DESIGNING WITH FIBERGLASS SUCKER RODS

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ABSTRACT

The fiberglass sucker rod design process has come a long way since the introduction of fiberglass sucker rods in the late 1970's. For the past 15 years fiberglass sucker rods have continued to gain acceptance in the oil field as a viable means to enhance the capabilities of beam pumping systems. With the advent of affordable predictive computer programs, in combination with this continued success and acceptance, more producers are finding themselves faced with the challenge of designing beam lift systems that utilize fiberglass sucker rods. The purpose of this paper is to give the designer of beam lift systems some guidelines to become more effective when designing optimum fiberglass sucker rod beam lift systems.

IDENTIFYING A FIBERGLASS CANDIDATE

The first step in obtaining a sound system design is to identify a good candidate. In the early years, fiberglass sucker rod manufacturers didn't have the experience or the resources that would enable them to install fiberglass sucker rods in ideal applications. Therefore many rod strings were installed in what today would be considered a poor fiberglass system candidate.

Fiberglass sucker rod manufacturers got a beneficial boost during the boom of the early 80's. Not so much because of the boom itself or by the acceptance of the product in the oil industry, but by the shortages of many system components. Companies that supplied pumping units and rod strings were operating at close to capacity and were unable to fill many orders. Oil companies were forced to utilize some of the smaller existing equipment and steel sucker rods were in such high demand that they were hard to locate. Many operators who at first were reluctant to try fiberglass sucker rods were now beginning to utilize them as fillers to complete a rod string. This was good and bad for the fiberglass rod manufacturer and the oil industry. It was good because it assisted in developing a learning curve that is being utilized today. It was bad because many rod strings were damaged as a result of poor application thereby leaving the user with a negative impression of fiberglass sucker rods.

The following list identifies some of the best fiberglass sucker rod candidates. Each will be discussed in detail.

FIBERGLASS SUCKER ROD CANDIDATES

1. Wells with High Fluid Levels

2. Wells with Overloaded Surface and Downhole Equipment

3. Wells experiencing Frequent Rod Failures

4. Wells with the Capacity to Increase Production with Existing Equipment

5. Deep Wells

HIGH FLUID LEVELS

Wells with high fluid levels pose an ongoing problem in the oil field. They are difficult to effectively treat with chemicals possibly causing corrosion problems not only to the rod string but also to the tubing and casing. Not only are they a problem to treat but a high fluid level indicates the well is potentially capable of producing more fluid. In many cases the existing surface equipment is already heavily loaded and has limited capacity to increase the production rate to lower the fluid level. Or in other cases, particularly in the mature waterfloods, the well performance far exceeds the capacity of the existing equipment.

Fiberglass sucker rods possess a host of physical characteristics to combat these types of situations. Fiberglass sucker rods are made from a reinforced plastic material which is considered to be corrosion resistant. Fiberglass sucker rod systems usually consist of anywhere from 50% to 70% fiberglass, with the remaining portion of the rod string consisting of steel sucker rods. This reduces the amount of the rod string that is exposed to corrosive fluids. Fiberglass sucker rods also possess a relatively low modulus of elasticity. This physical characteristic enables the rod string to stretch thereby increasing the production rate. In addition, fiberglass sucker rods are lighter than steel sucker rods (See Table 1) which allows the existing equipment to do more work without being overloaded.

OVERLOADED EQUIPMENT

Equipment overloads reduce the life expectancy of pumping units and rod strings and increase operating costs. Fiberglass sucker rods weigh approximately 70% less than steel sucker rods of comparable size (i.e. 1.0" steel sucker rod weighs 2.904 lbs/ft - 1.0" fiberglass sucker rod weighs 0.80 lbs/ft). This reduces the weight of the rod string which eliminates the necessity of purchasing or moving larger pumping units on to the well.

The capacity of a gearbox to lift fluid is somewhat limited by the weight of the sucker rod string. Reducing the overall rod string weight increases the capacity of the gearbox to lift fluid. A lighter weight rod string also requires less horsepower to lift an equal amount of fluid.

WELLS EXPERIENCING FREQUENT ROD FAILURES

As the team management philosophy continues to grow in the oil industry, operators are tracking well problems more closely today than ever before. Many have developed specialized failure analysis committees, consisting of many of their alliance partners and field specialists, to analyze each well. Potential well problems are being identified more rapidly and are being solved in a more orderly fashion. One of the biggest problems in the oil field is frequent rod parts due to either corrosion or overloaded equipment.

Every fiberglass rod is manufactured by a process called pultrusion. Tiny fiberglass fibers are saturated with a thermoset resin system and pulled through a heated die. A steel endfitting is attached to each end of the sucker rod. Therefore, fiberglass sucker rods are virtually corrosion resistant. The endfittings are made with a grade C or K type of material which is more corrosion resistant than other grades of steel offered by suppliers. Stress and corrosion go hand in hand. Due to the light weight fiberglass sucker rods the overall rod string weight is reduced significantly thereby reducing the stress applied to the rod string. The reduction in the amount of steel sucker rods in the pumping system reduces the stresses applied to the steel portion of the rod string. Therefore, rod loads are less, which increases life expectancy of the rod string portion of the pumping system.

As mentioned before, the light weight characteristic of the fiberglass sucker rods also reduces the loads applied to the surface equipment. This reduces the likelihood of overloaded surface equipment which can be very expensive to repair or replace.

WELLS WITH THE CAPACITY TO INCREASE PRODUCTION WITH EXISTING SURFACE EQUIPMENT

Excluding the cost of drilling or completing a well, the most expensive part of the pumping system is the pumping unit. When it has been determined that a newly drilled well will be put on production a pumping unit is sized to achieve a given production rate. Many times however, the well has a greater potential to produce more fluid than originally estimated, either due to better than expected wellbore performance, or due to some sort of secondary recovery method. Usually the operator takes these types of situations into consideration during the unit sizing, but in the instances that this is not the case the operator has a few alternatives.

The light weight characteristic of a fiberglass sucker rod has already been mentioned and will solve many of these types of problems. Fiberglass sucker rods also possess a low modulus of elasticity. The modulus of fiberglass sucker rods is about 7.0×10^6. The modulus of steel sucker rods is about 30.5×10^6. Basically this means that fiberglass sucker rods will stretch approximately 4 times more than steel sucker rods. The ability to stretch allows a fiberglass sucker rod system to obtain substantial overtravel, which in turn produces more fluid. An increase in production rate with a steel sucker rod system generally results in increased surface equipment loads. However, with a fiberglass sucker rod system the reduction in rod weight balances out the increased loads resulting from the production increase. Therefore, increased production rates maybe realized without overloading surface equipment.

