

[54] **ONE-FOLD UNITARY STEEL SUCKER ROD STRING**

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[22] Filed: **Jan. 9, 1975**

[21] Appl. No.: **539,826**

Related U.S. Application Data

[60] Continuation of Ser. No. 285,572, Sept. 1, 1972, abandoned, which is a division of Ser. No. 36,107, May 11, 1970, Pat. No. 3,689,326.

[52] **U.S. Cl.** **29/183.5**; 29/193; 148/34; 242/54

[51] **Int. Cl.²** **B21C 37/00**

[58] **Field of Search**..... 29/183.5, 191.6, 193; 166/75, 105; 148/34; 242/54, 158 R, 174

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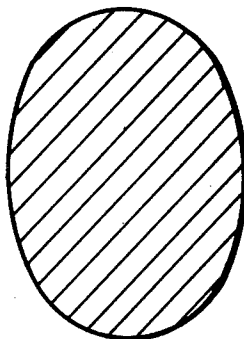
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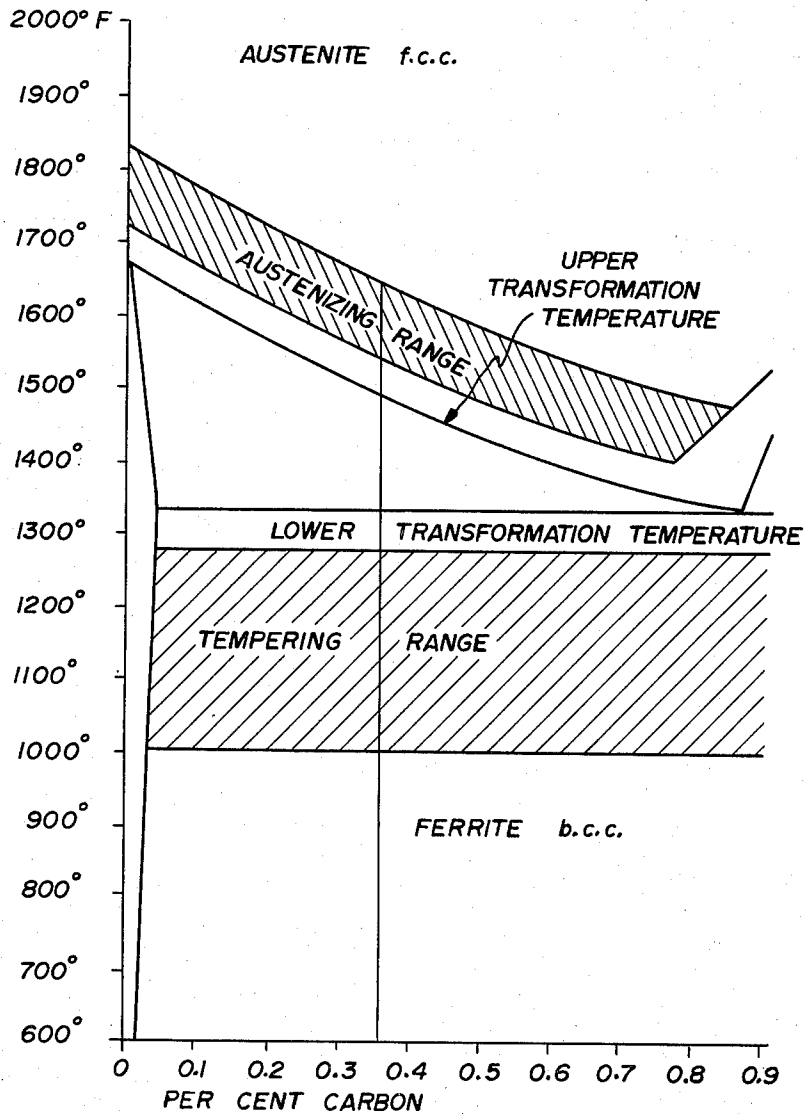
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ABSTRACT

Mill coils of steel sucker rod are joined end to end by flash butt welding and straightened to form a rod string. The string is heated in less than 60 seconds to above its A_{c3} temperature to convert ferritic grain structure to austenitic structure. It is hot rolled to deform its circular cross section to oval form. The ovalled rod is then quenched to 600°C and slowly cooled to room temperature to avoid development of martensite. The string is then coiled with its minor diameter in the coil plane without stressing the steel beyond its .2% offset yield. The product is a continuous ovalled sucker rod string in coiled form particularly adapted to be transported.

