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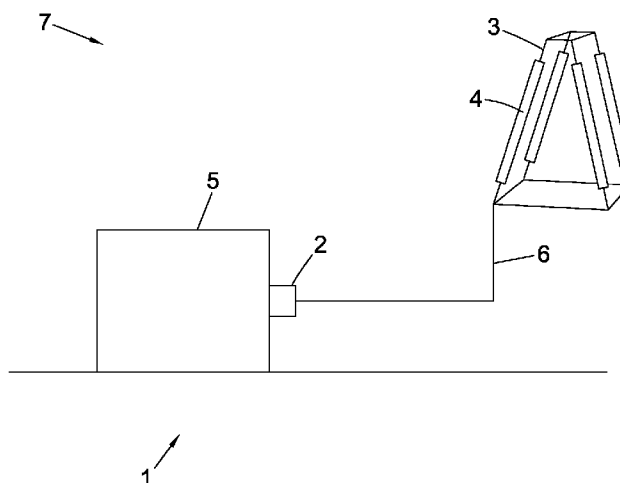


Fig. 1

(57) **Abstract:** A cathodic protection system is provided in which a sacrificial anode (which may be part of an array of anodes) is connected to a structure to be protected, such as a pipeline, valve, platform, ship's hull, offshore wind power structure or other sub-sea structure. The system comprises a sacrificial anode; and a rare-earth or alnico magnet; wherein the sacrificial anode is electrically connected to the magnet; and wherein the magnet is attached to the structure to be protected by means of magnetic force so as to provide both physical attachment and electrical connection between the magnet and the structure, such that the sacrificial anode is electrically connected to the structure via the magnet. An anode assembly, a device for and method of connecting a sacrificial anode to a structure to be protected are also provided.



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Cathodic protection systems

The present invention relates to a sacrificial anode assembly and cathodic protection system in which a sacrificial anode is connected to a structure to be protected. More particularly the invention relates to the use of a magnet to provide both physical and electrical connection. The invention also extends to a device for connecting a sacrificial anode to a structure to be protected in a cathodic protection system, comprising a magnet, and a method of connecting a sacrificial anode to a structure.

Cathodic protection systems are used to protect metal structures from corrosion, in particular subsea metal structures and components such as pipelines, valves, platforms, ship hulls and offshore wind power structures. Such systems essentially work by making the structure into the cathode of an electrochemical cell. A sacrificial anode(s) made of a more electrochemically active material than the structure (i.e. it is more susceptible to corrosion than the material of the structure) is electrically connected to the structure. Electrons flow from the anode to the structure and negatively polarise the structure, which thereby becomes a cathode. The sacrificial anode corrodes in preference to the structure to be protected, hence the term "sacrificial", thereby protecting the structure from corrosion. When it has corroded to a certain level the sacrificial anode is then replaced with a new anode. Arrays of multiple anodes are often used, with an array being connected to a structure via a connecting cable.

Anodes therefore need to be both initially installed (for example retrofitted to existing structures) and then replaced when required, which presents a number of difficulties given the typically subsea environment in which they are used.

A system was developed during the 1950's, as disclosed in GB 908310, in which an anode is mounted to an object to be protected by means of a metal magnet, the magnet also providing the necessary electrical connection. This enabled an anode to be easily attached and replaced. However a number of problems with the use of such metal magnets were discovered, as set out for example in GB 1015648 and US 3513082. As discussed in these documents, a particular problem with metal magnets is corrosion. A water film will likely remain at the interface between the magnet and the surface of the structure to which it is attached, resulting in corrosion of the magnet surface and/or the surface of the

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structure. The electrical conduction and magnetic connection can thus reduce to a level such that the anode is no longer fit for purpose.

Other problems noted with metal magnets are their limited magnetic power and manufacturing difficulties, resulting in limitations in the size of anodes that they can be used to mount and the size of structures that they can be used to protect.

The use of ceramic magnets as an alternative to metal magnets has also been considered in the prior art. As taught in US 3513082, ceramic magnets are resistant to corrosion and moreover do not possess a potential relative to the surface to be protected such that there is no corrosion around or under the magnet.

They can also be made of all shapes and sizes and thus assembled into bigger units to provide larger scale protection. However such ceramic magnets cannot provide the electrical connection necessary for sacrificial anodes. Therefore if a ceramic magnet is used, the electrical connection has to be effected separately, such as in US 3513082. In this document, a ceramic magnet has a threaded opening into which a threaded bar of a sacrificial anode is fitted. The magnet provides the physical connection to the ship to be protected. The end of the bar of the anode has a contact terminal which is electrically connected by various components to the ship to effect the electrical connection. Such a system is therefore necessarily more complex than one in which an electrically conductive magnet is used, however it was considered necessary to use ceramic magnets to avoid the corrosion problems of electrically conductive metal magnets.

US 7402233 also notes problems, in particular corrosion, with the use of metal magnets to physically and electrically attach anodes to the structure to be protected. It aims to solve the problem through the use of a ceramic magnet, however in this invention the ceramic magnet is embedded within the anode and a conductive adhesive is used to provide electrical connection between the anode and the structure. Thus, as with US 3513082, this system is more complex than one in which an electrically conductive magnet is used, however it was considered necessary.

US 3772179 is a further example of the general understanding that corrosion prevents good electrical contact between an electrically conductive magnet and a structure to be protected. In the solution proposed in this patent, a ceramic magnet is used to provide physical connection between the anode and the structure, whilst an electrically conductive spring member is used to provide the

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electrical connection. Parts of the spring member are coated with a soft metal to prevent corrosion.

The normal methods now used in practice to connect individual sacrificial anodes or anode arrays (via a cable) to a structure to be protected are either
5 mechanical connections e.g. the use of clamps or bolts, or welding, typically friction stud welding. Various different types of anodes and anode connections such as clamps are manufactured by the company Deepwater Corrosion Services Inc. : www.stoprust.com. Individual anodes are described that are welded or bolted to the hull of a ship. Anode arrays (the "Retropod") are also described wherein the
10 cable from the array is connected for example to a pipeline via a clamp (the "Retroclamp"). The Retroclamp can also carry an anode material itself to form a stand-alone system (as opposed to connecting a cable from an anode array). Anode installation clamps are also described for example in GB 2464213 which teaches a C-shaped clamp that engages and clamps sacrificial anodes to a subsea
15 pipeline to be protected. However such clamping systems need to be installed and replaced by a diver, involve some expense and complexity and the types of structure that they can be connected to can be limited (e.g. to pipeline applications). There is also the risk of damage to the structure due to the force of the clamp.

