CHALLENGES IN DESIGNING A 10 kV SKIN EFFECT TRACE HEATING SYSTEM

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Abstract – A risk assessment for operating a skin effect trace heating system at 10 kVac in hazardous locations was conducted. The primary risk identified was the possible occurrence of electrostatic and partial discharges containing sufficient energy to trigger an explosion. Several skin effect insulated conductor (cable) designs were assessed against this risk by performing partial discharge measurements and ignition proof testing as a function of voltage and temperature. Certification according to the IECEx product scheme for increased safety “eb” was carried out by using IEC 60079-33 to allow incorporation of the type tests in IEEE Std 844.1-2017/CSA C22.2 No. 293.1-17 and by including the ignition tests from IEC 60079-7. It was found that the transferred charge could be substantially reduced by incorporating a semi-conductive shield around the insulation layer in the skin effect insulated conductor. With this shielded configuration, ignition in an explosive atmosphere did not occur up to the test voltages required for a 10 kVac rating.

Index Terms — skin effect trace heating, partial discharge, ignition testing, explosion protection, hazardous locations.

I. INTRODUCTION

A. Application of Skin Effect Trace Heating Systems in Long Pipelines

Operators of cross-country pipelines transporting heavy or waxy crude must ensure proper flow of the pipeline’s contents in order to operate efficiently. This is accomplished by controlling fluid viscosity. Various methods used for flow assurance include the addition of chemical additives or diluents, blending of different crude grades, thermally insulating the pipeline, bulk heating or re-heating of the fluid contents at intervals along the pipeline and using heated recirculating fluids, steam or electric trace heating along the length of the pipeline. Each method has an associated cost and performance window that can be evaluated against the project design requirements.

Electric skin effect trace heating systems have an established history of use for maintaining temperatures in long pipelines. The 670 km long continuously heated Mangala Development Pipeline in India (see Fig. 1) was designed to provide flow assurance using a skin effect trace heating system [1]. Skin effect trace heating systems are well suited for these applications because their circuit lengths can extend up to 10 to 20 kilometers depending on the design.

Fig. 1 Mangala Development Pipeline under construction

B. Skin Effect Heating Principle of Operation and System Overview

Skin effect trace heating systems are designed for heating long lengths of pipe. The system is comprised of a continuous carbon steel heat tube that is welded or strapped to the carrier pipe to be heated, a power box, a number of pull/splice boxes, an end termination box, a cable running within the heat tube (known as the skin effect insulated conductor in IEEE Std.844.1-2017/CSA C22.2 No. 293.1-17), and splices for the cable (see Figs. 2 & 3). The current flowing in the cable creates a magnetic field which keeps the return current flowing along the inner surface of the heat tube, thus ensuring that the outside of the heat tube is effectively at earth (zero) potential. Heat generation is based on the combined electrical phenomena of Ohm’s law, skin effect and proximity effect in ferromagnetic conductive materials under alternating current (AC). Skin effect trace heating technology is very efficient since all of the heat is generated inside the thermal insulation envelope. The low impedance and high voltage capability of the skin effect heater enables it to operate over long circuit lengths at relatively high power.

The skin effect insulated conductor and the heat tube are connected together to make a series circuit. The relationship between the heat tube size, the skin effect insulated conductor size, the power frequency and the applied voltage determines the output power. Skin effect trace heating systems for cross-country oil pipelines typically operate in the range of 0.4 to 0.7 volts per meter, at 80 to 120 amps. The applied voltage is directly proportional to the length of the heater, so doubling the circuit length requires doubling the applied voltage. Historically, skin effect insulated conductors that can operate at up to 5000 Vac at commercial power frequency inside the heat tube have been used, but extending circuit lengths to meet current market needs requires higher voltages. Since current flows on the inside surface of the heat tube, and since the skin effect insulated conductor forms an integral part of the heater, utilization of standard shielded medium voltage wire becomes problematic with relation to temperatures and shield grounding.

