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Optimization of Stress Relief Groove Length

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Abstract

Rotary shouldered connections (RSCs) on a bottom hole assembly (BHA) are typically the fatigue-critical links when subjected to rotating bending loads. In many cases, the pin component of a RSC is weaker than the box component. Hence, enhancing the fatigue life of the pin component would strengthen the overall connection. Results from finite element analysis (FEA) studies, full scale fatigue tests, and field use have proven the benefits of using a Stress Relief Groove (SRG) on the pin component.

Different SRG designs are currently being used, especially in terms of the SRG length. API Spec 7-2 requires a 1″-long SRG, whereas a ¾″-long SRG is suggested in DS-1 by TH-Hill. The tolerance for the length of both designs is 0-1/32″. Fatigue life is one factor to consider for choosing the design. On the other hand, because threads get damaged from time to time and need recuts, reduction of the SRG length would help increase the number of allowable recuts. Hence, there is a need to determine an optimal SRG length in consideration of both fatigue resistance and recut length.

To this end, an FEA study is conducted to predict the fatigue life of a pin component as a function of the varied SRG lengths. API connection NC38 is considered as a benchmark example. Four different SRG lengths, 5/8″, 3/4″, 7/8″, and 1″, are used. An axi-symmetric finite element model is constructed to simulate the bending behavior of the connection. An advanced fatigue analysis method is then employed to compute the fatigue life of the connection with a given SRG length. The effect of angular orientation of the section modeled is evaluated by considering four different sections, 90° apart on the circumference, and the worst orientation is adopted for life predictions. The numerical results show that the ⅞″-long SRG gives the longest fatigue life of the pin component with a given bending moment. It is also observed that a connection with a ¾″-long SRG has similar fatigue strength as that with a 1″-long SRG. Therefore, it is recommended to choose ¾″ over 1″ from the perspective of both fatigue strength and recut length. The same method can easily be applied to other types of RSCs to determine the optimal SRG lengths.

Introduction

Fatigue damage is accountable for most of the drill string failures. It starts when a drill string is subjected to severe repeated cyclic loads induced by a combination of rotation and bending. Fatigue damage is cumulative and irreversible, and it progresses until a fatigue crack is formed. If the crack were not identified during inspection prior to running a new job, the crack could propagate during the job and lead to a twist-off. Fatigue critical features on a BHA include threaded connections, port holes, and fillet radii at the transitions of diameter changes, with threaded connections being typically the weakest links.

It is the interest of the oil and gas industry to use most fatigue resistant features on a drill string. In many cases, the pin component of a RSC is weaker than the box component. Hence, enhancing the fatigue life of the pin component would strengthen the overall connection. Results from FEA studies, full scale fatigue tests, and field use have proven the benefits of using an SRG on the pin component. Nonetheless, different SRG designs are currently being used, especially in terms of the SRG length. API Spec7-2 requires that an SRG be 1″-long. whereas a ¾″-long SRG is described as an option in API RP7G, sixteenth edition. The shorter groove is acceptable to the inspection standard DS-1 by TH-Hill, and supported by a paper by Ellis Reynolds and Lee. The tolerance for the length of both designs is 0-1/32″. Fatigue life is one factor to consider for choosing the design. On the other hand, because threads get damaged from time to time and need recuts, reduction of the SRG length would help increase the number of allowable recuts, and therefore the life of the connection. Hence, there is a need to determine an optimal SRG length in consideration of both fatigue resistance and recut length.

In this study, an FEA study is conducted to predict the fatigue life of a pin component as a function of the varied SRG length. API connection NC38 is considered as a benchmark example. Four different SRG lengths, 5/8″, 3/4″, 7/8″, and 1″, are used in the parametric study.

Method

A rotary shouldered threaded connection consists of a pin component and a box component, mated on shoulders and tapered threads, as shown in Figure 1. Actual representation of the geometry requires a full three-dimensional (3-D) finite element model due to presence of helix cuts on both pin and box components.

