Next generation heating of subsea oil production pipelines

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ABSTRACT

A development programme founded by the Norwegian Research Council for further increase the competitiveness of the direct electrical heating (DEH) technology was initiated in 2016 and will finish at the end of 2018. The partners in this project have long experience in development, manufacturing, installation of DEH systems and expertise inside all research areas inside DEH. The primary scientific and technological objective is to develop the technology for a low-cost, light-weight and high-efficiency DEH flow assurance system for an expanded application range. The improvements are reduced supply current, losses, weight and costs. Additionally the DEH system should be easier to install and applicable down to water depths of 3000 m.

KEY WORDS: Direct Electrical Heating; Power frequency; Flowlines; Pipelines; Flow Assurance; Hydrate Management.

INTRODUCTION

DEH is developed for hydrate management of pipelines and uses electrical heating in order to ensure that the pipe content temperature is above plug and wax formation temperature. The method is applicable for continuous heating, heating during shut down and reheating form cooled down pipeline. It has also been used for melting of wax/plugs.

This paper considers the basis to determine heat input to the steel pipe and improvements in order to increase the applicability of DEH, i.e. increasing the efficiency of DEH. This activity is one of the work packages for the development programme, which includes:

- guidelines for mitigation of ac corrosion,
- increasing the efficiency of DEH,
- development of wet mateable connector,
- development of supply power cables,
- installation techniques of power cable risers and DEH, pipelines for deep-water applications,
- technical and economic assessments.
- The optimization of heat input in the steel pipe.

Increasing the power frequency from the normal power frequency of 50/60 Hz to a frequency range of 100-200 Hz, provides clear benefits (Lervik et al. ISOPE 2016):

- reduction of needed DEH-current, which directly considerably reduces the cross-section of the DEH-cable,
- reduced interference with neighbouring installations,
- reduced complexity and size of the DEH grounding system,
- reduced potential practical issues with designing to avoid ac corrosion and thus easing the design of continuous operation.

An important activity for increasing the efficiency of DEH are related to electrical and magnetic properties of steel pipe materials. Both steel pipe of carbon steel (X60, X65, etc.) and steel with 13% Cr content (13Cr) are relevant. The magnetic and electrical properties of these two materials are considerably different and are characterized by that the heat development in carbon steel pipes occurs mainly in a few millimetres depth of the outer surface of the pipe, while for Cr13 heat development is more evenly distributed through the cross section. This implies that surface treatment (grit blasting) in general has larger impact of the heating properties for carbon steel than for 13Cr.

Both mechanical stresses and heat treatment influences the steel pipe properties. All these factors are important regarding optimizing the heat input to the steel pipe. Through the DEH development work material properties are mainly determined on full scale test arrangement. By this method the heat development in the steel pipe and current distribution are determined, but gives no specific information of steel pipe characteristics. Measurements of specific data requires dedicated test equipment that reflects the electromagnetic conditions for the DEH configuration. Obtaining these specific data is required to study the factors that influences the efficiency and required for improvement of DEH.

An example of a DEH pipeline at 3000 m water depth is selected to illustrate the achievement with higher power frequency.

NOMENCLATURE

CTZ – current transfer zone at the terminations at both pipeline ends
DC – direct current
DEH –direct electrical heating
DEHS - direct electrical heating system

DEH FC – DEH feeder cable (two core armoured cable of coaxial design)
FEA – Finite Element Analysis
DEH RC – electrical ricer cable (similar design as DEH FC)
PBC – piggyback cable (power cable routed along the pipeline and terminated at the far end
R, r – resistance
X, x - reactance
Z – impedance
WMC- wet mateable connector

DEH APPLICATION

DEH has been installed down to 1050 m water depth and is now considered for field developments of 3000 m water depths. The principle layout is shown in Fig, 1. The WMC connects the DEH RC (routed from hang off top side) to the DEH FC, which is connected to the near end and far end PBC. The new developed WMC make installation easier as connection to the DEH pipeline can be done subsea. Development are being carried out on the DEH RC to make the use of coaxial design feasible for ultra deep water. Using of higher power frequency is beneficial due to reduced cross section and weight. Furthermore, the bottleneck of exceeding limit cable temperatures particularly close to hang-off is easier to solve since the supply current and heat generation in the cable is considerably reduced by using higher frequency.

