DEEP OFFSHORE TECHNOLOGY INTERNATIONAL ASIA / PACIFIC

ADVANCES IN SUBSEA & DEEPWATER PIPELINE PRE-COMMISSIONING

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Background

The increasing number of subsea and deepwater developments brings new challenges where there are no surface connections to the pipeline available for pipeline testing and pre-commissioning.

Once constructed / installed such subsea and deepwater systems still have to undergo certain pre-commissioning and commissioning operations, from initial flooding, gauging & testing up to final start up.

Whilst the provision of such services in shallow water and topside-to-topside developments is routinely achieved, providing the same services at water depths in excess of 1,000m poses many challenges. In this paper we shall review the unique challenges in providing such services deepwater, and then review current / planned technologies including:

- Flooding and pigging subsea pipelines using a Remote Flooding Module (RFM) – by using the available hydrostatic head to flood and pig subsea pipelines whilst meeting the project requirements in terms of pig speed, filtration and chemical treatment.
- Use of subsea ROV driven pumping units for completion of flooding and pressurisation – by using the hydraulic power from a work class ROV to power a custom built pump skid built connected on to the RFM allowing all pigging and pipeline testing to be performed subsea
- Use of smart gauge tools (SGT) to gauge pipelines without using aluminium gauge plates – this allows the gauging of lines with reduced bore PLETs at each end. Also the ability to communicate the result of the gauging run thru-wall without the need to recover the gauge plate to surface. This allows testing without pig recovery.
- Use of subsea data loggers to record pressures and temperatures during subsea testing, and use of systems to transmit this data to surface real-time during the test period

1.0 Asia Pacific Deepwater Market Overview

Looking at the Asia Pacific Market, the following table shows some of the deepwater projects currently in progress within the region.

Country	Development	Production system	Status	Onstream	Water (ft)	Operator
ASIA-PACIFIC						
India	D6	Subsea	Under development	2008	3000	Reliance
India	G1-GS15	Subsea	Producing	2007	1500	ONGC
Australia	Gorgon	Subsea	Under development	2010	4300	Chevron
Malaysia	Gumusut	Semisubmersible	Under development	2010	3000	Shell
Malaysia	Kikeh	Spar	Producing	2007	4400	Murphy
India	MA	FPSO	Under development	2008	4000	Reliance
Australia	Pluto	Subsea	Under development	2010	3300	Woodside
Australia	Stybarrow	FPSO	Producing	2007	2700	BHP Billiton
Australia	Van Gogh	FPSO	Under development	2009	1200	Apache
Australia	Vincent	FPSO	Under development	2008	1500	Woodside

***Figure 1** – Asia Pacific Deepwater Developments*

Looking at Australia in more detail we have visibility on the following deepwater prospects:

Operator	Field	Year Discovered	Status	WD (M)	Development Type
Chevron	Gorgon Central	1983	Firm Plan	250	Subsea Satellite to Onshore Facility
Chevron	Gorgon North	1981	Firm Plan	246	Subsea Satellite to Onshore Facility
Chevron	Gorgon South	1980	Firm Plan	220	Subsea Satellite to Onshore Facility
Chevron	Jansz SE/Io South	2000	Firm Plan	1300	Subsea Satellite to Onshore Facility
Chevron	Wheatstone	2004	Firm Plan	216	Subsea Satellite to Fixed Production
Exxon Mobil	Jansz	2002	Firm Plan	1300	Subsea Satellite to Onshore Facility
Inpex	Ichthys	2000	Firm Plan	230	Floating Production
Shell	Prelude/Tocatta	2007	Probable	200	Fixed & Floating Production and Subsea
Woodside	Brecknock	1979	Possible	300	Floating Production
Woodside	Calliance	2000	Possible	420	Subsea Satellite to Floating Production
Woodside	Pluto	2005	Under Development	976	Fixed Production Platform and Subsea
Woodside	Sunrise	1974	Possible	180	Fixed Production Platform and Subsea
Woodside	Torosa	1971	Possible	250	Fixed & Floating Production and Subsea
Woodside	Troubador	1974	Possible	160	Subsea Satellite to Fixed Production

