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Hioki et al.

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(54) **ELECTROMAGNETIC FORMING METHOD**

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PCT Pub. Date: **Sep. 6, 2019**

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B21D 39/06 (2006.01)
B21D 39/08 (2006.01)

(52) **U.S. Cl.**
CPC ***B21D 26/14*** (2013.01); ***B21D 39/06*** (2013.01); ***B21D 39/08*** (2013.01)

(58) **Field of Classification Search**
CPC B21D 26/00; B21D 26/14; B21D 26/031; B21D 26/033; B21D 26/047; B21D 39/08; B21D 39/06
See application file for complete search history.

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(57) **ABSTRACT**

An electromagnetic forming method includes: a step of setting pipe periphery members at plural positions along an axial direction of a pipe material; a step of setting a coil unit on a side of one end, in the axial direction, of the pipe material, the coil unit including a conductor wound portion, conductor extension portions, and a resin-made conductor support portion; a step of setting a support member on a side of the other end, in the axial direction, of the pipe material; a coil unit holding step; a coil setting step; and a swaging step. The coil setting step and the swaging step are performed in this order at each of the plural positions of the pipe material while the coil unit is kept held by the support member.

20 Claims, 27 Drawing Sheets

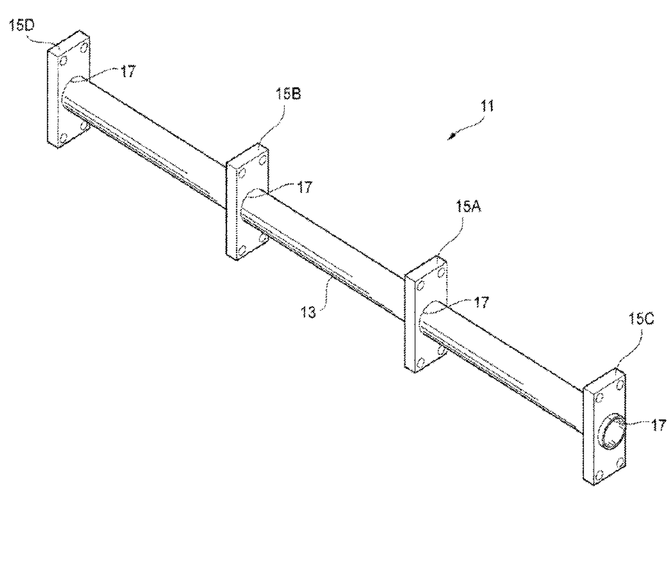


FIG. 1

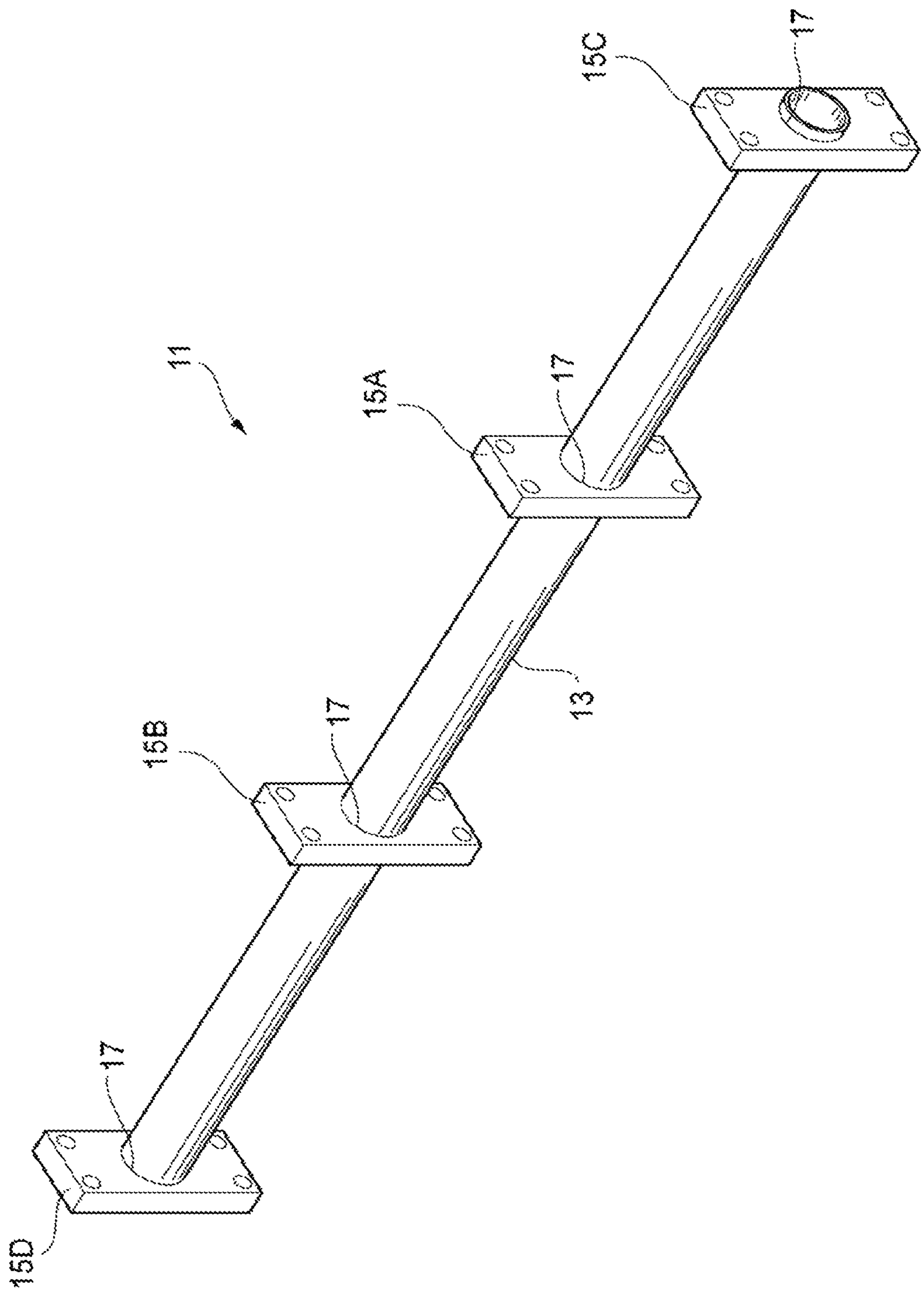
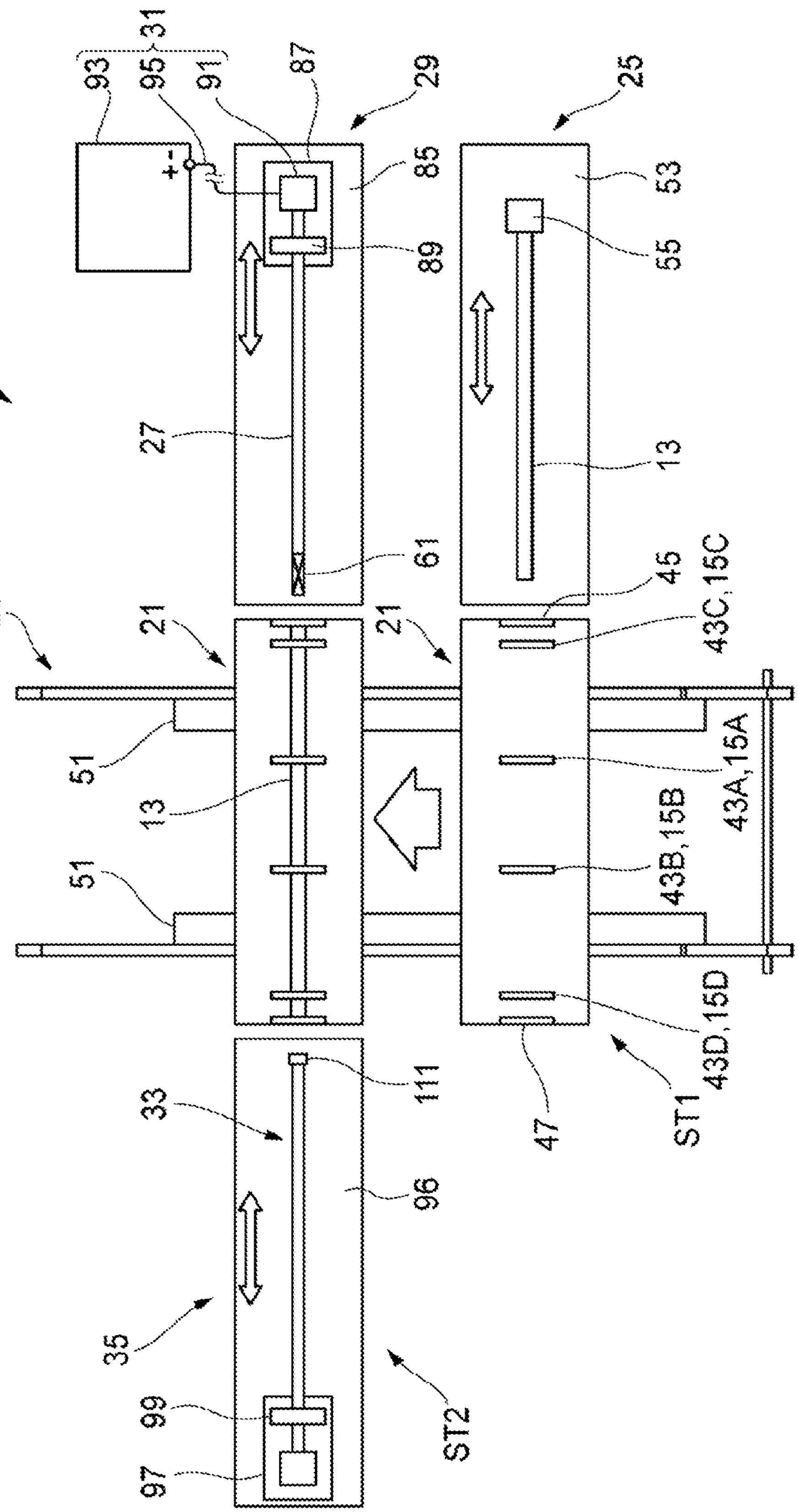


FIG. 2



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61
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43C,15C
51
13
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43B,15B
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43D,15D
111
33
47
ST1
96
35
99
97
ST2

FIG. 3

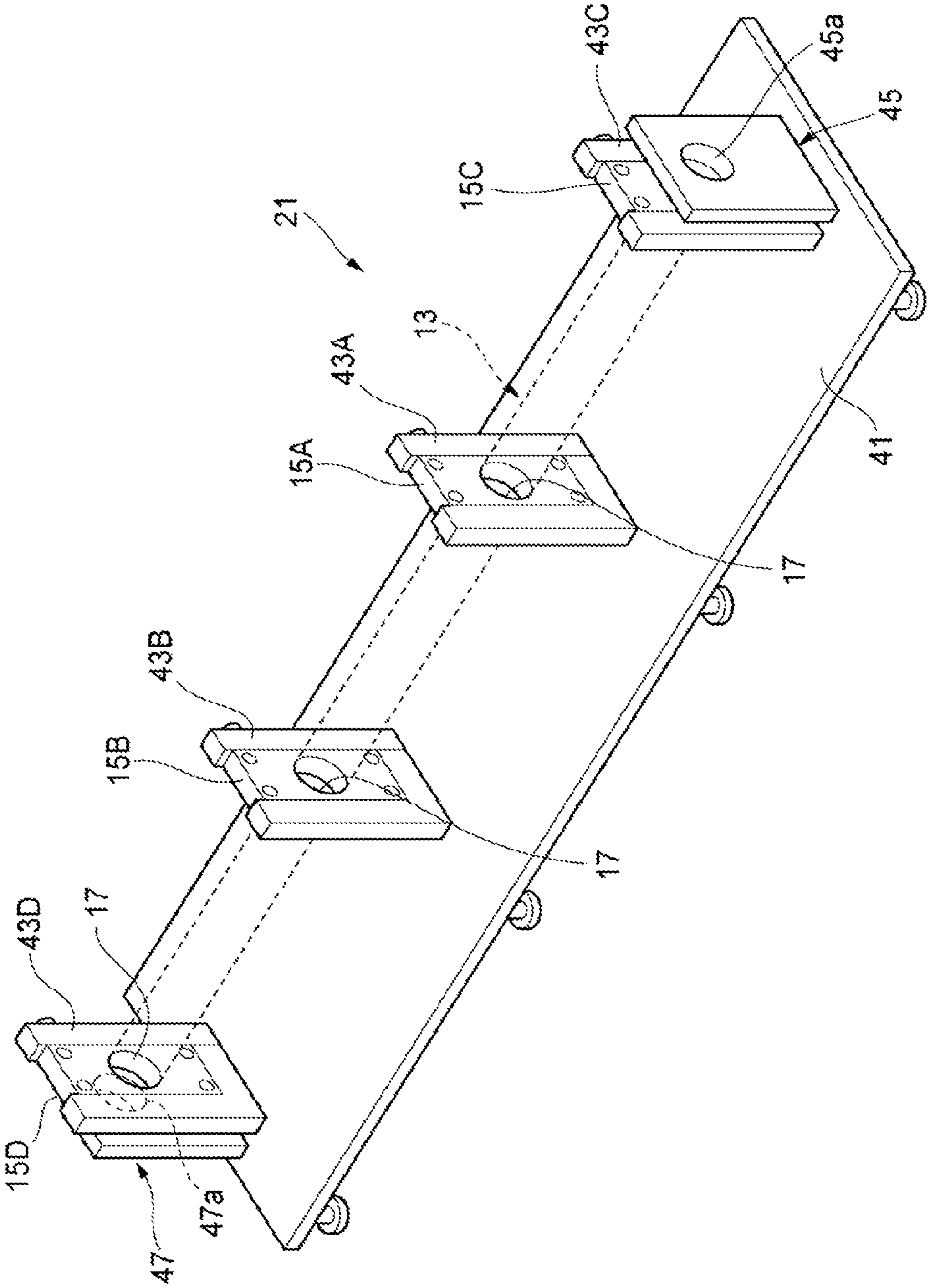


FIG. 4

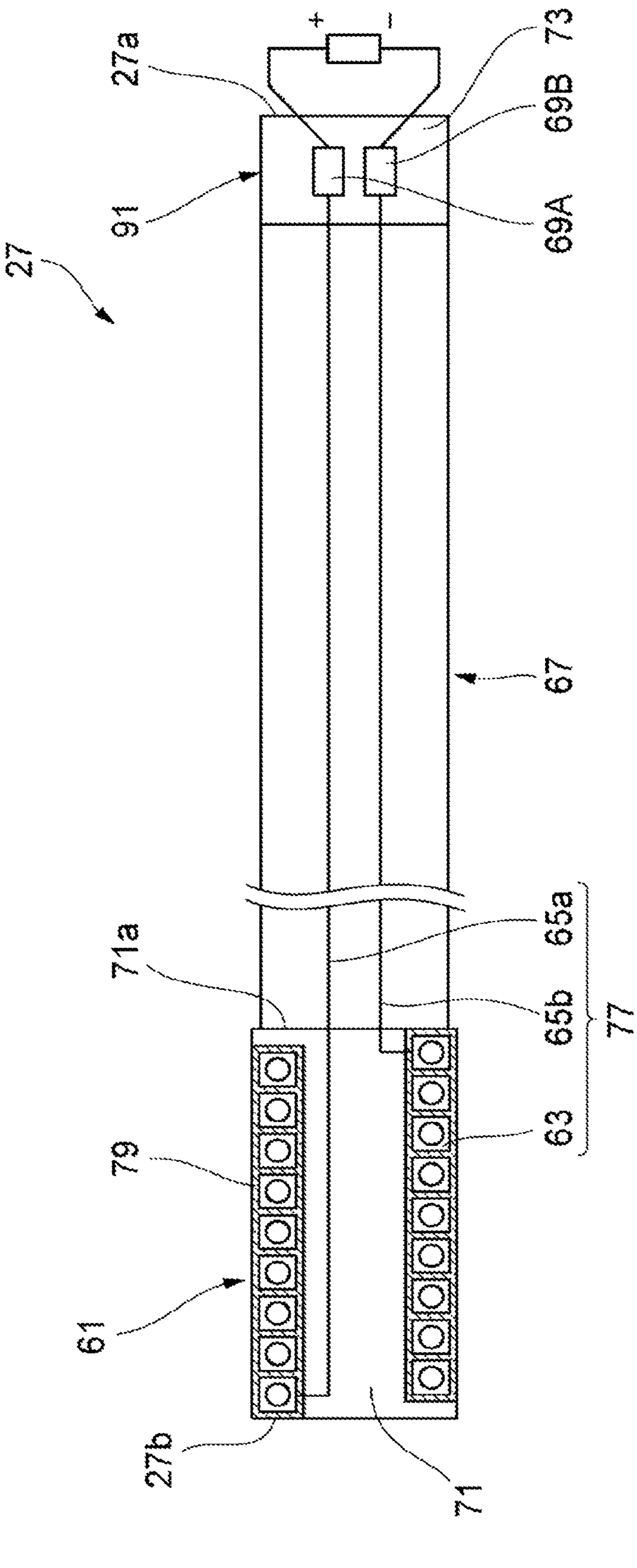
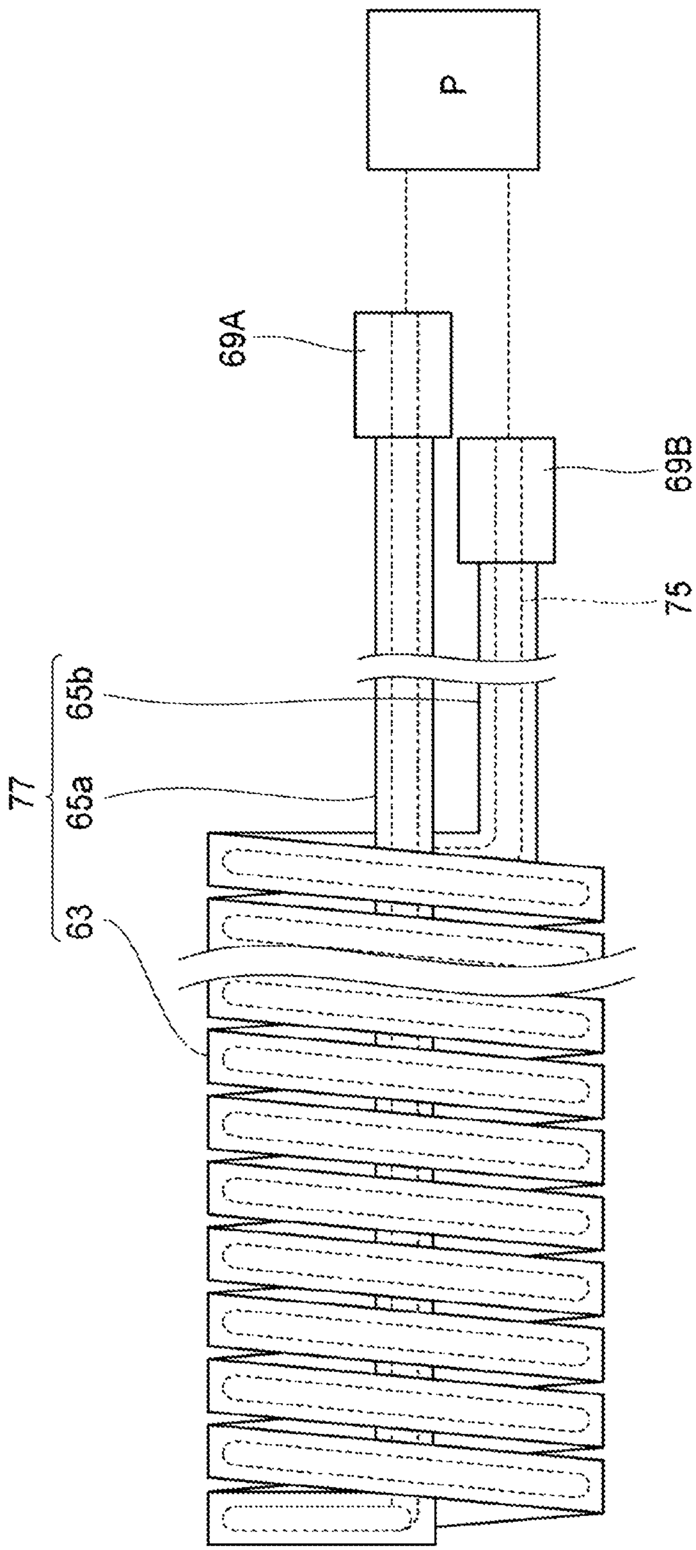


