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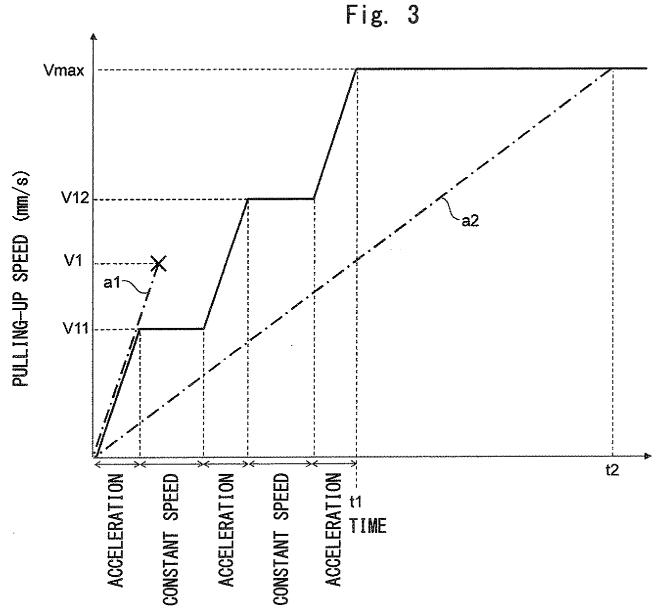
(54) UPWARD-DRAWING CONTINUOUS CASTING METHOD

(57) A pulling-up-type continuous casting method according to an aspect of the present invention is a pulling-up-type continuous casing method for pulling up molten metal (M1) held in a holding furnace (101) by using a starter (ST). When the starter (ST) is accelerated to a predetermined pulling-up speed at a start of casting, the pulling-up-type continuous casting method includes a first acceleration section in which the starter (ST) is accelerated from a standstill state to a first speed at a first acceleration, a second acceleration section in which the starter (ST) is accelerated from the first speed to a second speed at a second acceleration, and a constant speed section in which the starter (ST) is pulled up at the first speed, the constant speed section being positioned between the first and second acceleration sections.

Fig. 3



Description

Technical Field

[0001] The present invention relates to a pulling-up-type continuous casting method.

Background Art

[0002] Patent Literature 1 proposed a free casting method as a revolutionary pulling-up-type continuous casting method that does not requires any mold. As shown in Patent Literature 1, after a starter is submerged into the surface of a melted metal (molten metal) (i.e., molten-metal surface), the starter is pulled up, so that some of the molten metal follows the starter and is drawn by the starter by the surface film of the molten metal and/or the surface tension. Note that it is possible to continuously cast a cast-metal article having a desired cross-sectional shape by drawing the molten metal and cooling the drawn molten metal through a shape defining member disposed in the vicinity of the molten-metal surface.

[0003] In the ordinary continuous casting method, the shape in the longitudinal direction as well as the shape in cross section is defined by the mold. In the continuous casting method, in particular, since the solidified metal (i.e., cast-metal article) needs to pass through inside the mold, the cast-metal article has a shape extending on a straight-line in the longitudinal direction.

[0004] In contrast to this, the shape defining member used in the free casting method defines only the cross-sectional shape of the cast-metal article, while it does not define the shape in the longitudinal direction. Further, since the shape defining member can be moved in the direction parallel to the molten-metal surface (i.e., in the horizontal direction), cast-metal articles having various shapes in the longitudinal direction can be produced. For example, Patent Literature 1 discloses a hollow cast-metal article (i.e., a pipe) having a zigzag shape or a helical shape in the longitudinal direction rather than the straight-line shape.

Citation List

Patent Literature

[0005] Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2012-61518

Summary of Invention

Technical Problem

[0006] The present inventors have found the following problem.

[0007] In the free casting method disclosed in Patent Literature 1, a cooling gas is blown on cast metal following the starter immediately after the cast metal is solidified and the molten metal is thereby indirectly cooled. It should be noted that the casting process needs to be advanced in a state where the speed at which the solidification advances from the top toward the bottom of the cast metal (hereinafter called a "solidifying speed") is substantially equal to the pulling-up speed. For example, if only the pulling-up speed is increased while maintaining the cooling power for the pulled-up molten metal unchanged (i.e., while maintaining the solidifying speed unchanged), the solidification interface rises and hence the pulled-up molten metal is torn apart. That is, if the cooling power is determined, an appropriate pulling-up speed corresponding to that cooling power is determined. Note that to increase the pulling-up speed and thereby improve productivity, the above-described cooling power needs to be increased.

[0008] At the start of casting, the starter is accelerated from a standstill state to a desired pulling-up speed (i.e., the above-described appropriate pulling-up speed corresponding to the cooling power). However, there has been a problem that if the acceleration for the pulling-up operation is too high, the molten metal pulled-up by the starter is torn apart before the pulling-up speed of the starter reaches the desired pulling-up speed, thus making the casting itself impossible. Further, there is another problem that if the acceleration for the pulling-up operation is lowered in order to prevent the molten metal from being torn apart due to the acceleration, it takes time before the pulling-up speed of the starter reaches the desired pulling-up speed, thus deteriorating productivity.

[0009] The present invention has been made in view of the above-described problems, and an object thereof is to provide a pulling-up-type continuous casting method that has excellent productivity while preventing the pulled-up molten metal from being torn apart during the acceleration.

Solution to Problem

[0010] A pulling-up-type continuous casting method according to an aspect of the present invention is

> a pulling-up-type continuous casing method for pulling up molten metal held in a holding furnace by using a starter, in which
> when the starter is accelerated to a predetermined pulling-up speed at a start of casting, the pulling-up-type continuous casting method includes:
>
> > a first acceleration section in which the starter is accelerated from a standstill state to a first speed at a first acceleration;
> > a second acceleration section in which the starter is accelerated from the first speed to a second speed at a second acceleration; and
> > a constant speed section in which the starter is pulled up at the first speed, the constant speed section being positioned between the first and

second acceleration sections.

[0011] This configuration can provide a pulling-up-type continuous casting method that has excellent productivity while preventing the pulled-up molten metal from being torn apart during the acceleration.

[0012] The first acceleration is preferably an acceleration that will cause a tearing in the molten metal pulled-up by the starter before the pulling-up speed of the starter reaches the predetermined pulling-up speed if the starter is continuously accelerated from the standstill state at that acceleration, and the second acceleration is preferably an acceleration that will cause a tearing in the molten metal pulled-up by the starter before the pulling-up speed of the starter reaches the predetermined pulling-up speed if the starter is continuously accelerated from the standstill state at that acceleration. It is possible to improve productivity even further.

[0013] Further, the first and second accelerations are preferably equal to each other. In this case, each of the first and second accelerations is particularly preferably a maximum acceleration that a pulling-up machine that pulls up the starter can deliver.

[0014] Further, the pulling-up-type continuous casting method may further include a third acceleration section in which the starter is accelerated from the second speed to a third speed at a third acceleration, and a constant speed section in which the starter is pulled up at the second speed, the constant speed section being positioned between the second and third acceleration sections.

[0015] Alternatively, the second acceleration may be higher than the first acceleration. In this case, the second acceleration is preferably a maximum acceleration that a pulling-up machine that pulls up the starter can deliver.

Advantageous Effects of Invention

[0016] According to the present invention, it is possible to provide a pulling-up-type continuous casting method that has excellent productivity while preventing the pulled-up molten metal from being torn apart during the acceleration.

