New hydrostatic test fixture design for Subsea connectors (ROV application)

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Abstract: In this study, a new hydrostatic fixture mainly designed to perform hydrotest, including set of twelve Subsea connector whereas, end application is Subsea ROV (Remote operating vehicle). Wherein, all connector and fixture assembly will be submerged in a chamber with full of water and will be applied 10000 PSI (68.94 MPa) pressure on it. Once hydrotest performed, then need to check whether water particle enter through the connector's backend or not, if water particle noticed, then that connector will be rejected. Here need to design hydrotest fixture for connector which need to withstand 12000 PSI (82.74 MPa) pressure so that test will be performed at 10000 PSI pressure. Henceforth, need to create concept design, then will be perform FEA analysis, including numeric calculation. Doing this, need to ensure weight reduction and optimized design for easy handling of whole fixture assembly.

Experimental validation will perform on hydrotest fixture by using FEA /Hyper mesh analysis, nondestructive and Brinell hardness test. Results and conclusions will be drawn.

Index Terms - Pressure, Stress, Yield strength, Factor of Safety, O-Ring, Custom bolt.

INTRODUCTION

Hydrotest fixture design are generally deals with tremendous hydro pressure wherein, fixture need to withstand massive pressure while it will perform. Here, hydro test fixture concept design needs to take care with light weight material and with minimum weight. In line with it, the material of the fixture should be high Tensile strength, yield strength properties with minimum 1.0 factor of safety consideration. Another approach is needed to take care of optimized design. Wherein, need weight optimization, so that it will be easily handle while hydro test fixture will be loading and unloading from hydro test fixture holder in hydrostatic chamber. That is why design optimized technique is required for weight optimization. Here two types of optimizations can be considered. **Size optimization** in which physical dimensions such as cross section of a structure used as a design variable and **shape optimization**, whereas the geometric boundary of the structure is varied to obtain the optimal shape.

Hydrotest fixture has designed for Subsea connector testing while twelve set of Subsea electrical power connector can be tested at a time. The connectors end application is in **Remote operating vehicle (ROV), Autonomous underwater vehicle (AUV)** etc. Whereas those vehicles will be in operation for capturing videos, photos of creatures in deep sea. The depth rating approximately more than **five kilometers** from earth surface. That is why open face pressure will be **10000 PSI** (68.94 MPa) under sea. So, before in actual operation, the hydrostatic fixture should hold the twelve Subsea connectors at its position firmly after tightening with its back side thread, while performing the hydro test. So, hydrostatic fixture needs to design for more pressure like **12000 PSI** (82.74 MPa) so that connectors can tested at 10000 PSI pressure.

To get actual fixture components, like round shape, upper manifold and lower manifold need to manufacture from round blank metal piece. The bank fed into the shaper and milling machine to get desire shape. Other operations like O-Ring groove make through lathe machine, for counterbore hole make with drilling machine, thread operation will make with taps. Sharp corner removed and chamfer will be provided. Also, good amount of surface finish will be maintained in O-Ring groove area and other mating areas. Once all operations done need to do non-destructive test for upper and lower manifold whether any internal hair crack is present or not. So that, it will make sure robustness of the hydrotest fixture.

LITERATURE REVIEW

[1] "Buckling of composite cylindrical shells with ovality and thickness variation subjected to hydrostatic pressure" by Zhun Li, Ke-chun Shen, Xin-hu Zhang, Guang Pan

In this research paper, how composite material behave in hydrostatic pressure that explained. The composite materials have many fields like in the aviation structural fields, aerospace industry, marine application etc. Due to the low density of material, we can achieve high strength and good corrosion resistance, it is the replacement of the traditional metal structures. The carbon fiber reinforced polymers (CFRP) composite materials which consist of carbon fibers and resin matrix have been used to build the pressure vessel of underwater vehicle for a decade. As underwater vehicles operate normally in deep water, the pressure shells require high strength and stability to resist the extreme external hydrostatic pressure it's all around. This the common structure of underwater vehicle. In previous research we can understand behavior of the high external pressure which will lead to the buckling of the pressure vessel, which is a direct threat to the operational safety of underwater vehicle. Therefore, buckling must be taken into consideration carefully in the design of composite pressure vessel.

