

(19)



(11)

EP 3 678 800 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:

03.11.2021 Bulletin 2021/44

(51) Int Cl.:

B21J 5/08 ^(2006.01)

B21J 9/08 ^(2006.01)

(86) International application number:

PCT/JP2018/033303

(21) Application number: **18773649.1**

(22) Date of filing: **07.09.2018**

(87) International publication number:

WO 2019/050018 (14.03.2019 Gazette 2019/11)

(54) METHOD AND APPARATUS FOR SHAFT DIAMETER ENLARGEMENT

VERFAHREN UND VORRICHTUNG ZUR SCHAFTDURCHMESSERVERGRÖßERUNG

PROCÉDÉ ET APPAREIL PERMETTANT D'AGRANDIR LE DIAMÈTRE D'UN ARBRE

(84) Designated Contracting States:

**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**

(30) Priority: **08.09.2017 JP 2017173281**

23.07.2018 JP 2018138035

(43) Date of publication of application:

15.07.2020 Bulletin 2020/29

(73) Proprietor: **Neturen Co., Ltd.**

Tokyo 141-8639 (JP)

(72) Inventors:

- **KUWAHARA Yoshitaka**
Tokyo 141-8639 (JP)

• **OKAMOTO Mitsuhiro**

Tokyo 141-8639 (JP)

• **IKEDA Takashi**

Tokyo 141-8639 (JP)

• **MORI Kazuki**

Tokyo 141-8639 (JP)

(74) Representative: **Zimmermann & Partner**

Patentanwälte mbB

Postfach 330 920

80069 München (DE)

(56) References cited:

JP-A- 2005 088 066 JP-A- 2007 167 882

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 3 678 800 B1

Description

Technical Field

[0001] The present invention relates to a shaft diameter enlarging method and a shaft diameter enlarging apparatus, such as disclosed in document JP2007-167882A.

Background Art

[0002] A shaft with a large-diameter portion at an intermediate portion of the shaft may be provided by cutting a thick shaft, by a combination of plastic working such as forging and finishing by a cutting or the like, or by joining an additional member on the shaft by welding. However, cutting takes a lot of efforts, and is uneconomical due to a lot of waste of material. Further, it is difficult to form a large-diameter portion at an intermediate portion when a workpiece is long-sized. With the method of joining the additional member on the workpiece by welding, there is effect of welding heat.

[0003] A shaft diameter enlarging method is a solution to the above problems. With the shaft diameter enlarging method, an intermediate portion of a shaft is enlarged by applying a rotation, compression force, and bending to the shaft. In this way, a large-diameter portion is easily formed at the intermediate portion of the shaft, and there is no need for cutting or welding.

[0004] The shaft diameter enlargement will be described in detail. A linear shaft is held by a pair of holders arranged with a gap provided between the holders. Then, with a rotation being applied about the axis of the shaft, at least one of the holders is moved in the direction toward the other holder, and one of the holders is biased gradually in a direction intersecting an axial line. Accordingly, the compression force and the bending force is applied to the shaft under a condition in which compression stress continuously acts at an outer side of the bending, whereby the shaft between the holders is plastically deformed in a radial direction. Subsequently, the bias of the holder is recovered gradually while maintaining the condition in which the compression stress continuously acts at the outer side the bending. In this way, the intermediate portion of the shaft is enlarged.

[0005] When applying the bending and the rotation on the shaft, the rotation is performed while applying the compression force, and the bending is performed so as to obtain a desired shape. Thereafter, a bend restoration is performed, and the compression and the rotation are stopped. Thus, when the material of the shaft is a high strength steel or a large axial steel material, high compression force is required, and it is inevitable that an apparatus for performing the shaft diameter enlarging method on the shaft become large-sized. If the compression force is low, the number of rotations for shaft diameter enlargement for obtaining a desired shape increases, so that it takes much time. Further, the enlargement rate

(the outer diameter of the enlarged intermediate portion of the shaft divided by the diameter of the original shaft) is limited to be about two times at the maximum, and therefore, applicable components are limited.

[0006] According to a first related art shaft diameter enlarging method, deformation resistance of a shaft is reduced by heating the shaft before or during the shaft diameter enlargement (see, e.g., JP2005-088066A). With this related art, the intermediate portion of the shaft can be enlarged by smaller compression force, and the size of apparatus is prevented from becoming large. Further, since the plastic deformability of the shaft is improved, and the enlargement rate can be increased.

[0007] In a second related art shaft diameter enlarging method, a shaft is heated to a temperature above the blue brittleness range, in view of the fact that, if the shaft is heated to be in the blue brittleness range, the shaft is hardened due to the blue brittleness effect so that the deformation resistance becomes high, in which case a desired enlarged portion may not be obtained, and there may be a defect such as a crack in the shaft (see, e.g., JP2007-167882A). As an example, in a case where the shaft is made of structural carbon steel JIS-S45C, when the temperature of the shaft is about 400°C or below, due to the effect of the blue brittleness, the enlargement rate is not affected by the heating of the shaft. When the shaft is heated to 580°C or above, more than double enlargement rate can be obtained, and a cracking damage can be suppressed.

Summary

[0008] Similarly to the shaft diameter enlargement, forging involves a plastic deformation of a workpiece. The workpiece is typically heated to 700°C to 850°C in so-called warm forging, and the workpiece is typically heated to 950°C or above in hot forging (including sub hot forging). Thus, like the forging, it may be conceivable also with regard to the shaft diameter enlargement in which the shaft is heated to 580°C or above, to heat the shaft to a warm temperature range (700°C to 850°C) or a hot temperature range (950°C or above). However, in the shaft diameter enlargement, the shaft is subject to the rotation, the compression force, and the bending, and so that load also acts on the holders holding the shaft. Further, the holders are typically made of tool steel such as die steel and high speed tool steel. The tempering temperature range of such tool steels is about 500°C to 580°C. Furthermore, the time during which the shaft contacts with the holders is relatively longer than the time during which the workpiece contacts with a die in forging. Thus, in a case where the shaft is heated to the warm temperature range or the hot temperature range, the hardness of the holders may become lower due to tempering. When the hardness of the holders is lowered, the durability of the holders against repeated use is lowered so that the lifetime of the holders may be shortened.

[0009] The present invention provides a shaft diameter

enlarging method according to claim 1 and a shaft diameter enlarging apparatus according to claim 5 which can increase an enlargement rate, prevent a crack caused by enlargement, and reduce running cost.

[0010] According to the present invention, a shaft diameter enlarging method for enlarging an intermediate portion of a shaft is provided. The shaft diameter enlarging method includes holding the shaft by a pair of holders with a gap between the pair of holders in an axial direction of the shaft, applying compression force in the axial direction to the intermediate portion arranged between the pair of holders, and applying alternating load in a direction intersecting the axial direction to the intermediate portion to enlarge the intermediate portion. The method further comprises heating at least a portion of the shaft including the intermediate portion before the enlarging of the intermediate portion, and/or heating the intermediate portion during the enlarging of the intermediate portion. When enlarging the intermediate portion, a temperature of the intermediate portion is set to be above a blue brittleness temperature range of the shaft, and a temperature of the holders is set to be below a tempering temperature range of the holders.