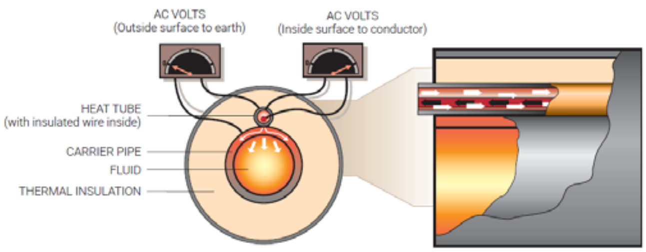


Fig. 2 Sectional Views of Skin Effect Heating System and Carrier Pipe

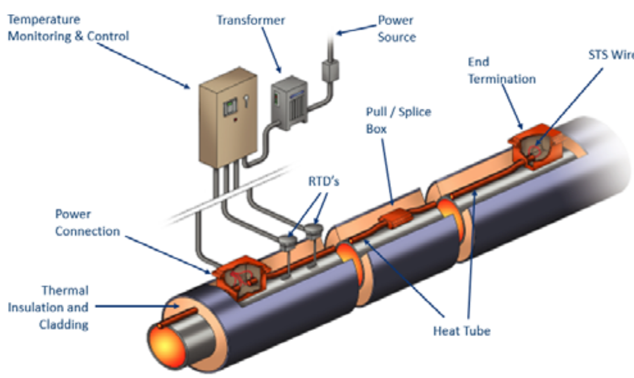


Fig. 3 Skin Effect System Overview

C. Need for Longer Circuit Lengths

The recovery of heavy waxy crude from oil fields located in distant regions increasingly relies on long cross-country pipelines as a means for its transport to market. These projects often require the ability to heat the entire length of the pipeline for flow assurance. For skin effect trace heating systems, each circuit along a pipeline must have access to a power feed or connection point. The total number of power feeds depends on the maximum voltage rating of the skin effect system. A higher operating voltage results in longer circuit lengths and fewer power feeds for the pipeline project. To date, the voltage rating of skin effect trace heating systems has been limited by the onset of substantial partial discharge above 5 kVac, which is the upper voltage limit referenced in IEEE Std 844.1-2017/CSA C22.2 No. 293.1-17 [2]. Increasing the operating voltage to 10 kVac would essentially double the maximum circuit length and cut in half the number of power feed points required. This can lead to significantly lower total-installed and operational costs for pipeline operators.

D. Purpose of Paper

The purpose of this paper is to share the approaches taken (1) to develop and certify a skin effect trace heating system that operates at voltages above the existing limits of the IEEE standard, and (2) to obtain certification within the IECEx system that presently has no formal standard for skin effect trace heating. This paper will also indicate the design changes and testing requirements to assure safe and reliable performance at a 10 kVac operating voltage.

II. RISK ASSESSMENT FOR OPERATING AT 10kV

A. Special Investigation of Skin Effect Trace Heating System

In a skin effect trace heating system, the cable lies along the inner surface of the carbon steel heat tube in an eccentric arrangement. Raising the potential on the skin effect insulated conductor creates a high electric field in the region that lies between it and the grounded heat tube as illustrated in Fig. 4. This arrangement facilitates the onset of partial discharge when the local electric field exceeds the dielectric strength of the surrounding medium (air).

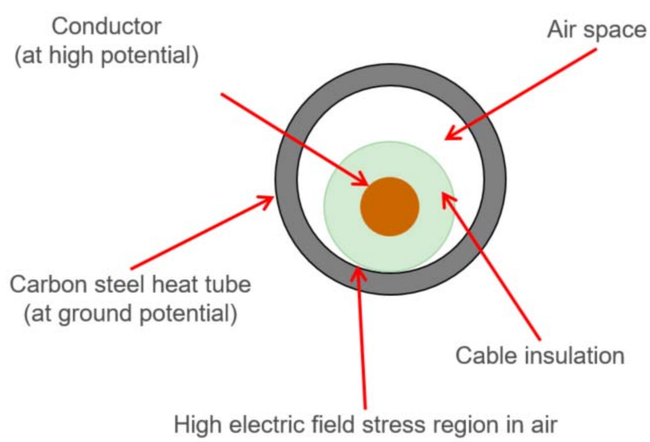


Fig. 4 Cross-section view of skin effect insulated conductor lying inside carbon steel heat tube

Note 1 in the Scope clause of IEEE Std 844.1-2017/CSA C22.2 No. 293.1-17 provides guidance for operating above 5 kVac: *"Requirements for certification at voltages above 5 kVac or skin effect insulated conductor insulation temperatures above 260 °C may be considered under a special investigation by an accredited certification body."* A preliminary analysis was conducted by the authors of this paper. The goal was to assess the risks of operating a skin effect trace heating system at 10 kVac.

The concern identified was the possible occurrence of electrostatic and partial discharges at 10 kVac due to an unsuitable conductor insulation system. This scenario is analogous to what has been observed in insulated windings of non-sparking rotating electrical machines up to 15 kVac [3]. Such discharges can contain sufficient energy to trigger ignition in an explosive atmosphere.

B. Physical Background of Partial Discharges

The explosion protection of equipment includes a risk assessment with respect to potential ignition sources. Main ignition sources for high voltage products like heating devices are electrical discharge and the operating temperature.

The subdivision of electrical discharges with the possibility of an ignition of an explosive atmosphere must be assessed (Fig. 5). In principle, a test sample of an insulation system can be defined by two electrodes connected with the high voltage and an insulation material sandwiched in between them.

