



(11)

EP 3 868 979 A1

(12)

EUROPEAN PATENT APPLICATION

published in accordance with Art. 153(4) EPC

(43) Date of publication:
25.08.2021 Bulletin 2021/34

(51) Int Cl.: **E04G 21/12**^(2006.01) **E02D 29/045**^(2006.01)

(21) Application number: **20873341.0**

(86) International application number:
PCT/CN2020/120426

(22) Date of filing: **12.10.2020**

(87) International publication number:
WO 2021/088596 (14.05.2021 Gazette 2021/19)

(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**
 Designated Extension States:
BA ME
 Designated Validation States:
KH MA MD TN

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(30) Priority: 04.11.2019 CN 201911066339

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(54) **METHOD FOR TENSIONING PREFABRICATED COMPONENT EMPLOYING CENTROID TRACKING AND SEAM WIDTH CONTROL**

(57) Provided are a tensioning method of prefabricated component based on centroid tracking and seam width control, comprising: Step 1 of establishing a coordinate set Ω of center points of micro-segments of a centerline of a rubber gasket, and a coordinate set Π of center points of bolt hole positions; Step 2 of calculating to obtain a geometric centroid of the rubber gasket and a centroid of reaction force of the rubber gasket respectively; Step 3 of calculating a centroid of tension force of a Jack; Step 4 of performing tensioning on prefabricated components

of assembly type based on the seam width control; Step 5 of performing tensioning on prefabricated components of assembly type based on the centroid tracking. The method can realize that when the prefabricated component is tensioned, the rubber gasket is evenly compressed, and width of seam of which is same at all positions of the seam. so as to improve assembly accuracy of large prefabricated components and construction quality of prefabricated structures of assembly type.

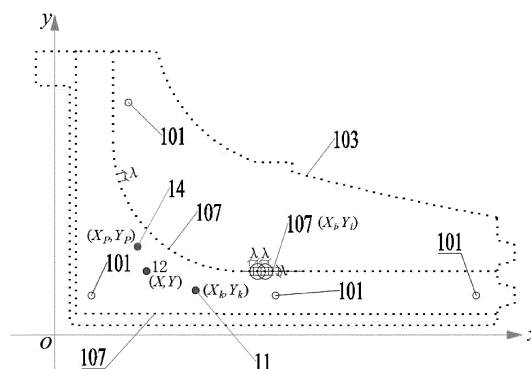


Fig.2

DescriptionTECHNICAL FIELD OF THE INVENTION

5 **[0001]** The invention relates to the technical field of building engineering, in particular to a tensioning method of prefabricated component based on centroid tracking and seam width control.

BACKGROUND OF THE INVENTION

10 **[0002]** Prefabricated assembly technology usually uses rubber gaskets as the key waterproof material for longitudinal and circumferential joints of assembly components when applied in underground structure. This material is usually composed of a non-linear elastic material. Under effect of the tensioning force of the assembly Jack, it can change shape following change of width of seam between the components. It on one hand can ensure waterproof and sealing performance seam between the components, on the other hand can provide cushioning effect for the components in the assembling and completing stages, so as to avoid quality degradation problems such as component cracking due to collision.

15 **[0003]** After rubber gaskets of the prefabricated components are in contact and compressed during assembling and tension process, it is required to ensure that the width of the seam between the assembled components is even, the rubber gasket is compressed evenly, with same elastic reaction force, in which centroid of reaction force of the rubber gasket is consistent with its plane centroid, so as to ensure the quality of assembly. However, since the width of the seam between the assembled components is often uneven due to various factors, elasticities of the rubber gasket at different portions of the components are different, and values of the elastic reaction forces are also different, such that inconsistency of the centroid of reaction force and the plane centroid of the rubber seal will arise. Therefore, it is required to monitor the tension force of the tension Jack corresponding to position of the bolt hole in real time, and determine the reaction force and the centroid of the reaction force of the rubber gasket under different assembly conditions by inverse calculation. Then by adjusting the tension force of the tension Jack, it is ensured that the centroid of the reaction force of the rubber gasket is coincident with the plane centroid as far as possible, so as to ensure the quality of assembly.

20 **[0004]** In assembling the components of assembly type, each component is required to be subjected to multi-point tension by using several Jacks. In order to realize even compressing on the rubber gasket in assembling the prefabricated components, and ensure that centroid of the reaction force of the rubber gasket is consistent with geometric centroid of the rubber gasket as far as possible, to ensure the quality of assembly, it is necessary to develop a tensioning method for the prefabricated components of assembly type, in which by dynamically tracking relationship between centroid position of the reaction force of the rubber gasket and geometric centroid position of the rubber gasket, tension load of several tension Jacks at the next moment is determined, to gradually approach target tension position of the component of assembly type, and reach a preset seam width and ensure that the seam width is even.

25 **[0005]** As shown in Figs. 1A, 1B and 1C, gaskets 7 and 6 are symmetrically arranged on contact surface 4 of former group of components B-2 and contact surface 5 of components B-1 to be assembled, and width of seam between two components is affected by magnitudes and positions of tension force of a plurality of Jacks through tension hole 1, elastic reaction force of the gasket and sliding friction force of adjacent components and cushion layer. Under effect of tension forces from multiple groups of Jacks at different positions, gaskets 6 and 7 are compressed to produce elastic reaction forces. However, due to irregularity of shapes of the components and the gaskets 6 and 7, centroid of effecting forces from multiple groups of Jack may not coincide with geometric centroid of the gaskets, so that centroid of elastic reaction forces produced by the gaskets does not coincide with their geometric centroid, resulting in inconsistent compression deformation of the gaskets at different positions of the seams.

SUMMARY OF AN EMBODIMENT OF THE INVENTION

30 **[0006]** Therefore, in view of above defects, inventor of an embodiment of the invention researched and invented a tensioning method of prefabricated component based on centroid tracking and seam width control, by dedicated researching and designing, and combining experience and achievements of long time in related industries, in order to overcome the above defects.