FIG. 5



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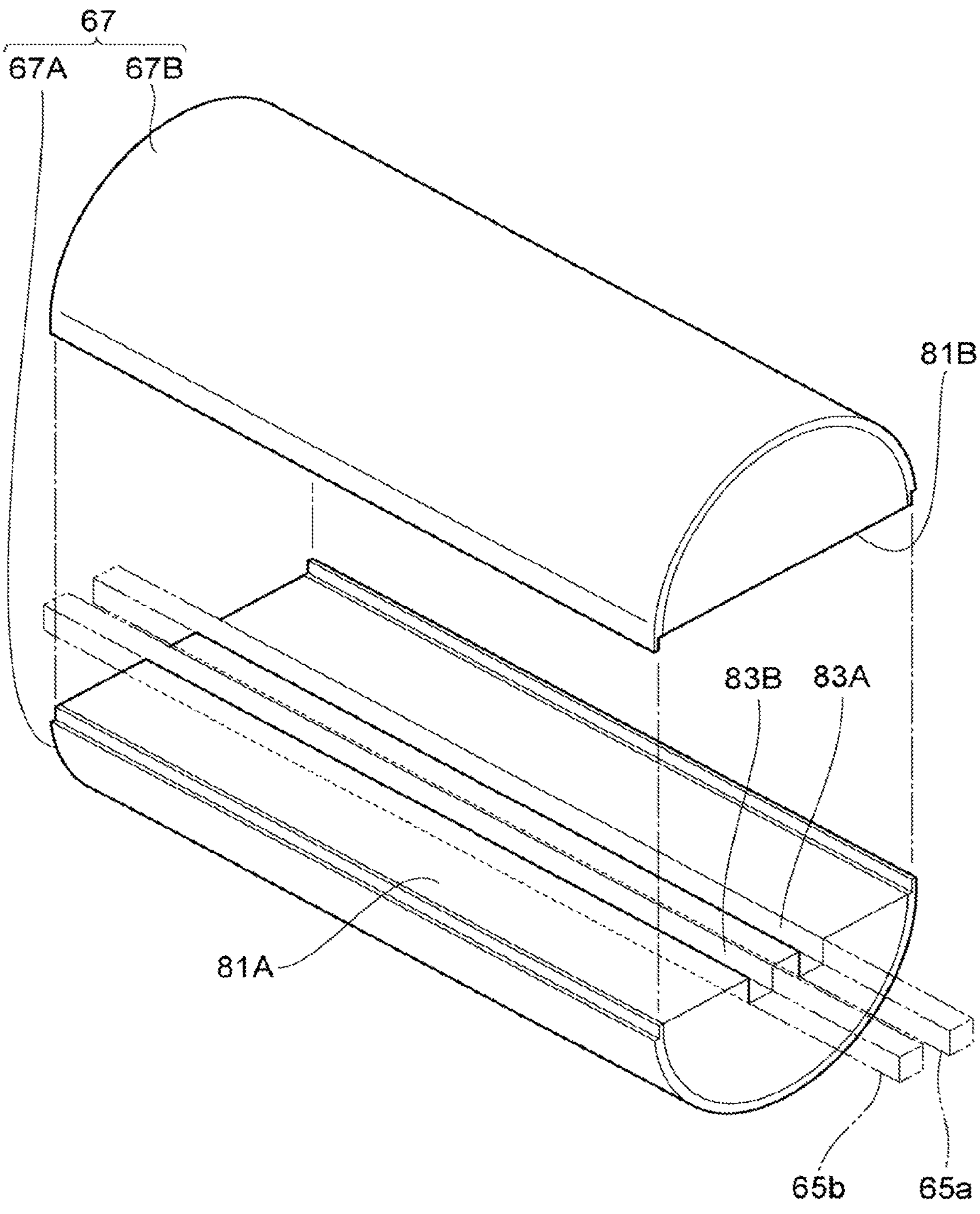

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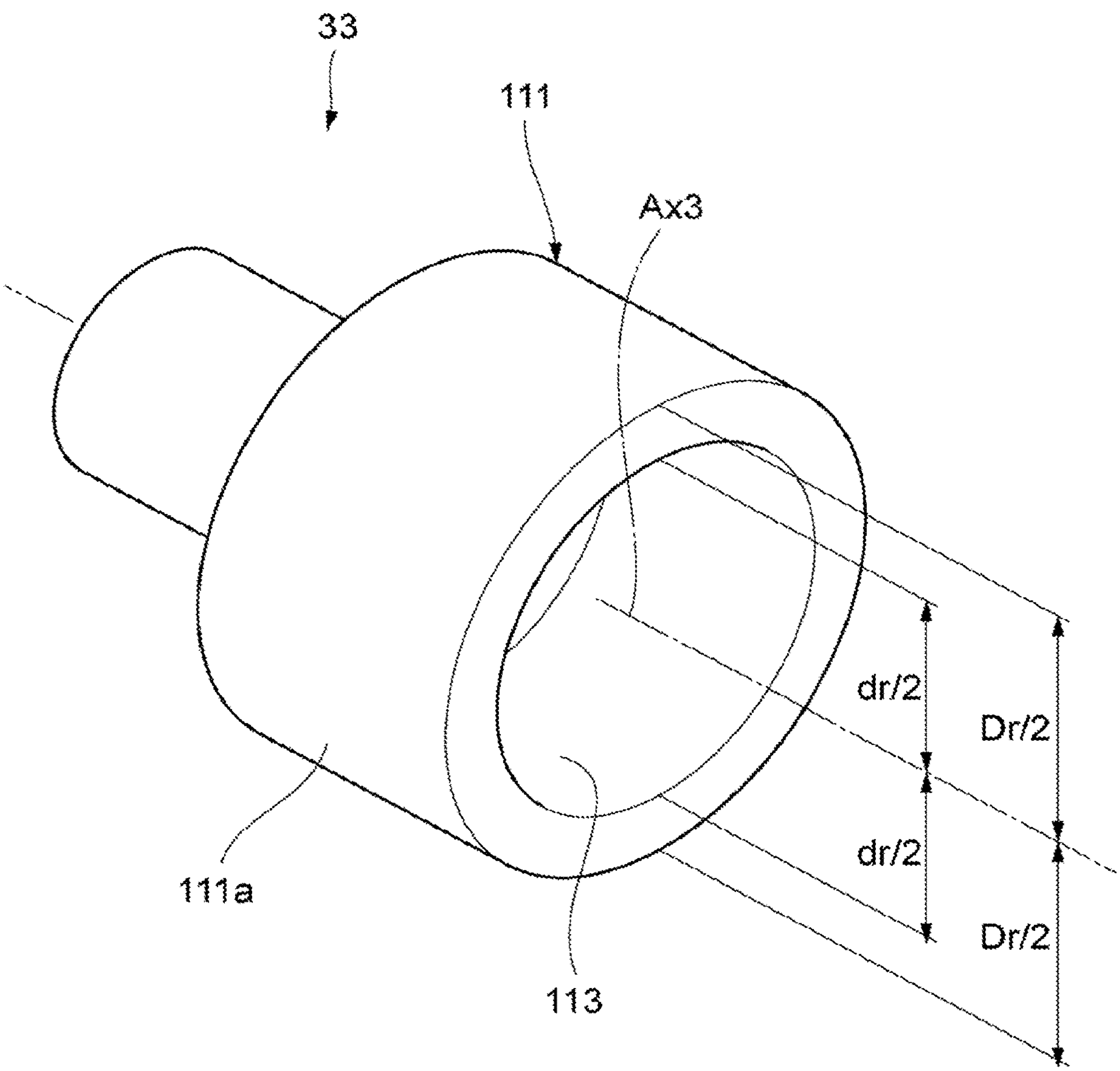
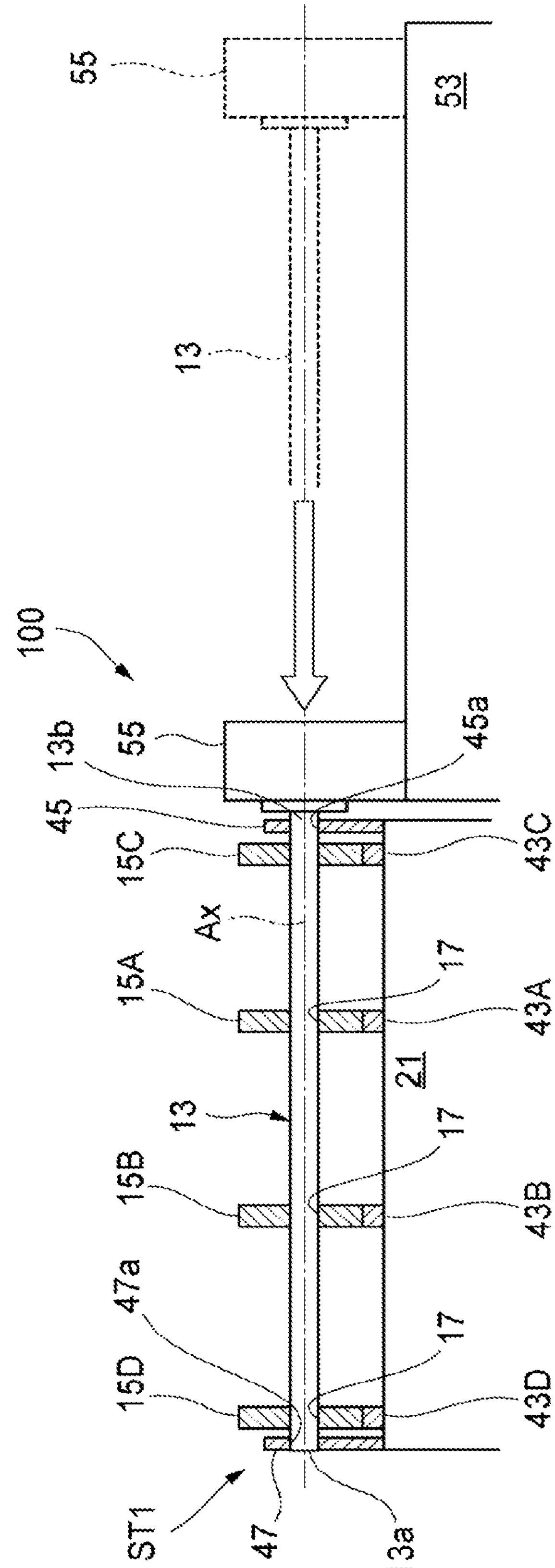


FIG. 8



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53
13
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13b
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15C
43C
Ax
15A
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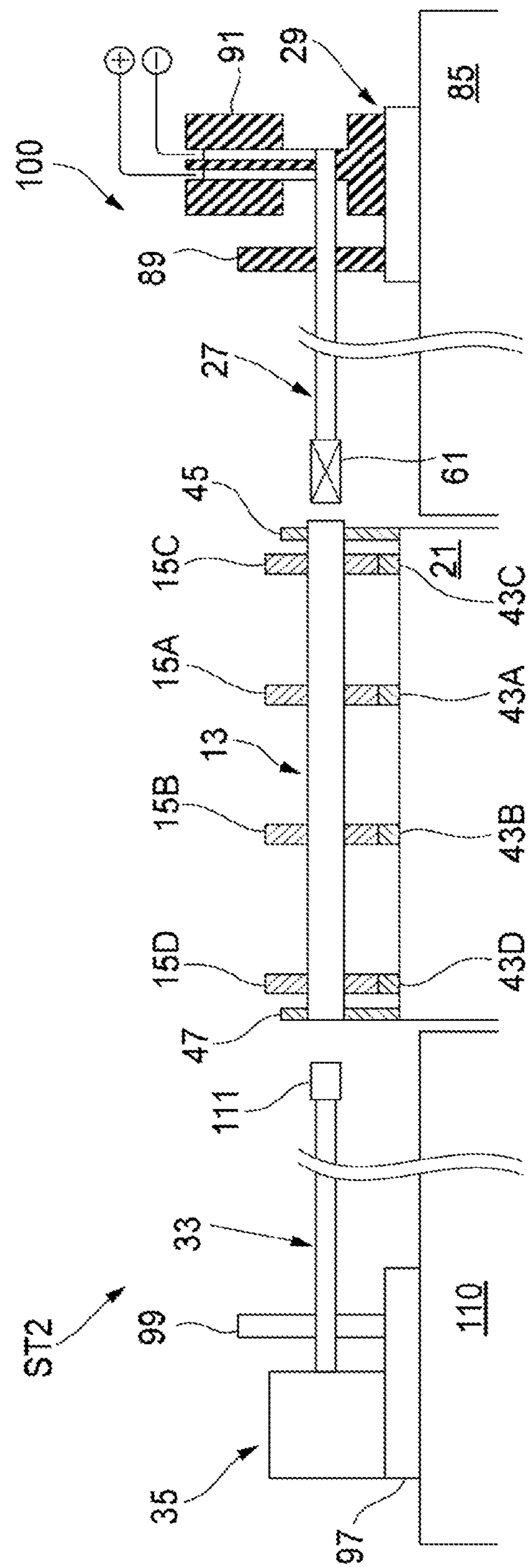
15B
43B
47a
17
15D
43D
ST1
47
13a

FIG. 9A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ST2
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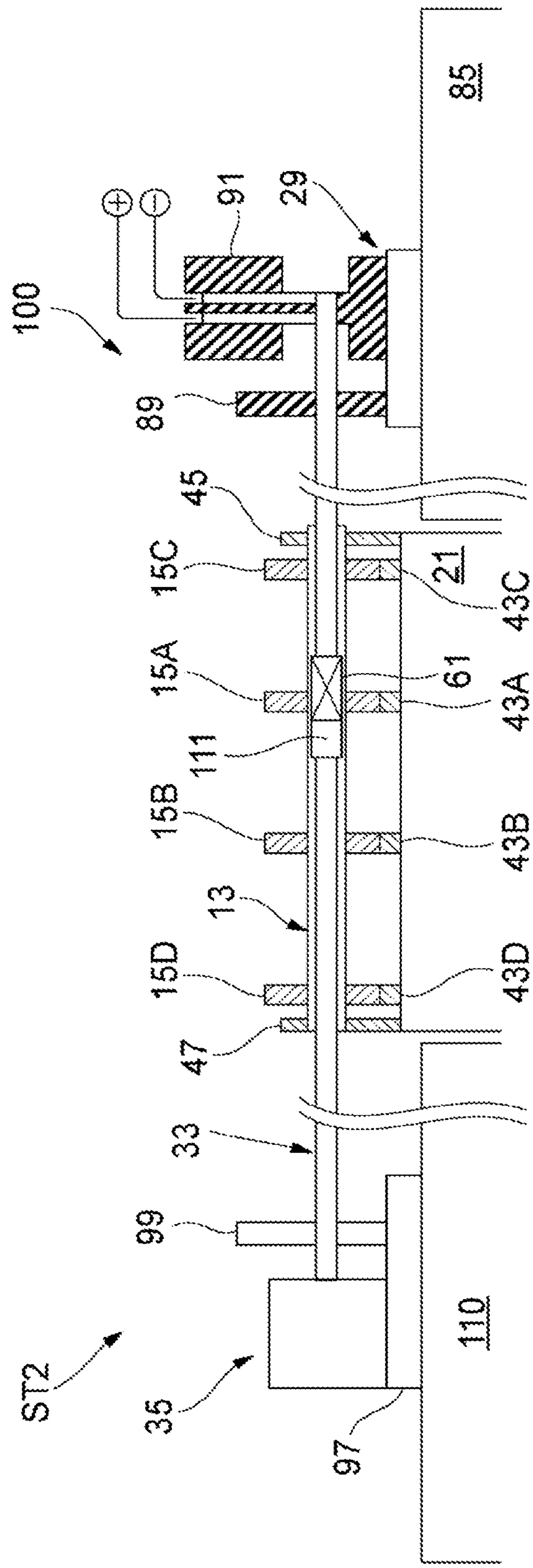
110
35
97

FIG. 9B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ST2
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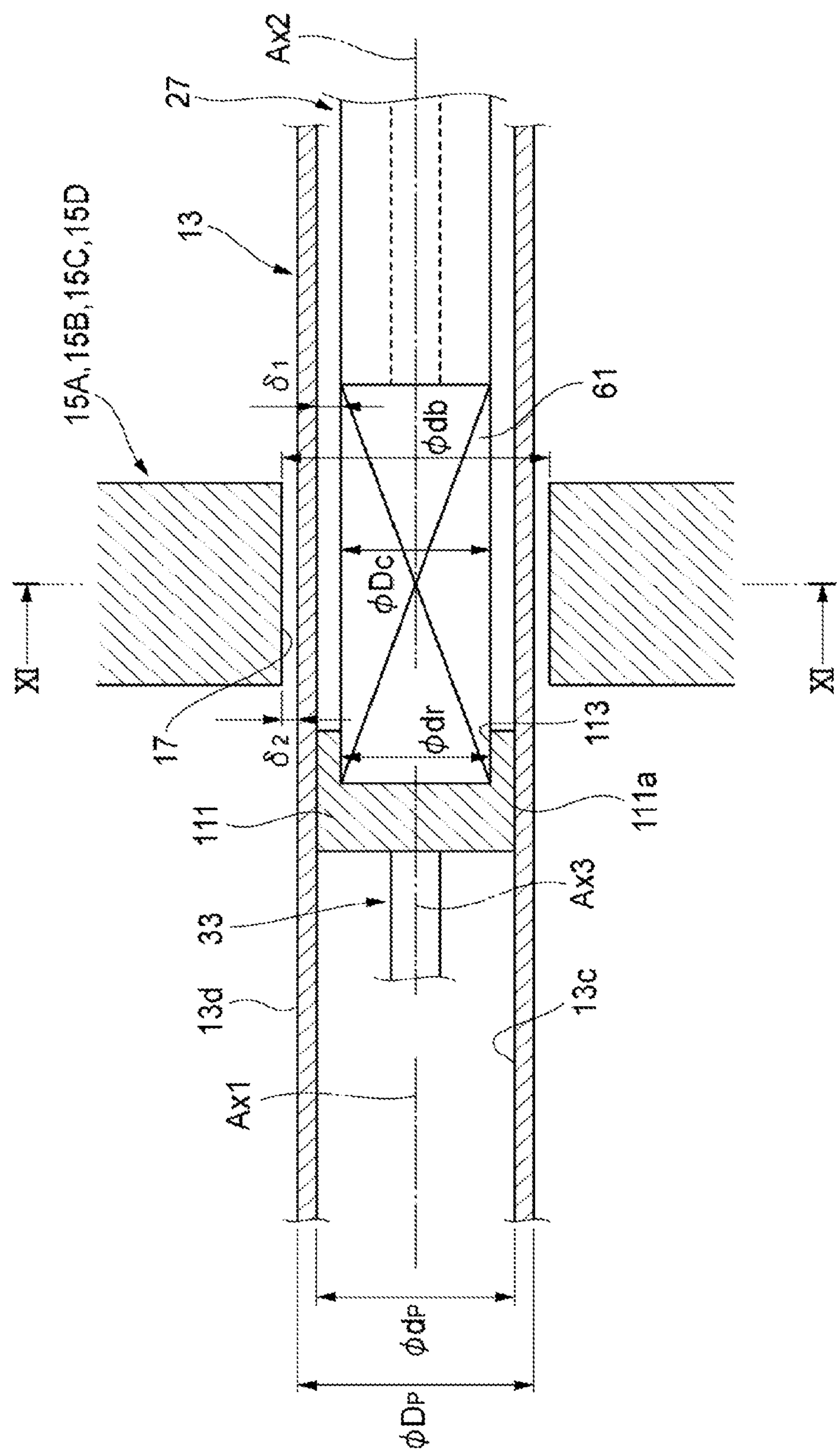
FIG. 10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φdb
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φDc
XI
XI
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δ2
φdr
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111a
111
33
Ax3
13d
13c
Ax1
φdP
φDP

