Sacrificial anode attachment to subsea thermally insulated pipelines

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Abstract

Wet thermal insulation coating systems are applied on subsea pipelines to maintain the transported fluid at a high temperature and this facilitates longer distances than if the pipeline was not thermally insulated.

To prevent external corrosion of these subsea pipelines made from carbon manganese steel by seawater the thermal insulation coating system must include a corrosion barrier - typically a primer layer applied directly on the outside surface of the bare steel during the pipe fabrication stage - which is combined with cathodic protection, in most cases by installation of sacrificial anodes.

The objective of this paper is to review alternative feasible technical solutions for connection and installation of sacrificial anodes on these pipelines to maintain the required thermal insulation properties and provide suitable cathodic protection to prevent external corrosion.

The main requirements these technical solutions must meet are:

1) Maintain suitable thermal insulation of the overall pipe joint fitted with anodes;
2) Prevent path for water ingress down to pipeline steel surface;
3) Maintain electrical connectivity of anode to pipe for life time of cathodic protection service;
4) Be suitable for large scale manufacturing production, and therefore commercially viable.

A list of advantages and drawbacks associated to each solution will be presented and discussed.

Keywords

Pipeline; insulation; anode; connection; solutions

Objective

The objective of this article is to review some alternative feasible technical solutions for connection and installation of sacrificial anodes on wet thermal insulation coated pipelines for subsea service. These technical solutions have also to maintain the required thermal insulation properties and provide suitable cathodic protection to the steel substrate subject to external corrosion by seawater.

Key requirements

These technical solutions must meet several key requirements:

1) *Maintain suitable thermal insulation of the overall pipe joint fitted with anodes;*

This is achieved by maintaining the integrity of the thermal insulation layer applied by the coating plant: the number of cuts though the insulation required performing an electrical connection between the pipe and the anode should be kept to a minimum and slower size to reduce possible heat losses at connection points.

2) *Prevent path for water ingress down to pipeline steel surface;*

The path that will connect the pipe to the anode must be sealed properly to prevent the external water to reach the pipe surface. This surface is also expected to be maintained at high temperature by the thermal insulation system.

3) *Maintain electrical connectivity of anode to pipe for the duration of the service life the cathodic protection system has been designed for;*

If conditions for corrosion to occur are met along the path that connects the pipe to the anode, this could result in loss of electrical connection and therefore of the cathodic protection provided locally by the sacrificial anode.

Resistance of the electrical connection between the pipe and sacrificial anode should not exceed 0.1 ohm [1, 2]. This requires to either using:

a) a short connection length,
b) a low resistance material,
c) a large cross-sectional area for the current path, or
d) a combination of all three.

4) *Be suitable for large scale manufacturing production, and therefore commercially viable.*

Cathodic protection by sacrificial anodes is a simple and cost effective solution to prevent steel pipes to corrode subsea. Therefore to maintain the suitability of this cathodic protection solution, it is essential that the method of electrically connecting the steel pipe surface and anode remains simple and cost effective for easily installation at manufacturing site.

Technical solutions

The technical solutions presented here will be articulated around the type of electrical connection selected between the pipe and the anode.

Type 1: Pin brazed cable connection

The electrical connection is achieved by pin brazing a cable to the steel pipe surface and to the anode steel inserts.

Those cables have typically the following characteristics:

a) Made with a core of copper, either single or multi stranded
b) Sheathed and insulated with PVC or XLPE layer, but not armoured
c) Have a cross section of 16 mm² or 25 mm²
d) Rated to an electric power supply standard, e.g. BS 6004

In this solution the electrical cable will have to go through the thermal insulation layer, and provides a great flexibility in the location where to install the anode.

Type 1 Configuration 1: Cable installed in the middle of the pipe joint

In this configuration a narrow cut-out is performed through the thermal insulation layer, large enough to enable the pin brazing operation and coating re-instatement afterwards.

This cut-out is required at each cable connection point on the pipe.