DEEP WELLS

Deep wells are ideal candidates for a fiberglass sucker rod system. Once again the light weight rod string allows the producer to move greater amounts of fluid from deeper depths with smaller surface equipment.

SELECTING SURFACE EQUIPMENT

After a good candidate has been selected it is necessary to determine the size and geometry of the pumping unit and relative horsepower requirements. Most of the fiberglass installations today are installations that replace an existing steel sucker rod string and the pumping unit size, geometry, and motor have already been determined.

Contrary to some beliefs in the oil field pumping unit geometry is not a factor in determining whether a well is a good or bad candidate for fiberglass sucker rods. When fiberglass sucker rods were first introduced into the oil field some of the installations where Class III lever systems (Mark II units) were used, the fiberglass portion experienced premature failures. This was primarily due to rod string design inexperience. In the early years fiberglass sucker rods were designed similarly to the way steel sucker rod systems are designed. Steel sucker rods have been in existence for many years and many "canned" formulas and experience factors have been developed by suppliers and producers. The American Petroleum Institutes' Recommended Practice for Design Calculations for Sucker Rod Pumping Systems, RP11L, was developed through years of study and evaluation. (Since it's original introduction it has been modified for designing with Class III lever systems.) The RP11L was developed to assist an operator in designing a steel sucker rod system that would produce approximately equal rod loading throughout the series of rod tapers in the rod string. Years of study and evaluation went into developing the correct amount of rod taper percentages with various pump diameters that would accomplish this task. Once a series of calculations were performed only one rod loading had to be calculated. The user was confident that the other tapers within the rod string would be approximately equal in loading. Fiberglass sucker rod systems CAN NOT be designed utilizing the RP11L but some of the design practices were incorporated into the early designs. In the early years a fiberglass system designer would utilize a wave equation and would rely on the top rod loading calculation. The loading throughout the other tapers in the rod string was considered to be insignificant. It wasn't until later, after years of some unpleasant experiences, that downhole rod loading became a factor that needed to be considered in designing a sound fiberglass sucker rod system. The downhole rod loading calculations utilized in todays computer predictive programs allows the user to insure proper tension loadings at the glass/steel interface (i.e. where the steel sucker rods are attached to the fiberglass portion of the rod string).

It doesn't matter what kind of pumping unit geometry is to be utilized in the system design. Conventional, Mark II, or Airbalance units are all good units when the rod string is designed properly. Different types of rod string designs are required for each different pumping unit geometry.

Since the mid 1980's we have found that when designing a beam lift pumping system one must consider the shape of the permissible load diagram. The permissible load diagram is defined for every type of pumping unit as a plot of polished rod load versus polished rod position. The polished rod load is the load which when multiplied by a torque factor for that polished rod position plus the structural unbalance will fully load the reducer to it's maximum rated capacity. The equation for permissible load at θ crank angle is as follows:

$$P.L. @ \theta = \frac{GBR + MAX.\ CBM\ (SIN\ \theta + BETA)}{TF @ \theta} + B$$

Where: $$MAX.\ CBM = \frac{TF\ (CBE - B)}{SIN\ \theta}$$

P.L.	- Permissible Load at θ Crank Angle
GBR	- Gearbox Reducer Rating
θ	- Crank Angle Position
BETA	- Phase Angle of Pumping Unit
TF	- Torque Factor at θ Crank Angle
B	- Structural Unbalance of Pumping Unit
CBE	- Counter Balance Effect

By inspection it can be determined that an increase or a decrease in counter balance effect will shift the permissible load diagram in an upward or downward direction on the Y-Axis load scale. During the upstroke the permissible load is limited to a predetermined load that is referred to as the structural capacity of the unit and on the down stroke the permissible load goes to zero in order to prevent slack from being put into the bridle.

A surface dynamometer card is a plot of polished rod load versus polished rod position. The shape of the dynamometer card and magnitude of the loads depends on the system design. How the dynamometer card fits into the permissible load diagram depends on the card shape and the amount of counter balance effect.

The Conventional pumping unit is readily available in the oil field and is very easy to design with. The unit provides a permissible load diagram that prefers dynamometer card shapes that slope up and to the right (See Figure #1). The following nondimensional equation assists in designing with all types of pumping units:

Fo/Skr

Where: Fo - Differential fluid load on a full plunger area

Skr - Pounds of load necessary to stretch the total rod string an amount equal to the polished rod stroke

The higher this value the more the dynamometer card shape will slope up to the right. Therefore larger Fo/Skr values are best for Conventional pumping units. For best results however Fo/Skr values should be less than 0.60 when designing a fiberglass sucker rod system. This can usually be accomplished by increasing the amount of fiberglass in the rod string, increasing pump diameter, reducing the surface stroke, or by utilizing a smaller diameter rod string. This same design approach should be used when designing with Air Balance units.

Mark II units permissible load diagrams tend to slope up and to the left (See Figure #2). With this type of pumping unit lower Fo/Skr values are desired. This can usually be accomplished by reducing the amount of fiberglass in the rod string, reducing the pump diameter, reducing the stroke length in conjunction with increasing the rod string diameter. Another good tip is to design a rod string that produces large amounts of overtravel where the peak polished rod load occurs very early in the stroke. Wells under strong floods tend to have fluid levels that can not be pumped down to the seating nipple thus providing a relatively high pump intake pressure. The Mark II geometry is a good unit when this situation occurs. Maximum overtravel can be obtained with the fiberglass in conjunction with the fast down stroke of the Mark II unit. Care should be taken to insure that wellbore performance can withstand the production rate and that down hole rod loading calculations are performed to insure adequate tension in the lowest fiberglass portion of the rod string.

DESIGN CRITERIA

One of the most common misconceptions when beginning any pumping system design is that the design being considered at the present time will be just like the last one completed. Many times inexperienced designers and producers assume that all wells within the same field will perform similarly. When designing any beam lift system each well should be considered individually.

As much well data as possible should be obtained. It should include the following:

1. Pumping Unit size, Structure Rating, and Maximum Stroke Length
2. Motor Size and type
3. Present production Rate

4. Oil and Water cuts and gravities

5. Tubing diameter and whether it is anchored or not

6. Deviation information

7. Productivity Index

8. Any dynamometer survey of present operating conditions

Each item on this list should be obtained before beginning any design.

