

March 30, 1954

E. M. IRWIN

2,673,613

APPARATUS AND METHOD FOR FATIGUE DETERMINATIONS

Filed Oct. 17, 1949

2 Sheets-Sheet 2

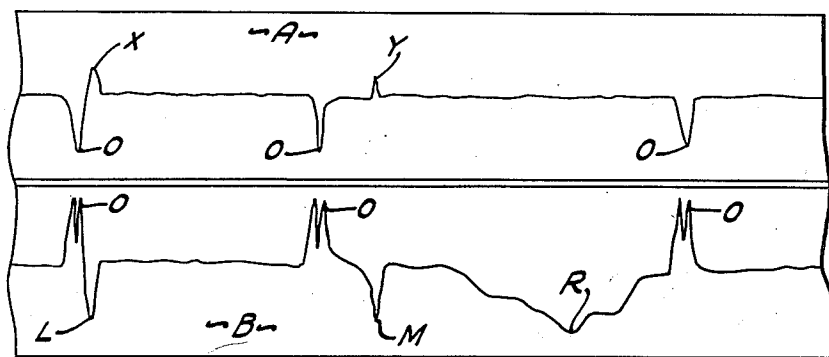


FIG. 2.

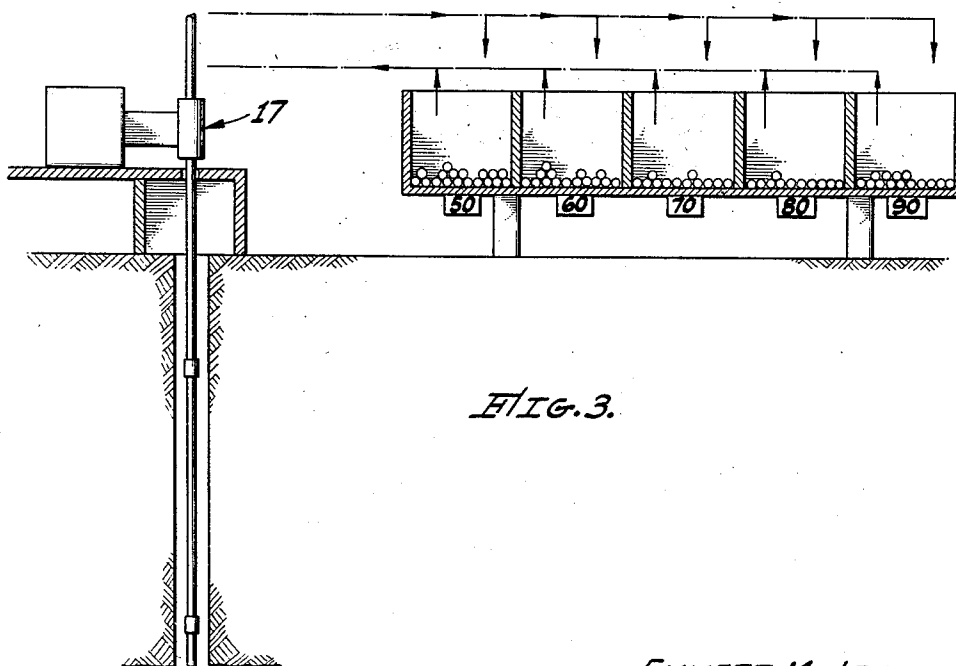


FIG. 3.

EMMETT M. IRWIN,
INVENTOR.

BY *W. J. Quinn*
ATTORNEY.

UNITED STATES PATENT OFFICE

2,673,613

APPARATUS AND METHOD FOR FATIGUE DETERMINATIONS

Emmett M. Irwin, San Marino, Calif.

Application October 17, 1949, Serial No. 121,672

7 Claims. (Cl. 166—1)

1

All known metals have been observed to have the characteristic of failing under certain types of strain, particularly strains which are cyclic in their nature. So long as these strains and stresses do not exceed a certain maximum for any particular metallic unit that unit may well stand up indefinitely. Let the maximum be exceeded, however, and the stresses cycled, failure usually occurs rapidly.