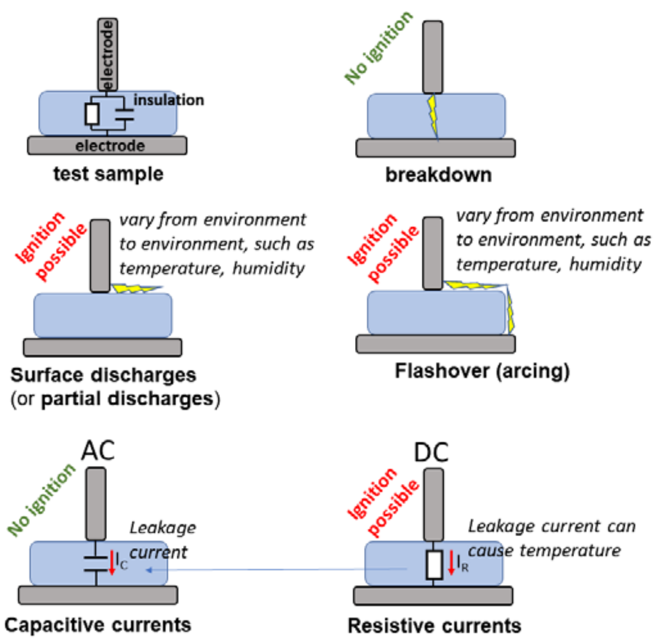


Fig. 5 Different types of discharges

An internal electrical breakdown of the insulation produces a spark without contact to the external environment and therefore no ignition of an explosive atmosphere can be supposed. Contrary to an internal breakdown, a flashover (arc) produces a possible ignitable discharge. The so-called breakdown voltage depends on temperature, humidity effects and especially on the electrical field strength.

In non-homogeneous electrical fields, partial discharges on a surface are possible. These partial discharges depend also on temperature, humidity effects and especially on the electrical field strength, and can ignite an explosive atmosphere if the energy exceeds the minimum ignition energy. Comparable to partial discharges are the electrostatic discharges as defined in IEC 60079-0 with ignition thresholds depending on the gas groups.

An additional consideration is the leakage current if a high voltage is connected to the electrodes. A simple electrical circuit diagram describes the insulation system by a parallel connection of a resistance and a capacitance. The capacitance produces a reactive current without an effect on ignition risks. The current through the resistance pathway produces a temperature increase and can be seen as a possible ignition source.

III. EXPERIMENTAL SETUP

A. Test Sample Description: Cables 1 - 5

Five different configurations of skin effect insulated conductors were considered for initial experimental evaluation. These are identified as cables 1 – 5 as shown in Fig 6. All cables had the following features in common:

- Conductors were stranded tin plated copper wires surrounded by a semi-conducting conductor shield
- Insulation materials were made of silicone rubber in order to meet the 150 °C operating temperature required for flow assurance applications and to provide resistance against partial discharge
- Insulation thicknesses were 3.5 mm

Fig. 6 Experimental cables 1 -- 5

Distinguishing features among the five cables are noted in Table I. Conductor size was 21.1 mm^2 for cables 1 – 4 and 6.1 mm^2 for cable 5. Cables 4 and 5 had tinned copper wire braids as a conductive insulation shield layer. Cables 1, 2 and 5 had silicone jackets while cable 4 had a wrapped polytetrafluoroethylene (PTFE) jacket. The red colored rib-shaped jacket in cable 1 had a higher durometer (hardness) than the black colored jacket with a similar cross section in cable 2. Cable 3 had no jacket over the insulation layer.

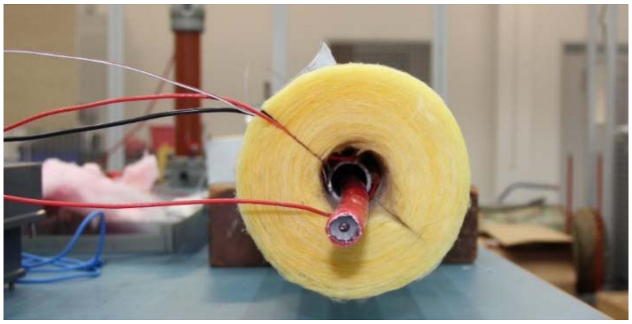
Table I
SAMPLES FOR TESTING

Cable	Conductor	Insulation Shield	Jacket / Outer Dia.
1	21.1 mm^2	None	Red rib shape /20 mm
2	21.1 mm^2	None	Black rib shape /20 mm
3	21.1 mm^2	None	None /16 mm
4	21.1 mm^2	Wire braid	White PTFE tape /18 mm
5	6.1 mm^2	Semi-conductive nonwoven tape and wire braid	Red circular /17 mm

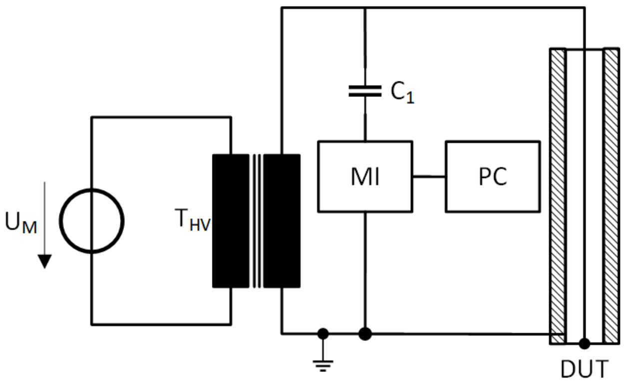
B. Partial Discharge Testing

Partial discharge tests were performed on the five different sample cables listed in Table I. In each case, the cable was installed inside a 3 m long thermally insulated carbon steel heat tube (see Fig. 7). The tests were carried out at an ambient temperature of 20 °C and also with the heat tube heated above 130 °C to investigate the influence of temperature. Additionally, the influence of aging of the skin effect insulated conductor on partial discharge performance was investigated. For this purpose, cable 1 was subjected to the two environmental conditioning cases listed below and the partial discharge results were compared against the same cable in new condition.

