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NEW THREE BALL JOINT CONFIGURATION FOR STEAM ASSISTED GRAVITY DRAINAGE OR CYCLIC STEAM STIMULATION-BASED HEAVY OIL PRODUCTION

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ABSTRACT

Individual Steam Assisted Gravity Drainage (SAGD) or Cyclic Steam Stimulation (CSS) wellheads experience thermally induced growth on the order of 0.5 m to 1 m and create a bending moment or side loading due to thermal expansion. This wellhead thermal growth is large enough that ball joints are usually located in the piping system adjacent to the wellhead to accommodate the required growth and reduce the stress on wellhead connections and improve long term sealing of pipes.

The new A-frame design includes just one uniaxial swivel joint arranged at one bottom end of the A-frame (piping side) and two multiaxial flexible joints arranged at the other points of the A-frame. This configuration allows for the full 3 degrees of freedom needed to accommodate vertical and horizontal misalignment between the wellhead and adjacent piping. However, the stability of new A-frame design with different nominal pipe sizes under sustained load cases need to be evaluated by pipe stress analysis. The results of analysis revealed that the new A-frame design will be stable under sustained load cases without any risk of sagging in the field. Moreover, the new A-frame design has already started to be implemented by industry and is validated under realistic field condition.

Keywords: Ball Joint, Swivel Joint, A-frame Design, SAGD, CSS

NOMENCLATURE

A	Inside diameter of ball joint
B	Overall length of ball joint
C	Center of ball joint
CNode	Connecting node
D	Outside diameter of ball joint
Flex	Multiaxial flexible joint
H	A-frame height
K1, K2	Initial and secondary stiffness
L	A-frame Span length
L1, L2	A-frame leg length
RX2, RY2, RZ2	Bi-linear rotational restraints
Rota	Uniaxial swivel joint
α, β, γ	A-frame angles

1. INTRODUCTION

There are two main methods for providing piping flexibility; the flexible joint method and the pipe loop method [1]. This paper explores how flexible joint method or specifically using ball joints with new configuration can benefit SAGD or CSS well head piping by providing flexibility to accommodate both operational and installation tolerances [2].

As shown in Figure 1, the common type of ball joint (occasionally called a ball-and-socket joint) is constructed with three main pieces. It has an inner ball shaped adapter enclosed by a two-piece, dome-shaped housing or casing and retainer. The sealing mass is placed at the seal groove and the seal cavity is completely enclosed by the adjacent surfaces. The sealing material substantially completely fills the seal cavity in which it is positioned. The compressive loading applied by screws and during installation phase is sufficient to cause the sealing material to flow into the casing wall irregularities and against the ball to form a tight seal. The joint is capable of rocking at the specific range permitted by the opening of the outer housing or retainer. It is also capable of rotating 360 deg. axially. Both uniaxial swivel joint (hereafter mentioned as Rota joint) and multiaxial flexible joint (hereafter mentioned as Flex joint) can be considered as design variants of ball joint design which provide rotation only and flex and rotation movements respectively. The moment required to rotate the joint is called the break-off moment, whose magnitude is available from the manufacturer of the joint. This break-off moment can have a significant effect on the flexibility of the piping system [1].

The vertical wellhead thermal growth or reduction have traditionally been accommodated by using two Rota joints and one Flex joint arranged in series with their axis nominally parallel, arranged at the three points of an inverted "V" [3]. This assemblage is known as A-frame (Figure 2). The A-frame solution with the traditional configuration generally works well enough once the installation of it is completed; however, this approach has some notable shortcomings – it is time consuming to install (which adds to expense) because of requirement to precise alignment and if precise alignment in the field is not achieved, it creates additional bending moments on the bottom Rota joints which could increase nominal break-off moment and result in pipe over stress and joint quality issues in the long term.

For the A-frame installation and erection, it should be noted that the above ball joints configuration concept provides the capability of folding/unfolding the spool by loosening the screws of one or all ball joints. Loosening the screws can reduce the break-off moment of the joint significantly and when installation process completed, they can be re-torqued by proper torqueing tools.

As shown in Figure 2, the new A-frame design is simple. The configuration of new A-frame design comprises two Flex and one Rota joints (Flex-Flex-Rota) which could accommodate all horizontal and vertical misalignment or installation tolerances without any precise alignment requirements [4].

2. A-FRAME DESIGN AND ANALYSIS

To compare the functionality of conventional and new A-frame configurations in both installation and operation phases, first it is necessary to understand the design methodology of the flexible piping system that comprises ball joints and its acceptability criteria.

