

(19)



(11)

EP 4 043 604 A1

(12)

EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:

17.08.2022 Bulletin 2022/33

(51) International Patent Classification (IPC):

C22C 38/04 ^(2006.01) **C21D 8/06** ^(2006.01)

(21) Application number: **20875556.1**

(86) International application number:

PCT/KR2020/013577

(22) Date of filing: **06.10.2020**

(87) International publication number:

WO 2021/071204 (15.04.2021 Gazette 2021/15)

(84) Designated Contracting States:

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

Designated Extension States:

BA ME

Designated Validation States:

KH MA MD TN

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(30) Priority: **08.10.2019 KR 20190124632**

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(54) **HIGH STRENGTH WIRE ROD HAVING NON-MAGNETIC PROPERTY AND METHOD FOR MANUFACTURING THEREOF**

(57) The present invention relates to a wire rod used as a material for a core wire for a power line and, more specifically, to a wire rod having both high strength and a non-magnetic property, and a method for manufacturing same.

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Description

[Technical Field]

5 **[0001]** The present disclosure relates to a wire rod used as a material for a core wire for a power line, and more particularly, to a wire rod having high strength and non-magnetic properties and a method for manufacturing the same.

[Background Art]

10 **[0002]** A power line in or outside the country is formed of a double structure in which in the outside of the power line, power transmission is carried out by an aluminum (Al) or aluminum alloy wire, and in the center of the power line, rigidity is maintained using a steel wire, an invar wire, or a composite material wire.

[0003] Power transmission is carried out by hanging the power line between a telephone pole and a steel tower, and the temperature of a transmission line is raised by electrical resistance and electromagnetic induction (induction from a core wire side) during the power transmission, thereby causing the power line to droop. This phenomenon is known as "sag".

[0004] In addition, since heat generation in transmission lines eventually causes power loss, there is a global trend to focus on development of rigidity to exert low sag properties together with non-magnetism.

20 **[0005]** A currently used core wire for power transmission is manufactured by adopting a high-strength carbon steel wire, an invar/invar alloy wire, or a composite material wire, and in applying these materials, there are merits and demerits as follows:

[0006] (1) A high-strength carbon steel wire is a most widely used material due to its high strength and low price, but a temperature rise by electromagnetic induction and a power loss therefrom occur due to the magnetic properties of a carbon steel. In addition, its coefficient of thermal expansion is at a level of 11 to $14 \times 10^{-6}/^{\circ}\text{C}$ to cause severe sag.

25 **[0007]** (2) In order to compensate for the demerit of the carbon steel wire as described above, invar (36% Ni) and an invar alloy were developed and partly applied, and in particular, the low coefficient of thermal expansion of the invar and invar alloy (0.2 to $5 \times 10^{-6}/^{\circ}\text{C}$) is used to develop a low sagging power line. However, the invar and invar alloy show ferromagnetic properties at or below a Curie temperature (about 230°C), so that an electromagnetic induction phenomenon is very common as compared with the case of using a carbon steel wire. Thus, a power loss is high as compared with the case of using a power line using a carbon steel wire, and also, expensive nickel (Ni) is added in a large amount to cause an economic demerit.

30 **[0008]** (3) As a composite material wire which was developed using only the merits of the high-strength carbon steel wire and the invar and invar alloy, carbon fiber, ceramic, plastic, and the like are used to manufacture a wire rod, which is then applied. The coefficient of thermal expansion of the composite material wire is lower than or equivalent to that of the invar wire. In addition, the electromagnetic induction phenomenon does not occur due to the non-magnetic properties, so that a power loss is in a very low level, and thus, the composite material wire may be a core wire having the best properties. However, the cost is very high, so that there is a limitation in applying the wire.

35 **[0009]** Thus, the development of a material exhibiting non-magnetic properties appropriate as a material of a core wire for a power line, shows low sag properties with a low coefficient of thermal expansion, and is economically advantageous, is demanded.