As indicated in Fig.1 the current is split between pipe and sea, where approximately 60% goes through the pipe and 40% in the sea at 50 Hz (Lervik, 1993; Nysveen, 2007). The total power supplied to the pipeline is typically 70%, and can be increased by a larger cable conductor cross section. Higher frequency may increase the efficiency. Even though a large portion of the current returns in sea, the losses in sea are small due to a low resistivity in sea. The pipeline is grounded at the ends through anodes (CTZ) and by intermediate anodes along the pipeline. The length of each CTZs is typically 50 m at 50 Hz and 25 m at 200 Hz.

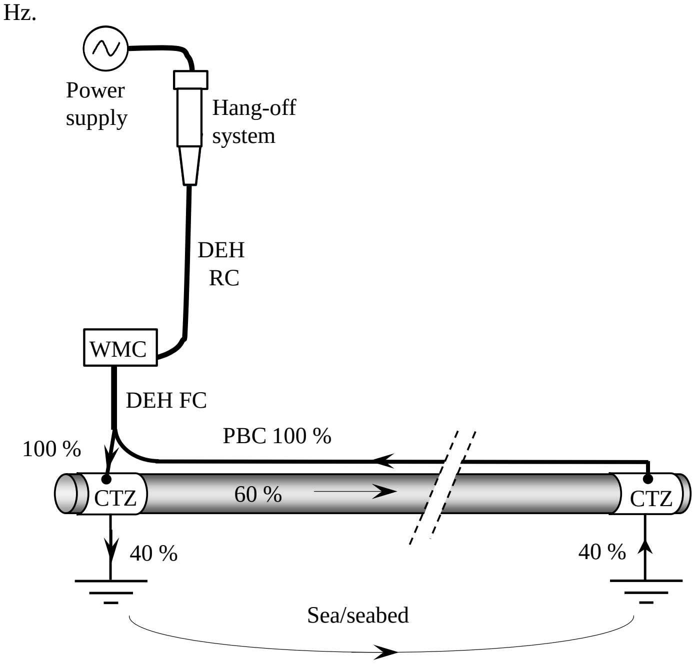

Fig. 1. DEH system with typical values of current distribution for a 12” pipeline at 50 Hz.

Experiences from installed DEH systems has shown a clear benefit between 50 and 60 Hz. For 60 Hz the supply current is decreased resulting in a reduced cable copper conductor cross section and reduced number of anodes in the grounding system in the current transfer zone at both pipe ends. The 60 Hz systems have cross section of 630 mm^2, while 1000 mm^2 is at present the minimum used at 50 Hz.

DEH ELECTRICAL CIRCUIT

Fig. 2 shows a simplified electrical circuit for the DEHS used in the FEA like COMSOL and Flux2d. Z_{s1} and Z_{s2} are the supply cable impedances for the two conductors (topside cables, DEH RC and DEH FC), Z_{PBC} is the PBC impedance, Z_{sea} is the seawater/seabed impedance, R_a represents the current transfer impedance in CTZ (resistive) and the pipe impedance split into two the resistive and reactive terms R_{Pipe} and X_{Pipe}. R_a can be neglected as it is in range of some milliohm.

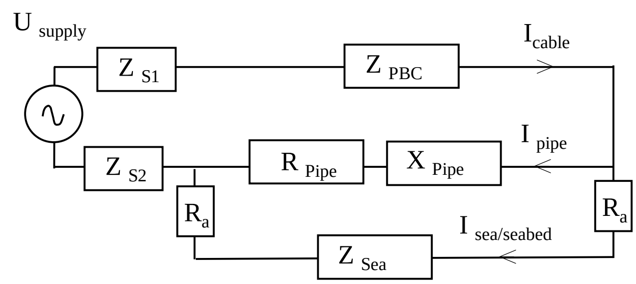

Fig. 2. DEHS equivalent electrical circuit.

R_{Pipe} and X_{Pipe} are decisive for the efficiency of the DEH system. R_{Pipe} reflects the heat generation in the steel pipe and X_{Pipe} determines the voltage drop due to electromagnetic field in the pipe. These two terms are dependent of the steel pipe material properties. Temperature, magnetic field exposure, power frequency, heat treatment, mechanical stresses, surface treatment (grit blasting during the thermal coating process) are factors that influences the steel pipe material properties. These factors are essential to quantify in order to give basis for optimizing the heat generation.