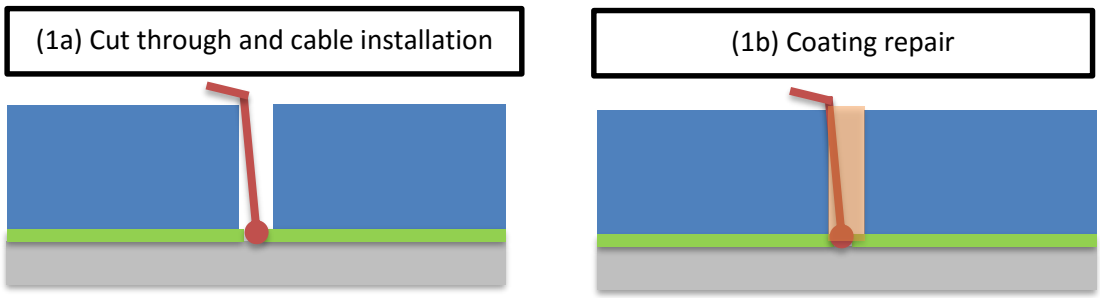

Figure 1 – Pin brazed cable in middle of pipe

Some advantages of this configuration are:

a) Enable to install the anode in the middle of the joint, and produce a balanced pipe joint weight for safe handling
b) Can be performed at coating plant, where all equipment and knowledge for coating reinstatement is available

Some drawbacks of this configuration are:

a) The localised cut through the thermal insulation may have to be enlarged to enable repair when the drilled hole is too narrow to enable liquid repair material to be poured down the bottom
b) No redundancy in electrical path, i.e. if the cable or the pin brazing point breaks then electrical connection between the anode and the pipe will be lost

Type 1 Configuration 2: Cable installed the end of the pipe joint (cutback area)

In this configuration no cut-out is performed through the thermal insulation layer as the cable is connected at the end of the coated pipe, i.e. in the cutback area where bare steel is exposed.

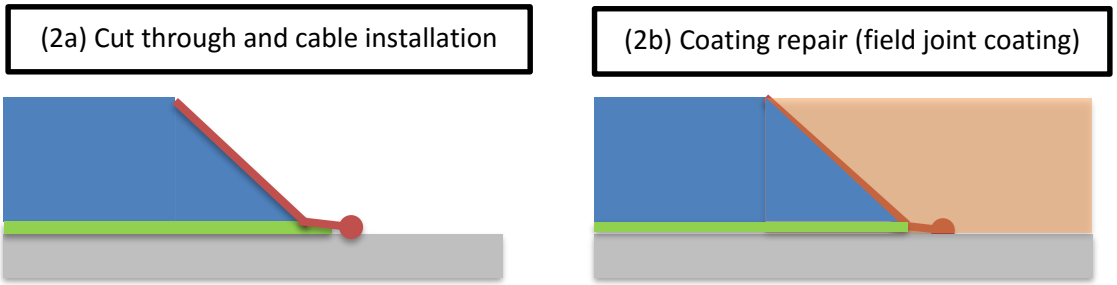

Figure 2 – Pin brazed cable at end of pipe

Some advantages of this configuration are:

a) No cut of the thermal insulation in the pipe body
b) No additional work at coating plant, the connection will be made by the pipeline installation contractor

Some drawbacks of this configuration are:

a) Requires the anode to be installed near the field joint, which would result in unbalanced pipe joint weight for safe handling if bracelet anodes have to be pre-installed
b) If anodes are installed on lay barge, cable installation would affect field joint coating application, and will slow down pipeline laying operations
c) No redundancy in electrical path, if the cable is cut, then there is complete loss of electrical connection between the anode and the pipe

How does Type 1 connection meet the key requirements?

1) *Maintain suitable thermal insulation of the overall pipe joint fitted with anodes;*

If installed at the cutback area, the pipe joint has full thermal insulation properties along its entire length. However in case of the cut-out option a local difference will be present but insignificant compare to the overall length of the thermally insulated pipe.