[0011] According to the present invention, a shaft diameter enlarging apparatus includes a pair of holders configured to hold a shaft with a gap between the pair of holders in an axial direction of the shaft, a presser configured to apply compression force in the axial direction to the intermediate portion arranged between the pair of holders, an alternating load generator configured to apply alternating load in a direction intersecting the axial direction to the intermediate portion to enlarge the intermediate portion, and a heating device configured to heat at least a portion of the shaft including the intermediate portion before the enlarging of the intermediate portion, and/or heat the intermediate portion during the enlarging of the intermediate portion. The heating device is configured to heat at least a portion of the shaft such that, during a period in which the compression force and the alternating load are applied to the intermediate portion of the shaft, a temperature of the intermediate portion is above a blue brittleness temperature range of the shaft, and a temperature of the pair of holders holding the shaft is below a tempering temperature range of the holders.

Brief Description of Drawings

[0012]

[fig.1]Fig. 1 is a schematic view illustrating an example of a shaft diameter enlarging apparatus according to an embodiment of the present invention.

[fig.2]Fig. 2 is a graph showing a relation between a temperature and a tensile strength in various steel materials having different carbon content.

[fig.3A]Fig. 3A is a schematic view illustrating an example of a shaft diameter enlarging method using the shaft diameter enlarging apparatus of Fig. 1.

[fig.3B]Fig. 3B is another schematic view illustrating the example of the shaft diameter enlarging method.

[fig.3C]Fig. 3C is another schematic view illustrating the example of the shaft diameter enlarging method.

[fig.3D]Fig. 3D is another schematic view illustrating the example of the shaft diameter enlarging method.

[fig.3E]Fig. 3E is another schematic view illustrating the example of the shaft diameter enlarging method.

[fig.4]Fig. 4 is a schematic view illustrating a shaft diameter enlarging method according to another embodiment of the present invention.

[fig.5]Fig. 5 is a schematic view illustrating a shaft diameter enlarging method according to another embodiment of the present invention.

[fig.6]Fig. 6 is a schematic view illustrating a shaft diameter enlarging method according to another embodiment of the present invention.

[fig.7]Fig. 7 is a schematic view illustrating a shaft diameter enlarging method according to another embodiment of the present invention.

[fig.8]Fig. 8 is a graph showing a counted number of rotations required to reach a predetermined enlargement rate and a result of checking of a presence of a crack for each test example.

[fig.9]Fig. 9 is a graph showing a result of an evaluation of an elliptic amount for each test example.

[fig.10]Fig. 10 is a schematic view illustrating an example of a heating device of the shaft diameter enlarging apparatus.

[fig.11]Fig. 11 is a schematic view illustrating another example of the heating device of the shaft diameter enlarging apparatus.

[fig.12]Fig. 12 is a schematic view illustrating another example of the heating device of the shaft diameter enlarging apparatus.

[fig.13]Fig. 13 is a schematic view illustrating another example of the heating device of the shaft diameter enlarging apparatus.

Embodiments of Invention

[0013] Fig. 1 illustrates an example of a shaft diameter enlarging apparatus according to an embodiment of the present invention.

[0014] A shaft diameter enlarging apparatus 1 illustrated in Fig. 1 is configured such that, when a pair of holders 2, 3 holding a shaft W with a gap in an axial direction of the shaft W are moved toward to each other in the axial direction of the shaft W, compression force in the axial direction is applied to the intermediate portion of the shaft W arranged between the pair of holders 2, 3, and an alternating load in a direction intersecting with the axial direction is applied to the intermediate portion of the shaft W arranged between the pair of holders 2, 3, so that the intermediate portion of the shaft W is enlarged while being compressed in the axial direction.

[0015] The holder 2 is supported by a support base 4 to be movable along a reference line A in which the shaft

W is arranged, and is moved by a translational drive unit 5 (an example of a presser). When the holder 2 is moved toward the holder 3 along the reference line A, the compression force in the axial direction is loaded to the intermediate portion of the shaft W held by the holders 2, 3, so as to compress the intermediate portion of the shaft W.

[0016] In the shaft diameter enlarging apparatus 1, when the shaft W is rotated by bending the intermediate portion of the shaft W by the bending angle, the alternating load in the direction intersecting with the axial direction acts on the intermediate portion of the shaft W. The holder 3 is tilted with respect to the reference line A by a tilt drive unit 6 (an example of an alternating load generator), so as to bend the intermediate portion of the shaft W by the bending angle. Further, in a state in which the intermediate portion of the shaft W is bent by the bending angle, the holder 3 is rotated by a rotary drive unit 7 (an example of the alternating load generator). The shaft W held by the holder 3 is rotated according to the rotation of the holder 3, and the holder 2 holding the shaft W is also rotated in response to the holder 3 and the shaft W.

[0017] A controller 8 controls the translational drive unit 5, the tilt drive unit 6, and the rotary drive unit 7 based on set conditions.

[0018] The intermediate portion of the shaft W is heated before the shaft diameter enlargement and/or during the shaft diameter enlargement. Only the intermediate portion may be heated, or the entire shaft W including the intermediate portion may be heated.

[0019] The shaft W can be heated by using a furnace such as a combustion furnace and an electric furnace. Alternatively, resistance heating or induction heating may be used to heat the shaft W. The resistance heating is performed by attaching an electrode to a workpiece in a contacting manner to directly pass electric current through the workpiece, so that the workpiece is heated by Joule heat. The induction heating is performed by arranging a heating coil connected to an AC power supply close to a workpiece, so that alternating flux generated by the heating coil is cross-linked with the workpiece to generate eddy current on the surface of the workpiece and to heat the surface of the workpiece by Joule heat.

[0020] In the resistance heating, the electrode is brought into contact with the intermediate portion of the shaft W held by the pair of holders 2, 3, so as to partially heat the intermediate portion. In the induction heating, the heating coil is arranged to be close to the intermediate portion of the shaft W held by the pair of holders 2, 3, so as to partially heat the intermediate portion. Both heating methods can be suitably used for heating during the shaft diameter enlargement. Particularly, it is preferable to use the induction heating by which the shaft W can be heating in a non-contacting manner.

[0021] When enlarging the intermediate portion of the shaft W, the temperature of the intermediate portion of the shaft W is set to be above the blue brittleness range of the shaft W and below the tempering temperature range of the holders 2, 3.

[0022] Fig. 2 shows a relation between a temperature and a tensile strength (stress) of various steel materials in which the carbon content is different.

[0023] A graph shown in Fig. 2 is from "the Japan Institute of Metals and Materials, the Iron and Steel Institute of Japan, 'Handbook of Steel Materials', first edition, Maruzen Inc., June 1967, p. 552". Basically, the tensile strength of the steel material reduces in accordance with an increase of the temperature of the steel material. This indicates that in the shaft diameter enlargement, the deformation resistance at the time of enlarging the intermediate portion of the shaft W can be reduced by increasing the temperature of the shaft W. However, in the blue brittleness range (in the illustrated example, the temperature range of about 200°C to 400°C), the tensile strength increases in accordance with the increase of the temperature. In the temperature range above the blue brittleness range, the tensile strength reduces again in accordance with the increase of the temperature.

