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(72) Inventors:
• **MAEDA Ryo**
Tokyo 100-8280 (JP)
• **NAKAYAMA Masato**
Tokyo 100-8280 (JP)
• **ABE Takashi**
Tokyo 100-8280 (JP)

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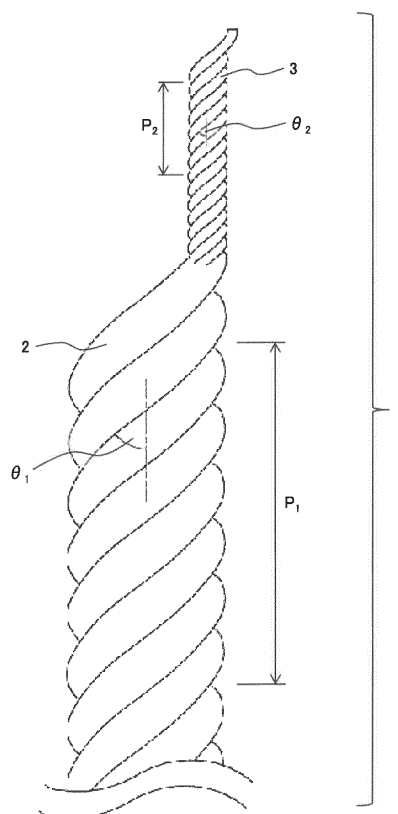
(74) Representative: **MERH-IP Matias Erny Reichl Hoffmann**
Patentanwälte PartG mbB
Paul-Heyse-Strasse 29
80336 München (DE)

(71) Applicant: **Hitachi, Ltd.**
Tokyo 100-8280 (JP)

(54) **ELEVATOR ROPE**

(57) Elevator ropes that allow reduction of the amount of change of rope elongation that results from a change in rope tension due to passengers getting in and off an elevator even if the breaking strength of ropes is improved to reduce the number of ropes are provided. An elevator rope of the present invention is an elevator rope formed by intertwisting a plurality of strands formed by intertwisting a plurality of steel wires, wherein when a diameter of the elevator rope is defined as d (mm), intervals between turns of the strands are defined as a rope pitch P_1 , and intervals between turns of the steel wires are defined as a strand pitch P_2 , a ratio a of P_1 to d , a ratio b of P_2 to d and a breaking strength T (N) of the elevator rope satisfy the following Formula A. In Formula A explained above, E denotes a modulus of longitudinal elasticity (MPa) of a material used in the elevator rope, G denotes a modulus of transverse elasticity (MPa) of the material used in the elevator rope, and N denotes the number of the strands.

FIG. 1



Description

Technical Field

5 **[0001]** The present invention relates to an elevator rope.

Background Art

10 **[0002]** Generally, an elevator car is suspended by a wire rope (hereinafter, referred to as a "rope" or "elevator rope"). This rope is wound around the drive sheave of a winding machine, and is driven by friction between the rope and the rope groove on the surface of the sheave to raise or lower the car.

[0003] Meanwhile, it is demanded, for example, for a machine-room-less elevator, in which a winding machine is installed in a hoistway, to have a smaller size of the winding machine in order to reduce the cross-sectional area of the hoistway. Means for realizing this include making the drive sheave thinner. Making the drive sheave thinner makes it possible to reduce the dimension of the axial length of the winding machine, and to reduce the size of the winding machine. Because of this, as elevator ropes, high-strength ropes that individually have high breaking strengths and allow reduction of the required number of ropes for suspending a car are demanded.

[0004] As a configuration for realizing high-strength ropes, for example, PTL 1 discloses an elevator main rope including: an IWRC (Independent Wire Rope Core) having a core strand, a plurality of peripheral strands arranged around the core strand, and a covering resin that covers the core strand and the plurality of peripheral strands; and a plurality of main strands arranged around the IWRC. In the elevator main rope, the plurality of peripheral strands are arranged at approximately equal intervals on the circumference of an imaginary-layer core circle on which the center of each of the plurality of peripheral strands is positioned, and the ratio, to the circumferential length of the imaginary-layer core circle, of the sum of gaps between pairs of peripheral strands that are included in the plurality of peripheral strands, and are each adjacent to each other in the circumferential direction of the imaginary-layer core circle is equal to or higher than 8.5%.

[0005] The rope disclosed in PTL 1 is constituted by elementary wires. The elementary wires are made thin by being subjected to wire drawing, and have a breaking strength which is increased to the level of 2300 MPa (the elementary-wire breaking strength of generally widely used elevator ropes is about 1620 to 1910 MPa). The strength of a rope improves in proportion to the elementary-wire strength, which allows reduction of the number of ropes.

Citation List

Patent Literature

35 **[0006]** PTL 1: WO2016/199204

Summary of Invention

Technical Problem

40 **[0007]** The number of ropes to be used for an elevator is determined on the basis of the ratio between the load to be borne per rope and the breaking strength, and improvement in the breaking strength per rope can reduce the number of ropes to be used per elevator. Although there is a method of improving the breaking strength per elementary wire constituting a wire rope as one of methods to improve the breaking strength of wire ropes, the modulus of elasticity per elementary wire is not proportional to the breaking strength, and so the rigidity of entire ropes lowers corresponding to the reduced number of ropes. Accordingly, for example, when the load on ropes changed suddenly due to passengers getting in and off an elevator, the amount of elongation or contraction of the ropes increases, and the ride comfort deteriorates inevitably.

[0008] In order to prevent this, elevator ropes are demanded to have characteristics of being not easily elongated even if tension is applied thereto. However, in PTL 1, attention is paid mainly to improvement of the service life of ropes enabled by suppression of contact between elementary wires having a higher strength, and rope elongation is not considered.

[0009] In view of the circumstance explained above, an object of the present invention is to provide elevator ropes that allow reduction of the amount of change of rope elongation that results from a change in rope tension due to passengers getting in and off an elevator even if the breaking strength of ropes is improved to reduce the number of ropes.

Solution to Problem

[0010] In order to achieve the object explained above, the present invention provides an elevator rope formed by intertwisting a plurality of strands formed by intertwisting a plurality of steel wires, wherein when a diameter of the elevator rope is defined as d (mm), intervals between turns of the strands are defined as a rope pitch P_1 , and intervals between turns of the steel wires are defined as a strand pitch P_2 , a ratio a of P_1 to d , a ratio b of P_2 to d and a breaking strength T (N) of the elevator rope satisfy the following Formula A.

[Equation 1]

$$b \geq \frac{4 \times a \times E \times T}{1.65 \times a \times d^2 \times \pi \times N \times E \times G - 40 \times E \times T - 1.2 \times a \times G \times T} \dots \text{Formula A}$$

[0011] In the formula explained above, E denotes a modulus of longitudinal elasticity (MPa) of a material used in the elevator rope, G denotes a modulus of transverse elasticity (MPa) of the material used in the elevator rope, and N denotes the number of the strands.

[0012] In addition, in order to achieve the object explained above, the present invention provides an elevator rope formed by intertwisting a plurality of strands formed by intertwisting a plurality of steel wires, wherein the steel wires are formed by intertwisting a plurality of elementary wires, and when a diameter of the elevator rope is defined as d (mm), intervals between turns of the strands are defined as a rope pitch P_1 , and intervals between turns of the steel wires are defined as a strand pitch P_2 , a ratio a of P_1 to d , a ratio b of P_2 to d and a breaking strength T (N) of the elevator rope satisfy Formula A explained above.

[0013] Specific configurations of the present invention are described in the scope of claims.

Advantageous Effects of Invention

[0014] The present invention can provide elevator wire ropes that allow reduction of the amount of change of rope elongation that results from a change in rope tension due to passengers getting in and off an elevator even if the breaking strength of ropes is improved to reduce the number of ropes.

[0015] Problems, configurations, and effects other than those explained above become apparent from the following explanation of embodiments.

Brief Description of Drawings

[0016]

Figure 1 is a side view schematically illustrating a first example of an elevator rope of the present invention.

Figure 2 is a side view schematically illustrating a second example of the elevator rope of the present invention.

Figure 3 is a figure illustrating a relationship between tension T and elongation δL_t and δL_p of the elevator rope.

Figure 4 is a cross-sectional schematic diagram of an elevator rope having an outermost layer which is constituted by ten strands.

Figure 5 is a cross-sectional schematic diagram of an elevator rope having an outermost layer which is constituted by six strands.

Figure 6 is a cross-sectional schematic diagram of an elevator rope including strands having outermost layers each constituted by six steel wires.

Figure 7 is a cross-sectional schematic diagram of an elevator rope including strands having outermost layers each constituted by twelve steel wires.

Figure 8 is a cross-sectional schematic diagram of an elevator rope (threefold-twisted) having steel wires formed by twisting elementary wires.

