TR A5943

Extreme Overheating in Self-regulating Heating Cables

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Extreme Overheating in Self-regulating Heating Cables

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RESULT (summary)

From offshore experience is reported several incidents where self-regulating heating cables have generated so intense heat that they have melted. Only the copper braid and strongly burned overjackets are remaining, together with strongly carbonised remnants of the active part of the cables. Furthermore is reported that earth leakage circuit breakers do not actuate by this type of failure, leading to damage (burning) of several meters of cable without disconnection from protectors.

Laboratory tests at SINTEF Energy Research confirm what the manufacturers of this type of cable have experienced. Penetration of saline water, either caused by mechanical damage of the cable or leaky terminations, will sooner or later result in cable breakdown. The seawater can cause arcing and spark discharges producing local superheating of the cable. Tests have shown that arcs and spark discharges can result in meltdown of copper strands in the current conductors, which presupposes a temperature of 1083 ^{0}C.

Experiences have shown that earth leakage circuit breakers can have malfunction due to mechanical weaknesses. For this type of cable, consisting of a high-resistance polymeric material being the active part, there may be cases where the earth currents are too small for the earth leakage circuit breakers to actuate. Any use of insulation detectors may, however, improve the safety.

When using self-regulating heating cables the manufacturers installation and layout manuals must be carefully followed. At piping where the heating cables are removed and put back again, the installation must be inspected and the cables checked. Maintenance routines including periodically visual inspection of the installation and checking of the cable should be worked out.

KEYWORDS

SELECTED BY AUTHOR(S)		
	Heating Cables	Extreme Overheating
	Self-regulating	Earth Leakage Circuit Breakers

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1 INTRODUCTION

In the autumn 2001 SINTEF Energy Research received the first enquiry from Statoil regarding extreme overheating in a self-regulating heating cable at Heidrun. At the same time we were informed that also (Norsk) Hydro had experienced similar problems at Snorre B. Some preliminary meetings were arranged, and the cables with the extreme overheating were handed over to SINTEF Energy Research for closer studies. Photos of the cables before dismantling were also presented, and in the following pages are some of these shown.

Figures 1 – 4 are showing the cables mounted in their installations. Both cables were used as frost protection of firewater, and are so-called low-temperature cables. The cable from Statoil was of a category named 3BTV2, manufactured by Raychem. The cable from (Norsk) Hydro was of a category named BSX 3-2, manufactured by Thermon.

Later on in the Project we also received an approx 1,5 m cable long from Åsgård B. This cable was of a category named 8XTV2, manufactured by Raychem. This is a high-temperature cable designed for processing plant, and is shown in Figure 5.

Cables with extreme overheating are also reported from Draupner and Sleipner, both with Statoil as operating company. TotalFinaElf Exploration Norge AS has also reported this kind of problems.

In the preliminary meetings it was decided to invite the two current cable suppliers to the project meetings. For Raychem this is Tyco Thermal Controls Norway AS, and for Thermon this is Tranberg AS.

In addition to the extreme overheating in the cables it was also reported that earth fault detectors and earth leakage circuit breakers not always alert or actuate by this type of failure. Neither do circuit breakers always actuate when failure arise. Production workers have heard crackling and observed bright flares from the cables. Breaking of circuits has been done manually in such cases.

[The Project was started late in spring 2002, and was terminated a year later. The results from the Project is presented in the Technical Report TR A5784 [1], translated into the present Technical Report (TR A5943).]

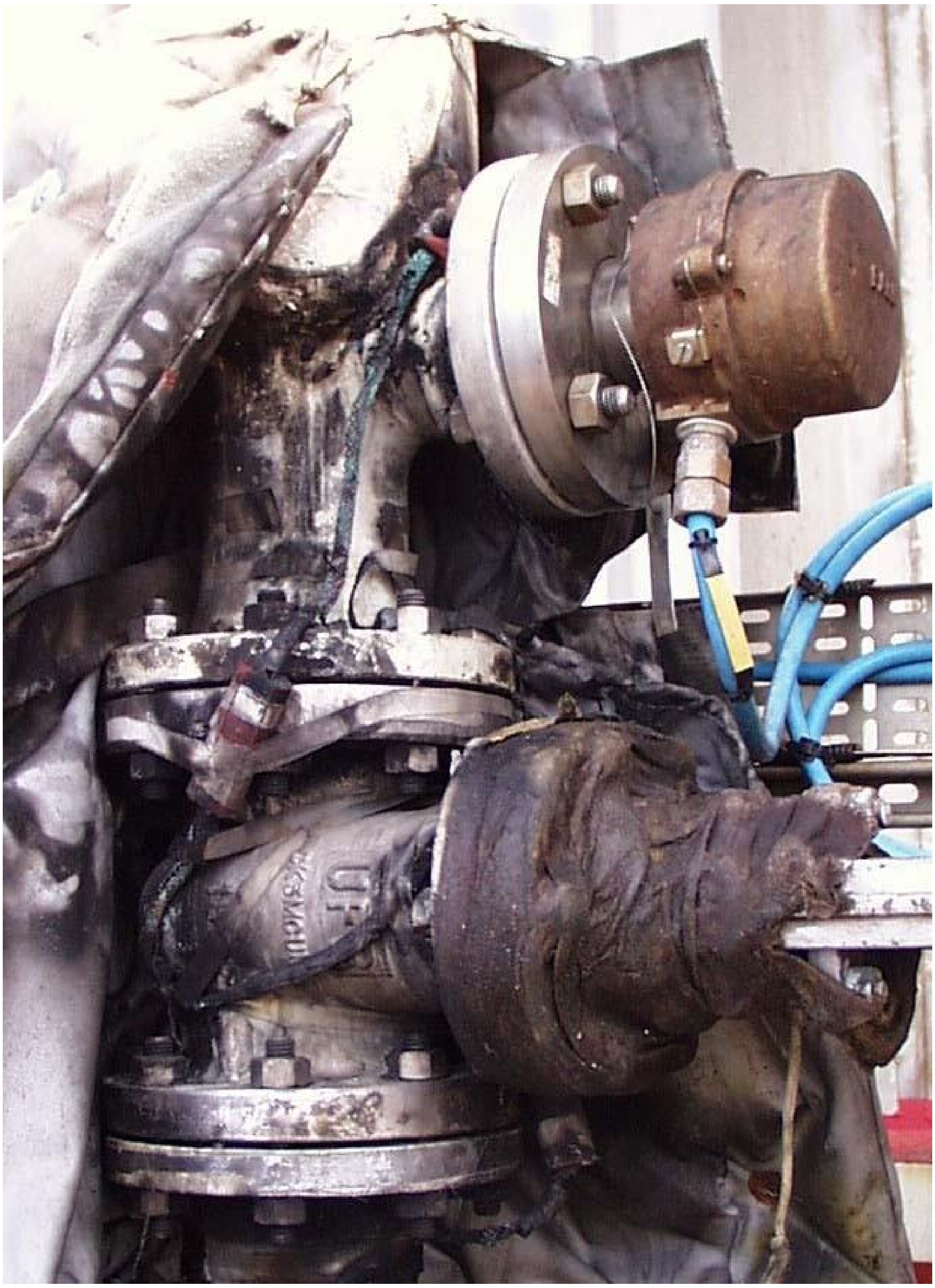


Figure 1: Burned cable, 3BTV2, at firewater pump at Heidrun.
The cable is destroyed by fire and thereafter pulled down by the insulating mat.