[0024] Accordingly, the temperature of the intermediate portion of the shaft W is set to be above the blue brittleness range of the shaft W. This makes it possible to reduce the deformation resistance at the time of enlarging the intermediate portion of the shaft W and to increase the enlargement rate. In addition, it is possible to prevent a crack resulting from the enlargement.

[0025] A solid round rod or a hollow round rod which is made of a steel material such as carbon steel for mechanical structure (e.g., JIS-S45C) or alloy steel for mechanical structure (e.g., JIS-SCr420H) and has a cross-sectional circular shape is used as the shaft W. The upper limit temperature of the blue brittleness range of JIS-S45C is less than 400°C, and the upper limit temperature of the blue brittleness range of JIS-SCr420H is also less than 400°C. Therefore, the temperature of the intermediate portion of the shaft W is preferably 400°C or more.

[0026] In the temperature range above the blue brittleness range, the tensile strength monotonously reduces in accordance with an increase of the temperature of the intermediate portion of the shaft W. Therefore, from a viewpoint of increasing the enlargement rate and preventing a crack resulting from the enlargement, there is no upper limit for the temperature of the intermediate portion of the shaft W. However, the hardness of the holders 2, 3 is lowered by tempering when the temperature of the holders 2, 3 is increased by the thermal conduction from the shaft W to the holders 2, 3 such that the temperature of the holders 2, 3 reaches the tempering temperature range. In view of this, the temperature of the holders 2, 3 is set to be below the tempering temperature range of the holders 2, 3. Accordingly, it is possible to prevent the hardness of the holders 2, 3 from being lowered by tempering and to extend the lifetime of the holders 2, 3.

[0027] Generally, the holders 2, 3 are made of tool steel such as the die steel (e.g., JIS-SKD61) or the high speed tool steel (e.g., JIS-SKH51). The tempering temperature range of JIS-SKD61 is 500°C to 560°C, and the temper-

ing temperature range of JIS-SKH51 is 560°C to 580°C. Therefore, the temperature of the holders 2, 3 is preferably below 580°C, more preferably below 500°C.

[0028] Considering the temperature increase of the holders 2, 3 due to the thermal conduction from the shaft W and also the thermal conduction loss, the upper limit temperature of the intermediate portion of the shaft W can be set to be slightly above the tempering temperature range of the holders 2, 3. For example, the upper limit temperature of the intermediate portion of the shaft W may be set to 700°C with respect a typical tempering temperature range (500°C to 580°C) of the holders 2, 3. Preferably, the upper limit temperature of the intermediate portion of the shaft W is below the tempering temperature range of the holders 2, 3, so that it is possible to ensure that the temperature of the holders 2, 3 does not reach the tempering temperature range.

[0029] An example of a shaft diameter enlarging method using the shaft diameter enlarging apparatus 1 will be described with reference to Figs. 3A to 3E.

[0030] In this example, as illustrated in Fig. 3A, the intermediate portion Wa of the shaft W is heated by a heating device 9 before the shaft diameter enlargement. The entire shaft W may be heated. Only the intermediate portion Wa of the shaft W or the entire shaft W is heated such that the temperature of the intermediate portion Wa exceeds the blue brittleness range of the shaft W at least at the time of starting the shaft diameter enlargement, in consideration of heat dissipation after the heating, preferably such that the temperature of the intermediate portion Wa is maintained above the blue brittleness range of the shaft W until the entire process of the shaft diameter enlargement is completed, and also in consideration of thermal conduction from the shaft W to the holders 2, 3 such that the holders 2, 3 holding the shaft W are maintained below the tempering temperature range.

[0031] Next, as illustrated in Fig. 3B, the shaft W is held by the holders 2, 3. An axial length L_0 of the intermediate portion Wa of the unprocessed shaft W is appropriately set according to the axial length L and the outer diameter D of the enlarged intermediate portion Wa in the relation with D_0 in which the outer diameter of the intermediate portion Wa is set as D_0 .

[0032] Next, as illustrated in Fig. 3C, in a state in which the shaft W is held by the holders 2, 3, the holder 2 is moved in a translational manner by the translational drive unit 5 (see Fig. 1) along the reference line A, and the compression force in the axial direction is applied to the intermediate portion Wa of the shaft W. In addition, the holder 3 is inclined by the tilt drive unit 6 (see Fig. 1) with respect to the reference line A, and is rotated by the rotary drive unit 7 (see Fig. 1).

[0033] The shaft W held by the holders 2, 3 is bent about a bending center O of the intermediate portion Wa on the reference line A, and is rotated about a central axis. The alternating load is applied to the bent intermediate portion Wa in the direction intersecting with the axial direction of the shaft W according to the bending and the

rotation of the shaft W. A bending angle θ of the intermediate portion Wa, that is, the inclination angle with respect to the reference line A of the holder 3 is set to an angle in which the bending of the shaft W is within the deformation of the elastic limit. The bending angle is varied according to the elastic limit of the material of the shaft W, but typically is about 2° to 4°.

[0034] Next, as illustrated in Fig. 3D, in the intermediate portion Wa of the shaft W, the inside of the bent portion is swelled by the plastic flow. Further, in accordance with the compression and the rotation of the shaft W, the swelling caused by the plastic flow grows over the entire circumference, and the intermediate portion Wa is enlarged gradually. Further, the compression of the shaft W by the translational movement of the holder 2 is stopped when the gap of the holders 2, 3 becomes a predetermined gap. Here, a process of enlarging the intermediate portion Wa of the shaft W is ended.

[0035] Next, as illustrated in Fig. 3E, with the compression force being continuously applied to the shaft W by the translational drive unit 5 and through the holders 2, 3, the holder 3 which is inclined with respect to the reference line A is arranged back along the reference line A, and the bending of the shaft W is restored. By the bend restoration of the shaft W, the thickness of the enlarged intermediate portion Wa (hereinafter, the enlarged portion) is made uniform over the entire circumference. The shaft diameter enlarging with respect to the shaft W is completed through the above steps, and the rotation of the shaft W is stopped. Thereafter, the cutting or the like is performed on the enlarged portion Wa as necessary, and the enlarged portion Wa is molded in a desired shape (e.g., a columnar shape).

[0036] Since the temperature of the intermediate portion Wa of the shaft W is set to be above the blue brittleness range of the shaft W, the deformation resistance of the shaft W is reduced, so that it is possible to increase the enlargement rate. For example, it is possible to obtain two times or more of the enlargement rate. Further, it is possible to prevent a crack resulting from the enlargement. In addition, since the holders 2, 3 are maintained to be below the tempering temperature range, it is possible to prevent the hardness of the holders 2, 3 from being lowered by tempering, thereby extending the lifetime of the holders 2, 3 and saving the running cost. Further, for the purpose of maintaining the holders 2, 3 to be below the tempering temperature range, the upper limit temperature of the intermediate portion Wa of the shaft W is set to be slightly above the tempering temperature range of the holders 2, 3 but below the warm temperature range. Thus, it is possible to suppress decarburization of the intermediate portion Wa, and to save the material by reducing the amount of cutting required for removing a scale generated on the surface of the intermediate portion Wa due to the decarburization or for removing the decarburization layer in which the strength is reduced due to the decarburization. It is also advantageous in that the running cost is further reduced by saving

the energy required to heat the shaft W.

