1st Conference on Asset Integrity Management in Oil & Gas "OFFSHORE"
25-26 June 2018
Tehran - Iran
The Islamic Republic of Iran
Ministry of Petroleum
IOEC
NIOC

Design Consideration of Subsea Smart Connectors with Annulus Test Port

Ali Shaghaghi Moghaddam[1] **, Saeid Mohammadnia**

Assistant Professor, Mechanical engineering department, Islamic Azad University, Takestan, Iran

Pipeline Engineer, Iranian offshore and construction company (IOEC), Vila street, Tehran

Abstract

Subsea pipelines are disposed to hazards and threats as a consequence of functional, environmental and accidental loads. Leakage, local buckling and full bore rupture are the most common failure modes in South Pars gas pipelines. For minor defects such as pinhole, smart clamps are deployed. For major defects like full bore rupture, special consideration shall be taken into account. Smart flanges and smart pipe to pipe connectors are used for subsea tie in application. Generally, subsea connectors shall cope with two main actions; 1) sealing and 2) gripping. Both sealing and gripping mechanism shall fit their services properly to guarantee reliable and durable product application. Considering the experiences in using repair products at several south pars pipelines, the idea of designing and manufacturing of optimized smart connectors were developed. The goal of this paper is to investigate the 4 inch smart flange and 4 inch hydraulic smart pipe to pipe connector. Unlike all of the previous products, to increase the reliability of the current connectors, three layers of elastomeric seals have been considered to backup each other. As a consequence, the annulus hydrotest can be performed at two ports. The gripping mechanism has been optimized to bear high axial force due to endcap effect, functional and environmental loads. The annulus hydrotest of 360 bar and main hydrotest of 300 bar have been successfully passed.

Keywords: Smart Connectors, pipeline failure, leakage, rupture, smart flange

1. Introduction

In shallow water offshore, the natural gas from wellhead jackets is transferred to onshore plant through export pipeline of different sizes, e.g. 24, 30, 32 inch. Export pipelines each with a piggy back line are used to transport raw material to onshore facilities. Due to presence of corrosive environment in sour services and probability of hydrate formation in the pipeline, mono-ethylene glycol (MEG) is introduced in the pipeline from offshore side. MEG is provided from onshore facility and exported to jacket through a 4inch line, piggy back line, which is secured to mainline through strapping [1]. According to the statistical analysis of the failures observed in South Pars gas pipelines, common failures can be categorized as: leakage, full bore rupture, local buckling, local corrosion, cold crack formation and etc. The root cause analysis of the failures is of great importance to persist the integrity of the pipeline. Upon occurring any failures in offshore pipelines, the corresponding remedial action shall be taken into account to bring the pipeline back into operation in the earliest time. The repair solution depends on the failure mode. A preliminary survey must be performed to figure out the failure on the pipeline. According to observed defect, the engineering judgment is required to decide on the repair solution and respective repair products. Several pipeline repair products have been introduced by manufacturers to offshore industry. Among them, smart flange, smart clamp and pipe to pipe connectors are the most common repair products.

- **Smart Flanges**

Smart Flanges are mechanical pipe end connectors which utilize grips that mechanically attach to a pipe and create a permanent, structural flanged end on the pipe. A dual seal are considered to deliver long-term integrity and comes equipped with a test port to verify the annulus seal. The connectors are capable of withstanding full pipeline axial, bending and torsional loads while withstanding hydrostatic loads from the pipeline.

- **Hydraulic Smart Flanges**

Hydraulic Smart Flanges (HSF) are hydraulically-set smart flange connectors in which sealing and gripping mechanisms are activated by hydraulic pressure. When actuated, HSF Connectors will structurally attach to and seal against the pipe. HSF Connectors can be designed in sizes and pressure ratings to meet any customer requirements.

- **Smart Clamp**

Smart Clamps are split mechanical fittings used to repair a damaged or leaking subsea pipeline. The fittings are available in structural and non-structural versions. The non-structural versions may be used to repair a pipeline that has

[1] Tel: +989127808909

only minor damage such as pinhole leaks, local pipe wall thinning or shallow dents. The structural versions, replace structural integrity in more severely damaged pipelines with cracked girth welds, kinks, or punctures.

- **Hydraulic Smart Clamp**

Hydraulic Activated Smart Clamps are innovative products designed to eliminate the time consuming bolt tightening procedure. These products are supplied in both sealing and structural models.