Various methods for connecting sacrificial anodes / the cable of a sacrificial
20 anode array are described in the book "Underwater repair technology", Woodhead, 1996. The use of friction stud welding is discussed in particular at pages 80-82. An advantage of this method is that it can be deployed by ROV (remotely operated vehicle). However the present inventors have recognised that the use of welding, particularly friction stud welding, has a number of disadvantages. It results in very
25 high hardness levels in the heat affected zone, and such high hardness can result in hydrogen induced stress cracking (HISC) and increased risk of fatigue cracks in the structure to be protected due to reduced ductility. Moreover, there is a risk of cracks due to the rapid cooling of the weld. Cracks in the structure to be protected are clearly highly undesirable and can lead to severe damage with negative
30 environmental and economic consequences. Furthermore, a permanent method of connection such as welding is clearly not ideal given that the anodes need to be removed and replaced when depleted.

Despite the disadvantages associated with the various known methods of attaching sacrificial anodes to structures to be protected, no method has yet been
35 proposed that overcomes these disadvantages.

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However, the present inventors have now surprisingly discovered that, contrary to the prejudice in the art against the use of metallic magnets, some particular metallic magnets can in fact be used successfully in the physical and electrical connection of anodes to a structure to be protected in a cathodic protection system.

According to a first aspect, the present invention provides a sacrificial anode assembly, comprising: a sacrificial anode; and a rare-earth or alnico magnet coupled to the anode via a fastener and arranged to attach the anode, via magnetic force, to a structure to be protected; wherein the magnet is electrically conductive and is arranged to provide electrical connection between the anode and the structure to be protected.

The electrical connection between the sacrificial anode and the magnet may preferably be via the fastener.

Rare-earth or alnico magnets are particularly preferred as they can supply sufficient magnetic force in order to both achieve good electric contact and to maintain a physical connection between the sacrificial anode and the structure. By using such magnets with good electrical conductivity, the electrical connection provided by the magnet is sufficient without the need for an additional electrical connector.

Alnico is a particularly useful magnetic material for the present invention since it has important corrosion resistant properties that help to avoid the problems in the prior art due to corrosion of metal magnets. It also provides a strong magnetic connection which has the advantages mentioned below in relation to neodymium magnets.

The most preferred type of rare-earth magnet is a neodymium magnet, e.g. comprising an alloy of neodymium, iron and boron. This provides a particularly high magnetic force that helps ensure electrical and physical contact between the anode and the structure throughout the lifetime of the system, by avoiding loss of contact due to environmental issues such as high sea currents. The strong magnetic force between the magnet and the structure also helps prevent development of deposits that would reduce electric contact/lead to corrosion. Neodymium magnets may preferably be coated with a more corrosion resistant metal alloy such as nickel or aluminium.

Due to the high strength of the magnet there is no limit to the size of anode or size of structure that can be protected.

The alnico or rare earth magnet is resistant to corrosion to the extent that over the lifetime of the anode it will provide adequate physical and electrical connection to the structure.

5 The use of such magnets therefore enables sacrificial anodes to be easily attached to a structure to be protected, without the need for e.g. welding or bolting, whereby the electrical connection is effected via the magnet such that an additional electrical connection is not required. This means that sacrificial anodes can be fitted and replaced quickly, easily and cost-effectively e.g. by a diver or remotely operated vehicle. Moreover, such magnets do not suffer from the corrosion
10 problems and limited strength issues of other metallic magnets recognised in the prior art, which led to the prejudice against the use of conductive metallic magnets in this technology.

Furthermore, the use of complex mechanical attachments such as clamps that have limited application and are time consuming to install can be avoided, as
15 can the issues with damage such as cracking associated with welding.

In addition to being corrosion resistant, the exposed surface(s) of the magnet are also provided with corrosion protection by the sacrificial anode.

The sacrificial anode may be made from any suitable material such as zinc, magnesium or aluminium, but a particularly preferred material is an Al-Zn-In alloy.

20 More than one magnet may be provided depending on the attachment force required. Each magnet may be attached by a different fastener, or a single fastener may attach more than one magnet. The shape of the anode assembly can be chosen so as to minimise the effect of undersea forces and thus minimise the magnetic attachment force required.

25 The magnet may be directly coupled to the anode via the fastener or indirectly coupled. For example, in one embodiment, the sacrificial anode has a metal strip (e.g. a carbon steel strip) extending therethrough. Typically, the anode is cast together with the metal strip during manufacture, for example it may be placed in the mould before the anode material is cast in the mould. The magnet is
30 coupled to the metal strip (and thereby the anode) via the fastener.

Preferably, to provide improved attachment to the structure, a second magnet is provided which is coupled to the metal strip via a second fastener, wherein the magnets are coupled to respective ends of the metal strip via the fasteners. The use of this metal strip offers the advantage that it is simpler to

attach magnets to the strip than directly to the anode material (in the case of thick anodes it would be particularly difficult to adequately attach the magnets).

In one embodiment, the fastener comprises a shaft portion and a housing into which the magnet is fitted. The magnet will generally not be welded to the housing but rather be glued for example with epoxy, or be attached by shrink fitting or pressing. The housing may provide mechanical protection against damage, which is particularly useful if the magnet is brittle.

The housing and/or the shaft are in contact with the magnet and are preferably electrically conductive so that the magnet and housing and/or shaft are electrically connected. Thus, electrical connection between the anode and the structure may be provided by means of the metal strip, housing and/or shaft and magnet. The housing preferably has an annular recess into which an annular magnet is fitted.