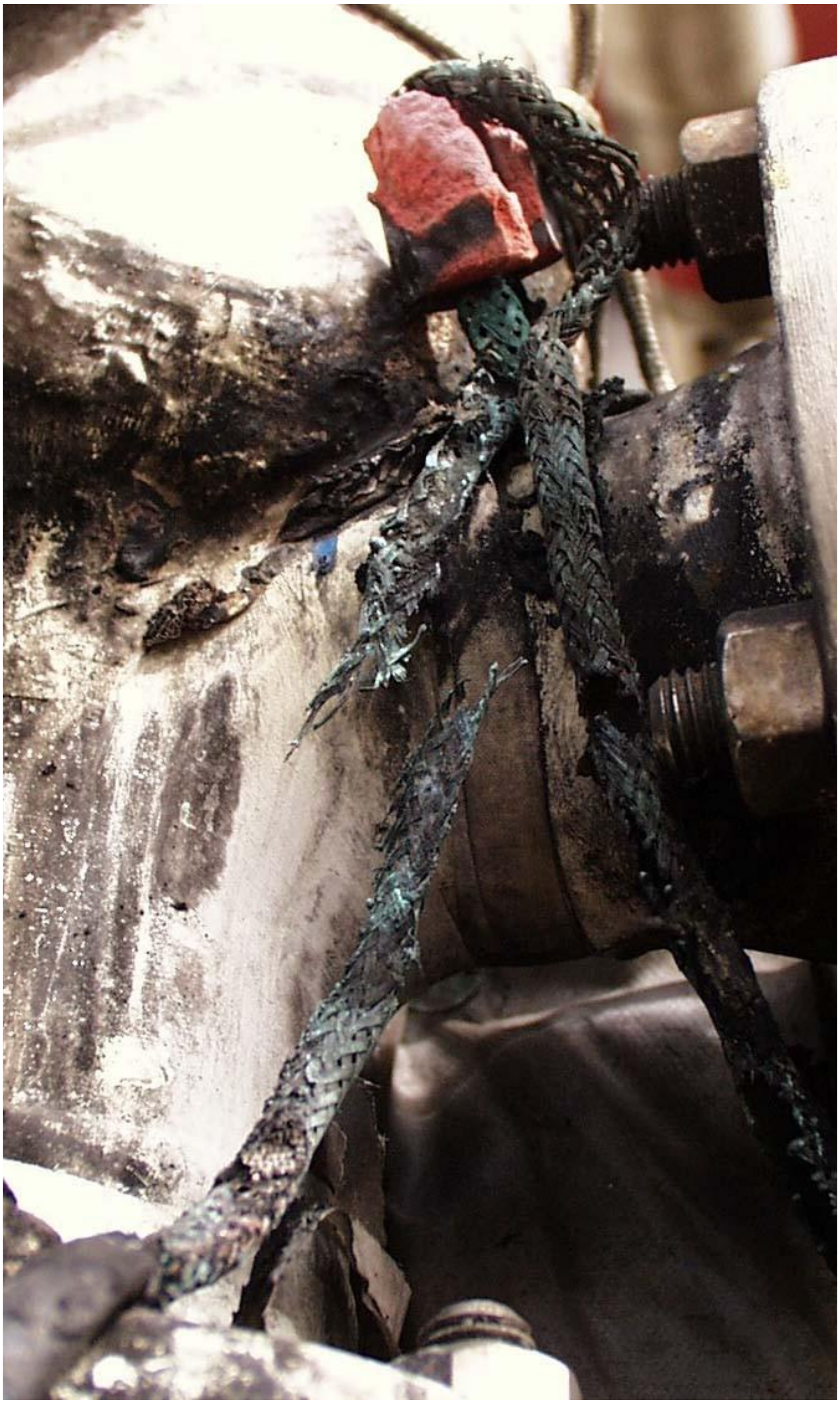


Figure 2: Same cable as shown in Figure 1.
The cable is completely burnt-out, only the metal screen is left. At the same time we also see a somewhat irregular installation of the cable.

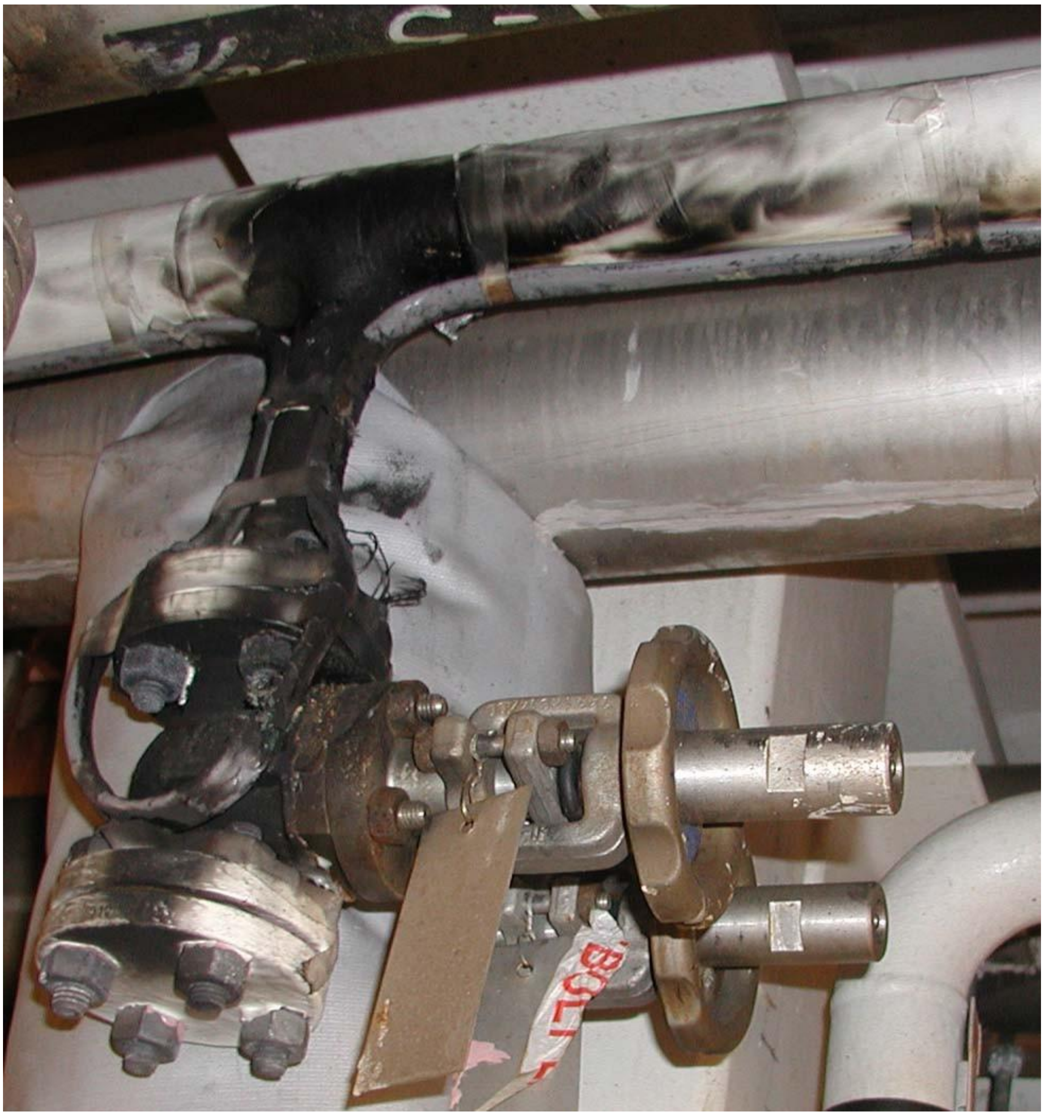


Figure 3: Burnt-out cable, BSX3-2, on a firewater pipe at Snorre B. A loop of the cable is laid around a flange. The point of failure on the cable seem to be situated close to the edge of the flange. An earth fault alarm led to detection of the failure.

Figure 4: Same cable as shown in Figure 3.
From the point of failure close to the flange the cable was burnt-out in length of four meter (from the point of failure in the direction to the coupling box).

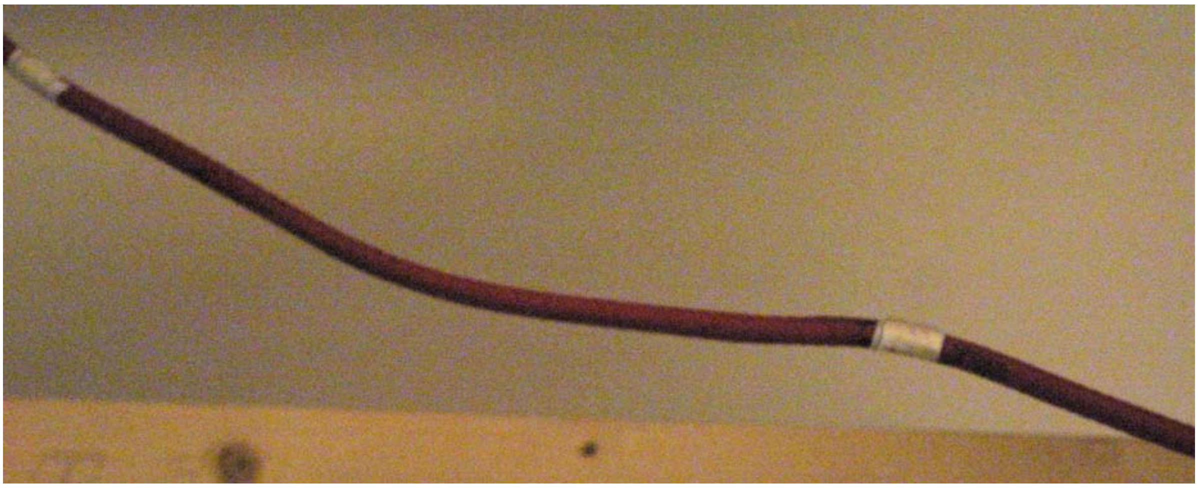


Figure 5: Cable 8XTV2, from Åsgård B. Production workers had observed bright flares from the cable during operation. The picture is showing the cable with voltage applied in the laboratory of SINTEF Energy Research. No visible activity in the cable.