- **Smart Hydraulic Pipe to Pipe Connectors**

Smart Hydraulic Pipe to Pipe Connectors are designed to provide structural connection against both pipe ends. These products eliminate the use of flange-flange or flange -smart flange connections for tie in and then significantly reduce repair dead time. In order to complete a pipeline repair, both pipeline ends are cut and beveled. Then the pipe to pipe connector is fully replaced on the pipeline at one side. The operator then reacts against the connector and move it until the half of the connector is stabbed over the bare pipe. Once stabbed, the operator starts setting the sealing and gripping mechanism on both pipe ends by hydraulic pressure. After installation, the annulus test will be performed on two test ports available on the products.

In south pars gas field, several failure have been detected up to now and different repair products have been deployed. Based on the experience of using repair products, the following drawbacks can be categorized:

- Leakage of the repair products during the hydrostatic
- Leakage of the repair products during operation
- Absence of annulus hydrotest ports (for some products) which lengthen the hydrotest time by pressurizing the whole pipeline
- More preliminary works to prepare the pipeline surface at the location of product installation

The objective of this paper is to present the design, fabrication and hydrotest issue of 4 inch smart flange and 4 inch smart hydraulic pipe to pipe connector. Client's points of view for reliable and durable repair and operator team's point of view for ease of installation have been considered during detail design. Considering the drawbacks of several repair products in south pars pipelines, the following indicators were considered for the design of the smart connectors.

- Considering Annulus Hydrotest port
- Provides multiple back-up leakage elastomer seals
- Considering back up rings to prevent seal extrusion
- Considering compound injection port
- Easy installation by the diver
- Bearing high bending moment and axial force
- Compensate pipeline ovality up to 3%
- 100 percent reliability to pass hydrotest after installation

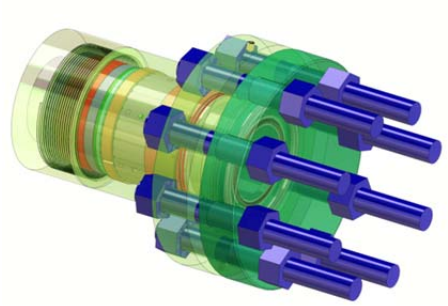
In the following the details of design, manufacturing and hydrotest will be provided

2. Design and fabrication

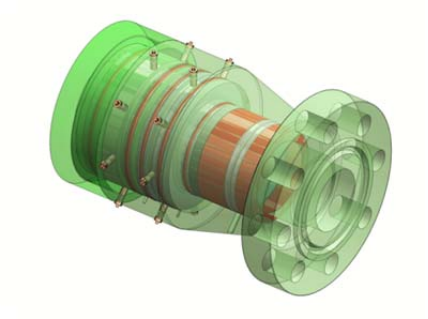
The design of the clamps, flanges and connectors will be in accordance with ASME VIII div 2, ASME PCC2 and verified against DNV-RP113, Recommended Practice for Pipeline Repair. General Design considerations are listed below:

- Products are designed to be used on pipe that meets the tolerances and ovality listed in API 5L.
- Nominal Pipe Size of any API Specification 5L pipe , e.g. 4inch and 32 inch, wall thickness and grade are considered.
- Design Temperature Range is considered as (0°C) to (100°C).
- Products will be applicable for standard service such as crude oil, natural gas, hydrocarbons, sour service, water or chemical injection, etc.
- Smart Clamps incorporate sacrificial anodes to provide cathodic protection.
- Dual seals each end would be supplied to enable a pressure verification test.

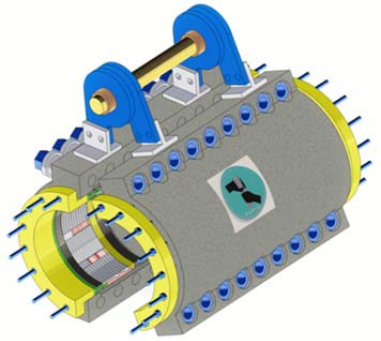
Based on the above assumption, the conceptual and detail design were performed. In Figure 1, design of different pipeline repair products are shown.