Brief Description of Drawings

[0017]

Fig. 1 is a schematic cross section of a free casting apparatus according to a first exemplary embodiment;
Fig. 2 is a plan view of a shape defining member 102 according to the first exemplary embodiment;
Fig. 3 is a schematic graph showing a pulling-up speed acceleration method according to the first exemplary embodiment;
Fig. 4 is a schematic graph showing a pulling-up speed acceleration method according to a modified example 1 of the first exemplary embodiment;
Fig. 5 is a schematic graph showing a pulling-up speed acceleration method according to a modified example 2 of the first exemplary embodiment;
Fig. 6 is a plan view of a shape defining member 102 according to a second exemplary embodiment; and
Fig. 7 is a side view of the shape defining member 102 according to the second exemplary embodiment.

Description of Embodiments

[0018] Specific exemplary embodiments to which the present invention is applied are explained hereinafter in detail with reference to the drawings. However, the present invention is not limited to exemplary embodiments shown below. Further, the following descriptions and the drawings are simplified as appropriate for clarifying the explanation.

(First exemplary embodiment)

[0019] Firstly, a free casting apparatus (pulling-up-type continuous casting apparatus) according to a first exemplary embodiment is explained with reference to Fig. 1. Fig. 1 is a schematic cross section of a free casting apparatus according to the first exemplary embodiment. As shown in Fig. 1, the free casting apparatus according to the first exemplary embodiment includes a molten-metal holding furnace 101, a shape defining member 102, a support rod 104, an actuator 105, a cooling gas nozzle(s) 106, and a pulling-up machine 108. In Fig. 1, the xyplane forms a horizontal plane and the z-axis direction is the vertical direction. More specifically, the positive direction on the z-axis is the vertically upward direction.

[0020] The molten-metal holding furnace 101 contains molten metal M1 such as aluminum or its alloy, and maintains the molten metal M1 at a predetermined temperature at which the molten metal M1 has fluidity. In the example shown in Fig. 1, since the molten-metal holding furnace 101 is not replenished with molten metal during the casting process, the surface of molten metal M1 (i.e., molten-metal surface) is lowered as the casting process advances. Alternatively, the molten-metal holding furnace 101 may be replenished with molten metal as required during the casting process so that the molten-metal surface is kept at a fixed level. Note that the position of the solidification interface SIF can be raised by increasing the setting temperature of the holding furnace and the position of the solidification interface SIF can be lowered by lowering the setting temperature of the holding furnace. Needless to say, the molten metal M1 may be a metal or an alloy other than aluminum.

[0021] The shape defining member 102 is made of ceramic or stainless steel, for example, and disposed near the molten-metal surface. In the example shown in Fig. 1, the shape defining member 102 is disposed so that its underside principal surface (undersurface) is in contact with the molten-metal surface. The shape defining member 102 can define the cross-sectional shape of cast metal M3 to be cast while preventing oxide films formed on the surface of the molten metal M1 and foreign substances floating on the surface of the molten metal M1 from entering the cast metal M3. The cast metal M3 shown in Fig. 1 is a solid cast-metal article having a platelike shape in a horizontal cross section (hereinafter referred to as "lateral cross section"). Note that needless to say, there is no particular restriction on the cross-sectional shape of the cast metal M3. The cast metal M3 may be, for example, a hollow cast-metal article such as a circular pipe and a rectangular pipe.

[0022] Fig. 2 is a plane view of the shape defining member 102 according to the first exemplary embodiment. Note that the cross section of the shape defining member 102 shown in Fig. 1 corresponds to a cross section taken along the line I-I in Fig. 2. As shown in Fig. 2, the shape defining member 102 has, for example, a rectangular shape as viewed from the top, and has a rectangular opening (molten-metal passage section 103) having a thickness t1 and a width w1 at the center thereof. The molten metal passes through the rectangular opening (molten-metal passage section 103).

[0023] Note that the xyz-coordinate system shown in Fig. 2 corresponds to that shown in Fig. 1.

[0024] As shown in Fig. 1, the molten metal M1 follows the cast metal M3 and is pulled up by the cast metal M3 by its surface film, the surface tension, and the like. Further, the molten metal M1 passes through the molten-metal passage section 103 of the shape defining member 102. That is, as the molten metal M1 passes through the molten-metal passage section 103 of the shape defining member 102, an external force is applied from the shape defining member 102 to the molten metal M1 and the cross-sectional shape of the cast metal M3 is thereby defined. Note that the molten metal that follows the cast metal M3 and is pulled up from the molten-metal surface by the surface film of the molten metal, the surface tension, and the like is called "held molten metal M2". Further, the boundary between the cast metal M3 and the held molten metal M2 is the solidification interface SIF.

[0025] The support rod 104 supports the shape defining member 102.

[0026] The support rod 104 is connected to the actuator 105. By the actuator 105, the shape defining member 102 can be moved in the up/down direction (vertical direction) and in the horizontal direction through the support rod 104. With this configuration, it is possible to move the shape defining member 102 downward as the molten-metal surface is lowered due to the advance of the casting process. Further, since the shape defining member 102 can be moved in the horizontal direction, the shape in the longitudinal direction of the cast metal M3 can be changed.

[0027] The cooling gas nozzle (cooling unit) 106 is cooling means for blowing a cooling gas (such as air, nitrogen, and argon) supplied from a cooling gas supply unit (not shown) on the cast metal M3 and thereby cooling the cast metal M3. The position of the solidification interface SIF can be lowered by increasing the flow rate of the cooling gas and can be raised by reducing the flow rate of the cooling gas. Note that although it is not shown in the figure, the cooling gas nozzle (cooling unit) 106 can also be moved in the horizontal direction and in the vertical direction in accordance with the movement of the shape defining member 102.

[0028] By cooling the cast metal M3 by the cooling gas while pulling up the cast metal M3 by using the pulling-up machine 108 connected to the starter ST, the held molten metal M2 located in the vicinity of the solidification interface SIF is successively solidified, and the cast metal M3 is thereby formed. The position of the solidification interface SIF can be raised by increasing the pulling-up speed of the pulling-up machine 108 and can be lowered by reducing the pulling-up speed.

[0029] Next, a free casting method according to a first exemplary embodiment is explained with reference to Fig. 1.

[0030] Firstly, the starter ST is lowered and made to pass through the molten-metal passage section 103 of the shape defining member 102, and the tip of the starter ST is submerged into the molten metal M1.

[0031] Next, the starter ST starts to be pulled up at a predetermined speed. Note that even when the starter ST is pulled away from the molten-metal surface, the molten metal M1 follows the starter ST and is pulled up from the molten-metal surface by the surface film, the surface tension, and the like, thus forming the held molten metal M2. As shown in Fig. 1, the held molten metal M2 is formed in the molten-metal passage section 103 of the shape defining member 102. That is, the held molten metal M2 is shaped into a given shape by the shape defining member 102.

[0032] Next, since the starter ST is cooled by the cooling gas blown from the cooling gas nozzle 106, the held molten metal M2 successively solidifies from its upper side toward its lower side. As a result, the cast metal M3 grows.

[0033] It should be noted that at the start of the casting, the pulling-up speed is accelerated (i.e., increased) from a standstill state to a desired pulling-up speed (i.e., an appropriate pulling-up speed corresponding to cooling power by the cooling gas nozzle 106). One of the features of the free casting method according to the first exemplary embodiment lies in the pulling-up speed acceleration method at the start of the casting. The pulling-up speed acceleration method at the start of the casting is explained hereinafter with reference to Fig. 3.