35 **[0007]** An object of an embodiment of the invention is to provide a tensioning method of prefabricated component based on centroid tracking and seam width control, which can realize that when the prefabricated component is tensioned, the rubber gasket is evenly compressed, and width of seam of which is same at all positions of the seam. so as to improve assembly accuracy of large prefabricated components and construction quality of prefabricated structures of assembly type.

40 **[0008]** In order to solve above problems, the invention discloses a tensioning method of prefabricated component based on centroid tracking and seam width control, comprising:

Step 1 of establishing a coordinate set Ω of center points of micro-segments of centerline of a rubber gasket and a coordinate set Π of center points of bolt hole positions;

Step 2 of calculating to obtain a geometric centroid of the rubber gasket and a centroid of reaction force of the rubber gasket respectively;

Step 3 of calculating a centroid of tension force of a Jack;

Step 4 of performing tensioning on prefabricated components of assembly type based on the seam width control;

Step 5 of performing tensioning on prefabricated components of assembly type based on the centroid tracking.

[0009] In said Step 2, because any point of the coordinate set Ω of center points of micro-segments of centerline of a rubber gasket represents a square micro-segment of the rubber gasket, length of each micro-segment of the rubber gasket is equal to width λ of the rubber gasket, and areas of all of the square micro-segments of the rubber gasket are $A_0=k^2$. For coordinates and areas of all points of the coordinate set Ω of center points of micro-segments of centerline of a rubber gasket, area moments are calculated for X axis and Y axis, so as to calculate geometric centroid (X, Y) of the rubber gasket, in which coordinate (X, Y) of the geometric centroid in the XOY plane is obtained by formulae 1 and 2:

$$X = \frac{\sum_{i=1}^n A_0 \times x_i}{\sum_{i=1}^n A_0} = \frac{A_0 \times \sum_{i=1}^n x_i}{nA_0} = \frac{\sum_{i=1}^n x_i}{n} \quad (1)$$

$$Y = \frac{\sum_{i=1}^n A_0 \times y_i}{\sum_{i=1}^n A_0} = \frac{A_0 \times \sum_{i=1}^n y_i}{nA_0} = \frac{\sum_{i=1}^n y_i}{n} \quad (2).$$

[0010] In said Step 2, after contact surfaces of prefabricated component to be assembled and assembled prefabricated component are in full contact, under static balance state of tension of the Jack, monitoring values Z_i of widths of seams of the contact surfaces of the prefabricated component to be assembled and the assembled prefabricated component are obtained by monitoring the width of seams between the contact surfaces of n different positions of the prefabricated component in real time, in which $i=1, 2, \dots, n$; since the contact surfaces of the prefabricated component to be assembled and the assembled prefabricated component have two rubber gaskets with exact same shape, and compression amount of the rubber gasket in same position is same, actual compression amount of the rubber gasket is result of initial thickness Z_0 of the rubber gasket subtracted by a half of measured value of actual seam width (that is, $Z_i/2$), that is, $Z_0 - Z_i/2$; according to the measured n values of the compression amount of rubber gaskets, a surface equation is established within a same plane coordinate system corresponding to the coordinate set Ω of center points of micro-segments of centerline of the rubber gasket, and the width and deformation amount of the seam are calculated according to coordinate of each point.; then a dynamic database Z_S is established according in order of time, and an elastic reaction force

$$F_i = E_{si} \times ((Z_0 - \frac{Z_i}{2}) / Z_0) \times A_0$$

of the rubber gasket is calculated for each point of the coordinate set Ω of center points of micro-segments of centerline of the rubber gasket, for elastic reaction force F_i of each point, a moment is calculated for X-axis and Y-axis of coordinate system. According to principle that moment of composite force is equal to sum of moments of the micro-segments, coordinates (X_K, Y_K) of the centroid of reaction force of the rubber gasket are obtained by formulae 3 and 4:

$$X_K = \frac{\sum_{i=1}^n F_i \times x_i}{\sum_{i=1}^n F_i} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0 \times x_i}{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times x_i}{\sum_{i=1}^n E_{si} \times Z_{Si}} \quad (3)$$

$$Y_K = \frac{\sum_{i=1}^n F_i \times y_i}{\sum_{i=1}^n F_i} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0 \times y_i}{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times y_i}{\sum_{i=1}^n E_{si} \times Z_{Si}} \quad (4)$$

[0011] Coordinates of centroid (X_p, Y_p) of the tension of the Jack in Step 3, can be calculated by formulae 5 and 6:

$$X_p = \frac{\sum_{i=1}^n P_i \times x_i}{\sum_{i=1}^n P_i} \quad (5)$$

$$Y_p = \frac{\sum_{i=1}^n P_i \times y_i}{\sum_{i=1}^n P_i} \quad (6)$$

[0012] In said Step 4, real-time monitoring is performed on measuring points of seam width corresponding to each tension point of the Jack, then monitoring values of measuring points of seam width corresponding to different tension points of the Jack are obtained, which is recorded as Z_i in which $i=1, 2, \dots, n$, in which n tension points of the Jack correspond to n measuring points of seam width, a final control target value of measuring point of the seam width is set as Z_0 . By a method of multi-point cooperative tension, the final control target can be realized by continuous equivalent tension for m times, in which control values of each tension of tension points of the Jack at n different positions is

$$Z_{Ki} = \frac{Z_i - Z_0}{m}$$

wherein $i=1, 2, \dots, n$. Required tension distance on tension point 1 of the Jack at different positions is converted into the tension force of the Jack, and oil pressure and oil speed of a hydraulic control center are controlled.

[0013] Design of the position of tension hole of the Jack of prefabricated component should meet the following principles:

- 1) in case that only one set of tension holes of the Jack are arranged for a group of components, the tension holes should be on position of the geometric centroid of the rubber gasket;
- 2) in case that two sets of tension holes of the Jack are arranged for a group of components, the tension holes should be on both sides of the geometric centroid of the rubber gasket while aligned on a same straight line;
- 3) in case that three or more sets of tension holes of the Jack are arranged for a group of components, the tension holes should be arranged around the position of geometric centroid of the rubber gasket.