[0037] In the example illustrated in Figs. 3A to 3E, the intermediate portion Wa of the shaft W is heated only before the shaft diameter enlargement. However, the intermediate portion Wa may be heated during the shaft diameter enlargement or may be heated before the shaft diameter enlargement and during the shaft diameter enlargement. By heating the intermediate portion Wa during of the shaft diameter enlargement, the temperature drop due to heat dissipation is prevented, so that it is possible to ensure that the temperature of the intermediate portion Wa is maintained above the blue brittleness range. Accordingly, it is possible to further increase the enlargement rate and to further prevent a crack from being generated by the enlargement.

[0038] In the example described above, the holder 3 is tilted with respect to the reference line A to bend the shaft W, and the shaft W is rotated about the central axis so that the alternating load is applied to the intermediate portion Wa of the shaft W. However, the method for applying alternating load to the intermediate portion Wa is not limited thereto.

[0039] In the example illustrated in Fig. 4, it is similar to the shaft diameter enlarging method illustrated in Figs. 3A to 3E in that alternating load is applied to the intermediate portion Wa by the bending and the rotation of the shaft W, but the shaft W is bent by sliding the holder 3 in a direction intersecting the reference line A rather than by tilting the holder 3.

[0040] In the example illustrated in Fig. 5, the holder 2 holds the shaft W in a non-rotatable and restrained manner, whereas the holder 3 holds the shaft W in a rotatable and unrestrained manner. In this state, the holder 3 is turned about the reference line A, whereby the intermediate portion Wa of the shaft W is bent, and the alternating load is applied to the bent intermediate portion Wa of the shaft W.

[0041] In the example illustrated in Fig. 6, the end portion of the shaft W is held by the holders 2, 3 in a non-rotatable and restrained manner, and the holder 3 is rotated about the reference line A in a reciprocating manner, so that the alternating load is applied to the intermediate portion Wa of the shaft W.

[0042] In the example illustrated in Fig. 7, bending or torsional vibration is applied to the shaft W by a vibration generator OSC, so that the alternating load is applied to the intermediate portion Wa of the shaft W.

[0043] Hereinafter, the description will be given about test examples.

[0044] In a first test example, in the shaft made of JIS-SCr420H, the entire shaft is heated in the electric furnace before the shaft diameter enlargement, and the shaft diameter enlargement is performed under the condition of the compression force of 2,000 kN and the bending angle of 4.0° by using the above-described shaft diameter enlarging apparatus 1. The upper limit temperature of the blue brittleness range of JIS-SCr420H is less than 400°C. While the temperature (the temperature at the time of

starting the shaft diameter enlargement) of the shaft is changed diversely, the number of the rotations required until the enlargement rate becomes 3.0 is measured, and the presence/absence of the crack in the obtained enlarged portion is checked. The presence/absence of the crack is checked by the color check using a color dye contrast penetrant. A result is shown in Fig. 8. In Fig. 8, a sample in which the crack is observed is indicated by "×", and a sample in which the crack is not observed is indicated by "O".

[0045] As shown in Fig. 8, it is found that when the temperature of the shaft is higher, the number of the rotations required until the enlargement rate becomes 3.0 tends to be smaller, and the deformation resistance is small. Further, in the samples in which the temperature of the shaft is 400°C or less, the crack is checked in the enlarged portion in all the samples. On the other hand, in the samples in which the temperature of the shaft is 400°C or more, the crack is not checked in the enlarged portion in all the samples. From the above, it is found that when the shaft diameter enlargement is performed in a state in which the intermediate portion of the shaft is made have the temperature above the blue brittleness range, it is possible to increase the enlargement rate and to prevent the occurrence of the crack caused by the enlargement.

[0046] Next, in a second test example, with respect to the shaft which is made of JIS-SCr420H and in which the solidification pattern observed in the sectional surface of a rolled steel bar is elliptic and the shaft which is made of JIS-SCr420H and in which the solidification pattern observed in the sectional surface of the rolled steel bar is rectangular, under the same processing conditions as that of the first test example, while the temperature (the temperature at the time of starting the shaft diameter enlargement) of the shaft is changed diversely, the shaft diameter enlargement is performed until the enlargement rate becomes 3.0, and the elliptic amount is evaluated which is a difference between the long diameter and the short diameter of the obtained enlarged portion. The solidification pattern of the shaft is a cross sectional shape of the shaft during forging of a continuous forging and rolling for producing the shaft. The solidification pattern generally relates to isotropy and anisotropy of a plastic deformation of the shaft. A result is shown in Fig. 9.

[0047] As shown in Fig. 9, in a case where the solidification pattern is elliptic and in a case where the solidification pattern is rectangular, the elliptic amount tends to be smaller when the temperature of the shaft is higher. That is, it is found that the enlargement progresses in an isotropic manner, and thus the deformation resistance is smaller when the temperature of the shaft is higher, and the deformation in a circumferential direction progresses uniformly such that the effect of the solidification pattern is hardly received. For example, in a case where the enlarged portion is processed in a columnar shape by the cutting after the shaft diameter enlargement, when the elliptic amount is smaller, the cutting allowance can be

made smaller, and the waste of the material can be reduced further, which is economical.

[0048] Next, some examples of the heating device 9 will be described.

[0049] In the example illustrated in Fig. 10, the heating device 9 is configured to heat the intermediate portion of the shaft W or the entire shaft W including the intermediate portion before the shaft diameter enlargement. The shaft W is heated by, for example, furnace heating, resistance heating, or induction heating. The heating device 9 is provided next to the pair of holders 2, 3. The shaft W heated by the heating device 9 is transferred from the heating device 9 to the pair of holders 2, 3 by a robot 10. The shaft W is then held by the pair of holders 2, 3 and is subjected to the shaft diameter enlargement.

[0050] In the example illustrated in Fig. 11, the heating device 9 is configured to heat the intermediate portion of the shaft W held by one of the holders 2, 3 before the shaft diameter enlargement by induction heating. The heating device 9 has a heating coil 11 of a spiral shape. The heating coil 11 is moved along the reference line A such that the shaft W held by the holder 2 is inserted into the heating coil 11. High frequency alternating current is applied to the heating coil 11 to heat the intermediate portion of the shaft W inside the heating coil 11 by induction heating. If the intermediate portion of the shaft W is longer than the entire length of the heating coil 11, the heating coil 11 may be moved along the reference line A. After the heating of the intermediate portion of the shaft W, the heating coil 11 is moved along the reference line A to remove the shaft W out of the heating coil 11. The heating coil 11 is then moved away from the reference line A. The shaft W is subsequently held by the pair of holders 2, 3 and is subjected to the shaft diameter enlargement.

