

Method for induction bend forming of a compression-resistant pipe
having a large wall thickness and a large diameter,
and induction pipe bending device

The invention relates to a method for induction bend forming of a compression-resistant pipe with a large wall thickness and a large diameter, in particular of a pipe in power plants and pipelines, with the features stated in the preamble of patent claim 1, as well as an induction pipe bending device suitable for carrying out same with the features stated in the preamble of patent claim 8.

Pipes made of steel that have a large wall thickness in order to withstand the stresses are needed for transmitting liquid and gaseous media under pressure. Such requirements apply, for example, to the transport of hot steam in power plants, where pipe bends are necessary to adapt the pipelines to the structural conditions, or to transport crude oil or natural gas in pipelines over long distances where double bends are used at regular intervals to compensate for thermally induced changes in length. A large opening cross-section and correspondingly a large outer pipe diameter is required to enable a high throughput. Pipes referred to in this method typically have nominal diameters greater than 300 mm and a diameter to wall thickness ratio of 10:1 to 100:1, typically of 20:1 to 70:1.

Such a method for induction bend forming has long been known, for example from DE2513561 A1, and has been continually improved in order to be able to produce very dimensionally accurate pipe bends despite the enormous dimensions and wall thicknesses of the pipes. While precise adherence to the specified bend angle is controlled for the pipe bending, two disadvantageous shape deviations remain in the region of the pipe bend. These are, on the one hand, the ovality, i.e., a deviation of the pipe cross-section from the desired ideal circular shape, and, on the other hand, a weakening of the wall thickness at the outer bend.

Round pipes with the above-mentioned size ratios are manufactured and delivered with ovalities of about 1%. A permissible out-of-roundness of the pipe bend after the induction bending process is 4% according to European and North American standards. Larger deviations are problematic because locally different tensile stresses occur at the pipe wall due to the internal pressure of the media passing through the pipe bend. In the case of high-pressure applications, for which these thick-walled pipes are particularly intended, such additional stresses that occur due to the out-of-roundness are relevant. Thus, because of the geometric deviation, the wall thickness often has to be chosen larger than it would be required computationally based on the fluid pressure alone.

The other disadvantageous effect on the pipe during induction bending is the different wall thickness distribution on the outer and inner bends. During bending around the neutral zone, which lies on the pipe's longitudinal axis, the pipe wall is subjected to tensile stress in the region of the outer bend to be formed. Since the outer bend is longer than the non-formed pipe section, a reduction in the wall thickness is inevitable. On the inner bend, on the other hand, compressive stresses are present during bending, and a wall thickness increase occurs because of the necessary shortening of the bend length. However, these unavoidable effects also lead to the fact that the strength calculation for the high-pressure application always has to be applied to the wall that is weakened the most, which is the wall on the outer bend. This is another reason why the wall thickness of the entire pipe must be selected significantly greater than on the straight sections so that sufficient strength is achieved in the pipe bend.

The problem addressed by the invention is that of reducing the geometric changes that weaken the strength of the pipe bend, such as ovality and wall thickness reduction.

According to the invention, the problem is solved by providing a method for induction bending with the features of claim 1 and an induction bending device for carrying out the method with the features of claim 8.

The method according to the invention is based on the fact that an artificial ovality is imposed on the pipe before the forming begins, specifically in the form of a so-called lying oval. Lying means that the longer diameter axis of the oval, which corresponds to the shape of the pipe cross-section, lies in the bending plane. Since in practice induction bend forming can only be performed in a horizontal plane because of the large mass of the pipes and the required fixed arrangement of the bending arm, the long diameter axis is at the same time oriented horizontally.

In order to achieve the lying ovality, according to the invention, the tube is vertically compressed in a pressing device by means of a press punch and a counter support, or by two press punches that work against one another before heating and thus before entering the forming zone, and is guided laterally in the horizontal direction.

The compression occurs preferably by the same degree of out-of-roundness that would occur in the case of the induction bend forming process for a pipe bend with a certain bend angle at the same type of pipe. Particular preference is given to a continuous adaptation of the degree of ovality during the execution of the pipe bending process so that initially smaller pre-ovalities are used that increase toward the pipe bending center because the greatest ovality would occur there without the pretreatment process according to the invention.