The problems presented by failures in metal through fatigue are general and widespread. They occur not only in structures which support varying loads but also in machines incorporating reciprocating moving parts subject to variations in loads. Wherever metal is subjected to stresses which vary, the problem is present. An outstanding example comprises the drill pipe used in oil drilling which extends downwardly into the earth, sometimes for miles, and also sucker rods used in pumping operation after the drilling is completed. Failures frequently occur in such installations at great depths below the surface and the resulting loss in time and energy is enormous. This oil well drilling equipment is frequently removed from the well, as in placing a new drill bit at the lower end. At such times it would be extremely desirable to remove weakened links or to rearrange them in the setup at positions in which their remaining strength would not be overtaxed. Their blind repositioning in the well without attention to their state of fatigue and in accordance with present methods insures that failure will result and at a position governed solely by chance.

The term "fatigue" has been applied in recent years to cyclic failures in steel. At an earlier time the term "crystallize" was used due, primarily, to the appearance of the steel at the point of failure. It is now understood that if metal is cycled at stresses above certain maximums, which are known as the fatigue limit, failure will eventually occur, and that the higher the stress is above the fatigue limit the more rapidly will that failure occur.

Even today the exact nature of fatigue failure is not completely understood. A great many observations have been made but the phenomenon is one which is difficult to observe as there have heretofore been no non-destructive methods of testing to determine the changes in the material. It has been believed that the hardness of the metal increased at the area of fatigue prior to failure. This has been difficult to determine exactly as a Rockwell or a Brinell test could not be made at the fatigue section as such a test

2

would of itself create a stress raiser building up stresses and strains which would accelerate fatigue failure. Also, hardness tests are never entirely satisfactory for it is impossible to test the identical spot twice. Only approximations are possible, therefore, in hardness testings. In addition to the supposed change in hardness preceding fatigue failure there is a slippage which occurs across the grains of the metal. This can be observed from "photomicrographs" made of the portion of the steel adjacent the failure. Here again the time over which the slippage occurred and its extent are difficult to determine as the only method of determination is by the destructive testing of the specimen.

The present invention provides an accurate non-destructive method of determining the nature and extent of fatigue present in the metal being tested. If one of the dynamometer indicating instruments is adjusted to read voltages which are in phase with the current it will necessarily read the watt loss occasioned by eddy currents. Any change in this loss will be occasioned by the change in the internal resistance of the steel since the voltage creating the eddy current remains substantially constant. Accordingly the dynamometer shows the slightest change or variation in the internal resistance of the steel.

A second dynamometer is adjusted to read voltages which are in quadrature to the current. These second voltages are affected mainly by changes in the stresses present in the specimen and, being in quadrature with the current, are unaffected by the changes reflected on the first dynamometer. The invention, accordingly, indicates two phenomena that occur during the fatiguing of steel, namely, the increase in hardness, and simultaneously the change in internal resistance of the steel.

It has been observed in the use of the present invention that there are several distinct stages in the fatigue failure. At first there occurs an increase in the internal stress in the steel without accompanying change in internal resistance. This gives an apparent change in hardness of the material and is indicated by the out-of-phase dynamometer, no change being indicated on the in-phase dynamometer. As the fatigue progresses further, and the hardness continues to increase, a change in the internal resistance appears, indicating strain, that is, slippage in the grains of the metal. In the latter stages of the failure this slippage increases at an accelerated

3

rate and little change in stress is noted. This relationship continues until failure occurs.

The information gained by testing and determining the fatigue level or the build-up in the stress present may be made use of in a novel manner to insure that upon the replacement of those units in operation under proper conditions they may provide a life comparable to the life of a new unstressed unit. This method has been applied successfully to fatigued oil well rods as will be described.

With an appreciation of the characteristics of metals and of the importance of determining the presence of fatigue therein in order to predetermine failure under load, it is a primary purpose of the present invention to provide a new and improved method and apparatus capable of indicating accurately the presence and the extent of fatigue in metal members.

A still further object of the invention is to provide a method, and an apparatus for carrying out that method, by which metallic units can be tested and simultaneous determinations made of the presence therein of stress and slippage or strain at each point throughout their length.