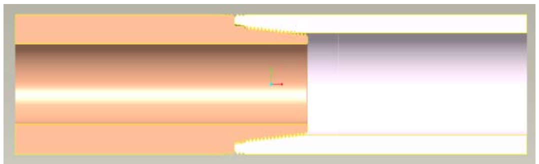

Figure 1: Rotary Shouldered Connection (Half-section view)

High-quality mesh with sufficient refinement is required at each thread groove if viewed in a sectional plane due to high stress concentration at the thread roots in order to capture the stress and strain gradients at the threads. Similarly, sufficient discretization along the circumference is also required to warrant small aspect ratios (ideally close to unity) of the 3D continuum elements, thereby leading to a prohibitively large model size. On the other hand, since the thread pitch is considerably smaller than the pitch diameter, a reasonable approximation is to take a section of the connection and model it with axi-symmetric elements that can account for asymmetric loads. The effect of angular orientation of the sectional plane on the fatigue life prediction can be assessed, and the orientation that gives the lowest life prediction is adopted for parametric studies. An example mesh of a threaded connection is shown in Figure 2.

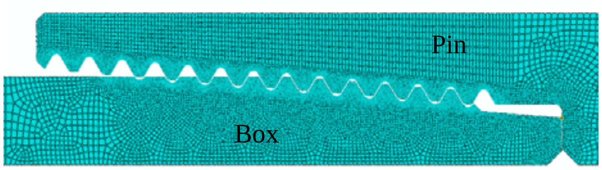

Figure 2: Example mesh of a threaded connection.

A stainless steel with 140 ksi yield strength is used for both pin and box components. Its properties at the rated temperature of the equipment are used. Frictional interactions with coefficient of friction 0.08 are defined between the shoulders and the threads, respectively. Nominal dimensions of the parts are considered. Make-up toque is applied with the interference fit technique: use a proper amount of initial interference on the shoulder face and generate the targeted makeup torque by resolving the interference during the solution process. This is followed by application of the targeted bending moment. The results obtained from this elasto-plastic FEA provides the stress and strain in critical regions such as thread roots and shoulder fillet radius. In general, yielding can be expected at the last few thread roots on the pin and shoulder fillet radius after the rated make-up torque is applied. The last engaged thread (LET) root on the pin and the last engaged thread root on the box are typically the two most fatigue critical locations. In a well-balanced connection, the pin component is weaker than the box component, and its LET root governs the fatigue life of the connection. The maximum principal strain algorithm with Morrow's mean stress correction criterion is used to compute fatigue life. To ensure that the LET root is indeed the weakest link on the pin, the shoulder fillet and the SRG, if used, are also evaluated. The shortest life is reported.

Results

A sensitivity analysis was performed to evaluate the effect of angular orientation on fatigue life, as was similarly done by Collins and Vaghi. Four different orientations, 90° apart, were considered, with the 0° section passing through the start of the threads. Stress plots of NC38 with a 1'' SRG and different sectional orientations are displayed in Figure 3. The numerical results indicated that the 0° section gives the most conservative results and hence all discussions in this study will be based on 0° section.

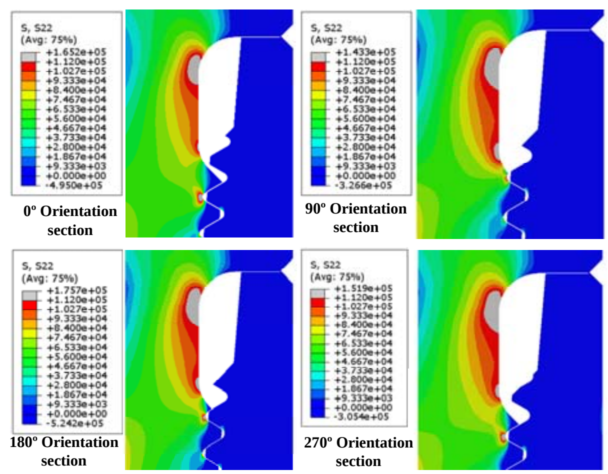

Figure 3: Stress plots of NC38 with different sectional orientations.

API connections NC38 is analyzed here. The outer diameter (OD) and the inner diameter (ID) of the NC38 connection are, respectively, 4.82″ and 2.5″. The only controlling parameter is the SRG length. Four different SRG lengths, 5/8″, 3/4″, 7/8″, and 1″, as well as the baseline case where SRG is not present, are considered. A constant bending moment, 20,000 Nm, is applied after application of the rated makeup torque.

Figure 4 displays stress plots of NC38 as a function of SRG length, which were generated from the solutions with makeup followed by bending.

