Controlling Sucker Rod Pin & Coupling Failures

By A. A. HARDY
W. C. Norris Manufacturer

ABSTRACT

As deeper and deeper wells are put on the pump, sucker rod strings are being subjected to higher and higher loads. As a consequence, joint failures are becoming more prevalent. This phenomenon is invariably due to corrosion fatigue. An understanding of the stresses and environment under which this occurs will suggest the means of control. Proper tightening procedures, corrosion inhibition, thread form and correct heat treating procedures are discussed.

FATIGUE FAILURES

Sucker rod pin and coupling breaks can be controlled. With a proper understanding of the basic causes of such breaks and proper controls in care and use, they can be practically eliminated. Contrary to first impressions, faulty material, faulty manufacturing processes or workmanship is so rare in these cases as to be practically nonexistant. All such breaks are fatigue failures hastened by corrosion. An understanding of the factors which contribute to early fatigue failure becomes the obvious tool needed in controlling such breaks.

The mechanism of fatigue failure has been described in many papers, articles and books and is beyond the scope of this paper. Suffice it to say they are brittle type fractures which occur at an average stress much below the ultimate strength or yield strength of the metal after a great number of stress reversals. In the cases we are considering they also start at the surface at a point of high local stress caused by notches or other surface imperfections and proceed, slowly at first, then more rapidly at right angels to the direction of principal stress.

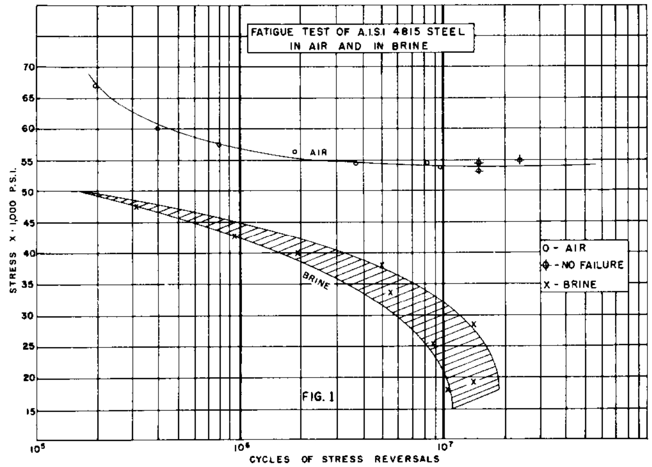
The property of steel which is a measure of its capacity to resist fatigue fractures is called its "fatigue endurance limit." This property, expressed in pounds per square inch, is that maximum stress level, under certain stated conditions, at or below which the metal will withstand an infinite number of stress reversals without failure.

Fig. 1 shows a graph wherein the fatigue endurance limit of A. I. S. I. 4815 steel was developed and defined for operation in air and in brine. To design sucker rods and to operate them so that they will not fail in fatigue, we not only must determine the fatigue endurance limit, but we must also determine what factors tend to lower it, i. e., what factors tend to reduce the stress level to a point where we may safely operate our sucker rods.

There are four main factors that influence the endurance level of steel used in sucker rod service. They are magnitude of stress, the corrosive nature of the environment, surface condition as influenced by notches such as the threads on the pins and in the couplings and the range of stress under which the parts operate. We will consider each of these four factors separately.

Magnitude of Stress

If the operating stress comes close to or exceeds the



endurance limit, fatigue failure is imminent. To correct this condition, we can raise the endurance limit by raising the ultimate strength of the metal through heat treatment or by using alloy steels, since the endurance limit is roughly proportional to ultimate strength, within limits. This is illustrated in Fig. 2.

It should be noted that for notched specimens such as the threaded sucker rod pins and couplings, or for corroding specimens, the optimum or maximum tensile strength lies at about 145,000 p.s.i. Nothing is gained by