***Figure 2** – Australia Deepwater Developments*

The offshore / deepwater pipeline market dynamics are explained further below:

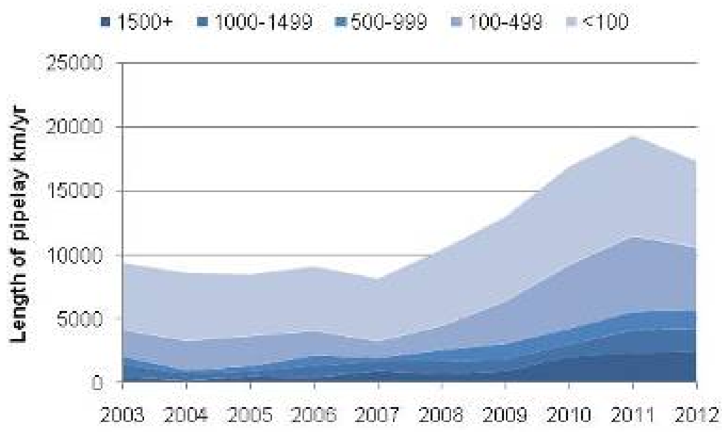


Figure 3 *– Global Offshore Pipe lay Forecast*

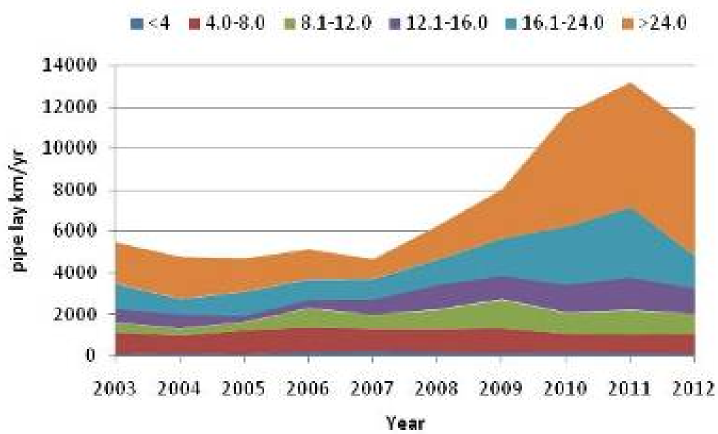


Figure 4 *– Global Pipe lay Forecast by diameter*

1.1 Market Overview Summary

From the data in section 1 we can draw the following conclusions:

a. That there are a large number of deepwater pipeline projects planned in the Asia Pacific region between 2008 and 2014

b. There is steep in crease in global deepwater pipeline installation planned in the next few years, peaking in 2011

c. Services and techniques will be required to assist with the pre-commissioning and commissioning of such pipeline systems

2.0 Pipeline Pre-commissioning – What Do We Mean?

The following flow chart illustrates the pre-commissioning process as typically applied to oil pipelines. The process for gas lines is similar but involved additional steps prior to handover such as removal of hydrotest water (dewatering), drying, MEG swabbing and nitrogen packing (these are not covered in this paper).