40 **[0010]** (Patent Document 1) Korean Patent Registration No. 10-0361969

[0011] (Patent Document 2) Korean Patent Registration No. 10-0507904

[Disclosure]

45

[Technical Problem]

[0012] An aspect of the present disclosure is to provide a wire rod which is appropriate as a material of a core wire for a power line and has high strength, non-magnetic properties, and a low coefficient of thermal expansion, and a method for manufacturing the same.

50 **[0013]** An object of the present disclosure is not limited to the above description. The object of the present disclosure will be understood from the entire content of the present specification, and a person skilled in the art to which the present disclosure pertains will understand an additional object of the present disclosure without difficulty.

55 [Technical Solution]

[0014] According to an aspect of the present disclosure, a non-magnetic wire rod includes, by weight: 27 to 42% of manganese (Mn), 0.35% or less (excluding 0%) of carbon (C), 0.5% or less of silicon (Si), 0.03% or less of phosphorus

(P), and 0.03% or less of sulfur (S), with a balance of Fe and other unavoidable impurities, wherein the wire rod has a Neel temperature of higher than 150°C.

[0015] According to another aspect of the present disclosure, a method for manufacturing a non-magnetic wire rod includes: preparing a steel piece or an ingot including, by weight: 27 to 42% of manganese (Mn), 0.35% or less (excluding 0%) of carbon (C), 0.5% or less of silicon (Si), 0.03% or less of phosphorus (P), and 0.03% or less of sulfur (S), with a balance of Fe and other unavoidable impurities; heat treating the steel piece or the ingot in a temperature range of 1000 to 1250°C to manufacture a billet; and subjecting the billet to wire rod rolling in a temperature range of 800 to 1250°C to manufacture a wire rod, wherein the wire rod has a Néel temperature of higher than 150°C.

[Advantageous Effects]

[0016] As set forth above, according to an exemplary embodiment in the present disclosure, a wire rod which has high strength and non-magnetic properties without using an expensive element or material and shows low sag properties is provided, which is economically favorable. In addition, the wire rod of the present disclosure may be applied appropriately as a material of a core wire for a power line.

[Best Mode for Invention]

[0017] The present inventors confirmed the limitation of existing materials which are used as a core wire for a power line, and conducted intensive research in order to develop a material showing high strength, non-magnetic properties, and low sag properties at low cost.

[0018] As a result, it was confirmed that manganese (Mn) is used in providing a wire rod as a target material, thereby greatly lowering manufacturing costs and providing a high-strength wire rod. In particular, it was confirmed that the present disclosure may have an effect of greatly reducing a power loss when used in an actual environment due to excellent non-magnetic properties and provide a wire rod showing low sag properties due to a low coefficient of thermal expansion, thereby completing the present disclosure.

[0019] Hereinafter, the present disclosure will be described in detail.

[0020] The non-magnetic wire rod according to an exemplary embodiment in the present disclosure may include, by weight: 27 to 42% of manganese (Mn), 0.35% or less (excluding 0%) of carbon (C), 0.5% or less of silicon (Si), 0.03% or less of phosphorus (P), and 0.03% or less of sulfur (S).

[0021] Hereinafter, the reason that the alloy composition of the wire rod provided in the present disclosure is limited as described above will be described in detail.

[0022] Meanwhile, unless otherwise particularly stated in the present disclosure, the content of each element is by weight and the ratio of the structure is by area.

Manganese (Mn): 27 to 42%

[0023] Since manganese (Mn) shows a structurally stable austenite structure with a higher content, it facilitates rod drawing of a wire rod. This effect may be obtained when Mn is added in an amount of 25% or more, but in this case, a Neel temperature of a wire rod is lowered to lower than 150°C and does not reach 150°C which is a continuous use temperature of a power line (for example, a thermal resistant aluminum power line), so that it is difficult to apply the wire rod in practical use.

[0024] That is, a material having a Mn content level of 25% shows a low Neel temperature and tends to expand at a coefficient of thermal expansion of more than $20 \times 10^{-6}/^{\circ}\text{C}$ due to an anti-invar effect at or higher than a Neel temperature, and thus, it is difficult to manufacture a wire rod appropriate for a core wire for a power line with the alloy system.