9 Claims, 4 Drawing Figures



FIG. 1.

F - FERRITE
P - PEARLITE
B - BAINITE
A - AUSTENITE
M - MARTENSITE

FOR:
1036 STEEL
0.37C, 1.45Mn, 0.25 Si
AUSTENITIZED AT 1550° F
GRAIN SIZE NO. 7
 $A_{c3} = 1470^{\circ} \text{F}$
 $A_{c1} = 1350^{\circ} \text{F}$

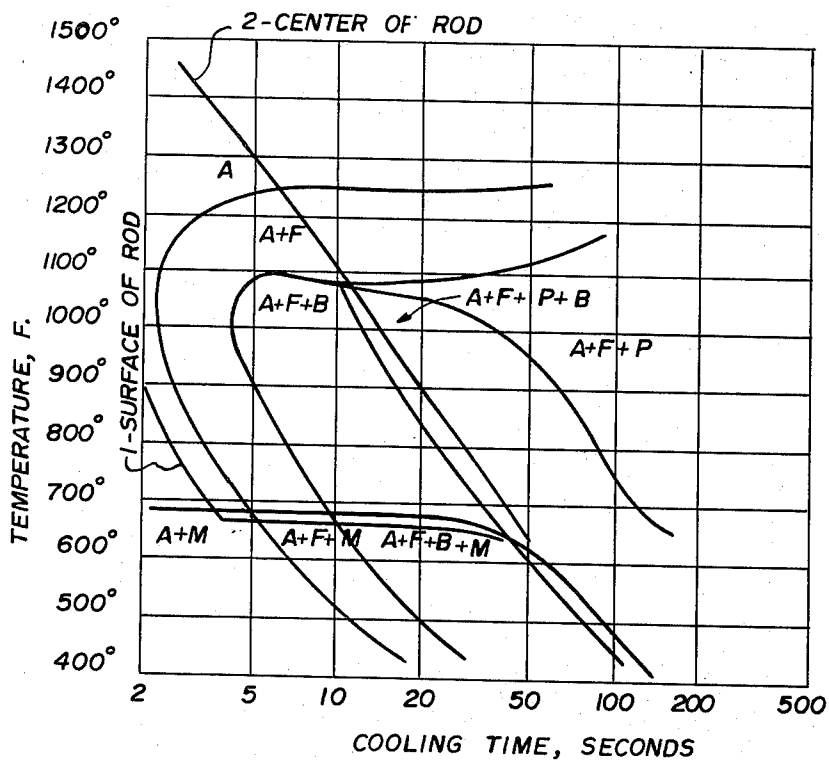
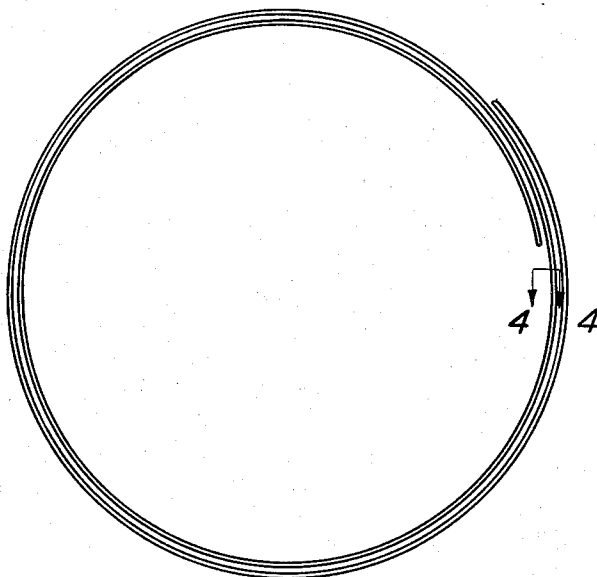
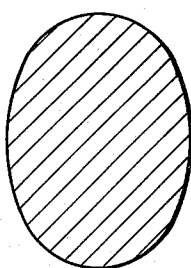


Fig. 2.

Fig. 3.Fig. 4.

ONE-FOLD UNITARY STEEL SUCKER ROD STRING

This is a continuation of application Ser. No. 285,572, now abandoned, filed Sept. 1, 1972, which was a division of Ser. No. 36,107, filed May 11, 1970, now U.S. Pat. No. 3,689,326.