All designs should be performed first with the lowest anticipated pump intake pressure. If a well will pump off and the design will achieve the desired production rate, the design should be performed in a pumped off condition. Once adequate equipment loadings have been obtained and the designer feels comfortable with the result another design should be completed utilizing the highest anticipated pump intake pressure. This will assist in sizing the length of the down hole pump and will give the producer an idea of what kind of production rate to expect when the well is put on pump. This is very important when designing with fiberglass due to the long down hole pump stroke that is usually achieved with the fiberglass pumping system at high pump intake pressures.

If a recent dynamometer survey is available a designer should model the system utilizing this information. This will provide optimum accuracy when a new system is recommended. Friction factors, equipment loading, and pump fillage are easily obtained from a dynamometer survey which will enable the designer to modify the new system to produce the best possible design.

GENERAL TYPES OF FIBERGLASS SUCKER ROD SYSTEMS

There are primarily three basic fiberglass sucker rod system designs. The following list describes each type of system:

1. Conventional (Fiberglass and Standard Steel) - FGS

2. Economic Sinkerbar (Fiberglass, Steel, Sinkerbars) - ESBD

3. Sinker Bar (Fiberglass, Sinkerbars) - FGSB

CONVENTIONAL (FIBERGLASS & STANDARD STEEL) - (FGS)

This is the most common type of fiberglass sucker rod design. This design is comprised of 40% to 65% fiberglass sucker rods and 60% to 35% standard steel sucker rods. The pumping unit geometry and the desired production rate and equipment loadings will determine the amount of fiberglass, stroke length, strokes per minute, and pump diameter, utilized. Design Example #1 describes a standard Conventional unit where 350 BFPD is desired. Design Example #2A describes a Mark II unit where the same amount of production is desired utilizing 1.0 inch fiberglass and Example #2B utilizes 1.25 inch fiberglass. With the Conventional unit, Example #1, a 55%-1.0 inch fiberglass 45%-0.875 inch steel sucker rod string is utilized. Note how the surface dynamometer card slopes slightly up and to the right. All equipment loads are acceptable to achieve maximum life expectancy. Example #2A utilizes a rod string consisting of 50%-1.0 inch fiberglass and 50%-0.875 inch steel. It uses a 1.50 inch pump but note how the surface dynamometer card slopes slightly up and to the right but not as severe as the dynamometer card in Example #1. This is due to the reduction of fiberglass within the rod string which causes the rod string to be stiffer than the rod string used in Example #1. Rod loading is slightly higher at 86% therefore a second design example is given. Example #2B utilizes a 40%-1.25 inch fiberglass and 60%-1.0 inch steel sucker rod string with a 1.50 inch pump. The surface dynamometer card slopes significantly up and to the left which is a direct result of the larger diameter, stiffer rod string. This design obtains the desired production rate with more than adequate equipment loadings. As mentioned before, it is often beneficial to use a slightly larger diameter rod string when designing with Mark II units. The reduction in the amount of fiberglass and increased life expectancy often offsets the slight increase in cost by going from a smaller diameter fiberglass rod to a larger diameter rod.

ECONOMICAL SINKER BAR DESIGNS (ESBD)

This type of design began in the mid 1980's. Computer predictive programs were becoming more advanced, readily available, and compression in the rod string was being addressed. Although compression in the rod string is now becoming a more controversial issue, it has been proven that it does exist, and does create additional problems within the pumping system. The idea behind this type of design is to concentrate the highest compressive loads, which occur at the bottom of the rod string, in a large diameter steel rod. It should be noted that when sinker bars are being discussed they are being referenced as a steel rod larger than 1.125 inches in diameter manufactured from a Grade C or K material. By keeping the largest compressive forces in the largest steel section of the rod string the designer reduces the amount of rod on tubing wear caused by the bending moment being created by the compression. It should be mentioned that there is no way possible to eliminate compression completely from a rod string. This type of design also helps provide the lowest fiberglass portion of the rod string with additional tensile load so that the fiberglass will not be in compression.

Example #3 illustrates an ESBD. The desired production rate for this design is 500 BFPD. Example #3 contains 60%-1.25 inch fiberglass, 34%-1.00 inch steel, and 6%-1.50 inch sinker bars. The equipment loadings are adequate to obtain maximum life expectancy. Note a minimum stress of 3396 psi is calculated at the bottom of the fiberglass section. Example #4 describes a FGS design with approximately the same amount of rod weight (buoyant weight Example #3 is 11688 lbs. and buoyant weight Example #4 is 11373 lbs). The equipment loads are thought to be very acceptable. Note that the minimum stress on the bottom fiberglass sucker rod is 3167 psi resulting in a reduction in compressive stress of 6.5%. Keep in mind that this minimum stress was calculated 448 feet up the hole where minimum stress would actually be higher.

Examples #3 and #4 where both performed with a Conventional pumping unit. The ESBD is very beneficial with the Mark II geometry. The additional weight and diameter of the sinker bars provides for a larger diameter and stiffer rod string (See Example #5). As mentioned before, one of the biggest obstacles when designing with a Mark II geometry is obtaining sound minimum loads on the rod string. The added weight of the sinker bars assists in overcoming this situation. Note that the minimum stress on the bottom fiberglass sucker rod is 4499 psi which is more than adequate. A comparison of equipment loading is described in Table #3.

SINKER BAR DESIGNS (FIBERGLASS AND SINKER BARS) - (FGSB)

This type of design consists of a portion of fiberglass, ranging from 70% to 80%, and the remaining 20% to 30% of the rod string consisting of sinker bars. This type of design has always been utilized for large volumes of production from relatively shallow depths. Experience has shown us that when considering wells with seating nipple depths greater than 6000 feet these types of designs are not very cost effective. This type of design has also been proven to be effective when designing a rod string where corrosion is difficult to control. The large amount of fiberglass is virtually corrosion resistant. The large diameter sinker bar, made from a Grade C or K material, can withstand corrosion for a much longer period of time than a standard steel sucker rod made from the same material. The stresses on the large diameter sinker bars are also relatively low which assists in keeping the string from being deteriorated by corrosion.

Example #6 illustrates a standard FGSB where the production desired is 850 BFPD from 4000 feet. A FGSB is also useful when utilizing a Mark II geometry.

OTHER KEY DESIGN COMPONENTS

One of the most important points to mention when designing with fiberglass sucker rods is that fiberglass sucker rod designs and steel sucker rod designs are completely different characters. Fiberglass sucker rods have completely different physical attributes than steel sucker rods. Therefore, steel sucker rod system design theory should NOT be utilized when designing fiberglass sucker rod systems.