[0025] Considering the fact, Mn may be included at 27% or more in the present disclosure. However, when the content is more than 42%, the Neel temperature is rather lowered and a Mn content is increased, and thus, manufacturing costs rise.

[0026] Therefore, the Mn may be included at 27 to 42% in the present disclosure.

Carbon (C): 0.35% or less (excluding 0%)

[0027] Carbon (C) is an element favorable to improve austenite stabilization, and improves rod drawing properties of a wire rod. In addition, since it has an excellent strength improvement effect, it may be added in terms of securing strength of a steel containing a certain amount or more of Mn.

[0028] However, when C is excessively added, the coefficient of thermal expansion of a wire rod tends to be rapidly increased, and thus, considering the fact, the content may be limited to 0.35% or less with 0% excluded.

Silicon (Si): 0.5% or less

[0029] Silicon (Si) is an element which is inevitably added in processes of deoxidation and dephosphorization of steel. The Si has no particular effect on the physical properties of a wire rod when added, but it is favorable to lower the content if possible. Specifically, since the Si may be included at up to 0.5% in the processes such as deoxidation and dephosphorization, its content may be limited to 0.5% or less.

[0030] Phosphorus (P): 0.03% or less and sulfur (S): 0.03% or less

[0031] Phosphorus (P) and sulfur (S) are impurities which are inevitably introduced in the manufacturing process of a steel, and when their contents are more than 0.03%, respectively, cracks occur during continuous casting and ingot casting. Therefore, it is necessary to control the contents of P and S to 0.03% or less.

[0032] As described above, the wire rod of the present disclosure may be manufactured only by including certain amounts of Mn and C and controlling the contents of impurity elements. However, for the purpose of further improving the physical properties of the wire rod, niobium (Nb) may be further included.

Niobium (Nb): 3.5% or less

[0033] Niobium (Nb) is effective for lowering the coefficient of thermal expansion of a wire rod when added in a certain amount, and may have a strength improvement effect by forming a Nb carbide.

[0034] However, when the content of Nb is more than 3.5%, the wire rod tends to be brittle due to the improved strength, and thus, the content may be limited to 3.5% or less.

[0035] The remaining component of the present disclosure is iron (Fe). However, since in the common manufacturing process, unintended impurities may be inevitably incorporated from raw materials or the surrounding environment, the component may not be excluded. Since these impurities are known to any person skilled in the common manufacturing process, the entire contents thereof are not particularly mentioned in the present specification.

[0036] The non-magnetic wire rod of the present disclosure having the alloy composition described above may include an austenite single phase structure as a microstructure, and by having the austenite single phase structure as such, non-magnetism may be maintained even when receiving external energy.

[0037] In particular, the non-magnetic wire rod of the present disclosure has an austenite phase having a high stability from optimization of an alloy composition, and the wire rod of the present disclosure may have the characteristics of a relative magnetic permeability of 1.05μ or less and a coefficient of thermal expansion at room temperature of $10 \times 10^{-6}/^{\circ}\text{C}$ or less therefrom.

[0038] A loss of a material exposed to an electromagnetic field by an eddy current is closely related to the magnetism of the material. Eddy current occurrence is increased with greater magnetism, so that the loss is increased. In general, magnetism is proportional to a magnetic permeability (μ). That is, the magnetism is increased with a higher magnetic permeability. The magnetic permeability is defined as a ratio of an induced magnetic field (B) to a magnetic field (H), that is, defined by a formula of $\mu=B/H$. That is to say, when the magnetic permeability is decreased, the magnetism of a material is decreased, and thus, when a material is exposed to an electric field, a loss of an eddy current on the surface is prevented to increase energy efficiency. Therefore, it is favorable to use a wire rod which has no magnetism and a low coefficient of thermal expansion as the material of a core wire for a power line, for preventing an energy loss and securing low sag properties.

[0039] In addition, since the non-magnetic wire rod of the present disclosure has a characteristic of having a Neel temperature of higher than 150°C , it may be appropriately applied as the material of a core wire for a power line.

[0040] Here, the Neel temperature refers to a temperature at which a paramagnetic material changes to an antiferromagnetic material, and it means that the higher the temperature is, the broader the temperature range causing magnetostriiction is.

