SUCKER ROD STRING SERVICE FACTORS

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ABSTRACT

The oil and gas production organizations have used the service factors applied to sucker rod string allowable loads and stresses for many years. However, many have used the service factor described in API RP 11BR[1] only to reduce the maximum allowable stress since they are operating in corrosive service. This paper will discuss the development of the service factors and provide recommendations not limiting the rod loading by using a derating factor.

INTRODUCTION

The Goodman diagram was originally published in 1926[2] to provide a graphical method to determine load range effects on the allowable stresses that can be applied to steel. This work was originally developed based on air fatigue using small, polished, rotational fatigue. The diagram has an upper limit of the tensile strength (T) of the steel being used when the maximum stress and minimum stress are equal. As the load or stress range applied between minimum and maximum is increased, the maximum allowable stress decreases to T/2. The minimum stress stays on the same slope with an intercept through zero. Figure 1 shows an example diagram of the original Goodman diagram.

The use of this curve and the development of the modified Goodman diagram found in API RP 11BR has been discussed by Hein and Hermanson.[3] The oil and gas industry recognized that the original Goodman diagram may not be applicable to sucker rod pumping since the downhole environment does not provide consistent loading. Additionally, the produced fluids lifted using steel sucker rods may be more corrosive than air. During the early 1960's an API Task Group met in the Mayo Hotel, Tulsa, OK., and provided more conservative load ranges and maxima. The y-intercept would have a safety factor of 2 which reduced the maximum tensile strength to T/4. The apex for the maximum T when the minimum and maximum loads/stresses were the same was agreed by averaging most attendees' number to T/1.75. These modifications were accepted and published in API RP 11BR. Figure 2 shows an example of the resulting modified Goodman diagram. The cross-hatched region shows API very conservative reductions compared to the original envelope from the Goodman Diagram. However, at this time, there were no fatigue tests conducted to verify these limitations.

The formula for the maximum allowable stress line is shown in this standard as:

$$Sa = \{(T/4) + 0.5625 * Smin\} * SF$$

Where: Sa = Allowable maximum stress
T = Tensile strength (p.s.i)
Smin = Allowable minimum stress
SF = Service Factor

SERVICE FACTORS

The service factor used in this formula is discussed in paragraph 4.1 of the RP 11BR standard. It states:

- "Since all well fluids are corrosive to some degree, if not 100% inhibited, and since the corrosivity of well fluids vary greatly, it is of extreme importance that the stress values determined from this diagram be adjusted by an appropriate service factor, based on the severity of the corrosion."
- "This service factor should be selected by each user as his experience indicates."
- "It could be greater than one, although normally it will be less than one, varying with severity of corrosion."

It has been observed over many years that many in the industry use a very conservative service factor since the produced fluids have high water cuts, the water typically is saltwater, and hydrogen sulfide and/or carbon dioxide may be present. These factors all contribute to making the fluids more corrosive. However, a prudent operator should know the effects of the fluids produced due to a variety of means from using corrosion coupons, determining iron or manganese counts or conducting a root cause failure analysis whenever there is a downhole failure of equipment. Typically, the solution to these problems is to provide a corrosion inhibition program. An effective inhibition program will help prevent surface facilities and flowline, production tubing and, most importantly, downhole casing failures. Thus, one has to wonder if an effective corrosion inhibition program is applied, then why then use a service factor less than one when designing the sucker rod string.

It should further be noted that a service factor greater than 1.0 could be used. While some may think this would overload the rod string, it really may just be applying good operation practice if corrosion treating is effective and operationally conditions that may overload the rod string, providing increased loading than normal design is applied. These increases may be from tagging bottom, over-pumping the well, having excess friction from sticking metal parts or from very viscous fluids.

CORROSION EFFECTS

Testing sucker rod steels in various fluids has been conducted and published.[4] These tests results are shown in Figure 3 where air fatigued steel life is compared to the slightly reduced life if the fluid is inhibited and very reduced life if the corrosive fluid is not treated. The performance of the rod when the fluid is inhibited provides validity to the recommendation that if the corrosive fluid is adequately inhibited, there should not be a need to reduce the allowable maximum load by using a service factor less than 1.0. This will provide more load or stress carrying ability for the designed rod string and may avoid changing to a higher grade of rods or changing to a larger rod string taper. This should result in a lower cost for purchasing the original or replacement rod string. However, this will not solve other operational problems that may limit overall rod string or downhole equipment life.

OTHER FACTORS TO CONSIDER

While keeping the service factor at 1.0 for design may be beneficial and easily handled in rod string design programs, of greater concern is the reduction that should be considered if used and even inspected rods are reused in a well. The reason for the concern is that depending on the class of inspected rods, there may be some reduction in the cross sectional area that remains. If the area is less than the original, new rod area, then rod cannot carry the same loads/stresses. Additionally, since fatigue cycles are cumulative, and inspections cannot determine the number or applied stress, then the remaining rod lift may be much less. As such, a service factor should be applied to limit the applied stresses. Examples of recommended reductions based on rod inspection life have already been provided.[3]

Another parameter that should be considered is if slim hole couplings are used in the rod string. These typically may not be called out or specified in a rod string computer program, but, work has been published and presented showing depending on the rod grade and coupling type, there should be a derating of the rod string since the slim hole coupling has a reduced cross sectional area and it becomes a weaker link in the rod string versus if only full sized couplings are used. There also are varying factors depending on the rod diameter size. An example derating has been discussed by Hein, based on the original work from Gipson and modified by Hermanson. The modified derating factor developed by Hermanson can be found in the 2008 edition of API RP 11BR.