In one embodiment, the shaft portion is arranged through an opening in the metal strip to thereby couple the magnet to the metal strip and thereby the anode. The fastener may therefore be a bolt with magnet housing, with the magnets being bolt-mounted magnets. It may be known as a "magnetic bolt". Such items may be available commercially, and are typically made of carbon steel, stainless steel or any other metal. A nut and washers may be provided to hold the bolt in place in the opening (hole) in the metal strip.

The metal strip and/or the fastener (e.g. the bolt and magnet housing) will generally be protected from corrosion as they are cathodically protected themselves by the anode material.

The invention also provides a cathodic protection system in which a sacrificial anode assembly as described above is connected to a structure to be protected. Preferably, the structure to be protected is a subsea structure. The structure may be a pipeline, valve, platform, ship's hull or offshore wind power structure. Since most of the structures that it is desired to protect are made from magnetically receptive materials, such as steels, the invention has wide ranging usage.

The invention further extends to a method of connecting a sacrificial anode assembly as described above to a structure to be protected, comprising: attaching the magnet to the structure to be protected by way of magnetic force so as to provide both physical attachment and electrical connection between the magnet

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and the structure; such that the sacrificial anode is electrically connected to the structure via the magnet.

Preferably, prior to attaching the magnet to the structure the method further comprises cleaning the surface of the structure where the magnet is to be attached, preferably including removing organic coatings and/or marine fouling and/or calcareous deposits. Such cleaning may be performed by a high pressure water jet operated by a diver or remotely operated subsea vehicle.

According to another aspect, the present invention provides a device for connecting a sacrificial anode to a structure to be protected in a cathodic protection system, comprising: an electrically conductive cable; an electrically conductive magnetic plate; and an electrically conductive magnet; wherein the electrically conductive cable is for providing an electrical connection between the anode and the magnetic plate, the cable being attached at an end to the magnetic plate; wherein the magnetic plate is attached to the magnet by magnetic force so that the magnetic plate is both physically attached and electrically connected to the magnet, the cable thereby being electrically connected to the magnet via the magnetic plate; wherein the magnet has a surface for attaching to the structure by magnetic force so as to provide both a physical attachment and electrical connection between the magnet and the structure; such that the device can thereby provide an electrical connection between the sacrificial anode and the structure.

The electrically conductive cable may be directly connected to the anode, or may be connected via other elements such as other conductive components. If the anode is part of an anode array, the cable will generally be connected to the array at a connection point that provides electrical connection with all the anodes. Thus in this embodiment it can be understood that more than one anode is provided.

In one embodiment, particularly in the case of an anode array, more than one electrically conductive cable is provided for providing an electrical connection between the anode (e.g. anode array) and the magnetic plate.

The electrically conductive magnet will need to supply sufficient magnetic force in order to both achieve good electric contact and to maintain a physical connection between the sacrificial anode and the structure. For this reason, it is highly preferred that the magnet is an alnico or rare earth magnet, such as a neodymium magnet comprising an alloy of neodymium, iron and boron. However, it will be appreciated that other types of strong magnet can be used.

The sacrificial anode will provide some corrosion protection to the magnet (and magnetic plate), in the same way that it protects the structure. However, in one preferred embodiment, the magnet, magnetic plate and connection between the cable and the magnetic plate are at least partially enclosed / encapsulated in a casting, preferably a polymeric casting, and in one embodiment an epoxy casting. Thus, the connection between the cable and the plate is isolated from the environment and accordingly corrosion of these elements due to the environment e.g. seawater is prevented. The casting also adds mechanical and electrical robustness. Thus, the casting provides significant advantages both in terms of function and longevity.

Preferably, the polymeric casting encloses the magnet, magnetic plate and connection between the cable and the magnetic plate except for the surface of the magnet for attaching to the structure. Generally, the cable protrudes from the casting for connecting to the sacrificial anode.

The cable may be a copper, aluminium or steel cable and is preferably an armoured cable. It preferably provides both physical and electrical connection between the sacrificial anode and the magnet.

The cable is attached at an end to the magnetic plate, for example it may be welded, soldered, brazed or fitted by mechanical means. The plate may be a steel plate. The use of such a magnetic plate is particularly advantageous (as opposed to say connecting the cable directly to the magnet) because it can be difficult to connect the cable directly to an alnico or neodymium magnet by soldering or welding due to the low curie point. The other side of the plate (opposite that to which the cable is attached) is attached to the magnet by magnetic force, thus providing both physical attachment and electrical connection between the plate and the magnet. Thus, the provision of the magnetic plate provides a simple effective means by which the cable can be put in electrical connection with the magnet.

The device can be installed on a structure to be protected by a diver or remotely operated vehicle. When the anode(s) are consumed, the entire device (e.g. including the anode, cable, magnetic plate and magnet) can be replaced.

In one application, the structure to be protected is a subsea structure, for example a pipeline, valve, platform, ship's hull or offshore wind power structure. The device can be retrofitted to existing structures.

Also provided is a cathodic protection system in which a sacrificial anode is connected to a structure to be protected using a device as described above. The

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structure to be protected may be a subsea structure, preferably a pipeline, valve, ship's hull or offshore wind power structure.

The sacrificial anode may be part of a remote array of anodes. In this case, the conductive cable provides an electrical connection between the array of anodes and the magnet.

In one embodiment, when the sacrificial anode(s) has been consumed, the sacrificial anode(s) (or in the case of an anode array, the complete array), cable, magnetic plate and magnet are replaced. In this way, these elements can be seen as essentially forming a "replaceable system".

In another aspect, the present invention provides a cathodic protection system in which a sacrificial anode is connected to a structure to be protected, comprising: a sacrificial anode; an electrically conductive magnet which is attached to the structure to be protected by means of magnetic force; an electrically conductive magnetic plate attached to the magnet; and an electrically conductive cable; wherein the sacrificial anode is connected to the electrically conductive magnetic plate via the conductive cable secured at one end to the magnetic plate; such that the sacrificial anode is electrically connected to the magnet via the conductive cable and the magnetic plate; the sacrificial anode thereby being electrically connected to the structure via the magnet, cable and plate; and wherein the magnet, magnetic plate and connection between the cable and the magnetic plate are at least partially enclosed in a polymeric casting so as to isolate the connection between the cable and the plate from the environment.

