Sucker Rods - New Design & Fabrication Methods Will Reduce Pin Failures

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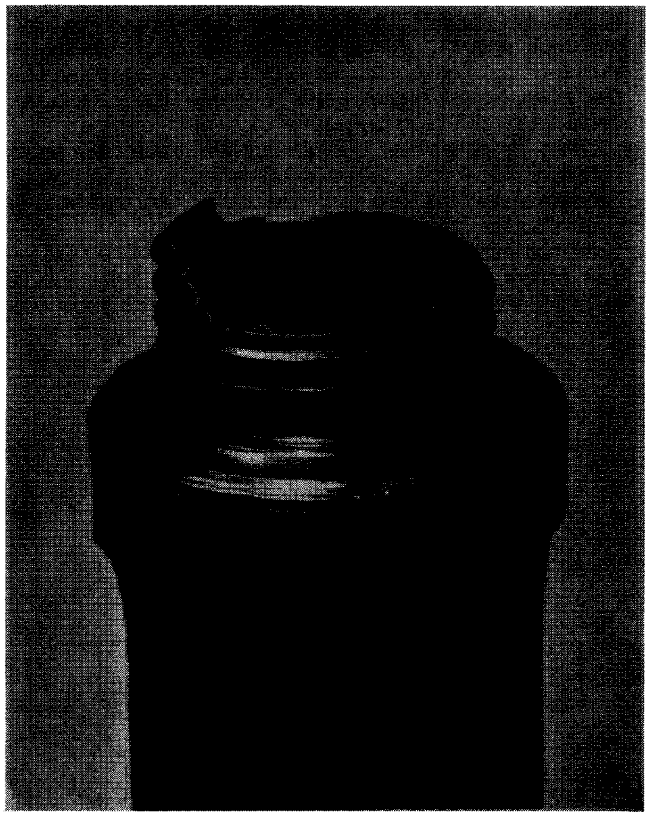


FIG. 1

ABSTRACT

Two new developments are eliminating costly sucker rod pin failures. The first is the undercut or stress-relieved pin which eliminates the critical point where all fatigue failures occur. The second is the thread rolling process which improves the fatigue resistance of the thread.

INTRODUCTION

It can generally be stated that there is only one type sucker rod pin failure: the progressive fatigue type originating at the root of the last full thread or at the root of the first or second partial runout thread (Fig. 1). This type failure has been very costly to the oil industry, and there are available many bulletins and publications outlining effective procedures for its elimination.[1, 2] The important factors stressed in these articles are that the threads should be undamaged, clean, adequately covered with metallic bearing lubricants and that the pin should be sufficiently prestressed to prevent, upon application of the maximum dynamic load, face separation between coupling and rod. Of course, one assumes that fluid lbs are precluded.

Although these procedures are effective, pin failures are still a common occurrence. These failures can be attributed to two factors: (1) the joint is improperly made-up, and (2) the sucker rod pin is super sensitive to fatigue.

The first factor, joint make-up, is undoubtedly the most important and is the cause of the great majority of all joint failures. Some small portion of such failures are because of design and metallurgy.

The second factor, pin sensitivity to fatigue, is the responsibility of rod manufacturers and standardization committees. Much thought, time, and money have been devoted to improving the design of the API sucker rod pin, and the only significant result has been accomplished by undercutting the pin shank below the minimum minor diameter of the thread (Fig. 2), a design principle which had been successfully used in many other fastener applications.

In addition to design modification, there has been developed a new fabrication procedure which greatly improves the fatigue resistant characteristics of the thread. This development is the rolled sucker rod thread which counteracts fatigue by altering the metallurgical structure at the thread root.