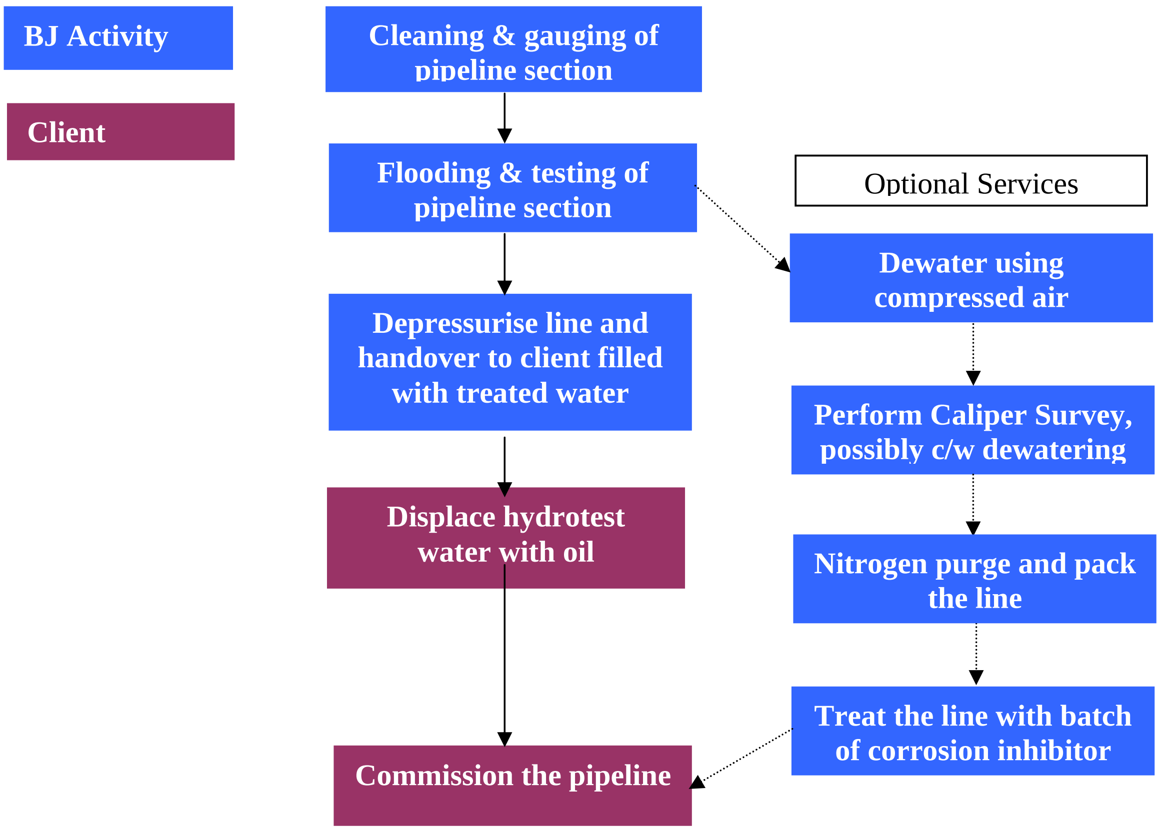


***Figure 5** – on LHS shows a typical offshore vessel based spread required to deliver the above services to a subsea pipeline.*

3.0 The Aims of Subsea Pipeline Flooding

The first subsea pigging units were conceived and developed to overcome the problems associated with flooding and pigging pipelines in deep water.

The latest subsea flooding device is the BJ RFM (Remote Flooding Module), which essentially achieves the same objectives using up to date ROV and Subsea technologies.

The RFM is a Subsea flow control and regulation system. Once positioned on the seabed and connected to the pipeline to be flooded or pigged by HP loading arm, it is “operated” by the ROV opening the valves to the pipeline.

The hydrostatic head of the sea then enters the pipeline through the RFM because of the differential pressure between the inside of the pipeline, which is at atmospheric pressure and the sea.