INFLUENCE ON THE RATING

For rating of DEH correct representation of steel pipe materials magnetic properties are important. The magnetic characteristics of carbon steels of X65 grade or similar differ considerably from 13Cr materials. Carbon steels are of magnetic materials, while 13Cr are low magnetic materials and is characterized by the relative magnetic permeability used in the FEA.

Measurements on test set-ups similar to the DEH applications are required to get a basis for the simulation model. These tests shall be carried out on the pipe joints at relevant magnetic flux density in the steel material. Important information is achieved by measurements with dedicated laboratory test equipment on specimens fabricated from actual pipe steel material. By this tests effects of surface treatment, mechanical stresses, heating etc. are studied.

For a DEH 12" pipeline the magnetic flux density in the steel is far below the saturation level for both carbon (X65) and 13Cr. This applies to the maximum power requirement of reheating the pipe content by 20ºC within 72 hours and a U-value of 4 W/m^2K. The flux density in the steel pipe is largest closest to the PBC. Fig. 3 shows the computed flux density through the pipe steel wall along the line (x) indicated in Fig. 5. The computations by FEA are carried out at 50, 100 and 200 Hz.

As seen the range of the flux density is within the same range for the three frequencies and the magnetic flux is concentrated close to the outer steel surface. Fig. 4 shows the computed relative flux density close to the outer steel surface along half of the circumference indicated in Fig. 5. The reference value is the maximum value given in Fig.3. The results in Figs. 3 and 4 states that for 50 – 200 Hz the field exposure is at the same level giving important information for measurements.

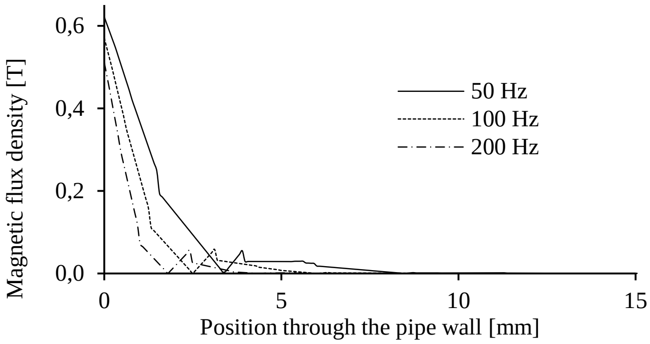

Fig. 3. Flux density through the pipe steel (carbon) wall.

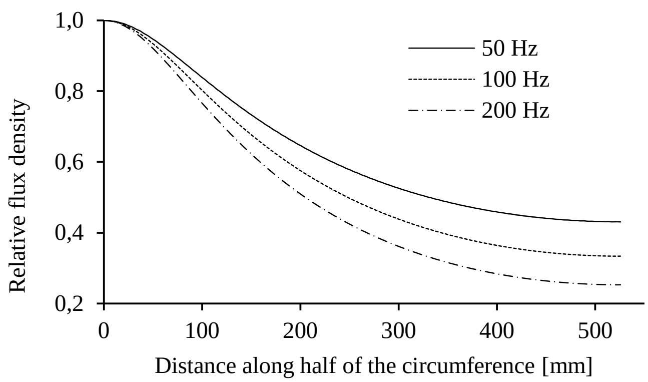

Fig. 4. Relative flux density close to the outer steel surface along half of the steel pipe circumference.

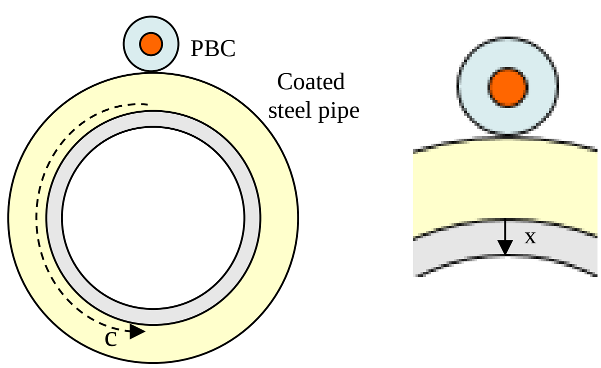

Fig. 5. Definition of C (position along half of the steel pipe circumference) and X (position through the steel pipe wall).

During heating the temperature may vary in the pipe steel material since the heat generation in the steel varies around the circumference. The maximum heat input is closest to the PBC since most of the current is conducted there. Due to the conductivity of steel, the temperature around the circumference, C in Fig 5) varies less than 1^{o}C.