Case 1: 672 h at 170 °C (dry)
Case 2: 336 h at 95 °C (95 % RH) followed by 336 h at 170 °C (dry)



(a)



(b)

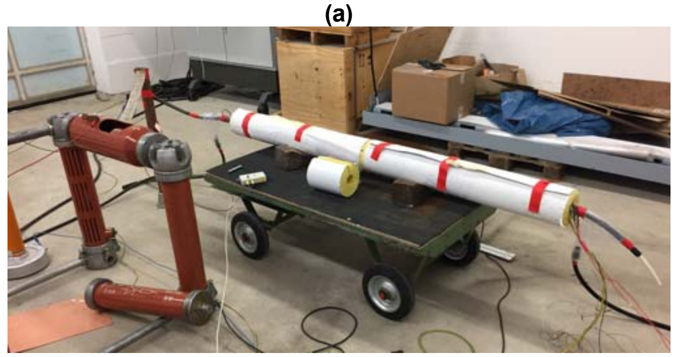
Fig. 7 (a) Partial discharge test setup of thermally insulated heat tube and skin effect insulated conductor, (b) Schematic illustration of the experimental partial discharge setup with high voltage transformer T_{HV}, capacitor C_1, measuring impedance MI and heat tube with skin effect insulated conductor (DUT, device under test).

C. *Ignition Proof Testing*

Two ignition tests were performed for all sample cables at room temperature in a 1" diameter heat tube under combustible gas contained in a plastic foil at a heat tube temperature of 170 °C (see Fig 8). The first ignition test was performed according to the requirements of IEC 60079-7, 6.2.3.1.2 'Impulse ignition test for Level of Protection "eb" stator insulation systems' (see Fig. 9) [4]. The cable samples were subjected to 10 voltage impulses with a voltage rise time between 0.2 µs and 0.5 µs, and with a time to half value which was at least 20 µs. An impulse voltage of not less than three times peak phase to earth voltage is required to pass the test. A combustible gas test mixture in air containing ethylene (7.8±1%) was used for a verification of the 10kV skin effect trace heating system for Equipment Group IIB. The combustible mixture was generated by the gas mixer M1 and was validated by the O_2 Analyzer A_1. The test voltage was monitored by the use of an oscilloscope O_1. The impulse test is intended to address randomly occurring switching transients in a Zone 1 area.

The second ignition test was performed according to the requirements of IEC 60079-7, 6.2.3.1.3 'Steady state ignition test for Levels of Protection "eb" and "ec" stator insulation systems' [3]. The cable samples were tested with a sinusoidal voltage of at least 1.5 times the rated r.m.s line voltage for at least 3 min. The test voltage required was 15 kV. The value of 1.5 times the rated r.m.s. line voltage includes a 50% addition of the rated voltage to cover lifetime and pollution effects. The experimental setup was comparable with Fig. 9, excluding D_1, S_1, C_1 and R_1.

(a)



(b)

Fig. 8(a) Sinusoidal ignition test of heat tube and skin effect insulated conductor under combustible gas contained in plastic foil, (b) Preparation for impulse ignition test in heat tube surrounded by thermal insulation.

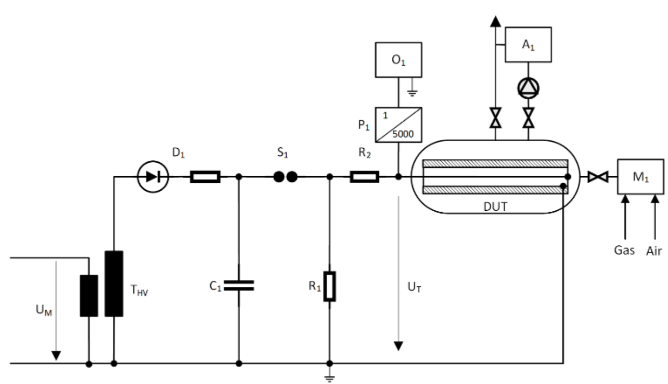


Fig. 9 Test setup for the impulse ignition test under IIB gas with high voltage transformer T_{HV}, rectifier D_1, spark gap S_1, discharge resistor R_1, dumping resistor R_2, surge capacity C_1, potentiometer P_1, oscilloscope O_1, gas mixer M_1, gas analyzer A_1 and heat tube with skin effect insulated conductor (DUT, device under test).

IV. RESULTS AND DATA ANALYSIS

A. Partial Discharge Tests

1) *Cables 1 – 5:* For the screening of various skin effect insulated conductor (cable) configurations and to enable the comparison to electrostatic risks which may occur with discharges in the nanocoulomb (nC) range, a partial discharge measurement device was used. Fig. 10 shows a typical result where over a specified time all discharges were measured as a function of the sinusoidal voltage. Each discharge is printed by a dot relative to the sinusoidal wave. The test voltage of this example was 10 kV and the median discharge value is calculated at 5.7 nC. It is important to recognize that during a test period of 30 seconds approximately 39000 discharges occurred, and some partial discharges have a value of about 15 nC. A spatial assignment for each individual discharge is not possible and therefore these discharges could have occurred at any location within the test setup.