2) *Prevent path for water ingress down to pipeline steel surface;*

The smaller the cut through, the smaller area of damaged coated pipe exposed to water ingress in the event the coating repair does not last the required service life.

3) *Maintain electrical connectivity of anode to pipe for life time of cathodic protection service;*

The integrity of the cable is usually maintained through the life especially if pre-coated cables are used; however connection points may be considered weaker due to the local stress area produced by the pin brazing operation and small size of the connection point.

Also the actual strength of the cable is limited and will not be able to support several loads in case the bracelet anode is hooked and becomes stuck during installation or service.

4) *Be suitable for large scale manufacturing production, and therefore commercially viable.*

Despite the high cost of copper compare with steel metal, the quantity required is more economical together with the benefit in achieving high electrical conductivity, and such electrical cables are readily available to purchase. In addition pin brazing equipment is cheap compared to arc welding equipment, and easier to qualify and to train operators.

The additional features when considering this type of connection are:

- Require the pin brazing procedure to be qualified – aluminothermy/thermite welding should not be considered due to poor control of the heat generated that could create localised hard spots on the steel surface. This could be prevented by preliminary welding a doubler plate; however this will consequently requires a pressure welding qualification (fillet weld) for the doubler plate to the steel pipe.
- When heat is applied for the coating repair (or field joint coating application), care must be taken to not damage the cable shield and prevent release of contaminants that could weaken the repair material. In some instances such contaminants would result in the repair material to crack and split.

Type 2: Fillet welded connection

The electrical connection is achieved by performing:

- a fillet weld of a doubler plate to the steel pipe surface,
- a fillet weld of the bracket on the doubler plate – the bracket makes the connection between the pipe surface and external coating surface,
- a fillet weld of a continuity strap between the bracket and the anode steel inserts.

A doubler plate is required to comply with pressure code regulations [3, 4, 5, 6, 7] when performing an arc welding connection to the pressure retaining component, i.e. in this case the pipe joint.

In this solution the bracket height will match the thickness of the thermal insulation layer and will have to be bespoke pre-fabricated.

The bracket could be supplied pre-coated with an anti-corrosion coating system, or such protective system must be applied as part of the re-instatement of the thermal insulation layer.

Type 2 Configuration 1: T-shape or stool

In this configuration a large cut-out is performed through the thermal insulation layer, large enough to enable the fillet welding operation and coating re-instatement afterwards. Typically the cut is between 0.5 and 1.0 meter long and all around the pipe circumference.

This cut-out is required at each bracket connection point on the pipe.

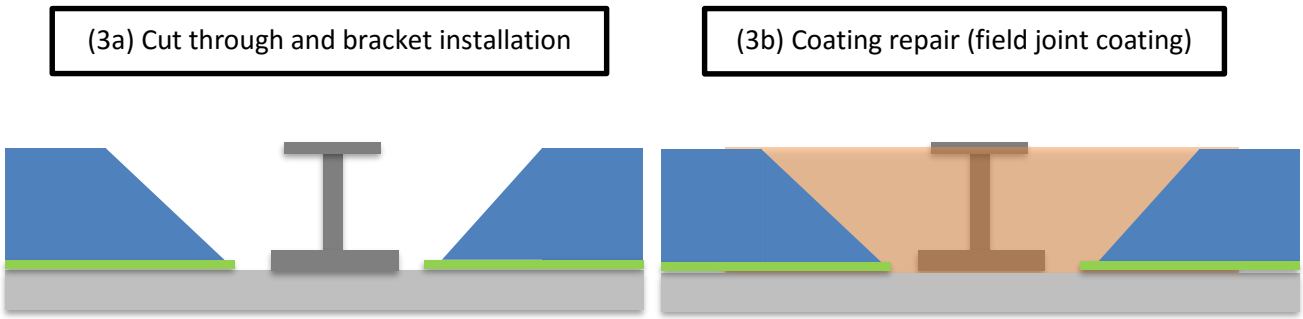

Figure 3 – Fillet welded T-shape or stool

Type 2 Configuration 2: U-shape

Similar to Configuration 1 where a large cut-out is performed and is required at each bracket connection point on the pipe.

