The effectiveness of Marine Breakaway Couplings in minimising risk to FPSO transfer operations

from the perspective of reeled or in-air catenary reeled configurations

August 2018

Content

1. Report purpose and objectives

This report considers the importance of Marine Breakaway Couplings (MBCs) within Floating Production Storage and Offloading unit (FPSO) hose with reel transfer operations and the specification and management requirements required to ensure safe, efficient and reliable operations.

Note: The purpose of this report is to not assess the advantages or disadvantages of different hose designs or to make any comparisons between hose manufacturers. Additionally, the purpose of this report is not to assess the advantages or disadvantages of various FPSO reeling designs.

2. Introduction and definition of an FPSO facility

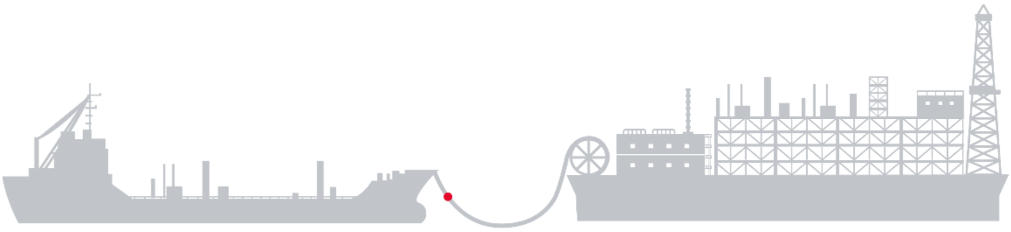
A Floating Production Storage and Offloading (FPSO) facility is defined by the Oil Companies International Marine Forum (OCIMF) as a floating system designed to:

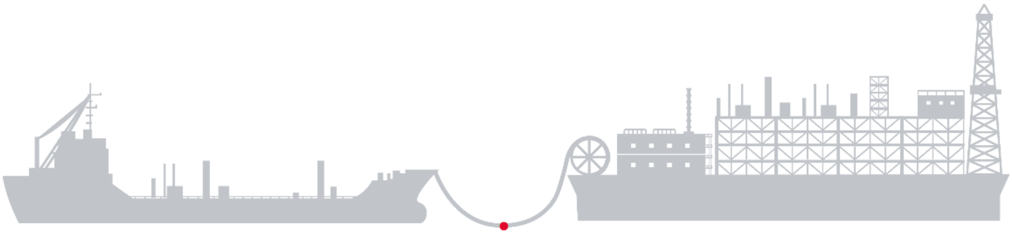
- Receive crude oil and/or gas from subsea wells or from a nearby wellhead facility;
- Separate and treat oil, gas, sediment and water;
- Store crude oil, liquefied gas and other petroleum products in dedicated storage (cargo) tanks within the hull structure;
- Export the crude oil/and or other petroleum products to an offtake tanker.

FPSOs generally have a ship-shaped hull; although cylindrical hulls are also in operation. The FSO (Floating Storage and Offloading) is similar to an FPSO - the only difference being is that oil and gas products are not processed on board.


MBC Installation options for Tanker Midship Manifold configurations

MBC Installation options for Bow Loading configurations





Illustrative summary of FPSO transfer configurations

FPSOs have evolved tremendously since the first FPSO began production in 1977. FPSOs are now considered the preferred option for offshore field developments as they offer a viable economical alternative to fixed pilled structures.

FPSOs are now deployed in deeper and harsher environments all over the world. There are approximately 300 FPSOs/FSOs in service.

Depending on the offshore environment, the FPSO can be tied to the sea bed by a variety of mooring systems. In calm offshore environments, spread mooring systems are preferred while in harsh/hurricane environments a dis-connectable turret mooring system may be preferred.

Depending on the field and subsea production system, FPSOs will offload cargo every week and sometimes several times in a week to either Conventional Tankers (CT) or dedicated Shuttle Tankers (ST). CTs tend to use standard mooring, cargo and positioning equipment whereas STs tend to stay on location without tug assistance.

The CT is defined as an oil tanker equipped for regular trading and not specially designed or adapted for loading at offshore terminals requiring specialised mooring or bow loading equipment. The CT has a fixed blade propeller without additional thrusters (OCIMF 2009).