[0014] In Said Step 5, due to difference in effective size and position of the Jack, the centroid of tension force of the Jack does not coincide with the geometric centroid of the rubber gasket, resulting in inconsistency of compression degree of the gasket, then the centroid of reaction force of the rubber gasket does not coincide with the geometric centroid of the rubber gasket. In order to achieve the goal that the centroid of reaction force of the rubber gasket coincides with the geometric centroid of the rubber gasket, the tension forces of each group of Jacks are adjusted, to make the centroid of tension force of the Jack and the centroid of reaction force of the rubber gasket are symmetrical with each other, with the geometric centroid of the rubber gasket as center, so that the centroid of reaction force of the rubber gasket tends to move gradually towards the geometric centroid of the rubber gasket, so that the centroid of tension force of the Jack is adjusted to be symmetrical with the position of the centroid of reaction force of the rubber gasket accordingly.

[0015] In said Step 1, the plane of the component on which the rubber gasket is located is captured by a camera device to obtain the image of the component, which is then subjected to correction of image distortion and tilt distortion, information in the image is corrected by manual guidance, and skeleton contour line of the rubber gasket in the image is recognized by image recognition technology, then a center line of the skeleton contour line in the image of the rubber gasket and a center point of bolt hole position are recognized, and any point in the image is selected as the origin to

establish a coordinate system, which is defined as the XOY plane coordinate system.

[0016] From above, the tensioning method of prefabricated component based on centroid tracking and seam width control of an embodiment of the invention based on centroid tracking and seam width control has at least following advantages:

1. The rubber gasket is evenly pressed in the assembly process of the prefabricated components, and the seam width is same all over the seam, so as to improve assembly accuracy of large prefabricated components and the construction quality of prefabricated structures of assembly type;
2. The tensioning method of prefabricated component based on centroid tracking and seam width control can improve the efficiency of assembly;
3. It can be applied in assembled structures such as transit stations, sections, entrances, air ducts and other assembly structures of railway and urban rail, large underground space development assembly structures, underground pipelines and comprehensive pipe corridor assembly structures, urban underground pedestrian passageways, underground road tunnel assembly structure, and other similar projects built in manner of prefabricated assembly, and has a wide range of promotion significance.

[0017] Details of the present invention can be obtained from the following description and the accompanying drawings.

DESCRIPTION OF THE FIGURES

[0018]

Figs. 1A and 1B shows a component in the tensioning method of prefabricated component based on centroid tracking and seam width control of an embodiment of the invention;

Fig. 1C shows an enlarged diagram of a part of Fig. 1B.

Figs. 1D and 1E show essential contour information in Fig. 1B and a partly enlarged diagram showing the compression-deformation relationship of the gasket;

Fig. 2 shows a set of calculation points for the essential contour information for reaction force calculation of the gasket, and a diagram showing position relationship among a centroid of effective force from the Jack, a centroid of reaction force and gasket and a geometric centroid of the gasket;

Fig. 3 shows principle of the tensioning method of prefabricated component based on centroid tracking and seam width control of an embodiment of the invention;

Figs. 4A and 4B show a reasonable arrangement range of a single-hole Jack of an embodiment of the invention;

Figs. 5A and 5B show a reasonable arrangement range of a double-holes Jack of an embodiment of the invention;

Figs. 6A and 6B show a reasonable arrangement range of a three-holes or multihole Jack of an embodiment of the invention;

[0019] Reference numerals are as following:

107: the center point of centerline of the rubber gasket;

13: micro-segment of the rubber gasket;

1: tension point of the Jack;

8, 9 and 10: measurement points for seam width;

11: geometric centroid of the rubber gasket;

12: centroid of reaction force of the rubber gasket;

14: centroid of tension force of the Jack.

DETAILED DESCRIPTION OF AN EMBODIMENT OF THE INVENTION

[0020] Figs. 1A to 6B shows the tensioning method of prefabricated component based on centroid tracking and seam width control of an embodiment of the invention.

[0021] The tensioning method of prefabricated component based on centroid tracking and seam width control of an embodiment of the invention comprises:

Step 1 of determining a coordinate set of center points of micro-segments of centerline of a rubber gasket and a coordinate set of center points of bolt hole positions position of a component, wherein the coordinate set of center points of micro-segments of centerline of a rubber gasket and the coordinate set of center points of bolt hole positions position of a component can be identified by image information;

[0022] Particularly, the plane of the component B-2 on which the rubber gasket is located is captured by a camera device to obtain an image of the component (refer to Figs.ID and IE), which is then subjected to correction of image distortion and tilt distortion, information in the image is corrected by manual guidance, and skeleton contour line of the rubber gasket in the image is recognized by image recognition technology, then a center line of the skeleton contour line 3 in the image of the rubber gasket and a center point of bolt hole position 1 are recognized, and any one point in the image is selected as the origin to establish a coordinate system for convenient use, in which corner point of the image can be selected as the coordinate origin to establish a twodimensional plane coordinate system, which is defined as the XOY plane coordinate system, as shown in Fig.2.

[0023] By using image processing technology, the coordinate set Ω 107 of center points of micro-segments of centerline of a rubber gasket, the coordinate set Π 101 of center points of bolt hole positions position of a component, and a coordinate set Γ 103 of points of outer contour line of component structure, which are stored in a computer database;

[0024] Step 2 of obtaining a geometric centroid of the rubber gasket and a centroid of reaction force of the rubber gasket;

(1) calculating the geometric centroid of the rubber gasket, in which because any point of the coordinate set Ω of center points of micro-segments of centerline of a rubber gasket represents a square micro-segment of the rubber gasket, length of each micro-segment of the rubber gasket is equal to width λ of the gasket, and areas of all of the square micro-segments of the rubber gasket are $A_0=\lambda^2$; for coordinates and areas of all points of the coordinate set Ω of center points of micro-segments of centerline of a rubber gasket, area moments are calculated for X axis and Y axis, so as to calculate geometric centroid K of the rubber gasket, in which there are n points in the coordinate set Ω of center points of micro-segments, and coordinate of the geometric centroid K in the XOY plane is obtained by formulae 1 and 2:

$$X = \frac{\sum_{i=1}^n A_0 \times x_i}{\sum_{i=1}^n A_0} = \frac{A_0 \times \sum_{i=1}^n x_i}{nA_0} = \frac{\sum_{i=1}^n x_i}{n} \quad (1)$$

$$Y = \frac{\sum_{i=1}^n A_0 \times y_i}{\sum_{i=1}^n A_0} = \frac{A_0 \times \sum_{i=1}^n y_i}{nA_0} = \frac{\sum_{i=1}^n y_i}{n} \quad (2);$$

