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New tool for internal pressure during fabrication and installation of mechanically lined pipelines using reel-lay method

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ABSTRACT

As an ideal use of corrosion-resistant alloys and low-alloy steels, Mechanically Lined Pipelines (MLPs) have been employed gradually for offshore exploitation. If the risk of thin-walled liner wrinkling is to be effectively averted, reel-lay is the most economical installation method for this type of pipeline, especially for deepwater oil and gas development. A suite of tools and corresponding techniques is proposed in this paper to realize the spooling-on of an MLP stalk with inner pressure to avoid detachment and wrinkling of the MLP liner. Additionally, The related numerical verification and a prototype test for a 5-in. MLP spooling-on tool are completed to prove the validity of this new technique and further illustrate the application effect of providing internal pressure during the spooling-on of MLP stalk to a reel.

1. Introduction

When compared with added corrosion inhibitors for transportation or laying submarine pipelines made of corrosion resistant alloys, MLPs have obvious economic benefits for offshore operations in the strong corrosive environments found in oil and gas fields. An MLP is a double-walled pipe consisting of a load-bearing, high- strength, low-alloy carbon steel outer pipe lined with a thin-walled sleeve made from a corrosion-resistant material [1–3]. However, due to high welding difficulty and low welding efficiency, a traditional s-lay approach requires more offshore operation time for the installation of MLP pipeline, which restricts the application of this type of tubular product. The industry believes that for MLP pipeline, the most efficient installation method is reel lay, which requires welding and reeling on land followed by unwinding and installing on site at sea.

However, during the spooling-on phase, when MLPs are exposed to bending, the thin liner may start to detach and wrinkle, as indicated by full-scale tests [4–6] and finite element analyses [7–12] and some of the approximate analytical solutions in the works of Vedeld et al. and Vasilikis and Karamanos [13,14]. Vasilikis and Karamanos [14] used an FE model to study the elastic detachment of the liner in an MLP and gained considerable insight into wrinkling. Subsea 7 and Butting launched a joint research project on the feasibility and significant advantages of installing MLP pipelines by the reel-lay method [15]. In their research, a total of nine test strings were used to demonstrate that for a high quality lined pipe, by applying internal pressure, the pipe could be installed on the seabed fully fit-for-purpose with no formation of any wrinkles.

All of the studies mentioned above have indicated that to employ reel installation of MLP pipeline, the key is to prevent any detaching, wrinkling or collapsing of the liner layer during the spooling-on phase. Furthermore, the specific behaviour of MLP when installed by reel-lay needs careful examination and testing to understand the influence of global plastic deformation from bending on mechanical contact between the liner pipe and the outer pipe and to determine the capacity of the liner pipe to survive the reeling process without local buckling. Motivated by this challenge, significant efforts have been undertaken by industrial and academic researchers to establish the extent to which lined pipe can be safely bent, identifying the main factors that influence liner detachment and wrinkling and finding ways to prevent any deformation or detachment within the pipe.

These studies have indicated that a certain internal pressure can delay liner detachment and wrinkling and increase the critical bending curvature of a MLP. During winding and unwinding, the internal pressure should be maintained between 5.0 and 25.0 bar absolute pressure because a pressure lower than 5.0 bar generally fails to remove the risk of detachment or wrinkle deformation, whilst a pressure higher than 25.0 bar would be impractical because of the tendency of the spooled pipe to straighten and spring out-

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ward from the storage drum and the risk of rapid expansion and release of large quantities of stored energy in the event of pipe failure.

In 2009, SUBSEA 7 LIMITED raised a smart pig moving back and forth to seal and pressurize an MLP stalk before its spooling-on [16], but the specific measures controlling the smart pig to lock and release were not elaborated. This paper provides a purely mechanical approach for pressurizing the MLP stalk and maintaining this pre-charge pressure during the joining of further individual lengths to the MLP stalk and winding the MLP stalk onto the reel. This system includes two purpose-designed packers, a long piston rod and two pre-charged pressure sources. Using this system, the repeated procedure of welding and spooling a pipe simple root is also presented in detail.

2. Mechanical components of this system

The sealed-in unit for MLP spooling-on is a Reel-side Packer, a Welding-end Packer and a long piston rod. The Reel-side Packer connects to the long piston rod relying on thread and the latter are mounted in the Reel-side Packer with rubber ring sealing.

2.1. The Reel-side Packer

The structure of Reel-side Packer 10 is visible in Fig. 1.

