INDUCTION HEATING OF LIVE PIPELINE FOR HYPERBARIC DIVER WELDING

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ABSTRACT

The Statoil Tampen Link project brought a 12" branch pipe into a 20" main line using a welded branch pipe and a hot-tap drill through. All conducted with diver operations on a high pressure gas pipeline at 145m (475') water depth. The paper describes the first subsea operational use of the EFD induction heating system which was used to provide the welding pre-heat. This provided high heat input, to counteract the cooling gas flow, without discomfort or hazard to the welder divers.

INTRODUCTION

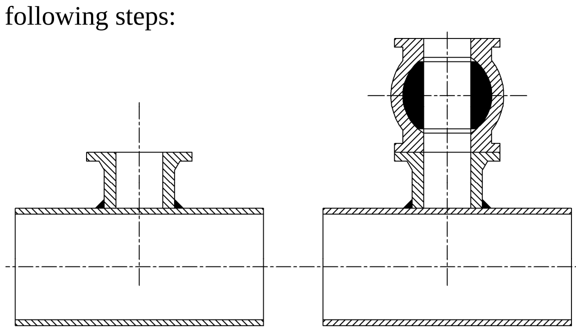
The need to bring in a new pipe branch to an existing pipeline often occurs as the production of some of the oldest North Sea fields are maximized and smaller fields are added in. Sometimes there are no branch positions to connect to and the production flow cannot be interrupted.

The Statoil Tampen link project brings the Statfjord field gas export into connection with the Shell UK FLAGS (Far North Liquids and Associated Gas System) export pipeline. It requires two hot tap operations. This paper concerns the hot-tap on the Stafjord end at a water depth of 145m (475 ft). During the welding operation the production gas pressure was approximately 150 bar (2175 psi).

Technip Norway was the overall contractor for the operations.

HOT TAP OPERATION

Simplistically, the hot tap operation has the following steps:

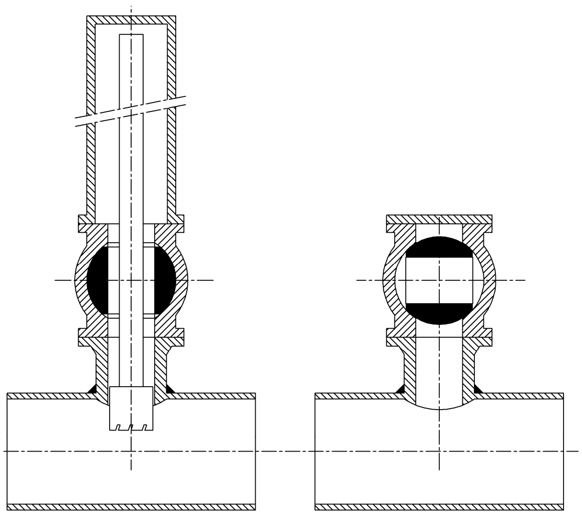


Blind branch welded to pipe. | Hot tapping ball valve fitted.

The first step of welding required a "butter" layer to be laid on the pipe. Once the butter layer was to the required thickness, the branch pipe was fitted and welded to the buttered layer with a GTAW (Gas Tungsten Arc Weld). On top of the branch pipe, a forged flange was welded on. Common for all these welds, is the need for preheating due to the structure's heat-sink caused by the gas flow inside the

20” live Tampen pipe.

The complete installation of the branch had many more operations and is reinforced with external clamps; a full description of which is not appropriate here.



Hot tapping tool seals to valve and drills through.

Valve closed, drill removed, branch complete.

After this, the operation continues with normal subsea techniques to complete the connection of the branch pipe.

Although it is never a “routine” operation, many hot taps have been performed in the North Sea and it is an important tool in the continuing development of field infrastructure.

Statoil have been developing a diverless hot-tap system as part of their Pipeline Repair System (PRS) – the world’s largest and most comprehensive suite of equipment for the repair and upgrade of pipeline assets.

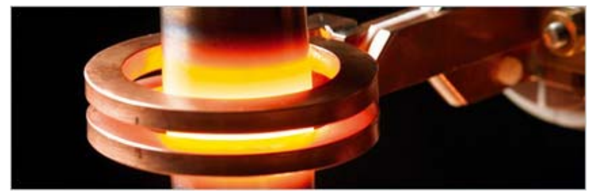
However, Statoil decided to use a diver-based hot tap for Tampen Link. The pre-heat technology is shared between the systems.

INDUCTION HEATING

The main pipeline was operating at high flow and pressure, creating a massive cooling effect. Traditionally, pipes are fitted with heating mats to bring temperatures to the required level for welding but mats could not be used in this project because the level of radiated heat would make the working conditions intolerable for the welder divers.

Induction heating was the only practical alternative providing massive heating, directly in the pipe, without consequent heating of the surroundings. The system used was from EFD Induction AS of Norway and had already been specified within the Statoil PRS but Tampen link was the first operation. Perry Slingsby packaged the system for subsea operations, providing all the power, instrumentation, control and operations support.