(2) calculating the centroid of reaction force of the rubber gasket, in which distance between the interface between prefabricated components to be assembled and assembled prefabricated components is monitored in real time by using laser or other measurement techniques; after contact surfaces of prefabricated component to be assembled and assembled prefabricated component are in full contact, under static balance state of tension of the Jack, n monitoring values Z_i of widths of seams of the contact surfaces of the prefabricated component to be assembled and the assembled prefabricated component are obtained by monitoring the width of seams between the contact surfaces of n different positions of the prefabricated component in real time, in which $i=1, 2, \dots, n$; since the contact surfaces of both of the prefabricated component to be assembled and the assembled prefabricated component have two rubber gaskets with exact same shape, and compression amount of the rubber gasket in same position is same, actual compression amount of the rubber gasket is result of initial thickness Z_0 of the rubber gasket subtracted by a half of measured value of actual seam width (that is, $Z_i/2$), that is, $Z_0-Z_i/2$; according to the measured n values of the compression amount of rubber gaskets, a surface equation is established within a same plane coordinate system corresponding to the coordinate set Ω of center points of micro-segments of centerline of the rubber gasket, and the width and deformation amount of the seam are calculated according to coordinate of each point.; then a dynamic database Z_S is established according in order of time, so that each subsequent tensioning can be retrieved for use from the database (the compression plane of the gasket also can be determined by actually measuring the seam widths at three non-collinear positions of the seams of the structure contour, then according to coordinate position information (x_i, y_i) of the plane on which the gasket is located, and angle relationship between the plane and the compression plane, value Z_i of the seam width corresponding to coordinate (x_i, y_i) of center point of each micro-segment of the centerline of each gasket is determined by inverse calculation according to the similar triangle rule).

1) according to the experimental data of rubber gasket material used in prefabricated components, corresponding

amount set E_s of deformation modulus of rubber gasket under different compression is established and stored in the computer database;

2) an elastic reaction force $F_i = E_{si} \times ((Z_0 - \frac{Z_i}{2}) / Z_0) \times A_0$ of the rubber gasket is calculated for each point of the coordinate set Ω of center points of micro-segments of centerline of the rubber gasket, for elastic reaction force F_i of each point, a moment is calculated for X-axis and Y-axis of coordinate system; according to principle that moment of composite force is equal to sum of moments of the micro-segments, coordinates of the centroid K_F of reaction force of the rubber gasket are obtained by formulae 3 and 4:

$$X_k = \frac{\sum_{i=1}^n F_i \times x_i}{\sum_{i=1}^n F_i} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0 \times x_i}{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times x_i}{\sum_{i=1}^n E_{si} \times Z_{Si}} \quad (3)$$

$$Y_k = \frac{\sum_{i=1}^n F_i \times y_i}{\sum_{i=1}^n F_i} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0 \times y_i}{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times y_i}{\sum_{i=1}^n E_{si} \times Z_{Si}} \quad (4);$$

[0025] The centroid of reaction force of the rubber gasket changes dynamically, in which the coordinates of centroid of reaction force of the rubber gasket are different under different tension balance.

[0026] Step 3 of calculating a centroid of tension force of a Jack;

when prefabricated components are assembled, generally multi-point cooperative tension is performed with different tension, assuming that number of tension points is n, the tension force on tension points are represented as P_i , in which in which $i=1, 2, \dots, n$; the centroid K_p of the tension of the Jack is calculated via formulae 5 and 6:

$$X_p = \frac{\sum_{i=1}^n P_i \times x_i}{\sum_{i=1}^n P_i} \quad (5)$$

$$Y_p = \frac{\sum_{i=1}^n P_i \times y_i}{\sum_{i=1}^n P_i} \quad (6);$$

[0027] Step 4 of performing tensioning on prefabricated components of assembly type based on the seam width control; As shown in Fig.2, when prefabricated components are being assembling, real-time monitoring is performed on measuring point 4 of seam width corresponding to each tension point 3 of the Jack, then monitoring values of measuring points of seam width corresponding to different tension points of the Jack are obtained, which is recorded as Z_i , in which $i=1, 2, \dots, n$, in which n tension points of the Jack correspond to n measuring points of seam width, a final control target value of measuring point of the seam width is set as Z_0 . By a method of multi-point cooperative tension, the final control target can be realized by continuous equivalent tension for m times, in which control values of each tension of tension points

$$Z_{Ki} = \frac{Z_i - Z_0}{m}$$

of the Jack at n different positions is Z_{Ki} , wherein $i=1, 2, \dots, n$. Required tension distance on tension point 3 of the Jack at different positions is converted into the tension force of the Jack, and oil pressure and oil speed of a hydraulic control center are controlled.

[0028] Further, arranging of the position of tension hole of the Jack of prefabricated component should meet the following principles as far as possible:

- 1) in case that only one set of tension holes of the Jack are arranged for a group of components, the tension holes should be on position of the geometric centroid of the rubber gasket, as shown in Figs.4A and 4B;
- 2) in case that two sets of tension holes of the Jack are arranged for a group of components, the tension holes should be on both sides of the geometric centroid of the rubber gasket while aligned on a same straight line, as shown in Figs.5A and 5B;
- 3) in case that three or more sets of tension holes of the Jack are arranged for a group of components, the tension holes should be arranged around the position of geometric centroid of the rubber gasket, as shown in Figs.6A and 6B.

[0029] Step 5 of performing tensioning on prefabricated components of assembly type based on the centroid tracking; positions of tension point of the Jack for the prefabricated component should be as close as possible to the measuring points of seam width, but due to various restrictions, it is hard to ensure that all measuring points of seam width correspond to the positions of tension point of the Jack, thus it is usually necessary to use actually measured data to calculate the seam width of tension point of the Jack, so the tensioning of the prefabricated component based on seam width control may lead to problems on tension quality and efficiency. In this case, assembling and tensioning work can be completed by the tensioning method on prefabricated components of assembly type based on the centroid tracking.