It should be noted that neither of these parameters are adequately discussed nor the recommended derating factors found in current, commercially available rod string design programs.

CONCLUSIONS & RECOMMENDATIONS

1. The API Modified Goodman Diagram (MGD) is very conservative, originally based on compromise and best guesses.
2. Many factors affect the fatigue life of sucker rods.
3. Corrosion inhibition is required for long life not only of the sucker rod string; but, surface flow lines and processing equipment, the tubing, pump and, most importantly, the downhole casing.
4. Since an adequate and effective corrosion inhibition program is required, applying the API RP 11BR M G D Service Factor with a value less than 1.0 adds more unnecessary conservatism.
5. While some operators may apply a SF greater than 1.0 for the rod string design, this practice usually cannot be supported by sucker rod manufacturers due to implied warranty (do it at your own risk).
6. Other factors such as use of slim hole couplings and rerunning used sucker rods should require the application of a SF but, most sucker rod lift well designers do not use them probably because most design computer programs do not include this information.

7. A joint industry program should be considered to conduct fatigue tests on coupled rods, applying current day understanding of fatigue and the factors that affect fatigue life, in order to ultimately change the MGD for rod string design

REFERENCES

1. API RP 11BR, "Recommended Practice for Care and Handling of Sucker Rods," API, Washington D.C., April, 2008.
2. J. Goodman, Mechanics Applied to Engineering, Vol. 1, Longman, Green & Co., New York, 1926.
3. N. W. Hein, Jr. & D. A. Hermanson, "A New Look at Sucker Rod Fatigue," SPE 26558, Richardson, TX.,1993.
4. H. E. Boyer, ed., Atlas of Fatigue Curves, ASM, Phoenix, 1986.
5. N. W. Hein, Jr., "Sucker Rod Lift," Chapter 11, Petroleum Engineering Handbook, SPE, Richardson, Vol. 4, 2007.

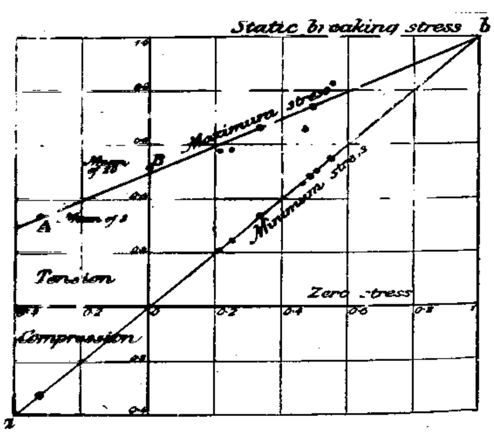

Figure 1 - Original Goodman Diagram (ref.1)

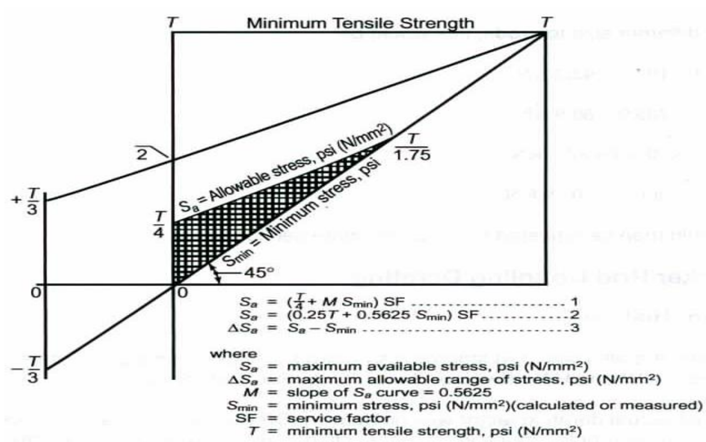

Figure 2 - Modified Goodman Diagram in API RP 11BR.(ref.2)

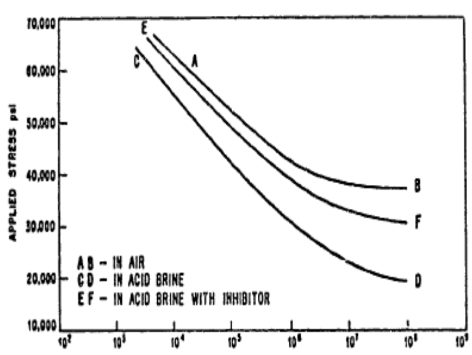

Figure 3 - Effect of corrosion on sucker rod life.(ref 4)