[0051] In the example illustrated in Fig. 12, the heating device 9 is configured to heat the intermediate portion of the shaft W held by the pair of holders 2, 3, before the shaft diameter enlargement and/or during the shaft diameter enlargement, by induction heating. The heating device 9 has a heating coil 12 of an arc shape. The heating coil 12 is placed close to the intermediate portion of the shaft W held by the pair of holders 2, 3, such that an inner peripheral surface of the heating coil 12 and an outer peripheral surface of the intermediate portion of the shaft W face each other. High frequency alternating current is applied to the heating coil 12 so that the intermediate portion of the shaft W facing the inner peripheral surface of the heating coil 12 heated by induction heating. The intermediate portion of the shaft W can be heated over its entire circumference by rotating the shaft W by the rotary drive unit 7 (see Fig. 1). If the intermediate portion of the shaft W is longer than the entire length of the heating coil 12, the heating coil 12 may be moved along the reference line A. When heating the intermediate portion of the shaft W during the shaft diameter enlargement, the heating coil 12 is moved radially outward in accordance with the enlargement of the intermediate

portion of the shaft W. The shaft diameter enlargement may be performed on the shaft W being heated in this way.

[0052] In the example illustrated in Fig. 13, the heating device 9 is configured to heat the intermediate portion of the shaft W held by the pair of holders 2, 3, before the shaft diameter enlargement and/or during the shaft diameter enlargement, by resistance heating. The heating device 9 has a pair of electrodes 13, 14 connectable to the holders 2, 3. Direct current or alternating current is applied between the pair of electrodes 13, 14 through the holders 2, 3 and the intermediate portion of the shaft W held by the holders 2, 3, whereby the intermediate portion of the shaft W is heated by resistance heating. The shaft diameter enlargement may be performed also on the shaft W being heated in this way.

Claims

1. A shaft diameter enlarging method for enlarging an intermediate portion of a shaft (W), the shaft diameter enlarging method comprising:

holding the shaft (W) by a pair of holders (2, 3) with a gap between the pair of holders (2, 3) in an axial direction of the shaft (W);
applying compression force in the axial direction to the intermediate portion arranged between the pair of holders (2, 3); and
applying alternating load in a direction intersecting the axial direction to the intermediate portion to enlarge the intermediate portion,
wherein the method further comprises:

heating at least a portion of the shaft (W) including the intermediate portion before the enlarging of the intermediate portion;
and/or
heating the intermediate portion during the enlarging of the intermediate portion, and

wherein, when enlarging the intermediate portion, a temperature of the intermediate portion is set to be above a blue brittleness temperature range of the shaft (W), and a temperature of the holders (2, 3) is set to be below a tempering temperature range of the holders (2, 3).

2. The shaft diameter enlarging method according to claim 1, wherein, when enlarging the intermediate portion, the temperature of the intermediate portion is set to be equal to or above 400°C, and the temperature of the holder (2, 3) is set to be below 580°C.

3. The shaft diameter enlarging method according to claim 1 or 2, wherein, when enlarging the intermediate portion, the temperature of the intermediate

portion is set to be in a range of 400°C to 700°C.

4. The shaft diameter enlarging method according to claim 1 or 2, wherein, when enlarging the intermediate portion, the temperature of the intermediate portion is set to be above the blue brittleness temperature range of the shaft (W) and below the tempering temperature range of the holders (2, 3). 5
5. A shaft diameter enlarging apparatus (1) comprising: 10
 - a pair of holders (2, 3) configured to hold a shaft (W) with a gap between the pair of holders (2, 3) in an axial direction of the shaft (W);
 - a presser (5) configured to apply compression force in the axial direction to the intermediate portion arranged between the pair of holders (2, 3); 15
 - an alternating load generator (6, 7) configured to apply alternating load in a direction intersecting the axial direction to the intermediate portion to enlarge the intermediate portion; and 20
 - a heating device (9) configured to:
 - heat at least a portion of the shaft (W) including the intermediate portion before the enlarging of the intermediate portion; and/or 25
 - heat the intermediate portion during the enlarging of the intermediate portion, 30

wherein the heating device (9) is configured to heat at least a portion of the shaft (W) such that, during a period in which the compression force and the alternating load are applied to the intermediate portion of the shaft (W), a temperature of the intermediate portion is above a blue brittleness temperature range of the shaft (W), and a temperature of the pair of holders (2, 3) holding the shaft (W) is below a tempering temperature range of the holders (2, 3). 35 40

Patentansprüche

1. Schaftdurchmesserervergrößerungsverfahren, um einen Zwischenabschnitt eines Schafts (W) zu vergrößern, wobei das Schaftdurchmesserervergrößerungsverfahren umfasst: 45
 - den Schaft (W) mittels eines Paares von Haltern (2, 3) mit einem Zwischenraum zwischen dem Paar von Haltern (2, 3) in einer axialen Richtung des Schafts (W) zu halten; 50
 - eine Druckkraft in der axialen Richtung auf den zwischen dem Paar von Haltern (2, 3) angeordneten Zwischenabschnitt anzulegen; und 55
 - eine Wechsellast in einer die axiale Richtung schneidenden Richtung an den Zwischenab-

schnitt anzulegen, um den Zwischenabschnitt zu vergrößern,
wobei das Verfahren darüber hinaus umfasst:

- zumindest einen Teil des Schafts (W), der den Zwischenabschnitt aufweist, vor dem Vergrößern des Zwischenabschnitts zu erwärmen; und/oder 5
 - den Zwischenabschnitt während des Vergrößerns des Zwischenabschnitts zu erwärmen, und 10
- wobei, wenn der Zwischenabschnitt vergrößert wird, eine Temperatur des Zwischenabschnitts oberhalb eines Temperaturbereichs für Blausprödigkeit des Schafts (W) eingestellt wird, und eine Temperatur der Halter (2, 3) so eingestellt wird, dass sie unterhalb eines Anlasstemperaturbereichs der Halter (2, 3) liegt.
2. Schaftdurchmesserervergrößerungsverfahren nach Anspruch 1, wobei, wenn der Zwischenabschnitt vergrößert wird, die Temperatur des Zwischenabschnitts auf gleich oder über 400°C eingestellt wird, und die Temperatur der Halter (2, 3) auf unter 580°C eingestellt wird. 25
 3. Schaftdurchmesserervergrößerungsverfahren nach Anspruch 1 oder 2, wobei, wenn der Zwischenabschnitt vergrößert wird, die Temperatur des Zwischenabschnitts so eingestellt wird, dass sie in einem Bereich von 400°C bis 700°C liegt. 30
 4. Schaftdurchmesserervergrößerungsverfahren nach Anspruch 1 oder 2, wobei, wenn der Zwischenabschnitt vergrößert wird, die Temperatur des Zwischenabschnitts so eingestellt wird, dass sie oberhalb eines Temperaturbereichs für Blausprödigkeit des Schafts (W) und unterhalb des Anlasstemperaturbereichs der Halter (2, 3) liegt. 35 40
 5. Schaftdurchmesserervergrößerungsvorrichtung (1), umfassend: 45

ein Paar von Haltern (2, 3), die dazu ausgelegt sind, einen Schaft (W) mit einem Zwischenraum zwischen dem Paar von Haltern (2, 3) in einer axialen Richtung des Schafts (W) zu halten; eine Pressvorrichtung (5), die dazu ausgelegt ist, eine Druckkraft in der axialen Richtung auf den zwischen dem Paar von Haltern (2, 3) angeordneten Zwischenabschnitt anzulegen; einen Wechsellastgenerator (6, 7), der dazu ausgelegt ist, eine Wechsellast in einer die axiale Richtung schneidenden Richtung an den Zwischenabschnitt anzulegen, um den Zwischenabschnitt zu vergrößern; und eine Erwärmungseinrichtung (9), die dazu aus-

gelegt ist:

zumindest einen Teil des Schafts (W), der den Zwischenabschnitt aufweist, vor dem Vergrößern des Zwischenabschnitts zu erwärmen; und/oder den Zwischenabschnitt während des Vergrößerns des Zwischenabschnitts zu erwärmen,

wobei die Erwärmungseinrichtung (9) dazu ausgelegt ist, zumindest einen Teil des Schafts (W) derart zu erwärmen, dass während eines Zeitraums, in dem die Druckkraft und die Wechselbelastung an den Zwischenabschnitt des Schafts (W) angelegt werden, eine Temperatur des Zwischenabschnitts oberhalb eines Temperaturbereichs für Blausprödigkeit des Schafts (W) liegt, und eine Temperatur des Paares von Haltern (2, 3), die den Schaft (W) halten, unterhalb eines Anlasstemperaturbereichs der Halter (2, 3) liegt.