[0030] As shown in Fig.3, due to difference in effective size and position of the Jack, the centroid 14 of tension force of the Jack does not coincide with the geometric centroid 12 of the rubber gasket, resulting in inconsistency of compression degree of the gasket, then the centroid 11 of reaction force of the rubber gasket does not coincide with the geometric centroid 12 of the rubber gasket. In order to achieve the goal that the centroid 11 of reaction force of the rubber gasket coincides with the geometric centroid 12 of the rubber gasket (in this condition, compression thickness at each position of the gasket is same, which means that the seam width is same in all parts of the seam, which achieves the ideal state of assembly), the tension forces of each group of Jacks are adjusted, to make the centroid 14 of tension force of the Jack and the centroid 11 of reaction force of the rubber gasket are symmetrical with each other, with the geometric centroid 12 of the rubber gasket as center, as shown as a and a' in the figure, so that the centroid of reaction force of the rubber gasket tends to move gradually towards the geometric centroid 12 of the rubber gasket along connection line aa' between 11 and 14. When the tension force of the Jack is adjusted, the deformation of the rubber gasket changes accordingly, and the position of the centroid 11 of reaction force changes accordingly to a position such as b'. By adjusting tension of the Jack, the centroid 14 of tension force of the Jack is adjusted to a position b which is symmetrical with the position of the centroid 11 of reaction force of the rubber gasket accordingly. By repeating the above centroid tracking method, the centroid 11 of reaction force of the rubber gasket constantly approaches the position of the geometric centroid 12 of the rubber gasket along $a' \rightarrow b' \rightarrow c' \rightarrow d'$, and the centroid 14 of tension force of the Jack also constantly approach the position of the geometric centroid 12 of the rubber gasket along $a \rightarrow b \rightarrow c \rightarrow d$ with changing of the position of the centroid 11 of reaction force of the rubber gasket, and finally realize that all of the centroid 14 of tension force of the Jack, the centroid 11 of reaction force of the gasket and the geometric centroid 12 of the gasket are consistent and compression degree all over the gasket is consistent, thus when assembling of the component is completed, the width all over the seam is equal.

[0031] In process of component assembly, the coordinates of geometric centroid 12, centroid 11 of reaction force of the rubber gasket, as well as the centroid 14 of tension force of the Jack are calculated in real time according to step 2 and step 3. By comparing the coordinates of the geometric centroid 12, the centroid 11 of reaction force of the rubber gasket, as well as the centroid 14 of tension force of the Jack, it is necessary to ensure that the coordinates of the centroid 11 of reaction force and the centroid 14 of tension force of the Jack are distributed on both sides of the geometrical centroid 12 of the gasket. Once the coordinates of the centroid 11 of reaction force and the centroid 14 of tension force of the Jack are distributed on the same side of the geometric centroid 12 of the gasket, a reminder can be sent automatically by a computer program, and through automatic optimization adjustment by the program or manual adjustment, to ensure that the assembly can be completed accurately and with high quality.

[0032] Therefore, advantages of the present invention include:

1. the rubber gasket is evenly pressed in the assembly process of the prefabricated components, and the seam width is same all over the seam, so as to improve assembly accuracy of large prefabricated components and the construction quality of prefabricated structures of assembly type;
2. the tensioning method of prefabricated component based on centroid tracking and seam width control can improve the efficiency of assembly;
3. it can be applied in assembled structures such as transit stations, sections, entrances, air ducts and other assembly structures of railway and urban rail, large underground space development assembly structures, underground pipelines and comprehensive pipe corridor assembly structures, urban underground pedestrian passageways, under-

ground road tunnel assembly structure, and other similar projects built in manner of prefabricated assembly, and has a wide range of promotion significance.

[0033] It is obvious that the above descriptions are only examples and are not intended to limit the disclosure, application or use of the present invention. Although the embodiments have been described in the embodiments and described in the drawings, the present invention does not limit the specific examples described by the examples of the drawings and described in the embodiments as currently considered the best mode to implement the teachings of an embodiment of the invention, the scope of the present invention will include any embodiments falling into the previous specification and the accompanying Claims.

Claims

1. A tensioning method of prefabricated component based on centroid tracking and seam width control, comprising:

Step 1 of establishing a coordinate set Ω of center points of micro-segments of a centerline of a rubber gasket, and a coordinate set Π of center points of bolt hole positions;

Step 2 of calculating to obtain a geometric centroid of the rubber gasket and a centroid of reaction force of the rubber gasket respectively;

Step 3 of calculating a centroid of tension force of a Jack;

Step 4 of performing tensioning on prefabricated components of assembly type based on the seam width control; and

Step 5 of performing tensioning on prefabricated components of assembly type based on the centroid tracking.

2. The tensioning method of prefabricated component based on centroid tracking and seam width control as in Claim 1, wherein in said Step 2, any point of the coordinate set Ω of center points of micro-segments of centerline of the rubber gasket represents a square micro-segment of the rubber gasket, length of each micro-segment of the rubber gasket is equal to width λ of the rubber gasket, and each of the square micro-segments of the rubber gasket is $A_0 = \lambda^2$; for coordinates and areas of all points of the coordinate set Ω of center points of micro-segments of centerline of the rubber gasket, area moments are calculated for X axis and Y axis, so as to calculate geometric centroid K of the rubber gasket, in which coordinates of the geometric centroid K in the XOY plane are obtained by formulae 1 and 2:

$$X = \frac{\sum_{i=1}^n A_0 \times x_i}{\sum_{i=1}^n A_0} = \frac{A_0 \times \sum_{i=1}^n x_i}{nA_0} = \frac{\sum_{i=1}^n x_i}{n} \quad (1)$$

$$Y = \frac{\sum_{i=1}^n A_0 \times y_i}{\sum_{i=1}^n A_0} = \frac{A_0 \times \sum_{i=1}^n y_i}{nA_0} = \frac{\sum_{i=1}^n y_i}{n} \quad (2).$$