UNDERCUT OR STRESS-RELIEVED PINS

Why do sucker rod pins always fail at the last thread or in the partial runout threads? From a geometrical standpoint this question would be extremely hard to answer because the cross-sectional area of the pin at

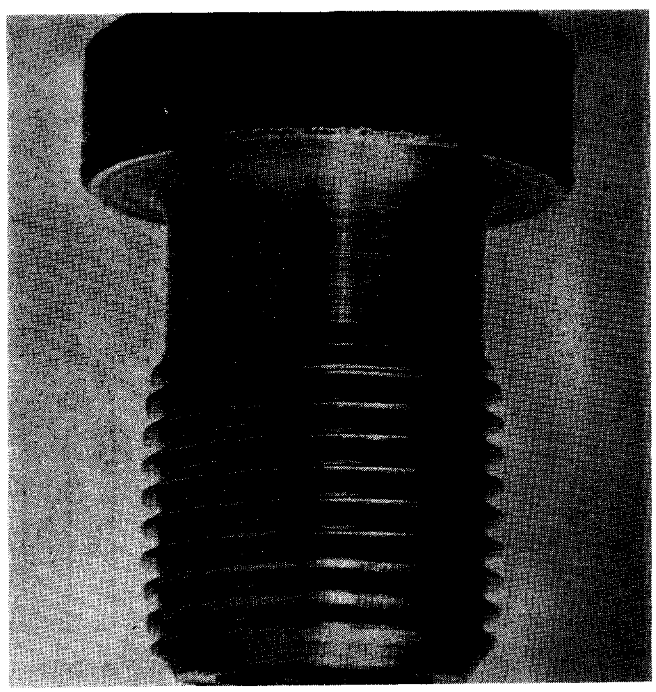


FIG. 2

the runout thread is greater than is the area below the full thread, so this area should be stronger. Furthermore, failure cannot be attributed entirely to notch effect because the roots of the partial threads are much wider than are those of the full thread, so the notch effect should be understandably less.

The answer to this problem is that the last full thread and the first runout thread are actually carrying a very high per cent of the load. Therefore, the areas at their roots are much more highly stressed than are any other area, and fatigue is caused to originate at this point.

Another factor responsible for many fatigue failures is the size limitations imposed on the rods and couplings by the tubing I. D. Fig. 3 shows the relationship between the cross-sectional areas of the various rod bodies, rod pins beneath the threads and at the undercut, and the couplings used with each rod. The cross-sectional area of each size sucker rod is expressed as 100 per cent, and the other areas are percentages of this base area.

Looking at this chart one can see that the relationship in areas for the 5/8 in. rod, pin and API coupling are, respectively, 100, 160, and 333 per cent. As all know, there is very little joint trouble on 5/8 in. rods.