Revendications

1. Procédé d'agrandissement de diamètre d'arbre destiné à agrandir une partie intermédiaire d'un arbre (W), le procédé d'agrandissement de diamètre d'arbre comprenant :

le maintien de l'arbre (W) par une paire de dispositifs de maintien (2, 3) avec un espacement entre la paire de dispositifs de maintien (2, 3) dans une direction axiale de l'arbre (W) ;
l'application d'une force de compression dans la direction axiale à la partie intermédiaire agencée entre la paire de dispositifs de maintien (2, 3) ; et
l'application d'une charge alternante dans une direction croisant la direction axiale à la partie intermédiaire pour agrandir la partie intermédiaire, sachant que le procédé comprend en outre :

le chauffage d'au moins une partie de l'arbre (W) incluant la partie intermédiaire avant l'agrandissement de la partie intermédiaire ; et/ou
le chauffage de la partie intermédiaire pendant l'agrandissement de la partie intermédiaire, et

sachant que, lors de l'agrandissement de la partie intermédiaire, une température de la partie intermédiaire est réglée pour être supérieure à une plage de température de fragilité au bleu de l'arbre (W), et une température des dispositifs de maintien (2, 3) est réglée pour être inférieure

à une plage de température de revenu des dispositifs de maintien (2, 3).

2. Le procédé d'agrandissement de diamètre d'arbre selon la revendication 1, sachant que, lors de l'agrandissement de la partie intermédiaire, la température de la partie intermédiaire est réglée pour être égale ou supérieure à 400 °C, et la température des dispositifs de maintien (2, 3) est réglée pour être inférieure à 580 °C.
3. Le procédé d'agrandissement de diamètre d'arbre selon la revendication 1 ou 2, sachant que, lors de l'agrandissement de la partie intermédiaire, la température de la partie intermédiaire est réglée pour être comprise dans une plage de 400 °C à 700 °C.
4. Le procédé d'agrandissement de diamètre d'arbre selon la revendication 1 ou 2, sachant que, lors de l'agrandissement de la partie intermédiaire, la température de la partie intermédiaire est réglée pour être supérieure à la plage de température de fragilité au bleu de l'arbre (W) et inférieure à la plage de température de revenu des dispositifs de maintien (2, 3).
5. Appareil d'agrandissement de diamètre d'arbre (1) comprenant :

une paire de dispositifs de maintien (2, 3) configurés pour maintenir un arbre (W) avec un espacement entre la paire de dispositifs de maintien (2, 3) dans une direction axiale de l'arbre (W) ;
un presseur (5) configuré pour appliquer une force de compression dans la direction axiale à la partie intermédiaire agencée entre la paire de dispositifs de maintien (2, 3) ;
un générateur de charge alternante (6, 7) configuré pour appliquer une charge alternante dans une direction croisant la direction axiale à la partie intermédiaire pour agrandir la partie intermédiaire ; et
un dispositif de chauffage (9) configuré pour :

chauffer au moins une partie de l'arbre (W) incluant la partie intermédiaire avant l'agrandissement de la partie intermédiaire ; et/ou
chauffer la partie intermédiaire pendant l'agrandissement de la partie intermédiaire,

sachant que le dispositif de chauffage (9) est configuré pour chauffer au moins une partie de l'arbre (W) de telle sorte que, pendant une période où la force de compression et la charge alternante sont appliquées à la partie intermédiaire de l'arbre (W), une température de la par-

tie intermédiaire soit supérieure à une plage de température de fragilité au bleu de l'arbre (W), et une température de la paire de dispositifs de maintien (2, 3) maintenant l'arbre (W) soit inférieure à une plage de température de revenu des dispositifs de maintien (2, 3). 5