[0034] Fig. 3 is a schematic graph showing a pulling-up speed acceleration method according to the first exemplary embodiment. The horizontal axis indicates the time and the vertical axis indicates the pulling-up speed (mm/s). In Fig. 3, a case where the starter is continuously accelerated at an acceleration a1 is indicated by an alternate long and short dash line for a comparison. In such a case, a tearing occurs in the held molten metal M2 before the pulling-up speed of the starter reaches a maximum pulling-up speed Vmax, which is the appropriate pulling-up speed corresponding to the cooling power by the cooling gas nozzle 106. Here, the acceleration a1 is, for example, the maximum acceleration that the pulling-up machine 108 can deliver. In Fig. 3, a tearing occurs in the held molten metal M2 at the point when the pulling-up speed reaches a speed V1.

[0035] Further, in Fig. 3, another case where the starter is continuously accelerated at an acceleration a2 to prevent the tearing of the held molten metal M2 is indicated by another alternate long and short dash line for a comparison. Here, the acceleration a2 is the maximum acceleration at which the pulling-up speed can reach the maximum pulling-up speed Vmax without causing any tearing in the held molten metal M2 even when the starter is continuously accelerated from the standstill state at that acceleration. That is, if the starter is continuously accelerated from the standstill state at an acceleration higher than the acceleration a2, a tearing occurs in the held molten metal M2 before the pulling-up speed reaches the maximum pulling-up speed Vmax. On the other hand, if the starter is continuously accelerated from the standstill state at an acceleration equal to or lower than the acceleration a2, the pulling-up speed can reach the maximum pulling-up speed Vmax without causing any tearing in the held molten metal M2. As shown in Fig. 3, when the starter is continuously accelerated at the acceleration a2, the pulling-up speed reaches the maximum pulling-up speed Vmax at a time t2. Therefore, productivity is poor.

[0036] Therefore, in the free casting method according to the first exemplary embodiment, a constant-speed operation section is provided between acceleration operation sections in order to improve productivity while preventing the held molten metal M2 from being torn apart. Specifically, in Fig. 3, the pulling-up operation is switched from the acceleration operation, in which the starter is accelerated at the acceleration a1, to the constant-speed operation before the pulling-up speed reaches the speed V1 at which a tearing would otherwise occur in the held molten metal M2. In Fig. 3, the pulling-up operation is switched to the constant-speed operation at the point when the pulling-up speed reaches a speed V11 (< V1). Note that the speed V11 is lower than the maximum pulling-up speed Vmax corresponding to the cooling power. Therefore, the position of the solidification interface SIF is lowered in the constant-speed operation section in which the starter is pulled up at the speed V11.

[0037] After the pulling-up speed is kept at the speed V11 for a predetermined period, the pulling-up operation is switched from the constant-speed operation to the acceleration operation in which the starter is accelerated at the acceleration a1 again. By providing the constant-speed operation section and thereby lowering the position of the solidification interface SIF, the tearing of the held molten metal M2, which would otherwise occur at the speed V1, can be prevented after the acceleration operation in which the starter is accelerated at the acceleration a1 is resumed. The acceleration in this acceleration operation section does not necessarily have to be equal to the acceleration in the previous acceleration operation section. However, the accelerations in both of the acceleration operation sections are preferably higher than the acceleration a2 in view of the resulting improvement in productivity. In other words, in view of the resulting improvement in the productivity, the acceleration in the acceleration operation section is preferably an acceleration that will cause a tearing in the held molten metal M2 before the pulling-up speed reaches the maximum pulling-up speed Vmax if the starter is continuously accelerated from the standstill state at that acceleration.

[0038] Further, in the example shown in Fig. 3, the pulling-up operation is switched to a constant-speed operation again at the point when the pulling-up speed reaches a speed V12 (> V1). After that, the pulling-up operation is switched to an acceleration operation in which the starter is accelerated at the acceleration a1 again and the pulling-up speed is eventually increased to the maximum pulling-up speed Vmax. That is, two constant-speed operation sections are provided. It should be noted that the number of constant-speed operation sections is preferably as small as possible in view of productivity. On the other hand, there are cases in which if the number of constant-speed operation sections is only one, a tearing occurs in the held molten metal M2 before the pulling-up speed reaches the maximum pulling-up speed Vmax. Therefore, a plurality of constant-speed operation sections may be provided in order to increase the pulling-up speed to the maximum pulling-up speed Vmax while preventing the held molten metal M2 from being torn apart.

[0039] Further, productivity can be improved by reducing the length of each constant-speed operation section. On the other hand, if the constant-speed operation section is too short, the position of the solidification interface SIF is not sufficiently lowered in the constant-speed operation section. As a result, a tearing is likely to occur in the held molten metal M2 when the pulling-up operation is switched to the acceleration operation.

[0040] Further, in the free casting method according to the first exemplary embodiment, the starter is accelerated at an acceleration that is higher than the acceleration a2 at which no tearing occurs in the held molten metal M2 even when the starter is continuously accelerated at that acceleration. Therefore, as shown in Fig. 3, the pulling-up speed reaches the maximum pulling-up speed Vmax at a time t1 (< t2). Therefore, productivity is excellent.

(Modified example 1 of first exemplary embodiment)

[0041] Next, a free casting method according to a modified example 1 of the first exemplary embodiment is explained with reference to Fig. 4. Fig. 4 is a schematic graph showing a pulling-up speed acceleration method according to the modified example 1 of the first exemplary embodiment. In Fig. 4, a case where the starter is continuously accelerated at an acceleration a3, which is lower than the acceleration a1 and higher than the acceleration a2, is indicated by another alternate long and short dash line for a comparison. If the starter is continuously accelerated at the acceleration a3, a tearing occurs in the held molten metal M2 before the pulling-up speed reaches the maximum pulling-up speed Vmax. However, as shown in Fig. 4, the tearing occurs in the held molten metal M2 at the point when the pulling-up speed reaches a speed V2 higher than the speed V1.

[0042] Therefore, in the free casting method according to the modified example 1 of the first exemplary embodiment, the pulling-up operation is switched to the constant-speed operation at the point when the pulling-up speed reaches a speed V21 that is higher than the speed V1 and lower than the speed V2. That is, in the example shown in Fig. 4, while the acceleration is lower than that in the example shown in Fig. 3, the number of constant-speed operation sections is only one. As shown above, the number of constant-speed operation sections is preferably optimized according to the acceleration. Further, the casting process is preferably started with the acceleration a3, which is lower than the acceleration a1, because a tearing is more likely to occur in the held molten metal M2 immediately after the casting process is started.

(Modified example 2 of first exemplary embodiment)

[0043] Next, a free casting method according to a modified example 2 of the first exemplary embodiment is explained with reference to Fig. 5. Fig. 5 is a schematic graph showing a pulling-up speed acceleration method according to the modified example 2 of the first exemplary embodiment. In Fig. 4, the acceleration before the constant-speed operation section and the acceleration after the constant-speed operation section are both the acceleration a3. In contrast to this, in Fig. 5, the acceleration after the constant-speed operation section is the acceleration a1, which is higher than the acceleration a3 which is the acceleration before the constant-speed operation section. This makes a time t4 at which the pulling-up speed reaches the maximum pulling-up speed Vmax in the modified example 2 earlier than the time t3 at which the pulling-up speed reaches the maximum pulling-up speed Vmax in the modified example 1. That is, the productivity in the free casting method according to the modified example 2 is higher than that in the free casting method according to the modified example 1.