FIG. 11

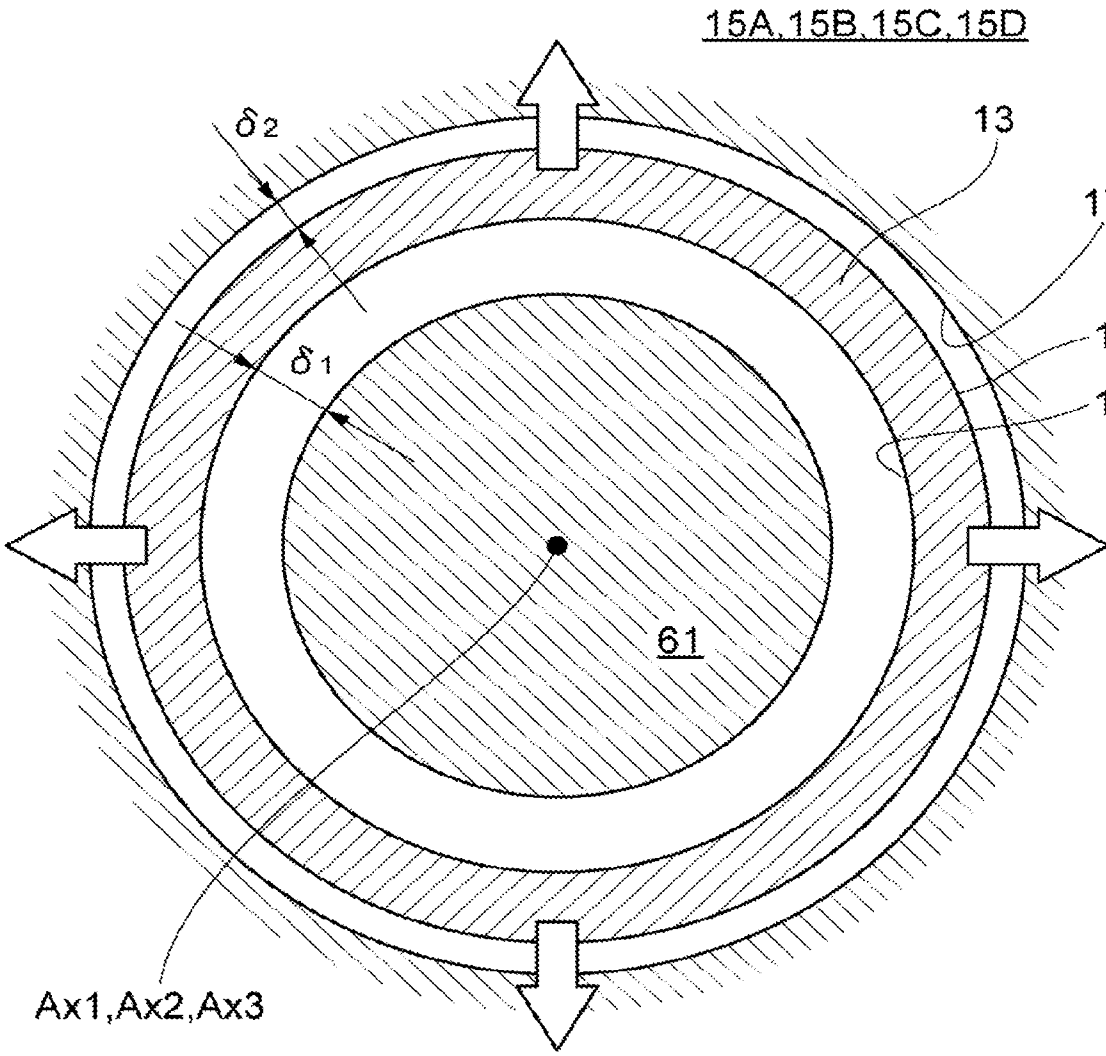


FIG. 12

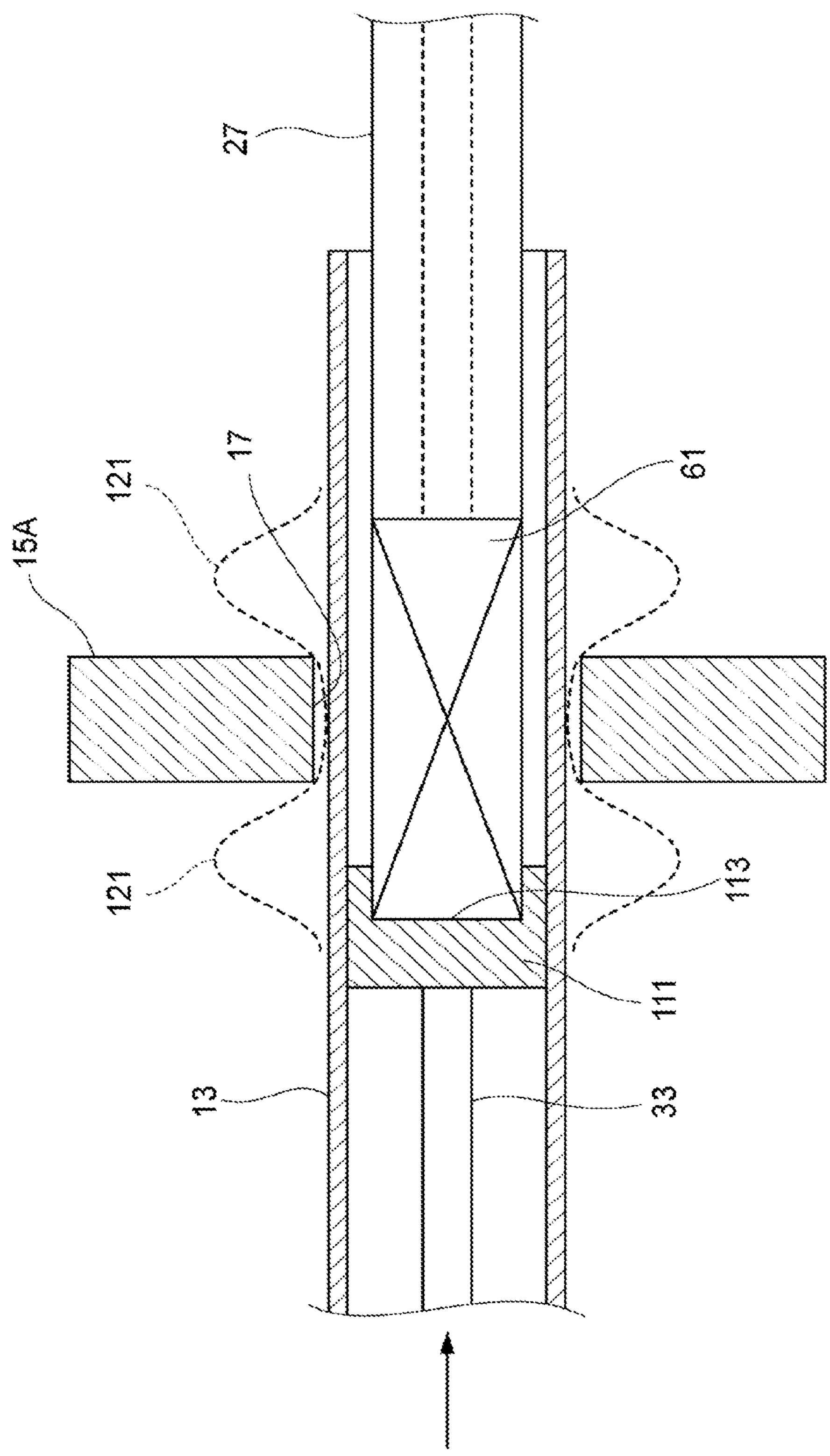


FIG. 13

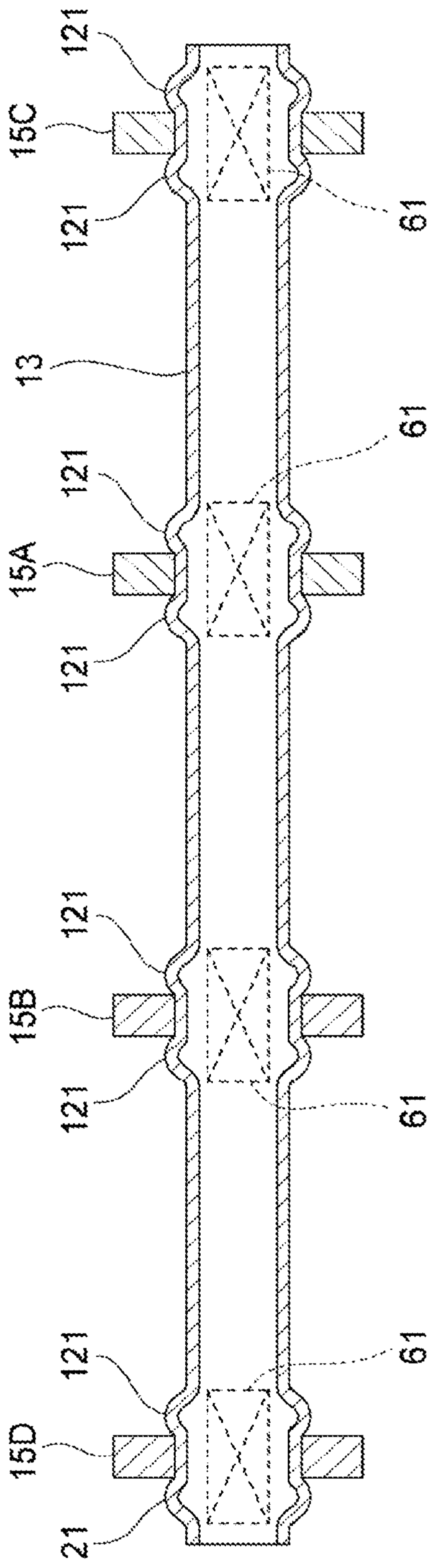


FIG. 14A

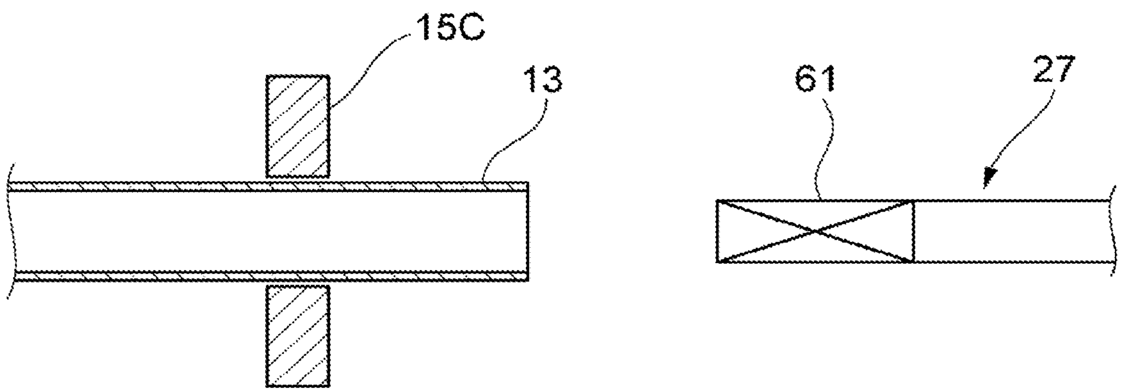


FIG. 14B

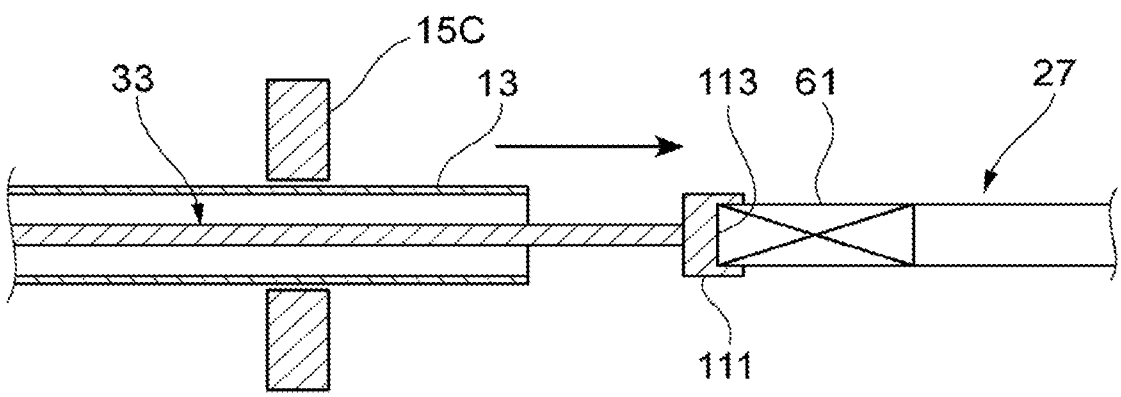


FIG. 14C

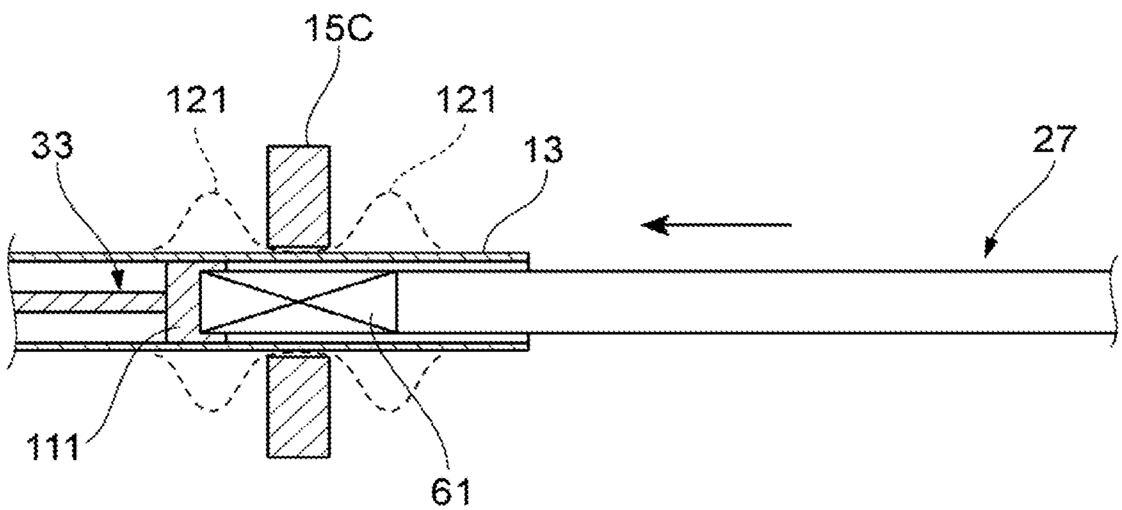
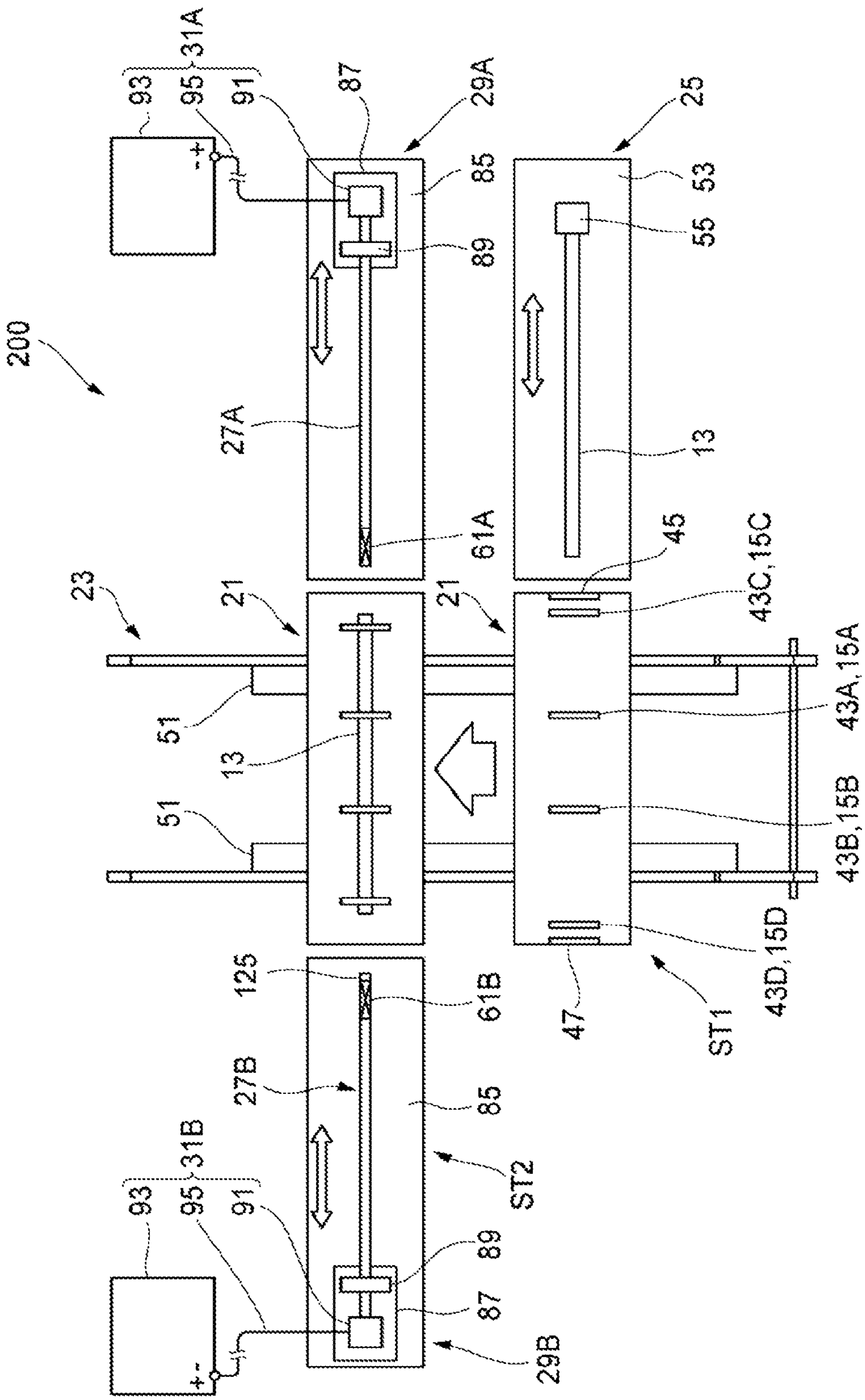


FIG. 15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43B,15B
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ST1
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ST2
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31B
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29B