[2] "Novel test method for the hydrostatic properties of syntactic foams" by Gang Liu

In this research paper, hydrostatic pressure properties has very important in characterizing the syntactic foams in **subsea** or underwater applications. However, they are rarely studied due to the lack of standardization like standard test methods and usable instruments. This is a novel method of describing the hydrostatic properties of syntactic foams based on the pressure build-up in under water, wherein, test arrangement has been built up with standard and which are accessible parts and components. The experiment has been carried out on two types of syntactic foams. First, the effect of the preliminary pressure cycles on the bulk modulus. The different hydrostatic yield and crush behaviors of the two types of syntactic foams has been publish in this test results. In the type I syntactic foam, which is composed of a lighter but weaker type of glass bubble, shows a hydrostatic compressive behavior dominated by the properties of the filler. The Type II syntactic foam, which is composed of a stronger but heavier type of glass bubble, shows a catastrophic failure mechanism relating both the crushing of the glass bubbles and the failure of the material.

[3] "Strain test and stress intensity assessment of a CPR1000 Nuclear Power Plant pressurizer during pre-delivery hydrostatic test" by Lin Lei, Xu Decheng, Yu Min, Xue Fei, Jiang Jiawang, Zhang Guodong, Zhao Wensheng

In this research paper, strain gages are applied to get the stress and strain of a CPR1000 Nuclear Power Plant pressurizer during the pre-delivery of hydrostatic test. Here the measured strain curves are conversed to find the distortion features of a cylinder. The longitudinal welds and girth welds have calculated with the stresses of cylindrical base metal and compared with the theoretical values. Mainly stresses of girth welds and upper head nozzle welds show its non-uniformity areas. The possible reasons are discussed for this uniqueness. The stress intensity has been calculated and evaluated according to its allowable limit. Since the effect of internal pressure rise-and-fall cycle to pressurizer's total fatigue life has been evaluated from the fatigue usage factor. The evaluated results demonstrate that the hydrostatic test has little effect on the truthfulness or fatigue life of the pressurizer. This test delivers the basic deformation data of the pressurizer, which plays an important role in the mature assessment and manage during operation.

PROBLEM STATEMENT

As need to do a physical hydrostatic test for Subsea Electrical connector, wherein, before execution of detail design, have captured numbers of problem for the test fixture below. The hydrotest fixture should withstand maximum 12000 PSI pressure. The fixture should hold minimum ten connectors at one time of test. The material should be lightweight with good yield strength properties. Diameter of the hydrotest fixture should be fit within Ø17.75 inch (Ø450.85 mm) because the diameter of hydrotest chamber is Ø17.75 inch. All connectors backside wire should come out through two lid holes of customized bolt, whereas two customized bolts will be tightened and will hold, whole hydrotest fixture. Final manufacturing drawing should be as per GD&T standard ASME-Y14.5.

METHODOLOGY

Step 1: Before going to start project, I have downloaded few relevant research paper. After downloaded I have gone through all research paper and got some Idea about latest technology and mathematical study about hydrotest fixture design.

Step2: After that studied, find out what are the CTQ (Critical to quality) and constrained are there so that it will help for making the concept model for fixture design.

Step 3: After that generated few concepts and along with all components which are required for whole fixture assembly. The concept done with the help of CAD software SolidWorks-17.

Step 4: After concept finalization I did numeric calculation for customized bolt and circumferential bolt. Also created O-Ring groove design. Then executed virtual analysis with the help of ANSYS using FEA software.

Step 5: From analysis report I finalized the design.

Step 6: Then Experimental test done. After that have compared with Experimental and analysis report.

MODELLING OF HYDRO TEST FEXTURE INCLUDING ALL COMPONENTS

I have made concept design with aid of Computer Aided Design (CAD) like Solidworks. It is easy to design with CAD software, because anytime we can modify, analyzed, and optimized the design. It is always help improvement of design with high productivity and high quality. We can also store CAD files in PLM (Product lifecycle management) software. CAD tool can be used in many industries like automotive, shipbuilding industry, Marine industry, aerospace industry etc. Below

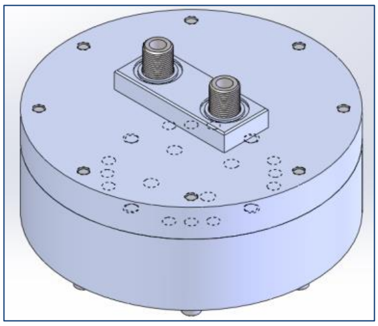


Fig. 1: Solidworks-17 Whole assembly

MATHEMETICAL APPROACH

Before analysis, have made some numeric calculation for preload of bolt, stress analysis for customized bolt etc.