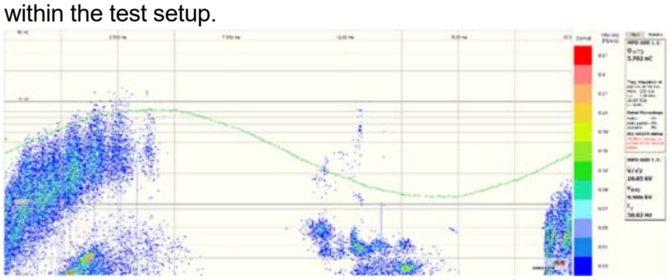


Fig. 10 Unipolar histogram of a test sample of skin effect insulated conductor at a sinusoidal voltage of 10 kV.

All five skin effect insulated conductors (cables 1 – 5) were tested in the heat tube at an ambient temperature of 20 °C and also at a temperature of 130 °C. Fig. 11 (a) shows the results of the partial discharge test for cable 1 in the heat tube. The measured values at both temperatures are plotted along with exponential curve fit lines. The plot of the curves for cables 2 – 5 was comparable. It can be seen that at a temperature of 130 °C nearly five times higher discharge values were detected compared to ambient temperature. While 13 nC in average was measured at an input voltage of 13 kV at ambient temperature, 61.7 nC in average was measured at an input voltage of 12 kV at 130 °C. This clearly shows how strongly the ambient conditions influence the charge behavior. This can be explained by the fact that not only is the ambient temperature increasing but the temperature of the insulating materials is increasing as well and thus partial discharges are favored [5].

Fig. 11 (b) shows the discharge values for all five cables under test at a heat tube temperature of 130 °C. Except for cable 3, an exponential curve can be seen for every measurement value of the different cable types. For cable 3, a linear fit was used due to the measurement results. The highest measured discharge values occurred with cable 1 and were 61.7 nC on average. For cables 2 and 3, the average discharge was about 47 nC, which equates to a reduction of 24 %. Cables 4 and 5 measured less than 10 nC on average--a maximum discharge value that is 9.7 % in relation to cable 1.

The requirement of IEC 60079-0 [6] is that for Group IIB equipment with EPL Gb the maximum acceptable transferred charge is 25 nC. This limit was met by all five cables in the application range of 5 kV. Cables 2, 4 and 5 do not exceed the 25 nC value even in the extended application range up to 10 kV.

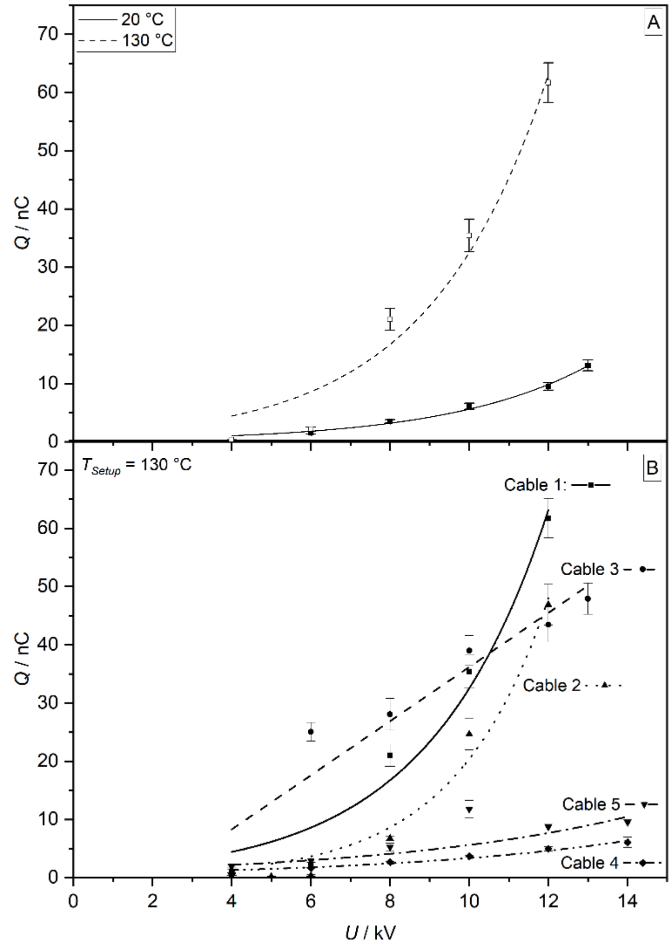


Fig. 11 (a) Partial discharge Q at a test voltage U up to 14 kV for cable 1 at 20 °C and 130 °C, (b) Partial discharge for 5 different cables at 130 °C

Cable 1 was subjected to two different aging procedures to analyze the impact of long-term use in relation to partial discharges (see Fig. 12). As can be seen, for a voltage up to 4 kV, aging has no significant impact on partial discharge activities. For a voltage of 8 kV, partial discharges of 31 nC occur on average for a new cable. Aging the cable for 672 h at 170 °C (dry) leads on average only to a slight increase in the partial discharge to 32 nC. The aging process of 336 h at 95 °C (95% RH) followed by 336 h at 170 °C (dry) leads to a 38% increase in the discharge to 43 nC at a voltage of 7 kV. This leads to the conclusion that a cable will not show any significant effects from being installed for a long period of time in a dry state with regard to an ignition hazard due to partial discharge. Leakage of ambient air into the system can lead to fluctuations in humidity. If this occurs, higher partial discharges can be expected. It is therefore important to ensure that a cable used for such a system already exhibits low partial discharge activity in the newly manufactured state.