FIG. 16

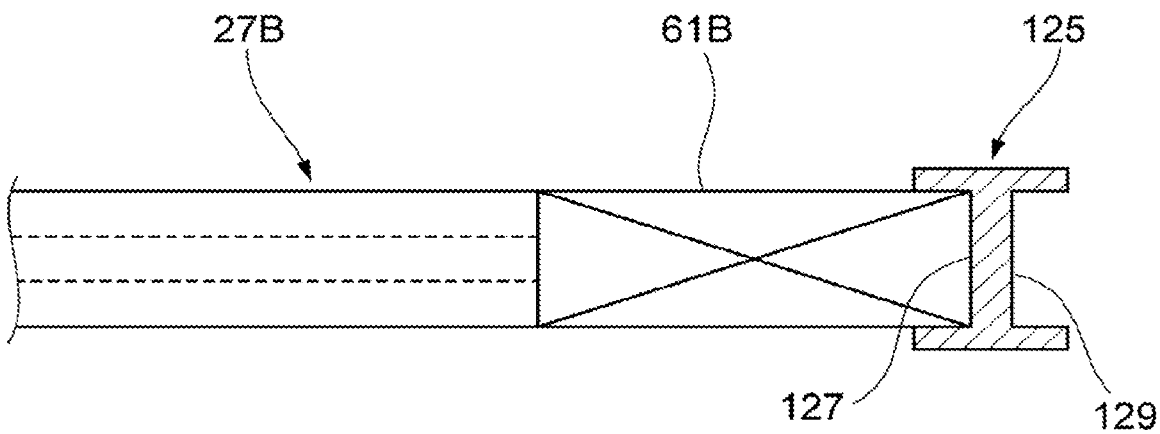


FIG. 17

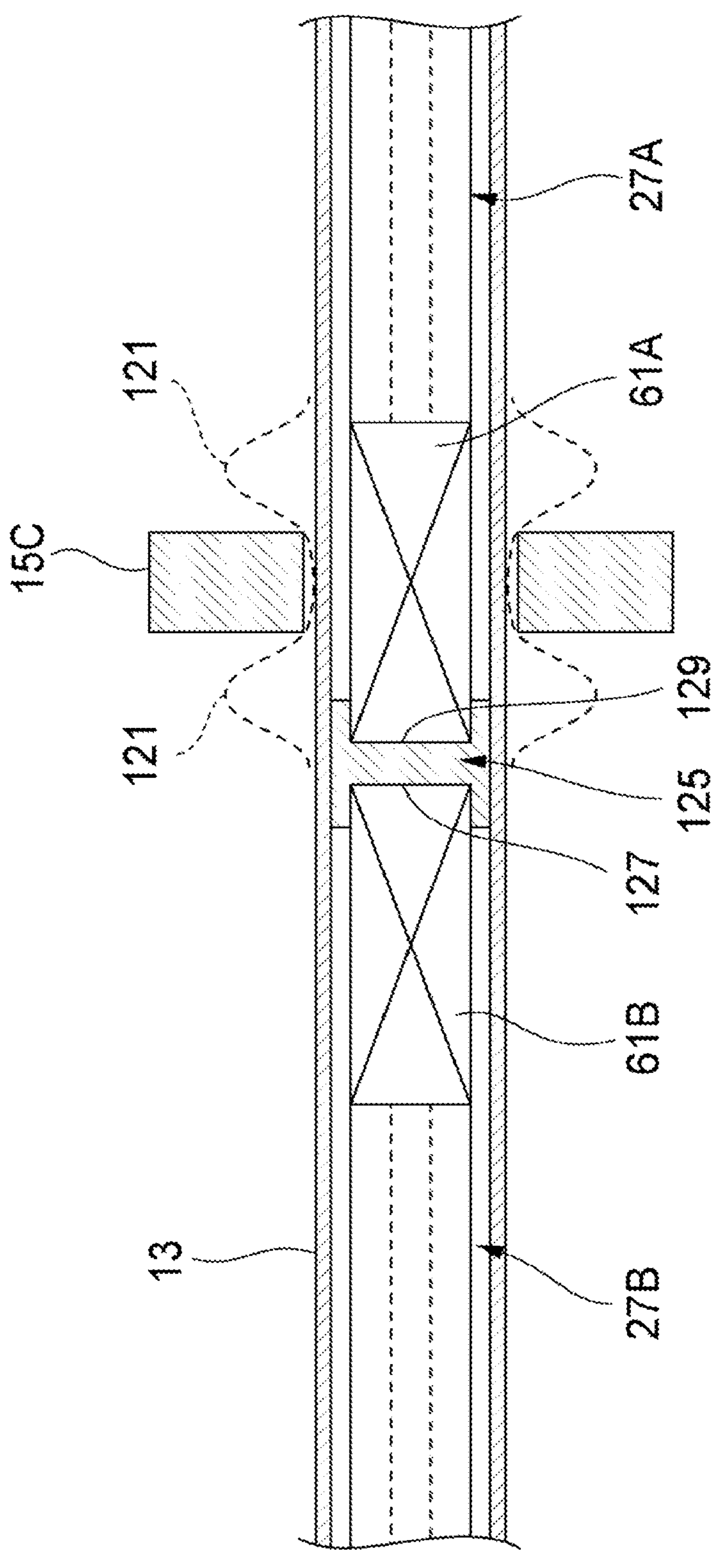
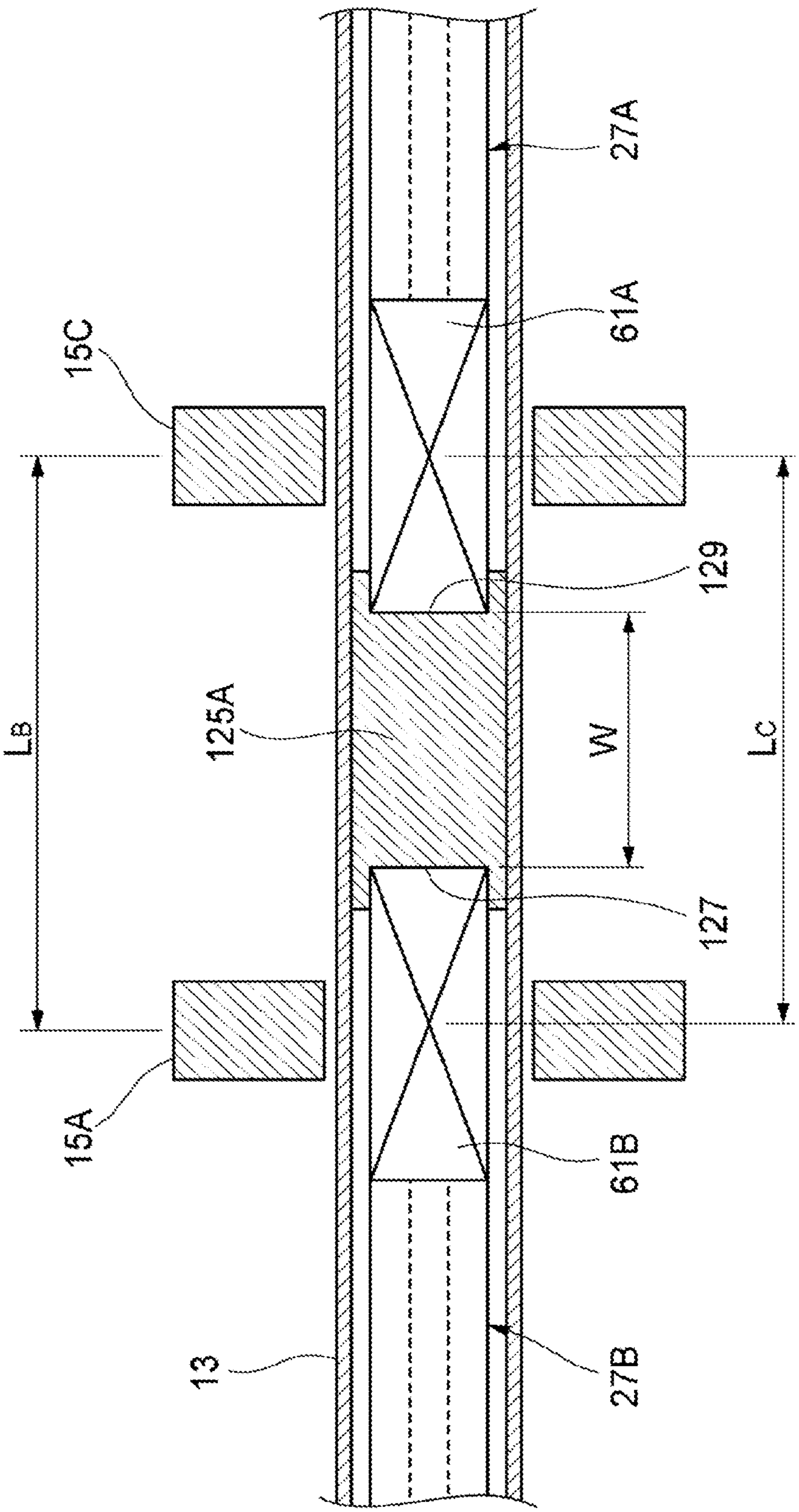
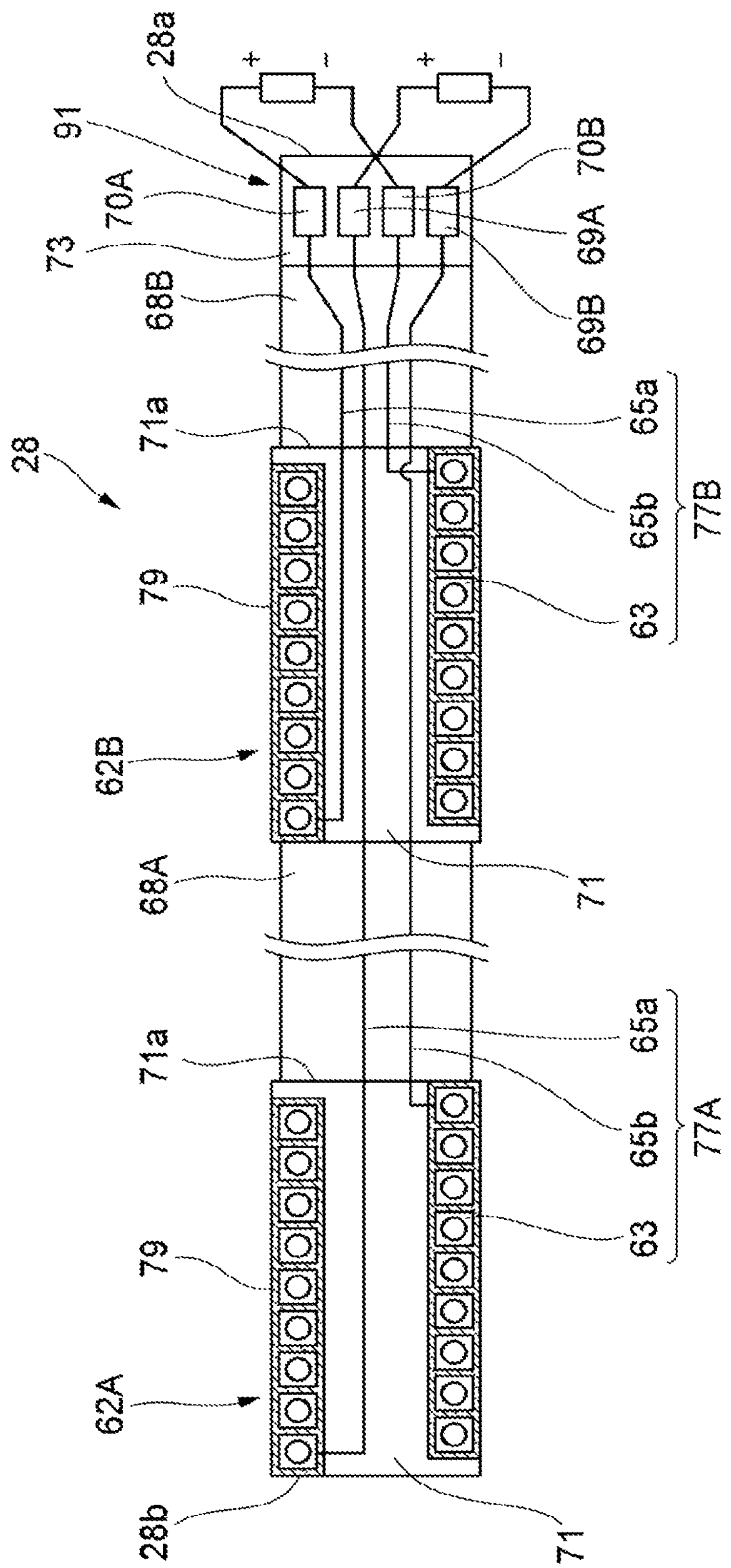


FIG. 18

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65b
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28b
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+
-
+
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FIG. 19