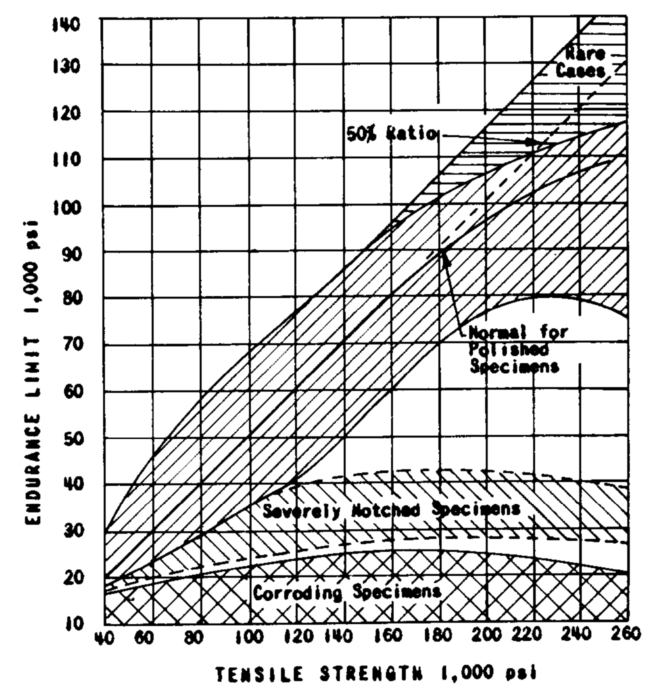


FIG. 2

utilizing higher strength steels. Moreover, the advantage tends to decrease beyond this point because of the greater notch sensitivity of the harder steels.

Conversely, if the operating stress comes dangerously close to the endurance limit, we sometimes can reduce the operating stress through redesign of the string or by increasing the metal area at the critical point; this is unfortunately not always possible in sucker rod string design.

Corrosive Environment

Both Fig. 1 and Fig. 2 illustrate how drastically a corrosive environment can and does reduce the endurance limit of steels. For instance, the polished specimens used in determining the endurance limit for A. I. S. I. 4815 steel shown in Fig. 1 could operate indefinitely at 50,000 p.s.i., yet failed at half that stress when operating in brine at 10^7 cycles. The obvious remedy under these conditions is to reduce or eliminate corrosion through the use of effective inhibitors or to exclude the corrosive fluid from the affected part. This we are able to do in the case of sucker rod pins and couplings through proper tightening of the joint.

The only other recourse we have under these circumstances is to operate under extremely low stresses and expect eventual failure anyway. Metal will proceed to failure with time, even at zero stress under a corrosive environment, as shown in Fig. 1. Actually, there is no true fatigue endurance limit under corrosive conditions.

Surface Conditions

Pits, grooves and notches in the surface of the metal will reduce the fatige endurance limit by a ratio of two or three to one, depending on the root sharpness of the notch. This, too, is illustrated in Fig. 2. In sucker rod pins and couplings the threads become inherent notches which must be considered in our design work. Their effect can be minimized in two ways: by rounding the roots to decrease the notch sensitivity and by increasing the affected metal area thus decreasing the stress.

Range of Stress

The range of stress, as illustrated by the Goodman diagram in Fig. 3 and by the modified diagram for A. I. S. I. 4621 steel shown in Fig. 4, very materially affects the fatigue endurance limit.[2] The stress-number of cycles curve shown in Fig. 1 is based on completely reversed cyclic stress from a maximum in tension to the same maximum in compression and back again. Under these conditions, the allowable range of stress is at a maximum, while the allowable maximum stress is at a minimum.

Conversely, at the other end of these diagrams, the allowable maximum stress coincides with the ultimate strength or the yield strength as the case may be, but the allowable range of stress becomes zero. Allowable maximum and range of stress vary between these limits, depending on the minimum stress at which the part is operated. This conception of allowable maximum stress or fatigue endurance limit, as governed by the range of stress, is becoming more and more recognized as an extremely important criteria in sucker rod design. For further information on its derivation, the reader is referred to an article entitled "Polished Rod Loads and Their Range of Stress."[3]

We should bear in mind that sucker rod pin and coupling failures are fatigue breaks caused by a high order of cyclic stress variations at or above the endurance limit as governed by operating conditions. Keeping in mind these limiting effects, let us investigate the controls we can initiate to prevent such failure.