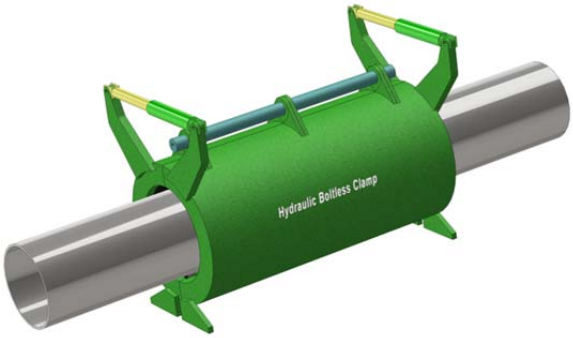
Smart Flange



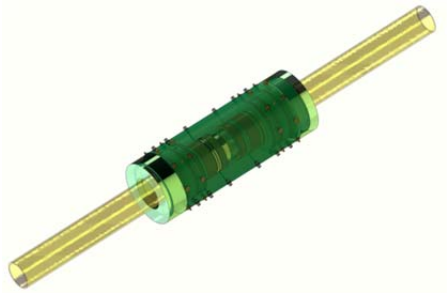
Hydraulic Smart Flange



Smart Clamp



Hydraulic Smart Clamp



Hydraulic Pipe to Pipe Connectors

Figure 1: Pipeline repair products

A detail design will be performed including FEA analysis of the product and hand calculations with respect to accepted codes and standards. All 3D models and detail drawings are generated using SolidWorks and AutoCAD. FEA analyses are performed by Abaqus and other respective softwares. A variety of software and standards have been used to design the smart connector.

Table 1: Software used for design of the smart connector

software	Application
Solidworks	3D design and map extraction
Tolanalyst	Tolerance Analysis
Adams	modeling Dynamic
Abaqus	Finite element analysis
Key to their steel	Material selection
MathCad	Computational
Ls dyna	Gasket Analysis
Bolt right	Calculations Bolt tightening

In designing and manufacturing smart connectors, the choice of materials suitable for the main body, internal parts and elastomer is very important. Because the smart connectors are under extreme axial loads, bending moment and high internal pressure, special consideration shall be taken into account for material selection. Details of materials are listed below.

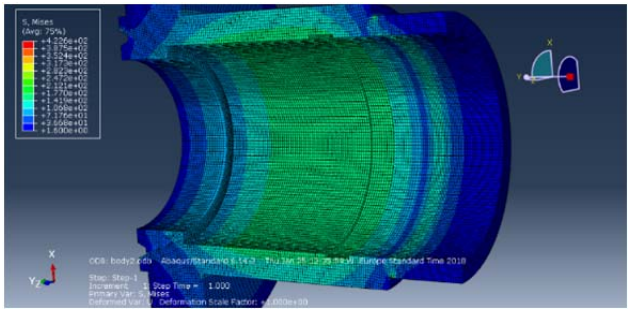
Table 2: Material Specification

Part	Material
Back-Up Ring	AISI 4140/ AISI 4340
blind flange	A105
Bolt	ASTM A193 Gr. B7
Cone	AISI 4140/ AISI 4340
End Cap	AISI 4140/ AISI 4340
Main Body	AISI 4140/ AISI 4340
Main Elastic Seal	FKM, NBR, HNBR
Nut	ASTM A194 Gr. 2H
Piston	AISI 4140/ AISI 4340
Piston Seal	FKM, NBR, HNBR
RTJ Gasket R39	Soft Iron
Slip Anchor	FKM, NBR, HNBR
Thrust Ring	FKM, NBR, HNBR

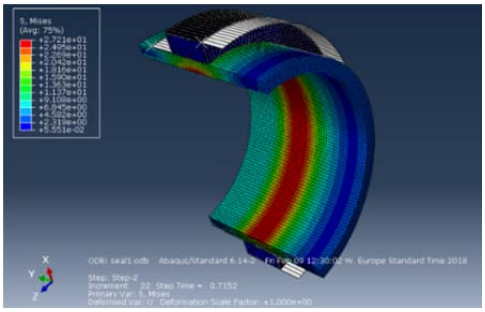
Due to the sensitivity of the smart-connector mechanism to bear a very high internal pressure, axial force and bending moment and to ensure that the elastomers are not extruded during operation, special attention should be paid to the fabrication methods. In order to achieve very close tolerances, the CNC methods should be used, and the original parts should be subjected to Grinding operations in order to achieve the required level of surface. The hardness of the interior parts should be considered in proportion to the application of that piece. Manufacturing are performed by CNC and high precise machining tools. All manufactured components are subjected to % 100 inspections and quality control.

3. 3D finite element analysis

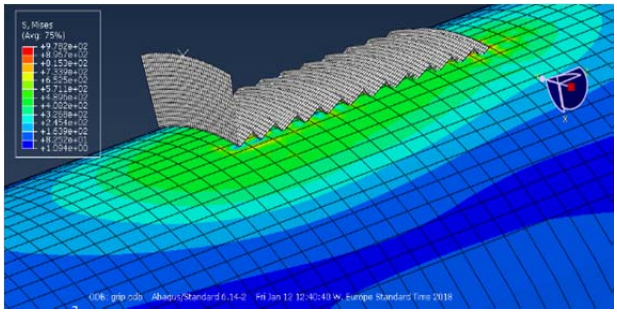
The comprehensive 3D finite element analysis on the smart connectors have been performed by Abaqus and Ls Dyna. All the metallic and elastomeric internal parts have been analyzed considering bending moment, axial force and internal pressure. In the following the finite element results would be presented.