In many cases oil producers often comment about the recommended pumping speed. Generally oil producers have preconceived rules that limit pumping speeds. It is a common practice, when designing fiberglass sucker rod systems, to run the unit a little faster than what an operator is used to. This is primarily due to the production rates desired and the benefit a user gets when pumping speed is increased with a fiberglass sucker rod system. The increased speed in conjunction with the relatively low modulus fiberglass material produces more downhole pump stroke which results in increased production rates.

The following is a common rule of thumb recommended by one of the fiberglass manufacturers. This rule of thumb is determined by polished rod velocity (PRV) and stroke lengths (SL). Polished rod velocity (PRV) is calculated by multiplying the recommended stroke length (SL) by the strokes per minute (SPM).

$$PRV = SL \times SPM$$

Where: PRV		- Polished rod velocity (Inches per Minute)
	SL	- Recommended Stroke Length (Inches)
	SPM	- Strokes per minute

For stroke lengths greater than or equal to 120 inches, recommended PRV should not exceed 1500 inches/minute. And for stroke lengths less than 120 inches, recommended PRV should not exceed 1350 inches/minute. Basically if an operator runs a unit at 10 SPM in the 144 inch stroke length the PRV calculates at 1440 inches per minute. Few operators would have a problem operating at this speed and stroke length. But if a design was recommended to be run 20 SPM in the 64 inch stroke length, many operators would find an alternative production system. But if the rule is followed the design where 20 SPM and the 64 inch surface stroke is recommended, a PRV of 1280 inches per minute is calculated. In other words the PRV is substantially reduced. Keep in mind that the second design would not be recommended for a 10,000 foot well but if the seating nipple depth was 3500 feet, it may be beneficial. This rule of thumb does not violate any of the pumping speed recommendations offered in the pumping unit manufacturers catalogs. After the design has been installed faster pumping speeds can be recommended only after a dynamometer survey has been performed and an adequate model has been calculated with a wave equation program. Once this has been completed increases in pumping speed can be tried and design output can be checked for overload conditions.

Utilizing different pump diameters is also a good component to change when designing with fiberglass sucker rods. Generally when an operator wants to increase production in a well three options are available, regardless of rod string type. Production rate is calculated by multiplying the SPM by the downhole pump stroke by a pump constant. If an operator is utilizing a steel sucker rod string they will generally increase the SPM first. If this does not get the production rate desired they will increase the surface stroke. These two changes are done first because they can be performed without pulling the well and are relatively inexpensive. The surface stroke is increased because steel sucker rod systems generally do not obtain overtravel, therefore the only way to increase the down hole pump stroke is to increase the surface stroke. The pump diameter is increased as a last resort. Each component change will affect the system by increasing rod, gearbox, and horsepower loads. When designing a fiberglass sucker rod system SPM is the only variable that is usually increased. It is often recommended to shorten the surface stroke and reduce the pump diameter. The surface stroke is reduced to reduce gearbox torque and provide for a faster pumping speed. The pump diameter is reduced sometimes to reduce the fluid load on the pump thereby reducing the amount of rod stretch. Rod stretch created by fluid load takes away from the fiberglass sucker rods ability to obtain overtravel and achieve the production rate.

A rule of thumb to follow when considering whether or not to reduce the pump diameter is if the downhole pump stroke is 10% less than or equal to the surface stroke and the gearbox is not overloaded then a reduction in pump diameter and an increase in pumping speed should give the result desired. A reduction in pump diameter also reduces rod stresses and surface equipment loadings.

DESIGN OUTPUT

Many factors come into play when deciding if a design can be determined good or bad. If production goals are achieved and equipment loads are within manufacturers limitations the design is usually considered to be good. There are "expert" predictive programs that will calculate a fiberglass sucker rod design based on existing equipment or production goals. Great care should be taken when using this type of method. Often the same end result can be achieved with a less expensive rod string and smaller surface equipment. Shorter stroke lengths and faster pumping speeds assist in using smaller pumping units. More or less fiberglass may be beneficial.

The topic of fiberglass life expectancy has become a major concern in the past few years to producers in the oil industry. It is known that fiberglass sucker rods have a definite fatigue life. Each manufacturer is required by the American Petroleum Institute to publish the life expectancy of their fiberglass sucker rod (See Table #4 and Figure #4). Life expectancy is a function of rod loading and pumping speed. In the early years this was not an issue that was seriously considered due to the belief that if the recommended design was loaded within the limits the manufacturer recommended, infinite life could be obtained. In the past several years it has become a practice to reduce the loading on the fiberglass sucker rod portion of the rod string to increase the rod life. If a fiberglass sucker rod system is designed to run 10 strokes per minute (SPM) to produce a given amount of fluid and the fiberglass portion of the rod string is loaded to 92%, a life expectancy of approximately 10,000,000 cycles can be expected. This correlates to approximately 1.9 years before the rod string may begin to fail due to fatigue. In many instances this value is very conservative due to the fact that the rod string operated at a higher pump intake pressure and a lower rod loading for a period of time. One rule that should be followed is that after two or three failures and after the fatigue life has been achieved the rod string should be replaced, barring any operational problems that could be causing the failures. If a fiberglass system is designed to run 10 SPM to produce a given amount of production and the fiberglass portion of the rod string is loaded to 80%, a life expectancy of 30,000,000 cycles can be expected. This correlates to approximately 5.71 years of life expectancy. Therefore rod loading should be a major consideration when designing with fiberglass sucker rods. Keep the rod loading as low as possible without over designing the system. Many times however this is not possible due to production rates desired and equipment constraints.

Rod loading is determined by a stress range diagram published by the fiberglass rod manufacturer (See Figure #3). Rod loading is calculated by entering the diagram on the Y-Axis with the calculated minimum stress. A horizontal line should be drawn from this point until it intersects the 45° line on the diagram. A vertical line should be drawn upward to the maximum allowable stress line. A horizontal line should then be drawn toward the Y-Axis to obtain the maximum allowable stress for the given minimum stress. The formula to calculate rod loading is as follows:

$$\text{Rod Loading \%} = \frac{\text{Max. Stress} - \text{Min. Stress}}{\text{Max. Allowable Stress} - \text{Min. Stress}} \times 100$$

Where:

Max. Stress	-	Maximum Rod Stress for given taper obtained from predictive or dynamometer
Min. Stress	-	Minimum Rod Stress for given taper obtained from predictive or dynamometer
Max. Allowable	-	Maximum Allowable Stress obtained from manufacturers Stress Range Diagram

Usually when the load on a steel rod string is calculated a service factor is applied to compensate for corrosion. When using fiberglass sucker rods a service factor for corrosion is not necessary. The only conditions where fiberglass would require a service factor is when they are being utilized in wells with bottom hole temperatures greater than 160° F. Table #5 shows a typical deration schedule for various temperatures. It should be noted that when determining whether a well is a good or bad candidate for fiberglass sucker rods bottom hole temperature should be a major factor. If the well is in an area that is known to be relatively hot it may be a good idea to refrain from using standard fiberglass sucker rods. There are some high temperature fiberglass sucker rods on the market but even they have shown only marginal success in wells with bottom hole temperatures greater than 260° F.