FIG. 20A

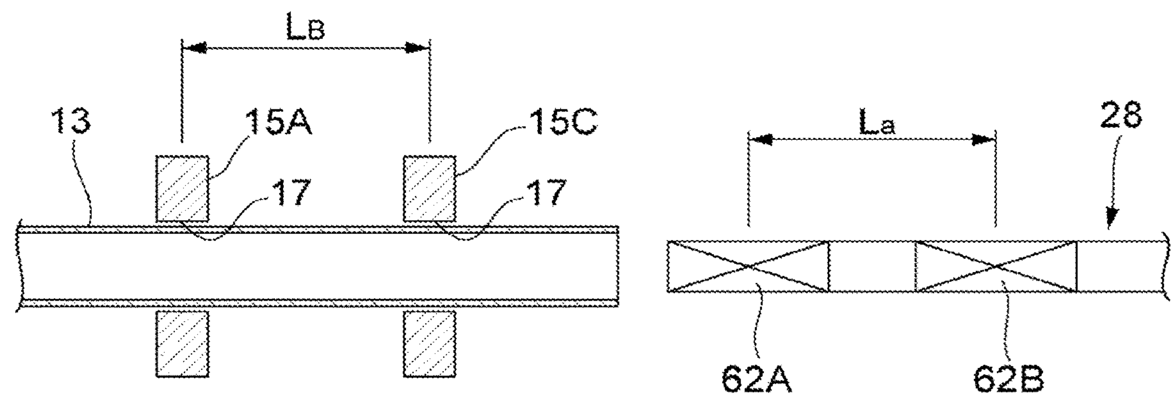


FIG. 20B

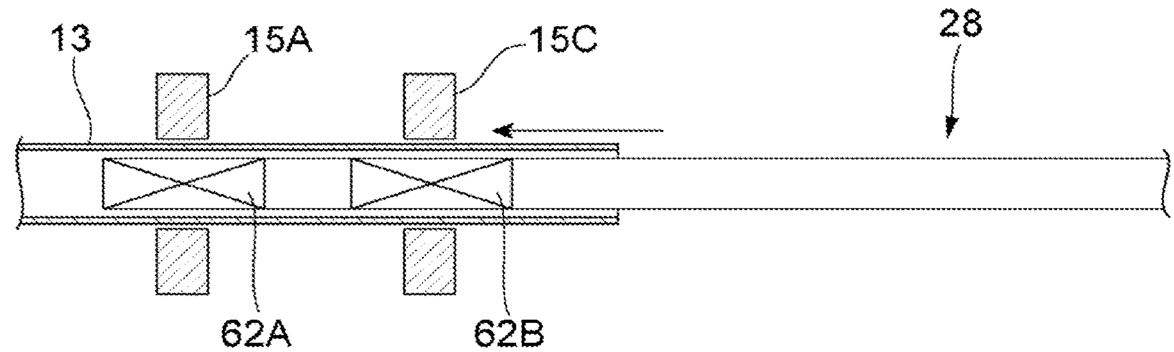


FIG. 20C

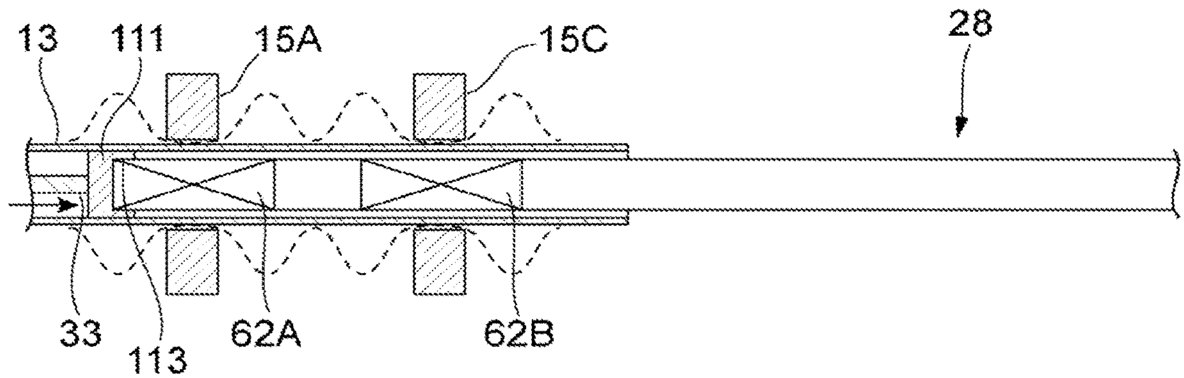


FIG. 21

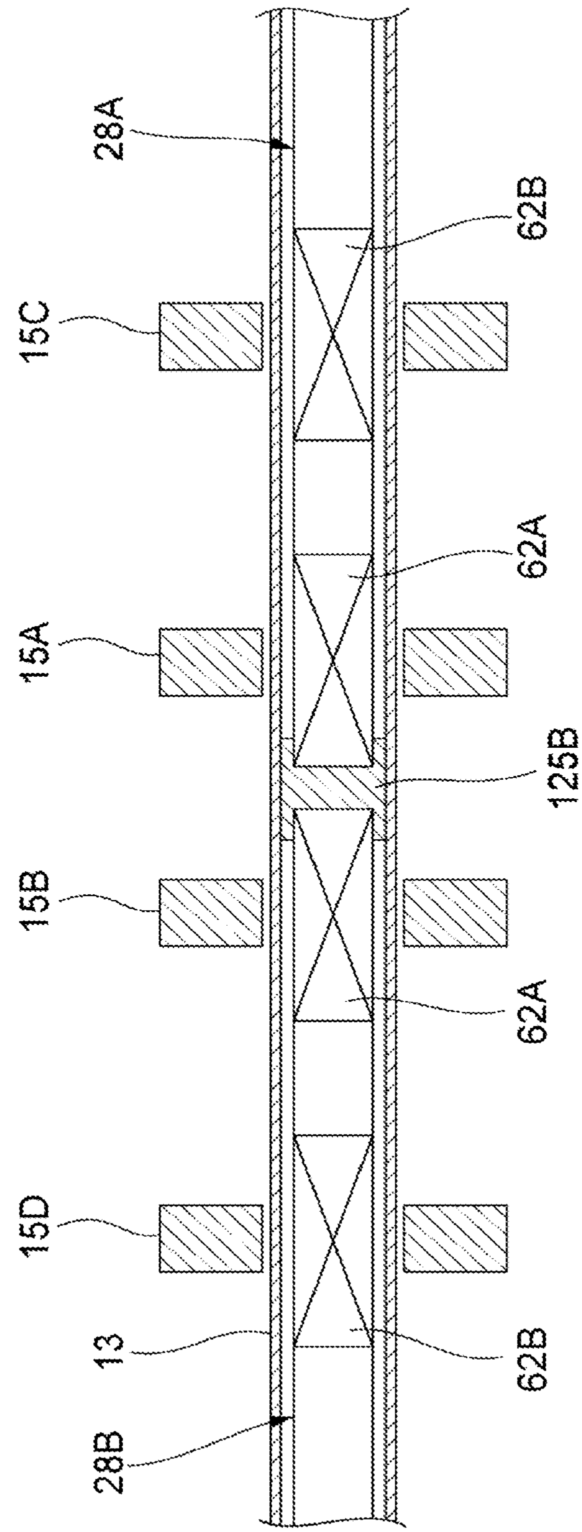


FIG. 22

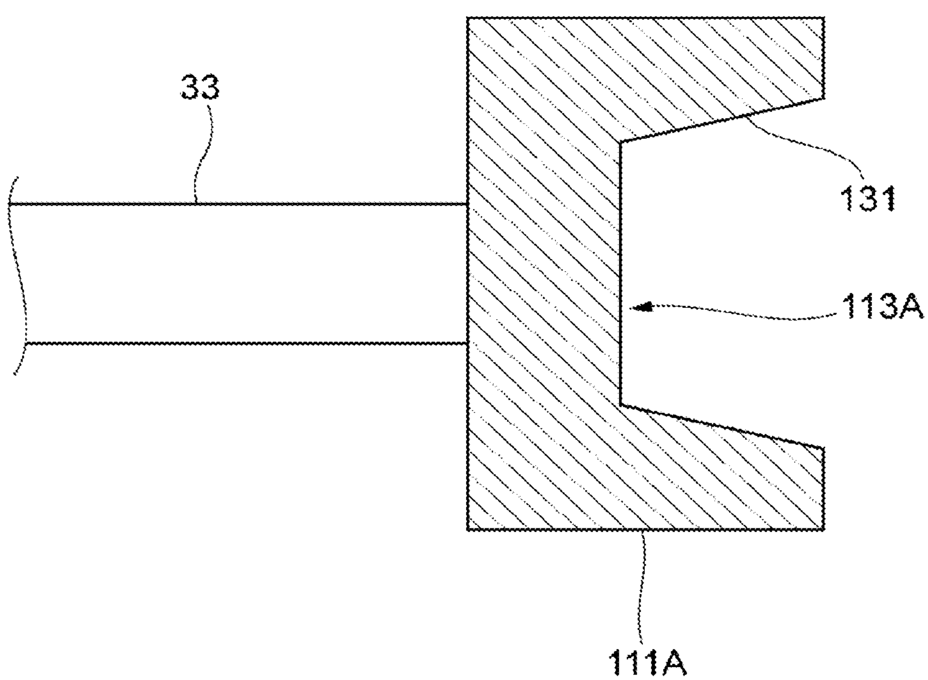


FIG. 23A

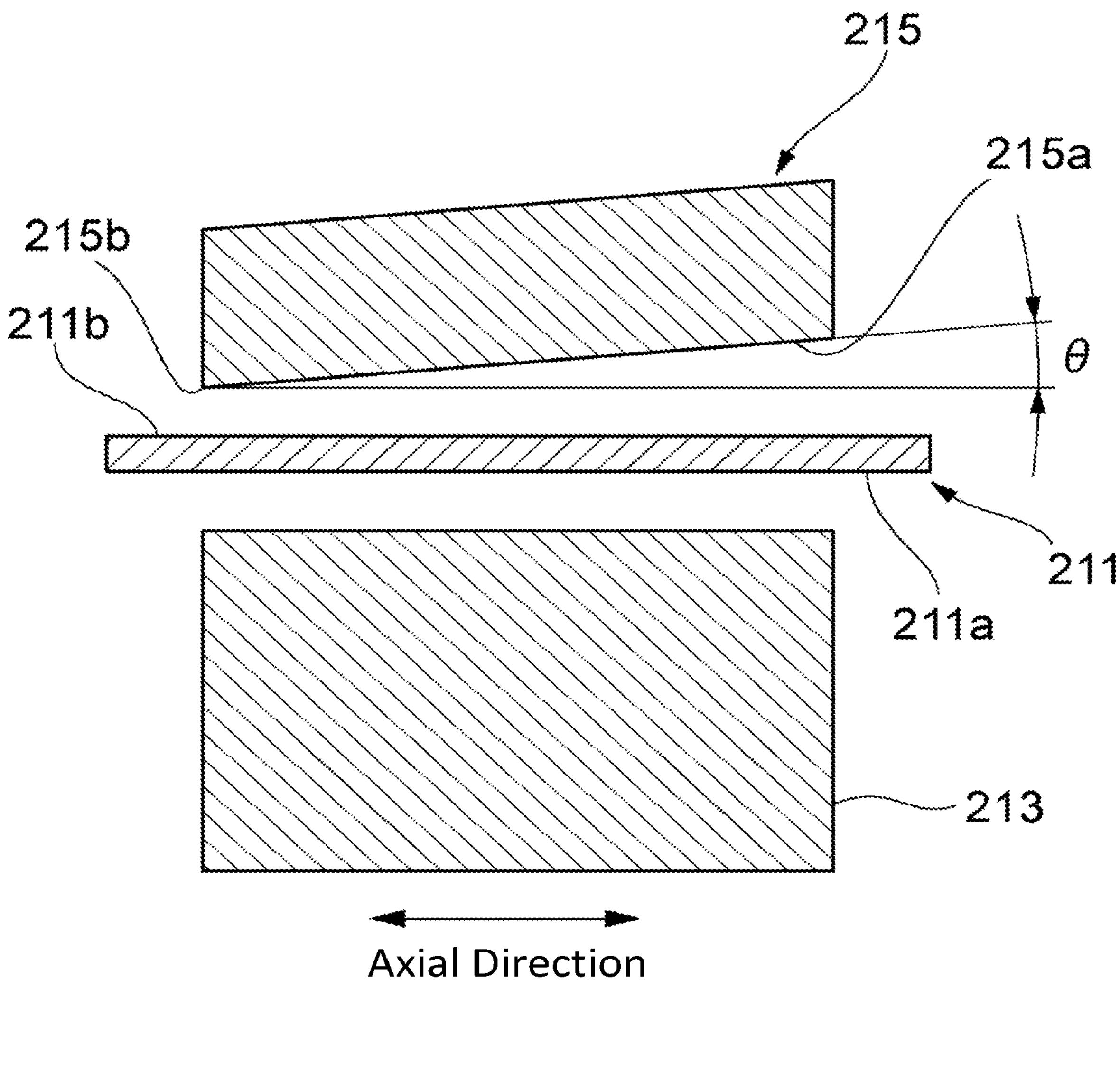


FIG. 23B

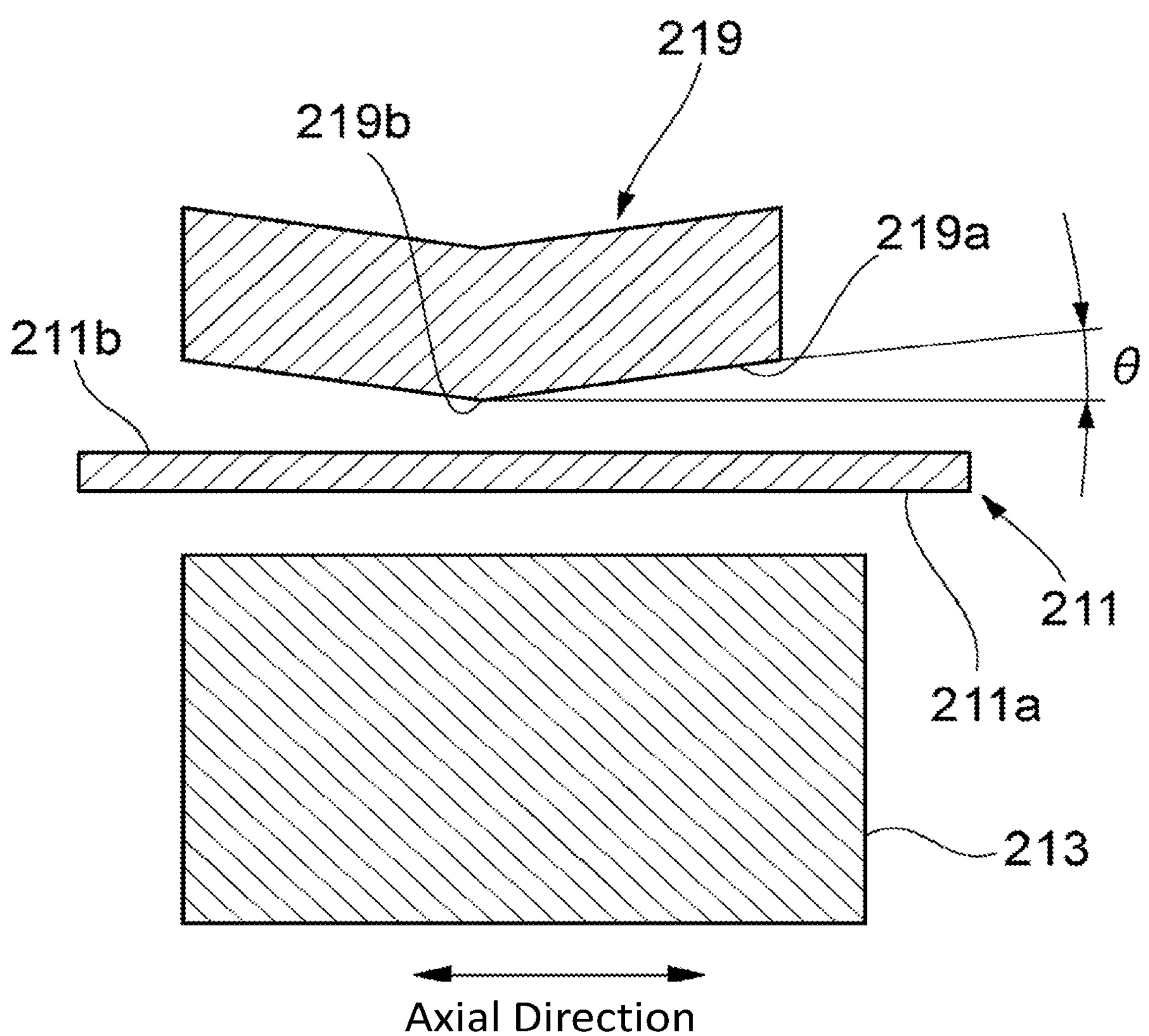


FIG. 24A

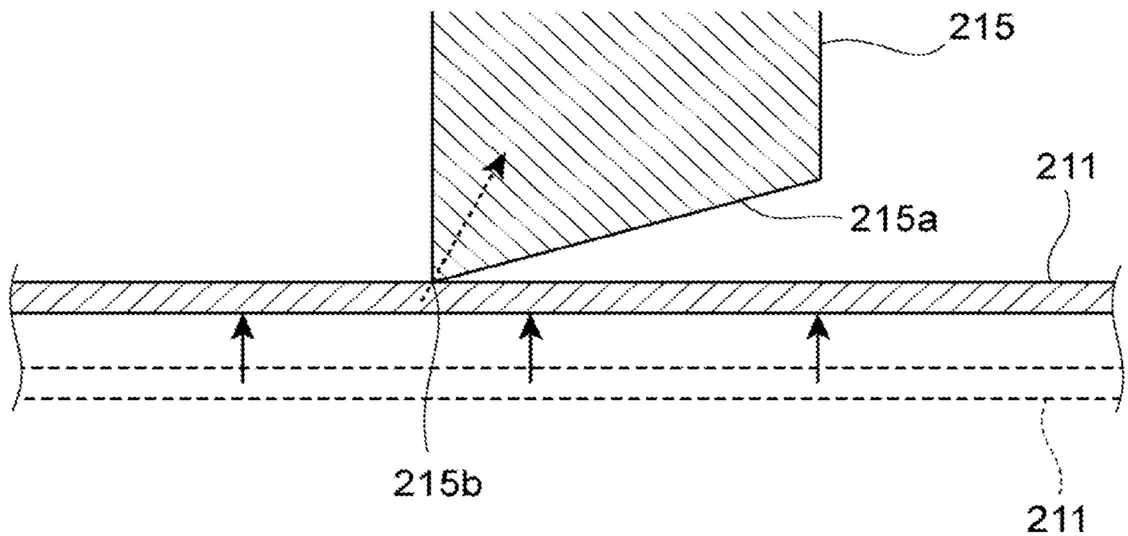
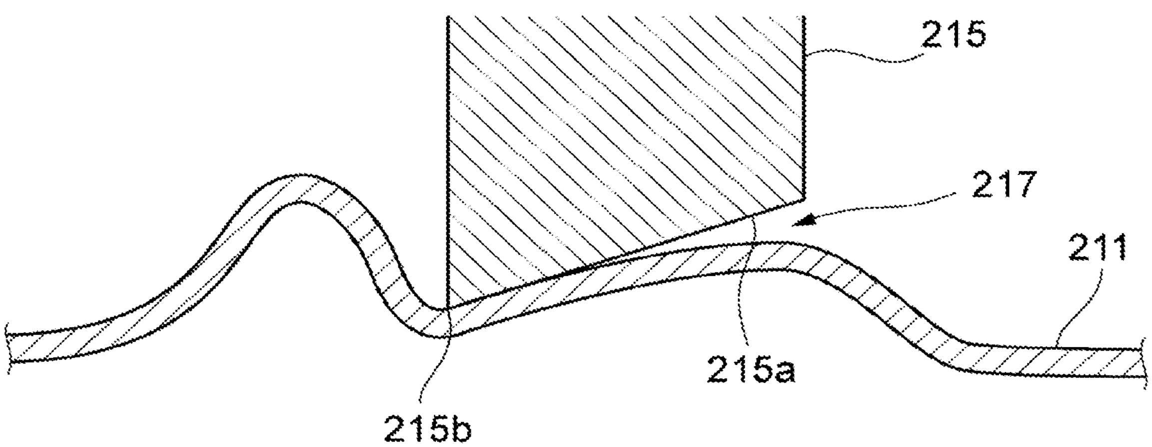


FIG. 24B



ELECTROMAGNETIC FORMING METHOD

TECHNICAL FIELD

The present invention relates to an electromagnetic forming method for swaging a pipe material onto pipe periphery members disposed outside the outer circumferential surface of the pipe material by expanding the pipe material by electromagnetic formation.

BACKGROUND ART

Many steel members are used in automobiles from the viewpoints of mechanical strength, cost, welding workability, etc. To meet the recent requirement of increase in fuel efficiency, some steel members have been replaced by lighter members and it has been studied to apply such lighter members to not only panel members but also frame members. Although frame members are typically manufactured by various manufacturing methods such as pressing, welding, and casting, they can also be manufactured through application of electromagnetic formation. For example, a method of disposing plural pipe periphery members such as brackets outside the outer circumferential surface of a long pipe material and fixing the pipe material onto the pipe periphery members through swaging by expanding the pipe material by electromagnetic formation is suggested (Patent Literature 1).

In electromagnetic formation, a target material to be subjected to formation is set in the vicinity of an inductor (coil) and energy charged in a capacitor is applied to the coil in the form of a large pulse current in a very short time of several milliseconds or less. As a result, an induction current flows through the target material to generate Lorentz force, thereby expanding the target material. Such fixing by swaging using electromagnetic formation causes no thermal strain. Therefore, a structural body can be produced with high accuracy, as compared with a welding method

CITATION LIST

Patent Literature

Patent Literature 1: JP-A-2017-131959

SUMMARY OF INVENTION

Technical Problems

Incidentally, examples of frame members of an automobile include a reinforcement member such as an instrument panel reinforcement member. Typically, the instrument panel reinforcement member has relatively long axial length and is provided with pipe periphery members such as brackets for attachment of members at plural positions in its longitudinal direction.

In manufacturing such a component by electromagnetic formation, a coil unit having a forming coil is inserted into a pipe material and the forming coil is set at an axial position inside the pipe material where a bracket is disposed. In this state, a pulse current is applied to the forming coil. At this time, since the pipe material is long, off-centering tends to occur between the pipe material and the coil unit inserted in the pipe material and hence a variation is prone to occur in the swaging state of the expanded pipe material in its circumferential direction.

Furthermore, the arrangement relationship between a pipe material and a pipe periphery member also influences a swaging result.

Each of FIG. **23**A and FIG. **23**B is a sectional view of essential parts of respective members in the case where a forming coil **213** is set so as to face the inner circumferential surface **211***a* of a pipe material **211**, a pipe periphery member **215** is set so as to face the outer circumferential surface **211***b* of the pipe material **211**, and the pipe material **211** is expanded by electromagnetic formation.

As shown in FIG. **23**A, in the case where the surface **215***a*, which faces the pipe material **211**, of the pipe periphery member **215** is inclined from the axial direction of the pipe material **211** (tapered) by an angle θ, when the pipe material **211** is expanded by electromagnetic formation, first, as shown in FIG. **24**A, the pipe material **211** touches a minimum diameter portion **215***b* of the inner circumferential surface of the pipe periphery member **215**. Then eddy current induced in the pipe material **211** flows to the side of the pipe periphery member **215** via the minimum diameter portion **215***b* and the electromagnetic force acting on the pipe material **211** is weakened. As a result, as shown in FIG. **24**B, a difference occurs between expansion forces acting on the pipe material **211** at the two respective end portions, in the axial direction, of the pipe periphery member **215**. Then, the swaging may become weaker in a region **217** opposite to the minimum diameter portion **215***b* in the axial direction. In addition, in the case of a pipe periphery member **219** shown in FIG. **23**B in which a minimum diameter portion **219***b* exists at the center, in the axial direction, of a confronting surface **219***a* and portions located on the two respective sides of the minimum diameter portion **219***b* in the axial direction are tapered, the swaging of the pipe material **211** likewise tends to become weaker at two end portions, in the axial direction, of the pipe periphery member **219**. As described above, in the case where a long pipe material is subjected to electromagnetic formation, the location of the forming coil inserted in the pipe material and the shape of the surface, facing the pipe material, of a pipe periphery member influence a swaging result.

In view of the above, an object of the present invention is to provide an electromagnetic forming method capable of swaging a long pipe material to a pipe periphery member so as to perform a uniform swaging by positioning a forming coil accurately by preventing an off-centering of the pipe material and a coil unit.

Solution to Problem

The present invention includes the following configurations.

(1) An electromagnetic forming method, including:

a step of setting pipe periphery members at plural positions along an axial direction of a pipe material;

a step of setting a coil unit on a side of one end, in the axial direction, of the pipe material, the coil unit including a conductor wound portion, conductor extension portions, one end portion of which is connected to the conductor wound portion and which extend in a longitudinal direction, and a resin-made conductor support portion that is provided along the longitudinal direction and that supports at least the conductor extension portions;

a step of setting a support member on a side of the other end, in the axial direction, of the pipe material, in which at least a tip of the support member on a side of the pipe material is made of an insulator;

a coil unit holding step of causing the coil unit and the support member to butt against each other by relatively moving the coil unit and the support member to each other in the axial direction of the pipe material, thereby causing the tip portion of the support member to hold the coil unit coaxially;

a coil setting step of setting the conductor wound portion of the coil unit at a position inside the pipe material where the conductor wound portion overlaps with the pipe periphery member; and

a swaging step of fixing the pipe periphery member to the pipe material by expanding the pipe material by electromagnetic force generated by energizing the conductor wound portion of the coil unit,

in which the coil setting step and the swaging step are performed in this order at each of the plural positions of the pipe material while the coil unit is kept held by the support member.

(2) An electromagnetic forming method, including:

a step of setting pipe periphery members at plural positions along an axial direction of a pipe material;

a step of setting a pair of coil units on a side of one end and a side of the other end, in the axial direction, of the pipe material, each of the coil units including a conductor wound portion, conductor extension portions, one end portion of which is connected to the conductor wound portion and which extend in a longitudinal direction, and a resin-made conductor support portion that is provided along the longitudinal direction and that supports at least the conductor extension portions;

a coil unit holding step of causing the pair of coil units to butt against each other by relatively moving the coil units to each other in the axial direction of the pipe material, thereby causing a tip portion of a support member to hold a tip portion of the coil unit which faces the support member coaxially, the support member being provided at an insertion-side tip of at least one of the coil units and at least two end portions of the support member in the axial direction being made of an insulator;

a coil setting step of setting the conductor wound portion of the coil unit at a position inside the pipe material where the conductor wound portion overlaps with the pipe periphery member; and

a swaging step of fixing the pipe periphery member to the pipe material by expanding the pipe material by electromagnetic force generated by energizing the conductor wound portion of the coil unit set at an axial position of the pipe periphery member,

in which the coil setting step and the swaging step are performed in this order at each of the plural positions of the pipe material while the coil unit is kept held by the support member.

Advantageous Effects of Invention

In the present invention, an off-centering of a pipe material and a coil unit can be prevented and a forming coil can be accurately positioned. As a result, a long pipe material can be swaged to a pipe periphery member so as to perform uniform swaging.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a perspective view schematically showing an appearance of a formed body produced by electromagnetic formation.

FIG. **2** is a schematic plan view of an electromagnetic forming machine.

FIG. **3** is a perspective view of a jig plate.

FIG. **4** is a schematic configuration view of a coil unit.

FIG. **5** is a schematic view for showing a sole configuration of a conductor used in the coil unit.

FIG. **6** is an exploded perspective view of a part of the conductor support portion.

FIG. **7** is an enlarged perspective view of a coil holding portion which is provided at the tip of a support rod.

FIG. **8** is a process explanation view for illustrating a pipe insertion process of inserting a pipe material into through-holes of brackets held on a jig plate in a pipe insertion stage.

FIG. **9**A is a process explanation view for illustrating, step by step, an expansion process of inserting the coil unit and the support rod into the pipe material supported on the jig plate and expanding the pipe material.

FIG. **9**B is another process explanation view for illustrating, step by step, the expansion process of inserting the coil unit and the support rod into the pipe material supported on the jig plate and expanding the pipe material.

FIG. **10** is a sectional view for showing a state that a coil portion is held by the coil holding portion inside the pipe material.

FIG. **11** is a schematic sectional view taken along line XI-XI in FIG. **10**.

FIG. **12** is a schematic structure view for showing how electromagnetic formation is performed on the pipe material by the coil portion.

FIG. **13** is a schematic sectional view for showing a state after the electromagnetic formation on the pipe material.

FIG. **14**A is a process explanation view for illustrating the procedure of a coil unit holding step and a coil moving step of a second electromagnetic forming method.

FIG. **14**B is another process explanation view for illustrating the procedure of the coil unit holding step and the coil moving step of the second electromagnetic forming method.

FIG. **14**C is a further process explanation view for illustrating the procedure of the coil unit holding step and the coil moving step of the second electromagnetic forming method.

FIG. **15** is a schematic plan view of an electromagnetic forming machine to perform a third electromagnetic forming method.

FIG. **16** is a schematic enlarged view of an insertion-side tip portion of a coil unit.

FIG. **17** is a schematic structure view for illustrating how electromagnetic formation is performed on a pipe material by a coil portion of the electromagnetic forming machine shown in FIG. **15**.