Induction heating comes in many forms and is used extensively in general industries from smelting through to motor vehicle assembly. The EFD technology was particularly suitable for subsea operations because the voltages and frequencies and earth fault detection system were compatible with the strictest personnel safety regulations.



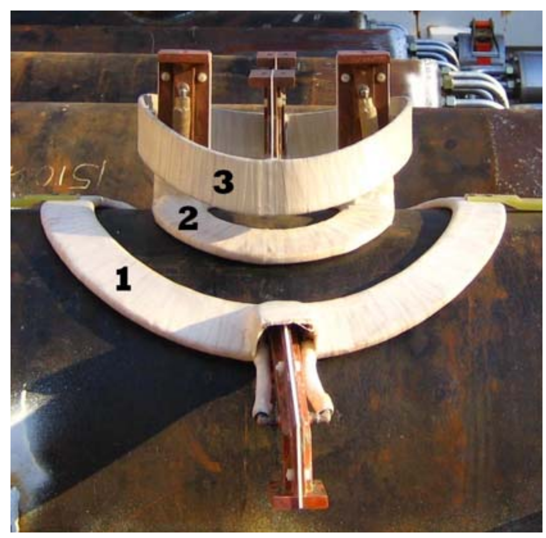
Induction heating

Fundamentally, the principle is that a large coil with high frequency alternating current will induce a heating effect in any adjacent metal surface. The heating is created by the eddy currents flowing against the electrical resistivity of the metal. Very high frequency also creates the “skin” effect where the impedance below the surface becomes higher.

The effect is highly localized and the EFD system is configured to provide a very small field radius. An intense heat is produced in metal close to the coil but the effect is short range.

The heat is developed in the workpiece only. The induction coils are internally cooled by fresh water flow and the external surfaces remain at a comfortable hand temperature, even at very high heating power.

Inductive heating has been used subsea before but some of the more primitive variants have undesirable effects on the surrounding equipment and on the divers themselves.



Three coils laid on a test pipe

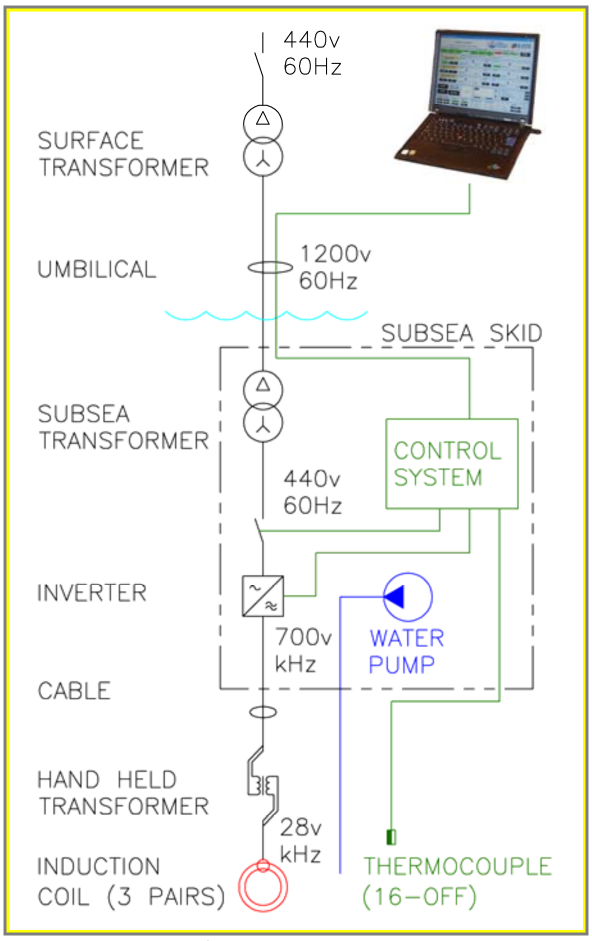
The coils are fabricated from copper and profiled to the pipe. Coils 1 and 2 were used to warm the face of the pipe so that a butter layer could be laid down. After grinding the butter layer flat, the branch is then set on top and all three coils are used while the branch is welded.

Welding the branch
(coils 2 and 3 not visible)

A total of 16 thermocouples were placed in the heated zones and in the welded area. These were continuously monitored for control of the heating and as a record of the weld.

EQUIPMENT

A primary objective of the system was to minimize the manual operations by the divers and move most controls to automatic processes or to the topside team. The bulk of the equipment was therefore placed in a large subsea workskid with only the induction coils and the thermocouples to be brought into the welding habitat.



Simplified single line diagram

The supply power on deck was standard ship voltage 440V at 60Hz. This was stepped up to 1200V to minimize the main umbilical size. A subsea transformer stepped the voltage back down to 440V 60Hz. The EFD inverters then stepped the voltage above 700V and increased the frequency to very high kHz range. Not shown in the line diagram are large capacitors which smooth and correct the power factor. The cables to the coils terminate in Hand Held Transformers, which are compact items fitted at the start of the induction coils and convert the voltage down to below 28V. This results in induction coils operating at low voltage but very high frequency.