10

15

20

25

30

35

40

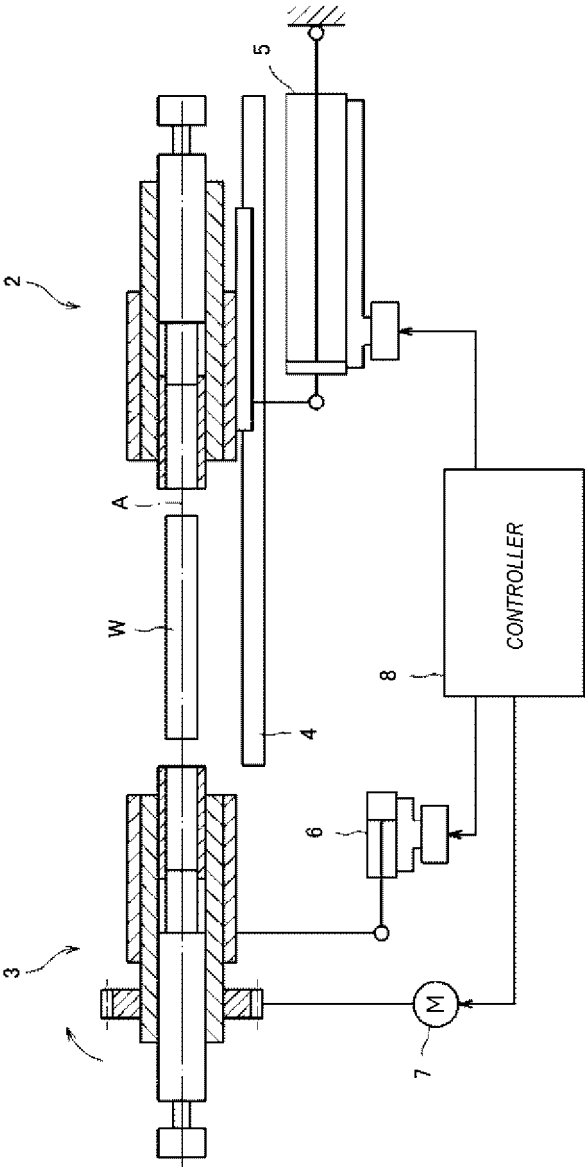
45

50

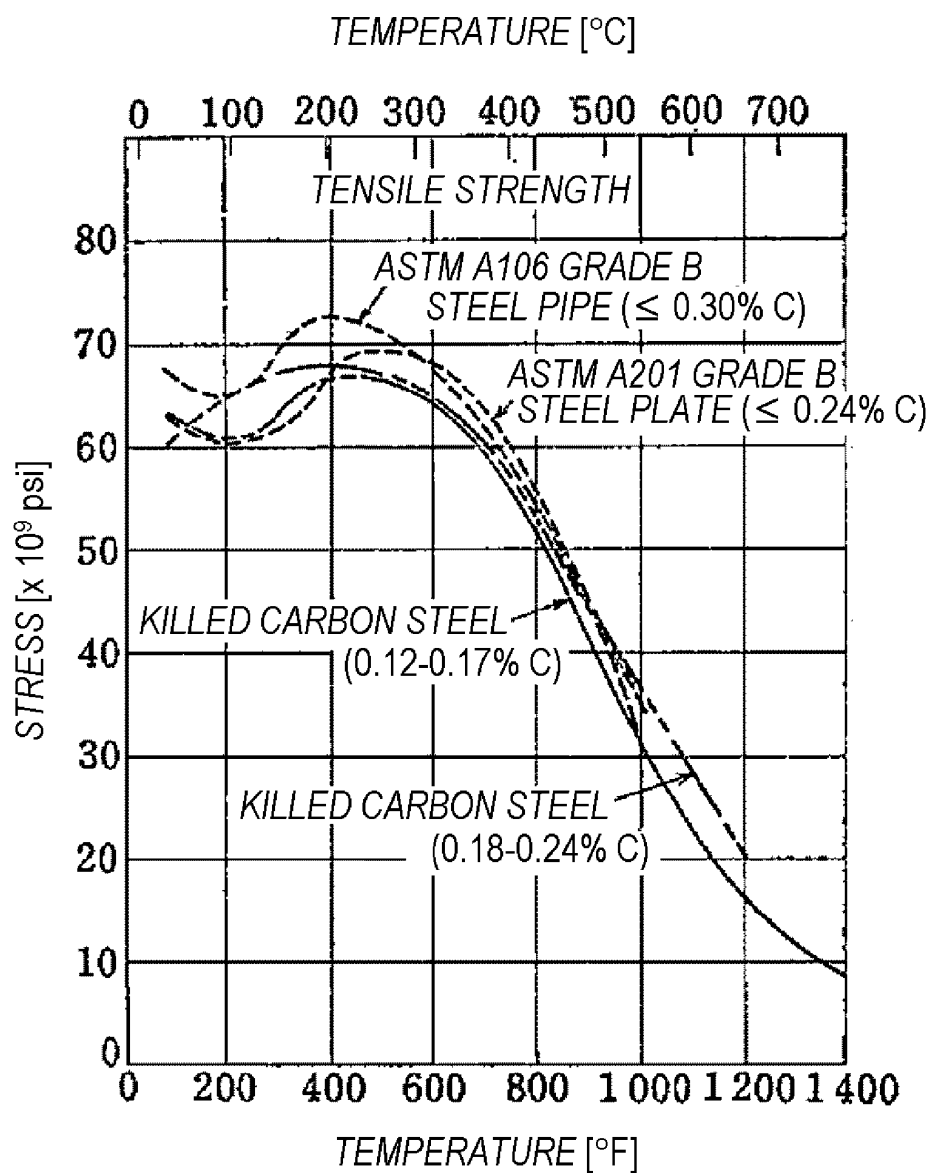
55

[Fig. 1]

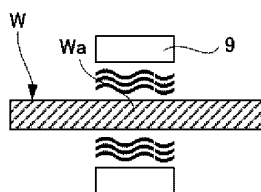
1



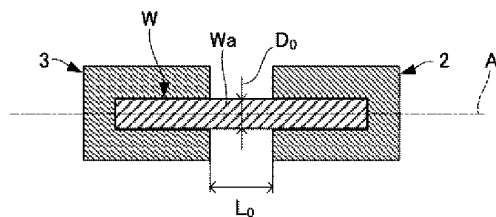
[Fig. 2]



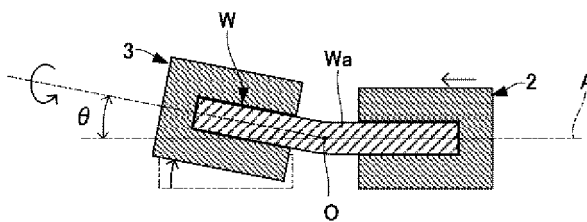
[Fig. 3A]



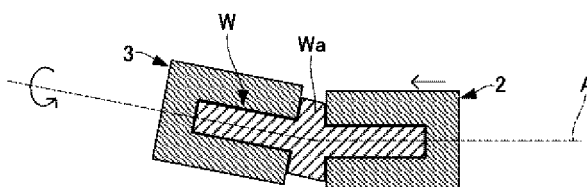
[Fig. 3B]



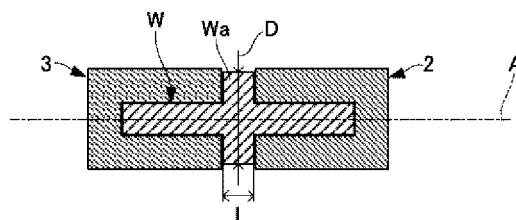
[Fig. 3C]



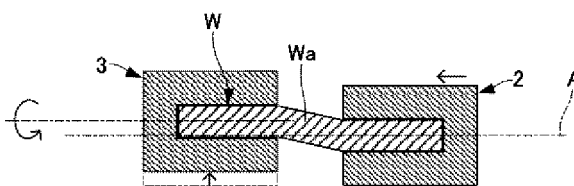
[Fig. 3D]



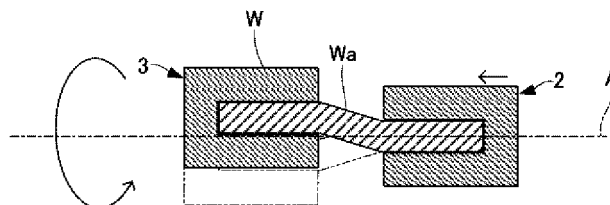
[Fig. 3E]



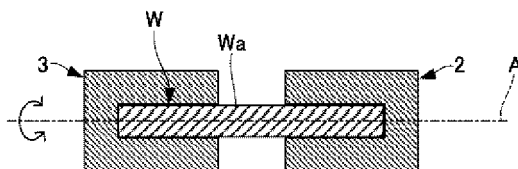
[Fig. 4]



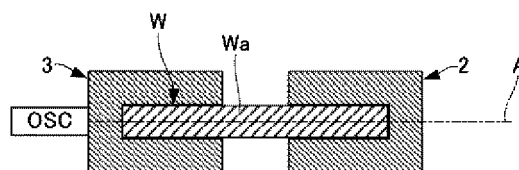
[Fig. 5]