The ST can be equipped with several bow and stern thrusters as well as a dynamic positioning system to keep the tanker on location during the loading operation.

The offloading operation from the FPSOs to the CTs or STs is done via marine hoses with the assistance of mooring systems and position keeping equipment.

During the offloading operation, marine hoses can be either in:

- A permanently floating configuration.
- Reeled floating or submarine configuration.
- Reeled in air catenary or submerged catenary.
- Chute system.

Example of reel application.

3. Foreseeable operational risks associated with FPSO loading

Evidential risks

Constant risk due to the character of operation.

- Hazards resulting from possible collision between the tanker and the FPSO and due to close proximity operation.

Variable risks

- Weather.
- Waves: swells and solitons.
- Procedural breach and human error.
- Equipment component or system failure: examples – valves and moorings, DP failure
- Terrorist attack.

Event risks

- Collision between tanker and FPSO.
- Tanker breakout.
- Pressure surge.
- Transfer failure.

Consequential risks

Direct: Immediate upon the event occurring

- FPSO, tanker and transfer equipment asset damage.
- Injury to operational personnel.
- Product spill – pollution.

Intervening risks: risk associated with those activities required in response to an event

- Injury to attending personal when recovering assets, commissioning equipment, clean-up of pollution.
- Re-commissioned system compromised state.

Indirect: subsequent to an event occurring

- Extended downtime and late deliveries.
- Clean up costs.
- Replacement asset and recommissioning costs.
- Litigation from government, employees, customers and locality interests.
- Damaged reputation.
- Compromised contracts.
- Threat to licenses.

4. Specific product transfer risks from FPSO to Convectional and dedicated Shuttle Tankers

During a tandem offloading operation between the FPSO and tanker, the tanker is stationed astern of the FPSO on approximately the same heading astern of the FPSO. The loading of the tanker is a complex operation conducted jointly by the FPSO and the tanker operational teams.

The Station keeping of offtake tankers can be challenging due to wind, waves and strong currents. Passive or active weathervaning is always a risky operation where tanker misalignments with the FPSO could lead to either tanker collision with the FPSO or tanker breakouts.

During the loading operation, while marine hoses are facilitating transfer of crude oil, the mooring equipment secures the FPSO and the shuttle tankers. This mooring equipment consists of hawser(s), chafe chain(s), quick release mechanism, supporting buoys as well as assistance from tug boats and/or dynamic positioning systems.

In addition to accidental uncontrolled release of oil to the environment, there are significant risks of serious personnel injury and extensive damage to the FPSO and tanker equipment following excessive loading and/or failure of mooring equipment. This excessive loading or failure of mooring equipment could be the consequence of tanker breakouts or excessive and damaging pressure surges.

A tanker breakout is a vessel moving off station and breaking its mooring hawser or similar such incident due to bad weather, strong under water currents, variable tides, tanker mis-manoeuvring, failure of deck equipment, blackout out of dynamic positioning systems.

An extreme and damaging pressure surge can be caused by the inadvertent sudden closure of the butterfly valve (if fitted) during full flow condition or the failure of slamming shut of the discs in the Bow Loading Coupler/North Sea Valve.

Following these incidents, if marine hoses are not fitted with Marine Breakaway Couplings (MBC), the hoses could be permanently compromised or ruptured and significant spill could occur.

Specific risks of FPSO transfer and the consequences of an incident

Tanker breakout

When the tanker drifts out of control following a tanker breakout then excessive load on the hoses, in the absence of MBCs, will cause rupture and extensive pollution will be inevitable. Several thousands of cubic meters of crude oil could be lost to the sea.

Expensive capital hoses would have to be replaced and the whole string would have to be inspected, tested either onshore or offshore before the FPSO could resume operation.