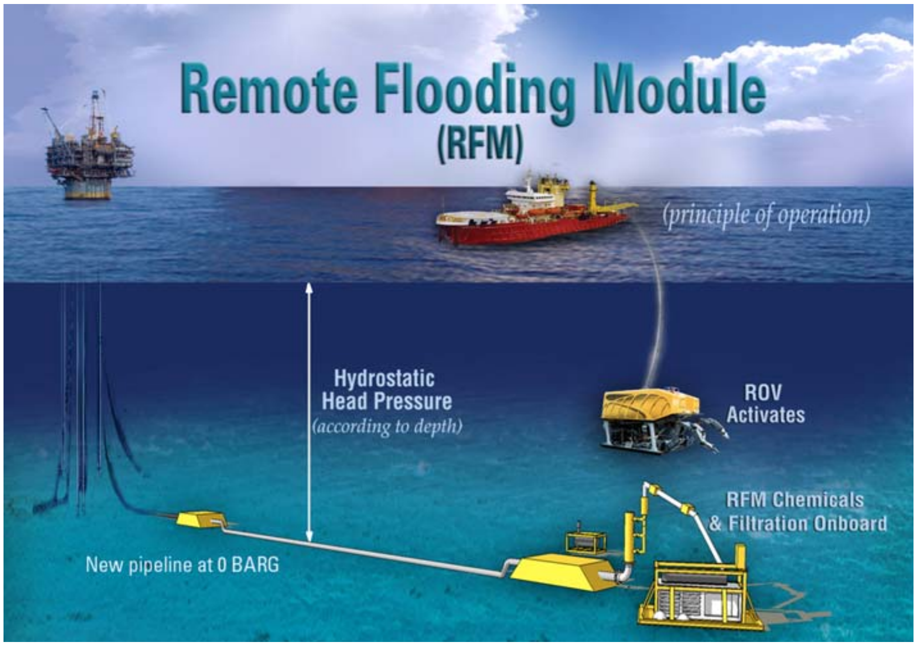


***Figure 6** – Overview of Remote Flooding Module*

Seawater enters the RFM via a filter manifold, which is installed at the specified filtration level, usually between 50 and 200 microns. It passes through a Venturi device, which creates a small pressure drop in the on board flexible RFM chemical tanks which are connected to the water flow pipework. This small differential pressure is used to induce anti-corrosion chemicals into the water flow at the desired rate. This is pre-set prior to deployment and ROV adjusted Subsea if necessary via control valves.

The chemically treated water flow is controlled to a pre-determined rate via a flow regulation system. This maintains the water flow at the desired speed to match specified or optimum pig speed or flooding rates. Again this can be pre-set prior to deployment and because the rate is controlled at a steady level the chemical inducement is assured throughout the entire “unassisted” operation. A Boost pump is required to complete final pigging operations due to pressure equalisation. This pump is ROV driven, usually operated when the ROV returns to location to disconnect and recover the RFM, and in Deepwater is required only for a very short time.

The vessel and ROV can leave the unit in isolation on the seabed during the unassisted operations and carry out other tasks. There is no need for connection to anything other than the pipeline. On board batteries power data-logging instrumentation which logs flows, chemical rates etc, and visual readouts allows the ROV to check status before it leaves and when it returns.

The RFM is positioned on the seabed by ROV and connected to the pipeline to be flooded via the innovative rigid loading arm pipe system. The ROV then positions itself on the unit’s roof from where it can view instruments and operate valves to monitor the initial stages of the operation and adjust if necessary chemical control valves.

Filtration and chemical treatment specifications are fully met by onboard facilities. Chemicals are stored onboard in flexible tanks and introduced by a Venturi system regulated by detecting changes in the water flow through the unit and automatically adjusting the chemical flow accordingly.

To summarise the aims of subsea pipeline flooding:

- Reduce the size of vessel required for pre-commissioning operations
- Negate the need for the vessel to remain on station during the bulk of the operations
- Remove the need for an expensive down-line, which is prone to damage
- Reduce schedule by increasing possible pig speed
- Reduce schedule by use of seabed water removing thermal stabilisation for Hydrotest
- Reduce crew size, equipment spread size, environmental impact by removal of diesel engines on pumps, improve safety by taking operations off-deck

4.0 Offshore Vessel Requirements – the Cost Driver

Previously in this paper I have described the functionality and development of subsea flooding and testing, and in the following section we look at the commercial drivers to use such a system. As an example we take the following pipeline as an example:

Line NPS	16”
Wall Thickness	12.5mm
Line Length	8KM
Water Depth at launcher	1000m
Water Depth at receiver	1000m
Water Temp at surface	28°C
Water Temp at Seabed	4°C
Average Flooding pig velocity required	0.5 m/sec
Flooding Rate Required	3,420 lpm

Table 1 – *Pipeline details (illustration)*

The important data from the above is that we need to inject 3,420 lpm of filtered, treated sea water into a pipeline at a water depth of 1000m. There are 2 ways to achieve this:

Use a Vessel Based Spread and Down-line

The vessel based spread must be designed to deliver 3,420 lpm in to the pipeline – hence the first consideration is the size of the down-line required. Having looked at the various pressure drops across the down-line, we then need to evaluate the pump power (HHP / BHP) required to overcome the system pressure losses and deliver the flow to the system.

Down-line Diameter	Down-line Length	Pressure Drop in barg *	HHP required for 1m/sec	BHP required for 1m/sec**
2”	1,200m	210 barg	1,600 HHP	2,560 BHP***
3”	1,200m	78 barg	594 HHP	1,014 BHP
4”	1,200m	24 barg	183 HHP	382 BHP****

Table 2 – *Pressure drops and HHP calculations vs. down-line diameter*

* Using Mears pipe flow calculator

** Based on 65% efficiency (centrifugal pump) plus 100bhp for engine ancillaries

*** Maximum power from portable, marinised diesel engines approx. 1,800 BHP

**** Pump packages rated at 350 to 500 BHP readily available

Thus taking the data in table 2 we can see that to flood this notional 16" pipeline at a depth of 1,000m would require:

- *A 4" x 1,200m down-line including reel and installation system*
- *A 4" hot stab to connect the hose to the subsea launcher*
- *2 qty diesel driven 500 bhp centrifugal pumps*
- *Lift pumps, break tanks, filters, chemical injection units and hoses*

To put this into perspective in figure 7 we show the deck space required on a DP vessel for the above spread (figure 8 illustrates space requirement for similar RFM spread):