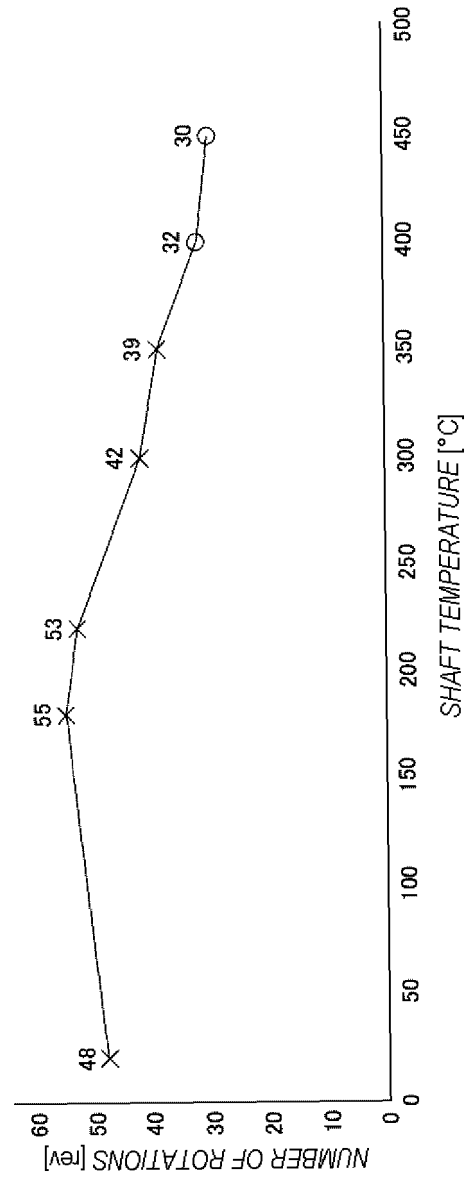
[Fig. 6]



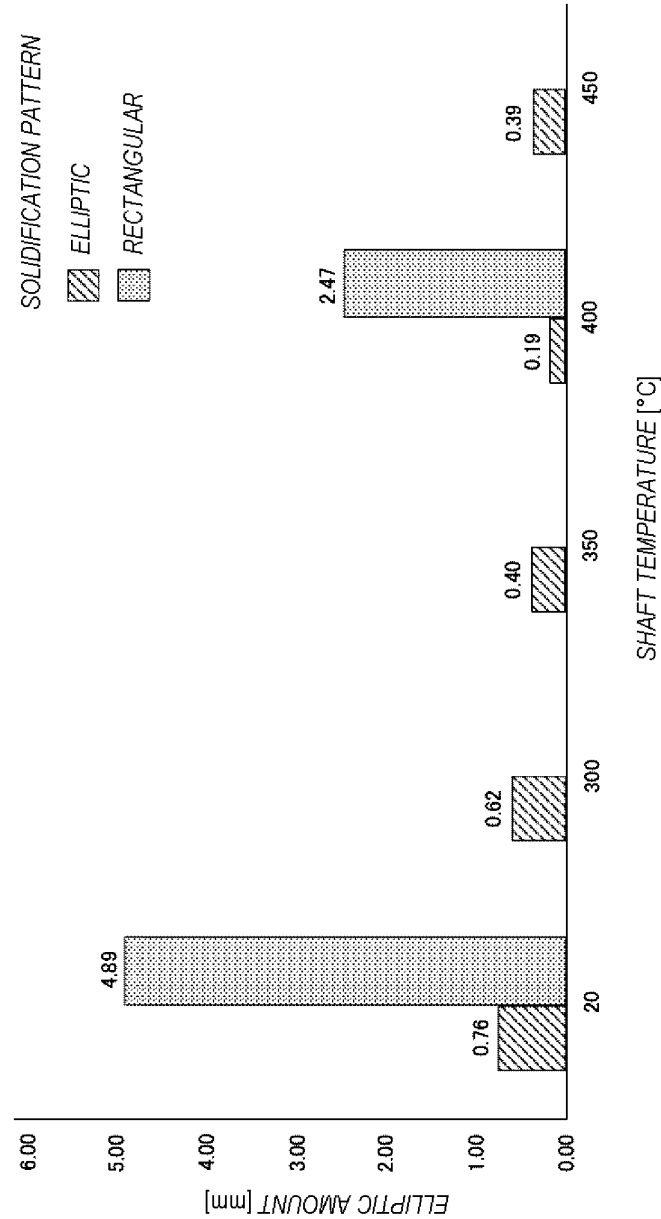
[Fig. 7]



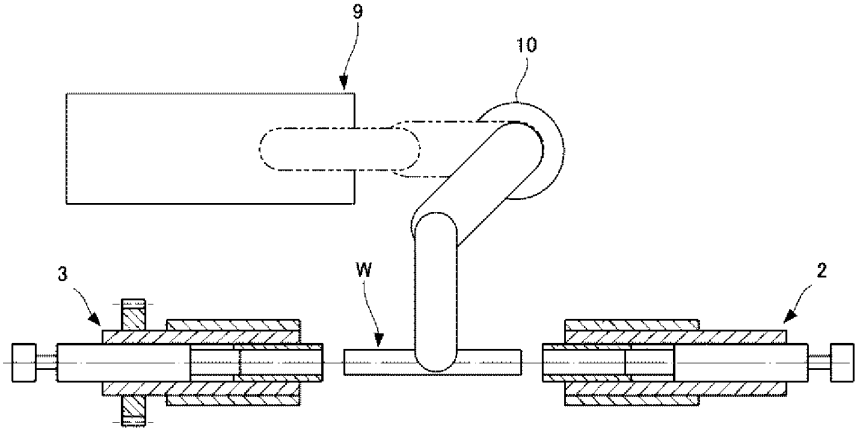
[Fig. 8]



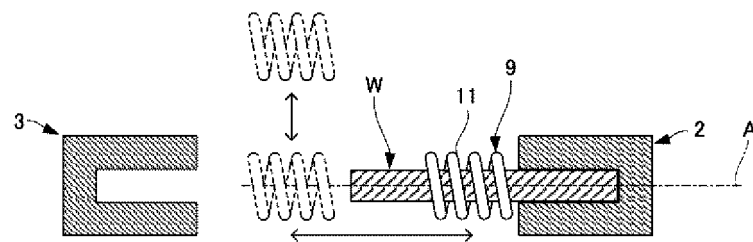
[Fig. 9]



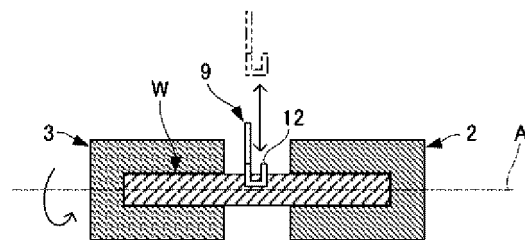
[Fig. 10]



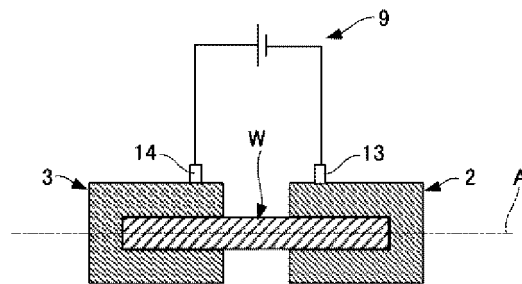
[Fig. 11]



[Fig. 12]



[Fig. 13]



REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2007167882 A [0001] [0007]
- JP 2005088066 A [0006]

Non-patent literature cited in the description

- the Japan Institute of Metals and Materials, the Iron and Steel Institute of Japan. Handbook of Steel Materials. Maruzen Inc, June 1967, 552 [0023]