The Release Status or Seal Status of the Reel-side Packer is controlled by air pressure imported through the long piston rod. Through Through-hole 22 the air pressure reaches Annular Gap 21 and pushes Plunger 16 and Slide Valve 15, whose Groove-Side 17 fits with Flange 18 on Central Tube 11 to limit the push stroke of Plunger 16. When Shoulder Holster 14 squeezes Rubber Ring 13, the Reel-side Packer will seal the inner space of the MLP pipeline to keep the pressure before it (see Fig. 1, a: Release Status and b: Seal Status). At least one Through-hole 22 is located in Central Tube 11 to send air pressure. Tail Sleeve 19 and Cylinder Liner 20 join Central Tube 11 to cover Plunger 16 and Slide Valve 15 and form Annular Gap 21. The Long Piston Rod 60 connects to Tail Sleeve 19 to induce high pressure to control the releasing and sealing of the Reel-side Packer. When this pressure is removed, the Reel-side Packer is released, being driven by the previously sealed pressure towards the welding-end packer along with the long piston rod, when the welding-end packer can lead-in protective pressure between itself and the reel-side packer to avoid collision.

For the Reel-side Packer, all threaded connections, such as the connection between Central Tube 11 and End Cap 12, the connection between Tail Sleeve 19 and Central Tube 11, and the connection between Tail Sleeve 19 and the Long Piston Rod, need embedded rubber rings for sealing. The contact faces between Plunger 16 and Central Tube 11, and between Plunger 16 and Cylinder Liner 20, also need sealing with elastometic washers.

2.2. The Welding-end Packer

Fig. 2 shows the detailed structure of the Welding-end Packer, which includes a Central Tube 31, an End Cap 32 with a central through hole, hermetically connected Tail Sleeve 39 and Cylinder Liner 40. Several Rubber Ring 33s spaced with intermediate ring 50s, Shoulder Holster 34, Slide Valve 35, and push Plunger 36 are also installed on Central Tube 31. Groove-Side 37 of Slide Valve 35 also fits with Flange 38 on Central Tube 31 to limit the push stroke of Plunger 36.

Between Plunger 36 and Tail Sleeve 39, an Annular Gap 41 is left, and the air pressure reaching this position induced by Inlet Connector 44 can impel Slide Valve 15 and Plunger 16 to squeeze the Rubber Ring 33s to seal the annular space between the Long Piston Rod and the MLP internal wall.

Another Inlet Connector 49 induces pressure reaching the annular space between End Cap 32 and the passing Long Piston Rod, and by Through-hole 48 the pressure of the MLP's internal annular space outside of the Long Piston Rod between the Reel-side Packer and the Welding-end Packer can be controlled.

Like the Reel-side Packer, the Welding-end Packer also needs sealing at these positions, including the sliding contact between the Long Piston Rod and the inwall of Central Tube 31, the threaded connections between Central Tube 31 and End Cap 32, between Central Tube 31 and Tail Sleeve 39, and the contact faces between Plunger 36 and Central Tube 31, between Plunger 36 and Cylinder Liner 40.

2.3. The Long Piston Rod

By its front-end thread, Long Piston Rod 60 connects to Tail Sleeve 19 of the Reel-side Packer and passes through Central Tube 31 of the Welding-end Packer under seal with elastometic washers.

Long Piston Rod 60 has two thread-connected segments, which both have a central-hole 63, and ball valve 65 is set in the middle, which is shown in Fig. 3. When ball valve 65 is open, the central-holes of the two segments are connected, and pressure can be individually transferred to the Reel-side Packer to control it. When ball valve 65 is closed, the central-hole of the front segment is sealed, and the segment behind ball valve 65 can be taken off.

3. Operation process of this system

As Fig. 4 shows, the operation process of this system includes four typical operating conditions, which are the welding condition, spooling-on condition, adding new MLP root condition, and the final sealing condition.

1. Connected to a pressure source at the initial end, the MLP stalk waiting for spooling-on is put into the Reel-side Packer connecting to the Long Piston Rod equipped with the Welding-end Packer.
2. Pressure (nitrogen, air or water source) applied from the outside end of the Long Piston Rod controls sealing of the Reel-side Packer, which is arranged in front of the MLP interface.
3. Starting the initial tip pressure, reel rotation and spooling-on of the MLP stalk and Welding MLP interfaces.
4. Adding one or more simple root(s) at the end of spooling-on the MLP stalk, and also the Long Piston Rod equipped with the Welding-end Packer needs to pass through the new simple root(s).
5. Pressure (nitrogen, air or water source) is applied from two Inlet Connectors at the end of the Welding-end Packer to control sealing of the Welding-end Packer and fill protective damping pressure in the MLP annular space between the two Packers.
6. Removing the pressure in the Long Piston Rod and unsealing the Reel-side Packer. Due to the annular pressure difference before and after the Reel-side Packer across the new weld(s) the Reel-side Packer connected to the Long Piston Rod is pushed towards the Welding-end Packer when the Long Piston Rod moves outside in the Central Tube of the Welding-end Packer. Here an annular damping pressure is applied between the two Packers to avoid collision between them.
7. With sealing of the Reel-side Packer controlled, the damping pressure between the two Packers is released.
8. The Welding-end Packer is unsealed. A drag chain is used to pull out the Welding-end Packer along the Long Piston Rod.
9. Again adding simple roots, step 5 and the following steps are repeated until the final MLP simple root is added.