Figure 9 is a graph illustrating a relationship between the strand-pitch multiple and the rope-pitch multiple at the time when the rope-distortion amount is 0.55%.

Figure 10 is a side view schematically illustrating an elevator rope fabricated for a test.

Figure 11 is a graph illustrating a relationship between the rope elongation amount δL_1 , and the rope pitch P_1 and the strand pitch P_2 .

Description of Embodiments

[0017] Hereinafter, embodiments of an elevator wire rope according to the present invention are explained with reference to Figure 1 and Figure 2.

[0018] Figure 1 is a side view schematically illustrating a first example of the elevator rope of the present invention. As illustrated in Figure 1, the elevator rope 1 is formed by intertwisting a plurality of strands 2 formed by intertwisting a plurality of steel wires 3. Figure 1 illustrates only one strand 2 and one steel wire 3 for better visibility of the drawing.

[0019] Although not illustrated in Figure 1, a core (a fiber core, a steel wire core, etc.) is arranged at the center of the elevator rope 1, and the strands 2 are twisted around the core. The plurality of strands 2 are arranged with nearly equal gaps therebetween on the same circumference. The same also applies to the steel wires 3. Note that, other than being arranged circumferentially each in a single layer in radial directions, the strands 2 and the steel wires 3 may be arranged in a plurality of layers such as a two-layer arrangement in which two layers of the strands 2 and/or two layers of the steel wires 3 are arranged on circumferences, a three-layer arrangement in which three layers of the strands 2 and/or three layers of the steel wires 3 are arranged on circumferences, and the like.

[0020] In the present invention, the longitudinal length (interval of turns) of one complete turn of one strand 2 constituting the elevator rope is defined as a rope pitch P_1 , and the longitudinal length (interval of turns) of one complete turn of a steel wire 3 constituting the strand 2 is defined as a strand pitch P_2 . In other words, the rope pitch P_1 is a longitudinal length over which one strand 2 makes one complete turn around the core, and the strand pitch P_2 is a longitudinal length over which one steel wire 3 makes one complete turn around the central axis of a strand.

[0021] Figure 2 is a side view schematically illustrating a second example of the elevator rope of the present invention. Figure 2 illustrates a steel wire 3 formed by intertwisting a plurality of elementary wires 3a. The present invention can also be applied to an elevator rope with such a configuration. The longitudinal length (interval of turns) of one complete turn of an elementary wire 3a constituting the steel wire 3 is defined as a steel-wire pitch P_3 .

[0022] Next, the mechanism of occurrence of elongation of an elevator rope is explained by using Figure 3. Figure 3 is a figure illustrating a relationship between tension T and elongation δL_τ and δL_ρ of the elevator rope. In a case discussed here, the tension T acts on twisted strands in the axial direction of a central axis 30 of the twist. Elongation of the strand 2 observed at this time is given as the sum of the elongation δL_τ produced by a shear force acting on cross-sections of the strand 2 to elongate the twist, and the elongation δL_ρ produced by tension acting in the axial direction of an axis 31 extending in the direction perpendicular to the cross-sections of the strand 2 to generate minute distortions in the strand 2 itself (there is an angle θ° formed between the central axis 30 of the twist and the axis 31 in the direction perpendicular to strand cross-sections).

[0023] Accordingly, elongation δL_1 observed when tension T_1 acts on elevator rope with a length L_1 in the direction of the central axis of the twist of the strand can be expressed by the following Formula (1). Similarly, elongation δL_2 observed when tension T_2 is applied in the direction of the central axis of the twist of a steel wire 3 with a length L_2 can be expressed by the following Formula (2), and elongation δL_3 observed when tension T_3 is applied in the direction of the central axis of the twist of an elementary wire 3a with a length L_3 can be expressed by the following Formula (3).

$$\delta L_1 = \delta L_{1\tau} + \delta L_{1\rho} \quad \text{Formula (1)}$$

$$\delta L_2 = \delta L_{2\tau} + \delta L_{2\rho} \quad \text{Formula (2)}$$

$$\delta L_3 = \delta L_{3\tau} + \delta L_{3\rho} \quad \text{Formula (3)}$$

where L_1 denotes the length (mm) of the twist of the strand in its central-axis direction, L_2 denotes the length (mm) of the twist of the steel wire in its central-axis direction, and L_3 denotes the length (mm) of the twist of the elementary wire in its central-axis direction.

[0024] Since, in a strand constituted by a plurality of steel wires being intertwisted, the direction perpendicular to strand cross-sections coincides with the direction of the central axis of the twist of the steel wires, tension that is applied in the direction perpendicular to the strand cross-sections is a force that is applied in the direction of the central axis of the twist of the steel wires. Therefore, the elongation $\delta L_{1\rho}$ caused by tension on the strand is presumably equal to the elongation δL_2 of the entire steel wires. This relationship also applies to a steel wire constituted by a plurality of elementary wires being intertwisted. By combining the relationships mentioned above, elongation of a twofold-twisted rope (a rope formed by twisting strands and steel wires in Figure 2) can be expressed by Formula (4), and elongation of a threefold-twisted rope (a rope formed by twisting strands, steel wires and elementary wires in Figure 3) can be expressed by

Formula (5).

$$\delta L_1 = \delta L_1 \tau + \delta L_2 \tau + \delta L_3 \rho \quad \text{Formula (4)}$$

$$\delta L_1 = \delta L_1 \tau + \delta L_2 \tau + \delta L_3 \tau + \delta L_3 \rho \quad \text{Formula (5)}$$

[0025] For Formulae (4) and (5), elongation $\delta L_1 \tau$ observed when the tension T_1 is applied in the direction of the central axis of the twist of strands with the length L_1 is obtained from the following Formula (6) where $K_1 \tau$ denotes the spring constant of the strands, and $K_1 \tau$ can be expressed by the following Formula (7). A similar formula is also seen when the spring constant of a coil spring is obtained, for example.

$$\delta L_1 \tau = T_1 / K_1 \tau \quad \text{Formula (6)}$$

$$K_1 \tau = 0.03 \times G \times S_1 / n_1 / d_0 \quad \text{Formula (7)}$$

[0026] Here, G denotes the modulus of transverse elasticity (MPa) of the strands, S_1 denotes the cross-sectional area (mm²) per strand, n_1 denotes the number of twists of the strands per length L_1 , and d_0 denotes the rope diameter (mm).

[0027] Similarly, elongation $\delta L_2 \tau$ observed when the tension T_2 is applied in the direction of the central axis of the twist of steel wires with the length L_2 is obtained from the following Formula (8) where $K_2 \tau$ denotes the spring constant of the steel wires, and $K_2 \tau$ can be expressed by a formula which is the following (9). Furthermore, elongation $\delta L_3 \tau$ observed when the tension T_3 is applied in the direction of the central axis of the twist of elementary wires with the length L_3 is obtained from the following Formula (10) where $K_3 \tau$ denotes the spring constant of the elementary wires, and $K_3 \tau$ can be expressed by a formula which is the following (11). It should be noted, however, that in the case of strands, there are geometrical constraints only in one axial direction (an up/down direction), but in the case of steel wires, there are geometrical constraints in three axial directions (all of an up/down direction, a front/rear direction and a left/right direction) since steel wires are twisted further. Accordingly, as the order of twist increases, the spring constant of steel wires increases, and so multiplication by a constraint coefficient is added.

$$\delta L_2 \tau = T_2 / K_2 \tau \quad \text{Formula (8)}$$

$$K_2 \tau = 0.03 \times \alpha \times G \times S_2 / n_2 / d_0 \quad \text{Formula (9)}$$

[0028] Here, S_2 denotes the cross-sectional area (mm²) per steel wire, n_2 denotes the number of twists of steel wires per length L_2 , and α denotes a constraint coefficient ($\alpha=10$).

$$\delta L_3 \tau = T_3 / K_3 \tau \quad \text{Formula (10)}$$

$$K_3 \tau = 0.03 \times \alpha^2 \times G \times S_3 / n_3 / d_0 \quad \text{Formula (11)}$$

[0029] Here, S_3 denotes the cross-sectional area (mm²) per elementary wire, n_3 denotes the number of twists of elementary wires per length L_3 , and α denotes a constraint coefficient ($\alpha=10$).