Due to the forced cross-sectional shape of the pipe as a horizontal oval prior to the inlet into the inductor, all the ovalities at the beginning, in the center and also at the end of the pipe bend are compensated, with the beginning being defined as the front end viewed in the feed direction. As a result, a pipe with a circular cross-section, with very small tolerances compared to conventional forming, is achieved. The apparent paradox that, according to the invention, a round cross-section at the beginning of the pipe bend is obtained in spite of an earlier artificially produced ovality before the beginning of pipe bending lies in the internal distribution of compressive and tensile stresses in the pipe bend. While these stresses without the measure according to the invention constitute the cause for ovalities, under the effect of the pretreatment according to the invention, all the effects compensate each other.

The second measure according to the invention for optimizing the pipe geometry during induction bend forming is based on the approach of at least shifting the unavoidable, different wall thickness distribution on the inside and outside of the pipe bend. By moving the neutral zone toward the outside, the wall thickness in the inner bend increases even more due to the natural volume constancy. However, this has no negative effects on the strength and the subsequent processability of the pipe bend. It is essential that this measure can be used to reduce the wall thickness reduction on the outer side so that according to the invention a greater wall thickness is obtained than was previously possible with the use of a similar pipe.

The wall thickness reduction in a 90° pipe bend produced according to the conventional induction bending method is up to 25% at a typical ratio of bending radius to pipe diameter of, for example, 1.5 : 1. According to the invention, the wall thickness reduction can be substantially reduced, in particular, halved. This means that the wall thickness at the outer bend is 12.5% greater with the method according to the invention than with the prior art. This also means that either a higher operating load is possible with the same wall thickness of the used pipe, or even a lower initial wall thickness can be selected under the same operating conditions. This, in turn, results in a saving in weight and costs.

The move of the neutral zone during pipe induction bend forming is achieved according to the invention in that the pipe cross-section is heated differently between the outside and inside of the pipe. In this case, the outer side of the bend is heated less than the inner side of the bend. Due to the higher temperature, the resistance to forming on the inside of the bend is less than on the outside of the bend, which results in the intended move of the neutral zone in the bend toward the outer side of the bend. The invention thus specifically utilizes the deformation temperature interval available for the material.

Forming with altered temperature profiles is performed according to the invention in a subregion of the bend angle. A transitional program takes place from the initial tangent into this subregion, in which the displacement from an initial position, where the move is gradually shifted from an initial position symmetrical to the pipe center toward the outside. A transitional program is also applied from the subregion into the end tangent, in which the temperature profile is once again oriented symmetrically.

Said partial region extends over approximately 80% - 90% of the provided bend angle. In this case, the partial region starts from the starting tangent at approximately 1° - 2° of the bend angle and ends approximately 1° - 2° before the transition to the end tangent.

The move of the temperature profile provided according to the invention is preferably based on an adjustment of the annular inductor in the bending plane, in particular toward the outside, preferably coupled with an adaptation of the electrical power in the induction device, i.e., a change in the heating power. Due to the inductor adjustment toward the outside, the inductor is closer to the pipe wall on the inside of the pipe bend than on the outside, so that stronger heating takes place here. With approximately 5 - 50 mm, the adjustment range is very small in relation to the used pipe diameters of larger than 600 mm. In order to effect heating of large wall thicknesses by induction, the air gap, that is, the distance between the annular inductor as a current-carrying conductor and the pipe jacket, must not be too great. On the other hand, metallic contact with the outer side of the pipe must be avoided under all circumstances. The diameter of the inductor is preferably set to $1.05 D_{\text{Pipe}}$ plus 25mm. For a pipe with diameter $D_{\text{Pipe}} = 1000$ mm, the resultant theoretical adjustment distance is 75mm, of which, however, practically only about 50mm can be used for achieving a laterally shifted temperature profile.

As an alternative or in addition to locally different heating, a targeted energy removal can also occur through local cooling.

