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This invention concerns the protection of drill pipe. It is especially concerned with providing cathodic protection to drill pipe.

In the art of drilling wells for the production of oil and gas, the most commonly used method is the so-called rotary drilling method. In the rotary drilling method, a drill bit is spaced at the lower end of a string of drill pipe which is supported from the surface of the earth. A drilling fluid is forced down through the drill string, through the drill bit, and up to the surface through the annulus between the drill pipe and the wall of the borehole. While the drilling fluid serves primarily to carry the rock cuttings from the drill bit to the surface, it also serves to lubricate and cool the drill bit. The drill bit obtains its rotary motion from the drill pipe which is rotated from the surface. The rotary-drilling system has been used very extensively for the last thirty or forty years; although it was used even before that.

The drill strings or pipes are subjected to very severe operating conditions. The length of the drill string, of course, is that required to drill the hole to the depth desired, which in many instances is up to 10,000 to 15,000 feet or deeper. The drill pipe, itself, is normally about 4 1/2 inches in diameter. In some instances it is desired to apply forces as high as 200,000 pounds or more to the bit in order to obtain optimum drilling conditions. This is obtained by many methods such as, for example, the addition of heavy sections of drill pipe commonly called drill collars, positioned near the bit. In deep holes, a high torsional stress is required to rotate the pipe and bit at high speed. The bending stresses are also very high where the direction of the hole changes or deviates from normal drilling. In addition, the bending stresses cause a high degree of shear and bending. These stresses cause fatigue and damage the pipe.

In addition to the extreme stresses placed on a string of drill pipe, the drill pipe, itself, frequently operates in rather corrosive environments. The corrosive environment may be due to several causes such as, for example, salt water, mud, or the gases encountered in drilling the well, which becomes mixed with the drilling fluid. Oxygen, which dissolves in the drilling fluid while it is in contact with air, also contributes to the corrosiveness.

Failure or breakage of the drill pipe is a major problem which has long plagued the industry. Over the years and throughout most of the period of extensive use of rotary drilling systems, much effort has been devoted toward reducing the failure of the drill pipe. One group of drill pipe failures is due to improper design, improper make-up of joints, faulty welding, excessive wear, and excessive stresses. These causes are fairly well understood now and can be largely prevented by proper design and construction and use of the pipe. A second group of drill pipe failures, and one of the biggest causes of failure, is corrosion fatigue. Corrosion fatigue of drill pipe is usually characterized by numerous small cracks near the point where the break in the drill pipe occurs. When corrosion occurs, rust tubercles form. The pits under the tubercles continue to penetrate which causes high stress concentrations. These high stress concentrations start corrosion fatigue cracks. The cracks are normally across the pipe and the breaks are transverse with little "necking" or ductility. This indicates that the stresses causing the break are longitudinal, that is, they are usually caused by alternate bending of the pipe.

Various corrosion inhibitors have been added to the drilling fluid in an attempt to reduce the corrosion fatigue of the drill pipe. Although inhibitors have been found to be helpful, they have limitations and they increase drilling costs. One definite limitation of corrosion in drilling with air. Drilling with air has become increasingly popular during the last ten years. In this method, air is the primary fluid that is circulated down through the drill pipe for removing the cuttings up through the annulus. If the hole is relatively dry, the gas stream moves the chips out of the hole and corrosion or corrosion fatigue is not normally considered to be a serious problem in this situation. If a considerable amount of water flows into the borehole from penetrated water-bearing sands, the present trends is to remove the water with foam. In this system, the produced water is thoroughly aerated and it may in many areas also contain hydrogen sulfide and/or carbon dioxide, all of which tend to cause corrosion of the external surface of the drill pipe. In drilling with foam, the amount of water flowing inside the drill pipe is relatively small. It therefore requires only a small amount of an effective inhibitor, such as sodium carbonate, to eliminate or greatly reduce the corrosion inside the drill pipe. However, it is not economical to attempt to inhibit the large volume of produced water on the outside of the drill pipe. It is thus seen that there is a need, which has existed for many years, for an inexpensive and effective way of preventing external corrosion of drill pipe. The present invention discloses such a system. In accordance with the present invention, the drill pipe is cathodically protected, preferably by means of zinc ring members cast in intimate contact with the external surface of the drill pipe.