According to a further aspect, the present invention provides a method of connecting a sacrificial anode to a structure to be protected in a cathodic protection system utilising a device as described above; comprising electrically connecting the electrically conductive cable to the sacrificial anode; and attaching the device to the structure by magnetic force so as to provide both physical attachment and electrical connection between the magnet and the structure; such that the sacrificial anode is electrically connected to the structure via the cable, plate and magnet.

In one embodiment, the anode is part of a remote array of anodes, thus the step of attaching the cable to the anode comprises attaching the cable to the array of anodes, such that the array of anodes is electrically connected to the structure via the cable, plate and magnet.

The structure to which the anode is connected may be a subsea structure, preferably a pipeline, valve, platform, ship's hull or offshore wind power structure.

Preferably, prior to attaching the device to the structure the method further comprises cleaning the surface of the structure where the device is to be attached. This may include removing organic coatings and/or marine fouling and/or calcareous deposits using e.g. a high pressure water jet operated by a diver or
5 remotely operated subsea vehicle.

According to a another aspect, the present invention provides a cathodic protection system in which a sacrificial anode is connected to a structure to be protected, comprising: a sacrificial anode; and a rare-earth or alnico magnet; wherein the sacrificial anode is electrically connected to the magnet; and wherein
10 the magnet is attached to the structure to be protected by means of magnetic force so as to provide both physical attachment and electrical connection between the magnet and the structure, such that the sacrificial anode is electrically connected to the structure via the magnet.

The sacrificial anode is preferably both electrically and physically connected
15 to the magnet and thereby to the structure.

The electrical connection between the sacrificial anode and the magnet may be direct (e.g. direct contact) or indirect (e.g. via other electrically conductive elements such as a plate and/or cable). The physical connection may also be direct or indirect e.g. via other elements such as a plate and/or cable. Preferably,
20 the electrical connection and physical connection between the anode and the magnet are provided in the same way e.g. by direct contact or via elements such as a plate and/or cable.

Rare-earth or alnico magnets are particularly preferred as they can supply sufficient magnetic force in order to both achieve good electric contact and to
25 maintain a physical connection between the sacrificial anode and the structure.

Alnico is a particularly useful magnetic material for the present invention since it has important corrosion resistant properties that help to avoid the problems in the prior art due to corrosion of metal magnets. It also provides a strong magnetic connection which has the advantages mentioned below in relation to
30 neodymium magnets.

The most preferred type of rare-earth magnet is a neodymium magnet, e.g. comprising an alloy of neodymium, iron and boron. This provides a particularly high magnetic force that helps ensure electrical and physical contact between the anode and the structure throughout the lifetime of the system, by avoiding loss of contact
35 due to environmental issues such as high sea currents. The strong magnetic force

between the magnet and the structure also helps prevent development of deposits that would reduce electric contact/lead to corrosion. Neodymium magnets may preferably be coated with a more corrosion resistant metal alloy such as nickel or aluminium.

5 Due to the high strength of the magnet there is no limit to the size of anode or size of structure that can be protected.

 The alnico or rare earth magnet is resistant to corrosion to the extent that over the lifetime of the anode it will provide adequate physical and electrical connection to the structure. Typically, when the sacrificial anode is replaced at the
10 end of its life, the magnet will also be replaced (although an embodiment can be envisaged in which the magnet is reused).

 Whilst it is highly preferred that the magnet is an alnico or rare earth magnet, it will be appreciated that other types of strong magnet could be used instead.

15 The use of such magnets therefore enables sacrificial anodes to be easily attached to a structure to be protected, whereby the electrical connection is effected via the magnet such that an additional electrical connection is not required. This means that sacrificial anodes can be fitted and replaced quickly, easily and cost-effectively e.g. by a diver or remotely operated vehicle. Moreover, such magnets
20 do not suffer from the corrosion problems and limited strength issues of other metallic magnets recognised in the prior art, which led to the prejudice against the use of conductive metallic magnets in this technology.

 Furthermore, the use of complex mechanical attachments such as clamps that have limited application and are time consuming to install can be avoided, as
25 can the issues with damage such as cracking associated with welding.

 In addition to being corrosion resistant, the exposed surface(s) of the magnet are also provided with corrosion protection by the sacrificial anode.

 The sacrificial anode may be made from any suitable material such as zinc, magnesium or aluminium, but a particularly preferred material is an Al-Zn-In alloy.

30 In one embodiment the anode may be directly attached to the magnet thus providing direct physical and electrical connection with the magnet. In another embodiment the anode may be attached to the magnet via one or more interim elements, such as an electrically conductive magnetic plate. The anode may be attached to one side of the magnetic plate (e.g. a steel plate), and the magnetic

plate attached at its opposite side via magnetic force to the magnet, such that the anode is physically attached and electrically connected to the magnet via the plate.

However, most preferably, the sacrificial anode is connected to the magnet via a cable. The cable is preferably a conductive cable, such as a copper, aluminium or steel cable, and provides both electrical and physical connection between the sacrificial anode and the magnet. The cable is preferably an armoured cable. In such an embodiment at one end the cable is attached to the anode.

Preferably, at the opposite end from the sacrificial anode, the cable is connected to the magnet via a magnetic plate attached to the magnet, the cable being secured to the magnetic plate. The cable may for example be welded, soldered, brazed or fitted by mechanical means to the plate. The plate may be a steel plate. The use of such a plate is advantageous because it can be difficult to connect the cable directly to the alnico or neodymium magnet by soldering or welding due to the low curie point. The other side of the plate is attached to the magnet by magnetic force, thus providing both physical attachment and electrical connection between the plate and the magnet.

In one embodiment, the sacrificial anode is part of a remote array of multiple anodes. In this case, the conductive cable provides an electrical connection between the array and the magnet.

