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(54) A SPHEROIDAL GRAPHITE IRON FOR CYLINDER HEADS AND METHOD FOR MANUFACTURING IT

KUGELFÖRMIGES GUSSEISEN FÜR ZYLINDERKÖPFE UND VERFAHREN ZUR HERSTELLUNG DAVON

FONTE A GRAPHITE SPHÉROÏDAL POUR CULASSES ET SON PROCÉDÉ DE FABRICATION

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(56) References cited:
WO-A1-2004/083474
WO-A1-2013/026124
JP-A- H05 311 316
JP-A- H09 209 073
JP-A- 2011 012 313
JP-A- 2012 122 085
SU-A1- 1 468 957
SU-A1- 1 560 606
US-A1- 2004 091 383
US-A1- 2006 037 675
US-A1- 2011 132 314

- **DATABASE WPI Week 198717 Thomson Scientific, London, GB; AN 1987-120668 XP002741514, -& SU 1 254 049 A1 (BELORUSSIAN POLY) 30 August 1986 (1986-08-30)**

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Description

TECHNICAL FIELD

[0001] The invention relates to spheroidal graphite iron for cylinder heads and to method for manufacturing it. The invention also relates to the use of spheroidal graphite iron in a cylinder head of an internal combustion engine, and to a cylinder head of an internal combustion engine of a marine vessel, which comprise a cylinder head manufactured from spheroidal graphite iron. Internal combustion engines are used, for example, as main propulsion engines or auxiliary engines in marine vessels or in power plants for the production of heat and/or electricity.

BACKGROUND

[0002] Internal combustion engines comprise a cylinder head. The cylinder head is the metal part of the engine that encloses and covers the cylinders. The cylinder head is often detachable and contains parts such as valves, valve seats and other e.g. coolant circulation.

The cylinder head helps to keep the engine cool while exposing to mechanical and thermal loads. Therefore there are high mechanical requirements for the cylinder head component and the cylinder head material.

From the prior art is known US2006037675, which discloses a method of preparing and forming parts of spheroidal graphite cast iron having high-grade mechanical characteristics.

From the prior art is known US2003116113, which discloses a method for the manufacture of crank cases and cylinder heads from gray cast iron. The method comprises steps of: providing a molten gray iron metal; alloying said molten gray iron metal prior to pouring with tin to a total tin content of about 0.05% to about 0.10% to provide a molten tin-alloyed gray iron metal; inoculating said molten tin-alloyed gray iron metal prior to pouring with a gray iron inoculant to a further silicon addition of from about 0.10% to about 0.12%; and casting an internal combustion engine part as soon as possible after said inoculation.

[0003] SU 1254049 discloses a cast iron with improved friction properties containg for example silicon, manganese, antimony, vanadium, niobium and molybdenum, and having complex carbides.

JP H05311316 discloses a structure of three layers, wherein to outer layer is hard. The composition of the outer layer is suitable for thin layers.

[0004] There are however some disadvantages and drawbacks relating to the known prior art. Modern cleaner fuels have higher combustion temperatures, which yields more efficient combustion. Higher combustion temperatures raise requirements for engine parts in thermal conductivity because of higher thermal loads.

[0005] Furthermore, high cylinder pressure is one of the solutions to reduce emissions. To do so, stronger material for the cylinder head is required to stand the high pressure of the engine.

SUMMARY

[0006] An object of the invention is to alleviate and eliminate the problems or drawbacks relating to the known prior art. Another object of the invention is to provide an improved cylinder head for internal combustion engine and means to achieve it. Another object of the invention is to provide a spheroidal graphite iron with improved thermal conductivity for use in engines component parts under thermal and mechanical loads. Another object of the invention is to provide enhanced performance against thermal and mechanical loads in cylinder heads and/or also other parts of the engine. Another object of the invention is to provide increased lifetime for cylinder head and/or also other parts of the engine.