BACKGROUND OF THE INVENTION

This invention relates to a continuous sucker rod string ovalled from a heat treated round sucker rod string and coiled for transport and use.

A large proportion of oil wells are equipped with bottom - hole pumps which pump oil to surface through a string of tubing. The pump is actuated by reciprocation of a string of sucker rods attached to the pump and contained within the tubing.

The string of sucker rods may be thousands of feet in length. It is made up of a large number of individual sucker rods joined end to end. Each sucker rod is about 30 feet long and has pin and box couplings at its ends for connection with other rods.

It is customary for a sucker rod manufacturer to purchase relatively coarse grained steel rod from a steel mill and treat it to produce a finished product having a fine grain size. For example, the sucker rod from a mill usually has a grain size equivalent No. 5 to No. 7 on the ASTM grain size chart. The manufacturer normalizes and tempers this material to produce an end product having a grain size equivalent to No. 8 to No. 9 on the chart.

This grain refinement is carried out to imbue the sucker rod with good yield strength (in the order of 65,000-75,000 psi for 13/16 inch diameter rod) and resistance to fatigue and corrosion failure. These qualities are needed because the sucker rods, particularly those used in the upper end of the string, are subjected to heavy cyclic loading in use.

There are a number of disadvantages inherent in conventional sucker rod strings. For example, the machined pin and box couplings are expensive. Their junctions with the main body of the sucker rod are the sites for the majority of string failures. In addition, the large couplings form restrictions in the annular space between the rod and tubing strings; this has the effect of reducing the volume of oil which can be pumped to surface. Finally, the running and pulling of the rod string is a lengthy operation; this is particularly due to having to break the sucker rods apart into short lengths for stacking in the derrick of the service rig.

It is desirable to substitute a onefold or continuous sucker rod string for the conventional string made up of coupled sucker rods. However, suitable equipment for running, pulling and transporting such a string has only recently been developed.

In my co-pending U.S. patent application Ser. No. 697,287 now Pat. No. 3,559,905, an apparatus which can be used to service a onefold sucker rod string is described. This apparatus is comprised of a pulling unit and a storing unit. The pulling unit includes a pair of opposed endless tracks which can be positioned over the well head and friction grip the rod between them. The tracks are driven to pull or feed the rod string out of or into the well. The storing unit comprises a horizontal, rotatable, circular channel or reel into which the rod string is fed as it comes out of the well. The channel forms the string into a large coil; the channel's inner diameter is of sufficient size so that the rod string

is not stressed beyond its 0.2% offset yield when so coiled.

In my U.S. Pat. No. 3,504,866, a transport reel for carrying the onefold sucker rod string back and forth to the well site is described. This apparatus also involves a rotatable, circular reel of the same size.

It will be appreciated from the foregoing that the key to handling a onefold sucker rod string lies in storing and transporting it in coil form without permanently deforming it to any substantial extent. It follows that it would be desirable to produce a onefold sucker rod string which is particularly adapted to be formed into a smaller coil without permanent deformation of the steel taking place. This would reduce the size of the equipment needed to handle it.

SUMMARY OF THE INVENTION

It is the primary object of this invention to produce a onefold, or continuous, sucker rod string which is well suited for forming into a relatively small coil without causing substantial permanent deformation of the steel.

A further object is to produce such a string having good yield strength and fatigue and corrosion resistance properties.

Another object is to produce such a onefold sucker rod string having a grain size no larger than No. 8 on the ASTM grain size chart.

Broadly stated, the invention comprises a coiled, continuous sucker rod string of oval cross section fabricated by rapidly heating a segment of a onefold, i.e., continuous, steel sucker rod string or like elongate article to above its A_c3 temperature to convert its ferritic or body centered cubic grain structure to the austenitic or face centered cubic form. The heating step is terminated before the segment reaches a temperature at which the austenite grains coarsen rapidly; additionally, the segment can be worked, as by stretching, during heating to aid in the retarding of grain growth. Once at temperature, the segment is hot worked to deform its circular cross section to an oval form. Hot working has the additional benefit of minimizing austenitic grain growth. The segment is then cooled. This is done in a manner which avoids substantial grain growth and the formation of martensite. Preferably the segment is rapidly cooled, as by quenching, to a temperature within the range 600°-700°F. Following this rapid cooling, the segment is slowly cooled to room temperature. During cooling, the austenitic structure is converted to a ferritic structure, which is the room temperature structure. By cooling rapidly, grain growth is minimized. By changing to slow cooling at a temperature above about 600°F, martensite development is minimized. The foregoing procedure is repeated for the other segments of the string; usually the string will be run through a processing line and the various operations carried out in sequence. As the last step in the method, the string is coiled with its minor diameter in the coil plane; coiling is done without permanently stressing the rod material beyond its 0.2% offset yield. In a preferred procedure, the string is reheated to a temperature less than its A_c1 temperature to relieve residual stresses and to convert any residual austenite to ferrite. It is then shot-blasted to clean it and to place its surface into compression.