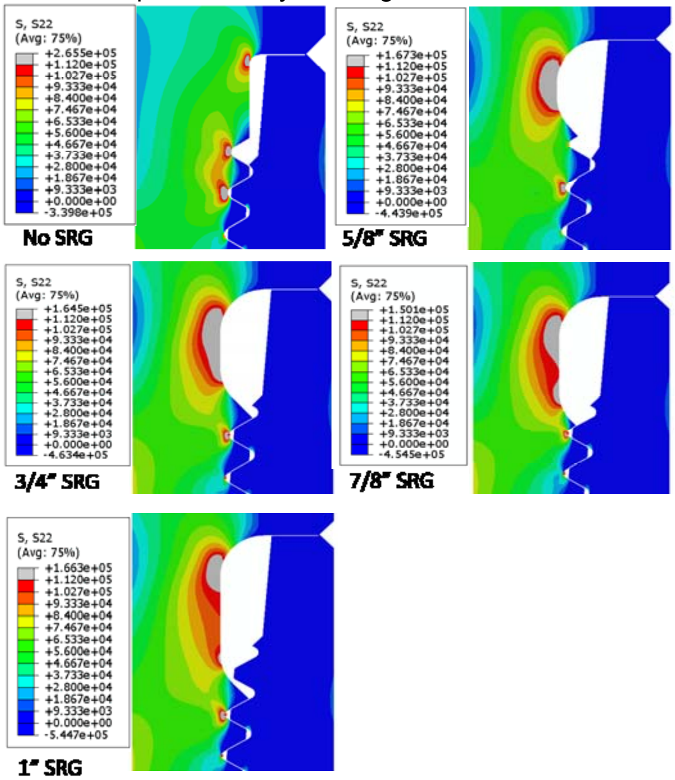

Figure 4: Stress plots of NC38 with different SRG lengths.

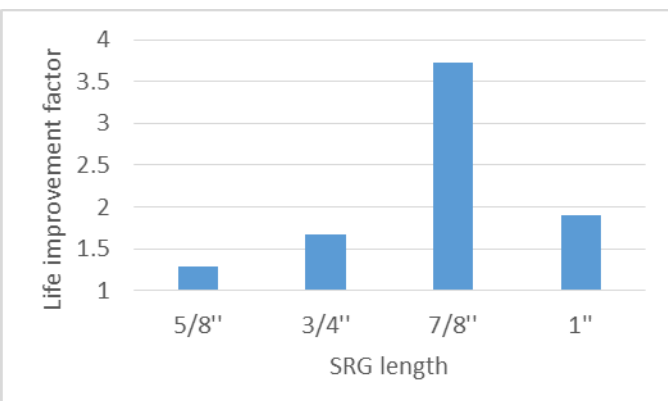

Figure 5: Fatigue life improvement of the designs with an SRG over the No SRG design as a function of SRG length.

The stresses and strains obtained at the LET root from FEA are used in computation of fatigue life for each design. The calculated fatigue lives of the designs with an SRG are compared with the No SRG design. **Error! Reference source not found.**5 displays the fatigue life improvement factor for the designs with various SRG lengths. Introducing an SRG with the length range considered gives rise to higher fatigue strength. The life improvement factor monotonically increases with the SRG length from 5/8'' to 7/8''. The maximum life gain is achieved when the SRG is 7/8'' long. Further increase of the SRG length will reduce the life improvement. These findings are in good agreement with those given above from the stress plots shown in Figure 4.

Conclusions

The predicted fatigue lives of NC38 with different SRG lengths have shown that the 7/8″ SRG gives the best fatigue performance of the pin component with a given bending moment. A 3/4″ SRG provides fatigue improvement similar to the 1″ SRG, while wear or remachining of the contact face will increase the SRG length over time, towards the optimum length. Therefore, it is recommended to choose 3/4″ over 1″ from the perspective of both fatigue strength and recut length. The same method can easily be applied to other types of RSCs to determine the optimal SRG lengths.

Acknowledgments

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Nomenclature

RSCs = *Rotary shouldered connections*
BHA = *Bottom hole assembly*
FEA = *Finite element analysis*
SRG = *Stress relief groove*
LET = *Last engaged thread*
MUT = *Make up torque*

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