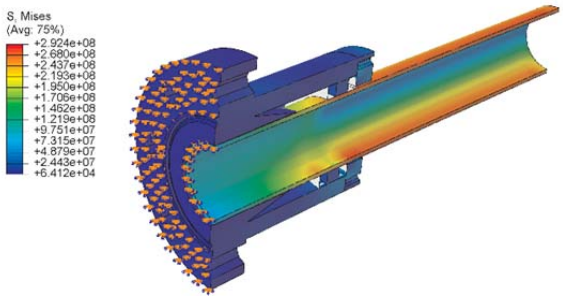
main body



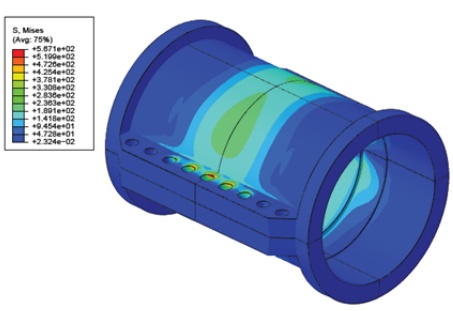
elastomeric seal compression



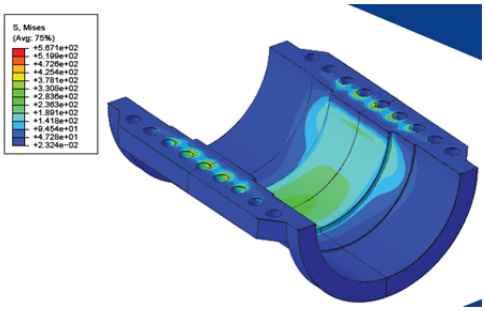
Gripping analysis



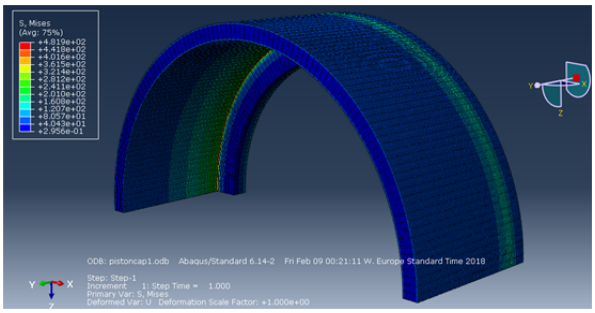
flange under bending



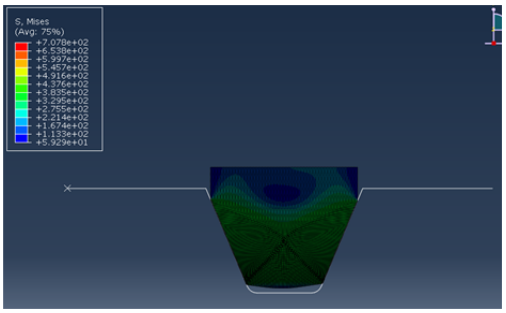
smart clamp main body



smart clamp half body



End Cap



RTJ

Figure 2: 3D finite element analysis

4. Hydrotest

The operating pressure of the 4-inch pipeline is about 210bar and the hydrostatic pressure is about 270 bar. Hydrotest set up of 4 inch smart connectors are shown below.