FIG. **18** is a schematic structure view for illustrating how electromagnetic formation is performed on a pipe material using a coil holding portion whose axial length is adjusted.

FIG. **19** is a schematic configuration view of a coil unit used in a fourth electromagnetic forming method.

FIG. **20**A is a process explanation view for illustrating the procedure of a coil moving step for moving the coil unit used in the fourth electromagnetic forming method, a coil unit holding step, and a swaging step.

FIG. **20**B is a process explanation view for illustrating the procedure of the coil moving step for moving the coil unit used in the fourth electromagnetic forming method, the coil unit holding step, and the swaging step.

FIG. **20**C is a process explanation view for illustrating the procedure of the coil moving step for moving the coil unit used in the fourth electromagnetic forming method, the coil unit holding step, and the swaging step.

FIG. **21** is a process explanation view for illustrating how electromagnetic formation to form brackets together is performed by inserting a pair of coil units from the two ends, in the axial direction, of a pipe material.

FIG. **22** is a schematic sectional view for showing another example of engagement recess of a coil holding portion.

FIG. **23**A is a partial sectional view for showing how electromagnetic formation for a pipe material in a related art is performed.

FIG. **23**B is another partial sectional view for showing how the electromagnetic formation for the pipe material in a related art is performed.

FIG. **24**A is a schematic explanatory view for illustrating how the pipe material is expanded in the electromagnetic formation for the pipe material in a related art.

FIG. **24**B is another schematic explanatory view for illustrating how the pipe material is expanded in the conventional electromagnetic formation for the pipe material in a related art.

DESCRIPTION OF EMBODIMENTS

Embodiments of the present invention will be hereinafter described in detail with reference to the drawings. The embodiments described below will be directed to an example in which brackets for attachment of members are attached to an instrument panel reinforcement member having a long axial length by electromagnetic formation. However, the present invention is not limited to the case and can also be applied to cases where rigid bodies such as pipe periphery members are attached to a pipe material for any of other uses and any other kinds of a pipe material.

<Configuration of Formed Body>

FIG. **1** is a perspective view schematically showing an appearance of a formed body produced by electromagnetic formation.

A formed body **11** has an aluminum pipe material (hereinafter abbreviated as a "pipe material") **13**, brackets **15**A and **15**B provided on the outer circumferential surfaces of intermediate portions, in the axial direction, of the pipe material **13**, and brackets **15**C and **15**D provided on the outer circumferential surfaces of two respective end portions of the pipe material **13**. Each of the brackets **15**A, **15**B, **15**C, and **15**D (pipe periphery members) has a circular through-hole **17** and is fixed to the pipe material **13** having a circular cross section in a state where the pipe material **13** is inserted through each of the through-hole **17**.

The pipe material **13** can be manufactured by extrusion molding or welding of a plate material, and is not limited to a circular pipe (the example shown). The pipe material **13** may be a tetragonal pipe having a square or rectangular cross section, a hexagonal pipe having a hexagonal cross section, or an octagonal pipe having an octagonal cross section. Preferable examples of the material of the pipe material **13** include an aluminum alloy (JIS 6000 series, JIS 7000 series, etc.). For example, a hollow pipe made of an aluminum alloy A6063 for extrusion can be used as the pipe material **13**.

The brackets **15**A, **15**B, **15**C, and **15**D (hereinafter also referred to together as "brackets **15**") are rigid members configured to be integrated with the pipe material **13** in the formation. The brackets **15** are metal members made of steel of, for example, the JIS standard SS400, an aluminum extrusion material (e.g., 6063T5 (JIS H 4100)), an aluminum casting (e.g., AC4CH AI (JIS H 5202)), or the like, and can be made of a resin injection-molded material in some use conditions of the formed body **11**. The through-holes **17** of the brackets **15** are preferably similar to the sectional shape of the pipe material **13**. For example, the through-holes **17** are preferably circular in the case where the pipe material **13** is a circular pipe. The through-holes **17** are formed so as to have an inner diameter that is slightly larger than the outer diameter of the pipe material **13** before expansion by electromagnetic formation.

<Configuration of Electromagnetic Forming Machine>

Next, the configuration of an electromagnetic forming machine **100** for manufacturing a formed body **11** by swaging the pipe material **13** onto the brackets **15** by electromagnetic formation will be described.

FIG. **2** is a schematic plan view of the electromagnetic forming machine **100**.

The electromagnetic forming machine **100** is equipped with plural jig plates **21**, a jig plate conveying mechanism **23**, a pipe material insertion mechanism **25**, an electromagnetic formation coil unit **27**, a coil moving mechanism **29**, a current supply unit **31**, a support rod (support member) **33**, and a support rod moving mechanism **35** for moving the support rod **33** in the axial direction.

The electromagnetic forming machine **100** includes a pipe insertion stage ST**1** and a pipe expansion stage ST**2**, and operates roughly in the following manner. In the pipe insertion stage ST**1**, the pipe material **13** is transferred to a jig plate **21** by the pipe material insertion mechanism **25**. The jig plate conveying mechanism **23** conveys, to the pipe expansion stage ST**2**, a jig plate **21** to which the pipe material **13** has been transferred.

In the pipe expansion stage ST**2**, the coil unit **27** is inserted by the coil moving mechanism **29** into the pipe material **13** supported by the jig plate **21**. Furthermore, the support rod **33** is inserted by the support rod moving mechanism **35** into the pipe material **13** supported by the jig plate **21**. Then the coil unit **27** is energized by the current supply unit **31**, thereby expanding the pipe material **13** by electromagnetic formation. A formed body **11** as described above is thus manufactured.

Next, the individual units of the above-described electromagnetic forming machine **100** will be described in detail in order.

<Jig Plate>

FIG. **3** is a perspective view of a jig plate **21**.

The jig plate **21** is equipped with a substrate **41**, bracket holders **43**A, **43**B, **43**C, and **43**D fixed to the substrate **41**, and pipe material positioning members **45** and **47** respectively disposed outside the bracket holders **43**C and **43**D in the axial direction. The brackets **15**A, **15**B, **15**C, and **15**D to be supported by the bracket holders **43**A, **43**B, **43**C and **43**D, and the pipe material **13** (drawn by broken lines in the figure) to be inserted in the through-holes **17** of the respective brackets **15**A, **15**B, **15**C, and **15**D are also shown in FIG. **3**.

The top surface of the substrate **41**, which is a single steel material, is formed with an electrically insulating layer made of a phenol resin (Bakelite (registered trademark)) or the like. Since the substrate **41** has so high stiffness that a warp is prevented, the substrate **41** can hold, with a small bend, a long member having a long axial length as compared with the diameter such as the pipe material **13**. Furthermore, the presence of the electrically insulating layer prevents induction current induced in the pipe material **13** from flowing into the substrate **41**.

The bracket holder **43**A receives the bracket **15**A, and they are fastened by, for example, a toggle clamp (not shown). In this manner, the bracket **15**A is held in a state that the through-hole **17** is positioned at a predetermined position. Likewise, the bracket holders **43**B, **43**C, and **43**D position and hold the respective brackets **15**B, **15**C, and **15**D. Thus, all of the through-holes **17** of the brackets **15**A, **15**B, **15**C, and **15**D held by the respective bracket holders **43**A, **43**B, **43**C, and **43**D are disposed so as to have the common axis.

The pipe material positioning members **45** and **47** support the end portions of the pipe material **13** inserted in the through-holes **17** and position the pipe material **13** so that its center axis coincides with the center axes of the respective through-holes **17**. Thus, a radial gap that is uniform in the circumferential direction is formed between the outer circumferential surface of the pipe material **13** and the inner circumferential surface of the through-hole **17** of each bracket.

Although there are no particular limitations on the positioning mechanism of each of the pipe material positioning members **45** and **47**, it may be a chuck mechanism capable of moving and adjusting the end portion of the pipe material **13** in the horizontal and vertical directions. As another example, as shown in FIG. **3**, each of the pipe material positioning members **45** and **47** may be a plate member through which a guide hole **45***a* or **47***a* whose diameter is approximately the same as the outer diameter of the pipe material **13** is formed such that its center axis coincides with the center axis of the through-holes **17**. In either case, an adjustment can be made so that the outer circumferential surface of the pipe material **13** is made parallel with the inner circumferential surfaces of the through-holes **17** in a cross section taken along the axial direction of the pipe material **13**, preferably with an inclination of less than 3°, more preferably with an inclination of less than 1°. As long as the above two kinds of surfaces are within the above inclination range, the pipe material **13** can be swaged satisfactorily so as to be in close contact with the inner circumferential surfaces of the through-holes **17**.

<Jig Plate Conveying Mechanism>

The jig plate conveying mechanism **23** shown in FIG. **2** includes a pair of conveying rails **51** and a conveyor (not shown) which is disposed along the conveying rails **51** and in which a conveyor chain circulates. The jig plates **21** are mounted on the conveyor and conveyed by the conveying rails **51** by driving the conveyor chain. That is, the jig plate conveying mechanism **23** conveys each jig plate **21** along the conveying rails **51** from the pipe insertion stage ST**1** to the pipe expansion stage ST**2**.

<Pipe Insertion Mechanism>

The pipe material insertion mechanism **25** in the pipe insertion stage ST**1** shown in FIG. **2** includes a base **53** disposed on the side of one end (on the right side in FIG. **2**) of the jig plate **21** and a pipe insertion driving unit **55** provided on the base **53**.

The pipe insertion driving unit **55** that supports one end portion of the pipe material **13** by means of a chuck mechanism (not shown) moves the pipe material **13** toward the jig plate **21** in the direction of its pipe axis. As a result, the pipe material **13** is inserted into the through-holes **17** (see FIG. **3**) of the brackets **15**A, **15**B, **15**C, and **15**D held by the respective bracket holders **43**A, **43**B, **43**C, and **43**D.

The jig plate **21** of the jig plate conveying mechanism **23** and the base **53** are arranged such that their top surfaces are parallel with each other. Thus, when the pipe material **13** is moved by the pipe insertion driving unit **55**, the pipe material **13** is inserted into the through-holes **17** of the brackets **15**A, **15**B, **15**C, and **15**D supported by the jig plate **21** side while being kept coaxial with the through-holes **17**. Further, the pipe material **13** is guided by the through-holes **17** and positioned by the pipe material positioning members **45** and **47** so as to be coaxial with the through-holes **17**. As a result, the pipe material **13** is set so as to be coaxial with the through-holes **17** with high accuracy.

<Coil Unit>

The coil unit **27** is set on one side (right side in FIG. **2**) of the jig plate **21** in the pipe expansion stage ST**2**. The coil unit **27** includes a coil portion **61** at its tip located on the side of the pipe expansion stage ST**2**.

FIG. **4** is a schematic configuration view of the coil unit **27**.

The coil unit **27** is formed so as to extend in the longitudinal direction from a base end **27***a* to a tip **27***b*, and is to be inserted into the pipe material **13** such that the tip **27***b* is inserted first (see FIG. **3**).

The coil unit **27** includes a conductor wound portion **63**, a pair of conductor extension portions **65***a* and **65***b*, end portions on one side of which are connected to the conductor wound portion **63** and which extend in the longitudinal direction, a resin conductor support portion **67** which is provided so as to extend in the longitudinal direction of the coil unit **27** and which supports at least the conductor extension portions **65***a* and **65***b*, and coil terminal portions **69**A and **69**B which are connected to end portions on the other side (base side) of the conductor support portion **67**.

The conductor wound portion **63** is disposed in a peripheral portion of a cylindrical resin core member **71**. The coil terminal portions **69**A and **69**B are disposed in a terminal support portion **73** which is provided on the base side of the conductor support portion **67**. The core member **71** may be formed either separately (i.e., so as to be separable) from the conductor support portion **67** or integrated with the conductor support portion **67**.

FIG. **5** is a schematic view for showing the sole configuration of a conductor used in the coil unit **27**.

The conductor wound portion **63** and the conductor extension portions **65***a* and **65***b* include a tubular conductor (hollow conductor) **77** having a central communication hole **75**. The communication hole **75** is also formed through the coil terminal portions **69**A and **69**B. A pump P is connected to the communication hole **75** and a cooling medium is supplied from the pump P to the communication hole **75**. The cooling medium cools the conductor wound portion **63** and the conductor extension portions **65**A and **65**B which generate heat during energization. Examples of the cooling medium include air, a nitrogen gas, an argon gas, and a helium gas.

An electrically insulating resin coating layer **79** covering the conductor **77** is provided on the outer circumferential surface of the conductor wound portion **63** shown in FIG. **4**. The resin coating layer **79** is formed by winding a glass fiber tape around the surface of the conductor **77**, then winding the resulting structure on the outer circumferential surface of the core member **71**, and impregnating the tape wound around the conductor **77** with a resin. The resin coating layer **79** is provided not only on the outer circumferential surface of the conductor wound portion **63** but also between adjacent conductors of the conductor wound portion **63** and on the inner circumferential surface of the conductor wound portion **63**. The outer circumferential surface of the resin coating layer **79** is finished into a smooth surface, by cutting, grinding, and polishing if necessary.

FIG. **6** is an exploded perspective view of a part of the conductor support portion **67**.

The conductor support portion **67** is provided so as to extend from the core member **71** to the terminal support portion **73** located on the side of the base end **27***a*, the members being shown in FIG. **4**. The conductor support portion **67** shown in FIG. **6** is a cylindrical member formed separately from the core member **71** and includes a pair of divisional pieces **67**A and **67**B which are semicircular in a cross section taken perpendicularly to the axial direction.

A division confronting surface (denoted by symbol **81**A in the example shown in FIG. **6**) of at least one of the pair of divisional pieces **67**A and **67**B is formed to have, along the longitudinal direction of the conductor support portion **67**, a pair of conductor holding portions **83**A and **83**B, which is respectively configured to hold the pair of conductor extension portions **65***a* and **65***b* so that they are spaced from each other by a predetermined interval. The conductor holding portions **83**A and **83**B receive the conductor extension portions **65***a* and **65***b* in their grooves, respectively, thereby protecting the conductor extension portions **65***a* and **65***b* from vibration to occur in the pair of conductor extension portions **65***a* and **65***b* through which currents flow in opposite directions.

<Coil Moving Mechanism>

Next, the coil moving mechanism **29** will be described.

The coil moving mechanism **29** in the pipe expansion stage ST**2** shown in FIG. **2** includes a base **85** disposed on one side (on the right side in FIG. **2**) of the jig plate **21** and a coil moving unit **87** which is provided on the base **85** and supports a base end portion of the coil unit **27**.

The coil moving unit **87** includes a chucking unit **89** for gripping the coil unit **27** and a driving unit (not shown) configured to move the coil unit **27** in the longitudinal direction. The driving unit drives the coil unit **27** in such a manner that the coil unit **27** can advance and retreat in the longitudinal direction.

The coil moving mechanism **29** supports the coil unit **27** such that the coil unit **27** can be inserted into and removed from the pipe material **13** while the coil unit **27** has the same axis with the pipe material **13**. The coil portion **61** can be set at a desired expansion position by moving the coil unit **27** by means of the coil moving mechanism **29**.

<Current Supply Unit>

The current supply unit **31** is configured to supply a current for electromagnetic formation to the coil portion **61** shown in FIG. **2**. The current supply unit **31** includes a terminal connection portion **91** for connection to the coil terminal portions **69**A and **69**B (see FIG. **4**) of the coil unit **27**, a power source unit **93**, and a high-voltage power cable **95** to connect the power source unit **93** to the coil terminal portions **69**A and **69**B.

The power source unit **93** is configured to output, in the form of a large pulse current, energy charged in a capacitor via a switch in a very short time of several milliseconds or less. The output pulse current is supplied to the coil portion **61** via the high-voltage power cable **95**. Energy that is input per one electromagnetic forming operation is about 20 kJ, for example.

Examples of the above-mentioned switch include a gap switch, a thyratron switch, a mechanical switch, a semiconductor switch, and an ignitron switch.

<Support Rod Moving Mechanism>

The support rod moving mechanism **35** is disposed on the side (left side in FIG. **2**) of the other end, opposite to the side of the one end where the coil moving mechanism **29** is disposed, of the jig plate **21** in the pipe expansion stage ST**2**. The support rod moving mechanism **35** includes a base **96** and a support rod moving unit **97** which is provided on the base **96** and supports the support rod **33** such that the support rod **33** can be desirably moved in the longitudinal direction.

The support rod moving unit **97** includes a chucking unit **99** which supports a base end portion of the support rod **33** and a driving unit (not shown) for moving the support rod **33** supported by the chucking unit **99** in the longitudinal direction. The driving unit drives the support rod **33** such that the support rod **33** can advance and retreat along the longitudinal direction.

FIG. **7** is an enlarged perspective view of a coil holding portion **111** which is provided at the tip of the support rod **33**.

The coil holding portion **111** is provided at the tip, located on the side of the jig plate **21** (see FIG. **2**), of the support rod **33**. The coil holding portion **111** is electrically insulating (an insulator) and is shaped like a bottom-closed cylinder. A cylindrical outer circumferential surface **111***a* of the coil holding portion **111** has an outer diameter Or being the same as or slightly smaller than the inner diameter of the pipe material **13**. The coil holding portion **111** is formed to have, in its tip portion, an engagement recess **113** which is circular in a cross section taken perpendicularly to the axial direction.

The engagement recess **113** has an inner diameter ϕdr being approximately equal to the outer diameter of the coil portion **61** of the coil unit **27** and is formed so as to be coaxial with the support rod **33**. The structure of the coil holding portion **111** is not limited to the one shown in FIG. **7**. The coil holding portion **111** may be in any form as long as it is configured so as to be able to hold the coil portion **61** of the coil unit **27** inside the pipe material **13**.

Other configurations other than the case where the entire coil holding portion **111** is an insulator can be used as long as at least the end surface, on the side where the engagement recess **113** is formed, of the coil holding portion **111** and the inner surfaces of its engagement recess **113** are electrically insulating.

<First Electromagnetic Forming Method>

Next, a procedure of forming a pipe material **13** shown in FIG. **1** by electromagnetic formation with the electromagnetic forming machine **100** having the above configuration will be described in order.

FIG. **8** is a process explanation view for showing a pipe insertion step of inserting a pipe material **13** into the through-holes **17** of brackets **15**A, **15**B, **15**C, and **15**D being held on a jig plate **21** in the pipe insertion stage ST**1**.

First, a pipe material **13** is prepared and attached to the chuck mechanism of the pipe insertion driving unit **55** of the pipe material insertion mechanism **25** shown in FIG. **2**.

Further, brackets **15**A, **15**B, **15**C, and **15**D are attached to the respective bracket holders **43**A, **43**B, **43**C, and **43**D of the jig plate **21**. The brackets **15**A, **15**B, **15**C, and **15**D are fixed to the respective bracket holders **43**A, **43**B, **43**C, and **43**D such that the through-holes **17** have a common axis. In this manner, the pipe material **13** supported by the pipe insertion driving unit **55**, the through-holes **17** of the brackets **15**A, **15**B, **15**C, and **15**D, and the guide holes **45***a* and **47***a* of the pipe material positioning members **45** and **47** are arranged coaxially so as to share the axial line Ax as the center axis.

(Pipe Insertion Step)

Next, the pipe material **13** is moved toward the jig plate **21** by driving of the pipe insertion driving unit **55**. As a result, one pipe end portion **13***a* of the pipe material **13** is inserted into the guide hole **45***a* of the pipe material positioning member **45**, the through-holes **17** of the brackets **15**C, **15**A, **15**B, and **15**D, and the guide hole **47***a* of the pipe material positioning member **47**, in this order. The one pipe end portion **13***a* located on the insertion tip side comes to be supported by the guide hole **47***a* of the pipe material positioning member **47** and the other pipe end portion **13***b* located on the insertion tail side comes to be supported by the guide hole **45***a* of the pipe material positioning member **45**.

In this manner, the pipe material **13** is positioned with respect to the brackets **15**A, **15**B, **15**C, and **15**D in a coaxial state in high accuracy such that they share the axial line Ax as the center axis. After transferring the pipe material **13** to the jig plate **21**, the pipe insertion driving unit **55** retreats to a retreat position (indicated by a broken line in FIG. **8**).

The jig plate conveying mechanism **23** shown in FIG. **2** conveys the jig plate **21** on which the above-described pipe material **13** has been supported in the pipe insertion stage ST**1**, to the pipe expansion stage ST**2**.