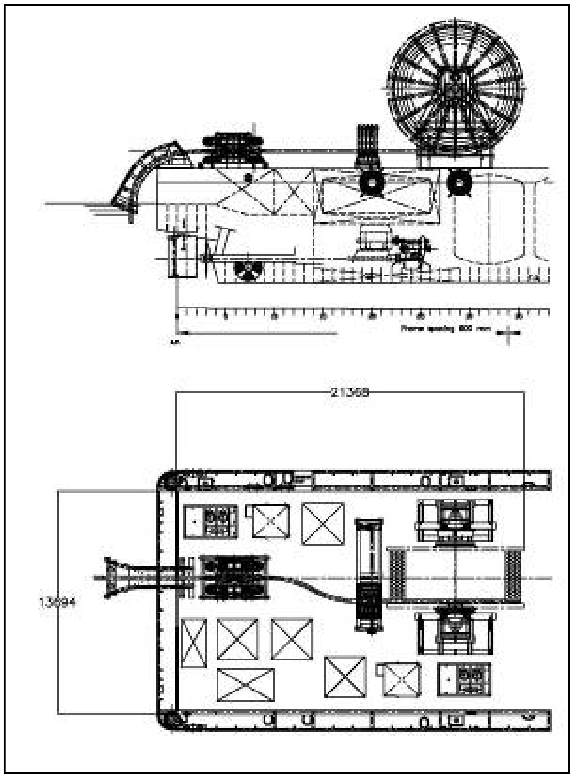


Figure 7 ***–*** *Vessel Space Requirement*

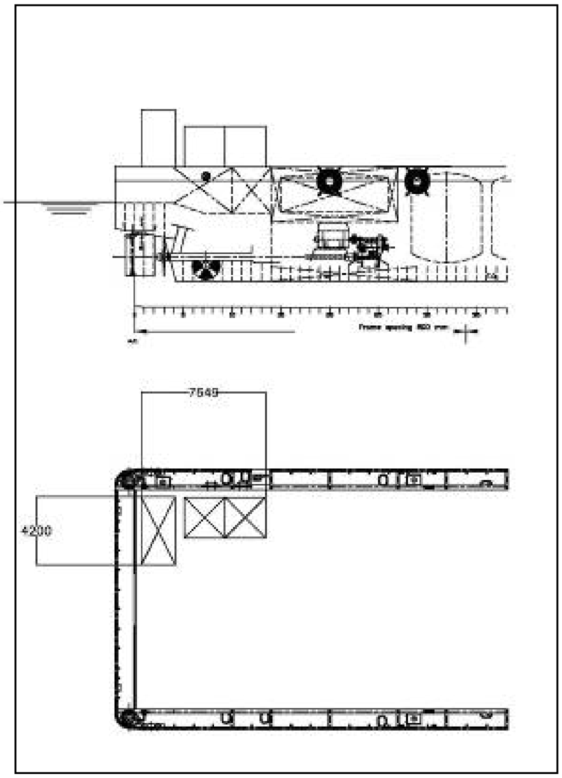


Figure 8 ***–*** *Reduced Space Using RFM*

The vessel based spread c/w down-line requires a deck space of approx. 290m^2 to flood a 16" pipeline at 0.5m/sec. To perform such an operations the following steps are required:

a.	*Deploy down-line and stab in to subsea launcher*	-	*12 hours*
b.	*Flood the 8km line at 0.5m/sec*	-	*5 hours*
c.	*Recover down-line to surface*	-	*12 hours*
d.	*Allow fill water temperature to stabilise*	-	*48 hours*
e.	***TOTAL TIME FOR FLOODING***	-	***77 HOURS***

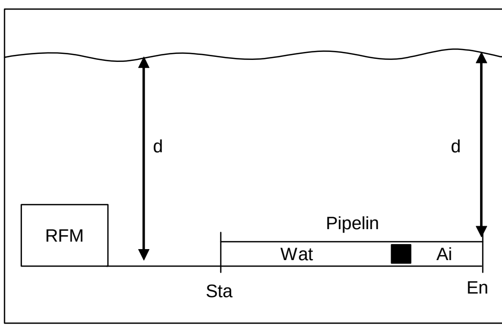
Use a Vessel Based RFM to Flood the Line

Figure 7 shows the deck space required for the RFM – this is approx. $32m^2$. The RFM can carry sufficient chemicals to fill 16" x 8km in a single deployment. Using the vessel crane the RFM can be quickly deployed subsea and connected to the subsea launcher. Thereafter it can perform the initial flooding of the pipeline at velocities up to 1m/sec.

Figure 9 *– RFM ready to deploy*

16" Pipeline

Predicted End Point of Flooding by RFM:



Data

Starting end depth	d1 =	**1000**	metres.
Finishing end depth	d2 =	**1000**	metres.
Total line length	L =	**8**	kilometres.
Internal diameter of line	b =	**371.4**	millimetres.
Assumed or required pig speed	v =	**0.5**	m/second.
Assumed pig (train) driving pressure		**2**	bar.
(If unknown, assume 1 bar per pig.)			
Slug length trapped air before boost		**81**	**metres.**
Proportion of line flooded by unassisted RFM =		**99.0**	**%.**
Time taken for filling by RFM at pig speed 0.5m/s is		**4.4**	**hours.**
Volume to be boost pumped for completion =		**8.8**	**cubic metres.**

Figure 10 – *RFM calculation for 16" x 8km line.*

In figure 8 we can see that the RFM can flood the line within 4.4 hours and that $8.8m^3$ has to be pumped by the ROV powered boost pump – please consider the line has been flooded with water at seabed ambient temperature.