An example of a successful MBC activation: Nigeria 2015

An FPSO was offloading crude oil to a shuttle tanker when the mooring hawser parted and the shuttle vessel drifted out of control. Extreme tensile loads were applied to the transfer hose system. This tanker breakout was caused by a Soliton (Solitary subsurface wave that can propagate along the boundary between water layers having different densities. Generally occurring in specific regions, solitons are often associated with large but short-term current velocities that can cause severe disruption to subsea operations while showing little indication of their presence on the surface). The MBCs activated successfully - preventing extensive pollution and damage.

Extreme and damaging pressure surge

Extreme pressure surges can be caused by the failure of the butterfly valve or the failure of the bow loading coupler. Following this kind of incident, an excessive and damaging surge could damage hoses, FPSO manifolds and a large spill could occur. The installation of a MBC will prevent the damage caused by this kind of surge and dissipate the energy of the surge.

An example of a damaging pressure surge caused by a bow loading coupler in 2007 in Norway:

During a loading operation, a hydraulic hose failed - leading to the coupler valve on the tanker's bow loading system to snap shut in 0.5 seconds as opposed to the normal 25-28 seconds. This caused a rapid and extreme buildup of pressure in the hoses of about 115 bars. An MBC was not fitted and the outcome was a ruptured hose at subsea. The oil spill into the sea was 4,400 m3 (27,700 Barrels). The operator was fined USD 4.62 Million. Additional costs which were not divulged included terminal downtime, the cost of replacing the damaged hoses, the cost of the support vessels, the clean-up operation and damage to the company's reputation.

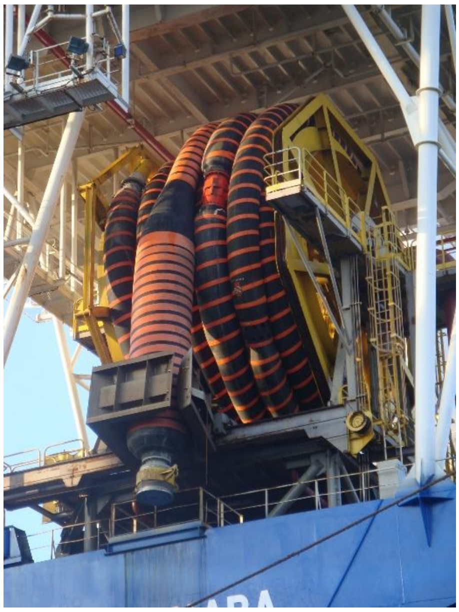
5. Introduction and definition of the Marine Breakaway Coupling

The Marine Breakaway Coupling is designed to prevent pollution and protect the hose systems and FPSO/tanker structures during either a tanker breakout or an extreme and damaging pressure surge. During these events, the MBC will activate, relieve the tension in the hoses and shut off the product flow in both directions. The industry standard is the Gall Thomson MBC which provides Field Verified proven technology.

The MBC is self-motivated and self-energized and does not rely on human activation. It is maintenance free for a minimum period for 3 to 5 years. Following a parting incident the device can be reinstated and reused.

The result of the coupling's function is a considerable reduction in oil pollution, prevention of damage to expensive capital equipment such as the hose string and structures of the mooring buoy (or storage vessel) off-take arm or sub-sea PLEM in the case of a CBM system, and shuttle tanker or barge manifold. Costly vessel downtime and clean-up operations are also greatly reduced.

Depending on the product transferred, the MBC can be of the Petal Valve or Flip-Flap Valve type. Petal Valve MBCs are generally supplied for crude oil application and Flip-Flap MBCs are used for refined products or low viscosity crude.



Examples of MBCs on reel

6. <u>Mitigating risk – use of Marine Breakaway Couplings and Bow Loading Couplers</u>

<u>Evolving risk due to increasingly exposed locations</u>

The OCIMF has identified that Marine offshore terminals, particularly FPSO/FSU facilities, are increasingly established further offshore in more exposed locations. Tanker loading operations are conducted in increasingly harsh environmental conditions and although equipment specifications may be increased, the risk of tanker breakout cannot be entirely discounted when moored with a hawser. Where offtake tankers operate in dynamic positioning mode, loss of position could similarly lead to over stress of the loading hose (OCIMF information paper on MBCs 2008).