The main power is controlled by a conventional distribution panel on the surface. Control and monitoring of all instrument functions used a PSSL developed package communicating on ProfiBus to the EFD inverter modules.

Of concern for any diving operations is the subsea electrical safety. The system had to satisfy both the IMCA AODC 035 guidelines and the local regulations for electrical and magnetic fields. The normal ROV approach of floating earth system with line insulation monitoring was used on all the main power lines sent subsea. For the Induction coils, the insulation resistance levels were heavily affected by the induction effect and the system was specially configured to maintain compliance with safety requirement. This meant a positive leakage current measurement.

Unlike some earlier systems, the pre-heat induction coils had no side effects for the diver personnel: there were no reports of any discomfort from either heat or electromagnetic effects.

Subsea work skid

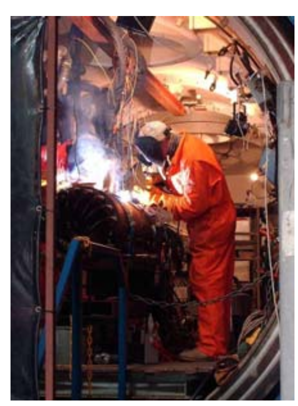
Most of the subsea equipment was packaged in the workskid. The only items the divers had to handle were the cables to the coils, which were stored in a basket area (on the right in the photo). The coils had to be kept dry and were stored in the welding habitat.

TESTING

As is common practice with critical subsea hyperbaric welding operations, the welding operation was extensively rehearsed on simulated pipes in the National Hyperbaric Centre, Aberdeen.

The gas flowing was simulated by a water cooled equivalent.


Chamber closed

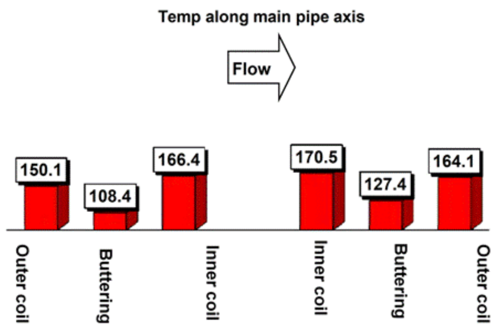

Trial run with chamber open

The trials had the purpose of training the welder divers in all the planned and contingency procedures, qualify the weld and allow a thorough proving of the pre-heat system.

The cooling effect had to be balanced with high heat to get the pipe weld area into the ideal temperature zone. The pre-heat system provided the responsiveness and precision to achieve this.

The 16-off thermocouples applied under the coils and in the weld zone were continuously monitored and logged to give a comprehensive picture and record. Power Trip alarms were individually assigned to the thermocouples. Delays were introduced to allow for momentary temperature spikes when the welding stick passed a thermocouple. The Trip alarms were important to avoid overheating of the pipe with possible collapse of the high pressure mother pipe as a result.

The following diagram illustrates some heating figures from these tests. Note how the butter layer is at a lower temperature than the heating coils either side. Also note how the water flow drags the heat downstream.



OPERATIONS

The offshore operations were conducted in July 2007 from the CSO Wellservicer. The welding was performed using an existing Technip habitat. The Pre-heat deployment skid was supported by a surface umbilical reeler and all the controls and power supplied from a simple control cabin.

Technip “PAWS” Habitat

Umbilical reeler

Control Cabin

Recovery of the Pre-heat skid

The system was deployed to seabed for a total of five days and remained powered up throughout. The pre-heat operated throughout all the welding operations and there were no major equipment incidents.

The pipe branch and the flange were successfully welded in place on first attempt with no re-work.

The most outstanding aspect of the system was the precise controllability and monitoring of the heat through all the operations.

An unexpected finding from the offshore operations was that the pre-heat temperature profile in a flowing gas pipe was significantly different from the profile obtained from a water cooled simulated pipe. The temperature “drag” profile shown on water cooled pipe was reversed and the coolest area is actually upstream! This effect has been seen before but not properly recorded: it has been partly masked by the control limitations of other pre-heat systems.

The implications of this to future hot taps are still being processed. In the operations the overall temperature spread was much greater than expected but the ability to fine-control the heating managed to keep the welding operation within range.

CONCLUSIONS

This first use of the EFD/PSSL Inductive Pre-heat system on a hyperbaric pipeline weld was a success. It demonstrated:

- A slim and unobtrusive installation around the weld with easy installation
- A very precise level degree of pre-heat control can be applied.
- An inductive heating system fully compliant with latest diving personnel safety rules and all relevant electrical and magnetic field safety guidelines.
- A compact deck-spread and single power and control umbilical to the seabed.
- Real-time temperature trend monitoring and recording.
- A comfortable working environment for the welder divers.