Here first explain bolt preload for circumferential bolts and torque required for tighten the bottom manifold with top manifold.

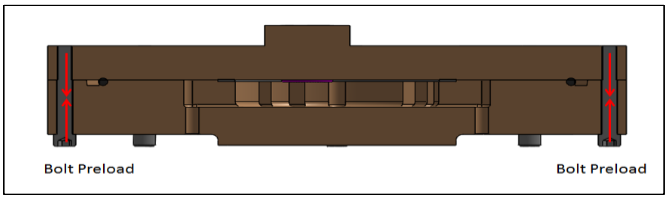


Fig. 2: Bolt preload

New hydrostatic test fixture design

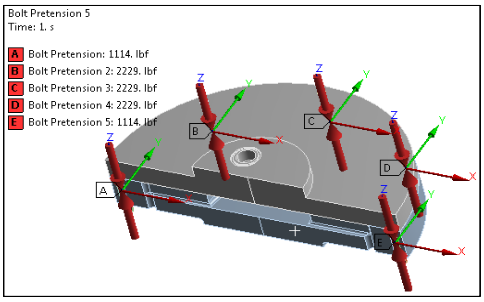


Fig. 3: Bolt preload

Here, 7/16"-20 UNC used for assembly of bottom and top manifold.

Input value:

Description	Abbreviation	Input Values	Unit	Reference
Bolt Details		7/16"-20 UNC		
Nominal bolt dia.	D	0.4375/11.1	Inch/mm	
Thread per Inch	TPI	20		ASME B1.1
Pitch	p	0.05		ASME B1.1
Thread minor dia.	Db	0.3767/9.6	Inch/mm	ASME B1.1
Allowable bolt stress	σ allow	20000/137.9	Psi/MPa	
Nut Factor	k	0.2		

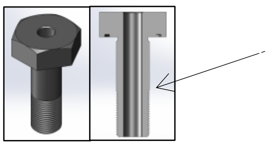
Output value:

Bolt area (A_b): π/4 x Db² = 0.11145 in² / 71.9 mm²

Bolt preload per Bolt (F_b): Allowable bolt stress x Bolt Area (σ allow x A_b) = 2229.005 Lbf / 9915.1 N

Torque per bolt (T) = Bolt preload x Nut Factor x Nominal bolt dia (Fb x k x D) = 195.04 Lbf.in

Now here another numeric calculation needs to do for customized bolt of 1"-14 UNS wherein, these two bolts will hold whole assembly and will have through hole as per fig-4 below, because all connectors pigtail wire need to pass through it.



Customized bolt design

Fig. 4: customized bolt

Input value:

Description	Abbreviation	Input Values	Unit	Reference
Pressure	P	12000	psi	Test pressure
Plug Thread Details		1"-14 UNS		ASME B1.1
Plug thread minor dia.	D_{minor}	0.9133/23.2	Inch/mm	ASME B1.1
Plug thread major dia.	D_{major}	0.9984/25.4	Inch/mm	ASME B1.1
Plug inner dia.	D_i	0.55/13.97	Inch/mm	user considered value
Allowable bolt stress	σ_{yield}	130000/896	Psi/MPa	SAE J429 Gr. 8/ ASTM A354 Gr. 8
Allowable Shear stress	τ_{allow}	20000/137.9	Psi/MPa	
Length of top rectangular plate	L	4/101.6	Inch/mm	Red area
Width of top rectangular plate	W	2/50.8	Inch/mm	Red area
No. of Bolt	n	2		

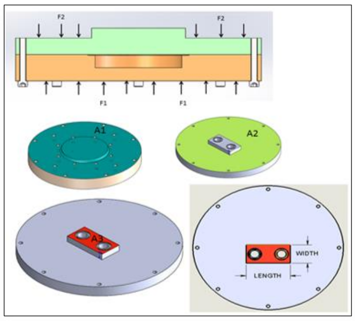


Fig. 5: Top and bottom manifold

Output value:

Area of top rectangular plate (A_3) = L x W = 8 in² /5161.2 mm²

Reaction Force coming at bolt in Y direction due to pressure unbalance (F_R) = Pressure x Area (A_3) = 96000 Lbf / 427029.2N

Stresses coming in Bolt $\sigma_{max} = F_R / A_3$ = 114961.5434 Psi / 792.6 MPa

Factor of Safety in Bolt (FOS) = $\sigma_{yield} / \sigma_{max}$ =1.13 Wherein, we need FOS>1 means design is safe.