The ball joints configuration is determined based on the piping layout, unsupported length, total expansion and/or differential settlement carried by assembly and installation tolerances. For large linear pipe expansion or large differential settlement of connected equipment or support, three joint configuration or A-frame design is preferred.

Typical design practice is to locate the bottom ball joints in a way to get the maximum span length (L) and then determine the A-frame legs dimensions (L1 and L2). The first design approach is to use symmetrical A-frame design which means approximately equal angle of beta and gamma and minimum 90-degree as an alpha. Another design approach is to start with small angle of beta and gamma or almost flat position and then increase the height of A-frame. Sometimes significant increase in L1, L2 and consequently H dimensions might be required [4]. A-frame dimensions are shown in Figure 3. Regardless of which design approach is being used, final A-frame design and configuration shall be evaluated by pipe stress analysis to ensure that the design meets the requirements of applicable design codes and maximum allowable equipment or nozzle loads at the end connections.

For pipe stress analysis, a numerical model of all piping components including ball joints needs to be developed. The concept of bi-linear rotational restraints can be used to simulate the ball joints. The key here is the NODE/CNODE pair (Figure 4). For Rota joint, five out of six restraints are rigid and the sixth is bi-linear rotational restraint. For Flex joint, three out of six restraints are rigid and the rest of the restraints are bi-linear rotational restraints. The initial stiffness (K1) is rigid and the ball joints go flexible (K2=1) when the break-free moment is reached (Figure 5). If the internal moment is less than the ball joint friction or break-free moment, it will not rotate. If the load or displacement is significant enough, the ball joint will rotate and carry the friction load [5].

The acceptability of the A-frame design using pipe stress analysis is determined by satisfying the following four criteria.

- Reaction moments of the ball joints (typically 2 out of 3) reached to the break-free moments under operational load cases.
- No over stress issues in the piping system under expansion load cases.
- No over loading issues of the connected equipment or flanges under operational load cases.
- No stability issues or sagging under sustained load cases.

2.1 New A-Frame Design Evaluation

New A-frame design with configuration of Flex-Flex-Rota can be compared to the configuration of Rota-Flex-Rota. From operational standpoint, since the break-off Flex moment of joint is less than or at a maximum equivalent to break-off rotational moment, the new design will satisfy all above criteria except the last one. Another word, if the conventional configuration is being designed properly and works well, replacing one Rota joint at the bottom of A-frame with Flex joint will improve the functionality of design. However, it could raise a concern regarding stability issues.

Additionally, as shown in Figure 6, the new A-frame design could provide more flexibility without requirement to precise alignment in installation phase. Depending on the A-frame legs dimensions and maximum flex angle of Flex joints, the permitted installation tolerances can be calculated. In figure 6, 15-degree flex angle is being assumed for Flex joint. It should be noted that bottom Flex joint can be located either on the wellhead side or piping side. However, because of wellhead drilling tolerances it is preferred to locate bottom Flex joint at the wellhead side. Flex-Flex-Flex or 3 Flex configuration might be considered as an alternative solution. However, because of stability issues is not recommended (Figure 7).

Figure 8 shows one of the typical SAGD piping layout on the wellhead which comprised three ball joints including two Flex and one Rota. Pipe stress analysis w/ CAESAR II is being performed to evaluate whether the new A-frame design can meet the acceptability criterion of stability under sustained load cases. Assumptions are as follows.

- Nominal Pipe Size and Schedule : 3-inch Sch. 160
- Piping material : A106 Gr. B
- Ball Joint material : A105
- Weight No Content load case
- Insulation density and thickness : 0.00018 kg/cm^3, 40mm
- Ambient temperature and no pressure
- Break-off flex moment : 685 N.M at 0 psi (normal to pipe axis)
- Break-off rotational moment : 1,016 N.M at 0 psi (about the pipe axis)
- Spool dimensions : Acc. to Figure 8, L = 2,040 mm

- Rota joint dimensions and weight : Acc. to figure 9, B = 9.75 in, C = 4.83 in, W = 54 lbs
- Flex joint dimensions and weight : Acc. to figure 9, B = 9.75in, C = 4.83in, W = 58 lbs

3. RESULTS AND DISCUSSION

Torsional moment about Z axis at the location of bottom Flex joint as a result of weight load case in terms of guide support location is shown in Figure 10. The results revealed that larger unsupported length could decrease the amount of torsional moment but increase the amount of bending moment about X axis at the bottom Flex joint. Lower torsional amount is due to equilibrium condition at the pipe which anchored at one side and attached to bottom Flex joint at another side. For X1/L ratio equal or greater than one, self-supporting A-frame design meets the requirements of stability criteria. It should be noted that the scope of analysis is just limited to weight load case and it is assumed that rotation about pipe axis at the guide support location is free.