Still another object of the invention is to provide a new and improved method for increasing the operative effectiveness of used and fatigued parts of apparatuses which includes the steps of determining the presence and the extent of the fatigue present and the repositioning of the units relative to each other in their reassembled condition as to insure that the loads assumed will be in inverse proportion to the fatigue present.

A still further object of the of the invention is to provide a method, and an apparatus for carrying it out, by which a running record may be made electrically of the strain or breaks which are present, and of the stress which is present, in each unit of length of a metallic member.

A still further object of the invention is to provide a method for testing metallic units to determine fatigue therein, and an apparatus for carrying that method out, in which simultaneous determinations are made of the watt loss occasioned by variations in resistance and the change in voltage in quadrature to the current in the specimen, the specimen having been subjected to a cyclic magnetic field.

Still another object of the invention is to provide an improved method, and an apparatus for carrying that method out, in which fatigued metallic members are simultaneously tested to obtain variations in resistance, which readings are correlated upon a continuing record to indicate the internal condition existing within the piece undergoing test.

Referring now to the drawings:

Figure 1 comprises a schematic diagram of the apparatus comprising the present invention, an element under test being shown positioned in the testing unit or coil;

Figure 2 is an enlarged showing of a length of the record showing chart A, which indicates the strain or slip between the grains of metal corresponding to a break which may be microscopic in nature, and chart B, which indicates stress in the unit undergoing test; and

Figure 3 is a flow diagram illustrating the removal of rods from an oil well while being tested to determine fatigue, their classifications according to fatigue present therein, and their relocation in the rod line in accordance with their fatigue condition.

Referring again to the drawings, and to Figure

4

1 in particular, the apparatus comprising the present invention is shown schematically. The exact physical embodiment and details of construction are not of the essence so long as they are such as to enable the unit to perform the functions to be described.

In the drawing a test specimen undergoing test, which may be of continuous length and sectional, is indicated generally by the reference character 10, and is supported for longitudinal movement upon suitable supporting means comprising, in the illustrated form, rollers 11. An exciting unit, indicated generally by the reference character 13, is connected to a suitable source of alternating current, preferably sixty cycles, through leads 14, and is formed with two aligned similarly wound coils P through which the test specimen 10 passes, as illustrated. An operator-controlled knob 16 enables the operator to vary the exciting current in the primary windings P and so to control the strength of the magnetic field created in the specimen undergoing test.

A secondary coil S is positioned midway between the primary coils P; the three coils together form a unit which is positioned right at the test specimen and which may be referred to as the testing coil unit, indicated generally by the reference character 17. Secondary coil S of the testing unit is connected through leads 19 and a double throw switch 15 to an amplifier unit, indicated generally by the reference character 20. Unit 20 may be eliminated if found unnecessary but is provided for purposes of increasing the sensitivity of the unit. A pair of dynamometers, indicated generally by the reference characters 21 and 22, have their movable coils 23 and 24, respectively, connected directly to the output of amplifier unit 20. In the event the latter is eliminated coils 23 and 24 would be connected directly to the double throw switch 15 and there-through to the leads 19 of the secondary S. The armature 26 of each dynamometer is suitably suspended, being controlled in its movement by the coils 23 and 24 in the respective units, and extends into operative relationship to its own chart on a continuously moving paper record sheet 25. Record 25 is provided with two continuous charts indicated by the reference character A for dynamometer 21 and by the reference character B for dynamometer 22. The record roll is suitably supported upon a roll 28 at its upper end and is drawn onto a roll 29 at its lower end after passing the armature 26 which in each instance is provided with suitable marking means capable of placing on the charts a continuous running record of their own displacement. Roller 29 is connected to and is driven by a driving unit 31 connected by suitable means, such as a shaft 30, to the rollers 11 so that the speed of travel of the record is synchronized with the speed of travel of the elements being tested.