Non-contact surface temperature measurements are taken on the inside and outside of the bend, and these values are provided to a control device. The temperature distribution can be updated via

the control device by increasing the cooling energy on the outside of the bend and/or by increasing the heating power at the inside of the bend and/or by changing the position of the inductor in the transverse direction.

In one preferred variant of the method according to the invention, a distance-controlled and at the same time, a performance-controlled method is provided.

This allows for a targeted influence of both the inner side of the bend and the outer side of the bend. The operator can select which side of the bend is to be primarily controlled by distance, and which side is to be controlled by energy and can specify the desired surface temperatures, including permissible tolerance ranges. The control device then automatically changes the position of the inductor in such a way that the desired relative distribution between the inner and outer sides of the pipe bend is reached and also adjusts the electrical power so that the absolute forming temperatures are reached.

Details of the invention are explained in more detail below with reference to the drawings. The figures show in detail:

Figure 1 a schematic view of an induction pipe bending device:

Figure 2 a top view of a pipe bend;

Figure 3 cross-sections according to the prior art in the cross-sectional planes marked in Figure 2;

Figure 4 cross-sections according to the invention in the cross-sectional planes marked in Figure 2;

Figure 5 a cross-section of the different wall thickness distribution in the center of the pipe bend;

Figure 6 a longitudinal section of the different wall thickness distribution in the center of the pipe bend, and

Figure 7 a pressing device for the pre-ovalization.

Figure 1 shows an induction pipe bending device 100 comprising a stationary machine bed 10 on which a holding device 11 for a pipe 1 is arranged. The holding device 11 grips the pipe 1 at its rear end and clamps it securely. In addition, the holding device 11 is movable in relation to the machine bed 10 in the direction of a pipe center axis 2, which at the same time indicates the feed direction. The feed is carried out via a hydraulic unit 12.

A bending arm 30 is pivotably mounted on a vertical bending axis 32, wherein the distance of the bending axis 32 can be adjusted perpendicular to the pipe center axis 2 in order to set the desired bending radius. A bending lock 31 with which the pipe 1 can be gripped and clamped is arranged on the bending arm 30.

Relatively close to the inductor 20 and to the heat-affected zone, a cooling device (not shown here) is arranged, with which, for example, cooling of the surface temperature is effected using water as soon as the corresponding length section has emerged from the forming zone.

An induction device comprises an annular inductor 20, which is positioned with its center in the region of the pipe center axis 2.

While the aforementioned features are also a component of the known induction pipe bending devices, according to the invention, on the one hand, a transverse adjusting device 21 is provided in order to be able to move the inductor 20 transversely to the longitudinal axis 2 of the pipe 1 being processed.

On the other hand, a pressing unit 50 is provided, of which a preferred embodiment is illustrated in Figure 7 in a view from the front, viewed from the machine bed 10 in the feed direction. In a rack 51, at least one hydraulic punch 52, 53 is arranged at the top and at the bottom, each of which being provided with a pressure roller 54, 55 in the form of a double cone or a rotational hyperboloid or an otherwise concave, rotationally symmetrical body. Through these forms, a load distribution is achieved with only one roller each on each side of the pipe 1 on two sufficiently spaced apart lines on the outer circumference of the pipe 1. This avoids running marks on the pipe jacket due to excessive surface pressure. The hydraulic punches 54, 55 are operated with the same stroke after a single adjustment to a center located on the tube center axis 2, such that the pressure rollers 54, 55 simultaneously contact the pipe jacket and then effect the forming procedure with equal forces. The pipe thus remains centered in the vertical plane during the entire execution of the bend forming process.

Two further hydraulic punches 56, 57, each having at least one guide roller 58, 59 at their end, are mounted on the right and left sides of the rack 51. In this way, the pipe 1 is also centered in the horizontal direction in such a way that it is compressed precisely with the pressure rollers 54, 55 on the middle axis 2 by means of the punches 52, 53 arranged above and below, and no eccentricities occur. By means of the hydraulic punches 56, 57 on the side, only the guide rollers 58, 59 are positioned and held, but no forming force is exerted by them on the pipe. The lateral guide rollers 58, 59 are preferably convex-crowned or cylindrical, in order to prevent shape-dependent securing of the pipe 1 on the guide rollers in the vertical direction.