The vessel based RFM spread requires a deck space of approx. $32m^2$ to flood a 16" pipeline at 0.5m/sec. To perform such an operations the following steps are required:

a.	*Deploy down-line and stab in to subsea launcher*	-	*2 hours*
b.	*Flood the 8km line at 0.5m/sec*	-	*5 hours*
c.	*Recover down-line to surface*	-	*2 hours*
d.	*Allow fill water temperature to stabilise*	-	*0 hours*
e.	***TOTAL TIME FOR FLOODING***	-	***9 HOURS***

4.1 Vessel Cost Summary

Looking at the example of flooding a 16” x 8km line at 1,000m water depth, we can draw the following conclusions:

1. *The down-line option requires almost 10x the deck space of the RFM option – with the current shortage of DP vessels and with vessel rates of around US$40,000 per day, this can have a major impact on overall project costs*
2. *As the RFM floods the line with ambient temperature water there is no stabilisation period – this could represent a saving of 2 days*
3. *The deployment and recovery time for the RFM is far quicker than for a 4” down-line*

As with all new technologies, there are circumstances where the RFM may not be suited to a deepwater project. These include:

- Where one or both ends of the line terminates at a platform / FPSO such as when using SCR’s
- Where a down-line will be deployed for other operations and can conveniently be used for flooding
- Where a large number of pigs are used
- Where the line has to be flooded with either fresh water or MEG
- Where one on of the line terminates in shallow water.

5.0 Advances Made in Subsea Pigging Equipment

The original Subsea Pigging Unit was designed by pre-commissioning Engineers with little input from ROV and Subsea specialists, despite efforts to include them.

Whilst the device was successful in achieving its' pre-commissioning objectives, it wasn't the most optimum method of operation for the ROV or deployment Vessel. Unwieldy HP flexible Jumper hoses, relatively crude instrumentation and brand new ways to use Choke Assemblies meant there were areas to improve, for example:

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- The RFM holds more chemical than the original Subsea unit, allowing less recovery and deployment cycles and use on longer and larger lines
- The RFM uses rigid loading arm technology to reduce Subsea connection times and reduce the risk of damage to HP flexible jumper hoses
- The RFM is extremely ROV friendly, ROV specialists were involved in design to ensure minimum ROV interface issues
- An on-board latching mechanism allows very fast ROV connection for boost pumping
- An on-board emergency release system means no risk of an ROV getting stuck on the RFM
- Advances in electronics means much more reliable instrumentation
- Deployment times are down to less than one hour in Deepwater

***Figure 11** – RFM loading arm stabbed in*

***Figure 12** – ROV operating RFM*

6.0 Development of Subsea Hydrotesting Unit

Recent developments in Subsea pumping systems have allowed ROV pump skids to carry out Subsea hydrotesting and leak testing of pipeline systems, thus allowing additional savings on Vessel size, cost etc. When used in conjunction with the RFM, significant overall benefits can be achieved. Naturally, the systems that can be tested are limited by the maximum performance available from an ROV test pump skid. The BJ SHP can produce over 40 litres per minute pressurisation rate from typical Project ROV's.

In section 4 we reviewed a down-line system required to flood a 16" x 8km line. Deepwater lines typically require hydrostatic testing at between 200 barg and 350 barg. A typical 4" down-line would not be rated for such pressures (specialised down-lines such as those produced by Deepflex and Technip can handle such pressures but are too costly for such applications). Thus a different down-line must then be deployed to in order to pressurise the line. Deployment times for the down-line will be similar to those of the flooding down-line.

***Figure 13** – SHP Unit*

A the SHP can be deployed with the RFM boost pump and hence there is no delay between completion of flooding and commencement of pressurisation – it is estimated this saves a minimum of 24 hours per pipeline.