[0044] As has been explained above, in the free casting method according to the first exemplary embodiment, a constant-speed operation section(s) is provided between acceleration operations at the start of the casting. This can prevent the held molten metal M2 from being torn apart even when the starter is accelerated at an acceleration that will cause a tearing in the held molten metal M2 if the starter is continuously accelerated at that acceleration. Further, the pulling-up speed can be increased to the maximum pulling-up speed Vmax in a shorter time period than the time period that is required in the related art. Therefore, productivity is excellent.

(Second exemplary embodiment)

[0045] Next, a free casting apparatus according to a second exemplary embodiment is explained with reference to Figs. 6 and 7. Fig. 6 is a plan view of a shape defining member 102 according to the second exemplary embodiment. Fig. 7 is a side view of the shape defining member 102 according to the second exemplary embodiment. Note that the xyz-coordinate systems shown in Figs. 6 and 7 correspond to that shown in Fig. 1.

[0046] The shape defining member 102 according to the first exemplary embodiment shown in Fig. 2 is composed of one plate. Therefore, the thickness t1 and the width w1 of the molten-metal passage section 103 are fixed. In contrast to this, the shape defining member 102 according to the second exemplary embodiment includes four rectangular shape defining plates 102a, 102b, 102c and 102d as shown in Fig. 6. That is, the shape defining member 102 according to the second exemplary embodiment is divided into a plurality of sections. With this configuration, it is possible to change the thickness t1 and the width w1 of the molten-metal passage section 103. Further, the four rectangular shape defining plates 102a, 102b, 102c and 102d can be moved in unison in the z-axis direction.

[0047] As shown in Fig. 6, the shape defining plates 102a and 102b are arranged to be opposed to each other in the x-axis direction. Further, as shown in Fig. 7, the shape defining plates 102a and 102b are disposed at the same height in the z-axis direction. The gap between the shape defining plates 102a and 102b defines the width w1 of the molten-metal passage section 103. Further, since each of the shape defining plates 102a and 102b can be independently moved in the x-axis direction, the width w1 can be changed. Note that, as shown in Figs. 6 and 7, a laser displacement gauge S1 and a laser reflector plate S2 may be provided on the shape defining plates 102a and 102b, respectively, in order to measure the width w1 of the molten-metal passage section 103.

[0048] Further, as shown in Fig. 6, the shape defining plates 102c and 102d are arranged to be opposed to each other in the y-axis direction. Further, the shape defining plates 102c and 102c are disposed at the same height in the z-axis direction. The gap between the shape defining plates 102c and 102d defines the thickness t1 of the molten-metal passage section 103. Further, since each of the shape defining plates 102c and 102d can be independently moved in the y-axis direction, the thickness t1 can be changed.

[0049] The shape defining plates 102a and 102b are disposed in such a manner that they are in contact with the top sides of the shape defining plates 102c and 102d.

[0050] Next, a driving mechanism for the shape defining plate 102a is explained with reference to Figs. 6 and

7. As shown in Figs. 6 and 7, the driving mechanism for the shape defining plate 102a includes slide tables T1 and T2, linear guides G11, G12, G21 and G22, actuators A1 and A2, and rods R1 and R2. Note that although each of the shape defining plates 102b, 102c and 102d also includes its driving mechanism as in the case of the shape defining plate 102a, the illustration of them is omitted in Figs. 6 and 7.

[0051] As shown in Figs. 6 and 7, the shape defining plate 102a is placed and fixed on the slide table T1, which can be slid in the x-axis direction. The slide table T1 is slidably placed on a pair of linear guides G11 and G12 extending in parallel with the x-axis direction. Further, the slide table T1 is connected to the rod R1 extending from the actuator A1 in the x-axis direction. With the above-described configuration, the shape defining plate 102a can be slid in the x-axis direction.

[0052] Further, as shown in Figs. 6 and 7, the linear guides G11 and G12 and the actuator A1 are placed and fixed on the slide table T2, which can be slid in the z-axis direction. The slide table T2 is slidably placed on a pair of linear guides G21 and G22 extending in parallel with the z-axis direction. Further, the slide table T2 is connected to the rod R2 extending from the actuator A2 in the z-axis direction. The linear guides G21 and G22 and the actuator A2 are fixed on a horizontal floor surface or a horizontal pedestal (not shown). With the above-described configuration, the shape defining plate 102a can be slid in the z-axis direction. Note that examples of the actuators A1 and A2 include a hydraulic cylinder, an air cylinder, and a motor.

[0053] As has been explained above, in the free casting apparatus according to the second exemplary embodiment, the shape of the molten-metal passage section 103 can be changed. Therefore, the cross-sectional shape of the cast metal M3 can be changed during the casting process.

[0054] Further, control may be performed so that the shape of the molten-metal passage section 103 is reduced in size in the acceleration operation section at the start of the casting. The tearing in the held molten metal M2 can be prevented or reduced even further by reducing the mass of the held molten metal M2.

[0055] Note that the present invention is not limited to the above-described exemplary embodiments, and various modifications can be made without departing the spirit and scope of the present invention.

[0056] For example, the present invention can be applied to a pulling-up-type continuous casting method in which the shape defining member 102 is not used, provided that the molten metal is pulled up by using a starter ST in the pulling-up-type continuous casting method.

[0057] This application is based upon and claims the benefit of priority from Japanese patent application No. 2013-158202, filed on July 30, 2013, the disclosure of which is incorporated herein in its entirety by reference.

Reference Signs List

[0058]

101 MOLTEN METAL HOLDING FURNACE
102 SHAPE DEFINING MEMBER
102a-102d SHAPE DEFINING PLATE
103 MOLTEN-METAL PASSAGE SECTION
104 SUPPORT ROD
105 ACTUATOR
106 COOLING GAS NOZZLE
108 PULLING-UP MACHINE
A1, A2 ACTUATOR
G11, G12, G21, G22 LINEAR GUIDE
M1 MOLTEN METAL
M2 HELD MOLTEN METAL
M3 CAST METAL
R1, R2 ROD
S1 LASER DISPLACEMENT GAUGE
S2 LASER REFLECTOR PLATE
SIF SOLIDIFICATION INTERFACE
ST STARTER
T1, T2 SLIDE TABLE

Claims

1. A pulling-up-type continuous casting method for pulling up molten metal held in a holding furnace by using a starter, wherein
when the starter is accelerated to a predetermined pulling-up speed at a start of casting, the pulling-up-type continuous casting method includes:

   a first acceleration section in which the starter is accelerated from a standstill state to a first speed at a first acceleration;
   a second acceleration section in which the starter is accelerated from the first speed to a second speed at a second acceleration; and
   a constant speed section in which the starter is pulled up at the first speed, the constant speed section being positioned between the first and second acceleration sections.

2. The pulling-up-type continuous casting method according to Claim 1, wherein
the first acceleration is an acceleration that will cause a tearing in the molten metal pulled-up by the starter before the pulling-up speed of the starter reaches the predetermined pulling-up speed if the starter is continuously accelerated from the standstill state at that acceleration, and
the second acceleration is an acceleration that will cause a tearing in the molten metal pulled-up by the starter before the pulling-up speed of the starter reaches the predetermined pulling-up speed if the starter is continuously accelerated from the standstill

state at that acceleration.

3. The pulling-up-type continuous casting method according to Claim 1 or 2, wherein the first and second accelerations are equal to each other.