(Setting Step for Coil Unit and Support Member)

FIG. **9**A and FIG. **9**B are process explanation views for illustrating, step by step, an expansion process for inserting the coil unit **27** and the support rod **33** into the pipe material **13** being supported on the jig plate **21** and expanding the pipe material **13**.

As shown in FIG. **9**A, on the jig plate **21** having been conveyed to the pipe expansion stage ST**2**, the coil unit **27** supported by the coil moving mechanism **29** and the support rod **33** supported by the support rod moving mechanism **35** are disposed so as to face each other in the center axis of the pipe material **13** such that their end portions face each other with the pipe material **13** interposed therebetween.

(Coil Moving Step)

Then, as shown in FIG. **9**B, the coil moving mechanism **29** moves the coil unit **27** toward the jig plate **21** and sets the coil portion **61** inside the pipe material **13** (inside the pipe material inner circumferential surface) at a position where the coil portion **61** overlaps with the bracket **15**A. When the coil unit **27** is inserted into the pipe material **13**, from the viewpoints of the ease of insertion of the coil and uniformity of electromagnetic formation, the coil unit **27** is preferably coaxial with the pipe material **13**. Although an example in which electromagnetic formation is performed at the axial position of the bracket **15**A will be described below, the order of execution of electromagnetic formation at the axial positions of the respective brackets **15**A, **15**B, **15**C, and **15**D can be set in a desired manner.

(Coil Unit Holding Step)

Then the support rod **33** is moved toward the jig plate **21** by driving the support rod moving unit **97** such that the coil holding portion **111** is butted against the coil portion **61**. In this manner, an insertion-side tip portion of the coil portion **61** is held by the coil holding portion **111** and the coil portion **61** is supported stably inside the pipe material **13**. The coil moving mechanism **29** restricts movement of the coil unit **27** in the axial direction with the coil portion **61** located at the position where the coil portion **61** is held by the coil holding portion **111**.

FIG. **10** is a sectional view for showing a state that the coil portion **61** is held by the coil holding portion **111** inside the pipe material **13**.

The coil holding portion **111** is moved while its cylindrical outer circumferential surface **111***a* slides on the inner circumferential surface **13***c* of the pipe material **13**, and hits the coil portion **61**. When the coil holding portion **111** hits the coil portion **61**, an insertion tip portion of the coil portion **61** having an outer diameter ϕDc ($\approx\phi$dr) is fitted into the engagement recess **113** having the inner diameter ϕdr. In this manner, the insertion tip portion of the coil portion **61** is held by the coil holding portion **111** inside the pipe material **13**.

Thus, the coil portion **61** is fixed to the inner circumferential surface of the pipe material **13** in the radial direction via the coil holding portion **111** at a position where the coil portion **61** overlaps with the bracket **15**A As a result, inside the pipe material **13**, the center axis Ax**1** of the pipe material **13**, the center axis Ax**2** of the coil unit **27**, and the center axis Ax**3** of the support rod **33** (coil holding portion **111**) coincide with each other.

The pipe material **13** is set coaxial with the through-holes **17** of the brackets **15**A, **15**B, **15**C, and **15**D by the above-described pipe material positioning members **45** and **47** (see FIG. **3**). Thus, the center axes of the through-holes **17** are also set coincident with the center axis Ax**1** of the pipe material **13**. The inner diameter ϕdb of the through-holes **17** is larger than the outer diameter ϕDp of the pipe material **13** ($\phi Dp<\phi db$).

The pipe material **13** and the coil unit **27** are set coaxial with each other when the coil unit **27** is held by the coil holding portion **111**. Alternatively, the pipe material **13** and the coil unit **27** may be kept coaxial with each other when the coil unit **27** is inserted into the pipe material **13**. In this case, the coil unit **27** can be prevented reliably from interfering with the other members in inserting. This coaxial state can be maintained by adjusting the coil moving unit **87** such as the chucking unit **89** shown in FIG. **2**.

FIG. **11** is a schematic sectional view taken along line XI-XI in FIG. **10**.

A gap δ**1** that is uniform in the circumferential direction is formed between the coil portion **61** and the inner circumferential surface **13***c* of the pipe material **13** in the case where the coil holding portion **111** (see FIG. **10**) supports the coil portion **61** coaxially. Furthermore, a gap δ**2** that is uniform in the circumferential direction is formed between the through-hole **17** of the bracket **15**A and the outer circumferential surface **13***d* of the pipe material **13**.

(Swaging Step)

Next, the coil portion **61** is energized by the current supply unit **31** (see FIG. **2**) in the state shown in FIG. **9**B.

FIG. **12** is a schematic structure view for showing how electromagnetic formation is performed on the pipe material **13** by the coil portion **61**. The bracket **15**C and the pipe material positioning member **45** (see FIG. **9**A) are omitted in FIG. **12**.

Induction current is induced in the pipe material **13** at an axial position where the bracket **15**A is disposed by a magnetic field generated by energization of the coil portion **61**. The pipe material **13** is expanded by Lorentz force generated by the induction current in a manner indicated by broken lines in the figure.

At this time, since the bracket **15**A is disposed at the center in the axial direction of the coil portion **61**, the outer circumferential surface of the pipe material **13** is expanded and pressed against the through-hole **17** of the bracket **15**A. Furthermore, ring-shaped swelled portions **121** are formed in the pipe material **13** on both sides of the bracket **15**A in the axial direction in the axial region (strong magnetic field region) where the coil portion **61** exists. As a result, a pair of swelled portions **121** are formed so that the bracket **15**A is sandwiched between them in the axial direction and the pipe material **13** is swaged onto the bracket **15**A.

Expansion of the pipe material **13** by electromagnetic formation is performed also on the brackets **15**B, **15**C, and **15**D shown in FIG. **9**B in the same manner as described above. That is, after the pipe material **13** is expanded by electromagnetic formation at the axial position of one bracket (e.g., bracket **15**A), the coil moving mechanism **29** cancels the restriction on the coil unit **27** in the axial direction and moves the coil portion **61** to the axial position of a bracket to be subjected to next electromagnetic formation. The support rod **33** is also moved so as to follow the coil portion **61** and to support the coil portion **61** at the movement destination inside the pipe material **13**.

The coil holding portion **111** may be separated from the coil portion **61** at each electromagnetic formation position and be butted against the coil portion **61** again at the next electromagnetic formation position. Alternatively, the support rod **33** may be moved to the next electromagnetic formation position in the axial direction while the state where the coil holding portion **111** has been fitted with the coil portion **61** in the first expansion is maintained.

FIG. **13** is a schematic sectional view for showing a state obtained after the electromagnetic formation on the pipe material **13** is finished.

The above-described expansion by electromagnetic formation is performed in order at the individual axial positions of the brackets **15**A, **15**B, **15**C, and **15**D As a result, the pipe material **13** is formed to have pairs of swelled portions **121** at the respective axial positions of the brackets **15**A, **15**B, **15**C, and **15**D, thereby performing swaging onto the **15**A, **15**B, **15**C, and **15**D.

After the above-described electromagnetic formation step, the fixing by the bracket holders **43**A, **43**B, **43**C, and **43**D (see FIG. **3**) is canceled and a formed body in which the brackets **15**A, **15**B, **15**C, and **15**D have been fixed by swaging is taken out. Thus, the formed body **11** in the state shown in FIG. **1** is obtained.

<Advantages of Coaxial Arrangement of Pipe Material, Coil, Etc.>

In the electromagnetic forming machine **100** having the above configuration, the coil portion **61** is set coaxially with the pipe material **13** at each expansion position of the pipe material **13**. The pipe material **13** is set coaxially with the through-holes **17** of the brackets **15**A, **15**B, **15**C, and **15**D. Furthermore, the coil portion **61** is fixed in the radial direction coaxially with the pipe material **13** inside the pipe material **13** by means of the coil holding portion **111** provided at the tip of the support rod **33**. Thus, as shown in FIG. **11**, the gap δ**1** between the coil portion **61** and the pipe material **13** and the gap δ**2** between the pipe material **13** and each of the brackets **15**A, **15**B, **15**C, and **15**D are made uniform in the circumferential direction with high accuracy.

Since the gap δ**1** is uniform in the circumferential direction, a magnetic field generated by the coil portion **61** covers the pipe material **13** uniformly and induction current that is uniform in the circumferential direction is induced in the pipe material **13**.

If the gap δ**1** is not uniform in the circumferential direction, the pipe material **13** has a portion that is close to the coil portion **61** and a portion that is distant from the coil portion **61** depending on the circumferential position and the magnitude of the induction current differs. As a result, the electromagnetic force acting on the pipe material **13** has a variation to cause the plastic deformation amount to vary depending on the position in the pipe material **13**.

In contrast, in the above-described configuration, since the gap δ**1** can be made uniform in the circumferential direction, uniform electromagnetic force acts on the pipe material **13** radially and the pipe material **13** is plastically deformed uniformly. As a result, occurrence of insufficient expansion illustrated as the region **217** shown in FIG. **24**B can be prevented.

Furthermore, since the gap **52** is uniform in the circumferential direction, the outer circumferential surface of a portion that expands in the circumferential direction and has been plastically deformed uniformly hits each of the bracket **15**A, **15**B, **15**C, or **15**D at the same time with approximately the same electromagnetic force. As a result, swelled portions

121, which are formed by swelling of the pipe material **13** in both sides in the axial direction of each of the bracket **15**A, **15**B, **15**C, or **15**D, are formed uniformly in the circumferential direction.

In the case where each bracket (pipe periphery member) is a metal member, if the pipe material **13** touches the ends of the through-hole **17** of the bracket with a difference in time in expanding, induction current induced in the pipe material **13** escapes from the first contact point to the bracket. As a result, the deformation amount is large at the first contact point and small in other portions, and swelled portions **121** have shapes that are not uniform in the circumferential direction and the radial direction. In this case, the intensity of swaging of the pipe material **13** onto the bracket becomes insufficient.

In contrast, in the electromagnetic forming machine **100** having the above configuration, since the pipe material **13** and the through-hole **17** of each bracket are positioned coaxially, the gap δ**2** becomes uniform in the circumferential direction and the pipe material **13** touches the ends of the through-hole **17** of the bracket without a difference in time. As a result, swelled portions **121** of the pipe material **13** are formed uniformly in the circumferential direction and the pipe material **13** is swaged onto the bracket strongly and uniformly in the circumferential direction. In this manner, the long pipe material **13** can be joined to each of the brackets **15**A, **15**B, **15**C, and **15**D in a uniform swaging state.

<Second Electromagnetic Forming Method>

Next, the procedure of a second electromagnetic forming method will be described.

FIG. **14**A to FIG. **14**C are process explanation views for illustrating the procedure of a coil unit holding step and a coil moving step of the second electromagnetic forming method. In the following description, members and portions being the same as the aforementioned ones will be given the same symbols, and the description therefor will be simplified or omitted.

The second electromagnetic forming method is the same in procedure as the above-described first electromagnetic forming method except that the coil unit holding step is performed before the coil moving step.

First, as shown in FIG. **9**A that was referred to above, a pipe material **13** are inserted into the through-holes **17** of respective brackets **15**A, **15**B, **15**C, and **15**D and two end portions, in the pipe axial direction, of the pipe material **13** are supported by the respective pipe material positioning members **45** and **47**. In this state, as shown in FIG. **14**A, the coil portion **61** of the coil unit **27** is disposed outside the one end, in the axial direction, of the pipe material **13**.

Then, as shown in FIG. **14**B, the support rod **33** is inserted into the pipe material **13** from the other end of the pipe material **13** and is caused to project beyond the one end of the pipe material **13** and hit a tip portion, located on the side of the pipe material **13**, of the coil portion **61**. As a result, the tip portion of the coil portion **61** is fitted into the engagement recess **113** of the coil holding portion **111** and the coil unit **27** is supported so as to be coaxial with the support rod **33**.

Then, as shown in FIG. **14**C, the coil unit **27** is moved toward the pipe material **13** with the tip portion of the coil portion **61** kept held by the coil holding portion **111**, and the coil portion **61** is caused to be located at a position (expansion position) where it overlaps with the bracket **15**C. At this time, the support rod **33** is pulled back to the inside of the pipe material **13** in accordance with the movement of the coil unit **27** and fixes the coil unit **27** in the radial direction inside the pipe material **13**. Furthermore, movement of the coil portion **61** in the axial direction is restricted because the coil unit **27** is fixed by the coil moving unit (not shown).

After the coil portion **61** has been set at the position where it overlaps with the bracket **15**C, the pipe material **13** is expanded by energizing the coil portion **61**. A portion, facing the coil portion **61**, of the pipe material **13** is deformed plastically toward the bracket **15**C, and swelled portions **121** are formed on the two respective sides, in the axial direction, of the bracket **15**C. As a result, the pipe material **13** is swaged onto the bracket **15**C.

In this procedure, since the coil holding portion **111** is fitted with the coil portion **61** outside the pipe material **13**, a state of holding of the coil portion **61** by the coil holding portion **111** can be checked easily. Furthermore, a holding state can be finely adjusted with high workability. Thus, a failure of engagement between the coil holding portion **111** and the coil portion **61** is less likely to occur and hence electromagnetic formation can be performed with high accuracy.

Furthermore, since the coil portion **61** is set at the position where it overlaps with the bracket **15**C while the coil unit **27** is held by the support rod **33**, the coil unit **27** is moved inside the pipe material **13** while being guided by the support rod **33**. As a result, the coil portion **61** can be set at the position where it overlaps with the bracket **15**C without interfering with (being caught on) the pipe material **13**, and the coil unit **27** can be positioned easily in the axial direction. Furthermore, a position of the coil unit **27** in the axial direction can be finely adjusted such that even more accurate electromagnetic formation is enabled.

Although in the above procedure the coil unit **27** and the coil holding portion **111** of the support rod **33** are butted against each other outside the pipe material **13**, they may be butted against each other inside the pipe material **13** and then pulled out of the pipe material **13** to check their engagement. In this case, the coil unit **27** and the coil holding portion **111** of the support rod **33** are restricted in the radial direction of the pipe material **13** when they are butted against each other, they can be positioned easily so as to be coaxial with each other.

<Third Electromagnetic Forming Method>

Next, the procedure of a third electromagnetic forming method will be described.

FIG. **15** is a schematic plan view of an electromagnetic forming machine **200** which performs the third electromagnetic forming method.

The electromagnetic forming machine **200** includes plural jig plates **21**, a jig plate conveying mechanism **23**, a pipe material insertion mechanism **25**, coil units **27**A and **27**B, coil moving mechanisms **29**A and **29**B, current supply units **31**A and **31**B, and a coil holding portion **125**. The coil moving mechanisms **29**A and **29**B and the current supply units **31**A and **31**B have the same configuration as those of the coil moving mechanism **29** and the current supply unit **31** of the above-described electromagnetic forming machine **100**, respectively.

The electromagnetic forming machine **200** includes the coil moving mechanism **29**B as an inverted (in the axial direction) version of the coil moving mechanism **29**A, in place of the support rod moving mechanism **35** (see FIG. **2**) of the above-described electromagnetic forming machine **100**. Furthermore, the coil holding portion (support member) **125** is attached to an insertion-side tip portion of the coil unit **27**B which is supported by the coil moving mechanism **29**. That is, the coil unit **27**B and the coil moving mechanism **29**B of this configuration also function as the above-described support rod **33** and support rod moving mechanism **35**, respectively.

FIG. **16** is a schematic enlarged view of the insertion-side tip portion of the coil unit **27**B.

The coil holding portion **125** which is attached to the insertion-side tip portion of a coil portion **61**B is formed with engagement recesses **127** and **129** at its two respective ends in the axial direction. The one engagement recess **127** is fitted with a tip portion of the coil portion **61**B and the coil holding portion **125** is thus integrated with the coil unit **27**B.

The engagement recess **129** of the coil holding portion **125** has the same shape as the engagement recess **113** of the above-described coil holding portion **111**. As described later, the engagement recess **129** is to be fitted with the tip portion of the coil portion **61**A of the coil unit **27**A shown in FIG. **15**.

FIG. **17** is a schematic structure view for illustrating how electromagnetic formation is performed on the pipe material **13** by the coil portion **61**A of the electromagnetic forming machine **200** shown in FIG. **15**.

The coil unit **27**A is inserted from the one end (right end in FIG. **17**) of the pipe material **13** and set at a position where the coil portion **61**A overlaps with the bracket **15**C. The coil unit **27**B is inserted from the other end (left end in FIG. **17**) of the pipe material **13** and the insertion-side tip portion of the coil portion **61**A is held by the coil holding portion **125** attached to the insertion-side tip portion. By energizing the coil portion **61**A in this state, the pipe material **13** is expanded and swaged onto the bracket **15**C.

With this configuration, the pipe material **13** can be expanded by inserting the plural coil units **27**A and **27**B into the pipe material **13**. As a result, the steps of inserting the above-described support rod **33** (see FIG. **2**) into the pipe material **13** and performing electromagnetic formation, pulling out the support rod **33** after the electromagnetic formation, and inserting the coil unit again from the support rod **33** insertion side and performing electromagnetic formation can be omitted. The productivity can thus be increased remarkably. In addition, the accuracy of electromagnetic expansion is increased because centering of both of the coil portions **61**A and **61**B can be made by the coil holding portion **125** which is attached to the tip portion of the coil portion **61**B.

Although in the above example the coil holding portion **125** is attached to the coil unit **27**B, the coil holding portion **125** may be attached to the coil unit **27**A.

Furthermore, although in the above process the coil unit **27**A and the coil holding portion **125** are butted against each other at a position (inside the pipe material **13**) where the coil portion **61**A overlaps with the bracket **15**C, they may be butted against each other at a position inside the pipe material **13** other than such a position that the coil portion **61**A overlaps with the bracket **15**C. In this case, the coil portion **61**A can be moved to the position where the coil portion **61**A overlaps with the bracket **15**C by moving the coil units **27**A and **28**B together while the coil unit **27**A is kept held by the coil holding portion **125**. This makes it possible to finely adjust the axial position of the coil portion **61**A and hence to perform electromagnetic formation with even higher accuracy.

Still further, the coil unit **27**A and the coil holding portion **125** may be butted against each other outside the pipe material **13**. In this case, bending of the coil unit **27**A can be reduced and hence the coil units **27**A and **28**B can adjusted easily so as to be coaxial with each other. Furthermore, a state of holding of the coil unit **27**A by the coil holding portion **125** can be checked easily and can be finely adjusted with high workability. As a result, the coil unit and the support member can be easily positioned so as to be coaxial with each other, the coil unit can be held reliably, and electromagnetic formation can be performed with high accuracy.

FIG. **18** is a schematic structure view for illustrating how electromagnetic formation is performed on the pipe material **13** using a coil holding portion **125**A whose axial length is adjusted.

The axial distance W between the bottom surfaces of the engagement recesses **129** and **127** for receiving the insertion-side tip portions of the coil portions **61**A and **61**B, respectively, is determined depending on an axial interval L_B between adjacent brackets (e.g., brackets **15**A and **15**C).

The illustrated example is directed to the case where electromagnetic formation is performed on the pipe material **13** at each of the axial positions of the brackets **15**A and **15**C. Now, the center of the coil portion **61**A is set at an axial position where the center of the coil portion **61**A overlaps with the bracket **15**C and the center of the coil portion **61**B is set at an axial position where the center of the coil portion **61**B overlaps with the bracket **15**A. The axial interval between the centers of the coil portions **61**A and **61**B in this state is represented by L_C.

In this case, the axial length W of the coil holding portion **125**A is set such that the axial intervals L_C and L_B are identical ($L_C=L_B$). In such a configuration, since the coil portions **61**A and **61**B of the coil units **27**A and **27**B are held by the coil holding portion **125**A, when the one coil portion **61**A is set at a position where the one coil portion **61**A overlaps with the bracket **15**C, the other coil portion **61**B is positioned at a position where the other coil portion **61**B overlaps with the bracket **15**A.

The pipe material **13** can be expanded at one time at the axial positions of the brackets **15**A and **15**C by energizing the coil portions **61**A and **61**B at the same time or successively in the state that the coil portions **61**A and **61**B are set as shown in FIG. **18**. As a result, the swaging step is simplified and the takt time of an electromagnetic forming process can be shortened.

<Fourth Electromagnetic Forming Method>

Next, the procedure of a fourth electromagnetic forming method will be described.