[0007] The object of the invention can be achieved by the features of independent claims. The invention relates to a spheroidal graphite iron for cylinder head of an internal combustion engine according to claim 1. In addition the invention relates to a method for manufacturing a cylinder head of an internal combustion engine according to claim 6, and the use of the spheroidal graphite iron in a cylinder head of an internal combustion engine according to claims 8, 9. One embodiment of the invention is a spheroidal graphite iron for cylinder head of an internal combustion engine, according to the claims where spheroidal graphite iron has a tensile strength in the range 350 - 480 MPa and a thermal conductivity in the range 38 - 45 W/(K*m), and where the composition of the spheroidal graphite iron in percentage by weight is: 3,0 to 4,5% of carbon (C), 1.0 to 1.5% silicon (Si), less than 0,8% manganese (Mn), less than 0,3% copper (Cu), 0,03 to 0,25% Vanadium (V), and 0,04 to 0,3% niobium (Nb), the rest being iron (Fe) and unavoidable impurities. The spheroidal graphite iron of the present invention comprises a microstructure ferritic ductile iron, which is precipitation hardened. Advantageously, the microstructure is substantially or fully ferritic. The substantially ferritic microstructure is at least 75 % (vol-%) ferritic. The substantially ferritic microstructure advantageously comprises max 25 vol-% perlite.

According to an additional embodiment of the invention, the spheroidal graphite iron has a tensile strength in the range 400 - 480 MPa.

According to an another embodiment of the invention; a method for manufacturing a cylinder head of an internal combustion engine from a spheroidal graphite iron having a tensile strength in the range 350 - 480 MPa and a thermal conductivity in the range 38 - 45 W/(K*m), the composition of spheroidal graphite iron in percentage by weight is: 3,0 to 4,5% of carbon (C), 1.0 to 1.5% silicon (Si), less than 0,8% manganese (Mn), less than 0,3% copper (Cu), 0,03 to 0,25% Vanadium (V), and 0,04 to 0,3% niobium (Nb), the rest being iron (Fe) and unavoidable impurities, said method comprises steps of:

a. casting the composition,

b. austenitizing at 900 - 1050°C for 1 - 48 hours,

c. cooling at rate of 1 - 80 °C/min to temperature 620 - 750 °C

d. holding at 620 - 750 °C for 1 - 75 hours

e. cooling at rate of 50 °C/hour to temperature of 200 °C

f. air cooling to room temperature to complete the precipitation hardening,

wherein the microstructure of the precipitation hardened spheroidal graphite iron being at least 75 vol% ferritic, and max 25 vol% perlite. In said method, the steps of austenitizing and cooling at rate of 1 - 80 °C/min to temperature 620 - 750 °C is used to create a supersaturated solid solution of Vanadium for precipitation. Essentially precipitation hardened microstructure is achieved by the method. Advantageously the microstructure is fully ferritic. The ferritic microstructure is at least 75 vol-% ferritic. The microstructure advantageously comprises max 25 vol-% perlite. The achieved mechanical properties result from precipitation hardening the composition according to an embodiment of the invention.

An additional embodiment of the invention is a cylinder head of the internal combustion engine manufactured of spheroidal graphite iron of the present invention.

An additional embodiment of the invention is an internal combustion engine comprising a cylinder head manufactured from spheroidal graphite iron of the present invention.

An additional embodiment of the invention is a marine vessel comprising a cylinder head in an internal combustion engine of the marine vessel, and the cylinder head is manufactured from spheroidal graphite iron of the present invention.

According to an embodiment of the invention, silicon (Si) is between 1,0 - 1,5 in percentage by weight.

According to a further embodiment of the invention, carbon (C) is between 3,7 - 4,3 in percentage by weight, to retain needed (normal) carbon equivalency (CE %).

According to a further embodiment of the invention, vanadium (V) is between 0,04 - 0,1 in percentage by weight, to improve precipitation strengthening effect.

[0008] The present invention and its embodiments offers advantages over the known prior art, such as increased thermal conductivity. The present invention and its embodiments provide increased temperature conductivity with relatively high mechanical properties. Increased thermal conductivity provides increased lifetime for cylinder heads and other components of the internal combustion engine by conducting the heat more efficiently and/or because of other mechanical properties. An embodiment of the invention provides enhanced performance against thermal and mechanical loads in cylinder heads and/or also other parts of the engine.

Increased thermal conductivity also enables higher temperatures in the engine, which yields more efficient combustion. Cleaner fuels also have higher combustion temperatures. Increased thermal conductivity also reduces more the stresses caused by thermal differences.