[0030] Note that the numbers of twists of strands, steel wires and elementary wires are values determined by the rope pitch P_1 , the strand pitch P_2 , and the steel-wire pitch P_3 , and assuming that the ratio of the rope pitch to the rope diameter d_0 is a (P_1/d_0), the ratio of the strand pitch to the rope diameter d_0 is b (P_2/d_0), and the ratio of the steel-wire pitch to the rope diameter d_0 is c (P_3/d_0), the numbers of twists of strands, steel wires and elementary wires can be expressed by Formulae (12) to (14).

$$n_1 = L_1 / (d_0 \times a) \quad \text{Formula (12)}$$

$$n_2 = L_2 / (d_0 \times b) \quad \text{Formula (13)}$$

$$n_3 = L_3 / (d_0 \times c) \quad \text{Formula (14)}$$

[0031] Next, a relationship between: the rope cross-sectional structure; the strand diameter, the steel-wire diameter, and the elementary-wire diameter; and the strand twist diameter, the steel-wire twist diameter, and the elementary-wire twist diameter is explained by using Figure 4 to Figure 8. Figure 4 is a cross-sectional schematic diagram of an elevator rope having an outermost layer constituted by ten strands. Figure 5 is a cross-sectional schematic diagram of an elevator rope having an outermost layer constituted by six strands. In Figure 4 and Figure 5, the numbers of steel wires of the outermost layers of the strands are nine. In addition, Figure 6 is a cross-sectional schematic diagram of an elevator rope including strands having outermost layers each constituted by six steel wires. Figure 7 is a cross-sectional schematic diagram of an elevator rope including strands having outermost layers each constituted by twelve steel wires. In Figure 6 and Figure 7, the numbers of strands at the outermost layers of the elevator ropes are eight. Furthermore, Figure 8 is a cross-sectional schematic diagram of an elevator rope (threefold-twisted) having steel wires formed by twisting elementary wires.

[0032] As illustrated in Figure 4 to Figure 8, strands, steel wires, and elementary wire are arranged almost evenly on circumferences. Accordingly, the strand diameter: d_1 , the steel-wire diameter: d_2 , the elementary-wire diameter: d_3 , the strand twist diameter: D_1 , the steel-wire twist diameter: D_2 , and the elementary-wire twist diameter: D_3 are obtained geometrically, and the relationships of the following Formulae (15) to (17) hold true.

$$d_1 = d_0 \times \sin(\pi/N_1) / (1 + \sin(\pi/N_1))$$

$$D_1 = d_0 - d_1 \quad \text{Formula (15)}$$

[0033] Here, N_1 denotes the number of outermost-layer strands.

$$d_2 = d_1 \times \sin(\pi/N_2) / (1 + \sin(\pi/N_2))$$

$$D_2 = d_1 - d_2 \quad \text{Formula (16)}$$

[0034] Here, N_2 denotes the number of outermost-layer steel wires.

$$d_3 = d_2 \times \sin(\pi/N_3) / (1 + \sin(\pi/N_3))$$

$$D_3 = d_2 - d_3 \quad \text{Formula (17)}$$

[0035] Here, N_3 denotes the number of outermost-layer elementary wires.

[0036] Next, tension to be applied per outermost-layer strand, outermost-layer steel wire, and outermost-layer elementary wire when tension T_0 is applied to a rope is obtained. The tension is determined by the ratios of the cross-sectional areas of strands, steel wires, and elementary wires, and can be obtained geometrically. When the tension to act on outermost-layer strands is defined as T_1 , the tension to act on outermost-layer steel wires is defined as T_2 , and the tension to act on outermost-layer elementary wires is defined as T_3 , T_1 , T_2 and T_3 can be expressed by formulae which are the following (18) to (20).

$$T_1 = T_0 / N_1 \quad \text{Formula (18)}$$

$$T_2 = T_1 \times (S_2 / S_1) \quad \text{Formula (19)}$$

$$T_3 = T_2 \times (S_3 / S_2) \quad \text{Formula (20)}$$

[0037] Next, a relationship between the strand, steel-wire, and elementary-wire twist angles of is explained. The twist angles are determined by the rope pitch P_1 , the strand pitch P_2 , the steel-wire pitch P_3 , the strand twist diameter, the steel-wire twist diameter, and the elementary-wire twist diameter, and can be expressed by the following Formulae (21) to (23).

$$\theta_1 = \tan^{-1} (D_1 \times \pi / (d_0 \times a)) \quad \text{Formula (21)}$$

$$\theta_2 = \tan^{-1} (D_2 \times \pi / (d_0 \times b)) \quad \text{Formula (22)}$$

$$\theta_3 = \tan^{-1} (D_3 \times \pi / (d_0 \times c)) \quad \text{Formula (23)}$$

[0038] Here, θ_1 denotes the strand twist angle (rad), θ_2 denotes the steel-wire twist angle (rad), and θ_3 denotes the elementary-wire twist angle (rad).

[0039] In addition, the lengths of strands, steel wires, and elementary wires can be obtained by uses their twist angles. In a strand constituted by intertwisting a plurality of steel wires, the length of the spiral of a twisted strand (the length of the strand when it is pulled tight) and the length of the twist of the steel wires in its central-axis direction are equal to each other. Similarly, in a steel wire constituted by intertwisting a plurality of elementary wires, the length of the spiral of a twisted steel wire (the length of the steel wire when it is pulled tight) and the length of the twist of the elementary wires in its central-axis direction are equal to each other. Accordingly, a relationship between the length of a strand in its central-axis direction: L_1 , the length of a steel wire in its central-axis direction: L_2 and the length of an elementary wire in its central-axis direction: L_3 can be expressed by the following Formulae (24) and (25).

$$L_2 = L_1 / \cos \theta_1 \quad \text{Formula (24)}$$

$$L_3 = L_2 / \cos \theta_2 \quad \text{Formula (25)}$$

[0040] Next, taking into consideration that the central axis of the twist of the steel wire and the perpendicular axis of a cross-section of the steel wire are angled relative to each other due to the twist of the steel wire, elongation δL_{2p} observed when the tension T_2 is applied in the direction of the central axis of the twist of a steel wire with the length L_2 can be obtained according to the following Formula (26) where K_{2p} denotes the spring constant of the steel wire, and K_{2p} can be expressed by the following Formula (27).

$$\delta L_{2p} = T_2 \times \cos \theta_2 / K_{2p} \quad \text{Formula (26)}$$

$$K_{2p} = E \times S_2 / (L_2 / \cos \theta_2) \quad \text{Formula (27)}$$

[0041] Here, E denotes the modulus of longitudinal elasticity (MPa) of the steel wire.

[0042] Similarly, taking into consideration that the central axis of the twist of the elementary wire and the perpendicular axis of a cross-section of the elementary wire are angled relative to each other due to the twist of the elementary wire, elongation δL_{3p} observed when the tension T_3 is applied in the direction of the central axis of the twist of a elementary wire with the length L_3 can be obtained according to the following Formula (28) where K_{3p} denotes the spring constant of the steel wire, and K_{3p} can be expressed by Formula (29).

$$\delta L_{3p} = T_3 \times \cos \theta_3 / K_{3p} \quad \text{Formula (28)}$$

$$K_{3p} = E \times S_3 / (L_3 / \cos \theta_3) \quad \text{Formula (29)}$$

[0043] Accordingly, by combining the calculation formulae of the Formula (1) to Formula (29) mentioned above, the

elongation amount: δL_1 observed when tension: T_0 is applied to a twofold-twisted rope with a rope diameter: d_0 and a length: L_1 which is constituted by N_1 strands and N_2 steel wires that are twisted at the ratio: a of the rope pitch to the rope diameter and at the ratio: b of the strand pitch to the rope diameter can be expressed by the following Formula (30). [Equation 2]

$$\frac{\delta L_1}{L_1} = \frac{4 T_0}{d_0^2 \pi N_1 E} \left(\frac{E \times 10^2}{3 a G} + \frac{E \times 10^1}{3 b G} + 1 \right) \quad \dots \text{Formula (30)}$$

[0044] Similarly, the elongation amount: δL_1 observed when tension: T_0 is applied to a threefold-twisted rope with a rope diameter: d_0 and a length: L_1 which is constituted by N_1 strands, N_2 steel wires, and N_3 elementary wires that are twisted at the ratio: a of the rope pitch to the rope diameter, the ratio: b of the strand pitch to the rope diameter, and the ratio c of the steel-wire pitch to the rope diameter can be expressed by the following Formula (31). [Equation 3]

$$\frac{\delta L_1}{L_1} = \frac{4 T_0}{d_0^2 \pi N_1 E} \left(\frac{E \times 10^2}{3 a G} + \frac{E \times 10^1}{3 b G} + \frac{E \times 10^0}{3 c G} + 1 \right) \quad \dots \text{Formula (31)}$$

[0045] From Formulae (30) and (31) mentioned above, it can be found that while the distortion amounts of both the twofold-twisted rope and the threefold-twisted rope decrease as the number of strands: N_1 increases, the number of steel wires: N_2 and the number of elementary wires: N_3 do not affect the rope distortion amounts. This is because while rope cross-sectional areas increase as the numbers of strands increase, the rope cross-sectional areas barely change even if the number of steel wires or the number of elementary wires is increased or decreased. Accordingly, when rope elongation is examined, it is not necessary to consider the number of steel wires: N_2 and the number of elementary wires: N_3 .