FIG. **19** is a schematic view for showing the configuration of a coil unit that is used in the fourth electromagnetic forming method.

In the coil unit **28** having this configuration, coil portions **62**A and **62**B are disposed at plural (two in the example of FIG. **19**) positions arranged in the axial direction. The coil portions **62**A and **62**B have the same configuration as the above-described coil portion **61**.

The coil portions **62**A and **62**B are coil portions that are independent of each other and are to be energized individually. A conductor support portion **68**A is provided so as to extend between the coil portions **62**A and **62**B and a conductor support portion **68**B is provided so as to extend between the coil portion **62**B and a base end **28***a*.

In a terminal connection portion **91**, coil terminal portions **69**A and **69**B are connected to the base ends of conductor extension portions **65***a* and **65***b* that extend from the coil portions **62**A, respectively. Coil terminal portions **70**A and **70**B are connected to the base ends of conductor extension portions **65***a* and **65***b* that extend from the coil portions **62**B, respectively.

FIG. **20**A to FIG. **20**C are process explanation views for illustrating the procedure of a coil moving step for moving the coil unit **28** used in the fourth electromagnetic forming method, a coil unit holding step, and a swaging step.

The coil unit **28** is set on the side of one end of the pipe material **13** as shown in FIG. **20**A and then inserted into the pipe material **13** as shown in FIG. **20**B. In the coil unit **28**, the axial interval La between the centers of the coil portions **62**A and **62**B are set equal to the axial interval L_B between the brackets **15**A and **15**C. Thus, the coil portions **62**A and **62**B are set at positions where they overlap with the respective brackets **15**A and **15**C at one time merely by inserting the coil portions **62**A and **62**B into the pipe material **13**.

Then the support rod **33** is inserted into the pipe material **13** from the other end of the pipe material **13**, and the coil holding portion (support member) **111** which is provided at the tip of the support rod **33** butts against the coil portion **62**A. The engagement recess **113** is fitted with the tip portion of the coil portion **62**A such that the coil holding portion **111** holds the coil unit **28** inside the pipe material **13**.

In this manner, the coil portions **62**A and **62**B are positioned so as to be coaxial with the pipe material **13**. The pipe material **13** is positioned so as to be coaxial with the through-holes **17** of the brackets **15**A and **15**C by pipe material positioning members (not shown). Furthermore, axial movement of the coil unit **28** is restricted by a coil moving unit (not shown).

Then, as shown in FIG. **20**C, the pipe material **13** is expanded and swelled portions **121** are formed by energizing the coil portions **62**A and **62**B being fixed inside the pipe material **13**, thereby swaging the pipe material **13** onto the brackets **15**A and **15**C.

Also in this case, the coil portions **62**A and **62**B may be set at respective desired expansion positions by causing the coil holding portion **111** to butt against and hold the coil portion **62**A inside the pipe material **13** at a position where the coil portion **62**A does not overlap a bracket or outside the pipe material **13**, and then moving the support rod **33** and the coil unit **28** together with the coil portion **62**A kept held by the coil holding portion **111**. Alternatively, the electromagnetic formation may be performed as the following: one of the coil portions **62**A and **62**B is set at a position where it overlaps with one of the brackets **15**A and **15**C and electromagnetic formation is performed and then the other of the coil portions **62**A and **62**B is set at a position where it overlaps with the other of the brackets **15**A and **15**C and electromagnetic formation is performed. In this manner, the coil portions **62**A and **62**B provided at the plural positions of the coil unit **28** may be used for electromagnetic formation successively.

Although the coil unit **28** having the above configuration is provided with the coil portions **62**A and **62**B at the two positions arranged in the longitudinal direction, the number of coil portions provided is not limited to two and may be three or more.

With the coil unit **28** having the above configuration, the individual coil portions can be positioned with high accuracy so as to be coaxial with the pipe material **13** because they are provided so as to be integrated with each other. Thus, the coil portions do not suffer different setting deviations and the positioning accuracy can be increased easily. As a result, work of positioning the coil portions is simplified, the working efficiency is increased, and the takt time is shortened.

FIG. **21** is a process explanation view for illustrating how electromagnetic formation involving the brackets **15**A, **15**B, **15**C, and **15**D is performed at one time by inserting a pair of coil units **28**A and **28**B from each of the two ends, in the axial direction, of the pipe material **13**.

Each of the coil units **28**A and **28**B has the same configuration as the above-described coil unit **28**. A coil holding portion **125**B is attached to an insertion-side tip portion of at least one of the coil units **28**A and **28**B. In this configuration, the coil holding portion **125**B is provided on the side of the coil unit **28**B.

The coil unit **28**A is inserted from the one end of the pipe material **13** and the coil unit **28**B is inserted from the other end of the pipe material **13**. A coil portion **62**A of the coil unit **28**A and the coil holding portion **125**B of the coil unit **28**B butt against each other and the coil portion **62**A of the coil unit **28**A is held by the coil holding portion **125**B.

As in the case shown in FIG. **18**, the axial length of the coil holding portion **125**B is set depending on the axial interval between the brackets **15**A and **15**B shown in FIG. **21**. As in the case shown in FIG. **20**A, the axial interval between the coil portions **62**A and **62**B is set equal to the axial interval between the brackets **15**A and **15**C and the axial interval between the brackets **15**B and **15**D shown in FIG. **21**.

Thus, when the coil portion **62**A of the coil unit **28**A (or **28**B) is positioned at a position where it overlaps with the bracket **15**A (or **15**B), all of the coil portions **62**A and **62**B are set at respective expansion positions, that is, positions where they overlap with the respective brackets **15**A, **15**B, **15**C, and **15**D.

Thus, in this configuration, all the coil portions can be set at desired axial positions by positioning at least one of the plural coil portions in the axial direction. As a result, work of positioning the coil portions can be made simpler, the working efficiency can be increased, and the takt time can be shortened. Also in this case, each of the coil portions **62**A and **62**B may be set at a desired expansion position by causing the coil holding portion **125**B to butt against and hold the coil portion **62**A inside the pipe material **13** at a position where the coil portion **62**A does not overlap with a bracket or outside the pipe material **13** and then moving the coil units **28**A and **28**B together with the coil portion **62**A kept held by the coil holding portion **125**B.

The invention is not limited to the above embodiments. In the invention, it is expected that constituent elements of embodiments are combined together and those skilled in the art make changes or conceive applications on the basis of the disclosure of the specification and common techniques and what result from those acts are included in the scope of protection.

Although the engagement recess of the coil holding portion is illustrated as a bottom-closed recess having a cylindrical inner circumferential surface, the shape of the engagement recess is not limited to this shape. For example, as shown in FIG. **22**, a coil holding portion **111**A may have an engagement recess **113**A having a side surface **131** that is tapered in a cross section taken perpendicularly to the axis such that the diameter of the engagement recess **113**A decreases gradually toward the insertion (directed to the coil portion) tail side (leftward in FIG. **22**).

In this case, when the coil holding portion **111**A is caused to butt against the coil portion, the coil portion is fitted into the engagement recess **113**A while being guided by the side surface **131**. Thus, the coil portion can be held coaxially with the support rod **33** with high accuracy even when the coil portion is off-centered a little, because the coil portion is inserted into the engagement recess **113**A while being guided by the side surface **131**.

Alternatively, the coil holding portion **111** may have a projection to be fitted into a recess formed on the coil portion side. That is, the engagement recess **113** may have any shape as long as the two sides are arranged coaxially as a result of fitting of a projection of one side into a recess of the other side.

As described above, the specification discloses the following items.

(1) An electromagnetic forming method, including:

a step of setting pipe periphery members at plural positions along an axial direction of a pipe material;

a step of setting a coil unit on a side of one end, in the axial direction, of the pipe material, the coil unit including a conductor wound portion, conductor extension portions, one end portion of which is connected to the conductor wound portion and which extend in a longitudinal direction, and a resin-made conductor support portion that is provided along the longitudinal direction and that supports at least the conductor extension portions;

a step of setting a support member on a side of the other end, in the axial direction, of the pipe material, in which at least a tip of the support member on a side of the pipe material is made of an insulator;

a coil unit holding step of causing the coil unit and the support member to butt against each other by relatively moving the coil unit and the support member to each other in the axial direction of the pipe material, thereby causing the tip portion of the support member to hold the coil unit coaxially;

a coil setting step of setting the conductor wound portion of the coil unit at a position inside the pipe material where the conductor wound portion overlaps with the pipe periphery member; and

a swaging step of fixing the pipe periphery member to the pipe material by expanding the pipe material by electromagnetic force generated by energizing the conductor wound portion of the coil unit,

in which the coil setting step and the swaging step are performed in this order at each of the plural positions of the pipe material while the coil unit is kept held by the support member.

In this electromagnetic forming method, since the insertion-side tip portion of the coil unit is held by the support member with high accuracy, the coil unit is not prone to be off-centered inside the pipe material even in the case where the coil unit is inserted into a long pipe material. As a result, a variation of electromagnetic formation on the pipe material is reduced and the pipe material can be joined to the pipe periphery members with uniform swaging states because the pipe material is fixed to the pipe periphery members satisfactorily. Furthermore, since the coil unit is fixed by the holding member so as not to move in the axial direction, the axial movement of the coil unit in electromagnetic formation can be reduced more easily than in the case where the axial movement is restricted only by the coil unit side.

(2) An electromagnetic forming method, including:

a step of setting pipe periphery members at plural positions along an axial direction of a pipe material;

a step of setting a pair of coil units on a side of one end and a side of the other end, in the axial direction, of the pipe material, each of the coil units including a conductor wound portion, conductor extension portions, one end portion of which is connected to the conductor wound portion and which extend in a longitudinal direction, and a resin-made conductor support portion that is provided along the longitudinal direction and that supports at least the conductor extension portions;

a coil unit holding step of causing the pair of coil units to butt against each other by relatively moving the coil units to each other in the axial direction of the pipe material, thereby causing a tip portion of a support member to hold a tip portion of the coil unit which faces the support member coaxially, the support member being provided at an insertion-side tip of at least one of the coil units and at least two end portions of the support member in the axial direction being made of an insulator;

a coil setting step of setting the conductor wound portion of the coil unit at a position inside the pipe material where the conductor wound portion overlaps with the pipe periphery member; and

a swaging step of fixing the pipe periphery member to the pipe material by expanding the pipe material by electromagnetic force generated by energizing the conductor wound portion of the coil unit set at an axial position of the pipe periphery member,

in which the coil setting step and the swaging step are performed in this order at each of the plural positions of the pipe material while the coil unit is kept held by the support member.

In this electromagnetic forming method, since the insertion-side tip portion of one coil unit is held by the support member with high accuracy, the coil unit is not prone to be off-centered inside the pipe material even in the case where the coil unit is inserted into a long pipe material. As a result, a variation of electromagnetic formation on the pipe material is reduced and the pipe material can be joined to the pipe periphery members with uniform swaging states because the pipe material is fixed to the pipe periphery members satisfactorily. Furthermore, since the coil unit is fixed by the holding member so as not to move in the axial direction, the axial movement of the one coil unit in electromagnetic formation can be reduced more easily than in the case where the axial movement is restricted only by the coil unit side. Still further, electromagnetic formation can be performed at plural expansion positions at one time or successively since the pair of coil units is inserted into the pipe material. As a result, the production efficiency can be increased than in the case where the holding member is pulled out of the pipe material and the coil unit is newly inserted for each expansion position.

(3) The electromagnetic forming method according to (1) or (2), in which the coil unit in which the conductor wound portion is provided at plural positions in the axial direction is used.

In this electromagnetic forming method, since the conductor wound portion is provided at plural positions, electromagnetic formation can be performed at one time or successively at plural positions and hence the production efficiency is increased.

(4) The electromagnetic forming method according to any one of (1) to (3), in which in the coil unit holding step, an engagement portion provided at an insertion-side tip of the support member is engaged with an insertion-side tip portion of the coil unit, thereby holding the coil unit and the support member coaxially.

In this electromagnetic forming method, the coil unit and the support member are accurately positioned so as to be coaxial with each other by the engagement portion.

(5) The electromagnetic forming method according to (4), in which an outer circumferential surface of the pipe material is set parallel with facing surfaces of the pipe peripheral members which face the outer circumferential surface in a cross section taken along the axial direction of the pipe material and the pipe peripheral members that are set outside the outer circumferential surface of the pipe material.

In this electromagnetic forming method, when the pipe material is expanded and comes into contact with a pipe periphery member, the entire outer circumferential surface of the portion concerned of the pipe material at the same time. Thus, induction current induced in the pipe material does not escape to the pipe periphery member locally and electromagnetic expansion force is generated uniformly in the circumferential direction of the pipe material. This enables uniform plastic deformation of the pipe material.

(6) The electromagnetic forming method according to any one of (1) to (5),

in which each of the pipe peripheral members includes a through-hole through which the pipe material to be inserted, and

in which the pipe material is supported such that the pipe material is coaxial with the through-holes.

In this electromagnetic forming method, since the inner circumferential surface of each through-hole is parallel with the outer circumferential surface of the pipe material, the gap between the inner circumferential surface and the outer circumferential surface is constant and hence the entire outer circumferential surface of the pipe material comes into contact with the inner circumferential surface of the through-hole simultaneously when the pipe material is expanded.

The present application is based on Japanese Patent Application No. 2018-37758 filed on Mar. 2, 2018, the entire subject matter of which is incorporated herein by reference.

REFERENCE SIGNS LIST

13: Aluminum pipe material (pipe material)
15, **15**A, **15**B, **15**C, **15**D: Bracket (pipe periphery member)
17: Through-hole
27, **27**A, **27**B, **27**C, **28**: Coil unit
33: Support rod (support member)
45, **47**: Pipe material positioning member
61, **61**A, **61**B, **62**A, **62**B: Coil portion
63: Conductor wound portion
65*a*, **65***b*: Conductor extension portion
67, **68**A, **68**B: Conductor support portion
75: Communication hole
77: Conductor
111, **125**, **125**A: Coil holding portion
113: Engagement recess (engagement portion)

The invention claimed is:

1. An electromagnetic forming method, comprising:

a step of setting pipe periphery members at plural positions along an axial direction of a pipe material;

a step of setting a coil unit on a side of one end, in the axial direction, of the pipe material, the coil unit including a conductor wound portion, conductor extension portions, one end portion of which is connected to the conductor wound portion and which extend in a longitudinal direction, and a resin-made conductor support portion that is provided along the longitudinal direction and that supports at least the conductor extension portions;

a step of setting a support member on a side of the other end, in the axial direction, of the pipe material, wherein at least a tip of the support member on a side of the pipe material is made of an insulator;

a coil unit holding step of causing the coil unit and the support member to butt against each other by relatively moving the coil unit and the support member to each other in the axial direction of the pipe material, thereby causing the tip portion of the support member to hold the coil unit coaxially;

a coil setting step of setting the conductor wound portion of the coil unit at a position inside the pipe material where the conductor wound portion overlaps with the pipe periphery member; and

a swaging step of fixing the pipe periphery member to the pipe material by expanding the pipe material by electromagnetic force generated by energizing the conductor wound portion of the coil unit,

wherein the coil setting step and the swaging step are performed in this order at each of the plural positions of the pipe material while the coil unit is kept held by the support member.

2. The electromagnetic forming method according to claim **1**, wherein the coil unit in which the conductor wound portion is provided at plural positions in the axial direction is used.

3. The electromagnetic forming method according to claim **2**, wherein in the coil unit holding step, an engagement portion provided at an insertion-side tip of the support member is engaged with an insertion-side tip portion of the coil unit, thereby holding the coil unit and the support member coaxially.

4. The electromagnetic forming method according to claim **3**,

wherein each of the pipe peripheral members includes a through-hole through which the pipe material is to be inserted,

wherein the pipe material is supported such that the pipe material is coaxial with the through-hole.

5. The electromagnetic forming method according to claim **2**,

wherein each of the pipe peripheral members includes a through-hole through which the pipe material is to be inserted,

wherein the pipe material is supported such that the pipe material is coaxial with the through-hole.

6. The electromagnetic forming method according to claim **1**, wherein in the coil unit holding step, an engagement portion provided at an insertion-side tip of the support member is engaged with an insertion-side tip portion of the coil unit, thereby holding the coil unit and the support member coaxially.

7. The electromagnetic forming method according to claim **6**, wherein an outer circumferential surface of the pipe material is set parallel with facing surfaces of the pipe peripheral members which face the outer circumferential surface in a cross section taken along the axial direction of the pipe material and the pipe peripheral members that are set outside the outer circumferential surface of the pipe material.

8. The electromagnetic forming method according to claim **7**,

wherein each of the pipe peripheral members includes a through-hole through which the pipe material is to be inserted,

wherein the pipe material is supported such that the pipe material is coaxial with the through-hole.

9. The electromagnetic forming method according to claim **6**,

wherein each of the pipe peripheral members includes a through-hole through which the pipe material is to be inserted,

wherein the pipe material is supported such that the pipe material is coaxial with the through-hole.

10. The electromagnetic forming method according to claim **1**,

wherein each of the pipe peripheral members includes a through-hole through which the pipe material is to be inserted,

wherein the pipe material is supported such that the pipe material is coaxial with the through-hole.

11. An electromagnetic forming method, comprising:

a step of setting pipe periphery members at plural positions along an axial direction of a pipe material;

a step of setting a pair of coil units on a side of one end and a side of the other end, in the axial direction, of the pipe material, each of the coil units including a conductor wound portion, conductor extension portions, one end portion of which is connected to the conductor wound portion and which extend in a longitudinal direction, and a resin-made conductor support portion that is provided along the longitudinal direction and that supports at least the conductor extension portions;

a coil unit holding step of causing the pair of coil units to butt against each other by relatively moving the coil units to each other in the axial direction of the pipe material, thereby causing a tip portion of a support member to hold a tip portion of the coil unit which faces the support member coaxially, the support member being provided at an insertion-side tip of at least one of the coil units and at least two end portions of the support member in the axial direction being made of an insulator;

a coil setting step of setting the conductor wound portion of the coil unit at a position inside the pipe material where the conductor wound portion overlaps with the pipe periphery member; and

a swaging step of fixing the pipe periphery member to the pipe material by expanding the pipe material by electromagnetic force generated by energizing the conductor wound portion of the coil unit set at an axial position of the pipe periphery member,

wherein the coil setting step and the swaging step are performed in this order at each of the plural positions of the pipe material while the coil unit is kept held by the support member.

12. The electromagnetic forming method according to claim **11**, wherein the coil unit in which the conductor wound portion is provided at plural positions in the axial direction is used.

13. The electromagnetic forming method according to claim **12**, wherein in the coil unit holding step, an engagement portion provided at an insertion-side tip of the support member is engaged with an insertion-side tip portion of the coil unit, thereby holding the coil unit and the support member coaxially.

14. The electromagnetic forming method according to claim **13**,

wherein each of the pipe peripheral members includes a through-hole through which the pipe material is to be inserted,

wherein the pipe material is supported such that the pipe material is coaxial with the through-hole.

15. The electromagnetic forming method according to claim **12**,

wherein each of the pipe peripheral members includes a through-hole through which the pipe material is to be inserted,

wherein the pipe material is supported such that the pipe material is coaxial with the through-hole.

16. The electromagnetic forming method according to claim **11**, wherein in the coil unit holding step, an engagement portion provided at an insertion-side tip of the support member is engaged with an insertion-side tip portion of the coil unit, thereby holding the coil unit and the support member coaxially.

17. The electromagnetic forming method according to claim **16**, wherein an outer circumferential surface of the pipe material is set parallel with facing surfaces of the pipe peripheral members which face the outer circumferential surface in a cross section taken along the axial direction of the pipe material and the pipe peripheral members that are set outside the outer circumferential surface of the pipe material.

18. The electromagnetic forming method according to claim **17**,

wherein each of the pipe peripheral members includes a through-hole through which the pipe material is to be inserted,

wherein the pipe material is supported such that the pipe material is coaxial with the through-hole.

19. The electromagnetic forming method according to claim **16**,

wherein each of the pipe peripheral members includes a through-hole through which the pipe material is to be inserted,

wherein the pipe material is supported such that the pipe material is coaxial with the through-hole.

20. The electromagnetic forming method according to claim **11**,

wherein each of the pipe peripheral members includes a through-hole through which the pipe material is to be inserted,

wherein the pipe material is supported such that the pipe material is coaxial with the through-hole.

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