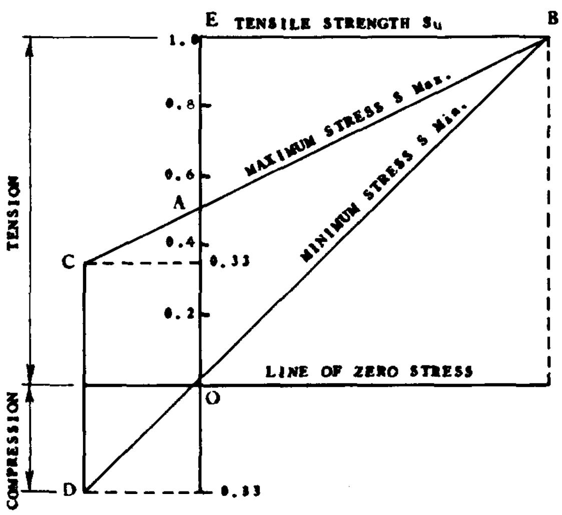


FIG. 3

RANGE OF STRESS LIMITS FOR 4621 SUCKER RODS
NON-CORROSIVE SERVICE

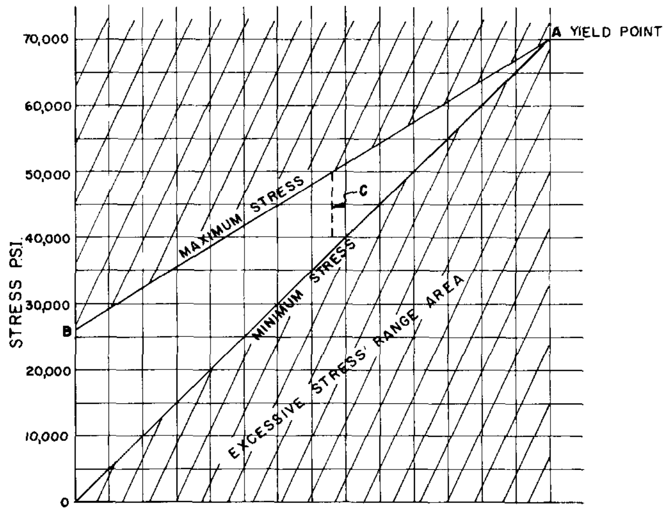


FIG. 4

PIN FAILURES

As wells become deeper and deeper, sucker rod strings and their joints are being subjected to higher and higher stress levels. As this occurs, pin breaks become more frequent. To understand the stresses involved, let us take a look at a simplified analogue, shown in Fig. 5.

Assume spring "B" to be exerting a pull of ten pounds in the assembly. There will then be a reacting pressure of ten pounds at the contact faces "A." Now, if we hang a load of six pounds on the hook, pressure at "A" will be reduced to four pounds, hence the faces must still be in contact. If the faces are still in contact, there has been no change in the length of the spring, and this means no change in stress or pull of the spring.

Therefore, as long as the load hung on the hook is less than the pull exerted by the spring, there will be no change in stress in the spring, nor will it be subjected to bending. When the load does exceed the spring's initial pull, the faces separate and not only is all the load carried directly by the spring, but having no support at the contact faces, it is also subjected to bending. The spring "B" is, of course, analogous to that part of the sucker rod pin which lies between its shoulder and the last full thread. The body "C" is analogous to the corresponding part of the coupling, and the initial load in spring "B" to the initial load set up in the pin by proper tightening of the joint.

Since pins fail in fatigue, such failures are caused by a high order of stress variations. In the analogue above, it is easily seen that as long as we have face pressure at "A" the spring is not subjected to stress variations. If pins and couplings are tightened, and stay tight, so that a pressure is generated at the faces greater than the load to which the string is subjected, the faces cannot separate, they will not be subjected to cyclic loading; ergo, they cannot fail. Two plus two equals four. It is just that simple.

For those interested in delving further into this question, a rigorous mathematical analysis of these stresses is contained in a paper titled "Sucker Rod Joint Failures" reproduced in the A. P. I. Drilling and Production Practice, 1952. The above analogy, of course, as here given is simplified and incomplete, but it does serve to illustrate the high importance of tightening the joint so that a sufficient preload is induced in the pin to prevent the contact faces from separating under load.

If this is not done, the pin, which is necessarily notched by the threads, will not only be subjected to a high range of stress but will also be subjected to bending. This will invariably be disastrous if any appreciable load is carried by the rod string. Following are the recommended torques to be applied to the various sizes of sucker rods. They are based on generating a load at the contact faces which will be higher than any load to which the string might be subjected.

Rod Size	High Tensile Grade	All Other Grades
1/2"	119	106
5/8"	240	213
3/4"	382	340
7/8"	576	512
1"	866	770
1-1/8"	1225	1089

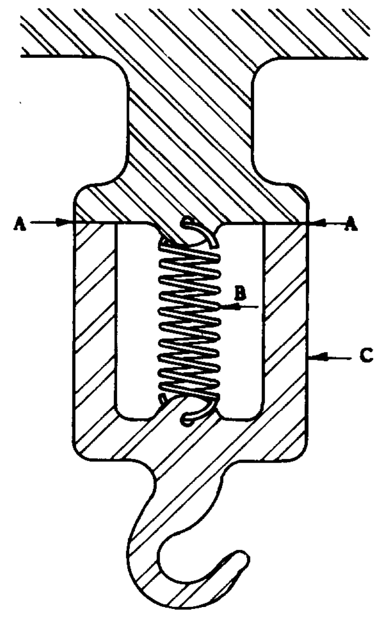
It is extremely important to realize that in applying the above torque, the joints must be clean, well greased and must reflect a free-running fit to the shoulder contact position. Even in this condition, only about ten per cent of the effort applied results in face pressure generation. The balance is absorbed in overcoming friction.