Pipeline	Nomial bore (inches)	Length (metres)	Vol/bar (litres)	Bar/min ex SHP	Test Pressure (bar)	Vol to test pressure (litres)	Time to test pressure (hours)
Line 1	12	9553	31.83	0.94	431	114523	7.62
Line 2	10	9577	21.71	1.38	431	9921	5.20
Line 3	10	9248	20.96	1.43	431	9580	5.02
Line 4	8	9553	13.57	2.21	431	6210	3.25
Line 5	8	9479	13.47	2.23	431	6162	3.23

***Table 3** – Example pressurisation times using SHP*

7.0 Smart Gauge Technology

Previous sections of this paper have dealt with the flooding and hydrostatic testing of deepwater pipelines – in this section we deal with the gauging of the line. All offshore pipeline pre-commissioning operations include the proving of the internal bore of the line – this is normally achieved by fitting a segmented aluminium disk (see figure 14) to one of the filling pigs, the disk having an outside diameter equal to between 95% and 97% of the minimum pipeline i.d. The principle is that any restriction in the line (buckle, dent etc.) would cause one of the aluminium "petals" to bend indicating a restriction in the line.

The gauge pig is then run as part of the pipeline filling pig train and most specifications require that the gauge plate be visually inspected prior to commencement of the hydrotest – thus ensure there is no mechanical damage with in the line that could be affected by the hydrostatic test – figure 15 shows a gauge plate received with some damage.

Figure 14 *–Gauge pig prior to launch*

Figure 15 *–Gauge plate with damage*

Removing and inspecting the gauge plate is a simple operation onshore, and for pipelines with above surface terminations, but requires additional work on pipelines terminating subsea and deepwater. Thus BJ developed the SMARTGAUGE™ to meet the following needs of deepwater pipelines:

1. *Allows lines with restrictions (heavy wall bends, PLET hub restrictions, reduced bore valves) to be gauged*
2. *Permits gauging data to be reviewed and analysed assist in pinpointing any restriction identified – allows valves etc to be discounted*
3. *Incorporates a system to remotely annunciate the result of the gauging run such the hydrotest can commence immediately upon completion of flooding without the need to recover the gauge plate to surface for visual inspection.*

A standard mechanical gauge plate gives no indication of where any damage occurred, making identifying location difficult, time consuming and expensive. Using the multi-channel BJ SMARTGAUGE™ tool with a segmented flexible gauge plate both the clock position and the location of multiple defects can be ascertained, reducing the time needed to find the problem. In a further enhancement for deepwater lines a pinger can be fitted to the tool, such that any damage to the be left in the receiver if no damage is detected or removed and repairs made prior to hydrotest in the event that damage has occurred. Valuable DSV time can be saved in either case.

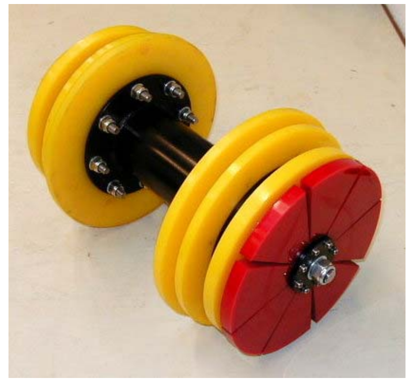

Figure 16 *–BJ SMARTGAUGE™*

8.0 Future developments

Improving ROV capabilities and advances in electronics will undoubtedly have positive benefits to remote flooding and pigging systems. Use of remote data transmission and signalling will also allow other associated tasks to be reduced in impact and cost or taken completely off of project critical paths.

All future developments will be driven by the same common objectives:

- **Reducing the in-field time required to complete subsea pre-commissioning services, hence saving on both the vessel costs and hire periods for pre-commissioning spreads**
- **Removing or replacing operational processes that have high risk (such as deployment of large diameter down-lines in deep water)**
- **Minimising offshore vessel deck space for pre-commissioning equipment, allowing smaller & cheaper vessels to be used**

Sources

Figure 1	Offshore Engineer
Figures 2 and 3	Australian Deepwater Development Market, Infield Ltd, Perth 2008
Figures 11 and 12	Technip UK Ltd
Figure 14	Profile Ltd, UK.
Other figures	BJ Services

References

1. Remote Deepwater Developments, Les Graves, World Pipelines, December 2007