This arrangement on the horizontal and vertical axes applies to a pipe bend that is carried out in a horizontal plane.

As Figure 7 shows, the compression occurs exclusively in the vertical direction, so that the cross-section of the pipe 1 takes the form of an oval, i.e., the long diameter axis extends horizontally. The ovality is shown overemphasized for illustrative purposes in the presentation according to Figure 7 as well as in Figure 3, which is explained below. In reality, the forced out-of-roundness is only about 1% of the pipe diameter at the beginning, 1.5% at the end, and up to 4% of the pipe diameter in the center of the pipe bend so that it is barely visible to the naked eye.

The rack 51 of the press unit 50 is of annular design, in the sense that it is closed in itself, i.e., unending. The outer shape is preferably diamond-shaped in the top view, with one of the punches 52, 53, 55, 56 being arranged at each corner point.

Figure 2 shows a pipe bend 3 with a beginning tangent 2 and a tangent 4. Three different section planes A-A, B-B and C-C are marked in Figure 2, with the section plane B-B being arranged in the

center of the pipe bend 3 because the greatest deviations of the wall thicknesses on the inner and outer parts of the bend are present there.

The cross-sections at the locations marked in Figure 2 that would result in an induction bending process according to the prior art are shown in Figure 3. Accordingly, the cross-section is circular only in the area A-A, i.e., at the end tangent 4 on the non-formed pipe 1 being processed. As a result of the forming process, a so-called standing ovality is obtained as the cross-section B-B in the middle of the bend 3, which also results in a lying ovality in the area C-C, that is, at the transition to the starting tangent 2.

By using the induction bending method according to the invention, on the other hand, circular shapes are formed for all three cross-sections A-A, B-B and C-C as shown in Figure 4.

Figure 5 shows the different wall thickness distributions on the pipe bend 3 in a further cross-sectional drawing in the plane B-B. The wall thickness is considerably thicker on the inner pipe bend 3.2 than on the outer pipe bend 3.1. A vertical axis 3.3 that characterizes the neutral zone is not at the center of the pipe cross-section but instead, is offset toward the outside of the pipe bend 3.1 according to the invention. According to the invention, this is achieved, for example, by the following asymmetrical temperature distribution in the forming zone:

Outside of the pipe bend 3.1 850°C

Inside of the pipe bend 3.2 1000°C

The inductor adjustment path at this point is only about 10 mm out of the center. This small adjustment path relative to the other geometrical dimensions is already sufficient to achieve the effects according to the invention.

Figure 6 shows the wall thickness distribution in a horizontal longitudinal section through the pipe bend 3. The dash-dotted line in the center represents the center axis 2 of the pipe. The neutral zone 3.3 runs parallel to it. The dashed lines in the area of the inner pipe bend 3.2 and the outer pipe bend 3.1 represent the wall thicknesses on the non-formed pipe 1. The solid lines show the wall thicknesses that arise after the bend forming is carried out. Again, the deviations are shown over-emphasized.

Examples of the wall thickness distribution for a processed pipe with a nominal wall thickness of 10 mm are shown below:

a) Induction bend forming according to the prior art:

Outside of the bend 3.1 7.5 mm (-25%)

Inside of the bend 3.2 15.0 mm (+50%)

Change to the inner pipe diameter (constriction):-1.25 mm

b) Induction bend forming according to the invention:

By suitably adapted temperatures, a shift of the neutral zone 3.3 inwards or outwards can be achieved. In general, an outward shift is aimed for according to the invention in order to halve the decrease:

Outside of the bend 3.1	8.75 mm (-12.5%)
Inside of the bend 3.2	17.50 mm (+ 75%)
Change of inner pipe diameter (constriction):	approx.-3.125 mm

Thus, the weakening of the outer side of the bend 3.1 has been reduced by half. The simultaneous increase in the wall thickness at the inner side of the bend 3.2 does, however, lead to a slight reduction in the inner diameter. The resulting reduction in the clear pipe cross-section by about 2 mm is negligible in light of the large diameters of the pipes used.