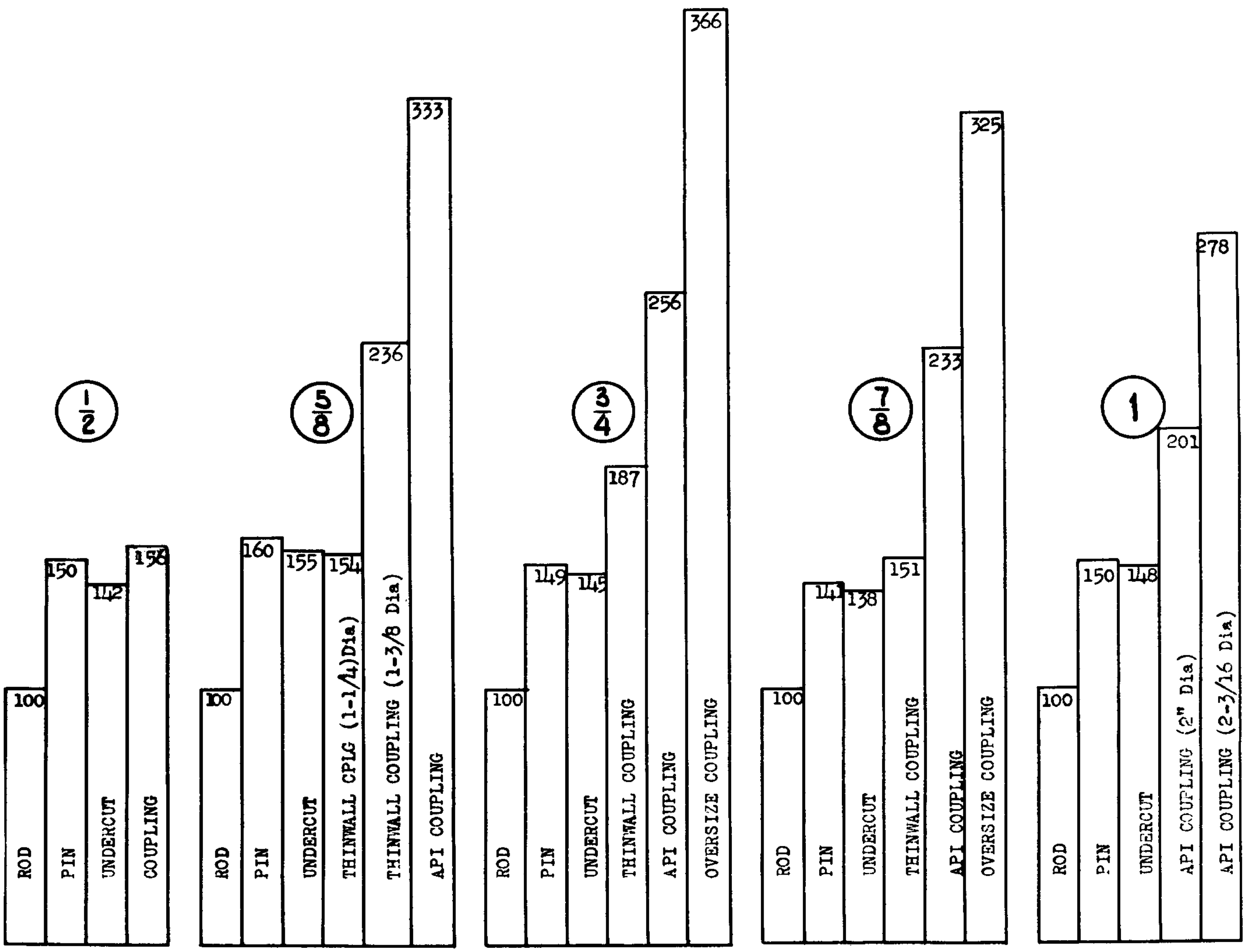
Moving across the chart to the 3/4 in. size one finds that the ratios are 100, 149, and 255 per cent. And although more joint trouble is experienced in the 3/4 in. than in the 5/8 in., the 3/4 in. rod is still relatively free of joint failures.

In the 7/8 in. size, one of the most popular combinations utilizes thinwall couplings, and this particular combination gives a high percentage of all pin failures. It should be noted how the area ratios are 100, 141, and 151 per cent; and compared to the 5/8 in. size there has been lost 19 per cent in pin area and 182 per cent in coupling area. This comparison surely explains why we have so much trouble with this combination.

The 1 in. ratios are 100, 150, and 201 per cent for 2 in. OD couplings. Here has been lost 10 per cent of the pin area and 132 per cent of the coupling area as compared to the losses in the 5/8 in. This combination is the second most troublesome, and only their limited use detracts from the situation.

