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Structural Optimization of Subsea Pressure Vessel Equipment for HPHT Application with a Design by Analysis Case Study of a Typical BOP

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Abstract:

High pressure and high temperature (HPHT) environment adds additional constraint to existing design concepts of pressure containment systems for subsea applications. This paper identifies the difficulties associated with designing subsea equipment, such as Ram Blow-Out Preventers, for these extreme environments. The paper proposes methodologies by which such equipment can be effectively designed for ultra-deep and HPHT applications. The designed equipment must satisfy stringent but necessary design safety and life limits. In optimizing a typical Ram BOP for HPHT application, this paper addresses relevant issues; highlights design difficulties; discusses appropriate design basis and solution methods.

Ram Blow-Out Preventers, or Ram BOPs, are critical and integral parts of both on-shore and offshore exploration, drilling, completion, and workover systems. A typical Ram BOP is designed based on API 6A, API 16A, and ASME *Section VIII Div. 2* codes. Past studies indicate that designing a Ram BOP for HPHT applications, using these conventional design methods, would likely result in excessively large designs that are not economically feasible. ASME *Section VIII Div. 3* code provides an alternative design basis for HPHT equipment. This code relaxes some conditions on stress limits, but provides stringent criteria against fatigue-fracture failure – the most common failure mode in HPHT pressure vessels. In this study, a modified concept BOP was designed by iterative stress and fracture based analyses using ASME *Section VIII Div. 3* methodologies.

This paper presents the ASME *Section-VIII Div. 3* methodologies that were used in a front end engineering design (FEED) study for an 18-3/4 ID Ram BOP, optimized for 350° F, 20,000 psi bore pressure, and 10,000 ft of water depth application. Using several iterative finite element analyses (FEA) and linear-elastic-fracture-mechanics (LEFM) methods, improved fracture-fatigue life was achieved. Depths and intensities of localized high stresses were minimized. In addition to the FEED study, concept of a unique manufacturing process involving chemical bonding and selectively laminating of NACE approved high strength materials (Huff et.al. 2008) was defined. The 18-20M Ram BOP preliminary design, presented in this paper, meets the required cycle life. The above methodologies can be extended to other pressure containment systems.

Introduction:

There are several possible classic failure modes for pressure vessels operating in high pressure and high temperature (HPHT) environment. Typically, oil-field equipment is considered to experience HPHT environment when pressure and temperature in the bore fluid exceed 15K psi and 250° F respectively. High pressure, high temperature, and external operating loads combined together can significantly increase stresses and strains in all pressure vessel equipment. The failure mechanisms are further compounded by reduced material properties at high temperatures. Overstress, brittle failure, creep, etc. are a few of the critical modes. In low pressure applications, the average and peak stresses along critical and stress concentration areas remain well managed. The cyclic application of loads, although important, does not become critical and large operating lives are realized. API 6A and API 16A provide the design guidelines which are based on ASME *Section VIII Div. 2* criteria. Pressure vessels designed for such environments while satisfying these codes have proven to provide adequate field lives.

Equipment for subsea applications faces added design constraints. Such pressure containment systems have to consider overstress failure due to static structural and thermal-mechanical loads, permanent plastic deformations due to high stress concentrations. In addition, stress fluctuations from cyclic load variations and functional failure due to large displacement and