Fig. 6 shows the results from FEA of the relative variation (referred to the maximum value) along half of the circumference indicated in Figure 5. As seen there is some difference between the three frequencies. The largest difference is farthest from the PBC, but at this position the heat generation is small. The corresponding steel pipe temperature is calculated at steady state conditions when the pipeline is surrounded by seawater. The computations by FEA are carried out for the selected 12" carbon steel pipe with a U-value of 4 W/m^{2}K filled with a mixture of oil, gas and water. Fig. 7 shows the relative temperature rise of the steel pipe around half of the circumference indicated in Figure 5. As seen the temperature varies only 6% for 200 Hz and 4% for 50 Hz, i.e. approximately 1^{o}C for a temperature rise of 20^{o}C.

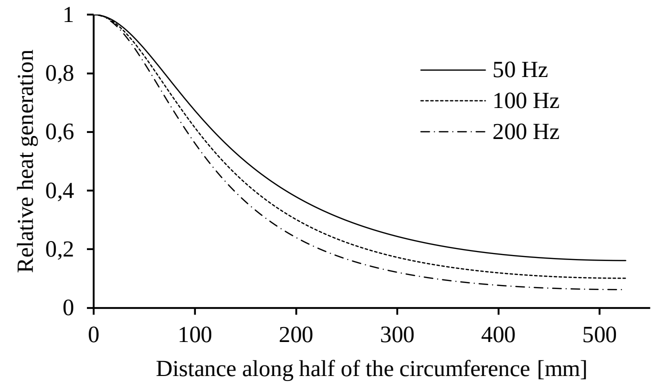

Fig. 6. Heat generation in the steel pipe around half of the circumference.

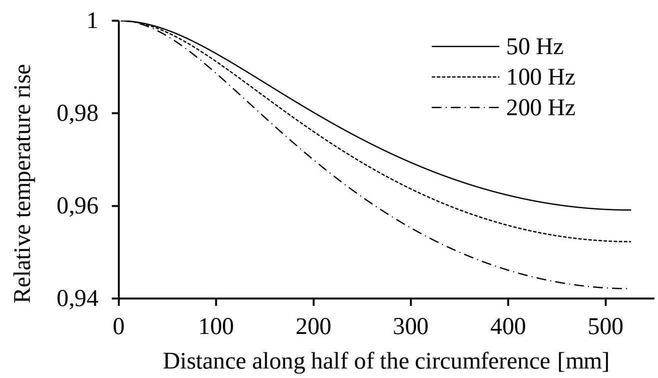

Fig. 7. Relative temperature rise in the steel pipe around half of the circumference.

For 13Cr steel pipes (low magnetic steel) the computations give almost identical results as Fig.7. However, the magnetic flux density is reduced compared to carbon steel pipes. The maximum flux density is approximately 0.1 T, which is considerably less than for carbon pipes see Fig. 8.

The magnetic relative permeability versus magnetic field determined by measurements on carbon steel specimens from two steel pipes of X65 grade is shown in Fig. 9. The results show considerably variation on the magnetic field and difference of the relative permeability between the two specimens. The tests are carried out applying constant magnetic field (DC). Similar measurements are carried out on 13Cr specimens. The results are shown in Fig. 10. The effect of heating the 13Cr specimens above 400^{o}C are included in the figure. Prior to the heating there were considerably variation on the magnetic field and difference of the relative permeability between the two specimens. After heating the relative permeability values was identical of the two specimens. Identical properties are favourable regarding rating of DEH.

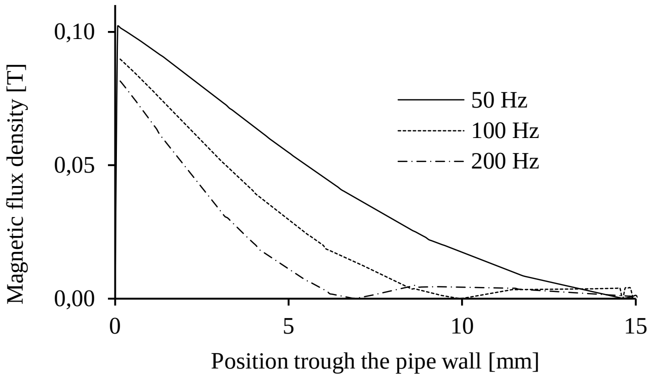

Fig. 8. Flux density through the pipe steel (carbon) wall.