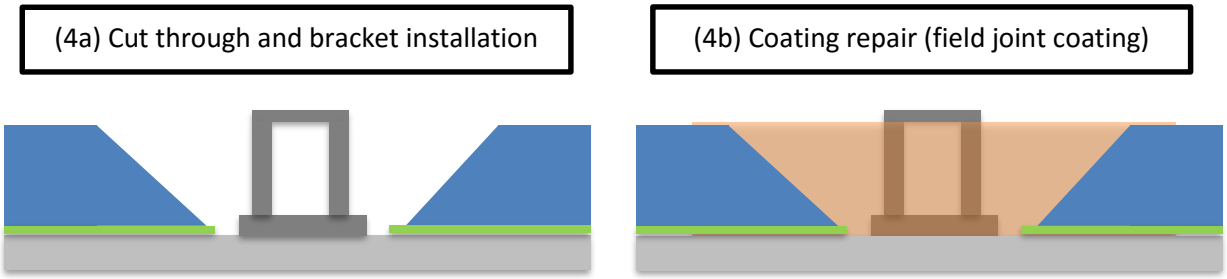

Figure 4 – Fillet welded U-shape

Some advantages of these two configurations are:

a) Enable to install the anode in the middle of the joint, and produce a balanced pipe joint weight for safe handling
b) Can be performed at coating plant where all equipment and knowledge for coating reinstatement is available
c) Configuration #2 (U-shape) provides dual redundancy in electrical path compared to Configuration #1 (T-shape)

Some drawbacks of these two configurations are:

a) Requires large cut through the thermal insulation which will require a large area to be repaired and will significantly change the thermal performance of the coated joint
b) No redundancy in electrical path for T-shape (configuration #1) and dual redundancy for U-shape (configuration #2): if the steel bar happened to corrode through its thickness during the life of service, electrical connection will be lost and cathodic protection will be no more available
c) Difficulty to suitable coat the bracket with high integrity anti-corrosion coating system such as Fusion Bonded Epoxy (FBE). Alternative liquid coating systems (epoxy based, visco-elastic, etc.) will have to be selected for their ability to provide strong adhesion to poorly abraded steel surface and to withstand the temperature of service.

How does Type 2 connection meet the key requirements?

1) *Maintain suitable thermal insulation of the overall pipe joint fitted with anodes;*

As a large cut-out is required through the thermal insulation coating system, the corresponding large repair will be less performant than the factory applied coating and result in lower thermal performance.

2) *Prevent path for water ingress down to pipeline steel surface;*

Provided the interface factory applied coating to repair material results in a water tight closure, the only remaining path for water ingress is the bracket top which is very small area compare with the overall coated pipe area.

3) *Maintain electrical connectivity of anode to pipe for life time of cathodic protection service;*

The fillet weld connections would provide a life time connection and the integrity of the bracket is maintained by the repair material surrounding it.

4) *Be suitable for large scale manufacturing production, and therefore commercially viable.*

For single anode bracelet installation per pipe joint, it is advisable to entirely coat the pipe prior anode installation to obtain the most uniform thermal performance on the final coated pipe.

It may be worth considering preliminary welding the doubler plates on bare pipe, recording the distance from one end to locate it after the thermal insulation coating is completed. This would reduce the size of the cut-out because a large surface of bare steel is required by the codes [3, 4, 5, 6, 7] for Non Destructive Examination (NDE) before and on completion of the doubler plate fillet welding.

For multiple anode bracelet installation per pipe joint, it may be worth considering building up the thermal insulation coating along the pipe length to reduce coating removal for the cut out windows where the brackets will be welded.