<u>OCIMF recommends emergency release capability</u>

The OCIMF has identified the types of emergency couplers as passive and active couplings. Considering the offshore environment within which FPSO conduct tandem offtake operations, and the risk of tanker breakout due to mooring hawsers, it is recommended to have an emergency release capability for the cargo hose system (OCIMF 2009).

<u>Automatic emergency activation: Marine Breakaway Coupling (MBC)</u>

The MBC is classed a passive device. The device is self-motivated and self-energized and does not rely on human activation. When called upon to operate, the coupling separates when its pre-set parting load is exceeded and relieves the tension in the hose system before it can rupture. On parting, the coupling's unique petal valve shuts off the line, either one side only or both sides of the parting point as required, and in a controlled or instantaneous manner as the operation dictates.

<u>Manual intervention activation: Bow Loading Connector/North Sea Valve (BLS)</u>

Active couplings such as the BLS are usually located at the end of the hose string and can be used only for dedicated shuttle tankers. The activation of a bow loading coupler needs a human intervention from the FPSO operational team and usually the disconnection sequence can take time as the following sequence of events need to take place: Emergency Shut Down activation (ESD), centrifugally operated cargo pumps must be stopped, the valves must then close, then the disconnection of the coupler can take place.

Given this extensive sequence and time procedure, a rapidly evolving tanker breakout scenario would cause the BLS method to be ineffective. Without the assistance of an MBC, the effectiveness of this method is therefore vulnerable to circumstance.

7. Confirmation research: MBC and BLS comparison: HAZOP North Sea and Brazil FPSO

The offloading system was examined from upstream of the offloading Emergency Shutdown (ESD) valve on the FPSO/terminal to the crude rundown line from the BLS of the shuttle tanker.

Three scenarios were analysed: storage, connection and offloading.

The Hazard and operability study considered the typical systems used in the North Sea; i.e. dual redundant dynamically positioned (DP2) shuttle tanker with BLS using green line system; and Brazil, where the systems are similar, except that the green line is generally not present on account of telemetry difficulties.

Where the causes and consequences varied between region (i.e. North Sea or Brazil) or configuration (i.e. whether an MBC was fitted), the outcomes were considered for each separate circumstance.

A total of 41 findings were identified during the Hazard and Operability study and 15 points of action/recommendations were made.

A total of nine deviations during offloading itself were identified where a differential between using an MBC or not were scored for risk using typical industry matrices to combine and determine incident severity and frequency. Similarly, where consequences varied for Brazilian or North Sea operations, the deviation was split up accordingly with the following outcome:

Hazard and operability study risk scoring results

Region	North Sea		Brazil	
Configuration	Excluding MBC	Including MBC	Excluding MBC	Including MBC
Risk score (severity x frequency)	130	87	210	131

This table demonstrates that risk of a failure (severity x frequency) is 33% lower when an MBC is utilised in North Sea operations and 38% lower when applied to Brazilian offloading operations.

The Hazard and operability study analysis indicates that use of an MBC in either region will reduce the risk inherent in offloading to a shuttle tanker.

It was subsequently noted by the study chair that the risk categories assigned to potential surge incidents (where the shut-off valve closes suddenly) reflected bias towards operational aspects, and that it could easily be argued that at a corporate level, the risk of continuing operations with a weakened hose would be likely to achieve a more critical assessment.

Offloading hoses typically have rated working pressures of around 20 bar and bursting pressures of between 100 and 200 bar. Whilst a pressure of 7 bar should break the green line and cause an emergency shutdown (ESD1/2), a valve slam shut event can quickly cause pressures that can damage the hose.

On the basis of the Hazard and Operability study findings, the Hazop team would recommend that there is a credible technical basis for deployment of the MBC in the North Sea and offshore Brazil.