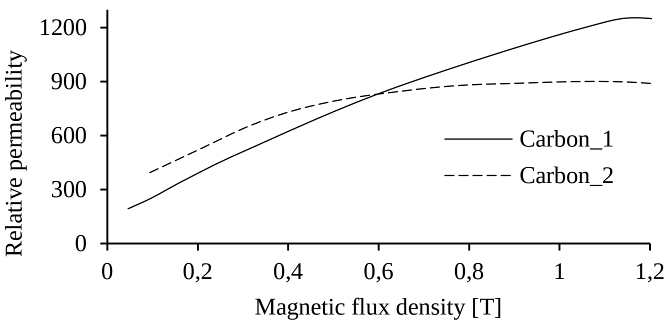

Fig. 9. Measurements of the magnetic relative permeability versus magnetic flux density on two specimens from two steel pipes of X65.

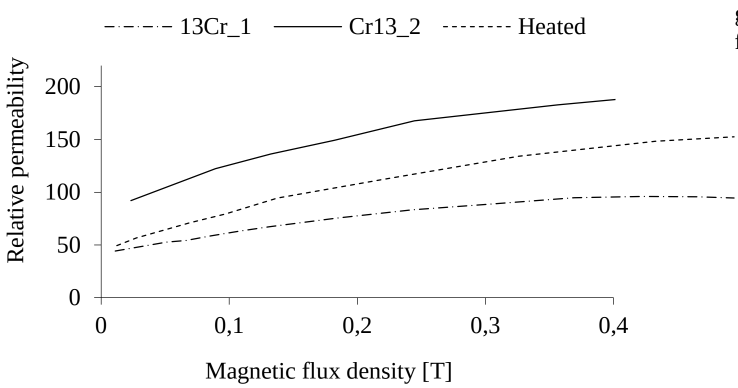

Fig. 10. Measurements of the magnetic relative permeability versus magnetic field on two specimens from two steel pipes of 13Cr.

In preparation for the thermal coating process the pipe joints are grit blasted. Measurements show that grit blasting affects the magnetic properties, which again changes the power loss. A series of measurements of the impedance, i.e. resistance and reactance, were performed on carbon steel specimens (rods) fabricated from pipe joints. The specimens surface were grit blasted according to a SA 2.5 grade. Figure 11 gives the results from grit blasting. The relative value of the resistive and reactive term referred to no blasting versus magnetic flux density are shown in the figure. The grit blasting has impact on both the resistive and reactive terms and reduces both terms. The x term was most influenced. This implies that for a DEH pipeline, see Fig. 2, the current in the steel pipe increases, but the resistive term that determines the generated heat in the steel pipe decreases. Since the generated heat is proportional with square of the current it is not possible to give a conclusion. Measurements on the pipe joints is therefore required. However, the tests carried out on specimens give important information regarding recommendations of surface treatment, i.e. by choosing a method that gives the highest r term and smallest x term.

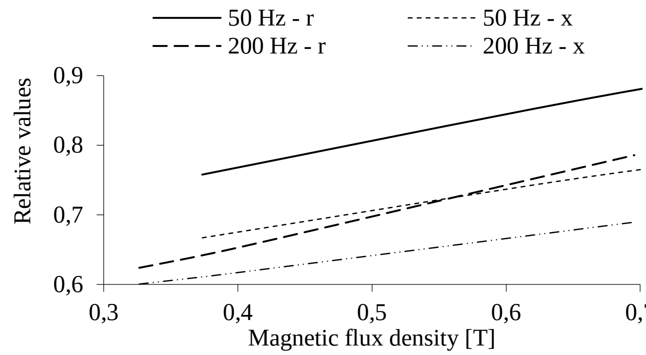

Figure 11. The relative value of the resistive and reactive terms referred to no blasting versus magnetic flux density for specimen of carbon steel (X65).

There is not observed effect of grit blasting on 13Cr. The reason is that the current in pipe of 13Cr is distributed in a considerably larger part of the cross section than is influenced by the grit blasting.

Measurements carried out on a large number of carbon pipe joints have shown that grit blasting reduces the values and the span of the relative permeability. The results from measurements on pipe joint prior and after the thermal coating process are shown in Fig. 12. These measurements are carried out at 50 Hz. It is expected that the effect of grit blasting on the heat generation is more pronounced at higher frequencies according to Fig 11.