The additional features when considering this type of connection are:

- Requires a pressure welding qualification for the doubler plate to the steel pipe, and eventually a separate one for the fillet welding if the same welding technique used to weld the doubler plate cannot be used to weld the bracket to the doubler plate.
- Doubler plates may be installed on bare steel prior coating application, so as brackets if the bare pipe fitted with protruding brackets can be fed into the coating plant afterwards – note typical restrictions in conveying rollers, induction coil diameter, etc.

Type 3: Contact pins

The electrical connection is achieved by using contact pins that will reach the steel pipe surface. The pins are distributed around the coated pipe surface and hold in place by a metallic strapping band to which the anode is then connected (bolted or welded).

An alternative solution would be to use a rigid plastic frame with an embedded copper band that will be in contact with the pins.

In this solution the length of the pins will exceed the thickness of the thermal insulation layer, and springs will be installed to maintain contact between the steel substrate and pin extremity. This will also provide some flexibility to accommodate the geometry of the pipe and insulation coating diameters (not perfectly circular).

This provides a great flexibility in the location where to install the anode.

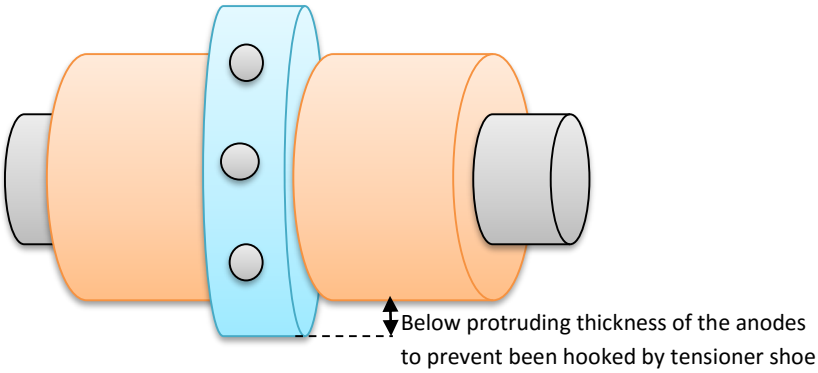

Figure 5 – External view of strapping band with pins

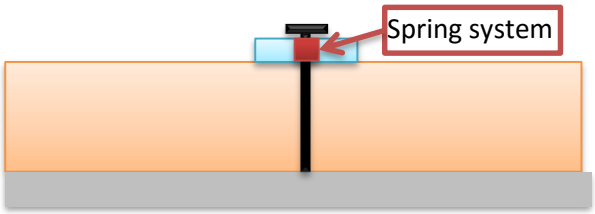

Figure 6 – Cross-sectional view of one pin

Some advantages of this configuration are:

a) Enable to install the anode in the middle of the joint and produce a balanced pipe joint weight for safe handling
b) Can be performed at coating plant as it requires low technology equipment to perform the holes (electrical driller)
c) Provides multiple redundancy in electrical path and better distributes the circulation of current from the cathodic protection

Some drawbacks of this configuration are:

a) Requires careful drilling of the holes for the pins through the thermal insulation coating but to stop at the pipe wall thickness
b) Pins could loosen up with time of service and electrical connection could be lost reducing the redundancy of connections available initially
c) If the band strap gets damages or dragged off its position during service electrical connection could be lost, and in the event pins are lost there could be water penetration through the drilled holes

How does Type 3 connection meet the key requirements?

1) *Maintain suitable thermal insulation of the overall pipe joint fitted with anodes;*

The small drilled holes even in quantity will not significantly affect the thermal performance of the insulation coating system, especially compare with the cut-out windows presented in the previous technical solutions.

2) *Prevent path for water ingress down to pipeline steel surface;*

The interface between the circular band and the insulation coating must be sealed to prevent water ingress through the holes drilled for the pins.

Where a rigid band is used, a hard sealant could be used, such as rubber ring, however in case of flexible band a soft sealant, such as silicone based, should be used to accommodate the movements of the band.