The sacrificial anode will provide some corrosion protection to the magnet (and steel plate if used), in the same way that it protects the structure. However, in one preferred embodiment, the magnet, magnetic plate and connection between the cable and the magnetic plate are enclosed / encapsulated in a casting except for the surface of the magnet for attaching to the structure, so as to isolate the connection between the cable and the plate from the environment. Thus, corrosion of these elements due to the environment e.g. seawater is prevented. The cable protrudes from the casting so as to be connected to the sacrificial anode. The casting is preferably a polymeric casting, and in one embodiment is an epoxy casting.

In one embodiment, when the sacrificial anode(s) has been consumed the sacrificial anode(s) (or in the case of an anode array, the complete array), cable, magnetic plate and magnet are replaced. In this way, these elements can be seen as essentially forming a "replaceable system".

The structure to be protected by the invention is typically a subsea structure, such as a pipeline, valve, platform, ship's hull or offshore wind power structure.

Since most of the structures that it is desired to protect are made from magnetically receptive materials, such as steels, the invention has wide ranging usage.

In yet another aspect, the present invention provides a method of connecting a sacrificial anode to a structure to be protected in a cathodic protection system, comprising: electrically connecting a sacrificial anode to an alnico or rare earth magnet; attaching the magnet to the structure to be protected by way of magnetic force so as to provide both physical attachment and electrical connection between the magnet and the structure; such that the sacrificial anode is electrically connected to the structure via the magnet. A preferred rare earth magnet is neodymium, e.g. comprising an alloy of neodymium, iron and boron.

Prior to attaching the magnet to the structure, organic coatings, marine fouling and in the case of bare steel oxides, calcareous deposits, that are present on the surface of the structure at the attachment area may be removed, e.g. by a high-pressure water jet, in order to improve the physical and electrical connection. The high pressure water jet may be operated by a diver or remotely operated subsea vehicle (ROV).

The magnet may be attached to the structure by a diver or a remotely operated subsea vehicle.

In one embodiment, the method further comprises electrically connecting the sacrificial anode to the magnet via an electrically conductive cable either directly or indirectly via other conductive elements. The anode may be electrically (and preferably physically) connected at one end of the cable, with the other end of the cable being directly or indirectly electrically (and preferably physically) connected to the magnet. The method may comprise connecting the cable to the magnet via an electrically conductive magnetic plate, by securing the cable to the magnetic plate and attaching the magnetic plate to the magnet via magnetic force.

The magnet, magnetic plate and connection between the cable and the magnetic plate may be enclosed in a casting, preferably a polymeric (e.g. epoxy casting), except for the surface of the magnet for attaching to the structure, so as to isolate the connection between the cable and the plate from the environment, and wherein the cable protrudes from the casting so as to be connected to the sacrificial anode. The sacrificial anode may be part of a remote array of anodes wherein the array is electrically connected to the magnet via the conductive cable.

Alternatively, the method may comprise directly connecting the sacrificial anode to the magnet, i.e. without the use of a cable.

According to yet another aspect, the invention provides a method of connecting a sacrificial anode to a structure to be protected in a cathodic protection system, comprising: providing an electrical connection between an anode and an electrically conductive magnetic plate by means of an electrically conductive cable, wherein the electrically conductive cable is attached to the magnetic plate; attaching the magnetic plate to an electrically conductive magnet by magnetic force so that the magnetic plate is both physically attached and electrically connected to the magnet; attaching the magnet to the structure to be protected by magnetic force so as to provide both a physical attachment and electrical connection between the magnet and the structure; such that the sacrificial anode is electrically connected to the structure via the cable, plate and magnet.

Preferably, the magnet is an alnico or rare earth magnet, most preferably a neodymium magnet.

The method may further include enclosing the magnet and magnetic plate including the attachment between the cable and the magnetic plate in a polymeric casting, except for a surface of the magnet that is attached to the structure, so as to isolate these parts from the environment, and allowing the cable to protrude from the casting for connection to the sacrificial anode.

According to yet another aspect, the present invention provides a method of protecting a structure with an array of sacrificial anodes, comprising: electrically connecting the array of anodes to an electrically conductive magnetic plate by means of an electrically conductive cable; attaching the electrically conductive magnetic plate to an electrically conductive magnet by means of magnetic force so that they are electrically connected; attaching the magnet to the structure by means of magnetic force so that they are electrically connected; such that the array is electrically connected to the structure via the cable, magnetic plate and magnet and can thereby provide cathodic protection to the structure.

As with the system previously described, the structure to be protected by the methods of the invention is typically a subsea structure, such as a pipeline, valve, platform, ship's hull or offshore wind power structure.

The various preferred features of the systems, assemblies, devices and methods described above may be equally applicable to each other

Preferred embodiments of the present invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Figure 1 illustrates a cathodic protection system in which an array of sacrificial anodes is connected to a structure to be protected using a magnetic device, according to an embodiment of the invention;

Figure 2 illustrates the magnetic device of Figure 1 for attaching a sacrificial anode to a structure to be protected in more detail;

Figure 3 is a top view of a sacrificial anode assembly according to an embodiment of the invention;

Figure 4 illustrates the sacrificial anode assembly of Figure 3 in side view;

Figure 5 is a bottom view of the sacrificial anode assembly of Figures 3 and 4, i.e. the side that is attached to a structure; and

Figure 6 illustrates an alternative anode that may be used in an anode assembly according to an embodiment of the invention.

Figure 1 illustrates a cathodic protection system 1 in which a remote anode array 3 of Al-Zn-In sacrificial anodes 4 is electrically connected and physically attached to a submerged structure to be protected 5 by an armoured aluminium cable 6 and a magnetic connector device 2. The entire system 1 is located under the sea 7. The structure 5 to be protected may be any subsea structure as previously described such as an offshore wind power structure, ship's hull or pipeline.

The magnetic connector device 2 is illustrated in more detail in Figure 2. The aluminium cable 6 is welded to a steel plate 8 so as to be both physically attached and electrically connected to the plate. The steel plate 8 is attached by magnetic force to a neodymium electrically conductive permanent magnet 9. Since the steel plate is electrically conductive, it provides an electrical connection between the cable 6 welded thereto and the neodymium magnet 9. Thus, the cable 6 is both physically attached and electrically connected to the magnet 9 via the plate 8.