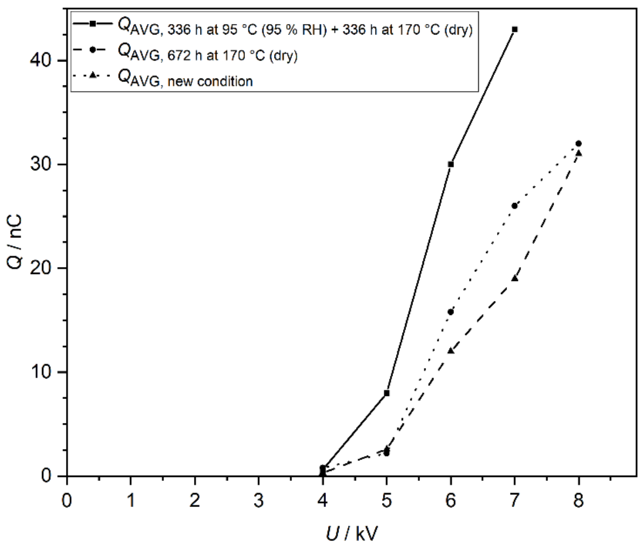


Fig. 12 Partial discharge Q at a test voltage U up to 8 kV for cable 1 in new condition and two environmentally conditioned cases.

2) *Skin Effect Insulated Conductor and Splice Joint with Semi-conductive Shield:* Partial discharge testing was carried out on a skin effect insulated conductor splice joint assembly. A semi-conductive shield made of silicone rubber surrounded all the insulation layers. The test setup is shown in Fig. 13 and was similar to that described earlier for partial discharge in section IIC except that no heat tube was present. The semi-conductive shield was used as the ground reference, thereby resulting in the detection of any partial discharge internal to the splice joint or the skin effect insulated conductor. The test procedure consisted of a series of stepped voltage ramps up to a maximum of 30 kVac and then back down to 10 kVac with pauses at each step to observe the partial discharge activity. The voltage applied and duration for each pause are listed in Table II.

Fig 13. Partial discharge test setup for skin effect insulated conductor splice joint assembly

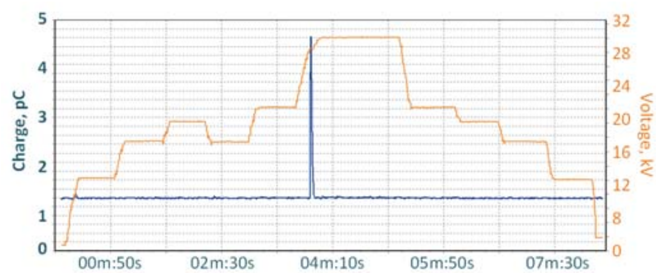
Table II
SEQUENCE FOR PARTIAL DISCHARGE TEST

Step #	Voltage / kV	Pause Duration / seconds
1	10	30
2	15	30
3	18	30
4	15	30
5	20	30
6	30	60
7	20	30
8	18	30
9	15	30
10	10	30

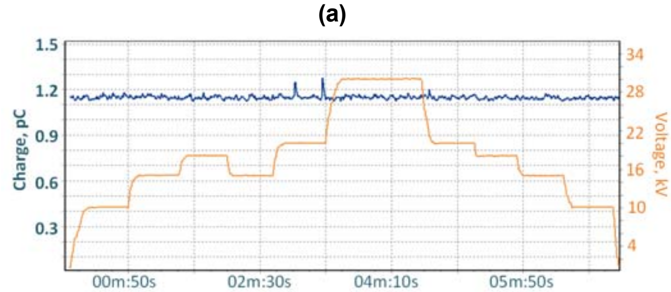
The results of this test for the skin effect insulated conductor splice joint assembly in new condition is shown in Fig.14 (a). The measured partial discharge level (dark blue line) was stable at 1.2 picocoulomb (pC) across all voltage steps (orange line), except for a burst of 5 pC that occurred at 29kV.

The skin effect insulated conductor splice joint assembly was then environmentally conditioned at 170 °C (dry) for 28 days and subsequently re-tested. The heat aging was performed to evaluate the effect of long-term use. The partial discharge graph after heat aging is shown in Fig. 14 (b). The measured partial discharge level (dark blue line) was stable at about 1.2 pC for all voltage steps (orange line) for the duration of the test.

The partial discharge level for both tests was well below the nC range across all voltages (0 – 30 kVac) and therefore should not be expected to pose an ignition risk up to 10 kVac for equipment group IIB.



(a)



(b)

Fig. 14 (a) Partial discharge measurement for new sample, (b) Partial discharge for environmentally conditioned sample.