It can therefore be seen that dirt, sand or grit in the joint, or a tight fit to start with, will quickly absorb the ten per cent mentioned above, resulting in insufficient face pressure. Remember that an initial load of ten tons at the faces is not sufficient to prevent face separation when the string is carrying a 21,000 pound load.

Proper Torque

How do we assure ourselves that the proper torque is applied? Remember that in the case of high tensile 1 in. rods, a torque of 866 foot pounds is represented by a pull of 86.6 lbs. at the end of a ten foot cheater. Also, a rod crew running a tapered string in a deep well, using snap wrenches, starts with the small rods in the morning and finishes with the large rods requiring the highest torque in the afternoon, after a long hard day. Human nature being what it is, this could be dangerous on our heavily loaded, deep strings.

On such heavily loaded deep strings, the one way to make certain that satisfactory joint tightness is obtained, is to use power tongs. A word of caution, however! Power tongs should be carefully maintained and calibrated regularly.



SPRING ANALOGUE

FIG. 5

The writer has seen tongs used that were putting out far less torque than they were supposed to put out due to worn, dirty gears which absorbed the power input in internal friction. He has also seen relief valves fail in hydraulic tongs, resulting in stripped pin threads. This latter case, however, required five to eight times the normal torque.

There are two other factors that influence the endurance limit of steel, which are not necessarily controlled by the proper tightening of the joint. They are the corrosive environment and the notch sensitivity of the threads. Proper tightness will exclude corrosive fluid, if the pin and coupling faces are smooth and not grooved or battered, because it will effect a metal to metal seal.

Furthermore, it is excellent practice to insert corrosion inhibiting grease in the couplings as they are run, to offset the corrosive effects of any fluid which might seep into the joint. The notch sensitivity of the threads has been minimized because of the rounded thread roots on the pin, specified in the A. P. I. standard for sucker rods.

COUPLING FAILURES

Coupling failures, too, are fatigue failures, hastened by corrosion and originating at stress raisers. If the break starts on the inside as is usually the case, the stress raisers, where the break originates, are the notches resulting from the necessary threads.

If the break starts on the outside, it originates in cracks in the hardened and ground case, which result from hammer blows liberally dealt in pulling the rods. Corrective procedures in this case are obvious. In either case, the four factors that influence endurance fatigue limit, mentioned in the first part of this paper, are still valid and govern these failures.

As far as magnitude of stress is concerned, the only means we have of reducing it is to increase the cross-sectional area of the metal. We are limited here, of course, by A. P. I. Standard 11-B which sets the dimensions which must be held. Sucker rod couplings, however, fall into two classes; standard diameter couplings and "slim

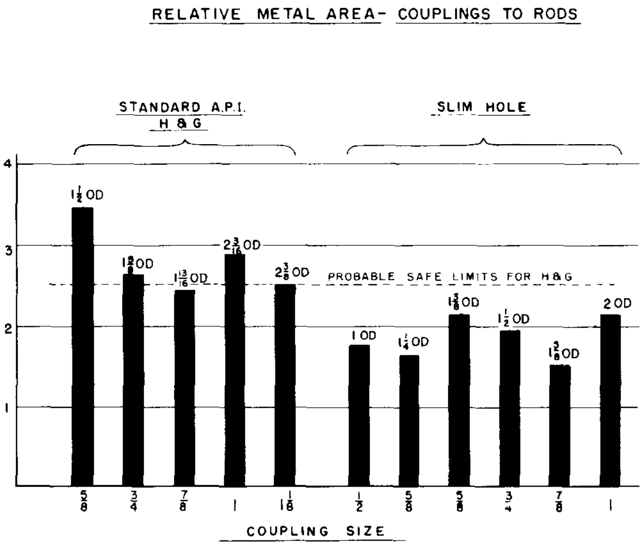


FIG. 6

hole" couplings.

This is illustrated in Fig. 6, which shows the ratio of metal area in the coupling to the metal area of the rod with which it is used. A few years ago "slim hole" couplings saw very little use and were not even recognized in the standard. With the advent of slim hole drilling and deeper and deeper wells, more and more of the small diameter couplings are being used. The smaller area of metal, together with the heavier loads, results in higher stresses and more fatigue breaks.