Anchor support assumption at the piping side and using of associated break-off flex/rotational moment at design pressure which typically are being assumed by pipe stress analysts may not be a conservative approach for the A-frame stability evaluation. Moreover, extra care must be taken when the results extend to the other piping layout, nominal pipe sizes or A-frame arrangements.

Break-off moments of FOGT's ball joints are based upon theoretical calculations substantiated by test data to provide the lowest torque in industry. This information is provided for the sole purpose of assisting piping designers to design piping systems that incorporate FOGT's ball joints. Extra care must be taken when different types of ball joints are being used because the break-off moments could be different.

4. DESIGN VALIDATION

New A-frame design with Flex-Flex-Rota configuration has been implemented within industry by couple companies such as Cenovus Energy. This is a part of new well pair and pad design approach as "zero-base," which basically means pads were designed to minimize initial costs & maximize operational efficiencies. The first redesigned well pad began construction in the third quarter of 2016. The new A-frame design not only contributes in well pad cost reduction program by minimizing the installation cost but also improves the functionality of the piping system in both operation and installation phases. Preliminary estimation is that the new A-frame design is being used in the service for at least one year and during the mentioned period is being operated flawlessly based on the feedback of the customers.

The novelty of the new A-frame design is in the ability to handle vertical and horizontal misalignment issues between the wellhead and adjacent piping during installation, reduce the installation times, increase the reliability of operation and reduce the nozzle loads at the wellhead side.

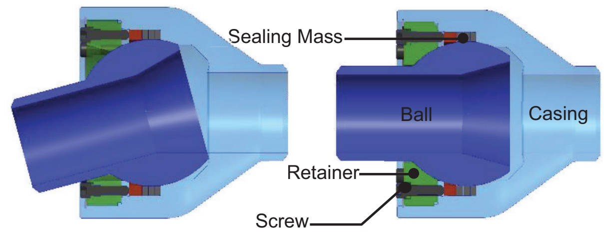

FIGURE 1: BALL JOINT DESIGN (RIGHT: UNIAXIAL SWIVEL JOINT, LEFT: MULTIAXIAL FLEXIBLE JOINT)

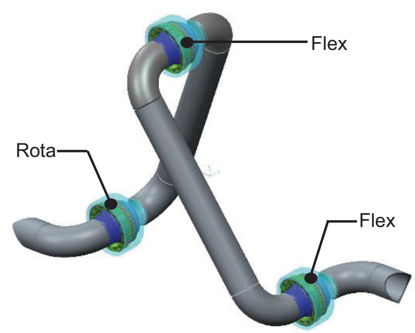

FIGURE 2: A-FRAME DESIGN (ROTA-FLEX-FLEX CONFIGURATION)

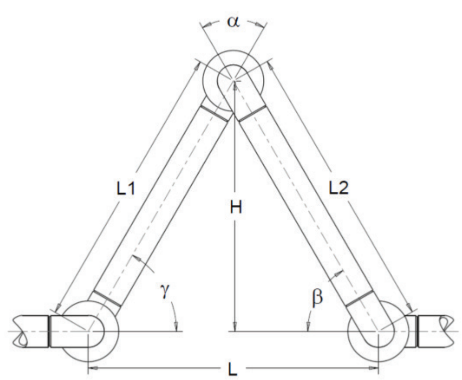

FIGURE 3: A-FRAME DIMENSIONS

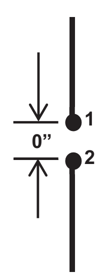

FIGURE 4: NODE/CNODE PAIR (NO PIPE EXISTS BETWEEN 1 & 2)