Example list of MBCs used on FPSO reels: some in combination with a Bow Loading Coupler in floating, submerged and in air catenary applications:

Project	Size	Type	Hose Configuration Type
Marlim Sul	20	CDC	Floating hose string
Golfinho	20	CDC	Floating hose string
Seillean	12	CDC	Floating hose string
Seillean	8	CDC	Floating hose string
White Rose	20	SCC	In air Catenary
Girassol	6	SCC	Floating hose string
Girassol	6	SCC	Floating hose string
Sable	16	SCC	Submerged Catenary
McCulloch	16	SCC	In air Catenary
Guillemot/Teal	16	SCC	In air Catenary
Guillemot/Teal	16	SCC	In air Catenary
Curlew	16	SCC	In air Catenary
Triton	16	SCC	In air Catenary
Triton	16	SCC	In air Catenary
Bleo Holm	16	SCC	Submerged Catenary
Ettrick	16	SCC	Submerged Catenary
Enfield	16	CDC	Floating hose string
Wenchang LPG	6	DNCC F/F	Floating hose string
Wenchang	16	SCC	Floating hose string
Wenchang 2	16	SCC	Floating hose string
Bongkot	10	SCC	Floating hose string
Bongkot	10	SCC	Floating hose string
Sakhalin	16	CDC	Floating hose string
Sakhalin	16	CDC	Floating hose string
Kraken	16	CDC	Submerged Catenary
Ngujima Yin	16	CDC	Floating hose string
Anchieta	20	CDC	Floating hose string
P17	20	CDC	Floating hose string
Capixaba	20	CDC	Floating hose string
Okha	16	CDC	Floating hose string
Nganhurra	16	CDC	Floating hose string
Aoka Mizu	16	SCC	Submerged Catenary
Prelude	16	CDC	Floating hose string
Culzean	16	CDC	Floating hose string

8. Case studies of FPSO Marine Breakaway Coupling applications and performance

Case Study 1 Performance: Successful MBC in air catenary configuration over 21 year period

Gall Thomson 16" Marine Breakaway Coupling Type STD SCC was commissioned by Golar-Nor Offshore AS for use on the FPSO Petrojarl I on the early production on Oseberg oilfield on Norwegian sector in 1986.

Petrojarl I is equipped with an Offloading crane on the port side aft. The catenary hoses (3 off) are installed on the jib end of the crane and hang in a loop between Petrojarl I and the shuttle tanker during offloading.

The MBC is installed in between jib end hose and the middle hose and is serviced at 5 yearly intervals by Gall Thomson.

During the 21 years of operation and with almost 1000 hook ups (offloadings) on both Norweigian and English Sectors, the MBC has performed faultlessly.

Source: Teekay FPSO Petrojarl I

Case Study 2 Activation: January 2008: Draugen loading terminal:

In connection with the loading of oil from Draugen to the tanker Navion Scandia on 10 January 2008 an incident resulted in the rupture of the loading hose. This led to the accidental discharge of around 6 m3 of oil into the sea.

The loading hose between the loading buoy on Draugen and the tanker Navion Scandia was equipped with a Marine Breakaway Coupling. The MBC prevented a larger discharge of oil.
The incident did not result in any direct hazard for the personnel on board the Navion Scandia or Draugen.

The emergency response organisation handled the situation in accordance with established routines.

Petroleum Safety Authority Norway's investigation identified seven nonconformities with the regulatory requirements. Two of the nonconformities are related to failure to observe the "see to duty", as well as inadequate management and control of contracts. The remaining nonconformities are related to inadequate maintenance management, competence management, follow-up after buoy loading incidents and the use of safety critical information, change management and the follow-up by management (Investigation report Draugen 2008)

Loading hose
Testing performed by ASAMS on the MBC after the incident concludes that it has worked according to its design.

MBC mounted on the part of the loading hose connected to the tanker

MBC mounted on the part of the loading hose connected to the FLP

<u>Case Study 3 Activation: in air catenary configuration by Statoil</u>

4 units of 20" Gall Thomson MBCs were commissioned by Statoil for use on the Gullfaks SPM-1 and 2 towers since the production start for this oilfield in 1986.

There is one MBC installed for each tower in the catenary hose string between the SPM and different shuttle tankers at the bottom part of the hose. Two spare MBCs are kept so that replacement of an MBC can be immediate in the event of an activation. Each spare MBC is also rotated to enable servicing.

Over the 21 years of service, performance has been consistently reliable and the MBCs have now completed seven service cycles – normally in connection with the exchange of the catenary hose string.