2 PROJECT PLAN

The original project plan, dated 2002-05-27, was worked out in collaboration with the project employers. The plan is shown in the following:

1. Examine disabled cables received (from Statoil and (Norsk) Hydro). Can they tell us something about the failure development?

2. Process answers from questionnaires sent to oil companies regarding empirical characteristics from failure situations.

3. Preliminary basic experiments on test objects where different failures are introduced to see the cause of the failure. Measurements of electric current and voltage are performed.

4. Mechanical outer abrasion of the cable.
   Test objects, about 5 m long, from each manufacturer (Raychem and Thermon) should be examined. (Rubbing or scraping hole in the insulation layer, resulting in partial contact between screen and semi-conducting material.)

5. Injecting fresh water and saline water.
   Test objects, 2 m long, are exposed to fresh water and saline water for some time (magnitude months) after damage of outer sheath.

6. Stretching, bending and squeezing of cable.
   What happens to the semi-conducting material when the cables are exposed to stretching and bending? Test objects, 2 m long, are exposed to tension of 5 kg and 10 kg, combined with bending till under minimum allowed bending radius. Separate test objects, also 2 m long, are exposed to squeezing. (Pressure not determined.)

7. Examination of protection device with recommendation of distribution network and protection of new installations.
   Find the cause of failing earth fault protection. Therefore all experiments are done with earth leakage circuit breaker in the circuit to find protection level. Load current and earth fault current are measured/recorded during the experiments.

8. Look at other possibilities for detecting such failures if they arise, and what possibilities one has to disconnect voltage in time.

9. Materials analysis of sheath and semi-conducting materials.
   Are combustible gases produced at overheating of sheath and semi-conducting materials?

During the Project the following items are removed/included:

Questionnaire was compiled and sent out. However, later on one got the opinion that this was not meaningful because the benefit of the questionnaire was not in proportion to the work related to answer and subsequent treatment.

Mechanical outer abrasion of cables and materials analysis of sheath and semi-conducting materials are not performed seeing that this was not possible within the framework of the Project.

On the other hand examination of the cable from Åsgård B is being included in the Project.

3 PRELIMINARY TESTS AND EXPERIMENTS

One possible cause of heat generation in cables can be conductor rupture with subsequent serial arcing. It is then assumed a very small distance between the conductors at the rupture location.

Hence preliminary tests were performed on a short piece of heating cable. The cable was opened and one of the conductors was cut off. Then voltage was applied to the test object, and the conductors at the rupture location were moved toward each other till an arc occurred. As a result an intensive heat generation originated, resulting in melt down of the semi-conducting material (see Figure 6). During this test a piece of the removed inner cable sheath was brought in contact with the area of intensive heat generation. This resulted in a heavy inflammation and combustion of even more semi-conducting material. The circuit breaker then cut off the voltage.

It should here be pointed out that the inflammation most probably was caused by plenty access of air (oxygen). This would not have been the case if the arc was closed in an unopened cable.

Figure 6: Combustion of the semi-conducting material in a self-regulating heating cable after a provoked serial arc.

Microscope picture of the rupture location where a serial arc has occurred, see Figure 7, clearly show that heat generation has been so intensive that the copper strands of the conductor has started to melt. Melting point of copper is 1083 ^{0}C.

Figure 7: Microscope picture of the rupture location where a serial arc has occurred (6 x magnification).

The opening of the damaged cables from Snorre B and Heidrun indicate almost totally burnt-out cables. Figure 8 is showing the Snorre B cable where the overjacket is removed. There are almost only carbonised remaindings left. Figure 9 is showing the same cable. Here the copper braid is opened. Notice that only one conductor is left, the others are melted away.

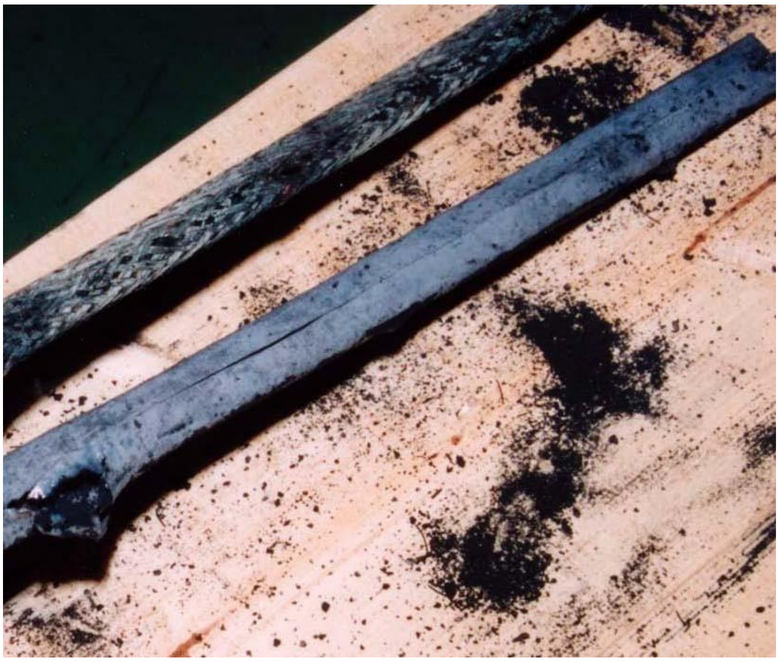


Figure 8: Outer sheath from Snorre B cable.

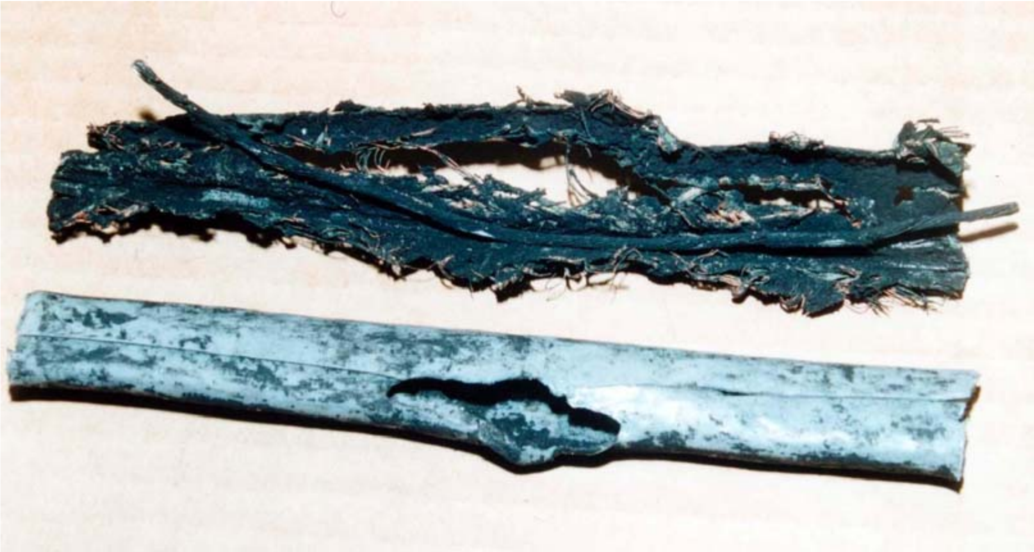


Figure 9: Copper braid of Snorre B cable opened. Just one conductor is remaining.

The following is to be mentioned here: Upon arrival of the Snorre B cable at SINTEF Energy Research it was observed that the specified cable termination (power boot) on the voltage side of the cable was not installed. Such a termination shall protect the cable against water penetration. Whether the cable termination was removed during disassembly or if it has been lacking all time is not known.

Figure 10 is displaying a piece of the cable from Heidrun. The overjacket is removed and the braid is opened. Here both the conductors are disappeared. As mentioned earlier the melting point of copper is 1083 ^{0}C. The temperature of both the two cables must therefore have been even higher, because the copper is almost vaporized.

Figure 10: A piece of the cable from Heidrun. Overjacket is removed and braid opened. Both conductors are disappeared.

4 TEST CONDITIONS AND TEST CIRCUITS FOR CABLES IN LONG-TERM TESTS

The actual cables were supplied by Tyco Thermal Controls Norway AS (3BTV2 and 8BTV2) and Tranberg AS (BSX-3-2 and BSX-8-2). In addition TotalFinaElf has delivered disassembled used cable (6ATV2). Stresses and layout of cables are shown in Table 1.

Table 1: Test conditions and "circuit distribution" for cables in long-term tests.