DESIGN EXAMPLES

It would be impossible to describe how to properly design every fiberglass sucker rod string in a short paper. Therefore three designs have been selected to show some of the methods that have already been discussed.

Example #7 illustrates a relatively shallow application where high volumes of fluid are required while utilizing a small pumping unit. An added common problem has been applied to this candidate. The well will contain 2 3/8" tubing.

Example #8 illustrates a well at an intermediate depth requiring a moderate production rate with a small pumping unit and 2 3/8" tubing.

Example #9 illustrates a deep well design.

Table 2

Category	Example #1	Example #2A	Example #2B
Pumping Unit	C456-256-120	M456-256-120	M456-256-120
Surface Stroke (in)	120	120	120
Seating Nipple Depth (ft)	7000	7000	7000
Motor Required HP (HP)	40.0	39.0	38.8
Pump Diameter (in)	1.50	1.50	1.50
SPM	10.5	10.5	10.0
Pump Intake Pressure (psi)	100	100	100
ROD DESIGN			
Fiberglass	3850' - 1.000"	3500' - 1.000"	2800' - 1.250"
Steel	3150' - 0.875"	3500' 0.875"	4200' - 1.000"
ROD LOADING:			
Fiberglass	80%	86%	67%
Steel	58%	64%	62%
Torque (M-IN-LBS)	368.3	358.6	373.7
Down Hole Pump Stroke (in)	135.1	134.7	138.0
Production (BFPD)	373	372	362
Polished Rod HP (HP)	27.2	27.8	29.3
Peak Polished Rod Load (lbs)	17239	18284	23121
Min. Polished Rod Load (lbs)	4775	4824	6797

Table 1

Rod Body Diameter (IN.)	Pin Diameter Steel (IN.)	Pin Diameter Fiberglass (IN.)	Steel WT./FT (LBS/FT)	Fiberglass WT./FT (LBS/FT)
0.750	0.750	0.625	1.634	0.483
0.875	0.875	0.750	2.224	0.611
1.000	1.000	0.875	2.904	0.819
1.125	1.125	NA	3.676	NA
1.250	** 0.625	1.000	4.500	1.288
1.500	** 0.750	1.125	6.000	1.905

All weights/ft. calculated with one coupling at end of rod

** Pin Diameter for steel sinker bars standard steel rods are not available in these diameters

Table 3

Category	Example #3	Example #4	Example #5
Pumping Unit	C456-256-120	C456-256-120	M456-256-120
Surface Stroke (in)	102.7	102.7	104
Seating Nipple Depth (ft)	7000	7000	7000
Motor Required HP (HP)	49.6	49.9	49.1
Pump Diameter (in)	1.75	1.75	1.75
SPM	12.0	12.0	11.5
Pump Intake Pressure (psi)	100	100	100
ROD DESIGN:			
Fiberglass	4200' - 1.250"	3752' - 1.250"	1500' - 1.250"
Steel	2380' - 1.000"	3248' - 1.000"	3080' - 1.000"
Steel	420' - 1.500"		420' - 1.500"
Bottom Taper Min. Stress			
Fiberglass	3396	3167	4499
Steel	- 483	- 3095	- 536
Steel	- 3095		- 3095
Torque (M-IN-LBS)	415.9	421.[illegible]	451.[illegible]
Down Hole Pump Stroke (in)	119.6	118.0	126.8
Production (BFPD)	512	506	521
Polished Rod HP (HP)	35.7	35.4	38.2
Peak Polished Rod Load (lbs)	25044	23548	26420
Min. Polished Rod Load (lbs)	6519	5707	7083
Bouyant Rod Wt. (lbs)	11688	11373	12948

Table 4

CYCLES TO FIRST EXPECTED FAILURE	ALLOWABLE RANGE MODIFIER
5.0 x 10^6	104%
7.5 x 10^6	100%
10.0 x 10^6	92%
15.0 x 10^6	85%
30.0 x 10^6	80%

COMPLIMENTS OF FIBERFLEX, INC.

Diagram is rated for 160°F and 7.5 x 10^6 Cycles to First Expected Failure

Table 5

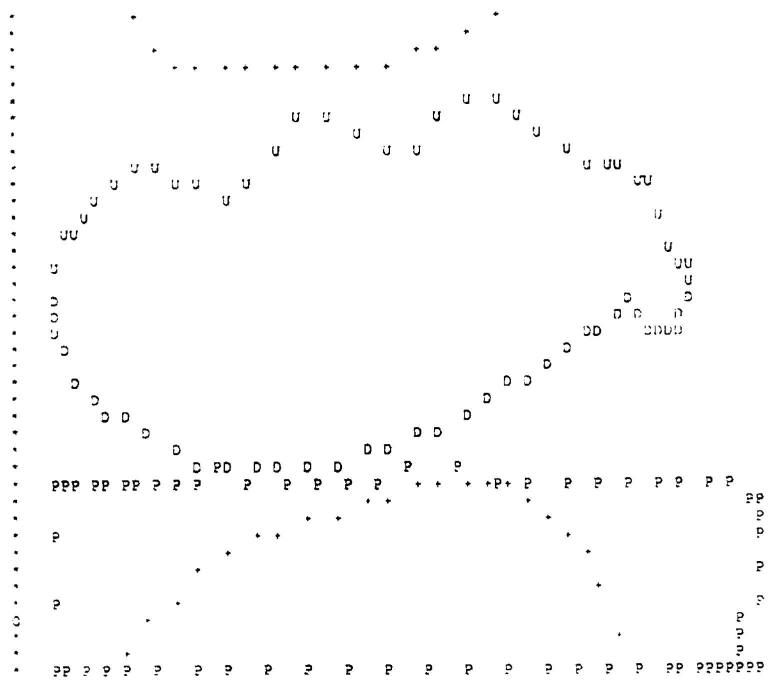
OPERATING TEMPERATURE (°F)	ALLOWABLE RANGE MODIFIER
RT	105%
160	100%
180	98%
200	95%
220	88%
240	80%