The exemplary embodiments of the invention presented in this patent application are not to be interpreted to pose limitations to the applicability of the appended claims. The verb "to comprise" is used in this patent application as an open limitation that does not exclude the existence of also unrecited features. The features recited in depending claims are mutually freely combinable unless otherwise explicitly stated.

The novel features which are considered as characteristic of the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

Next the invention will be described in greater detail with reference to exemplary embodiments

DETAILED DESCRIPTION

[0009] Silicon (Si) is an important and typical alloying element of spheroidal graphite irons because silicon is most important ferrite inducing and a graphite stabilizing alloying element in spheroidal graphite irons.

[0010] In typical spheroidal graphite irons silicon levels are usually over 2 % (by weigth). However, the content for Silicon of the present invention is 1,0 - 1,5 % (by weight) in order to ensure a good thermal conductivity.

[0011] Carbon is essential element relating to spheroidal graphite irons, iron alloys and steels. In spheroidal graphite irons carbon precipitates to graphite on the part that is not in form of carbides or dissolved with iron. The content of carbon is in range 3,0 - 4,5 % (by weight), however, preferable content for carbon is in range 3,7 - 4,3 % (by weight). The carbon content levels are dependent on the content of silicon which is required to achieve intended thermal conductivity.

[0012] Vanadium retards grain growth, even after hardening from high temperatures or after periods of extended heating. Vanadium is added to cast iron to stabilize cementite, increase hardness, and increase resistance to wear and heat. Vanadium is also used for precipitation hardening. The content of vanadium is in range 0,03 - 0,25 % (by weight). However, preferable content for vanadium is in range 0,04 - 0,1 % (by weight), in which range the hardening or strengthening effect of vanadium is optimal.

[0013] Niobium improves mechanical properties including hardness and wear resistance. Niobium is favourable in refining the graphite and is used to prevent austen-

ite grain size coarsening during high temperature heat-treatment. The content of niobium is in range 0,04 - 0,3 % (by weight).

[0014] Copper and manganese are not desired or not useful alloying elements because deteriorating effects to properties spheroidal graphite iron. The content of copper is less than 0,3 % (by weight). The content of manganese is less than 0,8 % (by weight). Copper is perlite inducing alloying element and thereby disturbs manufacturing ferritic or ferritic-perlitic spheroidal graphite irons. Manganese also has effect of inducing perlite or in high concentrations carbides.

[0015] The carbide inducing alloying elements should have low enough levels so that the composition of an embodiment of the present invention can be treated to have ferritic or mainly ferritic microstructure.

[0016] An example of an embodiment of the invention is a spheroidal graphite iron for cylinder head of an internal combustion engine, according to the claims. The spheroidal graphite iron has a tensile strength in the range 350 - 480 MPa and a thermal conductivity in the range 38 - 45 W/(K*m). The composition of the spheroidal graphite iron in percentage by weight is: 3,0 to 4,5% of carbon (C), 1 to 1.5% silicon (Si), less than 0,8% manganese (Mn), less than 0,3% copper (Cu), 0,03 to 0,25% Vanadium (V), and 0,04 to 0,3% niobium (Nb), the rest being iron (Fe) and unavoidable impurities in the composition.

[0017] The spheroidal graphite iron comprises a ferritic ductile iron, which is precipitation hardened. Advantageously, the microstructure is fully ferritic. The ferritic microstructure is at least 75 vol-% ferritic, and advantageously comprises max 25 vol-% perlite. The precipitation hardened microstructure and desired properties are achieved via heat treatment steps described below.

[0018] Another example of an embodiment of the invention is a method for manufacturing a cylinder head of an internal combustion engine from a spheroidal graphite iron having a tensile strength in the range 350 - 480 MPa and a thermal conductivity in the range 38 - 45 W/(K*m). The composition of spheroidal graphite iron in percentage by weight is: 3,0 to 4,5% of carbon (C), 1.0 to 1.5% silicon (Si), less than 0,8% manganese (Mn), less than 0,3% copper (Cu), 0,03 to 0,25% Vanadium (V), and 0,04 to 0,3% niobium (Nb), the rest being iron (Fe) and unavoidable impurities, said method comprises steps of:

a. casting the composition,

b. austenitizing at 900 - 1050°C for 1 - 48 hours,

c. cooling at rate of 1 - 80 °C/min to temperature 620 - 750 °C

d. holding at 620 - 750 °C for 1 - 75 hours

e. cooling at rate of 50 °C/hour to temperature of 200 °C

f. air cooling to room temperature to complete the precipitation hardening,

wherein the microstructure of the precipitation hardened spheroidal graphite iron being at least 75 vol% ferritic, and max 25 vol% perlite In the method, the steps of austenitizing and cooling at rate of 1 - 80 °C/min to temperature 620 - 750 °C is used to create a supersaturated solid solution of Vanadium for precipitation. Essentially precipitation hardened microstructure is achieved by the method. The desired properties are achieved via precipitation hardening the composition according to an embodiment of the invention.

[0019] The microstructure is at least 75 vol-% ferritic and may comprise max 25 vol-% perlite. Advantageously the microstructure is fully ferritic.

[0020] Advantageously the spheroidal graphite iron has a tensile strength in the range 400 - 480 MPa.

[0021] Another example of an embodiment of the invention is a cylinder head of the internal combustion engine manufactured from the said spheroidal graphite iron of the present invention.

[0022] Another example of an embodiment of the invention is an internal combustion engine comprising a cylinder head manufactured from spheroidal graphite iron of the present invention.

[0023] Another example of an embodiment of the invention is a marine vessel comprising a cylinder head in an internal combustion engine of the marine vessel, and the cylinder head is manufactured from spheroidal graphite iron of the present invention.

[0024] The internal combustion engines may be used, for example, as main propulsion engines or auxiliary engines in marine vessels but the internal combustion engines can also be used in power plants for the production of heat and/or electricity.

[0025] Advantageously, the spheroidal graphite iron comprises silicon (Si) between 1,0 - 1,5 in percentage by weight to achieve higher (than normal) thermal conductivity.

[0026] Advantageously, the spheroidal graphite iron comprises carbon (C) between 3,7 - 4,3 in percentage by weight, to retain needed (normal) carbon equivalency (CE %).

[0027] Advantageously, the spheroidal graphite iron comprises vanadium (V) between 0,04 - 0,1 in percentage by weight, to improve precipitation strengthening effect.

[0028] The invention has been explained above with reference to the aforementioned embodiments, and several advantages of the invention have been demonstrated. It is clear that the invention is not only restricted to these embodiments, but comprises all possible embodiments within the characteristics and scope of the inventive thought and the following patent claims.

Claims

1. A spheroidal graphite iron for cylinder head of an internal combustion engine, having a tensile strength in the range 350 - 480 MPa and a thermal conductivity in the range 38 - 45 W/(K*m), the composition of the spheroidal graphite iron in percentage by weight consisting of: 3,0 to 4,5% of carbon (C), 1.0 to 1.5% silicon (Si), less than 0,8% manganese (Mn), less than 0,3% copper (Cu), 0,03 to 0,25% Vanadium (V), and 0,04 to 0,3 niobium (Nb), the rest being iron (Fe) and unavoidable impurities, and the microstructure of the precipitation hardened spheroidal graphite iron being at least 75 vol-% ferritic, and max 25 vol% perlite.

2. A spheroidal graphite iron of claim 1, wherein spheroidal graphite iron having a tensile strength in the range 400 - 480 MPa.

3. A spheroidal graphite iron of any claim 1-2, wherein carbon (C) is between 3,7 - 4,3 in percentage by weight.

4. A spheroidal graphite iron of any claim 1-3, wherein Vanadium (V) is between 0,04 - 0,1 in percentage by weight.

5. A spheroidal graphite iron of claim 1-4, wherein the microstructure of the precipitation hardened spheroidal graphite iron is fully ferritic.