The magnet 9, steel plate 8 and connection between the aluminium cable 6 and the plate 8 are housed within a polymeric epoxy casting 11 so as to be isolated from the environment. The aluminium cable 6 protrudes from the casting 11 to as to extend to and connect with the anode array 3. The side 10 of the magnet 9 to be connected to the structure 5 (i.e. the side opposite that to which the plate 8 is attached) is however not sealed within the casting 11 and is instead exposed to the environment so that it can directly contact the structure 5. Prior to the magnet 9 being placed on the structure 5, organic coatings and marine fouling present on the

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surface of the structure 5 are removed by a diver-controlled or remotely operated vehicle (ROV)-controlled high pressure water jet.

Thus, the sacrificial anodes 4 of the anode array 3 are electrically and physically connected to the structure 5 by means of the aluminium cable 6, the steel plate 8 and the neodymium magnet 9. The sacrificial anodes corrode preferentially to the structure 5 to be protected (which becomes a cathode), thus protecting the structure 5 from corrosion.

When the sacrificial anodes 4 of the anode array 3 are depleted to such an extent that they no longer provide the structure 5 with adequate protection, the anode array 3 is replaced. The magnetic connector device 2 and the cable 6 are also replaced. Thus, the magnetic connector device 2, cable 6 and sacrificial anode array 3 can essentially be seen as one system: when the anodes 4 are consumed, the entire system will be removed and replaced with a new magnetic connector-cable-array system. An ROV or diver will remove the existing magnetic connector device 2 from the structure 5 and replace it with a new one. The removal and replacement is much easier than in prior art systems due to the magnetic connection rather than e.g. the friction stud welding of the prior art.

Figures 3, 4 and 5 illustrate a sacrificial anode assembly 20 according to an alternative embodiment of the invention. This anode assembly 20 is for direct connection to a structure, i.e. without the use of an anode cable. The assembly 20 comprises a sacrificial anode 21 having a metal (in this embodiment a carbon steel) strip 22 extending therethrough. Typically, the anode 21 is cast together with the metal strip 22 during manufacture. In the portions of the metal strip extending from either side of the anode, are holes (not shown) to which bolt mounted magnets 23 are coupled. Each bolt mounted magnet 23 comprises a shaft 24, a nut 25, washers 26 and 27, a housing 28 and an annular magnet 29 fixed (typically glued with epoxy) within the housing (the magnets 29 are only visible in Figure 5). The shaft 24 extends through the hole (not shown) and is held in place with nut 25. The strip 22, housing 28, shaft 23 and magnet 29 are electrically conductive. The shaft 24 and housing 28 are, in this embodiment, made of carbon steel. Typically, the magnet 29 is a neodymium magnet.

In use, the underside of the assembly 20 (as shown in Figure 5) is placed against the structure to be protected, the magnets 29 contact the surface of the structure and the assembly is thereby held in place by the magnetic force of magnets 29. The magnets 29 also provide electrical connection between the anode

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21 and the structure, since the strip 22, housing 28 and shaft 24 electrically connect the anode with the magnet 29, and the magnet 29 is in direct contact with the structure.

5 Figure 6 illustrates an alternative anode 31 that may be used in an anode assembly according to an embodiment of the invention. Anode 31 has a hole 32 through which a bolt mounted magnet 23 may be attached.

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Claims

1. A sacrificial anode assembly, comprising:
a sacrificial anode; and
5 a rare-earth or alnico magnet coupled to the anode via a fastener and arranged to attach the anode, via magnetic force, to a structure to be protected; wherein the magnet is electrically conductive and is arranged to provide electrical connection between the anode and the structure to be protected.
- 10 2. An assembly as claimed in claim 1, wherein the rare earth magnet is a neodymium magnet comprising an alloy of neodymium, iron and boron.
3. An assembly as claimed in claim 1 or 2, wherein the sacrificial anode has a metal strip extending therethrough, and wherein the magnet is coupled to the metal
15 strip and thereby the anode via the fastener.
4. An assembly as claimed in claim 3, further comprising a second magnet coupled to the metal strip via a second fastener, wherein the magnets are coupled to respective ends of the metal strip via the fasteners.
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5. An assembly as claimed in any preceding claim, wherein the fastener comprises a shaft portion and a housing into which the magnet is fitted, wherein the housing is preferably an electrically conductive housing.
- 25 6. An assembly as claimed in claim 5 when dependent on claim 3, 4 or 5, wherein the shaft portion is arranged through an opening in the metal strip to thereby couple the magnet to the metal strip and thereby the anode.
7. A cathodic protection system in which a sacrificial anode assembly as
30 claimed in any preceding claim is connected to a structure to be protected.
8. A system as claimed claim 7, wherein the structure to be protected is a subsea structure; preferably a pipeline, valve, platform, ship's hull or offshore wind power structure.
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9. A method of connecting a sacrificial anode assembly as claimed in any of claims 1 to 6 to a structure to be protected, comprising:

attaching the magnet to the structure to be protected by way of magnetic force so as to provide both physical attachment and electrical connection between the magnet and the structure;

such that the sacrificial anode is electrically connected to the structure via the magnet.

10. A method as claimed in claim 9, wherein prior to attaching the magnet to the structure the method further comprises cleaning the surface of the structure where the magnet is to be attached, preferably including removing organic coatings and/or marine fouling and/or calcareous deposits; wherein the surface is preferably cleaned by a high pressure water jet operated by a diver or remotely operated subsea vehicle.

11. A device for connecting a sacrificial anode to a structure to be protected in a cathodic protection system, comprising:

an electrically conductive cable;

an electrically conductive magnetic plate; and

an electrically conductive magnet;

wherein the electrically conductive cable is for providing an electrical connection between the anode and the magnetic plate, the cable being attached at an end to the magnetic plate;

wherein the magnetic plate is attached to the magnet by magnetic force so that the magnetic plate is both physically attached and electrically connected to the magnet, the cable thereby being electrically connected to the magnet via the magnetic plate;

wherein the magnet has a surface for attaching to the structure by magnetic force so as to provide both a physical attachment and electrical connection between the magnet and the structure;

such that the device can provide an electrical connection between the sacrificial anode and the structure.