Example 1

CATEGORY	EXAMPLE #1
Pumping Unit	C456-256-120
Surface Stroke (in.)	120
Seating Nipple Depth (ft.)	7000
Motor Required HP (HP)	40.0
Pump Diameter (in.)	1.50
SPM	10.5
Pump Intake Pressure (psi)	100
ROD DESIGN:	
Fiberglass	3850' - 1.000"
Steel	3150' - 0.875"
ROD LOADING:	
Fiberglass	80%
Steel	58%
Torque (M-IN-LBS)	368.3
Down Hole Pump Stroke (in)	135.1
Production (BFPD)	373
Polished Rod HP (HP)	27.2
Peak Polished Rod Load (lbs)	17239
Min. Polished Rod Load (lbs)	4775

Example 1 - Predicted Dynamometer Cards

UPSTROKE SURFACE LOADS ARE PLOTTED 'U'
DOWNSTROKE SURFACE LOADS ARE PLOTTED 'D'
PUMP LOADS ARE PLOTTED 'P'
PERMISSIBLE LOADS FOR REDUCER ARE PLOTTED '+'

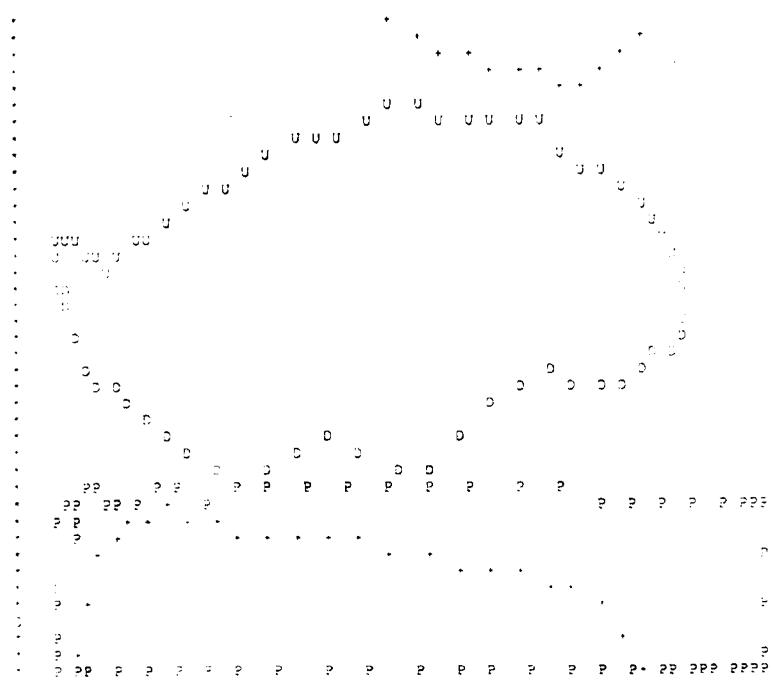


Example 2a

CATEGORY	EXAMPLE #2A
Pumping Unit	M456-256-120
Surface Stroke (in.)	120
Seating Nipple Depth (ft.)	7000
Motor Required HP (HP)	39.0
Pump Diameter (in.)	1.50
SPM	10.5
Pump Intake Pressure (psi)	100
ROD DESIGN:	
Fiberglass	3500' - 1.000"
Steel	3500' - 0.875"
ROD LOADING:	
Fiberglass	86%
Steel	58%
Torque (M-IN-LBS)	358.6
Down Hole Pump Stroke (in)	134.7
Production (BFPD)	372
Polished Rod HP (HP)	27.8
Peak Polished Rod Load (lbs)	18284
Min. Polished Rod Load (lbs)	4824

Example 2a - Predicted Dynamometer Cards

UPSTROKE SURFACE LOADS ARE PLOTTED 'U'
DOWNSTROKE SURFACE LOADS ARE PLOTTED 'D'
PUMP LOADS ARE PLOTTED 'P'
PERMISSIBLE LOADS FOR REDUCER ARE PLOTTED '+'

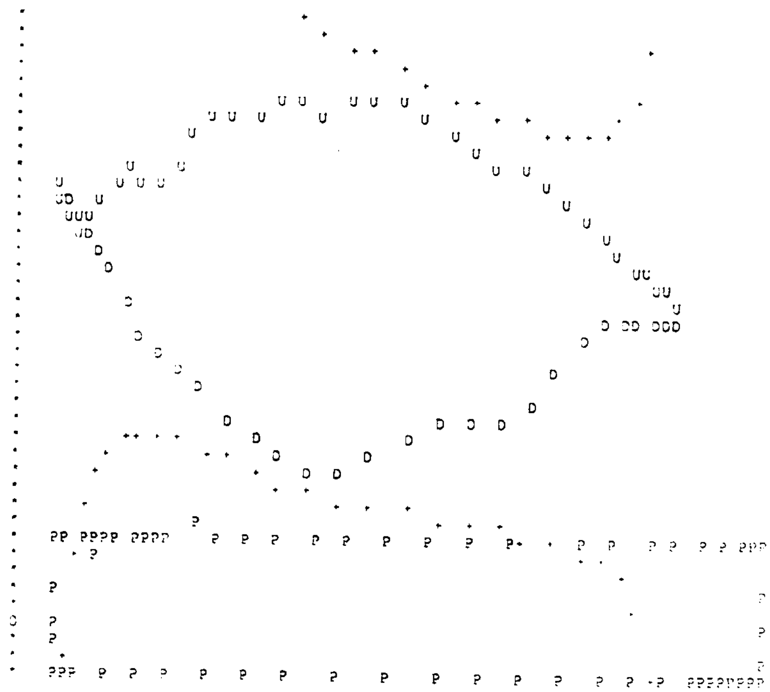


Example 2b

CATEGORY	EXAMPLE #2B
Pumping Unit	M456-256-120
Surface Stroke (in.)	120
Seating Nipple Depth (ft.)	7000
Motor Required HP (HP)	38.8
Pump Diameter (in.)	1.50
SPM	10.5
Pump Intake Pressure (psi)	100
ROD DESIGN:	
Fiberglass	2800' - 1.250"
Steel	4200' - 1.000"
ROD LOADING:	
Fiberglass	67%
Steel	62%
Torque (M-IN-LBS)	373.7
Down Hole Pump Stroke (in)	138.0
Production (BFPD)	362
Polished Rod HP (HP)	29.3
Peak Polished Rod Load (lbs)	23121
Min. Polished Rod Load (lbs)	6797