6. A method for manufacturing a cylinder head of an internal combustion engine from a spheroidal graphite iron having a tensile strength in the range 350 - 480 MPa and a thermal conductivity in the range 38 - 45 W/(K*m), the composition of spheroidal graphite iron in percentage by weight consisting of: 3,0 to 4,5% of carbon (C), 1.0 to 1.5% silicon (Si), less than 0,8% manganese (Mn), less than 0,3% copper (Cu), 0,03 to 0,25% Vanadium (V), and 0,04 to 0,3% niobium (Nb), the rest being iron (Fe) and unavoidable impurities and, said method comprising steps of:

    a. casting the composition,
    b. austenitizing at 900 - 1050°C for 1 - 48 hours,
    c. cooling at rate of 1 - 80 °C/min to temperature 620 - 750 °C
    d. holding at 620 - 750 °C for 1 - 75 hours to ensure fully ferritic matrix
    e. cooling at rate of 50 °C/hour to temperature of 200 °C
    f. air cooling to room temperature to complete the precipitation hardening,

    wherein the microstructure of the precipitation hardened spheroidal graphite iron being at least 75 vol-% ferritic, and max 25 vol% perlite.

7. A method according to claim 6, wherein the precipitation hardened microstructure of the spheroidal graphite iron is fully ferritic.

8. Use of spheroidal graphite iron of any claim 1 - 5 in a cylinder head of the internal combustion engine..

9. Use of spheroidal graphite iron of any claim 1 - 8 in a cylinder head of an internal combustion engine of a marine vessel.

Patentansprüche

1. Sphäroguss für einen Zylinderkopf eines Verbrennungsmotors mit einer Zugfestigkeit im Bereich von 350-480 MPa und einer Wärmeleitfähigkeit im Bereich von 38-45 W(K*m), wobei die Zusammensetzung des Sphärogusses in Gewichtsprozent aus: 3,0 bis 4,5% Kohlenstoff (C), 1,0 bis 1,5% Silicium (Si), weniger als 0,8% Mangan (Mn), weniger als 0,3% Kupfer (Cu), 0,03 bis 0,25% Vanadium (V) und 0,04 bis 0,3% Niob (Nb) besteht, wobei der Rest Eisen (Fe) und unvermeidbare Verunreinigungen ist, und die Mikrostruktur des ausscheidungsgehärteten Sphärogusses mindestens 75 Vol.-% ferritisch und höchstens 25 Vol.-% Perlit ist.

2. Sphäroguss nach Anspruch 1, wobei der Sphäroguss eine Zugfestigkeit im Bereich von 400-480 MPa aufweist.

3. Sphäroguss nach einem der Ansprüche 1-2, wobei der Kohlenstoff (C) zwischen 3,7 und 4,3 Gewichtsprozent liegt.

4. Sphäroguss nach einem der Ansprüche 1-3, wobei Vanadium (V) zwischen 0,04 und 0,1 Gewichtsprozent liegt.

5. Sphäroguss nach Anspruch 1-4, wobei die Mikrostruktur des ausscheidungsgehärteten Sphärogusses vollständig ferritisch ist.

6. Verfahren zur Herstellung eines Zylinderkopfes eines Verbrennungsmotors aus einem Sphäroguss mit einer Zugfestigkeit im Bereich von 350-480 MPa und einer Wärmeleitfähigkeit im Bereich von 38-45 W/(K*m), wobei die Zusammensetzung des Sphärogusses in Gewichtsprozent aus: 3,0 bis 4,5% Kohlenstoff (C), 1,0 bis 1,5% Silicium (Si), weniger als 0,8% Mangan(Mn), weniger als 0,3% Kupfer (Cu), 0,03 bis 0,25% Vanadium (V) und 0,04 bis 0,3% Niob (Nb) besteht, wobei der Rest Eisen (Fe) und unvermeidbare Verunreinigungen ist, und wobei das Verfahren die folgenden Schritte umfasst:

    a. Gießen der Zusammensetzung

b. Austenitisieren bei 900-1050 °C für 1-48 Stunden
c. Abkühlen bei einer Geschwindigkeit von 1-80 °C/min auf eine Temperatur von 620-750 °C
d. Halten bei 620-750 °C für 1-75 Stunden, um eine vollständig ferritische Matrix sicherzustellen
e. Abkühlen mit einer Geschwindigkeit von 50 °C/Stunde auf eine Temperatur von 200 °C
f. Luftkühlen auf Raumtemperatur, um die Ausscheidungshärtung zu vervollständigen,

wobei die Mikrostruktur des ausscheidungsgehärteten Sphärogusses mindestens 75 Vol.-% ferritisch und maximal 25 Vol.-% Perlit ist.