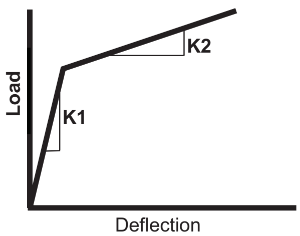

FIGURE 5: LOAD – DEFLECTION CURVE

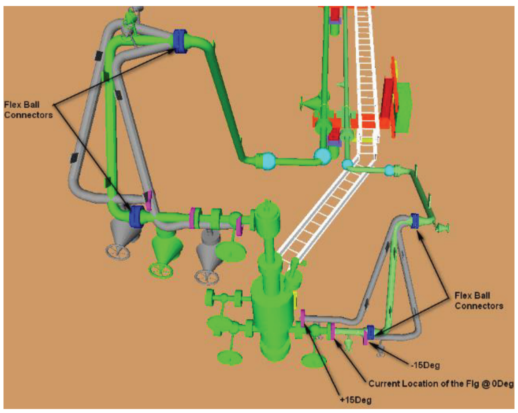

FIGURE 6: INSTALLATOIN TOLERANCE OF FLEX-FLEX-ROTA CONFIGURATION

FIGURE 7: SELF SUPPORTING A-FRAME (TOP: STABLE CONDITOIN, BOTTOM: SAGGED CONDITION)

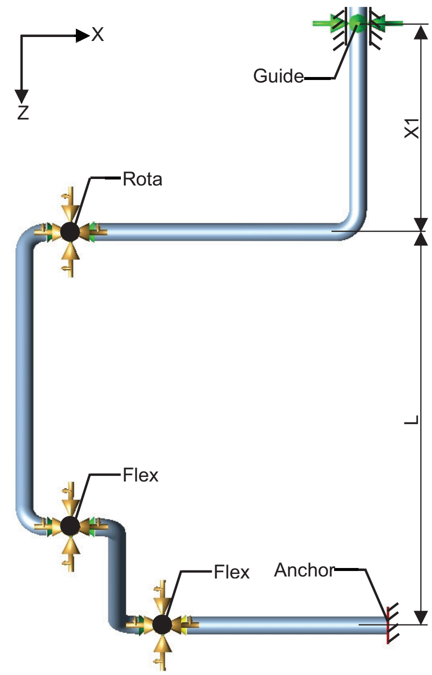

FIGURE 8: TYPICAL PIPING LAYOUT (TOP VIEW)

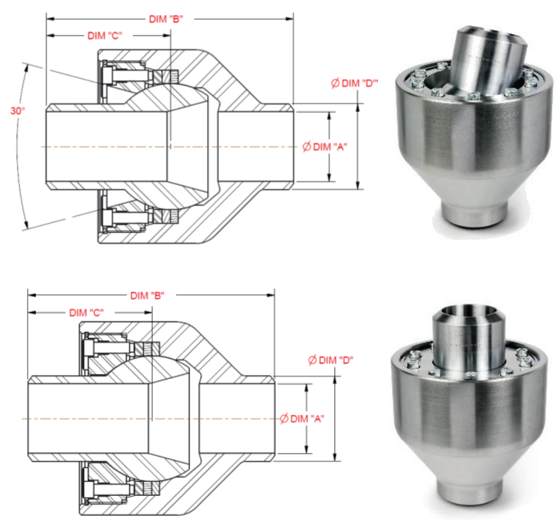

FIGURE 9: BALL JOINT DIMENISONS (TOP: FLEX, BOTTOM: ROTA)

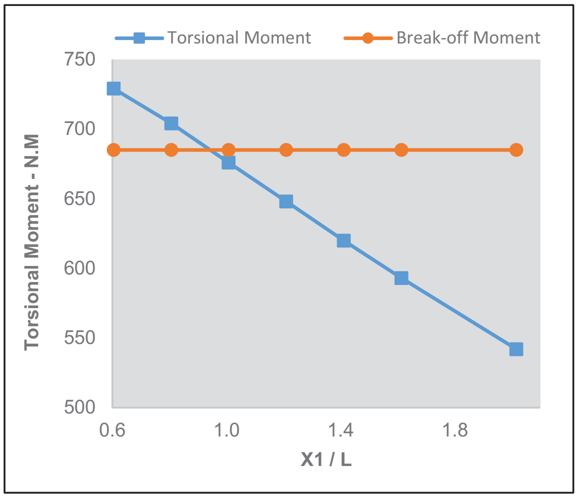

FIGURE 10: TORSOINAL MOMENT ABOUT Z AXIS AT BOTTOM FLEX JOINT

5. CONCLUSION

This works focuses on the stability evaluation of new A-frame design with Flex-Flex-Rota configuration. The results indicate the importance of the stability criteria which could potentially lead to joints leakage failure in the long term if sagged condition occurred.

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