Various objects and a better understanding of the invention can be had from the following description taken in conjunction with the drawing in which:

FIGURE 1 is a view of a string of drill pipe suspended in the borehole in which the pipe has cathodic protection.

FIGURE 2 is a section view taken along the line 2—2 of FIGURE 1.

Turning now to the drawing, there is illustrated a string of drill pipe 10 suspended in a well bore 12. The string of drill pipe 10 is normally made of high strength steel containing about 0.35 percent carbon and small amounts of alloying elements as chromium, nickel, molybdenum, etc. The string 10 is suspended from the surface by conventional equipment not shown and which also rotates the drill string. At the lower end of the drill string 10 is a bit 14. In the drill string 10 just about the bit 14 is a heavy section of drill pipe 16 which is commonly called a drill collar. The drill string 10 is made up of a large number of sections or joints of drill pipe which are normally about 30 feet long. Shown in FIGURE 1 is an upper section or joint 18 and a lower joint of drill pipe 20. Drill pipe joint 20 is connected to the section of pipe 18 by a tool joint 21 which comprises a box joint 22 and a pin joint 24 all in a conventional manner. It will be noted that the joint 21 is of a greater diameter and therefore of a greater wall thickness than the section of drill pipe itself. The reason for this, of course, is apparent inasmuch as it is the box and pin joint to which normally is applied the slip and other tools for tightening and loosening the joint.

Cathodic protection is obtained for the drill pipe by placing thereon a ring member which is made up of metallic material having an electrode potential more negative than the material of the tubular drill pipe section 20 upon which it is placed. Shown in FIGURE 1 is an upper anode ring 28A and a lower anode ring 28B.
Rings 28A and 28B are in intimate contact with the exterior of drill string section 20. It is preferred that the rings be cast about the pipe section which can be done without affecting the strength of the pipe. The molten zinc alloys with the steel surface, and as the solid zinc cools it shrinks more than the steel, all of which assures intimate and permanent contact between the two metals. The external or outside diameter of the rings should be less than the external diameter of box member 24. The ring members should also be placed as close to the tool joint 21 as possible, so long as the rings do not interfere with the tools used for making and breaking the joints. For example, in a typical 4½ inch drill pipe the zinc ring should be about 8 feet from the open end of the box joint on the section of pipe about 3 feet from the open end of the pin joint. While the ring members 28A and 28B should have a greater relative electromotive activity than the tubular section 20, it is preferred that the ring member be zinc when the drill pipe is steel. However, the invention is not limited to zinc or zinc-rich alloys. Other materials such as magnesium and aluminium alloys may be more suitable than zinc in some applications.

It is preferred that there be a zinc ring 28A and 28B at each end of the section 20. While the zinc is functioning as a galvanic anode, it is slowly consumed so the amount of zinc and the longitudinal length of the zinc ring should be great enough to last for the expected life of the drill pipe. However, it should not greatly increase the weight of the pipe, or have a diameter greater than the tool joints.

Corrosion, as it occurs on drill pipe is an electrochemical process and is associated with the flow of galvanic electric currents. The pipe corrodes at the anodic areas where the current flows from the steel into the surrounding mud or drilling fluid. When a more active or more anodic or more negative metal, as zinc, is in contact with the steel pipe, the zinc becomes active or anodic and it corrodes. Thus, the corrosion is transferred from the pipe to the zinc anode. This process is one form of cathodic protection.

In order to determine an indication of whether the placing of a zinc anode around drill pipe is effective, numerous laboratory fatigue tests were made. The machine employed in these tests was similar to the so-called Kenyon Fatigue Test Machine, described in "Rotating Wire Arc Fatigue Machine for Testing Small Diameter Wire," Proc. A.S.T.M., vol. 35, Part II, p. 156 (1935). In the machine used, there were two bearings, one Babbit metal bearing inclined from the vertical, and the other bearing opposite or counter inclined at a similar angle on the chuck of an electric motor. The wire test specimen was placed in these bearings and was thus held in curved form and in a vertical plane of pipe. The test specimens selected were steel wire with carbon content, heat treatment and physical properties similar to normalized drill pipe. The particular traction steel wire had a carbon content of .03 to .04% and had a tensile strength of about 200,000 psi. One end of the wire was attached to a small electric synchronous motor and the other end was allowed to adjust itself longitudinally in the inclined bearing. Means were provided to count the revolutions of the motor. In that machine, as the specimen was rotated, it automatically eliminated flexural shear at the free end and the specimen assumed the form of a circular arc.