The product is a onefold steel sucker rod string or like article having an oval cross section. The string is coiled so that its minor diameter is in the coil plane. The grain size of the steel is smaller than No. 8 on the ASTM chart. In this form the string, usually many thou-

sands of feet in length, is in a preferred condition for transport to a well site.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 is an iron carbon diagram for typical rod steels showing the preferred temperature to which we heat the material during the conversion step and the preferred tempering temperature range.

FIG. 2 is an equilibrium diagram showing the changes in structure which occur within a particular rod steel; curves 1 (temperature at the rod surface) and 2 (temperature at the rods center) represent the cooling curves which are preferred.

FIG. 3 is a schematic representation of the coiled, ovalled, continuous sucker rod string of the invention; and

FIG. 4 is a cross section of the sucker rod string of FIG. 3.

The steels suitable for grain refinement by the process by which the sucker rod strings of the invention are fabricated are all those which are hardenable by heat treatment, are ferritic rather than austenitic at room temperature, and become completely austenitic on heating to a suitable temperature. I have only practised the invention on steels used in the manufacture of sucker rods, such as 1036 carbon steel and 4621 low alloy steel. However, it is expected that the invention will find application with other articles such as oil well steel tubing and tubular marcaroni strings which have a similar composition to that of the sucker rod steels.

Before beginning my treating procedure, I provide a onefold, substantially straight length of sucker rod having a circular cross section and the required length. Sucker rod is customarily sold by steel mills in the form of small, permanently deformed coils having a diameter in the range of one-half inch in $1\frac{1}{2}$ inch and lengths of 10 feet to 25 feet as shown in Table 4 of manufacturer's specifications of sucker rods in the July/August, 1969 issue of Petroleum Equipment. Therefore it is usually necessary to join the ends of a number of mill coils together and to straighten the composite product.

The mill coils can be joined by flash butt welding. This is a known technique which combines resistance welding with forging.

By way of general explanation, a flash butt welder includes a transformer. Power is fed to the primary winding of the transformer. One side of the secondary winding of the transformer is connected to a stationery platten having copper clamping jaws. The other side of the secondary winding is connected to a moveable platten, also equipped with clamping jaws. The two rod ends to be welded together are each clamped in one set of the jaws. The moveable platten is biased to bring the rod ends together, thereby causing a short circuit. As a result, flashing and an expulsion of metal from the contact area occurs. The flow of current through the resistive rod ends results in the generation of heat therein. In a moment the ends are soft enough to permit the travelling platten to cause forging to take place. Fusion and forging, taking place at the same time, weld the rod ends together securely.

The literature indicates that a flash butt weld will usually have about 95 to 98% of the strength of the pieces which are joined. I modify the known procedure so as to produce welds which are stronger in tensile strength than the rod material itself.

More particularly, I modify the known procedure by treating the weld to re-orient its grain structure and remove hot cracks.

Before describing this modification, it is worth while to describe some of the structural defects which are developed in the rod during the welding operation. Hot rolled steel has, of course, a grain structure which is oriented in the direction of rolling. Since the rod work piece is to be used in tension and compression, it is desirable that its grain structure be aligned along the rod's longitudinal axis. During forging, the grain alignment of the rod ends is changed to a transverse position. This undesirable situation is aggravated by the fact that a temperature gradient exists from the weld interface along the rod ends during welding. As a result, forging occurs at portions of the rod ends which are at a temperature within the "blue - brittle" range. When at temperatures within this range, the rod steel is susceptible to cracking. It is common to have cracks, referred to as "hook" cracks, in the rod surface adjacent the weld interface. These cracks are, of course, a defect.