[0046] In addition, as Formulae (9) and (10) mentioned above indicate about twist pitches, rope elongation is affected less as the order of twist increases. With the ratio of steel-wire pitch: c , the influence is merely 1/100 of the ratio of rope pitch: a , which influence is a very small value. Accordingly, the steel-wire twist pitch can presumably be neglected in examination of rope elongation. Therefore, in the present invention, the rope pitch ratio a and the strand pitch ratio b may be defined, and so the ratio c of the pitch of steel wires which constitute the inside of a strand does not have to be considered.

[0047] If rope breaking strength is improved according to the principles explained above, about the problem that the load to be borne per rope increases and the rope elongation (rope-distortion amount) increases inevitably, it can be found from Formula (30) and Formula (31) mentioned above that the rope-distortion amount can be reduced by increasing the rope pitch P_1 and the strand pitch P_2 .

[0048] That is, as mentioned above, elongation that is produced by applying a load on twisted steel wires is the sum of elongation produced by elongation of the twist due to a shear force acting on rope cross-sections, and elongation produced by minute distortions of a strand itself due to a tension acting in the direction perpendicular to cross-sections. Therefore, by making the pitches of twists longer, it is possible to reduce elongation produced by the twists being elongated, and to suppress the overall elongation of the rope.

[0049] The configuration of an elevator rope in the present invention (the numbers of strands, steel wires and elementary wires) is arbitrary. In addition, twist pitches (of the steel wire 3 in the present invention) other than the outer two pieces (the rope 1 and the strand 2 in the present invention) constituting the elevator rope need not be considered in the present invention. For example, other than the configurations illustrated in Figure 1 and Figure 2, there is also a configuration of an elevator rope formed by intertwisting a plurality of unit ropes formed by intertwisting a plurality of strands, and in this case, twists of the elevator rope and the unit ropes may be made longer.

[0050] On the other hand, since as the rope pitch, the strand pitch, and the steel-wire pitch are made longer, the numbers of times of twist decrease, and it becomes easier for the twists to be untwisted, the form of a rope cannot be maintained in some cases. In that case, it becomes possible to keep the rope shape by covering the rope with plastic and/or resin.

[0051] Next, a design of an elevator rope by using Formulae (30) and (31) explained above is explained. Since if the distortion amount of a rope increases in an elevator, not only ride comfort is affected, but also the risk of stumbles at a step when passengers get in the car increases, a most relevelling apparatus is provided. However, there is a fear that toes and the like are caught by the floor if floor-levelling operation becomes too large, the variation of the car-floor has to be kept at or smaller than 75 mm (the value defined in Notice No. 1429 issued by the Japanese Ministry of Construction in 2000, "About Stipulation of Structural Method for Controller of Elevator").

[0052] Here, it is assumed that the tolerated rope-distortion amount is 0.092% when the distance to be travelled by an elevator in a typical high-rise apartment/office building: 80 m is used as a reference distance, and in addition the change amount of a load in the car is the rope factor of safety: 12 and the rope factor of safety: 10 (the minimum value of the safety value stipulated in the Building Standards Act). At this time, the tolerated distortion amount in a case where a rope having not been receiving a load is brought into the state of the factor of safety: 10 is 0.55%. Therefore, attaining the factor of safety of 10 or higher requires making the rope-distortion amount 0.55% or smaller.

[0053] Figure 9 is a graph illustrating a relationship between the strand-pitch multiple and the rope-pitch multiple at the time when the rope-distortion amount is 0.55%. The graph illustrates cases where the breaking strength of the material of steel wires is examined for four conditions which are 1770 MPa, 1910 MPa or lower, 2300 MPa or lower, and 3200 MPa. In the graph in Figure 9, the rope-distortion amount is smaller than 0.55% in areas outside each line (areas where the strand-pitch multiple and the rope-pitch multiple are large).

[0054] Here, elevator ropes with the breaking strength of 1770 MPa are "Grade B" (JIS G3525) elevator ropes stipulated in the JIS standards (Japanese Industrial Standards), and elevator ropes with the breaking strength of 1910 MPa are "Grade T" (JIS G3525) elevator ropes stipulated in the JIS. These two types of elevator ropes are generally widely used. Elevator ropes with the breaking strength of 2300 MPa and 3200 MPa have strength still higher than those of the elevator ropes mentioned above that are generally widely used.

[0055] As illustrated in Figure 9, it can be found that as the breaking strength of an elevator rope increases, it becomes necessary to increase the strand pitch and the rope pitch in order to attain the rope-distortion amount of 0.55% or smaller. It can be found that in the present invention, if $P_2=2.5$, and $P_i=17.2$ in a high-strength elevator rope with the breaking strength of 3200 MPa, the rope distortion of 0.55% or smaller can be achieved. In other words, even if elevator ropes are made stronger (breaking strength: 3200 MPa), and the number thereof is reduced, the rope distortion can be made 0.55% or smaller as long as $P_2=2.5$ and $P_i=17.2$, and the amount of change of rope elongation that occurs due to a change in rope tension can be reduced sufficiently.

[0056] Even in a case where strands and steel wires having breaking strengths other than those explained above are used, the rope pitch P_1 and the strand pitch P_2 that are required to make the rope-distortion amount 0.55% or smaller can be computed by substitution of the value of 1/10 (factor of safety: 10) of the rope breaking strength into Formula (32).

[0057] Next, a test for confirming the validity of the calculation based on the principles explained above was performed. Figure 10 is a side view schematically illustrating a rope fabricated for the test. In the elevator rope 101 for the test, the diameter d_0 of the elevator rope 1 is 8.0 (mm), the number N_1 of the strands 102 is four, the number of the steel wires 103 at the outermost layers of the strands 102 is seven, the number of the elementary wires 103a at the outermost layers of the steel wires 103 is seven, the original rope length (the length of the twist of the strands in its central-axis direction) L_1 is 21000 (mm), the applied load (tension T_0) is 6000 (N), the modulus of longitudinal elasticity E of the steel wires is 205000 MPa, and the modulus of transverse elasticity G of the steel wires is 170800 MPa. The surface of the elevator rope 101 is covered with a resin 104 so as to prevent deformation of the rope.

[0058] Figure 11 is a graph illustrating a relationship between the rope elongation amount δL_1 , and the rope pitch P_1 and the strand pitch P_2 . In Figure 11, calculated values and experimental values are compared. It is supposed that the rope pitch is P_1 (mm), the strand pitch is P_2 (mm), and the steel-wire pitch is P_3 (mm) in the elevator rope 101 in Figure 10, and experiments and calculation were performed for the following Conditions 1 to 3.

- Condition 1: $P_i=90$ (mm), $P_2=16$ (mm), $P_3=12$ (mm)
- Condition 2: $P_1=180$ (mm), $P_2=32$ (mm), $P_3=18$ (mm)
- Condition 3: $P_1=360$ (mm), $P_2=60$ (mm), $P_3=24$ (mm)

[0059] Figure 11 illustrates elongation-amount calculated values and experimental values (measurements) of each rope when $L_1=21000$ (mm) and $T_0=6000$ (N). The three levels exhibit errors between the calculated values and the experimental values which are smaller than $\pm 10\%$, and it can be confirmed that sufficient calculation accuracy is ensured.

[0060] From the matters that are discussed above, it can be found that "the ratio a of the rope pitch P_1 to the rope diameter d ," and "the ratio b of the strand pitch P_2 to the rope diameter d " may be kept in ranges that satisfy the following Formula (32) in order to suppress rope-distortion amounts to the predetermined rope-distortion amount (0.55%) or smaller which is a condition required for elevator wire ropes to satisfy.

[Equation 4]

$$\frac{4 T}{d^2 \pi N E} \left(\frac{E \times 10^2}{3 a G} + \frac{E \times 10^1}{3 b G} + 1 \right) \geq 0.55 \times 10^{-2} \quad \dots \text{Formula}$$

(32)

[0061] Rearranging Formula (32) explained above such that the left side becomes b gives Formula A mentioned above.

[0062] As has been explained above, it has been illustrated that the present invention can provide elevator wire ropes that allow reduction of the amount of change of rope elongation that results from a change in rope tension due to passengers getting in and off an elevator even if the breaking strength of ropes is improved to reduce the number of ropes.

[0063] Note that the present invention is not limited to the examples explained above, and includes various variants. For example, the examples explained above are explained in detail for explaining the present invention in an easy-to-understand manner, and the present invention is not necessarily limited to embodiments including all the configurations explained. In addition, it is also possible to replace some of configurations of an example with configurations of another example, and also possible to add configurations of an example to configurations of another example. Furthermore, addition, elimination and replacement of other configurations are possible for some of configurations of each example.