Figure 3: Hydrotest set up for smart hydraulic pipe to pipe connector

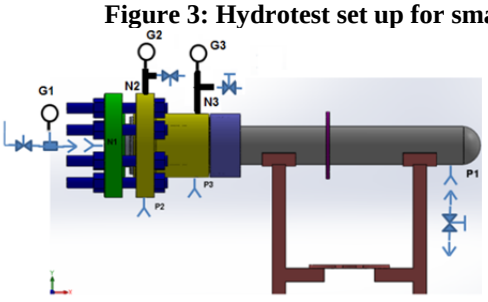
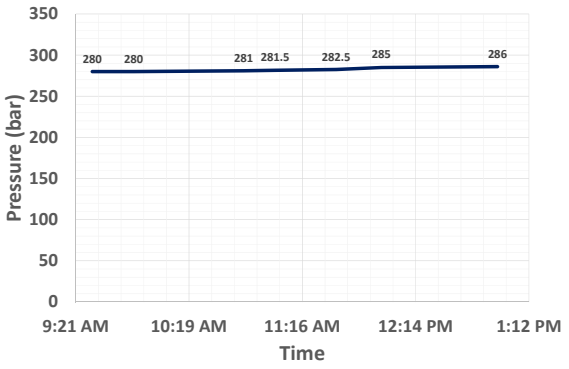
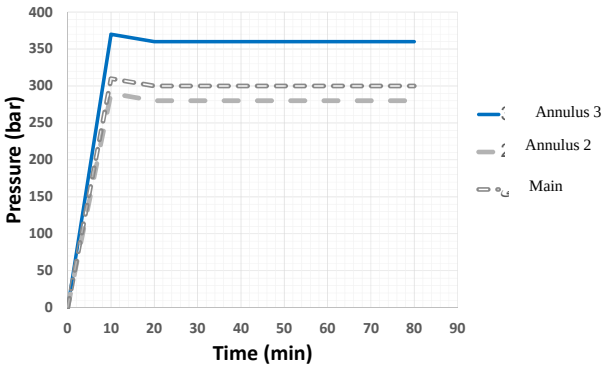


Figure 4: Hydrotest set up for smart flange

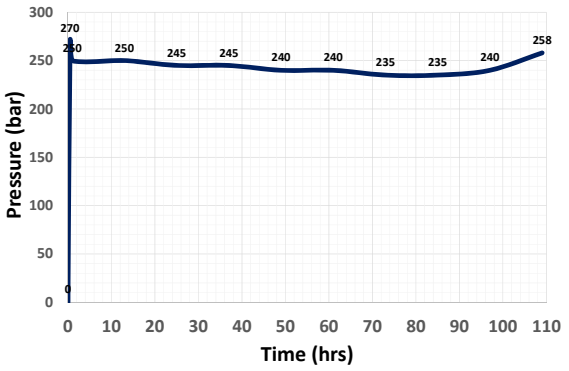
During hydrotest due to end cap effect, an axial force of about 60 ton force will be transferred to the smart connector. The gripping mechanism shall tolerate this axial force with the minimum axial movement along the pipeline. The axial movement of smart connector on the pipeline would be measured by means of dial micrometer. The hydrotest results are presented below.



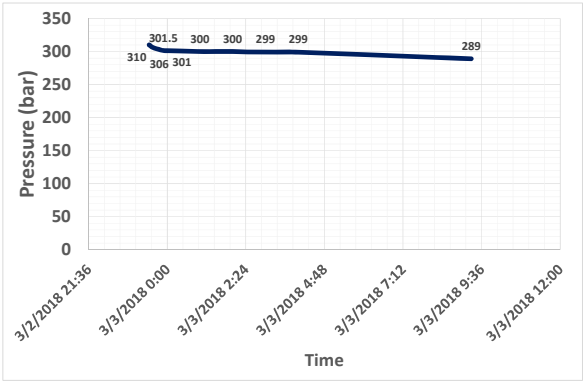
Hydrotest results for almost 4 hrs. (smart flange)



Hydrotest results for 1 hr. test (smart flange)



Hydrotest results for almost 4 days (smart flange)



Hydrotest results (smart connector)

Annulus hydrotest, 360 bar

Figure 5: Hydrotest results

Hydrotest results are presented in the following table:

Table: hydrotest results

Test type	Test pressure (bar)	Hold time (min)	Initial pressure (bar)	Stabilized pressure (bar)	Final pressure (bar)	Dial micrometer (mm)
Main test	**275**	**30**	**300**	**294**	**294**	**0.15**
Annulus test 3	**275**	**30**	**360**	**360**	**360**	**NA**
Annulus test 2	**275**	**30**	**302**	**299**	**299**	**NA**

5. Conclusion

In the present work design, fabrication and hydrotest of smart flange and hydraulic pipe to pipe connector were studied. In the present design, all considerations of client and installation team were taken into account. All the products are prepared with several layers of elastomeric seal to backup each other to prevent any possible leakage during hydrotest and operation. The creative idea of hydraulic pipe to pipe connector were introduced which considerably shorten the tie in operation. All the products are equipped with annulus hydrotest port to enable the hydrotest without pressurizing the whole pipeline. With the help of annulus test port, the down time of hydrotest would be reduced. Hydrotest of products were conducted with the pressure above 300 bar considering different holding times, from 1 hour to 5 days. No pressure drop and leakage were observed during main and annulus hydrotest.

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