Cable type	**Circuit 1** **Squeeze**	**Circuit 2** **Tension 5 kg**	**Circuit 3** **Tension 10 kg**	**Circuit 4** **Adding fresh water**	**Circuit 5** **Adding saline water**
Raychem 3BTV2-CT	X	X	X	X	X
Raychem 8BTV2-CT	X	X	X	X	X
Raychem Chemelex 6ATV2-CT (used/disassembled)	X	X	X		X
Thermon BSX-3-2-FOJ	X	X	X	X	X
Thermon BSX-8-2-FOJ	X	X	X	X	X

The cables are having voltage applied continuously. IT network/grid is used as model for the voltage supply. Nominal voltage 240 V then results in 240 V between conductors and 138 V between each conductor and braid. Every circuit is having an earth leakage circuit breaker. The voltage supply for the five circuits is equipped with earth fault detector and if possible other monitoring equipment. The saline water shall represent seawater, which contains about 3% salt.

Load currents and earth currents are measured continuously for every circuit.

5 TEST RIG

Figure 11 and 12 displays the front of the test rig with measuring equipment.

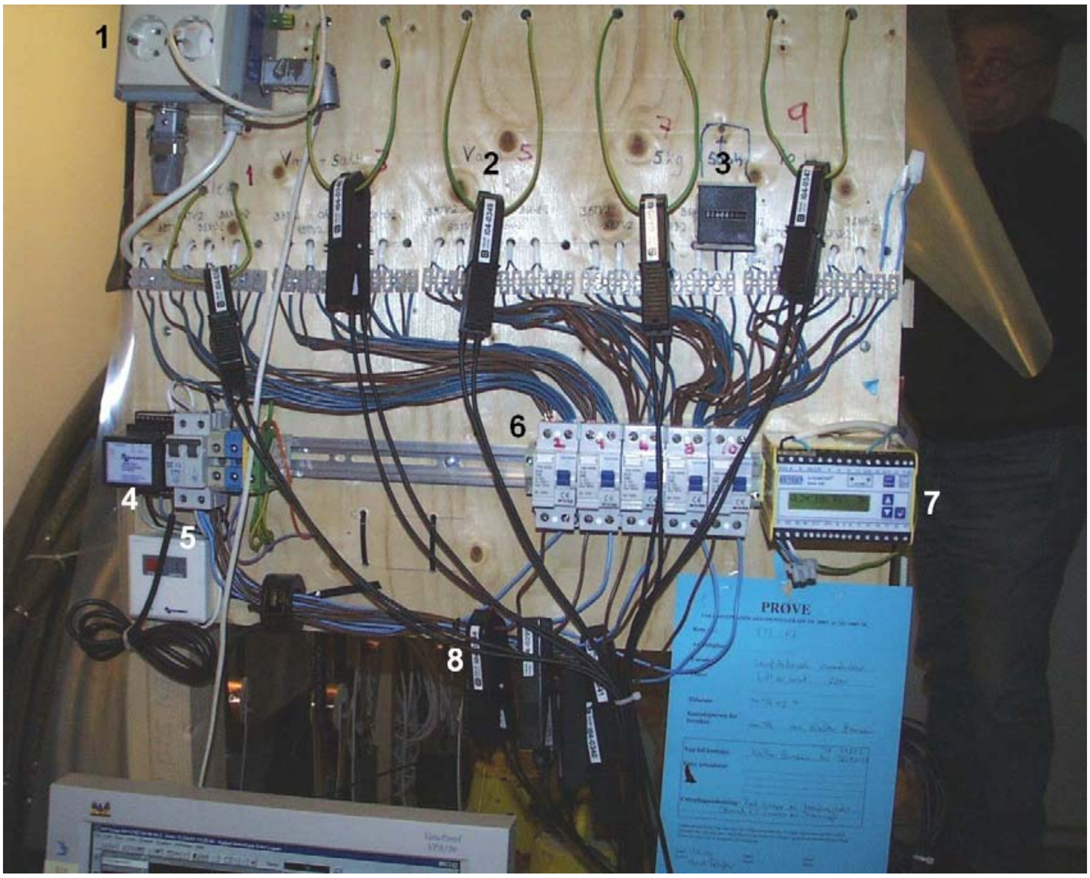


Figure 11: Front of test rig.

1. Switch for voltage supply interlocked through smoke detector.
2. Clip-on ammeters (five) for measuring earth current in each circuit.
3. Hour counter.
4. Earth-fault detector; joint instrument for all five circuits.
5. Circuit breaker (16 A); joint instrument for all five circuits.
6. Earth leakage circuit breakers (five); one for each circuit.
7. “Bender” insulating monitoring device; joint instrument for all five circuits.
8. Clip-on ammeters for measuring load current in each circuit.

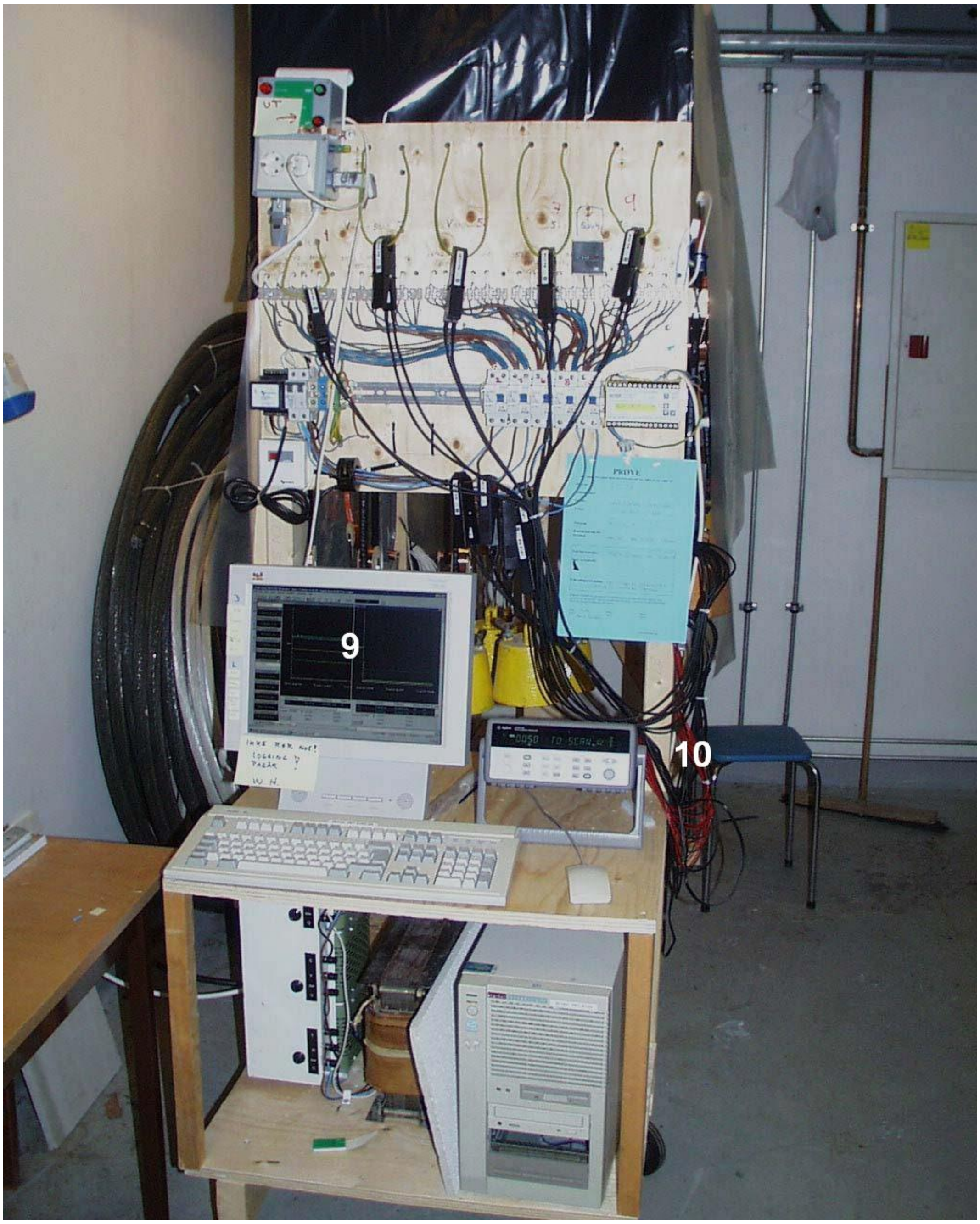


Figure 12: Front of test rig.

9. Computer for recording of measured data.
10. Data logger for logging of measured data.

Figures 13, 14, 15 and 16 are showing details from the mounting of cables in the test rig.