I undercut the flash and upset at each weld area to remove the crack - disturbed metal having an up-turned grain orientation. I then clamp the welded rod ends in the welder and heat them to about 1700°F, that is, into the austenitic temperature range. At the same time, I forge the undercut weld axially to increase its diameter above that of the rod. These operations have the effect of re-orienting and refining the grain structure developed by forging during the initial welding operation. When the weld is subsequently heat treated and hot rolled in accordance with the process described hereinbelow, the enlarged areas at the welds are worked to a greater extent than the rest of the string. This working operation causes grain refinement and re-orientation of the grain structure to take place along the longitudinal axis of the string. The end product has welds characterized by superior strength.

Following welding, the joined coils are unreeled and straightened. This may be done by feeding the string through a conventional pinch roll and straightening roll section.

Once joined and straightened, the rod string is advanced to the heating or austenizing operation. The string is rapidly heated to above its Ac_3 temperature to convert the ferritic structure to austenite. I heat the steel to about 50° to 150°F above the nominal Ac_3 temperature for the particular composition.

As will be explained below, the heating operation is followed by rapid cooling. It is known from U.S. Pat. No. 3,178,324, issued to Grange et al., that rapid heating of ferritic material to above the Ac_3 temperature followed by rapid cooling results in grain refinement. This teaching is incorporated in the procedure which I follow.

Rapid heating can be accomplished using an induction coil to raise the string to temperature in less than 60 seconds. As an illustration, I pass the rod string through an induction coil of 36 inch length at 8 feet per minute. The coil is set to raise the temperature of the string to 1550°-1750°F, preferably 1650°-1700°F. The Ac_3 temperature of most sucker rod material is about 1500°F. By operating at 1650°-1700°F, I provide a desirable safety margin. Heating above 1750°F is undesirable as rapid grain coarsening becomes a serious problem.

In a preferred embodiment, the rod string is worked, as by stretching, at the same time that it is heated. For

example, the string may be friction gripped before reaching the induction coil with a pinch roll and stretched using an endless track assembly located down line from the coil. A pull of 18,000 psi is suitable when treating sucker rod.

Immediately following heating, the string is hot worked, as by rolling. This is done primarily to oval it. As a result of being ovalled, the string can be formed without permanent deformation into a tighter coil than would otherwise be the case. In addition, hot rolling has the advantage of aiding in grain refinement.

The extent of reduction can vary. Listed in Table II are several standard size sucker rod diameters together with the minor diameters to which I usually reduce them.

Table II

Standard Size Diameter (Inches)	Reduced Diameter (Inches)
13/16	.605
3/4	.670
5/8	.570

Ovalling can be carried out in a standard rolling mill stand and will pose no problem for one skilled in the art.

The rod string is now cooled. This is done to convert the face centered cubic grain structure to body centered cubin form. The cooling operation is conducted in a manner which minimizes grain growth and martensite development. More specifically, the string is rapidly cooled, as by quenching with water. I cool in accordance with the cooling curve shown in FIG. 2. Rapid cooling is terminated while the nominal temperature of the rod is between 600° and 700°F. This is done to avoid the development of any substantial amount of martensite. It will be appreciated that martensite is undesirable since it is a hard, brittle constituent whose presence in the string can deleteriously affect its working performance.

The string is now in a condition suitable for coiling or further treatment. I prefer to cool the string slowly to room temperature, as by exposing it to ambient room conditions, and then temper it to relieve residual stresses and complete conversion of any retained austenite to ferrite. Tempering can be carried out by passing the string through the coil again to heat it to a temperature of between about 1000° and 1300°F, while simultaneously stretching it with an 18,000 psi pull. I find it desirable to shot-blast the string following tempering to put its surface into compression and remove corrosion - causing foreign objects on the string's surface.

In the final step of the process the finished rod string is formed into a coil with its minor diameter in the coil plane. The coil is of a size such that the rod material is not stressed beyond its 0.2% offset yield. For example, a 15 foot 8 inch inside diameter coil frame will not stress a rod string, originally having a diameter of 13/16 inches and formed of AISI 1036 steel having a minor diameter of 0.610 inches, beyond its 0.2% offset yield.

The product is a onefold steel sucker rod string of oval cross section formed into a coil with its minor diameter in the plane of the coil. A rod string having an original diameter of 13/16 inches and ovalled to 0.86 by 0.61 inches in accordance with the invention has an ultimate tensile strength of 140,000 psi.

The invention and its advantages will be more clearly understood by reviewing the following examples.

