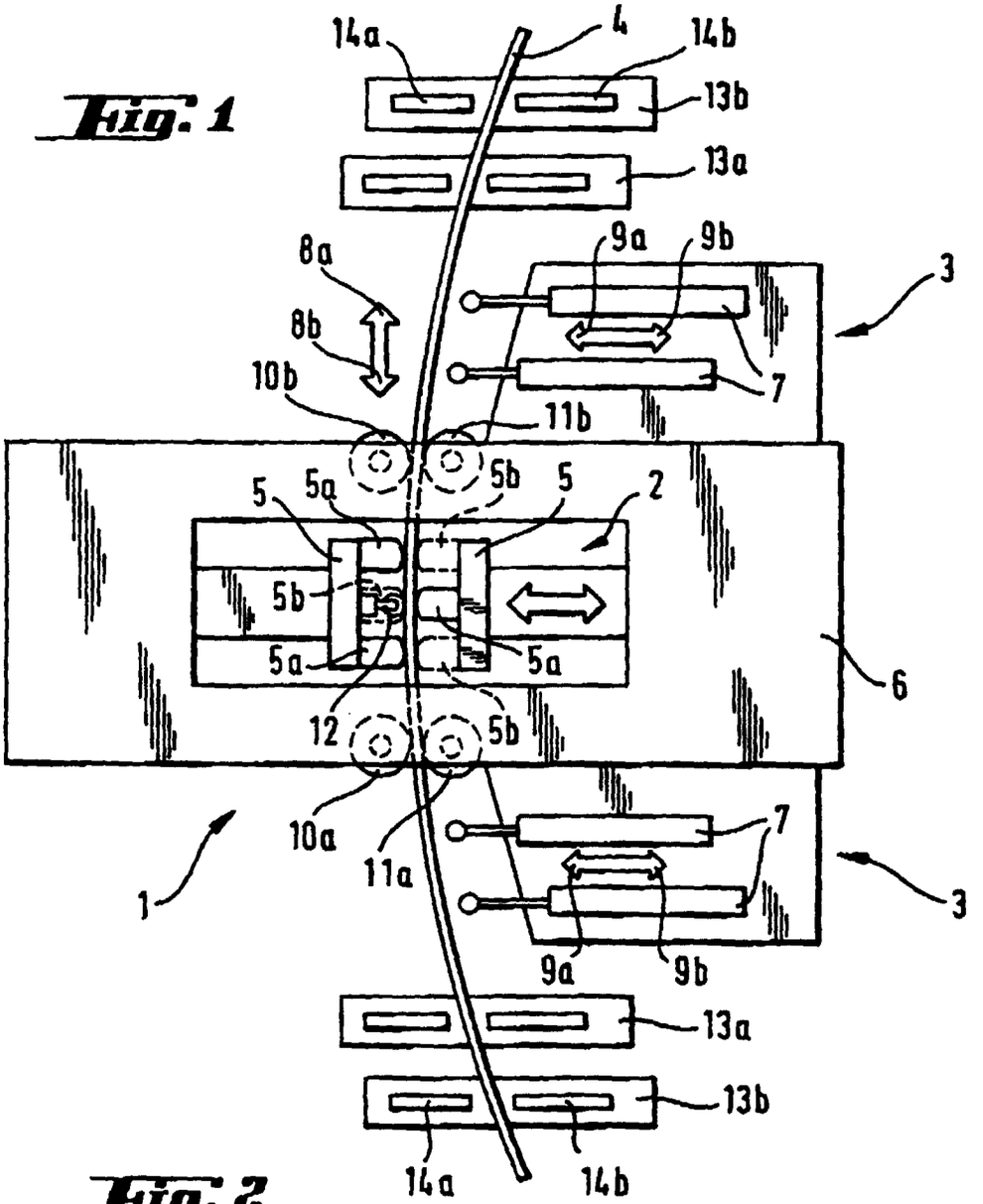
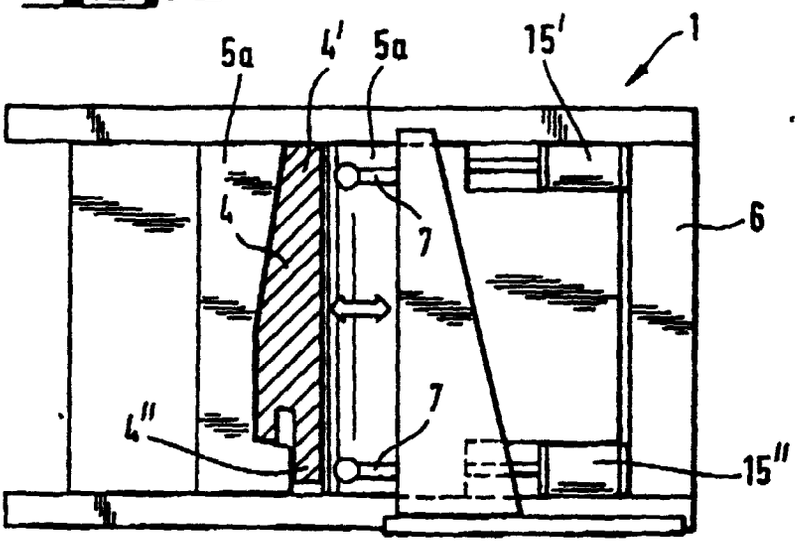

14a
4
14b
13b
13a
8a
9a
9b
3
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7
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5b
5
2
5b
5a
5a
6
12
5b
10a
11a
7
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3
9a
9b
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13b
14a
14b

Fig. 2


5a
4'
5a
15'
1
4
7
6
7
4''
15''

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 30 3665

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	GB 2 057 316 A (TI REYNOLDS LTD) 1 April 1981 * the whole document * -----	1,11	B21D7/06

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

B21D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	9 October 1997	Ris, M

CATEGORY OF CITED DOCUMENTS

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