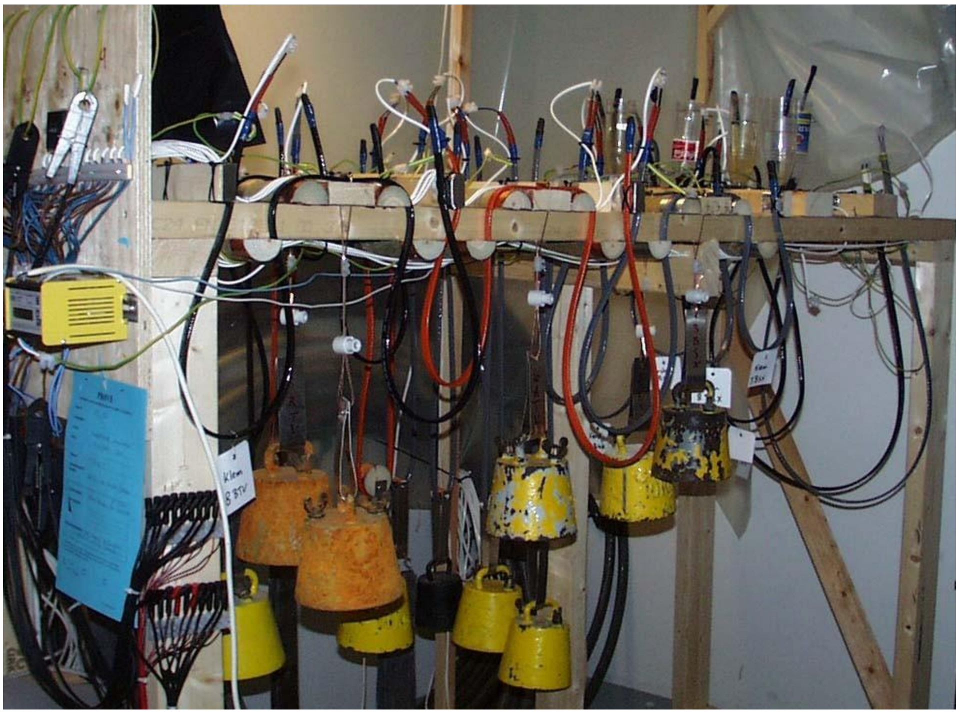


Figure 13: Overall view of cables mounted in test rig.

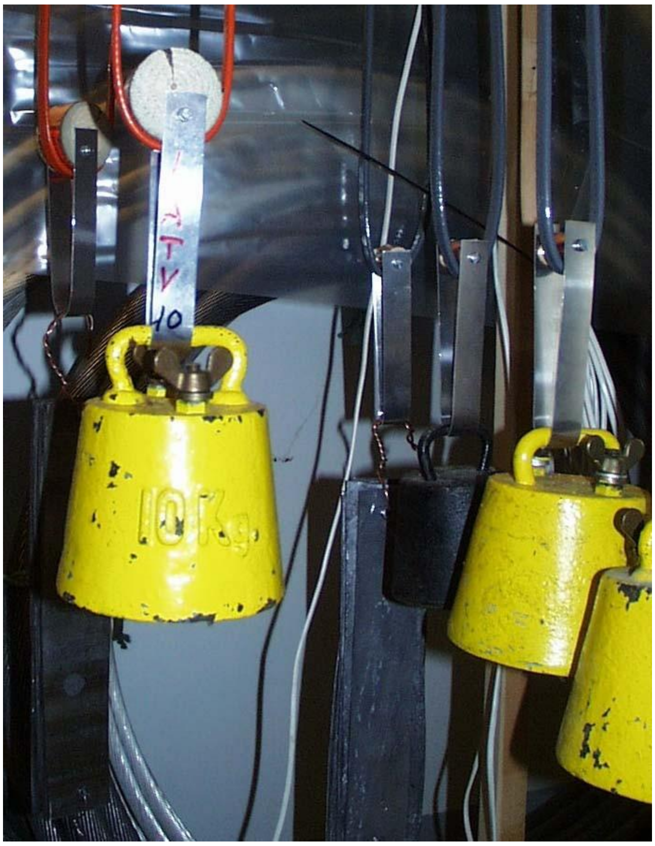


Figure 14: Tensions of 5 and 10 kg are applied to the cables by appending weights. These are hanging in circular blocks of wood with radius 12 and 28 mm.

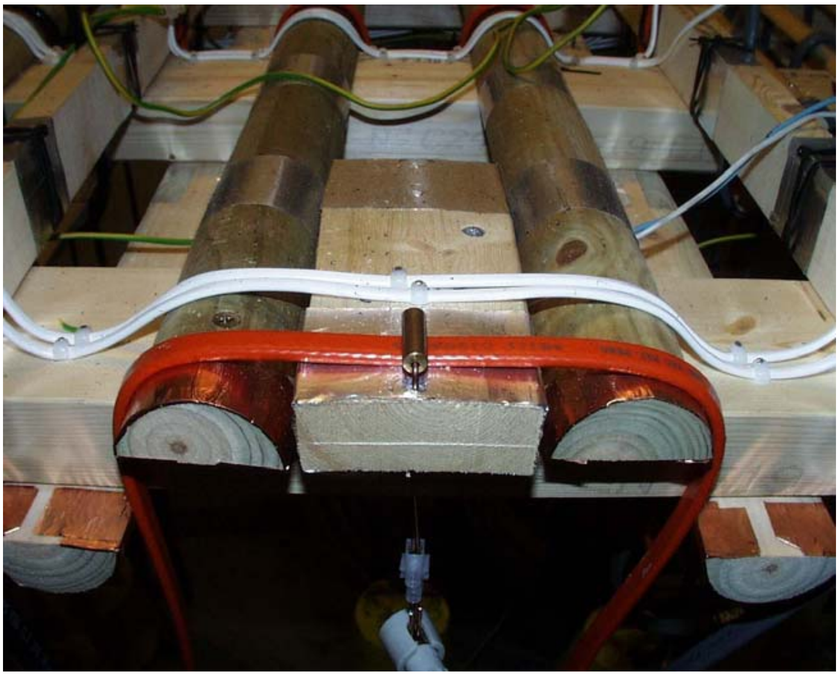


Figure 15: Pressure on the cables, 10 kg, is achieved by hanging weights mounted in 8 mm brass bolts lying transversely of the cables.

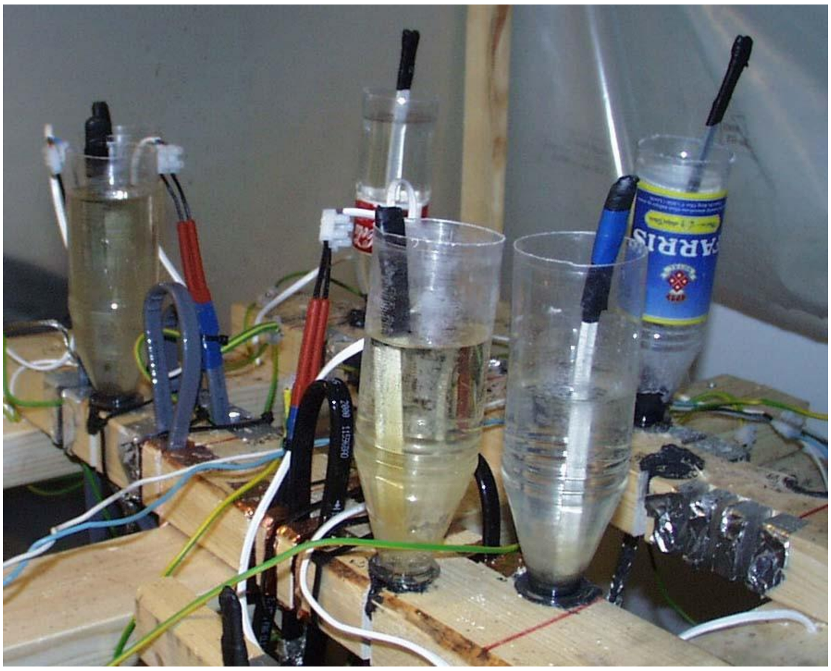


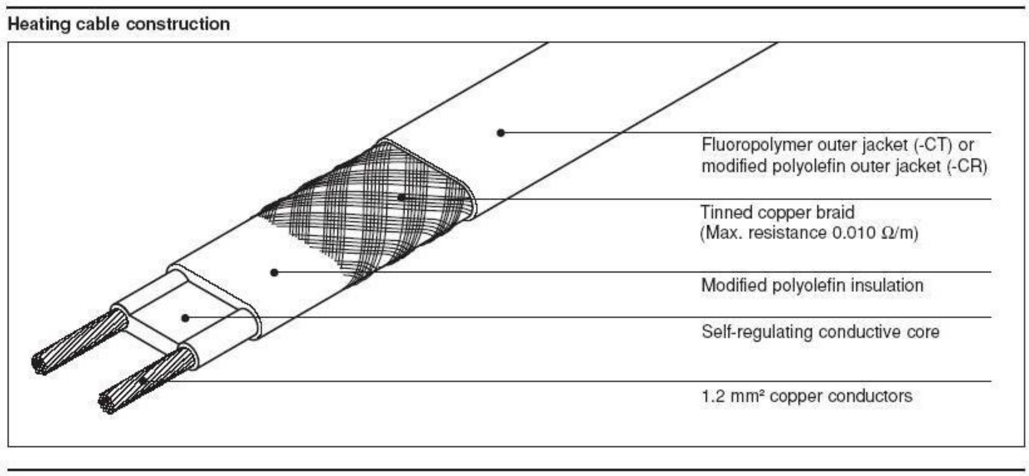
Figure 16: Fresh water and saline water (3% salt) are added to the cables by using plastic bottles without bottom. About 170 mm of the outer sheath is removed, and the braid is bent backwards. Inner insulation jacket is retained, and into this one is made a hole about 100 mm above the retracted braid. The cable is thread into the bottle till the retracted braid is entering the bottles nozzle, and the nozzle is then sealed with sealing compound. The cable end, insulated by self-amalgamating tape, is now projecting above the removed bottle bottom. The bottle is then mounted in the test rig, and filled with water.