3) *Maintain electrical connectivity of anode to pipe for life time of cathodic protection service;*

Due to the significant redundancy in contact points, electrical continuity throughout the life time is expected to be achieved.

4) *Be suitable for large scale manufacturing production, and therefore commercially viable.*

Once the design and procurement of the circular band to hold the pins is concluded, then including it in the anode installation step of the manufacturing process will be easier and provide adequate productivity.

The additional features when considering this type of connection are:

- The pins may be pre-coated (except at their ends) to prevent their corrosion in the event the sealant at band to insulation interface fails and water reaches the pins.
- The spring system may not necessary consist of a helical spring as these could be subject to stress corrosion cracking and fatigue stress cracking if incorrectly selected or manufactured. The spring system may be embedded in the pin itself.

Other considerations

Achieving high integrity of cathodic protection installation is even more challenging for Direct Electrical Heating (DEH) operating pipelines where higher current is involved and Alternating Current (AC) corrosion present a greater risk to the steel pipeline.

The repair of embedded connection (e.g. bracket or cable) is not feasible without destroying (cutting through) the insulation layer and repairing it afterwards. The repair will not provide the same thermal property (U-value) as the original factory applied coating, and usually performs thermally less efficiently. Therefore it is essential to limit area and volume to repair in thermally insulated pipelines.

Summary of technical solutions

The *Table **1*** summarises the three types of technical solutions presented above.

Table 1 – Summary of connection types

Connection Type	(1) pin brazed		(2) fillet welded		(3) contact pins
Configuration	(1) cable installed in the middle of pipe	(2) cable installed at cutback area of pipe	(1) T-shape bracket	(2) U-shape bracket	Multiple pins installed on a band
Location of connection	Flexible	Restricted to cutback areas	Limited by size of cut-out window for subsequent repair		Flexible
Connection redundancy	Proportional to the number of cables installed	Proportional to the number of cables installed	Limited to the size of the bracket		Proportional to the number of pins installed
Cut through insulation layer	Medium size (<0.5m)	None	Large size (>0.5m)		Small size (<10mm)
Cost estimate	*€*	-	*€€*		*€*
Repair of insulation layer	Required for a small volume	None	Required for a large volume		None
Cost estimate	*€*	-	*€€€**		-
Additional components to procure	Cables and brazing lugs	Cables and brazing lugs	Brackets		Ring band and pins
Cost estimate	*€*	*€*	*€€*		*€€€*
Qualifications required for connection	Pin brazing + operators	Pin brazing + operators	Fillet welding + welders + NDE		None
Cost estimate	*€*	*€*	*€€€**		-
Qualifications required for repairs	Insulation coating	None	Fillet welding Insulation coating		None
Cost estimate	*€*	-	*€€€*		-

Legend *Cost estimate*: *€* = Up to €10; *€€* = Up to €100; *€€€* = Up to €1k;* = cost may be higher depending on technology and material considered; transportation costs excluded.

The above costs could increase or decrease depending on the geographic location where the work is performed (cost of labour) and ordered quantity.

Discussion

From *Table **1*** Connection Type 1 appears to be the most advantageous cost solution from the other connection types; however, it is important to remember that for its Configuration 2 (i.e. electrical cable installed at cutback area) additional cost is expected to occur during field joint coating activity to maintain the integrity of the cable installed in the cutback area.

Connection Type 2 is unsurprisingly the most expensive solution due to the several additional activities it requires: fabrication of brackets, fillet welding, full insulation coating re-instatement, etc. It is essential to highlight that all these activities have to be performed one after the other, which increases the timeline for the manufacture of this connection type.

Connection Type 3 is the most challenging one in term of cost as it requires a very small amount of repair and no qualifications, which are significant savings, but has a large cost upfront for the supply of the ring band and pins. In addition the ring band will require a very specific design as this component is not standardised (yet!) in the industry and won't have a significant track record like the other connection types presented.

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