The field piece of each dynamometer includes a field exciting winding 33 connected through leads 34 to the two-pole concentrated windings 36 of a phase-shifting unit indicated generally, in the case of that unit connected to dynamometer 21, by the reference character 37, and in the case of that unit connected to dynamometer 22 by the reference character 38. Each phase shifter is connected through suitable leads 39 to a suitable three-phase source of alternating current of the same frequency as the current impressed upon the exciting unit 13 through the

5

leads 14. Each phase shifter 37 and 38 includes a rotatable knob 41 by which the angular position of the two-pole concentrated winding 36 of the connected phase shifter can be angularly adjusted for the purpose of controlling the phase of the secondary output into the leads 34 connected to the dynamometer exciting windings 33. Each knob 41 is provided with a dial 42 calibrated in degrees to indicate the angular relationship of the current and voltage in the secondary.

In addition to the elements which have been described and which comprise the continuously functioning parts of the apparatus, there are provided certain other units which are important for purposes of calibration and of initial setting. It is extremely desirable that a null balance be provided in the circuit of secondary S with a standard, unfatigued, unbroken unit positioned in the test coil unit 17. With the exciting fields of the dynamometers 21 and 22 properly energized in the manner to be described, and with the marking end of the armatures 26 operatively related with respect to their charts A and B, it is desirable that no indications be given by the secondary circuit of winding S in order that the pointers upon the armatures can be properly related to their zero positions. The presence of a winding 46 in one of the leads 19 leading to secondary S positioned in inductive relationship to a similar winding 47 enables the operator, by the adjustment of knob 48 of a unit 43 to vary the flow, including the phase, of current into the winding 47 and so oppose, to the extent necessary to render a null balance, the current flowing in the leads 19. The balance unit comprising a combined phase shifting and resistance unit 49, is provided with alternating current through leads 51 of the same frequency as that impressed upon leads 14 of exciter unit 13.

Before beginning a test it is important that the current flowing through exciting windings 33 of dynamometers 21 and 22 be so adjusted that the current in coil 33 of dynamometer 21 is in phase with the current impressed through leads 14, while the current flowing through winding 33 of dynamometer 22 is in quadrature therewith. To obtain this result and to make possible the necessary adjustments a pair of leads 56 are connected across a voltage drop 57 in the circuit of primaries P and are connected to a pair of fixed contacts of double throw switch 15. With the latter positioned as to conduct current from leads 56 to amplifier 20 voltage which is in phase with the initial exciting current is impressed upon the movable coils 23 and 24 of dynamometers 21 and 22, respectively. As dynamometer 21 is to measure in-phase voltage changes at this time, and while its movable coil 23 is connected as just stated, the phase shifter 37 is adjusted by its movable knob 41 until the current in exciting winding 33 is in phase with the current in movable coil 23. This relation is present when the right-hand displacement or deflection of armature 26 is a maximum. Then the dial 42 at the adjusted knob 41 is adjusted to give a zero reading.

Turning now to the calibration of dynamometer 22, its phase shifter 38 is adjusted until the current in its coil 33 is in phase with the current in movable coil 24 at which time the armature 26 will have a maximum deflection to the right. If then the dial 42 on its knob 41 is adjusted to zero and thereafter the knob 41 turned through ninety degrees to a reading of 270 the phase

6

shifter 38 will have been positioned as to effect a shift in the current in coil 33 so that it is in quadrature with the current in coil 24.

An alternative and possibly a preferred method of calibration of dynamometers 21 and 22 is in each instance to adjust the connected phase shifters so that the armature displacement is a minimum, that is, zero. In this case in each instance the current flowing through the dynamometer exciting winding 33 would be in quadrature with the current in the movable coil 23. In this adjustment following such a step no further adjustment would be necessary in the case of dynamometer 22, while in the case of dynamometer 21 the knob 41 would be rotated through ninety degrees, as indicated by the dial 42, so as to bring the current in exciting coil 33 from quadrature relationship to in-phase relationship with the current in movable coil 23.

In the operation and use of the present invention let it be assumed that the apparatus is positioned at the oil well and sucker rods are to be withdrawn and tested. The testing coil unit 17 is positioned at the top of the well so that the rods will travel upwardly through as they are pulled from the well. The remainder of the apparatus may be positioned at a distance and connected suitably through cables. In one preferred form the apparatus is mounted in an automotive truck positioned as close as convenient to the well.