Reference Signs List

[0064]

- | | |
|-------------|--|
| 1, 101... | elevator rope, |
| 2, 102... | strand, |
| 3, 103... | steel wire, |
| 3a, 103a... | elementary wire, |
| 104... | resin, |
| 30... | central axis of twists, |
| 31... | axis perpendicular to a strand cross-section |

Claims

1. An elevator rope formed by intertwisting a plurality of strands formed by intertwisting a plurality of steel wires, wherein when a diameter of the elevator rope is defined as d (mm), intervals between turns of the strands are defined as a rope pitch P_1 , and intervals between turns of the steel wires are defined as a strand pitch P_2 , a ratio a of the P_1 to the d, a ratio b of the P_2 to the d and a breaking strength T (N) of the elevator rope satisfy the following Formula A: [Equation 1]

$$b \geq \frac{4 \times a \times E \times T}{1.65 \times a \times d^2 \times \pi \times N \times E \times G - 40 \times E \times T - 1.2 \times a \times G \times T} \quad \dots \text{Formula A}$$

where, in Formula A explained above, E denotes a modulus of longitudinal elasticity (MPa) of a material used in the elevator rope, G denotes a modulus of transverse elasticity (MPa) of the material used in the elevator rope, and N denotes the number of the strands.

2. The elevator rope according to claim 1, wherein the P_1 is 17.2, and the P_2 is 2.5.
3. The elevator rope according to claim 1 or 2, wherein a breaking strength of the steel wires is 3200 MPa.
4. The elevator rope according to claim 1, wherein a breaking strength of the steel wires is 2300 MPa.
5. The elevator rope according to claim 1, wherein a breaking strength of the steel wires is 1910 MPa.
6. The elevator rope according to claim 1, wherein a breaking strength of the steel wires is 1770 MPa.

7. An elevator rope formed by intertwisting a plurality of strands formed by intertwisting a plurality of steel wires, wherein the steel wires are formed by intertwisting a plurality of elementary wires, and when a diameter of the elevator rope is defined as d (mm), intervals between turns of the strands are defined as a rope pitch P_1 , and intervals between turns of the steel wires are defined as a strand pitch P_2 , a ratio a of the P_1 to the d , a ratio b of the P_2 to the d and a breaking strength T (N) of the elevator rope satisfy the following Formula: [Equation 2]

$$b \geq \frac{4 \times a \times E \times T}{1.65 \times a \times d^2 \times \pi \times N \times E \times G - 40 \times E \times T - 1.2 \times a \times G \times T} \quad \dots \text{Formula A}$$

where, in Formula A explained above, E denotes a modulus of longitudinal elasticity (MPa) of a material used in the elevator rope, G denotes a modulus of transverse elasticity (MPa) of the material used in the elevator rope, and N denotes the number of the strands.

8. The elevator rope according to claim 7, wherein the P_1 is 17.2, and the P_2 is 2.5.
9. The elevator rope according to claim 7 or 8, wherein a breaking strength of the steel wires is 3200 MPa.
10. The elevator rope according to claim 7, wherein a breaking strength of the steel wires is 2300 MPa.
11. The elevator rope according to claim 7, wherein a breaking strength of the steel wires is 1910 MPa.
12. The elevator rope according to claim 7, wherein a breaking strength of the steel wires is 1770 MPa.