6 RESULTS
6.1 RESULTS FROM CABLES FOR LONG-TIME AGEING

Cables for long-time ageing were of the type "low-temperature cables". For cables with voltage applied the maximum exposure temperature is 65 ^{0}C. Cables without voltage have a maximum exposure temperature of 85 ^{0}C.

From Raychem the cables 3BTV2, 8BTV2 and 6ATV2 were tested. The last-mentioned cable is no longer manufactured. The tested one had been in operation, and was obtained from TotalFinaElf. From Thermon the cables BSX-3-2 and BSX-8-2 were tested.

Design 1 is showing the cable construction of a low-temperature cable.



Design 1: Sketch of a low-temperature heater cable construction (The BTV family from Raychem).

During the test period it had not been fail or breakdown on any of the cables being exposed to tension, pressure or added fresh water.

All failures occurred in cables exposed to added saline water. Two rounds of testing were made for these cables. First a round with five cables (3BTV2, 8BTV2, 6ATV2, BSX-3-2 and BSX-8-2), and another round with four cables (3BTV2, 8BTV2, BSX-3-2 and BSX-8-2).

Lifetime of the cables has varied from 300 to 700 hours. Two cables have broken down because the cable ends have caught fire; three cables have broken down because they have caught fire both in ends and under the salt-water surface. Four cables have broken down by catching fire under the water surface. All ends have been about 50 mm above water surface. Saline water coming up to these ends is probably caused by capillary attraction.

In all these cases the breakdowns have resulted in heavy smoke generation, which again has led to disconnection of the voltage by the smoke detector monitoring the test. Neither circuit breaker, earth fault detector nor earth leakage circuit breakers have come into operation.

That earth fault detector or circuit breaker has not come into operation in these cases is so far no surprise. The failures did originate on that part of the cables where the grounded shield was retracted, consequently there is no earth current causing any alert or disconnection. The circuit breaker disconnected during attempts to apply the voltage after the smoke detector had disconnected the experiment.

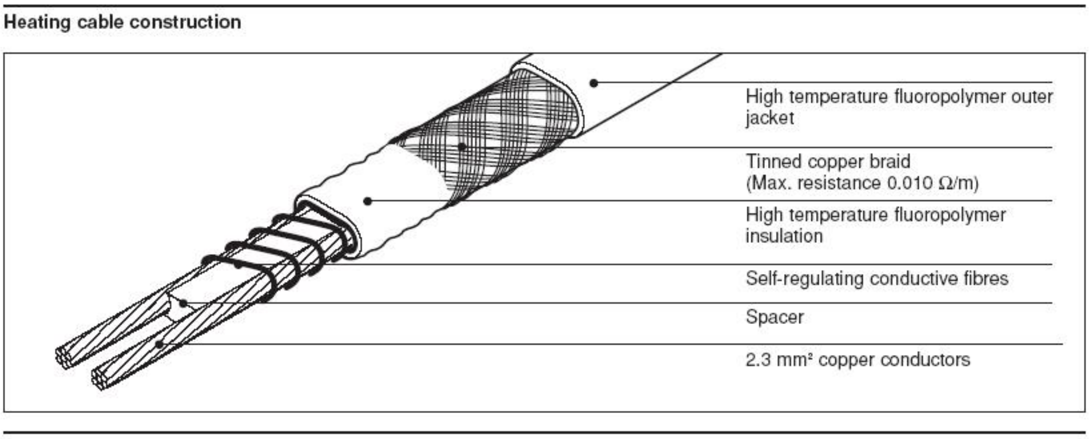
Figures 17 and 18 are showing examples of damaged cables.

Figure 17: Examples of damaged cables. From left to right:
1: Cable caught fire in at the end.
2: Cable caught fire under the water surface.
3: Cable caught fire under the water surface and in the end.
4: Cable caught fire under the water surface.
5: Cable caught fire under the water surface.

Figure 18: Close-up picture of the end of Cable 3 in Figure 17.

6.2 RESULTS FROM CABLES REMOVED FROM ÅSGÅRD B

The cable from Åsgård B is a so-called “high-temperature” cable. The cable construction 8XTV2 from Raychem is shown in Design 2. Maximum temperature with and without voltage applied is 120 ^{0}C and 215 ^{0}C respectively.



Design 2: Sketch of high-temperature heater cable construction (The XTV family from Raychem).

The cable was mounted in the test rig and applied voltage immediately after it arrived at SINTEF Energy Research. Except from the cable being hot, no abnormalities were observed during the first 200 hours. We were in advance informed that on the platform one had observed bright flares along the cable.

During a meeting with manufacturers, suppliers and project employers the free end of the cable was accidentally raised and placed over the framework in the test rig so that the free end was situated higher than the end having voltage applied. After a few minutes an intense light showed up under the outer sheath of the cable. See Figure 19.

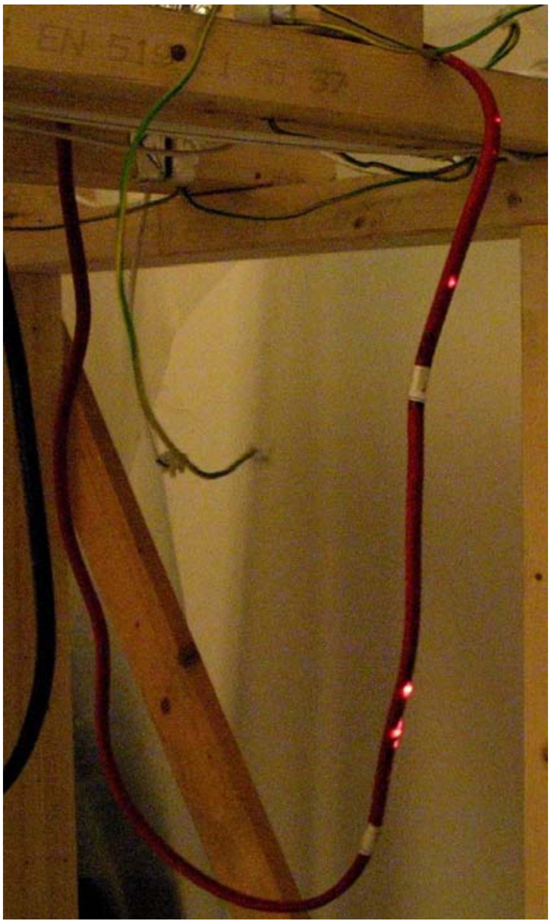


Figure 19:
Flares from cable 8XTV2 after the free end of the cable was raised.

Figure 20:
Flares evenly distributed along the cable after the cable has been snapped several times.

After a few minutes the flares came to an end. By snapping the cable by the finger the flares returned. The three following days the cable was snapped three times a day. Finally the flares were evenly distributed along the whole cable, and remained flaring (see Figure 20).

In order to study the further development without having the smoke detector to disconnect the voltage in case of the cable catching fire, the cable was moved to another setup with separate earth leakage circuit breaker and circuit breaker. However, it was not possible to apply voltage to the cable again, because the circuit breaker disconnected.

Pictures from the opening of the cable are showed in Figure 21 and 22. Figure 21 shows the end of the cable where voltage is applied. When SINTEF Energy Research received the cable the cable termination was lacking at this end. The cable termination shall, among other things, protect the cable against water penetration. Whether the specified termination had been removed at the dismounting or if it was lacking the whole time is not known.

Figure 21: Cable end for voltage connection. Specified cable termination is lacking.

Figure 22 is showing a piece of cable where the outer sheath and braid are removed. It is evidently that the inner sheath has several points where the plastic show traces of melting.

Figure 22: A piece of cable 8XTV2 with inner sheath. Distinct hotspots.