Before the pulling operation begins a standard test specimen is placed in the testing unit coil 17, a null balance is obtained by the adjustment of the resistance phase-shifting unit 49, and the phase shifters 37 and 38 are adjusted so that current flowing in exciting coil 33 of dynamometer 21 is in phase with the exciting current, while the current flowing in exciting coil 33 of dynamometer 22 is in quadrature with it, as previously described. The driving unit 31 of the recording unit is suitably connected to the rollers 11 of the test unit so that the travel of the charts will be synchronized with the movement of the rods. All is then in readiness for the test.

In the test itself the operator need only check to see that the various parts are performing their intended functions. Electrical adjustments having been made as stated the unit is self-operating, and as the rods are pulled from the well and through the test coil unit 17 a continuous record is made in charts A and B. As the apposed portions of the two parts indicate the characteristics of identical parts of the rods being tested it is possible by reading the charts together to determine the exact condition existing in each rod.

Referring to Figure 2 in particular, a portion of the running record comprising charts A and B is shown. It is to be remembered that chart A indicates the in-phase voltage, while chart B indicates the quadrature voltage as determined by dynamometers 21 and 22, respectively. Deflections in the two graphs which are opposite each other comprise indications taken at the same position in the elements being tested. In curve A the normal straight-line portion of each curve comprises the null balance point, the deflections upward, corresponding to movement in Figure 1, indicate points of higher electrical resistance which may be produced, and in the cases of points X and Y, are produced, by flaws or fractures. In the case of chart B it is noticed that directly opposite points X and Y of chart A are points L and M, respectively, which indicate

stress and fatigue in the rod being tested at the exact point at which a fracture has occurred as indicated in chart A. The maximum deflections indicated by the points O on both the charts are without significance as they represent variations resulting from the rod joints passing through the testing unit. Attention is particularly directed to point R in chart B which is a point of maximum deflection in a long, gradual curve. This represents a rod which is fatigued throughout a large part of its length, the maximum fatigue being at point R. No fracture has occurred in the rod as yet as indicated by the absence of any deflection to the left on chart A opposite point R. A rod of this type has been greatly weakened by fatigue and will fracture if unduly loaded. However, if no fracture is present and the rod in its future use is subjected to much lighter loads it can continue to function just as satisfactorily as a new rod.

The rods are pulled continuously from the well during the operation and each rod is charted as to its characteristics in the running record, as described. As the rods are pulled from the well they are disconnected one by one and removed to storage racks, as illustrated diagrammatically in Figure 3, bearing the reference characters 50, 60, 70, 80, and 90. Rack 50 is to receive rods substantially unstressed, unstrained, and in almost perfect condition. Rack 60 will receive the next classification of rods and so on until the rods which have entirely served their usefulness and are so defective as to be entitled to no further confidence will be placed in rack 90. Those rods placed in rack 90 will not be used again, but the rods classified in racks 50, 60, 70, and 80 will be used again and will be so positioned in the well that the loads to which they are subjected will not be in excess of their strength. As the rods at the upper end of the well are subjected to the greatest loads it follows that the poorest reusable rods, those in bin 80, will be taken first and will be repositioned lowest in the well to be followed by the rods in bin 70, then the rods in bin 60, and finally the rods in bin 50 which will be connected to new rods replacing those discarded in bin 90.

This classification of rods as they are withdrawn from the well and their repositioning, a movement indicated by the arrows in Figure 4, makes possible the intelligent and safe reuse of fatigued rods. Were the rods to be reused without being classified and repositioned according to strength unnecessary failures would occur in many instances, for the weakest rods would sometimes be positioned in the line at points in which they would be subjected to stress in excess of a safe maximum in view of their weakened condition. Under this repeated stress they would fail whereas if positioned where they would not be overstressed they might have lasted indefinitely.