3. The tensioning method of prefabricated component based on centroid tracking and seam width control as in Claim 1, wherein in said Step 2, after contact surfaces of prefabricated component to be assembled and assembled prefabricated component are in full contact, under static balance state of tension of the Jack, monitoring values Z_i of widths of seams of the contact surfaces of the prefabricated component to be assembled and the assembled prefabricated component are obtained by monitoring the width of seams between the contact surfaces of n different positions of the prefabricated component in real time, in which $i=1, 2, \dots, n$; since the contact surfaces of the prefabricated component to be assembled and the assembled prefabricated component have two rubber gaskets with exact same shape, and compression amount of the rubber gasket in same position is same, actual compression amount of the rubber gasket is result of initial thickness Z_0 of the rubber gasket subtracted by a half of measured value of actual seam width $Z_i/2$, that is, $Z_0 - Z_i/2$; according to the measured n values of the compression amount of rubber gaskets, a surface equation is established within a same plane coordinate system corresponding to the

coordinate set Ω of center points of micro-segments of centerline of the rubber gasket, and the width and deformation amount of the seam are calculated according to coordinate of each point.; then a dynamic database Z_S is established

according in order of time, and an elastic reaction force of the rubber gasket is calculated for each point of the coordinate set Ω of center points of micro-segments of centerline of the rubber gasket, for elastic reaction force F_i of each point, a moment is calculated for X-axis and Y-axis of coordinate system. According to principle that moment of composite force is equal to sum of moments of the micro-segments, coordinates of the centroid K_F of reaction force of the rubber gasket are obtained by formulae 3 and 4:

$$X_k = \frac{\sum_{i=1}^n F_i \times x_i}{\sum_{i=1}^n F_i} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0 \times x_i}{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times x_i}{\sum_{i=1}^n E_{si} \times Z_{Si}} \quad (3)$$

$$Y_k = \frac{\sum_{i=1}^n F_i \times y_i}{\sum_{i=1}^n F_i} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0 \times y_i}{\sum_{i=1}^n E_{si} \times Z_{Si} \times A_0} = \frac{\sum_{i=1}^n E_{si} \times Z_{Si} \times y_i}{\sum_{i=1}^n E_{si} \times Z_{Si}} \quad (4).$$

4. The tensioning method of prefabricated component based on centroid tracking and seam width control as in Claim 1, wherein coordinates of centroid K_P of the tension of the Jack in Step 3 are calculated by formulae 5 and 6:

$$X_P = \frac{\sum_{i=1}^n P_i \times x_i}{\sum_{i=1}^n P_i} \quad (5)$$

$$Y_P = \frac{\sum_{i=1}^n P_i \times y_i}{\sum_{i=1}^n P_i} \quad (6).$$

5. The tensioning method of prefabricated component based on centroid tracking and seam width control as in Claim 1, wherein in said Step 4, real-time monitoring is performed on measuring points of seam width corresponding to each tension point of the Jack, then monitoring values of measuring points of seam width corresponding to different tension points of the Jack are obtained, which is recorded as Z_i in which $i=1, 2, \dots, n$, in which n tension points of the Jack correspond to n measuring points of seam width, a final control target value of measuring point of the seam width is set as Z_0 . By a method of multi-point cooperative tension, the final control target can be realized by continuous equivalent tension for m times, in which control values of each tension of tension points of the Jack at n different

$$Z_{Ki} = \frac{Z_i - Z_0}{m}$$

positions is , wherein $i=1, 2, \dots, n$, required tension distance on tension point 1 of the Jack at different positions is converted into the tension force of the Jack, and oil pressure and oil speed of a hydraulic control center are controlled.

6. The tensioning method of prefabricated component based on centroid tracking and seam width control as in Claim 5, wherein setting of the position of tension hole of the Jack of prefabricated component should meet the following

principles:

- 1) in case that only one set of tension holes of the Jack are arranged for a group of components, the tension holes should be on position of the geometric centroid of the rubber gasket;
- 2) in case that two sets of tension holes of the Jack are arranged for a group of components, the tension holes should be on both sides of the geometric centroid of the rubber gasket while aligned on a same straight line;
- 3) in case that three or more sets of tension holes of the Jack are arranged for a group of components, the tension holes should be arranged around the position of geometric centroid of the rubber gasket.

7. The tensioning method of prefabricated component based on centroid tracking and seam width control as in Claim 1, wherein in said Step 5, due to difference in effective size and position of the Jack, the centroid of tension force of the Jack does not coincide with the geometric centroid of the rubber gasket, resulting in inconsistency of compression degree of the gasket, then the centroid of reaction force of the rubber gasket does not coincide with the geometric centroid of the rubber gasket. In order to achieve the goal that the centroid of reaction force of the rubber gasket coincides with the geometric centroid of the rubber gasket, the tension forces of each group of Jacks are adjusted, to make the centroid of tension force of the Jack and the centroid of reaction force of the rubber gasket are symmetrical with each other, with the geometric centroid of the rubber gasket as center, so that the centroid of reaction force of the rubber gasket tends to move gradually towards the geometric centroid of the rubber gasket, so that the centroid of tension force of the Jack is adjusted to be symmetrical with the position of the centroid of reaction force of the rubber gasket accordingly.
8. The tensioning method of prefabricated component based on centroid tracking and seam width control as in Claim 1, wherein in said step 1, the plane of the component on which the rubber gasket is located is captured by a camera device to obtain the image of the component, which is then subjected to correction of image distortion and tilt distortion, information in the image is corrected by manual guidance, and skeleton contour line of the rubber gasket in the image is recognized by image recognition technology, then a center line of the skeleton contour line in the image of the rubber gasket and a center point of bolt hole position are recognized, and any point in the image is selected as the origin to establish a coordinate system, which is defined as the XOY plane coordinate system.