The stress-strain relations for the rotating wire specimen are readily obtained by substituting for the extreme strain which is \( \frac{r}{R} \) in the relation:

\[
[B] = \frac{E \cdot \text{Strain}}{r}
\]

where

\( E \) is the elastic modulus of the wire
\( r \) is the radius of the wire
\( R \) is the radius of the circle in which the wire is bent after insertion in the inclined bearing and the chuck on the shaft of the synchronous motor.

Then the extreme stress is:

\[
\frac{E}{R} \cdot \sin \phi \cdot \frac{C}{2R}
\]

If \( C \) is the distance between the inclined bearing and the chuck, and \( \phi \) is the angle of the inclined bearing from the horizontal, then

\[
\frac{C}{2R} \cdot \sin \phi = \frac{E}{R} \cdot \text{Strain}
\]

Then the stress is:

\[
\frac{E \cdot \sin \phi}{C}
\]

where \( d \) is the diameter of the wire.

The wire specimen being tested was placed in the machine and in a solution of 3% NaCl. The wire specimens, when tested in the machine, each had a calculated stress of 40,000 p.s.i., thereon. The stress was calculated from the above formula. Test A was run on one wire specimen in which there was no cathodic protection. The number of cycles required to produce failure in this non-cathodic protected specimen was about 2.5 \( \times \) 10\(^5\). In another wire specimen in Test B, a zinc ring was molded about the wire in a position so that the ring was likewise submerged in the fluid or solution of 3% NaCl. Except for the zinc ring, Test B was identical to Test A. In Test B, the wire did not break until 102 \( \times \) 10\(^5\) cycles had been obtained. This was a 40-fold increase in life over that of the specimen in Test A which had no cathodic protection. Even then the wire in Test B broke in the air above the solution where cathodic protection was not effective. In the test with the small zinc ring cast on the wire, the potential was lowered to —96 volt almost immediately. These data, which are typical, and numerous other similar tests not herein reported, strongly suggest that zinc rings cast on drill pipe are effective in preventing external corrosion fatigue of the drill pipe.

While there are disclosed above but a limited number of embodiments of the system of the invention herein presented, it is possible to produce still other embodiments without departing from the inventive concept herein disclosed. It is therefore desired that only such limitations be imposed on the appended claims as are stated therein.

What is claimed is:

1. An apparatus for use in the drilling of a borehole in the earth which comprises in combination:
   a metallic tubular member;
   a material in intimate secure contact with said tubular member, such material being metallic and having an electrode potential more negative than the material of the tubular member; and
   a drill bit secured at the lower end of said tubular member.

2. A drill string for use with a bit for drilling a borehole in the earth which comprises:
   a metallic tubular member, a first portion of said tubular member being of a greater diameter than the remaining second portion of the tubular member;
   a zinc ring member surrounding the second portion of said tubular member in intimate and permanent contact, the outside diameter of said ring being not greater than the diameter of said first portion of said tubular member.

3. An apparatus as defined in claim 2 in which said zinc ring member has been cast around the exterior portion of said second portion of said tubular member.

4. An apparatus for use with a bit in drilling a borehole in the earth which comprises:
   a metallic tubular member for supporting said bit within the borehole; and,
   a ring member surrounding said tubular member in intimate contact therewith, said ring member having a
greater relative electromotive activity than said tubular member.

5. An apparatus for use in drilling a borehole in the earth which comprises:

- a metallic tubular member;
- a material in intimate secure contact with the exterior of said tubular member, such material being metallic and having an electrode potential more negative than that of the tubular member;
- a drill bit secured to the lower end of said tubular member; and
- means secured to said tubular member for protecting said material from excessive abrasion by the borehole wall.

6. An apparatus as defined in claim 5 in which said material is cast on the exterior of said tubular member.

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