Gullfaks has experienced two activations of the MBCs. The first activation was due to a rupture of hawsers and the second was caused by an unintended pressure surge build-up in the hose string due to an uncontrolled closing of the manifold butterfly valve on the shuttle tanker.

<u>Comparison</u>

The Statfjord field operated SPMs without Gall Thomson MBCs and a boom was damaged during a rupture of hawsers. An MBC would have protected the SPM against occurring damage. Statfjord no longer operates with SPMs.

9. Appreciating the characteristics of risk

The variables that increase operational risk are present with every operation. Risk increases when one or more variables become substantive and/or the interaction of two or more variables coincide to create a substantive new variable that also increases risk.

From the perspective of repeating activity (product transfers), the frequency and therefore the obvious aggregate increase in transfers over time will statistically increase risk due to the increased probability of substantive or coinciding variables. In other words, any single repeating activity will provoke any number of foreseen or unforeseen events given enough replications of that task.

Risk associated with repeating operational procedures is further increased due to 1/ the developing and therefore incomplete knowledge and limited control associated with aggregate asset depreciation (the interaction of different pieces of equipment; including equipment not within the immediate control of the operator), the environment, handling and maintenance and service and 2/ human interface as regards procedural familiarity (which can provoke subconscious task execution and procedural contempt due to over confidence and/or improvised necessity).

Foreseeable risk

Foreseeable risk must be assessed and appropriate measures taken to mitigate that risk in order to protect the company from litigation and damaged reputation. As shown later in this report, there is enough empirical evidence and operational experience available to the industry to confirm that fitting Marine Breakaway Couplings to FPSO transfer operations is an industry accepted practice in mitigating foreseeable risk.

Inclusion of the Marine Breakaway Coupling is therefore shown to be a requirement in minimizing foreseeable risk. However, it is important to comprehend and adhere to correct specification and commissioning procedures when installing MBCs into FPSO reel transfer operations.

10. Commissioning an MBC for operations with reeled or in-air catenary reeled configurations

Commissioning MBCs for reeled or in-air catenary reeled configurations requires additional and accurate specification data.

MBCs are calibrated by Gall Thomson to match the specification brief as provided by the engineering contractor. Equally important is the provision of full and correct data from other relevant providers such as participating hose manufacturers, reel manufacturers and FPSO operational engineers.

Tolerances are designed into the MBC so that should these be exceeded due to foreseen variables then the MBC will activate and minimise the consequences of an incident.

Below is a simplistic summary of the specification data that might be required from the perspective of MBC Management.
Note that this data consists of Constants in that should it change due to an evolving operational application or the MBC is planned to be moved to another application or configuration then the tolerance settings and even the specification of the MBC would need to be reviewed.

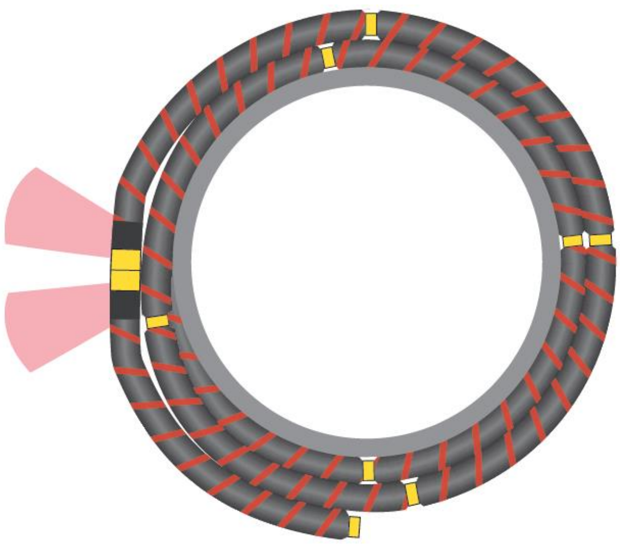
Application data: (media maximum flow rates, pressure, temperature)

Configuration data: (hose size, hose type – composition, construction, accurate hose bend stiffness data, MBC position in hose string, reel radius, purging pressure, purging process, flushing procedures…)

It is vital that an MBC management plan is in place so that a full record of the unit's application and specification is maintained over its lifecycle.