ANALYSYS

Now next step is analysis of whole hydrostatic fixture with ANSYS. Basically, the finite element method (FEM), help to solve engineering and mathematical physics problem. Typically, area like structural analysis, heat transfer analysis, fluid flow analysis, electromagnetic analysis etc.

Component	Aluminum block
Material	Aluminium 6061-T6
Young's Modulus (ksi) / MPa	104 / 717.1
Poisson's Ratio	0.33
Ultimate tensile Strength (ksi) /MPa	45 /310.2
Yield strength (ksi) / MPa	40 /275.7

Total Deformation

View 1 Scale: 5X

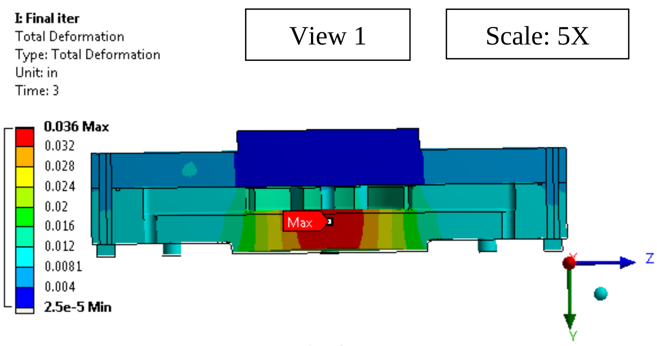


Fig.6

New hydrostatic test fixture design

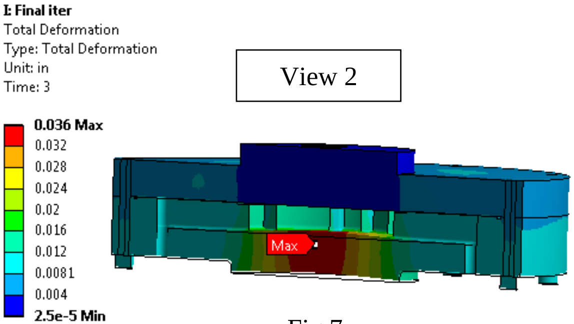
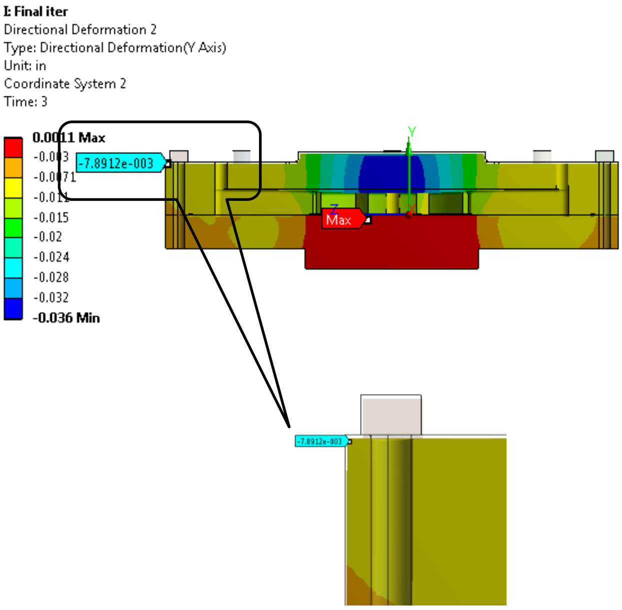