FIG. 1

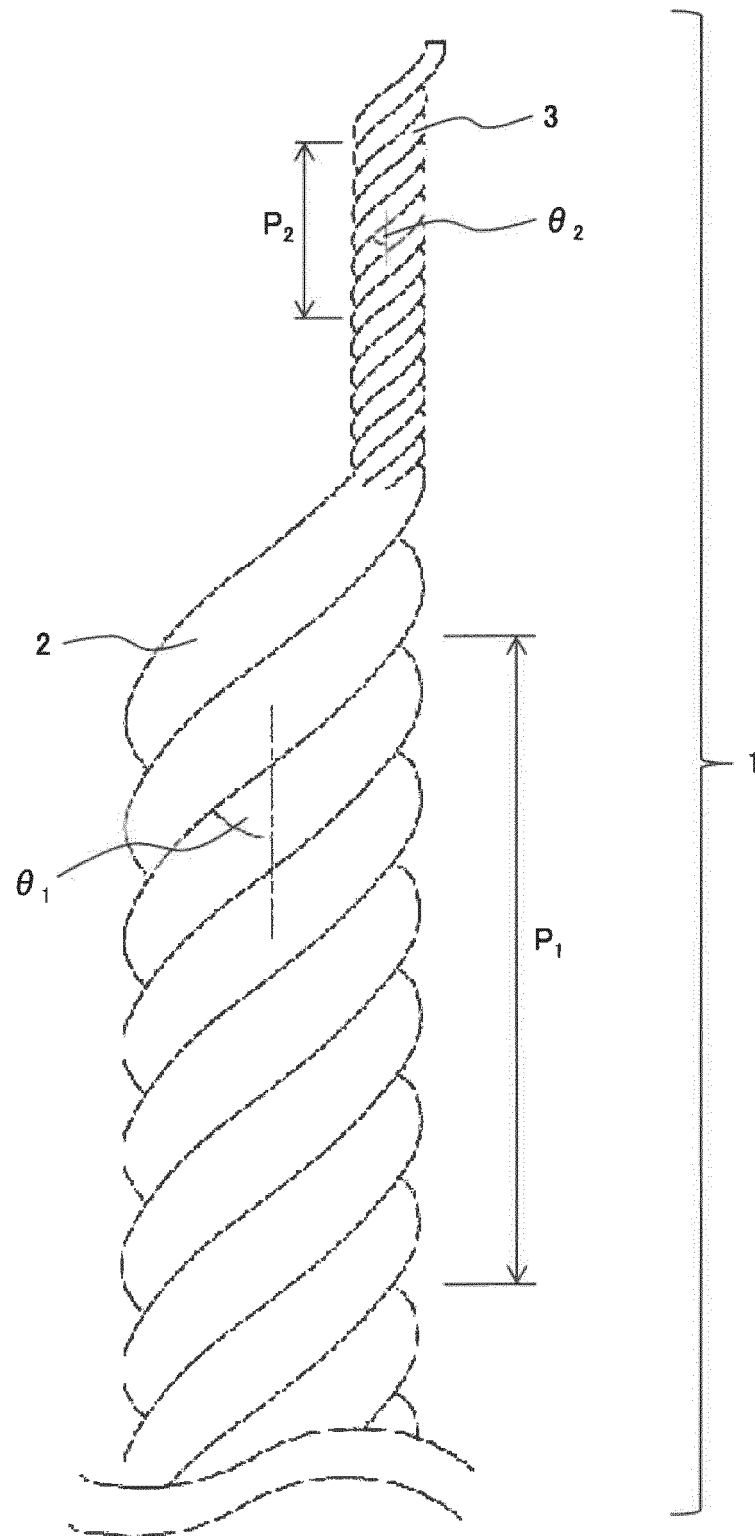


FIG. 2

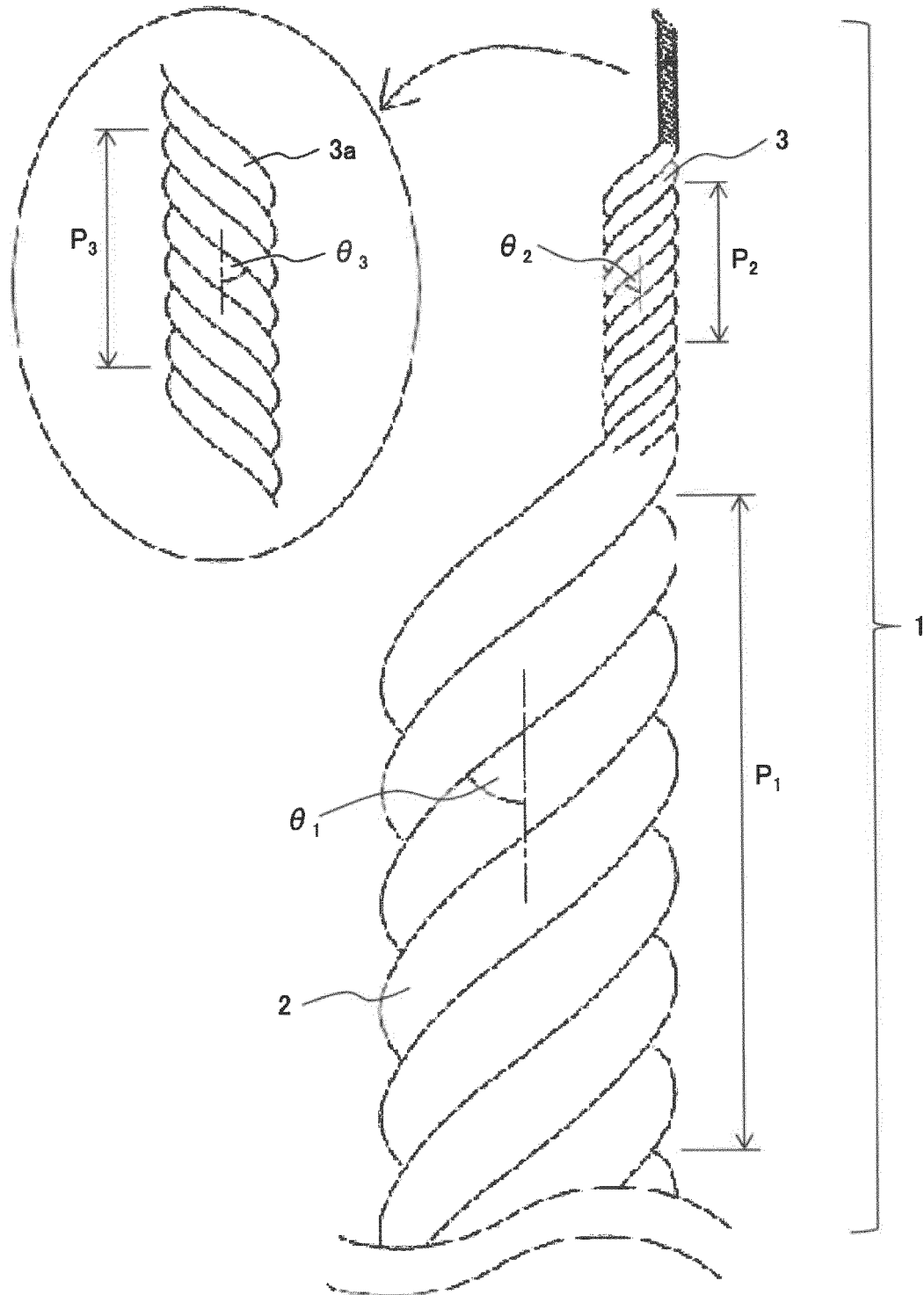


FIG. 3

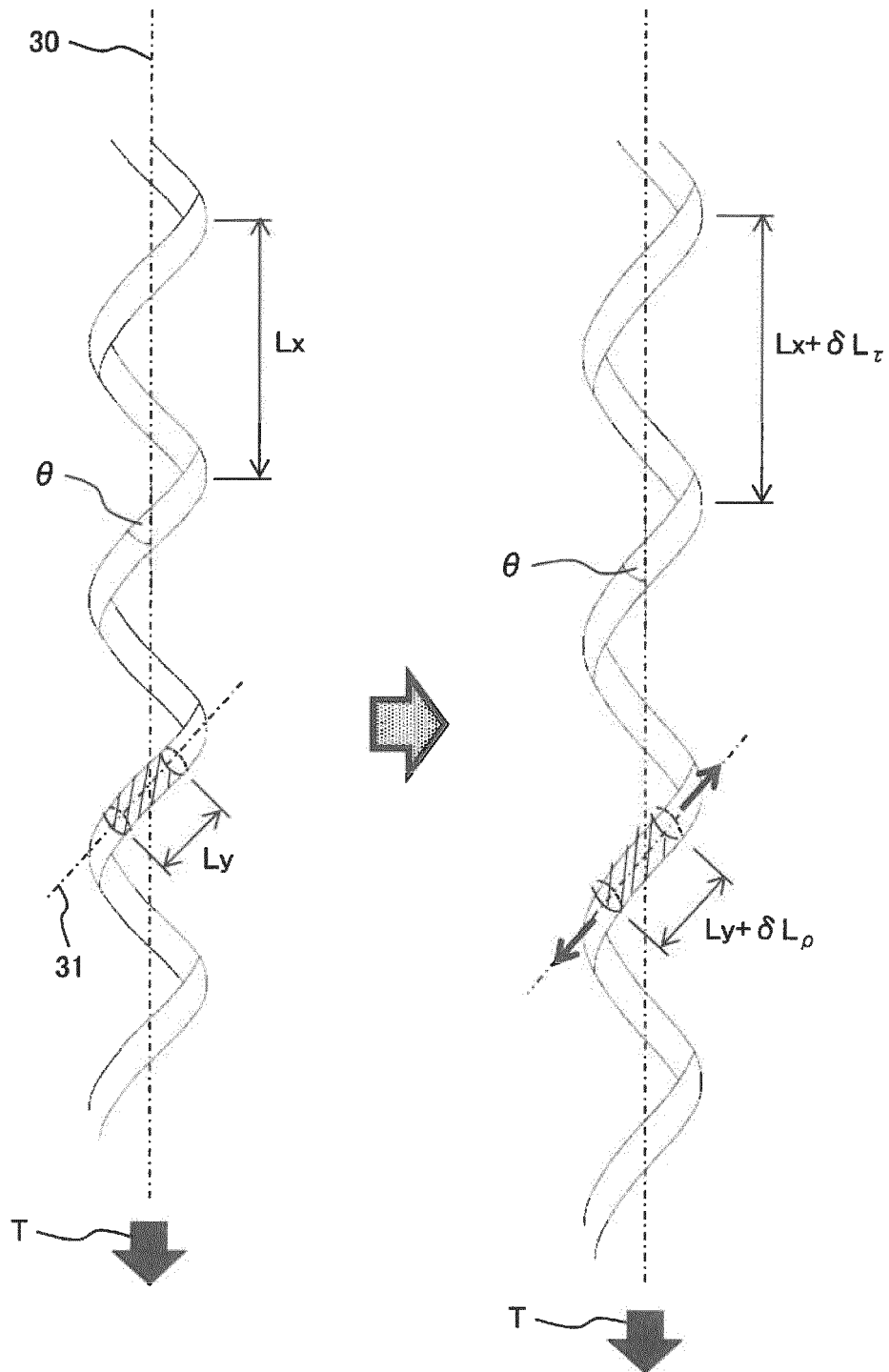


FIG. 4

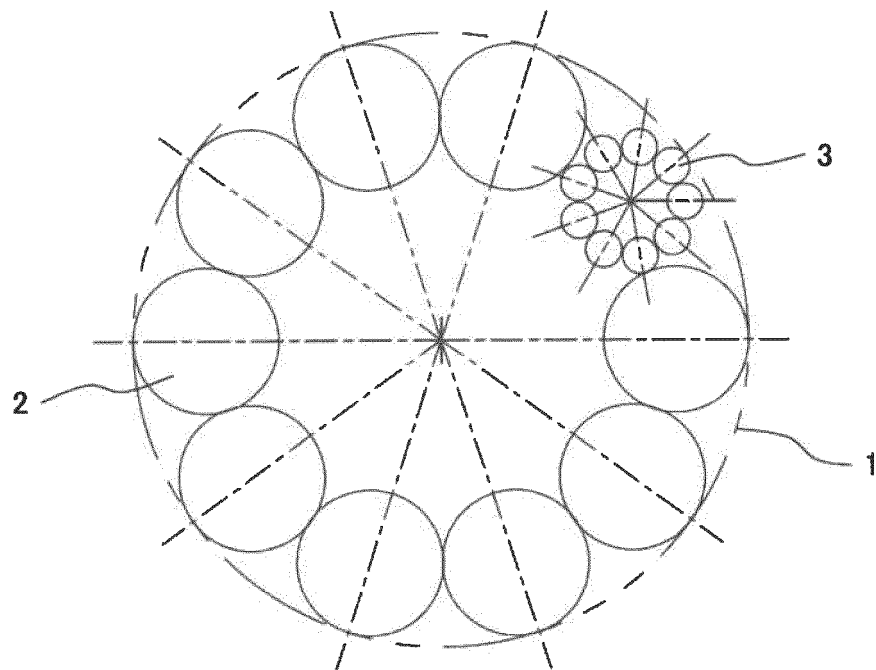


FIG. 5