Figure 23 is showing the cable fully opened. The heat generating part of the cable consists of an insulating spacer keeping the two conductors apart. Around this is “wrapped” self-regulating conductive fibres. From the figure are seen ruptures in several windings. All ruptures are at the flat side of the cable, which is between the live conductors. There is also plenty carbon along the whole inner part of the cable.

Figure 23: Cable 8XTV2 opened. There are several ruptures in the self-regulating conductive fibres “wrapped” around the live conductors. There is also plenty carbon along the whole inner part of the cable.

The temperature inside the cable has evidently been high. There may be several reasons for this, but at date we have no special theory that points out to be the most probable.

Saline water may have penetrated into the cable due to the lacking cable termination. It is, however, performed a test where the whole braid was put in de-ionized water added silver nitrate. If salt was present this would have resulted in precipitation of silver chloride, which did not occur. Supposing still that salt was present in the inner part of the cable, how would this have influenced upon the cables functionality?

The flares in the cable occurred when we moved the cable or snapped on it.

- Was there any water present resulting in leakage currents and overheating?
- Are there carbon/soot “sifting” in between the ruptures of the wrapped conductive “plastic wire”? Where does the carbon come from?
- Has overheating originated from poor contact between wrapped “plastic wire” and live conductors?
- Has the cable been subjected to increased temperature? Maximum continuous exposure temperature for this type of cable in live condition is 120 ^{0}C. Furthermore says the data sheet for the cable: “Maximum exposure temperature (intermittent power on) – 215 ^{0}C (20 bar saturated steam), maximum cumulative exposure 1000 hours”.
- Manufacturing defect in the self-regulating conductive fibres? Unequal resistance along the fibre? Low resistance where it has burned off?

6.3 SUPPLEMENTARY TESTS ON LOW-TEMPERATURE CABLE

To investigate the influence of salt water upon cable designed for frost protection, a 200 mm piece of cable was cut from the Thermon cable BSX-8-2. At one end 10 mm of the overjacket and insulation jacket was removed, and the braid was retracted. 10 mm of the active part of the cable was thus sticking out. The braid was then grounded and voltage was applied to the other end. The test equipment had a 16 A circuit breaker and earth leakage circuit breaker. Nothing happened when voltage was applied.

The cutting surface of the out sticking end was then moistened with saline water by use of a cotton stick (Q-tip). After a couple of minutes it started to glow in the cutting surface of the self-regulating element between the live conductors. After another half-a-minute the matrix then started to burn, and the end caught fire with flame and smoke development. When the flame arrived the grounded braid both earth leakage circuit breaker and overcurrent circuit breaker disconnected the voltage. See Figure 24 and 25.

Figure 24: Cable BSX-8-2. The cutting surface was gently moistened with saline water, which resulted in glowing in the cutting surface of the self-regulating element between the live conductors. After a short time the matrix started to burn.

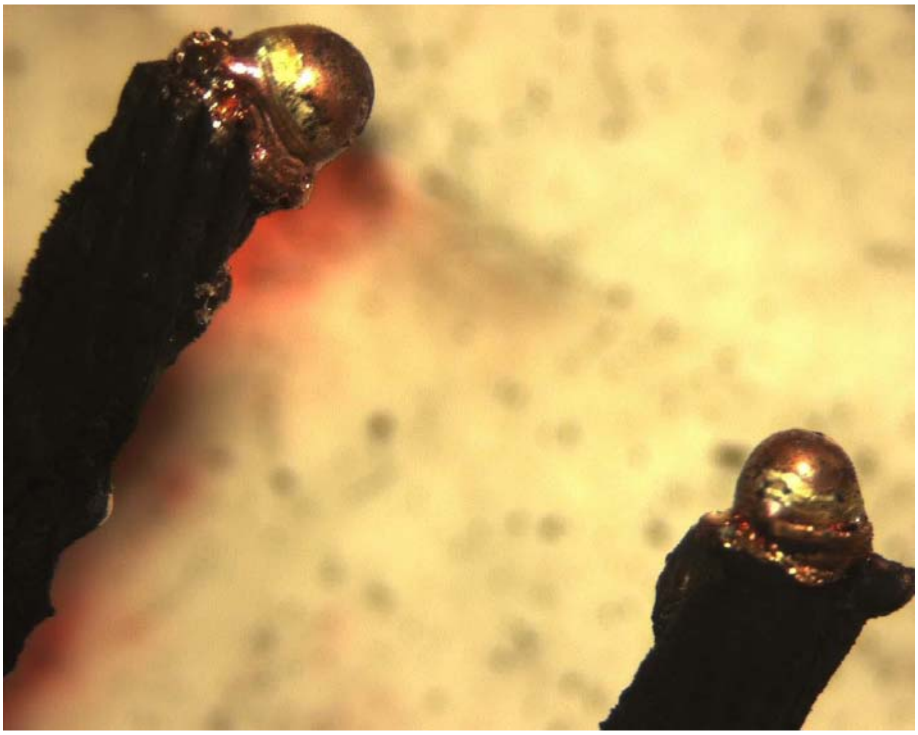


Figure 25: Microscope picture (6x magnitude) of cable end in Figure 24.
The copper of the live conductors has melted.

The purpose of this experiment was to get the cable to burn in the same way as the low-temperature cables we received from Heidrun and Snorre B. For those cases both conductors and most of the plastic materials were totally burned. This was not achieved in this experiment, something that may be due to the fact that we now had plenty access of air when the cable started to glow. From Figure 25 we can see that the copper of both the live conductors had started to melt. (The melting point of copper is as mentioned earlier 1083 ^{0}C.) The overcurrent circuit breaker of 16 A had not actuated at this moment time. If the plentiful access of air had not been present one cannot disregard that the glowing that melted the copper could have continued without resulting in the plastic materials had started to burn. Instead we might have got carbonization. This again could have resulted in the glowing continuing past the braid and along the cable without disconnection by circuit breaker or earth leakage circuit breaker.

6.4 TESTING OF SUPPLEMENTARY EQUIPMENT FOR MONITORING HEATING CABLES

It has been reported that earth leakage circuit breakers and circuit breakers have not reacted when extreme overheating took place in self-regulating heating cables. Therefore other supplementary control equipment may be of current interest.

ElDetector

The product has been under development and testing for a couple of years at ITP A/S in Billingstad, Norway. The detector shall be able to identify earth-leakage and electric arcs. In communication with the company the summer of 2002 they informed that they were not quite satisfied with the product, and further testing was necessary. They therefore wanted to take part in a project at SINTEF Energy Research later on. More supplementary information about the “ElDetector” can be found in a SINTEF Energy Research Memo dated 2002-04-16 [2].

Bender insulating monitoring device for IT – AC-systems

An older version of “Bender insulating monitoring device” model IRDH 250 MYX is installed at Heidrun. Whether this had actuated when the problems with the heater cable took place is not known. There is no report available. In a project meeting it was decided that a “Bender” should be installed in the test set-up. A picture of the installed model is shown in Figure 26. The installed monitoring device is designed for a maximum system by-pass capacity of 150 μF. The old model has a maximum value of 10 – 20 μF.

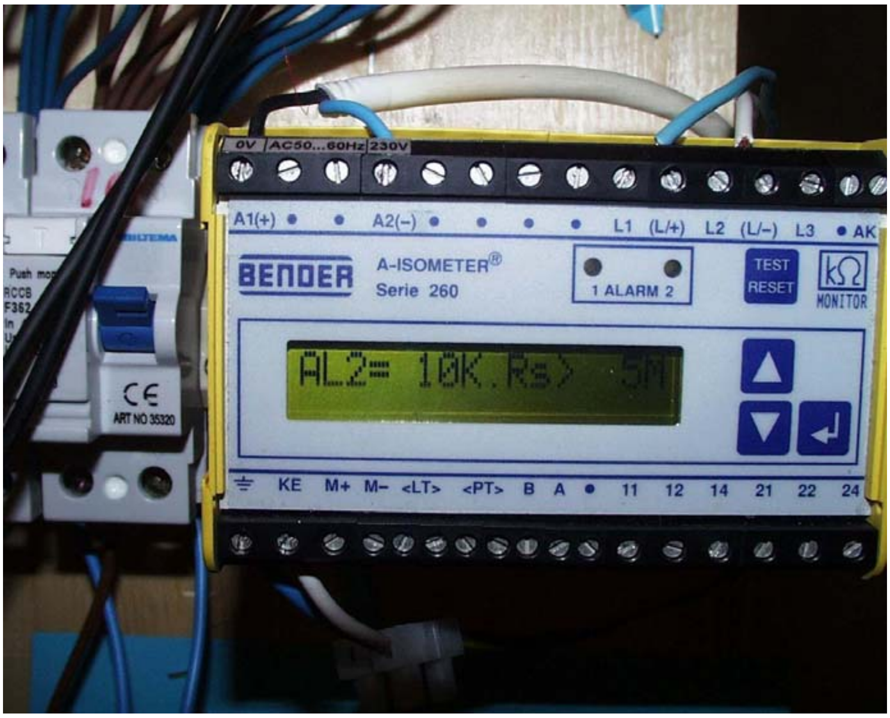


Figure 26: Bender insulating monitoring device installed in test set-up.