Patent Claims:

1. Method for induction bend forming of a compression-resistant pipe (1) having a large wall thickness and a large diameter, in particular, a pipe in power plants and pipelines, comprising at least the following steps
 - horizontal placement of the unprocessed pipe (1);
 - feeding the pipe (1) to the passage of a front pipe section through an annular inductor (20) of an electrical induction unit;
 - clamping the front pipe section in a bending lock (31) that is mounted on a bending arm (30), which is pivotable around a vertical axis of rotation (32) arranged laterally to the pipe (1); current supply to the induction unit for heating a pipe section;
 - deflecting the bending arm (30) by longitudinal feeding of the pipe (1) until the completion of the pipe bend (3);
 characterized in that
 - the pipe (1) is compressed vertically in a pressing unit (50) prior to introduction into the inductor (20), and in that a cross-section of the pipe (1) is forced into the shape of a lying oval, and
 - in that a temperature profile with a lower temperature at an outer side of the bend (3.2) and with a higher temperature at an inner side of the bend (3.1) is set at least during a partial portion of the pipe bending process by means of a transverse movement of the inductor (20) relative to the pipe (1).
2. Method as in claim 1, characterized in that the pipe (1) is always being compressed during the longitudinal feed.
3. Method as in claim 2, characterized in that the pipe (1) is continuously compressed during the longitudinal feed, the degree of the compression being progressively increased from an initial tangent (2) to the center of the pipe bend (3) and from there being reduced again to an end tangent (4).
4. Method as in one of the claims 1 to 3, characterized in that the temperature profile is adjusted by an increased local energy supply at one side of the bend (3.1, 3.2).
5. Method as in claim 4, characterized in that the distance between the inductor (20) and the inside of the bend (3.2) is reduced and at the same time is increased at the outside of the bend (3.1), and in that the absolute temperature level is adjusted by adapting the electrical current flowing in the inductor (20).
6. Method as in one of the claims 1 to 3, characterized in that the temperature profile is adjusted by an increased local energy removal at one side of the bend (3.1, 3.2).

7. Method as in claim 6, characterized in that the temperature at the inner side of the bend (3.2) is reduced by means of a cooling device and in that the absolute temperature level is adjusted by adaptation of the electrical current flowing in the inductor (20).
8. Induction pipe bending device (100) for compression-resistant pipes (1) having a large wall thickness and a large diameter, in particular for pipes in power plants and pipelines, comprising at least:
 - a machine bed (11) for horizontal positioning of an unprocessed pipe (1);
 - a feed unit (11) acting along the pipe axis;
 - an electrical induction unit with an annular inductor (20) for heating a pipe section;
 - a bending arm (30) that can be pivoted around a vertical axis of rotation (32) and has a bending lock (31) for clamping the pipe (1) as well as an adjustment device for adjusting the distance between the axis of rotation (32) and the bending lock (31);
 characterized in that
 - a pressing unit (50) is arranged upstream of the inductor (20) in the feed direction and has at least one punch (52) acting vertically on the pipe (1) and a counter support (53); and
 - in that the inductor (20) is mounted such that it can be moved transversely to the feed direction, and in that the electrical power of the induction unit can be adjusted via a control unit as a function of a transverse offset of the inductor (20) or vice versa.
9. Induction pipe bending device as in claim 8, characterized in that the pressing unit (50) has at least two hydraulically driven punches (52, 53) that act upon the pipe opposite to each other.
10. Induction pipe bending device as in claim 8 or 9, characterized in that the punches and counter-supports or the counter-acting punches (52, 53) each have at least one pressure roller (54, 55) having the shape of a double cone or a rotational hyperboloid.
11. Induction pipe bending device as in one of the preceding claims 8 to 10, characterized in that the punch and the counter support or the two punches (52, 53) are arranged at the top and at the bottom in a closed rack (51), and in that on both sides of the rack (51) at least one lateral guide roller (58, 59) is arranged.