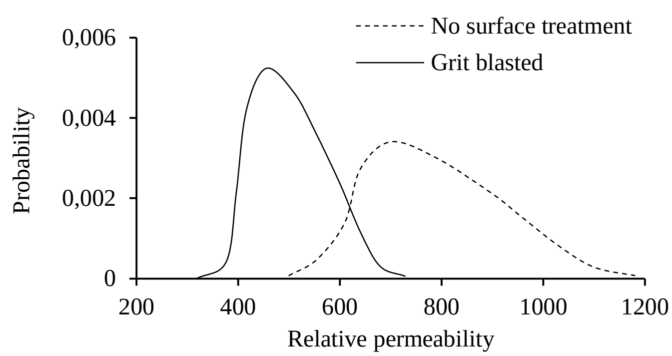

Fig. 12. The results from measurements on pipe joint prior and after the thermal coating process

AC CORROSION

For the present DEH system ac corrosion issues is solved by use of common bracelet aluminium anodes, which also function as a grounding system for the pipeline. The risk for ac corrosion is related to the transfer current density between steel pipe surface and anode surface and seawater. Additional anodes are required in the CTZs at the ends where the current is transferred to seawater, and also at intermediate distance along the pipeline in order to keep the induced pipe voltage at a sufficient low level. For the present design the CTZ length is approximately 50 m at 50 Hz. For 200 Hz the CTZ length and the amount of anodes are reduced. The transfer current is reduced by approximately 50% at 200 Hz compared to 50 Hz (Lervik, 2016).

The limits for aluminum anodes and steel materials are considered during the later field developments the limits has been reduced to recommended values of 20 A/m^2 for aluminum and 100 A/m^2 for carbon steel. For 50 Hz approximately 25 anodes are required in the CTZ, while for 200 Hz approximately 12 anodes are needed assuming equal limits. However, corrosion is expected to depend on the frequency and tests at higher frequencies need to be carried out.

EXAMPLE OF RATING AT 50 AND 200 HZ

The case study is a 12" coated pipeline with a U-value of 3 W/m^2K referred inner steel pipe diameter with a heated section of 15 km. The water depth is 3000 m. The heat requirement is to heat the pipe content from cooled down temperature of 5ºC to 25ºC within 72 hours. The pipeline is assumed filled with water.

DEH is supply from a vessel. The DEH RC is located inside a I-tube below seawater level and goes via a balcony to the wet-mateable connection (WMC) unit subsea, see Fig. 1. The WMC connects the DEH FC, which is split to the near and far end pipe connection by a PBC supplied with IPS (integrated protection system). The DEH RC and DEH RC are of coaxial design.

The DEH rating is carried out at 50 and 200 Hz. The results are summarized in Tab. 1.

Tab. 1. Power requirements and PBC conductor cross sections for the reheating case.

Power frequency	50	200
Supply Current	1100 A	660 A
Supply voltage	5,5 kV	13,2 kV
Power demand	1,9 MW	2,0 MW
Cable copper conductor cross section	800 mm^2	300 mm^2

As seen from Tab.1 the conductor cross section is considerably less for 200 Hz than for 50 Hz. 50 Hz needs a 12 kV cable insulation. 200 Hz requires 24 kV. However, the insulation thickness in only a few millimetres in difference.

The rating is carried out with copper conductors. For ultra deep waters aluminum conductors are relevant due to weight reduction. Cables with aluminum conductors require some additional cross section increase than with copper due to higher power loss.

CONCLUSIONS

Detailed representation of steel pipe materials magnetic properties is required in order to establish the equivalent circuit diagrams needed for rating of DEH by FEA.

Since the generated heat in the steel pipe depends on the magnetic field, measurements of the steel pipe properties need to be carried out with equal electromagnetic conditions as for the real DEH installation.

Mechanical stresses, grit blasting and temperature exposure influences the properties with a reduction of around 50% of both the relative permeability and the variation between the individual pipejoints.

Increased frequency reduces weight and size of the cables, and make DEH favourable for development at ultra deep waters but also for conventional water depths. The main challenge is related to development of a proper mechanical cable for ultra deep waters.

Rating of DEH pipes of carbon steel is more sensitive to surface treatment than 13Cr steel material. Surface treatment (grit blasting) reduces the variation of the material properties in the pipe joints and needs to be further studied in order to optimize DEH.

The surface treatment may have larger impact on the DEH rating by increased frequency for carbon steel pipes since the skin effect increases with increasing frequency.

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