[0041] Hereinafter, a method for manufacturing a non-magnetic wire rod according to another exemplary embodiment in the present disclosure will be described in detail.

[0042] First, a billet may be manufactured by preparing a steel piece or an ingot satisfying the alloy composition described above and then heat treating the steel piece or the ingot in a temperature range of 1000 to 1250°C .

[0043] When the temperature is lower than 1000°C in the heat treatment, hot deformation resistance is increased to cause a decrease in productivity, but when the temperature is higher than 1250°C , crystal grains may become coarsened to reduce toughness.

[0044] The heat-treated billet may be subjected to wire rod rolling to obtain a wire rod.

[0045] Here, the wire rod rolling is carried out as hot rolling and may be carried out in a temperature range of 800 to 1250°C . When the temperature is lower than 800°C in the hot rolling, a load is increased during the rolling and deformation resistance may be increased, but when the temperature is higher than 1250°C , crystal grains may be excessively coarsened to reduce toughness.

[0046] After performing hot rolling as described above, it is cooled to room temperature to obtain a wire rod having a

targeted microstructure and mechanical properties.

[0047] Here, since the cooling may depend on the conditions applied in the manufacturing process of a common wire rod, it is not particularly limited in the present disclosure, and any person skilled in the art may easily carry out it. However, as an example, the cooling may be performed as water cooling, at a cooling rate of 5°C/s or more.

[0048] The final wire rod manufactured with the alloy composition and the manufacturing conditions suggested in the present disclosure has an austenite phase having high stability as a microstructure, thereby securing excellent non-magnetic properties and having the characteristics of a low coefficient of thermal expansion together with high strength.

[0049] Hereinafter, the present disclosure will be specifically described through the following Examples. However, it should be noted that the following Examples are only for describing the present disclosure in detail by illustration, and are not intended to limit the right scope of the present disclosure. The reason is that the right scope of the present disclosure is determined by the matters described in the claims and reasonably inferred therefrom.

[Mode for Invention]

(Examples)

[0050] An ingot having the alloy composition shown in the following Table 1 was prepared, and then heated at 1200°C to manufacture a billet. Immediately after the heating, the billet was hot rolled to a diameter of 8 mm at 800 to 1200°C, and then water cooled at a cooling rate of 5°C/s or more to manufacture a wire rod having a diameter of 8 mm.

[0051] Thereafter, the mechanical properties (Neel temperature, coefficient of thermal expansion, and relative magnetic permeability) of each wire rod were measured.

[0052] The Neel temperature of each wire rod was deduced as a value calculated using a Thermo-Calc program, and the coefficient of thermal expansion was measured using dilatometry. In addition, a Ferromaster instrument available from Stefan Mayer Instruments was used to measure a relative magnetic permeability which is a magnetic permeability ratio in vacuum and in the air. Each physical property value is shown in the following Table 2.

[0053] Meanwhile, a carbon steel wire rod (KS D 3559 HSWR 67A) and an invar alloy (36% Ni) which are already used as a material for a power line were prepared for comparison, the mechanical properties were measured in the same manner, and the results are shown.

[Table 1]

Classification	Alloy composition (wt%)					
	C	Si	Mn	P	S	Nb
Conventional Example 1	Carbon steel wire rod					
Conventional Example 2	Invar alloy					
Comparative Example 1	0.01	0.3	25	0.014	0.021	0
Comparative Example 2	0.30	0.3	25	0.015	0.021	3.0
Inventive Example 1	0.01	0.3	27	0.013	0.021	0
Inventive Example 2	0.01	0.3	27	0.015	0.021	3.0
Inventive Example 3	0.15	0.2	31	0.022	0.012	0
Inventive Example 4	0.15	0.2	31	0.023	0.012	1.5
Inventive Example 5	0.01	0.3	31	0.014	0.021	3.0
Inventive Example 6	0.30	0.3	31	0.015	0.021	0
Inventive Example 7	0.30	0.3	31	0.013	0.021	3.0
Inventive Example 8	0.15	0.2	34.5	0.02	0.013	0
Inventive Example 9	0.02	0.2	34.5	0.02	0.016	0
Inventive Example 10	0.15	0.2	34.5	0.02	0.016	1.5
Inventive Example 11	0.15	0.2	41	0.02	0.014	1.5
Inventive Example 12	0.02	0.2	41	0.02	0.015	0