4. The pulling-up-type continuous casting method according to Claim 3, wherein each of the first and second accelerations is a maximum acceleration that a pulling-up machine that pulls up the starter can deliver.

5. The pulling-up-type continuous casting method according to any one of Claims 1 to 4, wherein the pulling-up-type continuous casting method further includes:

   a third acceleration section in which the starter is accelerated from the second speed to a third speed at a third acceleration; and
   a constant speed section in which the starter is pulled up at the second speed, the constant speed section being positioned between the second and third acceleration sections.

6. The pulling-up-type continuous casting method according to Claim 1 or 2, wherein the second acceleration is higher than the first acceleration.

7. The pulling-up-type continuous casting method according to Claim 6, wherein the second acceleration is a maximum acceleration that a pulling-up machine that pulls up the starter can deliver.

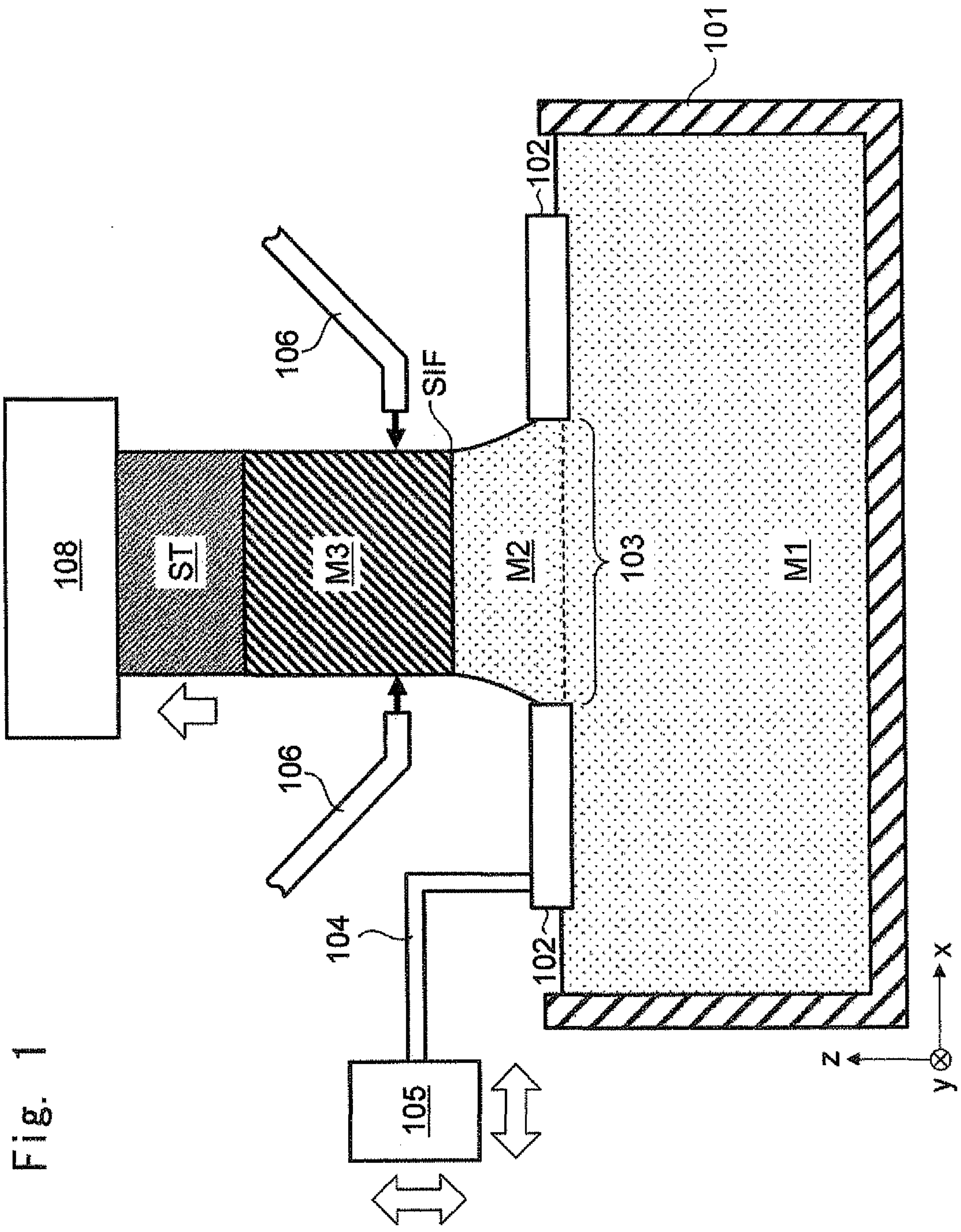


Fig. 1

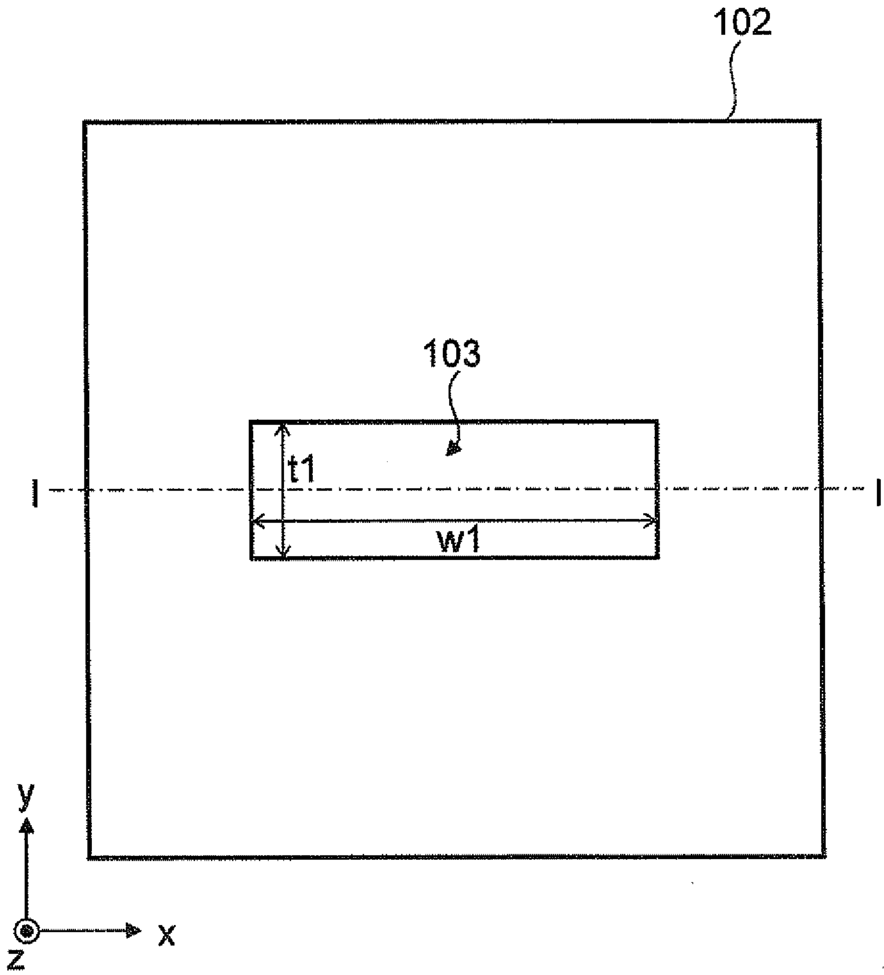
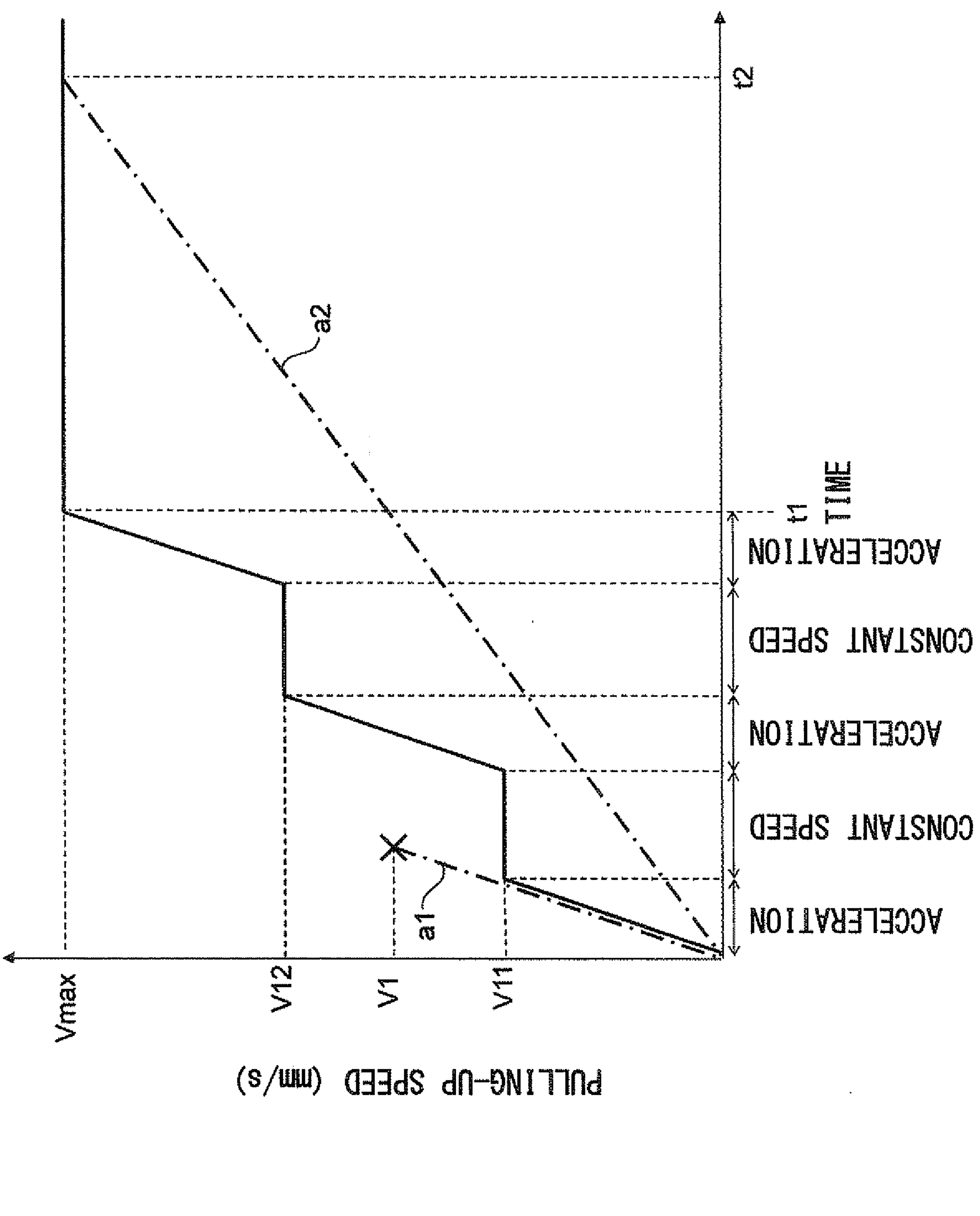


Fig. 2

Fig. 3



PULLING-UP SPEED (mm/s)
Vmax
V12
V1
V11
a1
a2
ACCELERATION
CONSTANT SPEED
ACCELERATION
CONSTANT SPEED
ACCELERATION
t1
TIME
t2