In short the “Bender” works in the following way: The installations/cables it is monitoring must be separated from the rest of the system by an isolation transformer. Electric pulses, 27 V DC, are emitted between one of the phases and ground. Then new pulses are emitted between the other phase and ground. The “Bender” then performs a calculation of the insulation resistance of the circuit. The “Bender” also produces an alarm if the insulation resistance between the phases and braid goes below an adjusted value. In our case this value was set to 10 kΩ.

Together with the “Bender” were installed to new cables having supply of saline water. Nothing happened during the first three weeks (500 hours). Then alarm was triggered for phase 2. The calculated insulation resistance indicated 7,1 - 9,6 kΩ. The error message was located to one of the newly installed cables. The earth leakage measurements of the circuit showed 8 – 10 mA. (The earth leakage circuit breaker in the system shall not disconnect before at 30 mA.) In the following week (170 hours) we had alarm every time we filled the bottle with saline water. (The water evaporates, therefore refilling is necessary.) The insulation resistance in this period alternated between 4,5 and 6 kΩ. The earth leakage current in the same period was measured to 10 – 17 mA. The earth leakage circuit breaker then disconnected the voltage.

Briefly summarized the insulating monitoring device produced alarm for a whole week before the earth leakage circuit breaker disconnected the voltage.

In the middle of February 2003 the other cable having salt water supply was still installed together with the “Bender”. No error messages had occurred till then. The test was stopped at the end of February 2003.

6.5 TESTING OF EARTH LEAKAGE CIRCUIT BREAKER FROM HEIDRUN

It is reported that the combined fuse and earth leakage circuit breaker at Heidrun did not disconnect when the overheating of the heater cable took place. This breaker was of the model “STAHL, 16 A, Model No. 8562/44-2075-160”.

The circuit breaker from Heidrun was tested in the laboratory. No malfunction neither regarding earth leakage circuit breaker nor circuit breaker occurred.

In addition we refer to SINTEF Energy Research Project Memo AN 02.14.23 dated 2002-05-27 [3] where malfunction of earth leakage circuit breakers are discussed among other things.

Malfunction may occur because of mechanical failure of the trip gear. The trip gear can “hang”. It is therefore recommended to “move” this every month or at least once a year.

7 MEETINGS WITH MANUFACTURERS AND SUPPLIERS

Two meetings were arranged with manufacturers and suppliers to give these the opportunity to present their views upon the problems arisen concerning extreme overheating in the heater cables.

According to Thermon Europe by Rudolf Pommè such problems with arcs and spark discharges has been known since the middle of the seventies, and particularly in cables without a braid. See separate appendix in SINTEF Energy Research Project Memo AN 02.14.23 dated 2002-05-27 [3].

The reasons of the problems are presumably mainly related to mechanical damages and the presence of an electrolyte (for example saline water) inside the cable. The manufacturers participating in the two meetings also pointed this out. At the same time it was strongly focused on mounting instructions for cable terminations. The importance of watertight cable ends, not only at the end of the cable, but also inside the coupling box, was called attention to. Water can penetrate into the boxes during washing and cleaning of installations. If the cable end inside the box is not watertight this may lead to penetration of water and salts into the cable.

Installation of cables must be done according to directions from the manufacturer. Extra padding must protect the cable when having sharp edges of flanges or similar components. It is also important that clamping of cable follows given directions, particularly if a cable has been unfixed because of piping, and then being put back in place again.

IEEE Std 515-1997 for “Testing, Design Installation, and Maintenance of Electrical Resistance Heat Tracing for Industrial Applications” together with the directions from the manufacturers have clear descriptions for most of these approaches.

As for maintenance and inspection the same standard also has clear guidelines. From these can be mentioned:

- Periodical maintenance also includes use of Megger on the cables. The cable is disconnected voltage and should be measured by Megger at 500, 1000, 1500, 2000 and 2500 V. All measured values shall be equal and not below 10 MΩ in case of the cable being O.K..
- When recording maintenance data a special form shall be used, the so-called “Maintenance Log Record”, for introduction of visual and electrical observations/ measurements.
- All circuits with heater cables shall be equipped with earth leakage circuit breakers.

During these two meetings the manufacturers and suppliers were shown experimental layout, test rig and some of the test results achieved in the laboratory. Problems with the low-temperature cables, that is the cables for frost protection, were explained by penetration of saline water. As for the high-temperature cable (8XTV2 from Åsgård B), which began to glow when the meeting participants were present, they had no satisfactory explanation of this phenomenon.

8 DISCUSSION

In the laboratory experiments carried out one has not succeeded in provoking exactly what is observed offshore, where several meters of cable are totally burned, but without resulting in triggering of the protection.

The experiments confirm, however, the experiences that penetration of saline water into self-regulating heating cables will result in breakdown of the cables after a shorter or longer time. Penetration of saline water may result in arcs or spark discharges inside the cable, and this again can lead to very high temperatures for small areas. The experiments have proved that arcs and spark discharges can result in temperatures up till the melting point of cupper, i.e. 1083 ^{0}C.

Earth leakage circuit breakers have according to verbal reports offshore not been triggering at extreme overheating in the cables. One reason of malfunction can be mechanical failure. Another reason may be that the earth failure currents some times are not high enough (30 mA) to cause triggering. At the meeting mentioned in the former chapter, the following examples were brought out:

A pin halfway between the two live conductors punctures a heater cable of 8 W/foot (that is 24 W/m). Since the pin also penetrates the braid, which is grounded, the pin will also be grounded. The current running in the self-regulating element between the live conductors will be 0,1 A for 1 m cable. (240 V and 24 W give 0,1 A per meter.) In a 100 mm piece of the cable therefore only 0,01 A (10 mA) will run in the plastic material. For 10 mm cable the current will be 1 mA. If the whole current, 1 mA, is running through the pin this ground current will be too low to trigger the earth-leakage circuit breaker. At mechanical failure of the cable, which result in contact between braid and self-regulating element, it is therefore vital how close the live conductors are to this contact to trigger the earth leakage circuit breaker.

IEEE Std 515-1997 describes routines for installation, measurements on preinstalled cable and routines for maintenance and inspection. A lot of this is concerning measurements both on cable and other equipment together with visual inspections. In addition a logbook shall be kept so that the “history” of the cable can be checked if necessary. All these necessary and partly time-consuming routines call for trained personnel to look after these tasks. Regarding the consequences a glowing cable can lead to in an EX environment, these tasks should be given high priority.

A Bender insulating monitoring device was installed together with to new cables having supply of saline water. The Bender produced alarm for one week before the earth leakage circuit breaker disconnected. Together with the alarm from the Bender were measured ground currents in the range of 4-17 mA. One should notice that at previous breakdowns of cables supplied with saline water, we have not measured any increase in ground currents before breakdown. The breakdown has occurred relatively fast without any recorded increase in ground current. Thus the last failure has had a slower rate in failure development than the former breakdowns. One might therefore assume that it is not for certain that the Bender will always produce alarm “early enough”.

9 CONCLUSIONS

If one still wants to use self-regulating heating cables the manufacturers directions for assembly and installation must be followed strictly. This applies particularly to installations of cable terminations preventing saline water from penetrating into the cable, and includes both ends of the cable. The cables should likewise be equipped with extra bolster/protection against any sharp edges.

By work that calls for disassembly and reassembling of cables one must perform check measurements (use of Megger) and visual inspection of the cables.

Routines for periodical inspections and maintenance should be worked out.

To reduce the risk of mechanical malfunction of earth leakage circuit breakers, these should be “moved” once a month, at least once a year.

As supplementary equipment to earth-leakage circuit breakers, installation of insulating monitoring devices might increase the safety of the installation.

10 REFERENCES

[1] SINTEF Energy Research Technical Report TR A5784 (in Norwegian): “Ekstrem varmgang i selvregulerende varmekabler”, W. Hansen, 2003-02-10.

[2] SINTEF Energy Research Memo (in Norwegian): “Varmgang i varmekabler. Utdypende kommentarer til vårt og arbeidsgruppens forslag til spørreskjema. Utprøving av El-detektor”, W. Hansen, 2002-04-16, Fortrolig (Restricted).

[3] SINTEF Energy Research Project Memo (in Norwegian): ”Ekstrem varmgang i selvregulerende varmekabler. Spørreskjema, prosjektplan og prøveoppsett”, W. Hansen, 2002-05-27.

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