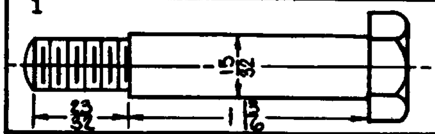
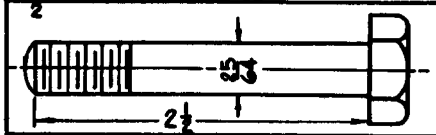
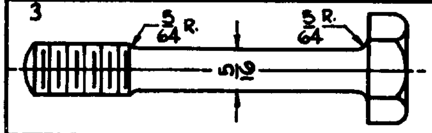
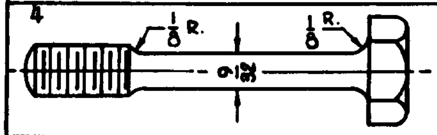
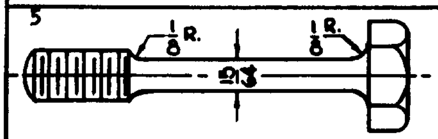
Going back to the 1/2 in. rod one finds, the poorest ratios of all — 100, 150, and 156 per cent. Yet this joint has been trouble free because the 1/2 in. rod has, as a standard, the undercut design.

As one can easily understand, the nut and bolt industry was faced with the identical problem. However, this industry was able to solve its problems with good design practice, and a review of what it considers good and bad



AREAS AS PERCENTAGE OF ROD BODY AREA

Fig. 3

BOLT DESIGN	BOLT BODY		BOLT BODY AREA IN PER CENT OF AREA AT ROOT OF THREAD	REPEATED IMPACT FATIGUE LIMIT					
				STEEL A		STEEL B		STEEL C	
	DIAMETER IN INCHES	AREA IN SQ. INCH.		INCH-POUNDS	PER CENT	INCH-POUNDS	PER CENT	INCH-POUNDS	PER CENT
1 	15/32	0.175	230	1.73	100	1.73	100		
2 	25/64	0.122	160	2.60	150	2.26	130	2.17	100
3 	5/16	0.076	100	4.34	250	2.78	160	3.47	160
4 	9/32	0.060	78	5.21	300	2.95	170	5.21	240
5 	15/64	0.044	57	6.51	375	3.65	210		

	COMPOSITION IN PER CENT					ULTIMATE (PSI)	YIELD (PSI)	PER CENT ELONGATION	PERCENT REDUCTION IN AREA	BOLT ULTIMATE
	C	Mn	P	S	Si					
STEEL A	0.15	0.65	0.095	0.186	0.04	78,200		12.8	56.0	93,900
STEEL B	0.25	0.75	0.019	0.024	0.25	96,400		12.8	54.0	118,900
STEEL C	0.33	0.70	0.039	0.027	0.18	85,300-99,600	>68,300	16-10		118,000

Fig. 4

practice shows how the present API design can be improved.

Fig. 4[3] shows the results of laboratory work done on bolts and shows how the repeated impact fatigue limit of the bolt was improved by undercutting the bolt shank. One can see how the fatigue limit increased from 100 to 150 to 250 to 300 and finally to 375 per cent as the shank cross-sectional area was, using steel A, reduced from 230 to 160 to 100 to 78 and 57 per cent respectively of the area below the threads. The only variable here was the diameter of the shank and the radii beneath the head and at the end of the thread.

Referring to Fig. 5[3], which outlines the rules for good bolt practice, one will notice under "A" that it is wrong to nave all the threads fully engaged by the nut, exactly what occurs with the present API design, for the runout thread on the sucker rod pin is fully engaged in the coupling and stops abruptly with the coupling thread. However, the correct design as indicated in "A" would be to extend the thread at least one diameter beyond engagement and, thus, make the shank more elastic and distribute the strain over a considerable length. This particular rule is actually the only one which the API design violates, and this violation is confirmed by our field experience because all our failures occur at this one point.

Continuing on with Fig. 5 one will also notice that rules "B" and "C" are adhered to by the API rod. Rule "B" states that the runout angle of the thread should not exceed 15°, and the API runout angle is only 9°. Rule "C" refers to the radius between the face and shank, and all know that the API rod has a generous radius, a point at which a rod has never failed.