Example 2b - Predicted Dynamometer Cards

UPSTROKE SURFACE LOADS ARE PLOTTED 'U'
DOWNSTROKE SURFACE LOADS ARE PLOTTED 'D'
PUMP LOADS ARE PLOTTED 'P'
PERMISSIBLE LOADS FOR REDUCER ARE PLOTTED '+'



Example 3

CATEGORY	EXAMPLE #3	
Pumping Unit	C456-256-120	
Surface Stroke (in.)	102.7	
Seating Nipple Depth (ft.)	7000	
Motor Required HP (HP)	49.6	
Pump Diameter (in.)	1.75	
SPM	12.0	
Pump Intake Pressure (psi)	100	
ROD DESIGN:		
Fiberglass	4200' - 1.250"	
Steel	2380' - 1.000"	
Steel	420' - 1.500"	
ROD LOADING:	Percentage	Bottom Taper Min. Stress
Fiberglass	76%	3396
Steel	61%	-483
Steel	23%	-3095
Torque (M-IN-LBS)	418.9	
Down Hole Pump Stroke (in)	119.6	
Production (BFPD)	512	
Polished Rod HP (HP)	35.7	
Peak Polished Rod Load (lbs)	25044	
Min. Polished Rod Load (lbs)	6519	
Buoyant Rod Wt. (lbs)	11688	

Example 4

CATEGORY	EXAMPLE #4	
Pumping Unit	C456-256-120	
Surface Stroke (in.)	102.7	
Seating Nipple Depth (ft.)	7000	
Motor Required HP (HP)	49.9	
Pump Diameter (in.)	1.75	
SPM	12.0	
Pump Intake Pressure (psi)	100	
ROD DESIGN:		
Fiberglass	3752' - 1.250"	
Steel	3248' - 1.000"	
ROD LOADING:	Percentage	Bottom Taper Min. Stress
Fiberglass	74%	3167
Steel	62%	-3095
Torque (M-IN-LBS)	421.1	
Down Hole Pump Stroke (in)	118.0	
Production (BFPD)	506	
Polished Rod HP (HP)	35.4	
Peak Polished Rod Load (lbs)	23548	
Min. Polished Rod Load (lbs)	5707	
Buoyant Rod Wt. (lbs)	11373	

Example 5

CATEGORY	EXAMPLE #5	
Pumping Unit	M456-256-120	
Surface Stroke (in.)	104.0	
Seating Nipple Depth (ft.)	7000	
Motor Required HP (HP)	49.1	
Pump Diameter (in.)	1.75	
SPM	11.5	
Pump Intake Pressure (psi)	100	
ROD DESIGN:		
Fiberglass	3500' - 1.250"	
Steel	3080' - 1.000"	
Steel	420' - 1.500"	
ROD LOADING:	Percentage	Bottom Taper Min. Stress
Fiberglass	79%	4499
Steel	69%	-536
Steel	22%	-3095
Torque (M-IN-LBS)	451.1	
Down Hole Pump Stroke (in)	126.8	
Production (BFPD)	521	
Polished Rod HP (HP)	38.2	
Peak Polished Rod Load (lbs)	26420	
Min. Polished Rod Load (lbs)	7083	
Buoyant Rod Wt. (lbs)	12948	

Example 6

CATEGORY	EXAMPLE #6
Pumping Unit	C456-305-100
Surface Stroke (in.)	100
Seating Nipple Depth (ft.)	4000
Motor Required HP (HP)	54.6
Pump Diameter (in.)	2.25
SPM	12.5
Pump Intake Pressure (psi)	200
ROD DESIGN:	
Fiberglass	3000' - 1.250"
Steel	1000' - 1.750"
ROD LOADING:	
Fiberglass	72%
Steel	18%
Torque (M-IN-LBS)	433.9
Down Hole Pump Stroke (in)	118.9
Production (BFPD)	878
Polished Rod HP (HP)	36.4
Peak Polished Rod Load (lbs)	21730
Min. Polished Rod Load (lbs)	4928

Examples 7, 8, & 9

Category	Example #7	Example #8	Example #9
Pumping Unit	C228-246-86	C456-305-144	C640-365-168
Surface Stroke (in)	73.5	125.2	146.5
Seating Nipple Depth (ft)	3500	7700	11800
Motor Required HP (HP)	38.2	51.4	69.5
Pump Diameter (in)	2.00	1.25	1.25
SPM	16.5	12.5	10.5
Pump Intake Pressure (psi)	200	100	100
ROD DESIGN:			
Fiberglass	2450' - 1.000"	4620' - 1.000"	7080' - 1.250"
Steel	1050' - 1.500"	2849' - 0.875"	2360' - 1.000"
Steel		231' - 1.500"	2360' - 0.875"
ROD LOADING:			
Fiberglass	76%	79%	78%
Steel	18%	55%	61%
Steel		15%	61%
Torque (M-IN-LBS)	219.8	400.6	626.7
Down Hole Pump Stroke (in)	95.5	170.0	189.1
Production (BFPD)	733	387	363
Polished Rod HP (HP)	27.7	36.0	47.7
Peak Polished Rod Load (lbs)	15238	18041	28904
Min. Polished Rod Load (lbs)	3529	5748	10616