EXAMPLE I

Eight coils of AISI 1036 13/16 inch outside diameter rod were flash butt welded end to end using a Taylor-Winfield model B-9 hand-operated flash butt welder equipped with a 100 KVA transformer with 440 volt primary winding and approximately 4-7 volts across the secondary winding. As each weld was performed, the flash was removed by grinding. Grinding was continued so as to undercut below the nominal surface of the rod to provide a concave undercut of about three-fourths inch in length and 1/32 inch depth at the deepest point. Each undercut weld was then re-heated in the welder to about 1700°F and forged to increase its diameter to about seven-eighths inch.

The joined coils were unreeled and fed through a conventional pinch roll and straightening roll section to produce a substantially straight rod string.

The rod string was fed at 8 feet per minute directly into a solenoid-type, 36 inches long induction coil having 44 turns of 3/4 × 3/4 inch rectangular copper tubing, the coil having an inside diameter of 2 1/8 inch. The coil was provided with single phase alternating current at 9600 cycles per second at approximately 400 volts. The coil was tuned to raise the temperature of the rod string to about 1650°F.

After heating, the string was continuously fed into a set of 3/8 inch diameter ovalling rolls having a 1 inch radius concave contour to oval the string to 0.610 × 0.86 inch.

The ovalled string was fed through a rotating quench head having four water nozzles. This head directed about 16 U.S. gallons per minute at the string, and reduced its temperature to about 650°F.

The string was then cooled slowly to room temperature by exposing it to ambient conditions.

Throughout the heating, rolling and cooling operations the string was gripped upline with the pinch and ovalling rolls and downline with a track pulling unit to exert a pull of 18,000 psi on the string.

The product was formed into a coil having an inner diameter of 15 feet 8 inches by feeding it into a rotating reel. The string was oval in shape, having a minor diameter of 0.610 inches and a major diameter of 0.86 inch. The grain size was about No. 9 on the ASTM grain size chart.

The string, which had been coiled with its minor diameter in the coil plane, was subsequently unreeled and found to be free of permanent bends. It was then tempered by again passing it through the induction coil at 12 feet per minute to raise its temperature to about 1250°F. The string was slowly cooled to an ambient temperature using forced air and exposure to room conditions. During tempering, the string was stretched with an 18,000 psi pull.

After cooling, the string was passed through a conventional shot-blasting cleaning unit to remove scale and put its surface into residual compression. It was then coated with rust inhibitor.

The string was coiled in the aforementioned reel with its minor diameter in the plane of the coil to provide a continuous product in a form ready for transportation.

What I claim as my invention is:

1. A onefold unitary steel sucker rod string, several thousands of feet in length, produced from rods of circular cross section, between about three-fourths inch

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to about seven-eighths inch in diameter to a rod having an oval cross section substantially completely throughout its length and formed into a tight coil, said string having a minor diameter of about 0.570 inch to about 0.670 inch in the coil plane, said coil being of sufficiently large inside diameter whereby the rod string is not stressed beyond its 0.2 offset yield.

2. A sucker rod string as defined by claim 1, having a grain size smaller than No. 8 on the ASTM chart.

3. A sucker rod string as defined by claim 1, produced from circular rods having a diameter of about 3/16 inch ovalled to a minor diameter of about 0.610 inch and a major diameter of about 0.86 inch, said coil having an inner diameter of about 15 feet 8 inches.

4. A sucker rod string as defined by claim 3, having a grain size smaller than No. 8 on the ASTM chart.

5. A continuous unitary sucker rod string, several thousands of feet in length produced from rods of circular cross section of a diameter between about one-half inch to about 1½ inches, said sucker rod string having an oval cross section substantially completely

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throughout its length and being formed into a tight coil, said string having its minor diameter in the coil plane and said coil being of sufficiently large inside diameter whereby the rod string is not stressed beyond its 0.2 offset yield.

6. The coiled sucker rod string of claim 5, wherein said string is composed of steel which is predominantly ferritic at room temperature.

7. The coiled sucker rod string of claim 6, wherein said string has been tempered and wherein the surface of the string is in compression and substantially free of corrosion-causing foreign objects.

8. The coiled sucker rod string as defined by claim 6, having a grain size smaller than No. 8 on the ASTM chart.

9. The coiled sucker rod string of claim 6, wherein the grain alignment is substantially longitudinal with the rod string throughout its length and said rod string is substantially free of hook cracks.

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