Rules "D" and "E" refer to the proper method of undercutting or stress relieving, and indicate that, when bolts are subject to bending stresses or tension impact stresses, this is the best design. If a sucker rod joint is properly torqued up bending stresses can be neglected because of the close tolerance on face parallelism between coupling and rod. And one should also be concerned with tension impact for that is the exact nature of the sucker rod string pumping cycle.

Rule "D" states that the minimum diameter of the undercut should be slightly less than the root diameter of the thread.

Rule "E" refers to the length of the undercut and states it that should be one-half the diameter of the pin.

By applying these rules to sucker rod pins and by calculating the length of engagement that will develop maximum strength of an assembled threaded unit,[4] one can arrive at a theoretical design for undercut sucker rod pins.

Fig. 2 is typical of the various undercut pins now being manufactured. All the present undercut designs are similar to this and, it might be add, interchangeable. Each has been modified from the theoretical in consideration of practical aspects such as keeping the total pin length under 2 in. so API couplings can be used and,

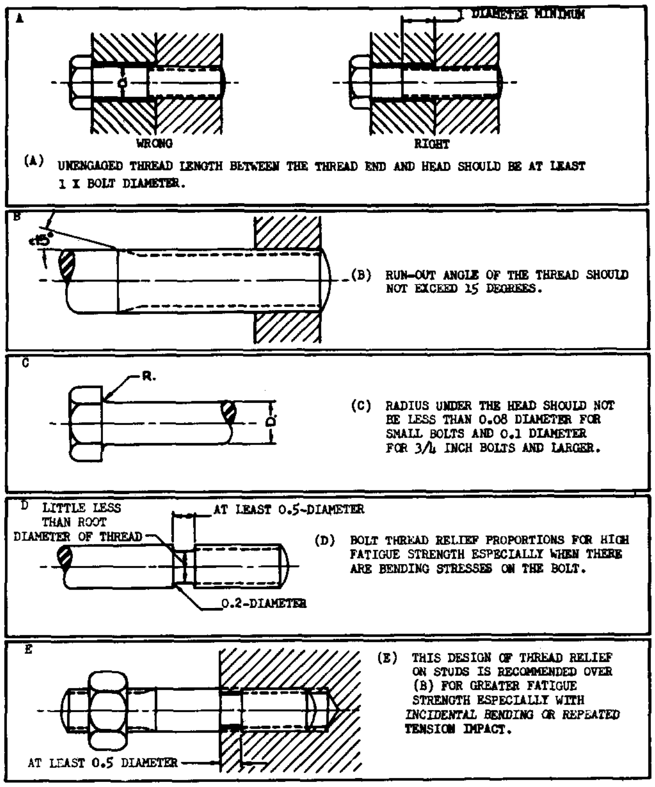


Fig. 5

in some cases, using one length undercut on all size rods to simplify design and gaging. The modifications were based on laboratory tests and results of past field tests with undercut designs.

Historically, the undercut sucker rod pin is not new to the industry. My records show that, in 1930, the undercut was investigated by the Gulf Research Laboratory under the direction of Messrs. Vollmer and Wescott. Since that time there have been other studies made and reported to the standardization committee of the API[5]. A brief summary of the conclusions of these various tests indicates that the undercut rods gave superior service in every instance. However, it was felt that make-up was the key to joint service and that a poorly made-up joint would fail even though undercut. The undercutting would prolong only slightly the life on a poorly made-up joint.

Despite this successful past history undercut rods were never extensively used because of their premium cost. Today, however, the undercut design is available at no extra cost, and the lower costs have provided a considerable impetus to their use. For instance one producer has already reported to the API Standardization Committee on Sucker Rods of a test using 85,000 ft of undercut 1 in., 7/8 in., and 3/4 in. rods in a field that had a history of chronic pin failures. These rods were stressed to 42,000 psi and, at last report, only two failures had occurred: both failures occurred soon after installation and were attributed to improper make-up.