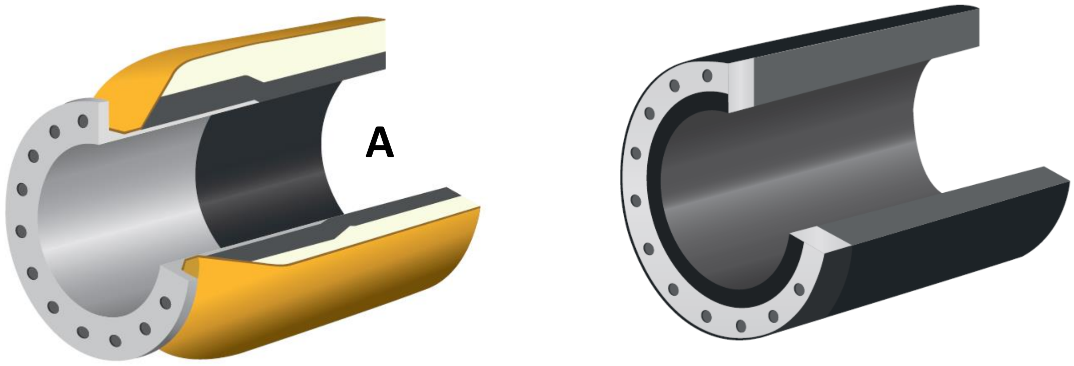
11. Potential issues due to incorrect or incomplete specification data or MBC commissioning mismanagement

Placing an incorrectly calibrated MBC into a hose reel: an examination of the issues and solutions.



Above is an illustration demonstrating the hose wrapping discrepancy on the FPSO reel caused by an MBC fitted to a Nipple Hose type. There is a distinct interruption in the otherwise natural radius of the Coil. The level of this imperfect hose adherence on the FPSO reel mainly depends on the two variables of reel radius at the point of MBC positioning and the length of Nipple within the connecting hoses adjacent to the MBC.

The level of imperfect hose adherence on the FPSO reel therefore depends on the Nipple hose specification, bend stiffness at zero pressure and at system pressure.

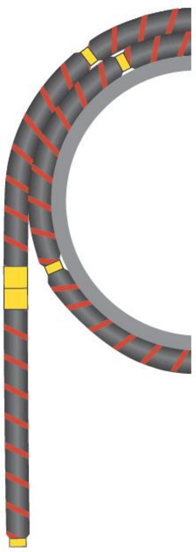


Above are simple illustrations demonstrating the difference between Nipple and Nippleless hose designs. Note A where the length of the Nipple may potentially influence hose wrapping discrepancy due to the level of hose adherence on the FPSO reel.

Should the stress on the breakstuds exceed the calibrated tolerances then the MBC will respond as designed. The level of imperfect hose adherence on the FPSO reel could therefore present a bending moment on the MBC that might potentially provoke an unintended activation.

This issue is overcome in one of two ways.