[Table 2]

Classification	Neel temperature (°C)	Coefficient of thermal expansion ($\times 10^{-6}/^{\circ}\text{C}$, 25°C)	Relative magnetic permeability (μ , relative to vacuum magnetic permeability)
Conventional Example 1	-	12.3	212
Conventional Example 2	230 (Curie temperature)	2.3	1721
Comparative Example 1	149	11.8	1.05 or less
Comparative Example 2	146	12.2	1.05 or less
Inventive Example 1	162	9.8	1.05 or less
Inventive Example 2	168	8.8	1.05 or less
Inventive Example 3	192	7.8	1.05 or less
Inventive Example 4	205	7.6	1.05 or less
Inventive Example 5	202	7.5	1.05 or less
Inventive Example 6	198	8.2	1.05 or less
Inventive Example 7	201	7.9	1.05 or less
Inventive Example 8	208	7.5	1.05 or less
Inventive Example 9	221	7.2	1.05 or less
Inventive Example 10	213	7.3	1.05 or less
Inventive Example 11	236	7.1	1.05 or less
Inventive Example 12	242	7.0	1.05 or less

[0054] It was found that the carbon steel wire rod (Conventional Example 1) which is applied as a material for a power line had a high relative magnetic permeability, so that non-magnetic properties were low, and it was confirmed that the coefficient of thermal expansion was relatively high.

[0055] The invar alloy wire rod having 36% of nickel (Conventional Example 2) had the lowest coefficient of thermal expansion, but a very high relative magnetic permeability, and showed a Curie temperature of 230°C.

[0056] As described above, the carbon steel wire rod had high heat generation when used due to its high coefficient of thermal expansion and high magnetic permeability of the carbon, and caused sag to show a high power loss. Meanwhile, since an invar alloy had an excellent characteristic of the coefficient of thermal expansion, it is favorable in terms of sag, but it had 8 to 9 times higher magnetic permeability than a carbon steel and showed a large amount of heat generation, thereby having a large power loss.

[0057] Comparative Examples 1 and 2 including 25% of manganese had a Neel temperature of lower than 150°C and had a limitation in actual application. It was confirmed that though the coefficient of thermal expansion was relatively

high, but the microstructure was formed of austenite by a large amount of manganese to greatly improve the magnetic permeability.

[0058] Meanwhile, it was found that Inventive Examples 1 to 12 including 27% or more manganese (Mn) had a Neel temperature of 150°C or higher, a much lower coefficient of thermal expansion than a conventional carbon steel wire rod, and an excellent relative magnetic permeability of 1.05 or less, thereby showing excellent non-magnetic properties.

[0059] Considering the results, as the content of Mn in the wire rod is increased, a Neel temperature is raised, and a volume change due to the electromagnetic properties occurs at the temperature (Neel temperature) or lower, which offsets the thermal expansion to lower the coefficient of thermal expansion.

[0060] In particular, when Mn is included at 27% or more in a steel, the coefficient of thermal expansion at room temperature is lowered to $10 \times 10^{-6}/^{\circ}\text{C}$ or lower. In addition, an invar and an invar alloy show ferromagnetic properties at a Curie temperature or lower, but unlike the invar and the invar alloy, the wire rod of the present disclosure shows antiferromagnetic properties at a Neel temperature or lower to obtain the non-magnetic properties.

[0061] Furthermore, the wire rod of the present disclosure allows manufacture of a high-strength steel wire by the effect of austenite work hardening during rod drawing.

[0062] As an example, the wire rod having a diameter of 8 mm (Inventive Example 1) had a tensile strength of about 600 MPa, but when it was subjected to rod drawing to a diameter of 6 mm, the tensile strength was improved to a level of 1300 MPa, and further, when it was subjected to rod drawing to a diameter of 4 mm, the tensile strength was increased to 1700 MPa, and when subjected to rod drawing to a diameter of 3 mm, the tensile strength was increased to 2100 MPa.