7. Verfahren nach Anspruch 6, wobei die ausscheidungsgehärtete Mikrostruktur des Sphärogusses vollständig ferritisch ist.

8. Verwendung eines Sphärogusses nach einem der Ansprüche 1 bis 5 in einem Zylinderkopf des Verbrennungsmotors.

9. Verwendung eines Sphärogusses nach einem der Ansprüche 1-8 in einem Zylinderkopf eines Verbrennungsmotors eines Wasserfahrzeugs.

Revendications

1. Fonte à graphite sphéroïde pour culasse d'un moteur à combustion interne, possédant une résistance à la traction dans la gamme comprise entre 350 et 480 MPa et une conductivité thermique dans la gamme comprise entre 38 et 45 W/(K*m), la composition de la fonte à graphite sphéroïde en pourcentage massique étant constituée : de 3,0 à 4,5 % de carbone (C), de 1,0 à 1,5 % de silicium (Si), de moins de 0,8 % de manganèse (Mn), de moins de 0,3 % de cuivre (Cu), de 0,03 à 0,25 % de vanadium (V), et de 0,04 à 0,3 % de niobium (Nb), le reste étant du fer et des impuretés inévitables, et la microstructure de la fonte à graphite sphéroïde durcie par précipitation étant d'au moins 75 % ferritique en volume, et au maximum de 25 % perlite en volume.

2. Fonte à graphite sphéroïde selon la revendication 1, dans laquelle la fonte à graphite sphéroïde possède une résistance à la traction dans la gamme comprise entre 400 et 480 MPa.

3. Fonte à graphite sphéroïde selon la revendication 1 ou 2, dans laquelle le carbone (C) est compris entre 3,7 et 4,3 en pourcentage massique.

4. Fonte à graphite sphéroïde selon l'une quelconque des revendications 1 à 3, dans laquelle le vanadium (V) est compris entre 0,04 et 0,1 en pourcentage massique.

5. Fonte à graphite sphéroïde selon l'une quelconque des revendication 1 à 4, dans laquelle la microstructure de la fonte à graphite sphéroïde durcie par précipitation est entièrement ferritique.

6. Procédé de fabrication d'une culasse d'un moteur à combustion interne à partir d'une fonte à graphite sphéroïde possédant une résistance à la traction dans la gamme comprise entre 350 et 480 MPa et une conductivité thermique dans la gamme comprise entre 38 et 45 W/(K*m), la composition de fonte à graphite sphéroïde en pourcentage massique étant constituée : de 3,0 à 4,5 % de carbone (C), de 1,0 à 1,5 % de silicium (Si), de moins de 0,8 % de manganèse (Mn), de moins de 0,3 % de cuivre (Cu), de 0,03 à 0,25 % de vanadium (V), et de 0,04 à 0,3 % de niobium (Nb), le reste étant du fer et des impuretés inévitables et,
ledit procédé comprenant les étapes de :

a. coulage de la composition,
b. austénitisation à une température comprise entre 900 et 1050 °C pendant une période de temps comprise entre 1 et 48 heures,
c. refroidissement à un taux compris entre 1 et 80 °C/min à une température comprise entre 620 et 752 °C
d. maintien à une température comprise entre 620 et 750 °C pendant une période de temps comprise entre 1 et 75 heures pour s'assurer d'une matrice entièrement ferritique
e. refroidissement un taux de 50 °C/heure à une température de 200 °C
f. refroidissement à l'air à la température ambiante pour finaliser le durcissement par précipitation,

dans lequel la microstructure de la fonte à graphite sphéroïde durcie par précipitation étant d'au moins 75 % ferritique en volume, et au maximum de 25 % perlite en volume.

7. Procédé selon la revendication 6, dans lequel la microstructure durcie par précipitation de la fonte à graphite sphéroïde est entièrement ferritique.

8. Utilisation de la fonte à graphite sphéroïde selon l'une quelconque des revendication 1 à 5 dans une culasse du moteur à combustion interne.

9. Utilisation de la fonte à graphite sphéroïde selon l'une quelconque des revendication 1 à 8 dans une culasse d'un moteur à combustion interne d'un vaisseau marin.

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 2006037675 A **[0002]**
- US 2003116113 A **[0002]**
- SU 1254049 **[0003]**
- JP H05311316 B **[0003]**