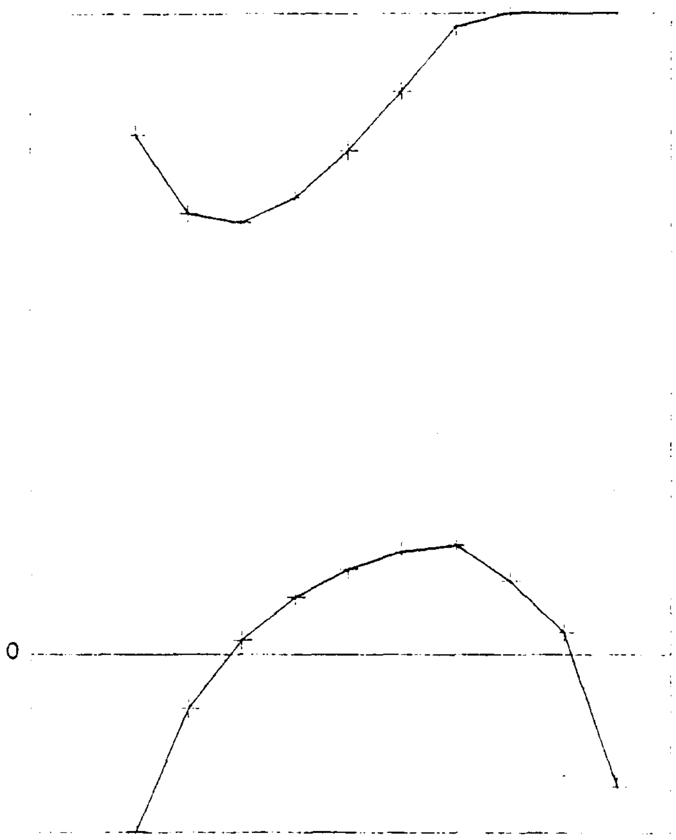


Figure 1

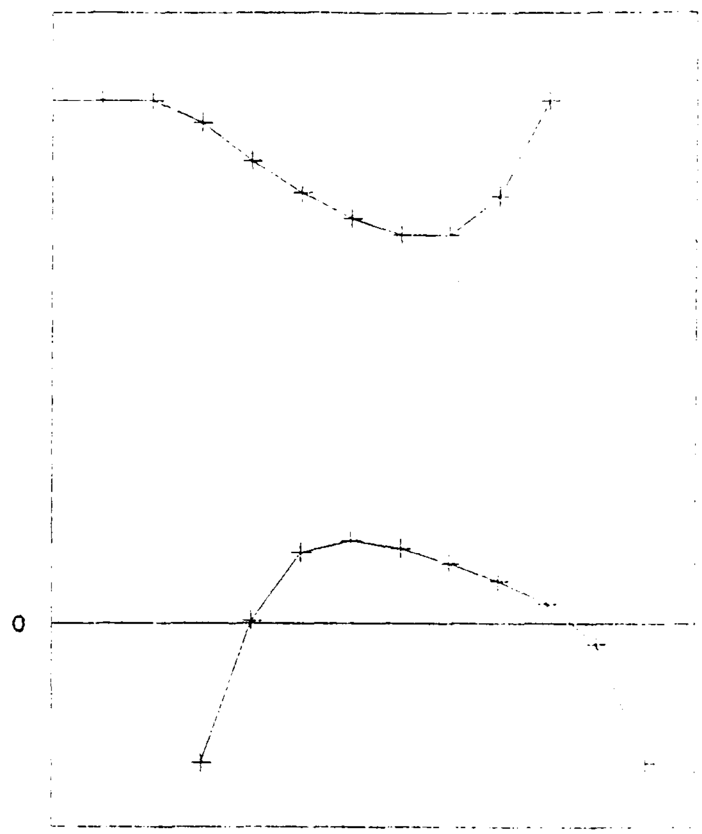


Figure 2

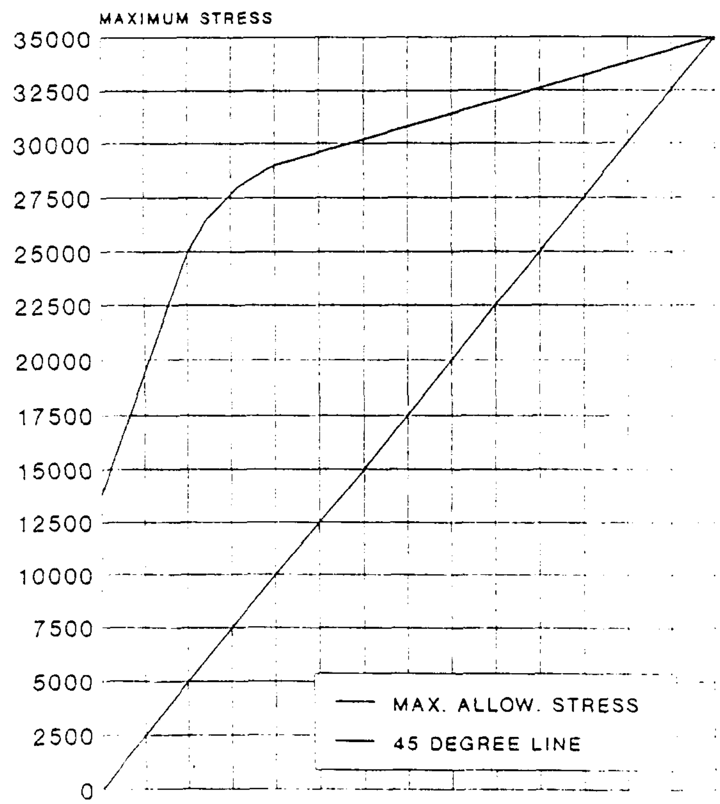


Figure 3 - Stress Range Diagram

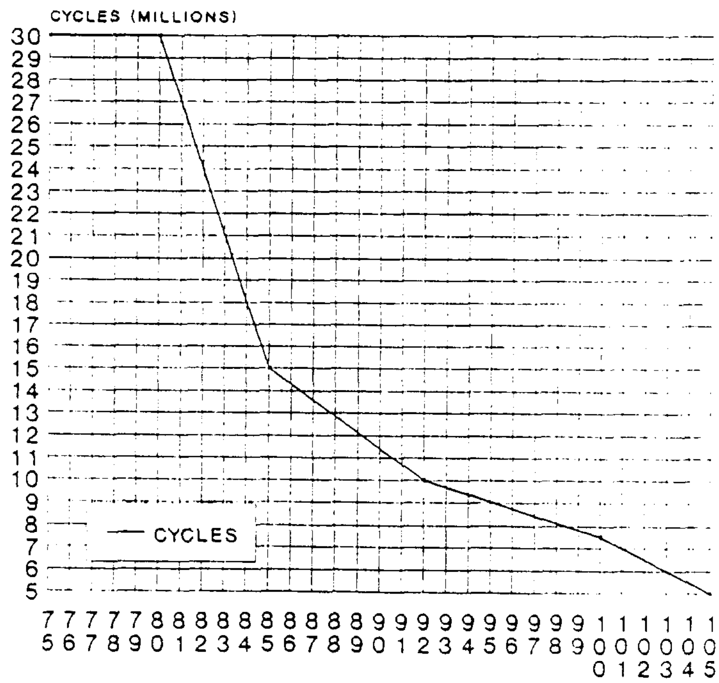


Figure 4 - Cycles to First Expected Failure