Fig. 4

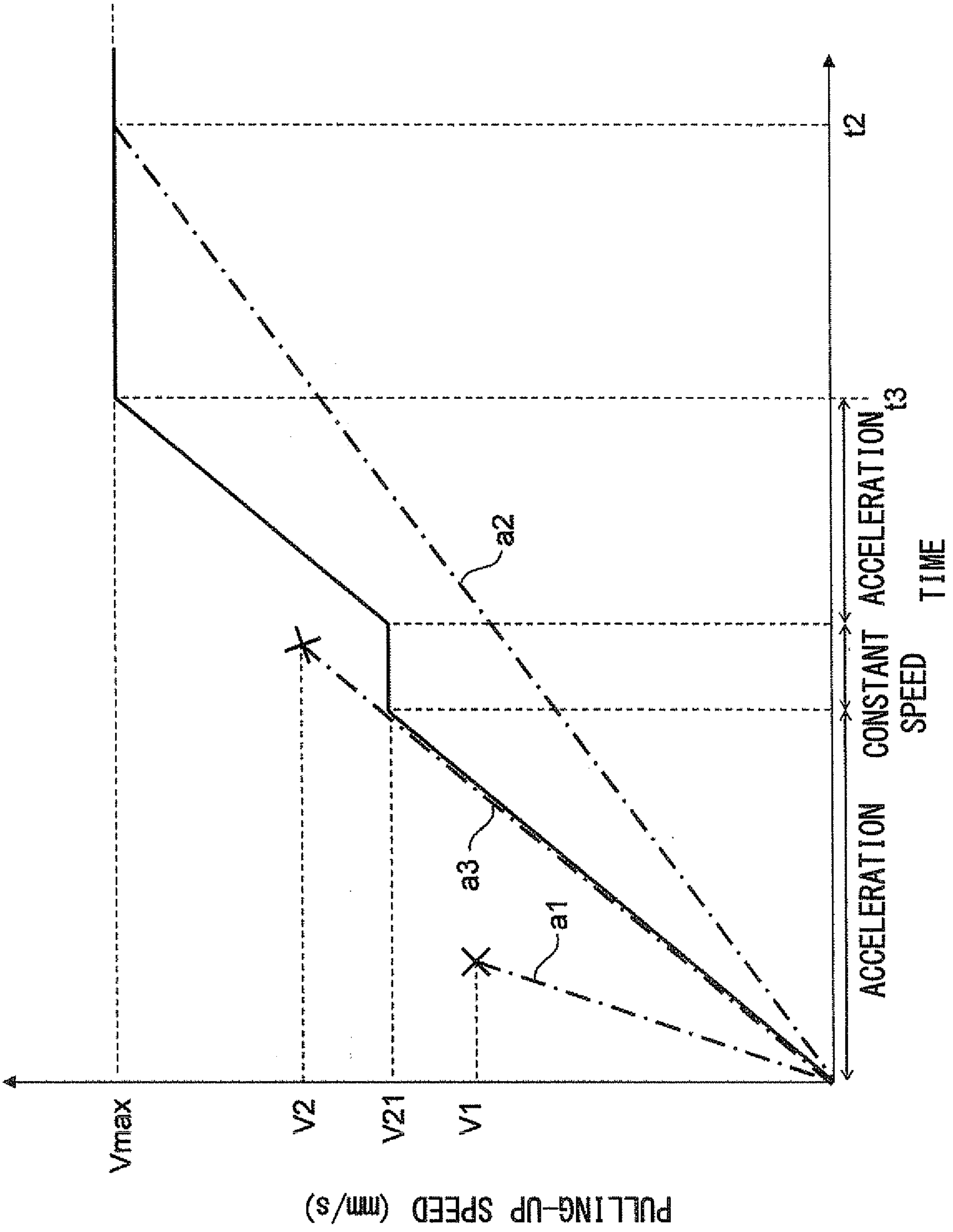

PULLING-UP SPEED (mm/s)
Vmax
V2
V21
V1
a1
a2
a3
ACCELERATION
CONSTANT SPEED