[0063] As such, the wire rod of the present disclosure may have greatly improved tensile strength by increasing a processing amount, but shows a tendency of having reduced toughness with higher strength, and thus, the target rigidity may be matched by performing the heat treatment between fabricating processes.

[0064] Currently, since a material having a tensile strength of 1300 MPa or more is used as a material for a power line and even a tensile strength up to 2100 MPa is applied, the wire rod of the present disclosure may be subjected to rod drawing by adjusting the processing amount and the number of heat treatments to match the physical properties of the wire rod to those required for the actual use and then be applied.

Claims

1. A non-magnetic high-strength wire rod comprising, by weight: 27 to 42% of manganese (Mn), 0.35% or less (excluding 0%) of carbon (C), 0.5% or less of silicon (Si), 0.03% or less of phosphorus (P), and 0.03% or less of sulfur (S), with a balance of Fe and other unavoidable impurities, wherein the wire rod has a Neel temperature of higher than 150°C.
2. The non-magnetic high-strength wire rod of claim 1, further comprising: 3.5% or less of niobium (Nb).
3. The non-magnetic high-strength wire rod of claim 1, wherein the wire rod includes an austenite single phase structure as a microstructure.
4. The non-magnetic high-strength wire rod of claim 1, wherein the wire rod has a coefficient of thermal expansion at room temperature of $10 \times 10^{-6}/^{\circ}\text{C}$ or less.
5. The non-magnetic high-strength wire rod of claim 1, wherein the wire rod has a relative magnetic permeability of 1.05 μ or less.
6. A method for manufacturing a non-magnetic high-strength wire rod, the method comprising: preparing a steel piece or an ingot including, by weight: 27 to 42% of manganese (Mn), 0.35% or less (excluding 0%) of carbon (C), 0.5% or less of silicon (Si), 0.03% or less of phosphorus (P), and 0.03% or less of sulfur (S), with a balance of Fe and other unavoidable impurities, heat treating the steel piece or the ingot in a temperature range of 1000 to 1250°C to manufacture a billet, and subjecting the billet to wire rod rolling in a temperature range of 800 to 1250°C to manufacture a wire rod, wherein the wire rod has a Neel temperature of higher than 150°C.
7. The method for manufacturing a non-magnetic high-strength wire rod of claim 6, wherein the steel piece or the ingot further includes 3.5% or less of niobium (Nb).

INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2020/013577

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i; C21D 8/06(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)

C22C 38/04; B21F 1/02; B21F 27/10; B23K 35/30; C21D 8/00; C22C 38/00; C22C 38/06; C22C 38/38; C21D 8/06

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

Korean utility models and applications for utility models: IPC as above

Japanese utility models and applications for utility models: IPC as above

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

eKOMPASS (KIPO internal) & keywords: 비자성(nonmagnetic), 고강도(high strength), 선재(wire rod), 전력선(power line),
닐온도(neel temperature), 망간(manganese), 탄소(carbon), 실리콘(silicon), 니오븀(niobium)**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2017-169811 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 05 October 2017. See paragraphs [0019] and [0072]-[0076] and claim 1.	1-7
A	JP 09-085372 A (SUMITOMO METAL IND., LTD.) 31 March 1997. See abstract and claims 1-4.	1-7
A	KR 10-2013-0139626 A (POSCO) 23 December 2013. See paragraphs [0034]-[0037] and claim 1.	1-7
A	JP 54-081118 A (SUMITOMO METAL IND., LTD.) 28 June 1979. See abstract and claims 1-4.	1-7
A	JP 2013-023743 A (KOBE STEEL LTD.) 04 February 2013. See paragraphs [0046]-[0047] and claim 1.	1-7

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

* Special categories of cited documents:

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Date of the actual completion of the international search

23 December 2020

Date of mailing of the international search report

23 December 2020

Name and mailing address of the ISA/KR

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Telephone No.

Form PCT/ISA/210 (second sheet) (July 2019)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2020/013577

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- KR 100507904 [0011]