B. Ignition Proof Tests

1) *Cables 1 – 5:* Each of the five skin effect insulated conductor (cable) types were tested in a stepwise fashion with increased impulse and sinusoidal voltages at a heat tube temperature of 170 °C.

Table III shows the results for the Impulse ignition test. For a 5 kV application, the cables must pass a 21.2 kV test voltage and for the 10 kV application, 42.3 kV is required. As can be seen, all cables pass the test with at least 28.5 kV. This means that all cables are suitable for a 5 kV application. Due to the previous results from the partial discharge test, cables 2 and 4 were additionally tested with the higher voltage for the 10 kV application. Both cables passed this test at 10 pulses with a voltage of at least 42.3 kV. The surrounding gas mixture was not ignited until a voltage of 48.8 kV.

TABLE III
IMPULSE IGNITION TEST

Cable	Voltage / kV	Ignition
1	20.2	No
	28.5	No
2	20.1	No
	28.4	No
	42.5[a]	No
3	20.1	No
	28.4	No
4	20.3	No
	28.4	No
	42.5[a]	No
	48.8	Yes
5	20.2	No
	28.5	No

[a] Test voltage for 10 kV application

Table IV shows the results of the steady state ignition tests. For the 10 kV application, all cables were required to pass a test voltage of 15 kV. In contrast to the test with impulse voltage, ignition was triggered for all cables. However, this only occurred above a test voltage of 15 kV. For cable 4 it was noted that an ignition of the surrounding gas mixture did not occur until a voltage of 26.5 kV had been reached. On average, this is an additional 6 kV higher compared to the other cables.

TABLE IV
STEADY STATE IGNITION TEST

Cable	Voltage / kV	Time / s	Ignition
1	15.2	180	No
	18.1	145	Yes
2	15.3	180	No
	18.0	180	No
	21.4	8	Yes
3	15.1	180	No
	18.2	180	No
	20.5	70	Yes
4	15.2	180	No
	18.1	180	No
	20.4	180	No
	22.7	180	No
	26.5	90	Yes
5	15.1	180	No
	18.2	180	No
	20.5	120	Yes

It can be seen that the results of the ignition tests correlate with the results of the partial discharge tests. If the charge transferred by partial discharge is below 10 nC, this cable also passes the ignition test, as is the case with cable 4, for example. At higher partial discharges, it can be seen that the ignition tests did not pass with an increased voltage (e.g. cable 1). This shows that the previous discharge measurement of the cables already provides an approximate statement about the ignition behavior in combustible gas mixtures.

2) *Skin Effect Insulated Conductor with Semi-conducting Shield:* Results from the partial discharge and ignition proof tests suggested that completely surrounding the silicone insulation with a semi-conducting shield could offer a solution for reducing the possibility of ignition in a 10 kVac application. To verify this, ignition proof tests were performed on two skin effect insulated conductor samples: one with a circular semi-conducting shield and one with a rib-shaped semi-conducting shield as shown in Fig. 15. The insulation thickness was 3.5 mm for both samples. The ignition test procedure was the same as previously described in section III C and the heat tube was held at a temperature of 170 °C during the test. The semi-conductive shields were in physical and electrical contact with the heat tube, i.e., no external jacket was present.

Fig 15. Semi-conductive Shielded Skin Effect Insulated Conductors

Table V shows the results for the impulse ignition tests. For both skin effect insulated conductors, subjecting each to 10 high voltage impulses resulted in no ignition of the surrounding gas mixture up to a test voltage of 42.5 kV. Comparable to the previous tests, ignition was only triggered with a test voltage of 48.8 kV.

TABLE V
IMPULSE IGNITION TEST

Cable	Voltage / kV	Ignition
Round	24.8	No
	35.0	No
	40.8	No
	42.5[a]	No
	48.8	Yes
Ribbed	27.7	No
	33.8	No
	37.9	No
	40.4	No
	42.5[a]	No

[a] Test voltage for 10 kV application

Table VI shows the results of the steady state ignition tests. For the 10 kV application, both cables pass the steady state ignition test with a test voltage of 15 kV. The test was continued up to a voltage of 22.1 kV and did not trigger ignition of the gas mixture. Comparing these results with those from cables 1 - 5, it can be observed that completely surrounding the silicone insulation with a semi-conducting shield prevents ignition of the surrounding gas due to partial discharge. This effect is valid up to 22.1 kV for the cables used in this ignition study. The partial discharge results from the semi-conductive samples tested in section IV A suggest that these samples may also pass ignition testing up to 30 kV.

TABLE VI
STEADY STATE IGNITION TEST

Cable	Voltage / kV	Time / s	Ignition
Round	13.1	180	No
	15.2	180	No
	18.1	180	No
	20.2	180	No
	22.1	180	No
Ribbed	13.1	180	No
	15.2	180	No
	18.0	180	No
	20.1	180	No
	22.1	180	No

V. IECEx CERTIFICATION

A. Standards Background Situation

First published in 1985, IEEE 844 has been and still is the only published standard addressing skin effect trace heating. The standard has been updated several times over the years. In 2017, IEEE 844.1/CSA C22.2 No. 293.1 was jointly published by the IEEE and CSA as the first internationally recognized standard for skin effect trace heating. The 2017 version was heavily revised in order to align it more closely with IEC standards, however it is currently only adopted in the US and Canada.