ACCELERATION
t3
t2
TIME

Fig. 5

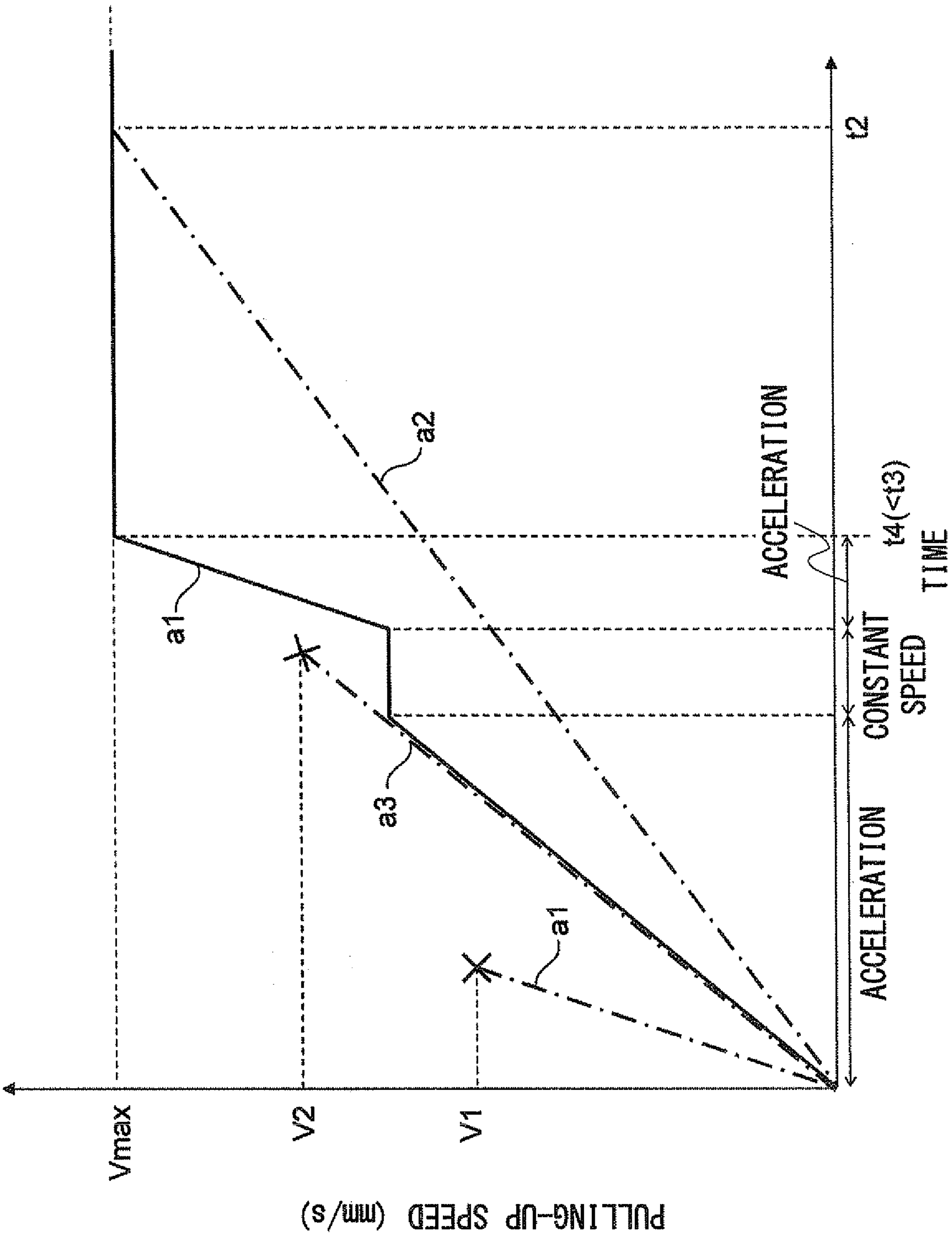
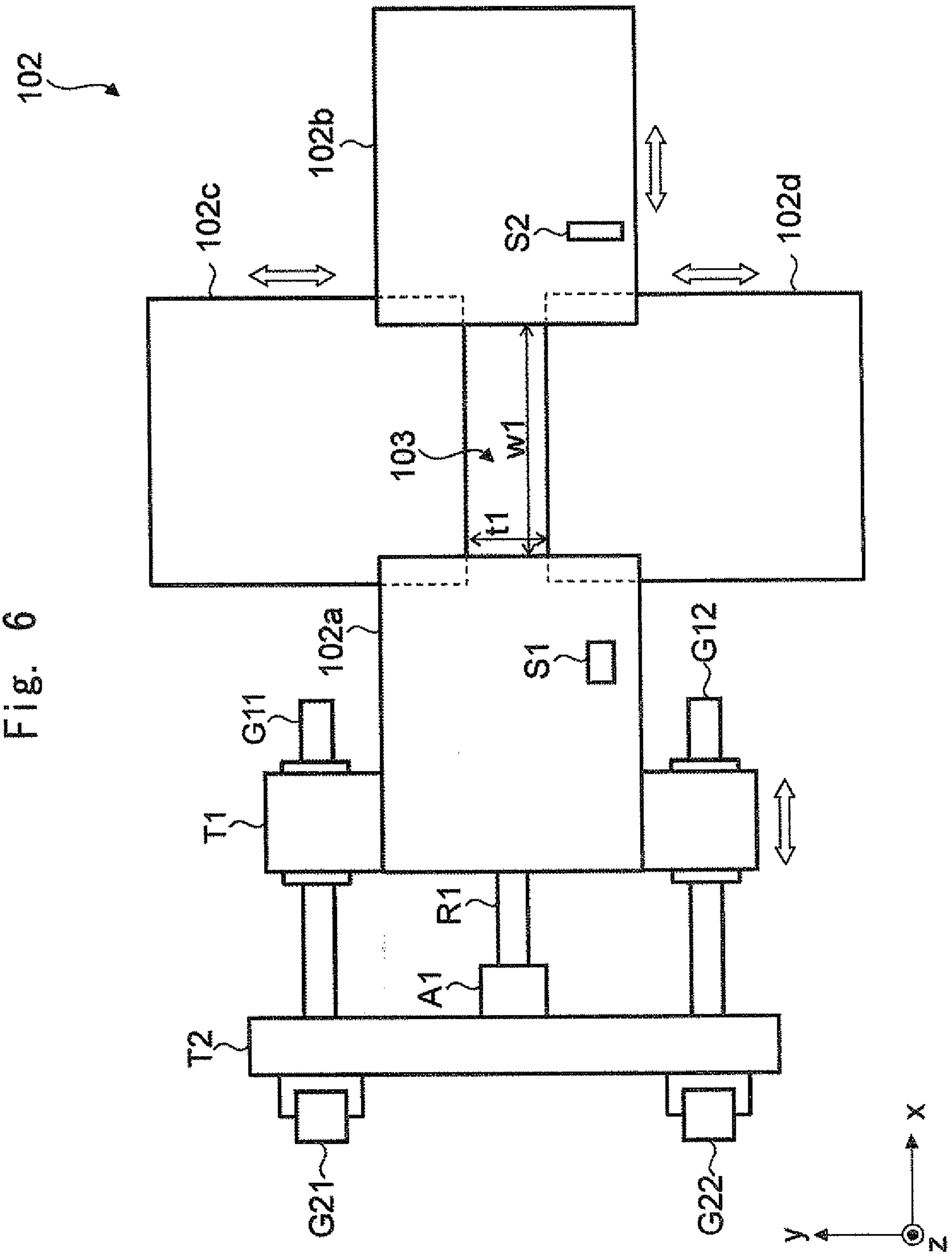