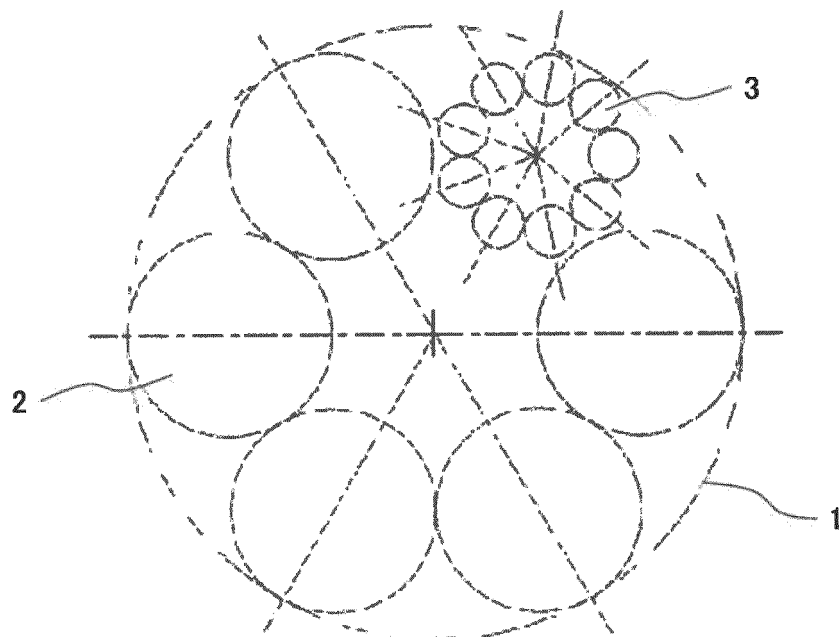


FIG. 6

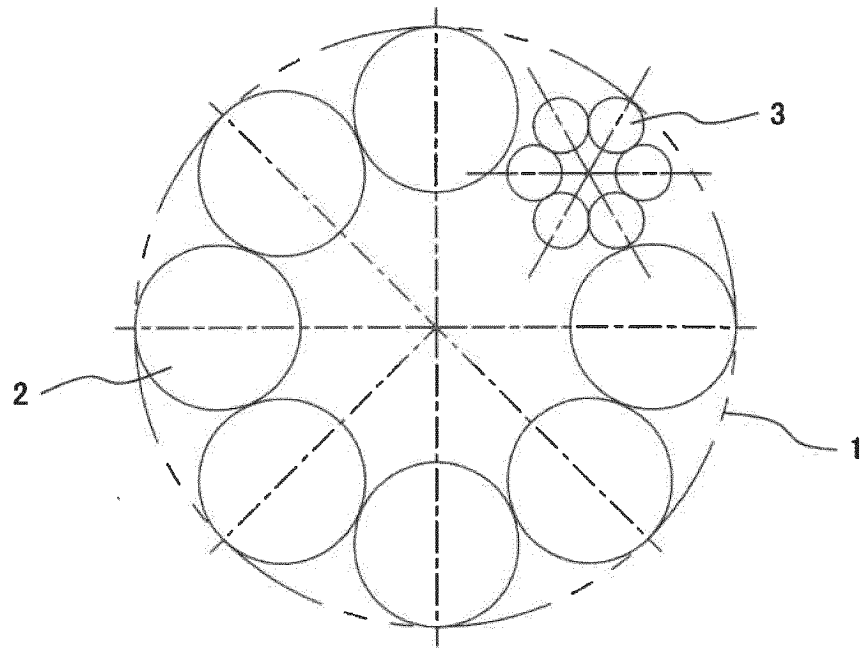


FIG. 7

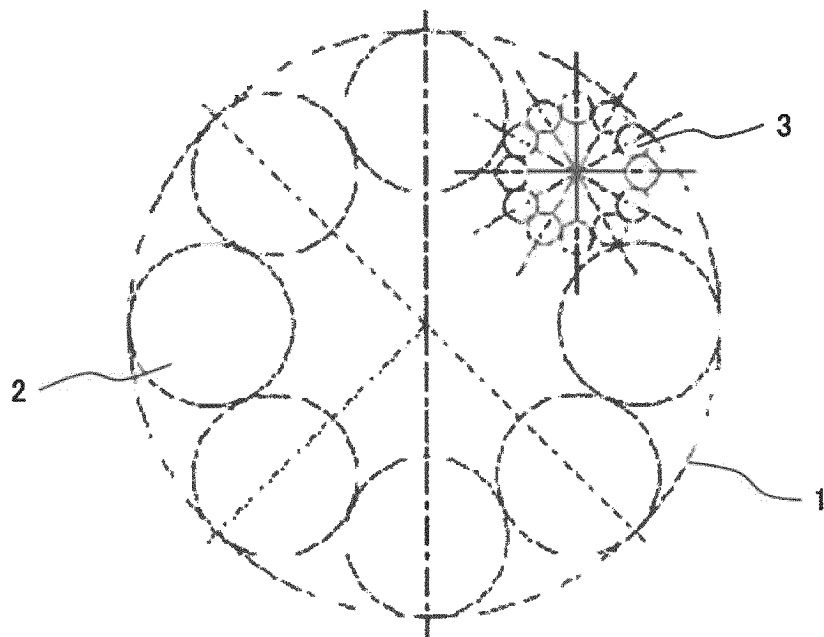


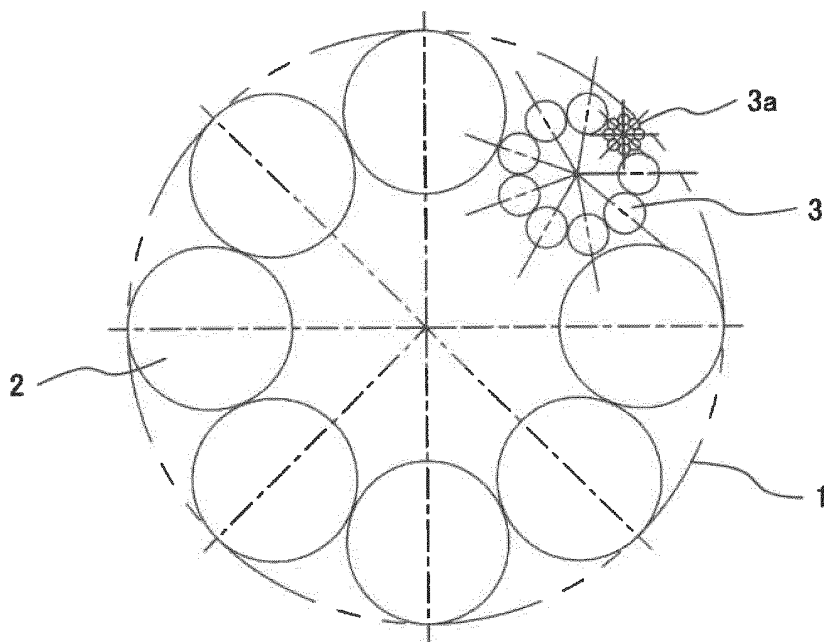
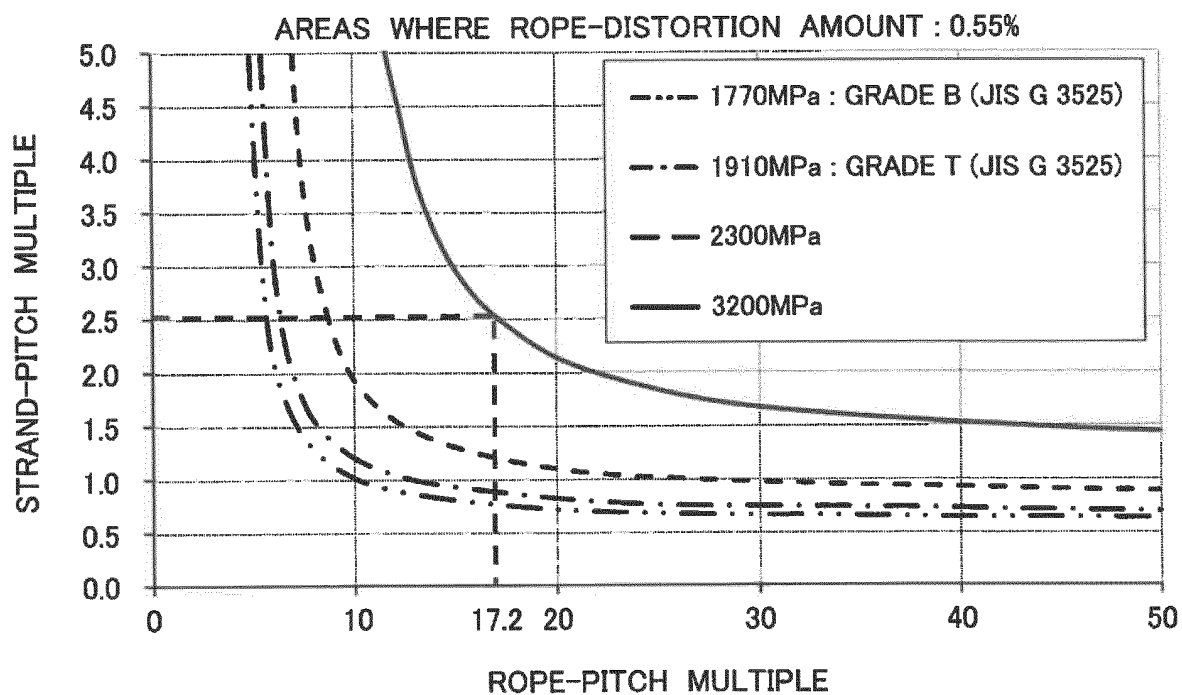
FIG. 8**FIG. 9**