Fig.7

Axial Deformation



Top surface of flange is deformed down by 4.8 thou

Fig.8

Maximum deformation 0.036 inch (0.9mm) is observed in axial direction

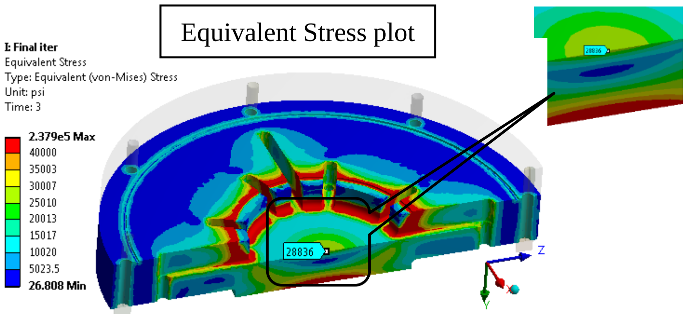


Fig.9

Max Equivalent Stress = 28.8 ksi
Yield strength = 40 ksi, FOS = 1.38

Note: The stresses at constraint locations and at contact are ignored.

Max Principal Stress Plot

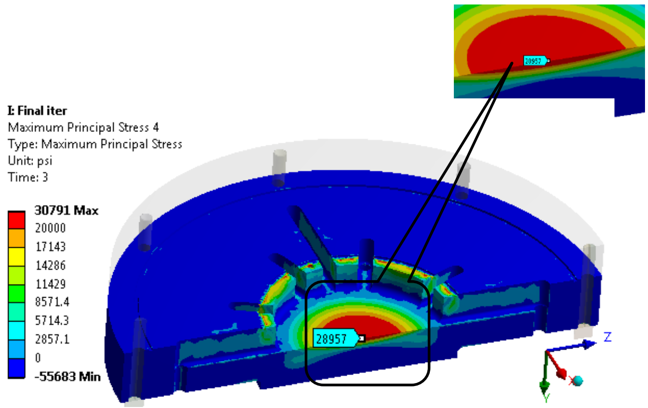


Fig.10

Max Principal Stress = 28.9 ksi /199.3 MPa (tensile)

Note: The stresses at constraint locations and at contact are ignored.

The Maximum tensile stress 28.8 Ksi /198.6 MPa observed in bottom plate.

TEST RECOMMENDED FOR HYDROTEST FIXTURE:

Before actual testing need to test for hydrostatic fixture's bottom manifold and top manifold.
Test recommended: Nondestructive test and hardness test.

In nondestructive test we need to check whether hair carack or internal crack is present in two plates.

In hardness teat need with Brinell hardness **95 MPa.**

EXPERIMENTAL SET UP:

Once fixture' component test done, then need to assemble whole fixture with maximum ten numbers of connectors and need to assemble with hydrotest fixture holder as per fig.11. Then whole assembly will be placed at hydrotest chamber as per below fig.12. Then it will be locked. After that water flow will allow to the chamber until camber is not filled with water. Then slowly water pressure will be applied first 5000 Psi, 8000 Psi, 10000 Psi and lastly 12000Psi will be applied.

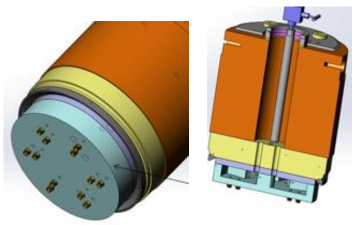


Fig.11

Hydrostatic fixture full and cut section

New hydrostatic test fixture design

Fig.12

Then need to release all pressure and drained out all water from chamber. After that need to open the hydrotest fixture and need to check, whether any water particle pass through back side of the connectors. If not, then all connectors are full proof else, will be reject.

RESULT AND CONLUSION:

As per our design and simulation analysis with CAD software and ANSYS software we got almost similar result while it was performing. It seems that fixture taking same pressure 12000 Psi maximum while performing in actual test set-up.

The maximum tensile stress 28.8 Ksi (198.6 Mpa) observed at bottom plate which is good result obtained from analysis. Factor of safety also received from analysis 1.38 wherein we require more than 1.0. So, from this result I can say the design is robust and according to the result all actual parts made.

Simulation Result	Experimental result
When 12000 PSI / 82.74 MPa applied on test fixture maximum tensile strength observed 28.8 Ksi (198.6 Mpa) which is good for the specified material.	In experiment result after applying the 12000 PSI / 82.74 MPa on test fixture didn't observe any kind of tensile, buckling and other failure.

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