PULLING-UP SPEED (mm/s)
Vmax
V2
V1
a1
a2
a3
a1
t2
t4(<t3)
ACCELERATION
CONSTANT SPEED
ACCELERATION
TIME

Fig. 6


102
102b
102c
102d
S2
103
w1
t1
102a
S1
G11
G12
T1
R1
A1
T2
G21
G22
x
y
z

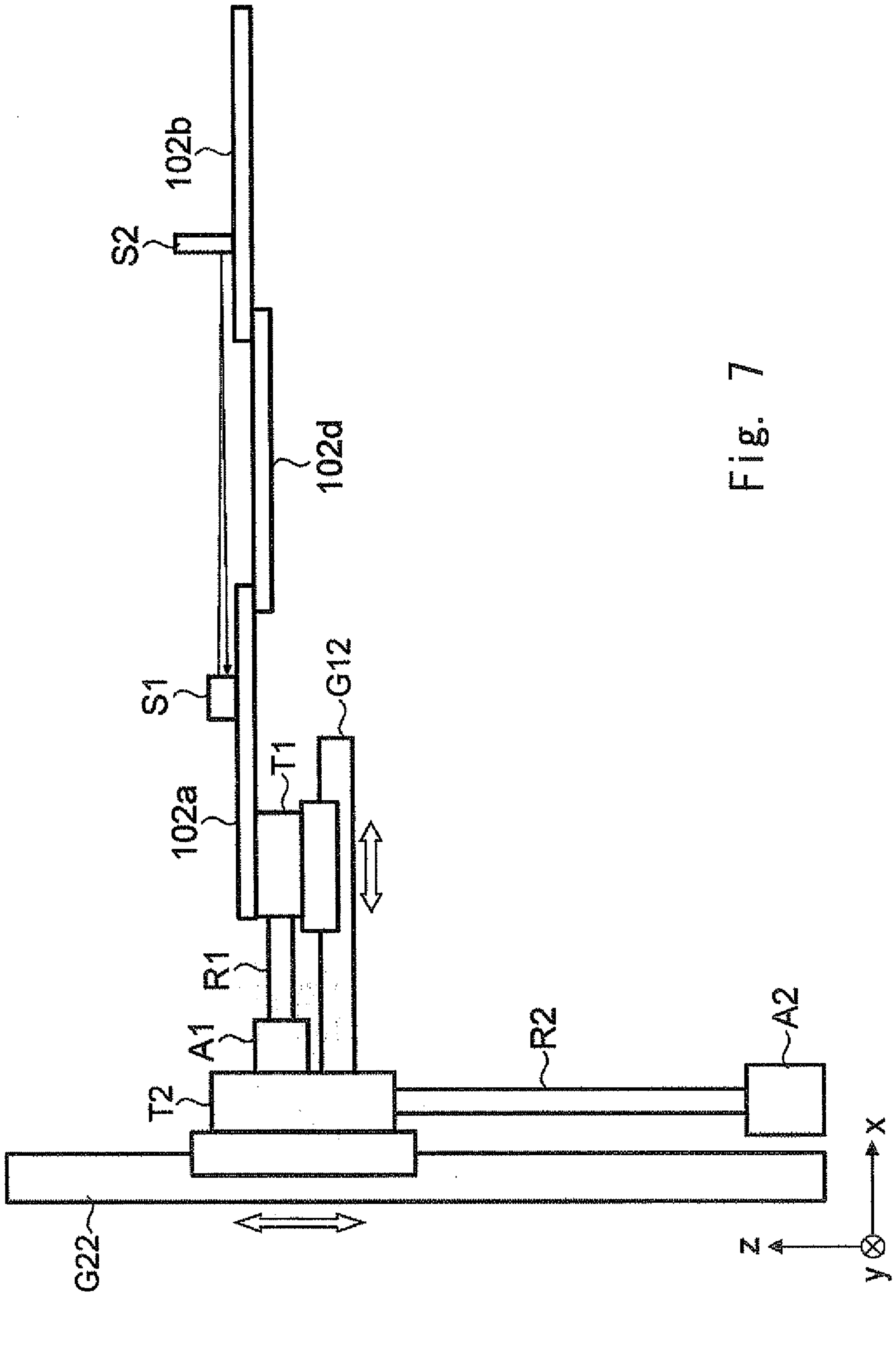


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/003010

A. CLASSIFICATION OF SUBJECT MATTER
B22D11/01(2006.01)i, *B22D11/04*(2006.01)i, *B22D11/20*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B22D11/01, B22D11/04, B22D11/20

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2014
Kokai Jitsuyo Shinan Koho	1971-2014	Toroku Jitsuyo Shinan Koho	1994-2014

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2012-61518 A (Toyota Central Research and Development Laboratories, Inc.), 29 March 2012 (29.03.2012), paragraphs [0008] to [0054]; fig. 1, 2 & US 2013/0171021 A1 & WO 2012/035752 A1	1-7
A	JP 4-81666 A (Kubota Corp.), 16 March 1992 (16.03.1992), Detailed Explanation of the Invention; fig. 1, 5 (Family: none)	1-7
A	JP 59-169651 A (Kabushiki Kaisha OCC), 25 September 1984 (25.09.1984), Detailed Explanation of the Invention; fig. 3 (Family: none)	1-7

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

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Date of the actual completion of the international search 11 August, 2014 (11.08.14)	Date of mailing of the international search report 19 August, 2014 (19.08.14)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/003010

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2-205232 A (Director General of National Research Institute for Science and Technology Agency), 15 August 1990 (15.08.1990), Detailed Explanation of the Invention; fig. 1 (Family: none)	1-7
A	JP 63-199049 A (Sumitomo Electric Industries, Ltd.), 17 August 1988 (17.08.1988), Detailed Explanation of the Invention; fig. 3 (Family: none)	1-7
A	JP 61-30259 A (General Electric Co.), 12 February 1986 (12.02.1986), Detailed Explanation of the Invention & US 4865116 A & EP 168693 A1	1-7
A	JP 2011-230136 A (JFE Steel Corp.), 17 November 2011 (17.11.2011), paragraphs [0020] to [0040]; fig. 1 (Family: none)	1-7
A	JP 7-185764 A (Sumitomo Metal Industries, Ltd.), 25 July 1995 (25.07.1995), paragraphs [0007] to [0056]; fig. 1, 5, 13 (Family: none)	1-7
A	JP 61-38739 A (Nichidoku Jukogyo Yugen Kaisha), 24 February 1986 (24.02.1986), Detailed Explanation of the Invention; fig. 1 & US 4714106 A & GB 2161730 A & DE 3426168 A1	1-7

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- JP 2012061518 A **[0005]**
- JP 2013158202 A **[0057]**