FIG. 10

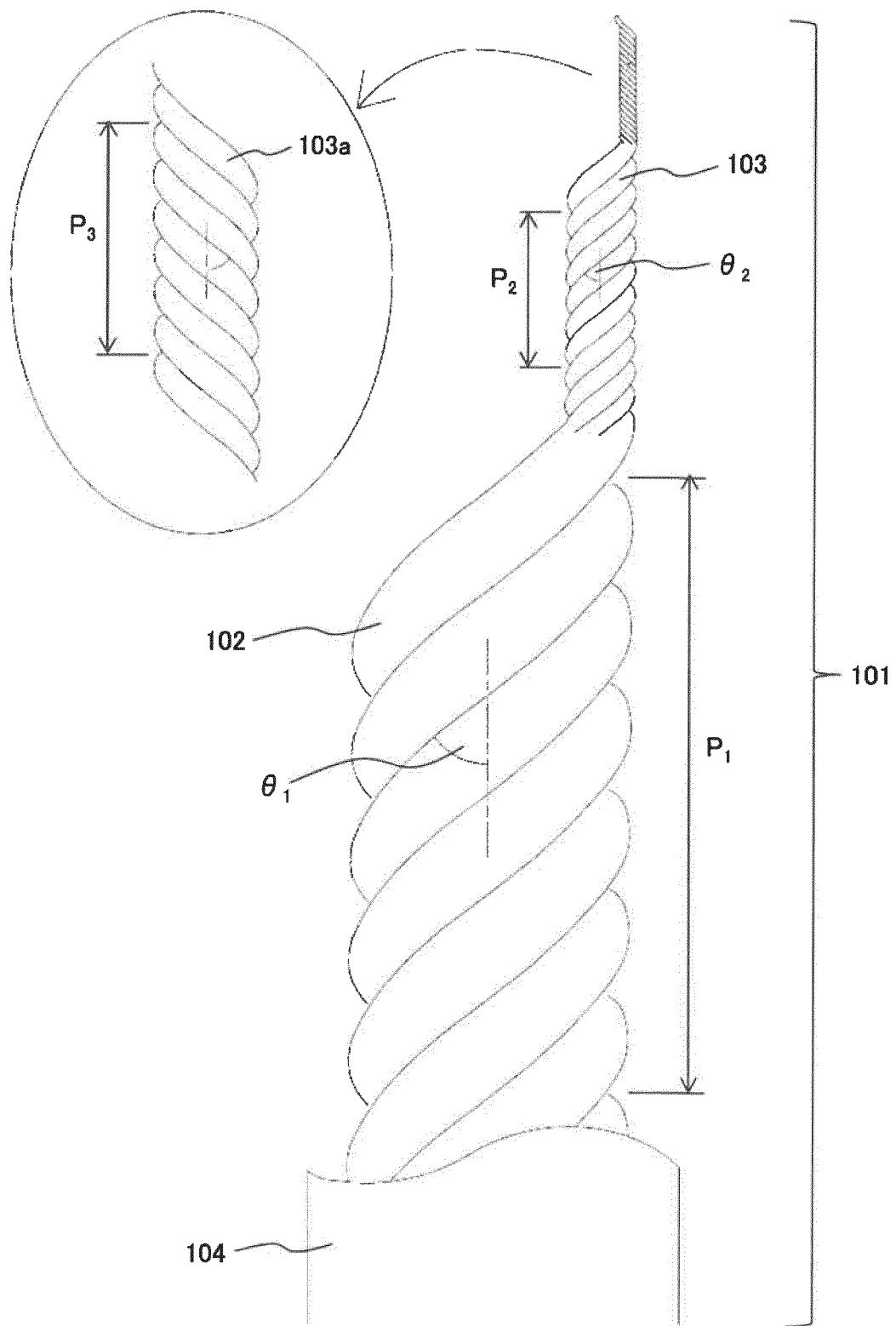
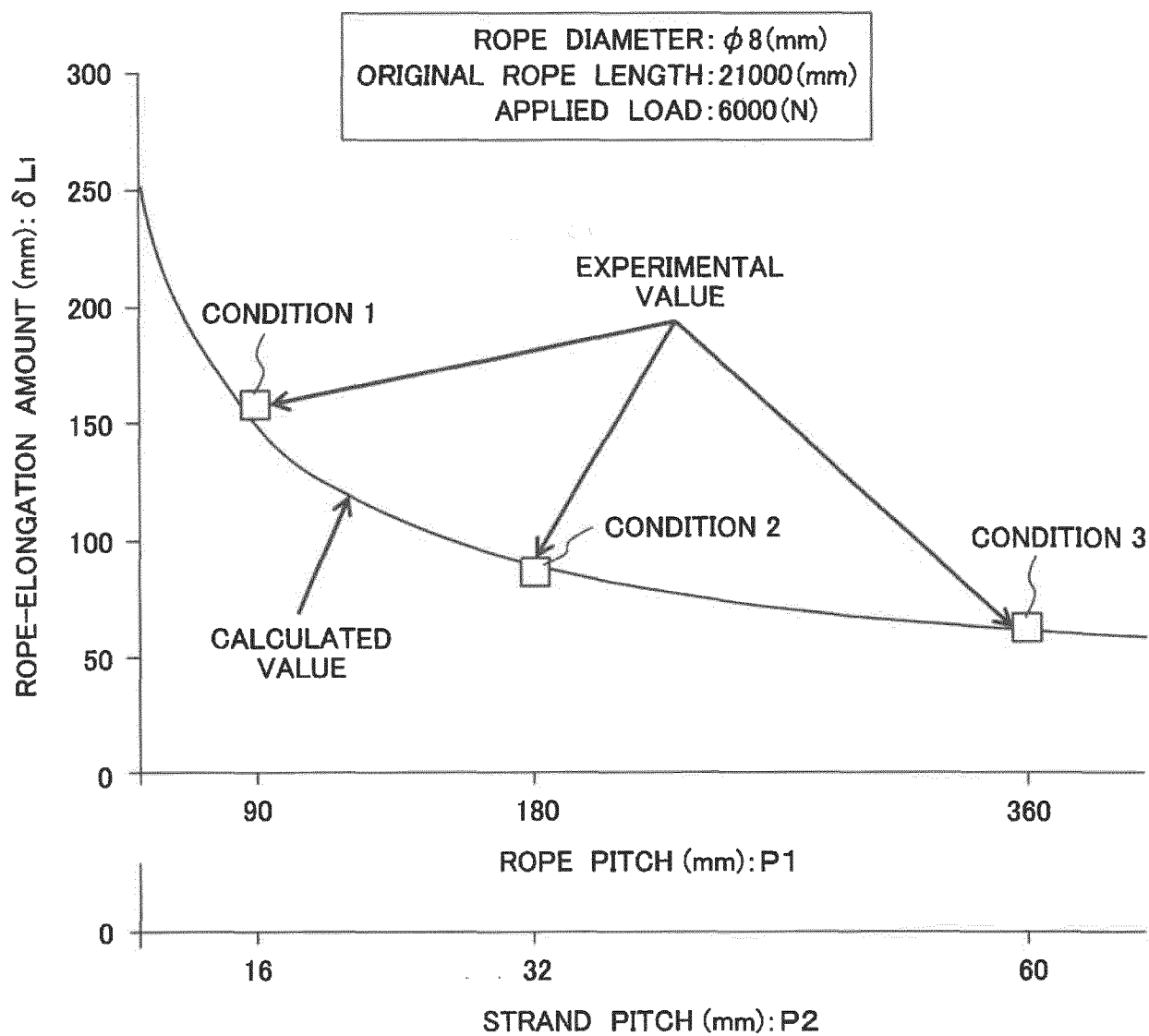


FIG. 11



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2018/026671

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. B66B7/06(2006.01) i, D07B1/06(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)

Int.Cl. B66B7/06, D07B1/06

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

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2018

Registered utility model specifications of Japan 1996-2018

Published registered utility model applications of Japan 1994-2018

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 2016-094677 A (TOKYO SEIKO CO., LTD.) 26 May 2016 (Family: none)	1-12
A	JP 2016-011481 A (SHINKO KOSEN KOGYO KK) 21 January 2016 (Family: none)	1-12
A	JP 5-125676 A (TOKYO SEIKO CO., LTD.) 21 May 1993 (Family: none)	1-12

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Date of the actual completion of the international search
25.09.2018Date of mailing of the international search report
09.10.2018Name and mailing address of the ISA/
Japan Patent Office
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Tokyo 100-8915, Japan

Authorized officer

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2018/026671

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 2006-052483 A (HITACHI BUILDING SYSTEMS CO., LTD.) 23 February 2006 (Family: none)	1-12
A	JP 2012-020793 A (HITACHI, LTD.; TOKYO SEIKO CO., LTD.) 02 February 2012 & US 2012/0005998 A1 & EP 2407592 A2 & CN 102398817 A	1-12
A	JP 2-169786 A (SUMITOMO ELECTRIC INDUSTRIES, LTD.) 29 June 1990 (Family: none)	1-12

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Patent documents cited in the description

- WO 2016199204 A [0006]