Because of this renewed interest in and complete success of undercut rods, the API Standardization Committee on Sucker Rods is considering the adoption of this design as the new API standard. And to facilitate its adoption as the API standard, the committee would appreciate any additional field test reports from those who are already using undercuts. This procedure would eliminate all costly pin failures caused by the old design.

ROLLED THREADS

Inasmuch as the notch effect of the threadroot was the cause of fatigue failure in sucker rod pins, methods other than design were being developed, concurrently with the undercut pin, to reduce this effect. For example, thread rolling, because of its success on other types of threaded parts, was adapted to the sucker rod fabricating process. Rod manufacturers can now furnish rolled threads on conventional API style sucker rod pins or on undercut pins.

A review of the literature on the subject of thread rolling showed that investigators found rolling increased the fatigue life of threads anywhere from 30 to 100 per cent. A typical example showed that studs with threads made by the ginding, cutting and rolling methods had fatigue strengths of 29,000 psi, 30,000 psi, and 57,000 psi respectively.

Fig. 6 illustrates how thread rolling actually cold works or reshapes the steel fibers so they follow the controur of the thread rather than cut the fibers as has always been done in the past. This cold working increased the tensile properties of the steel and gives a dense,

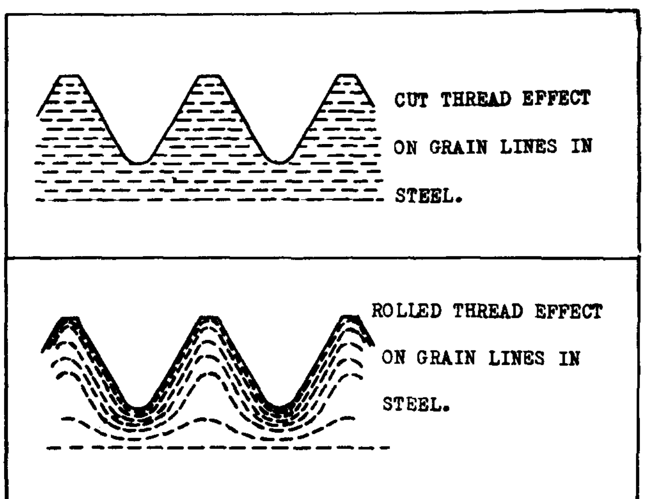


Fig. 6

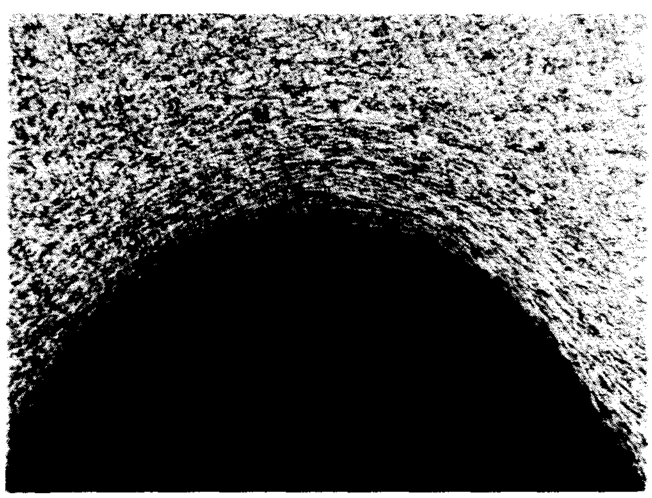


FIG. 7

compressed structure at the very root of the thread. Since fatigue can occur only in tension these compressive forces counteract it. Fig. 7 shows the grain flow around the root of a rolled thread.

The rolling process also gives a smooth burnished surface without any tool marks and tears which could serve as stress concentration points. Furthermore, this fine micro-finish offers less frictional drag on make-up so more of the applied torque goes to prestressing the pin, and all know how important it is to prestress sucker rod pins. And since there are no high spots to be beaten down on application of the pumping load there is less tendency for the coupling to work loose.

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