While the particular apparatus herein shown and described in detail is fully capable of attaining the objects and providing the advantages hereinbefore stated, it is to be understood that it is merely illustrative of the presently preferred embodiment of the invention and that no limitations are intended to the details of construction or design herein shown other than as defined in the appended claims.

I claim:

1. In an apparatus for determining fatigue damage in a magnetizable element comprising a first coil to impress an alternating current field upon an element being tested and means to indi-

cate the presence and extent of fatigue damage, said means including a second coil positioned in inductive relationship to said element as to have induced therein a current flow by the magnetic field of said element, a pair of dynamometers each including an indicating armature coil connected to said second coil and an exciting field coil, current sources each including an operator adjustable phase shifter connected to said exciting field coils to supply current in phase with the current in said armature coils to one of said exciting coils and in quadrature to the current in said armature coils to the other of said exciting coils, and an adjustable combined phase-shifting-and-resistance unit connected in inductive relationship to the circuit of said second coil and said armature coils to obtain a null balance for said armature coils with a standard unfatigued specimen element operatively positioned relative to said first and second coils.

2. A method of servicing multiple length sucker rods in a well comprising the steps of withdrawing said rod from the well, impressing an alternating current magnetic field upon said rod progressively along its length as it is withdrawn, simultaneously inducing into a fatigue indicator unit a current flow by the magnetic field of said rod, recording on a continuous record synchronized to the withdrawal of said rod the voltages which are in-phase with and in quadrature with said indicator current to indicate the fatigue in the individual length of rod, segregating the individual lengths of said rod having generally similar fatigue indications into groups, and replacing said rod in the well by groups with the group of rods having the indications of greatest fatigue at the bottom and the group having the indications of least fatigue at the top.

3. A method of servicing multiple length sucker rods in a well comprising the steps of withdrawing said rod from the well, impressing an alternating current magnetic field upon said rod progressively along its length as it is withdrawn from the well, inducing a flow of current in a testing circuit by the magnetic field present in said rod at a particular point past which said rod is moved in being withdrawn, recording on a first continuous record the voltage of the induced current in said testing circuit which is in phase with the current, simultaneously recording on a second continuous record the voltage of the induced current in quadrature with said current, said first and second continuous records being synchronized with each other and with the rate of withdrawal of said rod from the well, comparing said voltage records to determine the fatigue in the individual lengths of said rod, classifying and segregating the lengths of said rod having substantially the same fatigue records into groups, and returning said lengths of rod to said well, the lengths of rod of the group having least fatigue being positioned in the well at the height therein at which maximum loads are encountered while the lengths of rod of the groups having greater fatigue are positioned in the well at heights such that the loads thereon are proportioned in accordance with the likelihood of fatigue failure.

4. The method recited in claim 3 characterized in that the lengths of rods in the groups having the smallest in-phase voltage are discarded.

5. The method recited in claim 3 characterized in that the lengths of rods for which the in-phase voltage records disclose minimum voltage

at one or more points along each length are discarded.

6. The method recited in claim 3 characterized in that the lengths of rods for which the in-phase and quadrature voltage records indicate substantially constant voltages for the entire length of rod are repositioned in the well as to assume greater than minimum loads.

7. The method recited in claim 3 characterized in that the lengths of rods for which the quadrature voltage record discloses substantial variations from an established norm are reassigned to heights in the well at which less than maximum loads are present.

EMMETT M. IRWIN.

References Cited in the file of this patent

UNITED STATES PATENTS

	Number	Name	Date
5	1,686,815	Imes -----	Oct. 9, 1928
	1,813,746	Kinsley -----	July 7, 1931
	1,897,634	De Forest -----	Feb. 14, 1933
	1,906,551	De Forest -----	May 2, 1933
	1,933,547	Drake et al. -----	Nov. 7, 1933
10	2,098,991	Zuschlag -----	Nov. 16, 1937
	2,124,579	Knerr et al. -----	July 26, 1938
	2,290,330	Irwin -----	July 21, 1942
	2,405,859	Somes -----	Aug. 13, 1946
	2,435,985	Stewart et al. -----	Feb. 17, 1948
15	2,507,863	Mesh -----	May 16, 1950