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12. A device as claimed in claim 11, wherein the magnet is an alnico or rare earth magnet, preferably a neodymium magnet comprising an alloy of neodymium, iron and boron.
- 5 13. A device as claimed in claim 11 or 12, wherein the magnet, magnetic plate and connection between the cable and the magnetic plate are at least partially enclosed in a polymeric casting so as to isolate the connection between the cable and the plate from the environment.
- 10 14. A device as claimed in claim 13, wherein the polymeric casting encloses the magnet, magnetic plate and connection between the cable and the magnetic plate except for the surface of the magnet for attaching to the structure.
- 15 15. A device as claimed in claim 13 or 14, wherein the cable protrudes from the casting for connecting to the sacrificial anode.
16. A cathodic protection system in which a sacrificial anode is connected to a structure to be protected by a device as claimed in any of claims 11 to 15.
- 20 17. A system as claimed in claim 16, wherein the sacrificial anode is part of a remote array of anodes and the array is electrically connected to the magnetic plate and thus the magnet via the conductive cable.
- 25 18. A system as claimed in claim 16 or 17 wherein the structure to be protected is a subsea structure, preferably a pipeline, valve, platform, ship's hull or offshore wind power structure.
- 30 19. A method of connecting a sacrificial anode to a structure to be protected in a cathodic protection system, utilising a device as claimed in any of claims 10 to 13, comprising:
- electrically connecting the electrically conductive cable to the sacrificial anode; and
- attaching the device to the structure by magnetic force so as to provide both physical attachment and electrical connection between the magnet and the
- 35 structure;

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such that the sacrificial anode is electrically connected to the structure via the cable, plate and magnet.

20. A method as claimed in claim 19, wherein the anode is part of a remote
5 array of anodes, and wherein the step of attaching the cable to the anode
comprises attaching the cable to the array of anodes, such that the array of anodes
is electrically connected to the structure via the cable, plate and magnet.

21. A method as claimed in claim 19 or 20, wherein the structure to which the
10 anode is connected is a subsea structure, preferably a pipeline, valve, platform,
ship's hull or offshore wind power structure.

22. A method as claimed in any of claims 19 to 21, wherein prior to attaching
the device to the structure the method further comprises cleaning the surface of the
15 structure where the device is to be attached, preferably including removing organic
coatings and/or marine fouling and/or calcareous deposits; wherein the surface is
preferably cleaned by a high pressure water jet operated by a diver or remotely
operated subsea vehicle.

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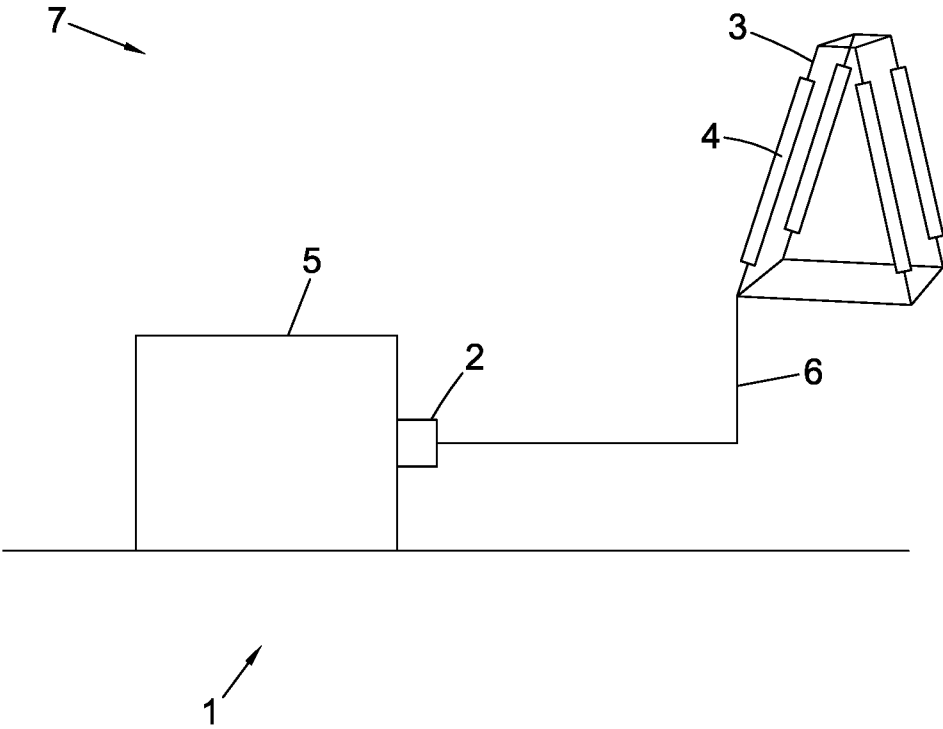