A certification in the IECEx product certification scheme is always related to IEC standards of the IEC 60079 series. Fundamental requirements for electrical Ex Equipment are defined in IEC 60079-0 [6]. Specific requirements for trace heating systems and other heating equipment are specified in IEC/IEEE 60079-30-1 [7] and IEC 60079-7 [4] so that certification should be done according to one of these standards. These standards do not however address the unique aspects of skin effect trace heating systems.

Type of protection "increased safety", Ex "eb", is based on the principle of prevention of ignition of a potentially explosive atmosphere, which can also penetrate the enclosure, by the equipment. This means that the equipment must not attain temperatures above the temperature class of gases that may occur at the place of use, nor may electrically or mechanically generated sparks be allowed to occur. This applies both to normal operation and to foreseeable faults. For Level of Protection “eb” the standard allows the use of a rated voltage up to 11 kV rms, ac or dc. One requirement is that the Ex Equipment encloses all bare and conductive live parts. For a skin effect trace heating system the heating cable is connected to the heating tube. Thereby an electrical potential is not present on the outside of the heating tube due to the skin effect. But this protection principle is not covered by this standard.

The scope of IEC/IEEE 60079-30-1 covers electrical resistance trace heaters for series trace heaters, parallel trace heaters, trace heater pads and trace heater panels. Certification of skin effect trace heating systems in line with IEC 60079-7 and/or IEC/IEEE 60079-30-1 is therefore not possible.

“The purpose of IEC 60079-33 special protection “s” for any equipment protection level (EPL) is to allow design, assessment and testing of equipment or parts of equipment that cannot be fully assessed within a recognized type of protection or combination of recognized types of protection because of functional or operational limitations” and where the desired equipment protection level can be achieved by the use of this standard. Special protection “s” allows a design concept that cannot comply in full with recognized types of protection, or where the design concept is not covered by recognized types of protection.” [8]

B. Certification Test Plan and Results

To evaluate and ensure a high protection level of the high voltage skin effect trace heating system which is comparable to the harmonized IEC 60079 standard series, the type tests in accordance to IEEE Std 844.1-2017/CSA C22.2 No. 293.1-17 were conducted. Dielectric testing was conducted at 21 kV and the U-bend test was conducted at 30 kV. The trace heating system or defined samples were also subjected to all applicable tests of IEC 60079-0 and IEC 60079-7. This ensures that all enclosure components have a minimum Ingress Protection of IP54. All relevant type tests of IEC/IEEE 60079-30-1 are equivalent to the type tests defined in IEEE Std 844.1-2017/CSA C22.2 No. 293.1-17. As a result, additional tests were performed such as the Abrasion resistance test and Skin effect power, end termination, splice and pull box type tests.

The applied voltage of up to 10 kV carries the risk of high partial discharges that can serve as a source of ignition. For this reason, the two ignition tests from IEC 60079-7 mentioned previously in section IIIC were also performed in the certification process.

The system design and construction review, type testing and certification was performed by one IECEx ExTL and reviewed by two independent IECEx ExCBs to ensure that finally the safety level of the skin effect trace heating system is comparable to the recognized ignition protection types of the IEC 60079 series.

As a result, the high voltage skin effect trace heating system for a rated voltage up to 10 kV was certified for the following specification: Ex eb sb IIB T6…T3 Gb. Certification for the ATEX system can also be completed using the same approach as shown in this paper.

VI. CONCLUSION

In designing a skin effect trace heating system to operate at voltages above those encompassed the existing standards, it is necessary to first identify and then address the possible risks due to higher voltages, giving particular consideration to hazardous locations and operating temperatures. A key risk for operating at 10 kVac is the possible occurrence of electrostatic and partial discharges due to an unsuitable insulation system.

At voltages above 5 kVac, unshielded skin effect insulated conductors have partial discharge levels that are strongly dependent upon temperature. However, thermal heat aging in a dry state has no significant impact on partial discharge activity suggesting that the ignition hazard does not change much over time.

The results from ignition tests on skin effect insulated conductors correlate with the partial discharge levels and provide an approximate guideline for the ignition behavior in the presence of combustible gases:

- For unshielded configurations, high levels of partial discharge occur in the nanocoulomb range above 5 kV and ignition of a combustible gas atmosphere is triggered under these test conditions.

- For fully shielded configurations, partial discharge is contained to less than 10 picocoulombs up to 30 kVac and no ignition occurs.

Testing results demonstrate that including an outer semiconductive insulation shield in the skin effect insulated conductor design and having it in contact with the heat tube effectively mitigates the ignition risk due to partial discharge up to at least 10 kVac in a skin effect trace heating system.

IECEx certification for a 10 kV skin effect trace heating system could be realized using a scheme based on the harmonized IEC 60079 standard series. The risks from partial discharge can be addressed using ignition tests from IEC 60079-7. The type tests for Skin Effect Trace Heating in accordance to IEEE Std 844.1-2017/CSA C22.2 No. 293.1-17 can be incorporated into the test plan through special protection “s” allowed by IEC 60079-33.

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IX. VITAE

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