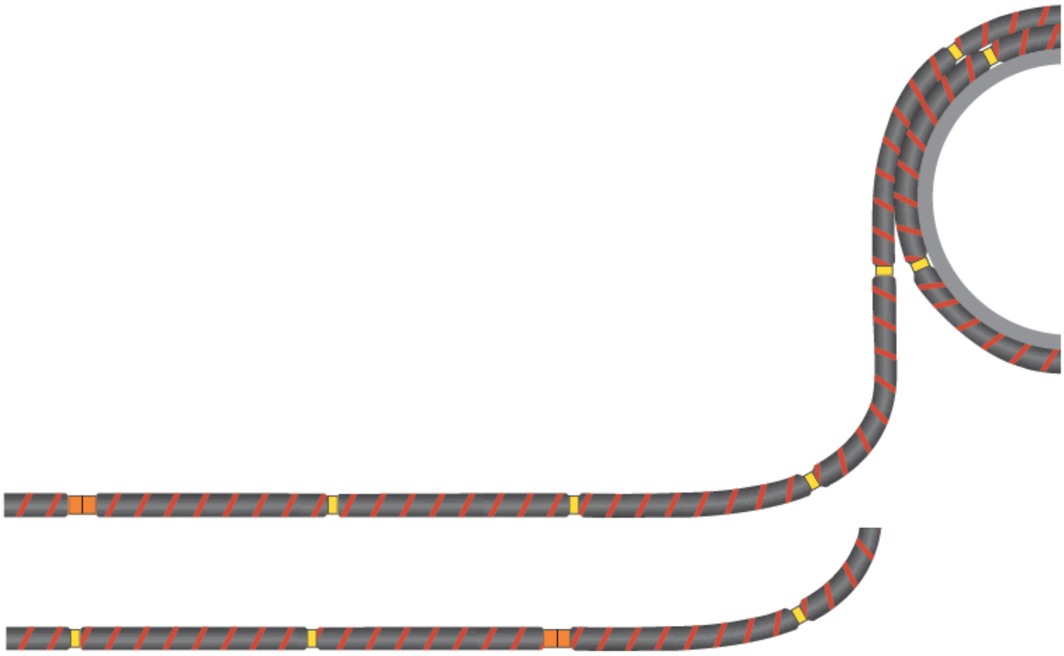
The first is to design the configuration so that the MBC is not wound to reel but is instead hung from the reel. This Hanging Vine reel configuration is an efficient solution and preserves zero hose adherence on the FPSO reel discrepancy. Whether the hose type is Nipple or Nippleless becomes irrelevant.



The second option is to make clear the intention to wind the MBC to the reel at the time of MBC specification and provide actual configuration data, this then allows the tolerances of the MBC to take account of the additional variables presented by hose adherence on the FPSO reel discrepancy as a consequence of the hose type employed and the reel design.

The MBC manufacturer should be involved in the design phase at the earliest opportunity, preferably at the FEED stage, in order to provide the optimal solution.

Illustration of typical MBC configuration options within a hose string where account has been taken during specification.



Both solutions are suitable for both nipple and nippless hose types.

10. Conclusions

1. **Foreseeable risk:** In-field empirical evidence and commonly accepted methods of assessing risk confirms there is a foreseeable risk of pollution, injury and asset damage to FPSO operations when transferring product.
2. **Use of Marine Breakaway Couplings**: In-field case study evidence confirms Marine Breakaway Couplings are proven to enable managed risk assessments and procedures and minimise risk to FPSO operations of pollution, injury and asset damage whether the FPSO has a permanently floating hose configuration or reeled hose configuration.
3. **Risk of not using Marine Breakaway Couplings:** In-field case study evidence confirms the non-use of Marine Breakaway Couplings in FPSOs can result in uncontrolled and even unpredictable consequences when an incident occurs. Non-use of MBCs therefore provides an unacceptable and unnecessary risk to FPSO operations.
4. **Limitations of Bow Loading Connector/North Sea Valve (BLS)**: In-field empirical evidence and research confirms that the application of Bow Loading Connector/North Sea Valve (BLS) without MBCs will substantially compromise the delivery of an effective and practical emergency release system; although a combination of BLS and MBC configuration does offer a good solution.
5. **Importance of specification data**: Full and accurate data regarding the application and configuration of transfer systems is crucial in ensuring MBCs are calibrated to correct tolerances, avoiding unintended activation.
6. **Importance of MBC management**: A commissioned MBC should be logged and monitored to ensure it remains assigned to the correct application and transfer configuration for which it was calibrated. This extends to adhering to recommended service procedures for the operational life of the unit. Where an MBC is to be recommissioned to another application or configuration, then complete specification data should be provided to the MBC manufacturer to confirm or ensure correct calibration.
7. **Importance of Reel configuration**: MBCs wound on reels and connected to Nipple Hoses may occasionally spuriously activate where the MBC has not been calibrated for the particular operation due to incomplete or inaccurate hose manufacturer or application data. The risk is low but substantive. The solution is to correctly calibrate the MBC during the specification process.
8. Transit solutions that can be manufactured together with the MBC should be evaluated at the design stage as another way to mitigate unintended activation when the MBC is deployed with stiff nipple hoses.

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