Fig. 1

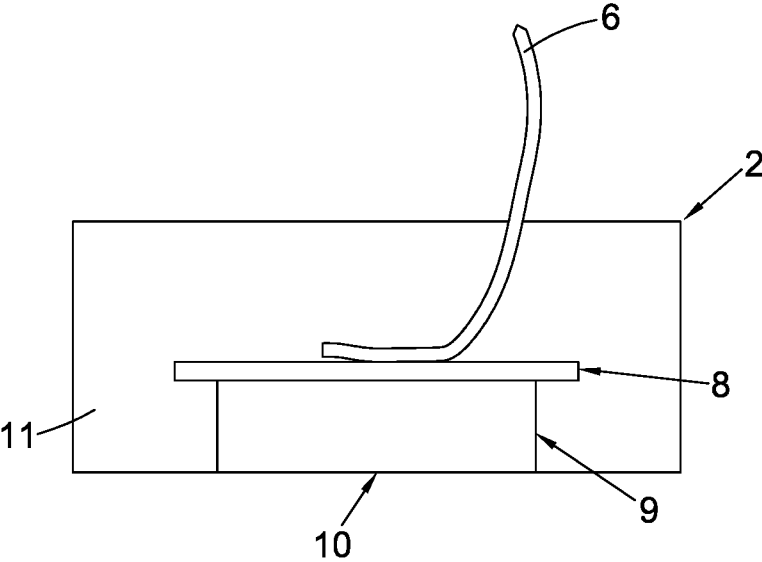


Fig. 2

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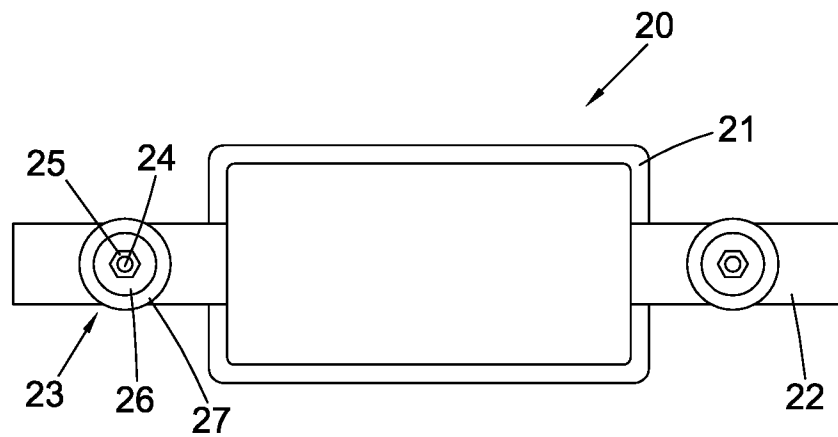


Fig. 3

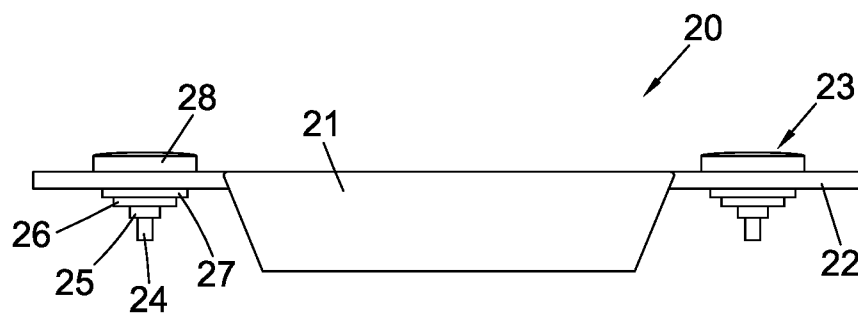


Fig. 4

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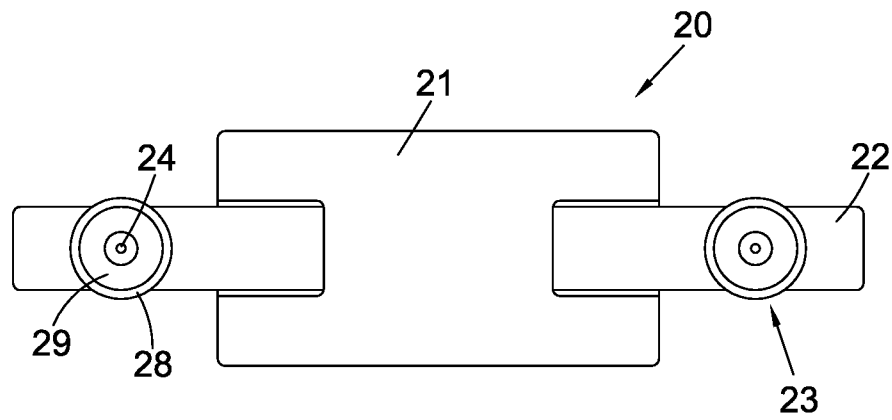


Fig. 5

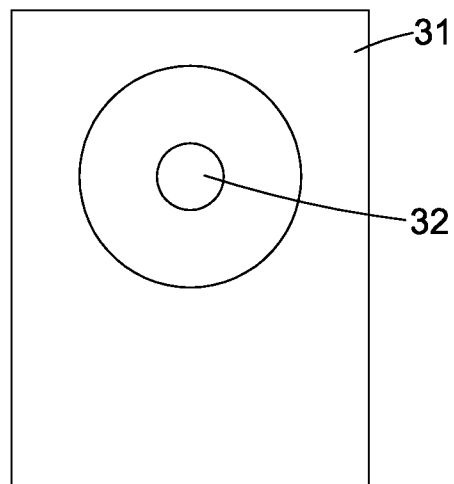


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/NO2016/050147

A. CLASSIFICATION OF SUBJECT MATTER C23F 13/06 (2006.01), C23F 13/18 (2006.01), E21B 41/02 (2006.01) 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) ICP and CPC: C23F E21B H01R FI: 4K060 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched DK, NO, SE, FI: Classes as above. Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPODOC, WPI, FULL TEXT: ENGLISH, GERMAN, FRENCH, Elsevier, Compx, Inspec, OnePetro		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2008274359 A (TOKYO ELECTRIC POWER CO INC) 2008.11.13 See claims, figures, paragraphs [0003], [0008], [0014], [0018] and [0024] - [0031].	1-10
X	WO 2013/186548 A2 (FUGO SUBSEA SERVICES LIMITED) 2013.12.19 See abstract, page 1 lines 15-16, page 2 line 25-page 3 line 5, page 9 line 9-page 13 line 8, page 14 lines 23-25 and figures.	11-12, 16-22
Y	Same passages as above.	13-15
Y	DE 2923825 A1 (HÖSSEL, L.) 1980.12.18 See page 3, 4th paragraph – page 4, 3rd paragraph and figures.	13-15
Y	EP 2868774 A2 (MAGONTEC GMBH) 2015.05.06 See paragraph [0001], [0003], [0005], [0007] and [0010] - [0019].	13-15
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: “A” document defining the general state of the art which is not considered to be of particular relevance “E” earlier application or patent but published on or after the international filing date “L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) “O” document referring to an oral disclosure, use, exhibition or other means “P” document published prior to the international filing date but later than the priority date claimed “T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention “X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone “Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art “&” document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
21/09/2016		03/10/2016
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/NO2016/050147

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