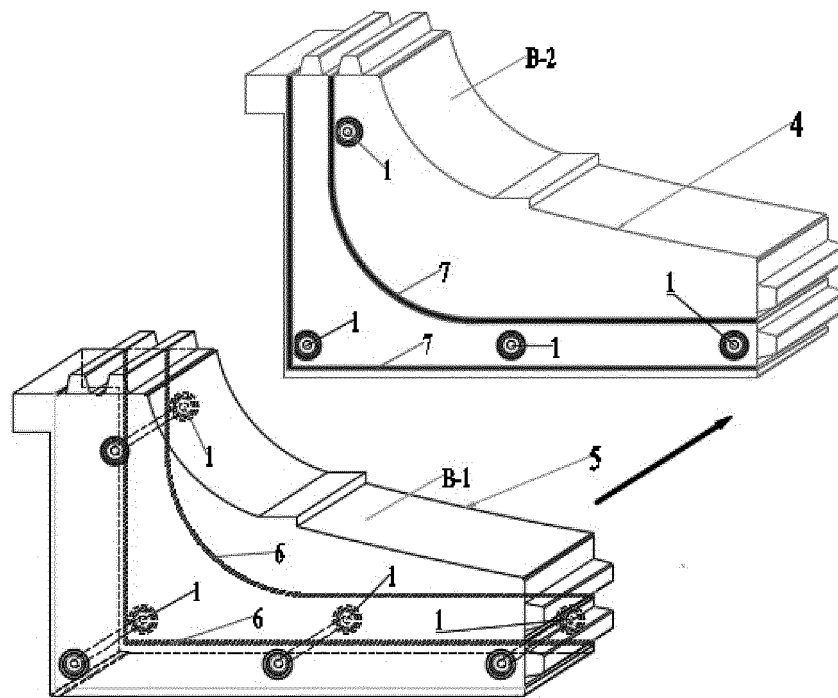


Fig. 1A

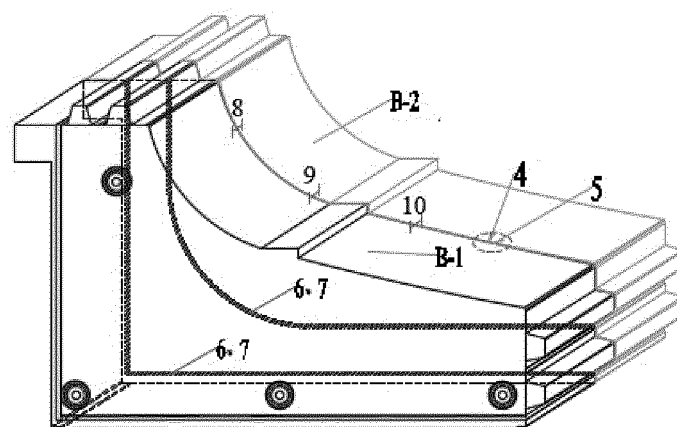


Fig. 1B

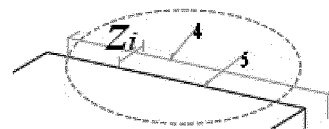


Fig. 1C

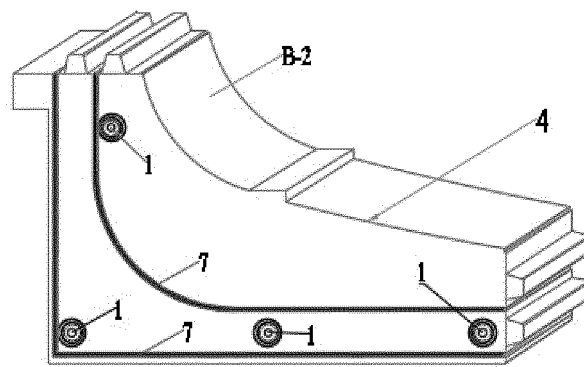


Fig. 1D

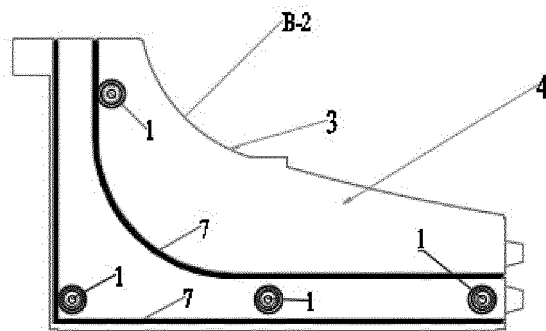


Fig. 1E

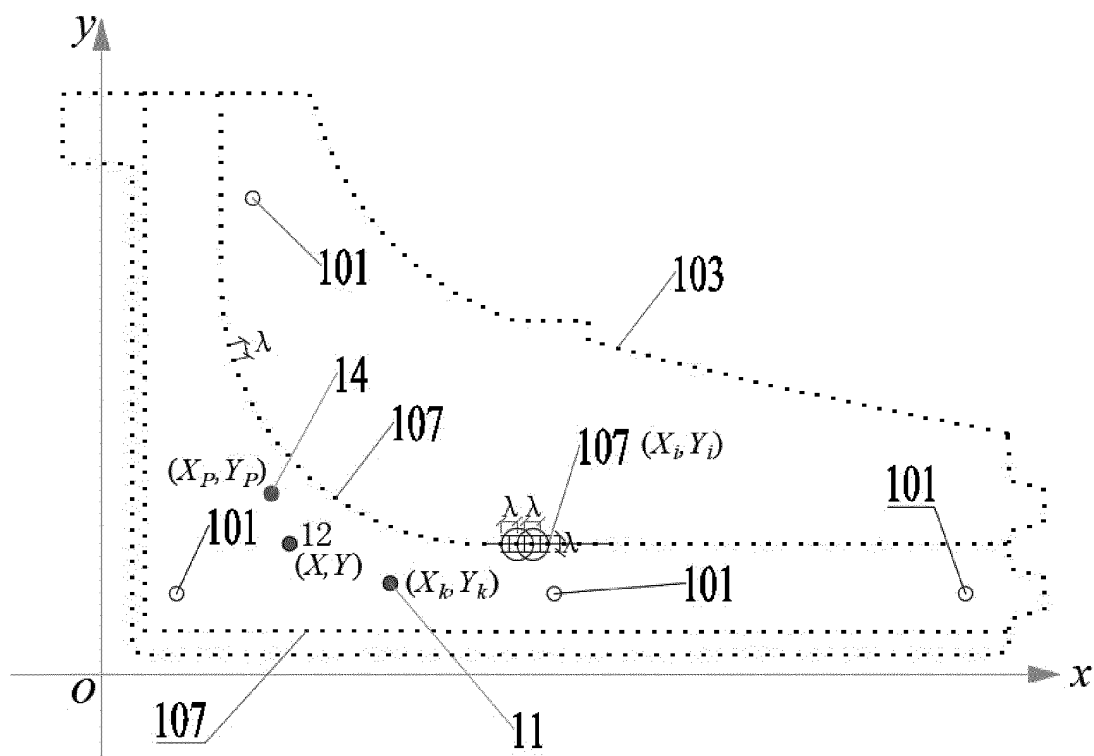


Fig.2

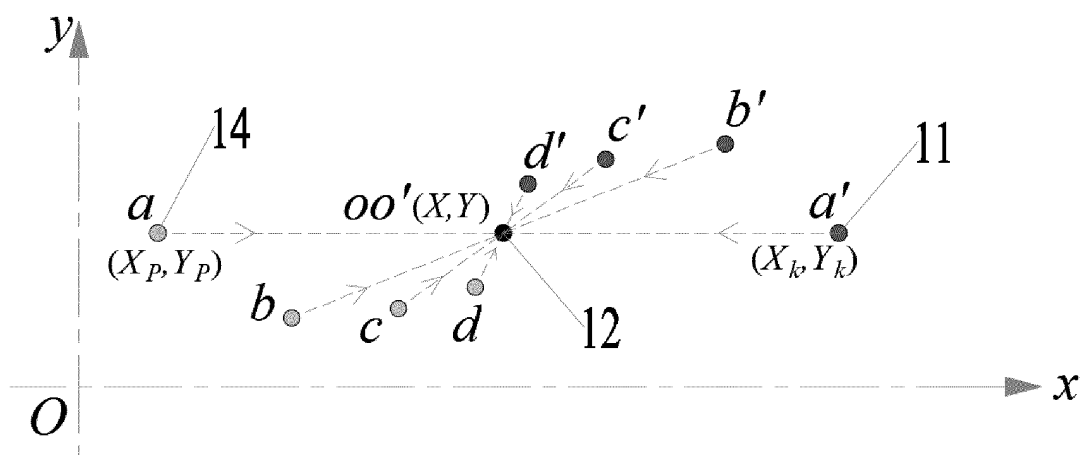


Fig.3

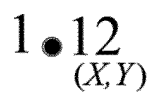


Fig.4A

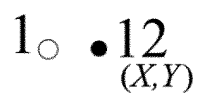
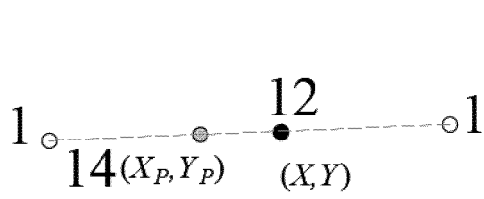
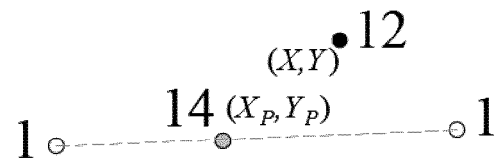


Fig.4B



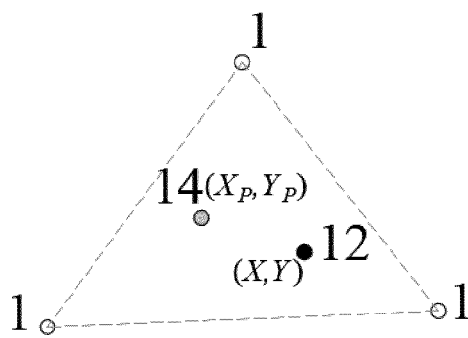
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Fig. 5A



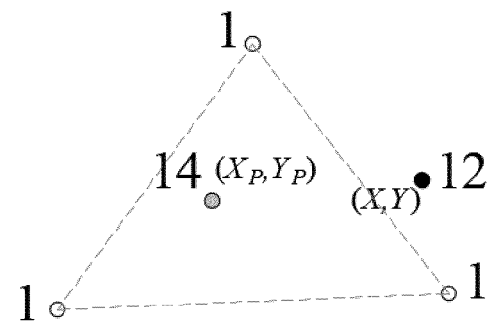
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Fig. 5B



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Fig. 6A



×

Fig. 6B

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2020/120426

A. CLASSIFICATION OF SUBJECT MATTER

E04G 21/12(2006.01)i; E02D 29/045(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E04G, E02D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNABS, VEN, CNKI: 预制, 装配, 张拉, 应力, 形心, 缝, 宽, 密封垫, 