Since we cannot decrease the magnitude of the stresses involved, we can only raise the fatigue endurance limit of the steel we use to combat this situation. As shown by Fig. 2, and as mentioned above, this can be done by heat-treating the proper coupling steel to the optimum strength level. We do this by oil quenching and drawing to a hardness level of Rockwell 'C' 25 to 30.

As mentioned above, any higher hardness than this would increase the brittleness and notch sensitivity of the metal and would defeat our purpose. The writer has seen a coupling thoroughly shattered which had a through Rockwell 'C' hardness of 45.

Case hardening or surface hardening of "slim hole" couplings, in particular to minimize wear when rubbing against the tubing, should be very carefully avoided. The hardened case is highly susceptible to cracking from hammering and adds nothing in the way of strength to the coupling. This has been proved in straight tensile tests. The hardened case actually decreases the load-carrying capacity of the coupling because the difference in grain structure and composition of the case and core causes them to act, not as a unit, but as two separate metals.

For instance, a case 0.050 inches thick on a 7/8 inch "slim hole" coupling accounts for a little over 13 per cent of the metal area and would consequently raise the effective stress on the balance of the area that much closer to the fatigue endurance limit where our margin of safety is critically small.

Corrosion and Stress

As far as corrosive environment is concerned, loading the couplings with some corrosion-inhibiting grease, as mentioned above under the discussion on pins, has proved to be very effective. Then too, as mentioned before, proper tightening can exclude the corrosive fluid from the inside of the coupling, if the coupling face and pin shoulder face are not battered.

As for notch sensitivity, the A. P. I. standard does not specify rounded thread roots in the coupling as it does on the pins. Such a requirement would be helpful and advantageous. This can be done within limits, however, and still stay within standard requirements.

As far as range of stress in the coupling is concerned, there is very little we can do to limit it as we can in the pin by proper tightening. Proper control of range of stress in overall string design, however, will reflect advantageously in the couplings.

One final word of caution is very appropriate: if the sucker rod string has been operated with insufficiently tightened joints, and particularly, if pin or coupling breaks have already been experienced, it is very probable that other pins or couplings or both have developed fatigue cracks as shown in Fig. 7. Neither of these examples failed in service. No amount of care or proper tightening would have prevented ultimate and rapid failure.

CONCLUSIONS

Recognizing that sucker rod pin and coupling failures are fatigue failures hastened by corrosion, and recognizing those factors which affect the fatigue limit or life of the metal we use, there are several steps we can take to prevent these troublesome breaks.

1. Of prime importance is proper tightness of the joint. This can only be consistently attained by using power tongs.
2. Power tongs should be regularly and carefully maintained. It is very important that they be regularly and carefully calibrated and checked.
3. Before tightening, joints should be clean, well greased and reflect a free-running fit to the shoulder contact.
4. Shoulder faces should be smooth and free from defects which might prevent metal to metal sealing.
5. A corrosion inhibiting type grease should be used

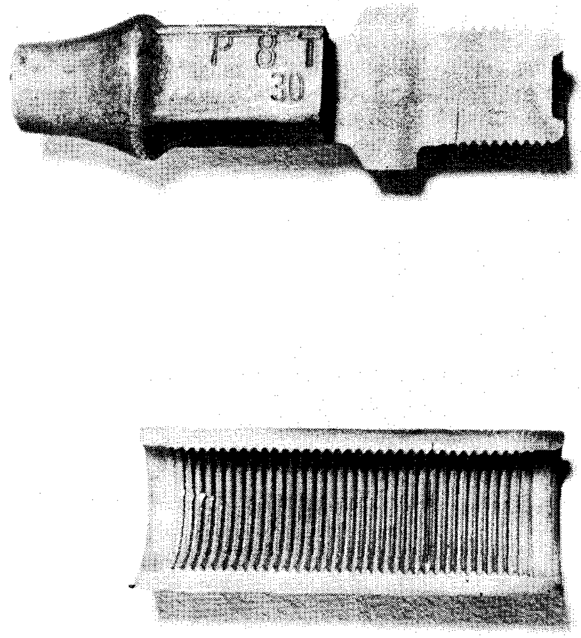


FIG. 7

inside the joints.

6. "Slim hole" couplings should be through hardened and in no case surface hardened only. Wrench flats should be omitted.
7. Couplings should never be hammered to loosen them. If the practice of hammering cannot be stopped, don't use surface hardened couplings.
8. Coupling threads as well as pin threads should have rounded roots.
9. Sucker rod strings should be so designed that the range of stress to which they are subjected is within allowable limits. This will reflect to advantage for the joints as well as the rods.
10. Proper procedures and proper tightening will not prevent pins or couplings from failing if fatigue cracks have already developed. It will, however, prevent new ones from starting.

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