控制, prefabricat+, prefab, assembl+, pull+, draw+, stress, strain, center, slot, width, length, pressuriz+, windtight, airproof, seal+, hermet+, mat, control+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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PX	CN 110894727 A (BEIJING URBAN CONSTRUCTION DESIGN & DEVELOPMENT GROUP CO., LTD.) 20 March 2020 (2020-03-20) description, paragraphs 92-239, figures 1-17	1-8
A	CN 107345401 A (SUBWAY ENGINEERING CO., LTD. OF CHINA RAILWAY 16TH BUREAU GROUP CO., LTD. et al.) 14 November 2017 (2017-11-14) description, paragraphs 33-56, figures 1-2	1-8
A	CN 104947709 A (SHANGHAI MUNICIPAL ENGINEERING DESIGN INSTITUTE (GROUP) CO., LTD.) 30 September 2015 (2015-09-30) entire document	1-8
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A	JP H04106236 A (ASAHI CONCRETE WORKS) 08 April 1992 (1992-04-08) entire document	1-8

☒ Further documents are listed in the continuation of Box C.
 ☒ See patent family annex.

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Date of the actual completion of the international search

06 January 2021

Date of mailing of the international search report

15 January 2021

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2020/120426

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

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Form PCT/ISA/210 (patent family annex) (January 2015)