1958

The development of a device to replace the oil well dynamometer

Jerry Bernard Overton

Recommended Citation

Overton, Jerry Bernard, "The development of a device to replace the oil well dynamometer" (1958). *Masters Theses*. 2542.
https://scholarsmine.mst.edu/masters_theses/2542

THE DEVELOPMENT OF
A DEVICE TO REPLACE
THE OIL WELL DYNAMOMETER

BY

Jerry Bernard Overton

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, MINING ENGINEERING--

PETROLEUM ENGINEERING OPTION

Rolla, Missouri

1958

Approved by J. P. Govier
Professor of Petroleum Engineering

ACKNOWLEDGEMENT

The author is deeply indebted to the following men whose assistance was invaluable: Dr. George B. Clark, Chairman of the Mining Department; Professor J. P. Govier, Petroleum Engineering Department; Professor R. F. Davidson, Chairman of the Mechanics Department; Professor R. D. Caudle, Mining Department; and Mr. Don Bordon, Electrical Engineering Department.

The Lufkin Pump Company very generously donated the complete pump installation. A J-F dynamometer was loaned to the Mining Department by Johnson-Fagg Engineering. The author is also grateful to the Texas Company for allowing him to test the strain recording apparatus in their Illinois District and to the District Texaco Engineering staff for providing many helpful suggestions.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

The mechanical dynamometer is recognized as being a valuable tool in measuring resultant forces acting on the polished rod of an oil well pump. The dynamometer is used extensively to determine loads, torque, and horsepower. "It is also used to determine pump action and trouble-shoot for any seemingly abnormal pumping condition."(1)

Although it is desirous to periodically make dynamometer studies, it is also very time consuming. Because of high labor costs, it has been almost discontinued by many companies. The author became convinced that a less costly method of obtaining the same information could be developed. This method was the use of electrical resistance strain gages and a recording oscillograph.

In order to compare the two methods, a study was made of the dynamometer and its operation. Following this study, several tests using both the dynamometer and the oscillograph were made on the simulated well,

---

(1) Fagg, L. W., Dynamometer Charts and Well Weighing, Petroleum Transactions, A.I.M.E., Vol. 189, 1950.

M.S.M. No. 1. Finally, a test was made on an actual producing well in Illinois, Texas Company's Teatman No. 1. The remaining part of the thesis contains: The Selection of Proper Equipment; The Development of Operational Procedure; The Laboratory Testing; The Field Testing; and the Conclusion.

THE OIL WELL DYNAMOMETER

"The polished rod dynamometer has been for many years a recognized tool for measuring loads, torques, and horsepower. It is also used to determine pump action and trouble-shoot for any seemingly abnormal pumping condition."(2)

A dynamometer card is a continuous recording of the resultant of all forces acting along the axis of the polished rod at any instant during one pumping stroke. The load is recorded with respect to polished rod position: i.e., load versus displacement.

Each point on the load curve represents a force, which is the resultant of the following component forces:

1. The total weight of the sucker rod string in the well fluid.

2. The total weight of the fluid on the pump plunger. This is a tensional force due to the volume of fluid in the tubing above the plunger.

3. Accelerating factors, either positive or negative. The rod string is constantly accelerating or deaccelerating causing dynamic force on the rod acting opposite the direction of acceleration.

---

(2) Fagg, op. cit., p. 2.

4. All forces resulting from friction between the sucker rods and tubing, and sucker rods and well fluid.

5. Any additional forces due to vibration of the sucker rod string.

6. Special forces caused by abnormal conditions in the well. One example of this would be the movement of unanchored tubing.

The dynamometer card is a composite record from which load analysis can be made in both directions; that is, through the rod string to the downhole pump and through the pumping unit to the prime mover. It is the basis for stress analysis of the entire lifting system.(3)

In order to illustrate the method of analysing a dynamometer card, a typical card, figure #1 was chosen.

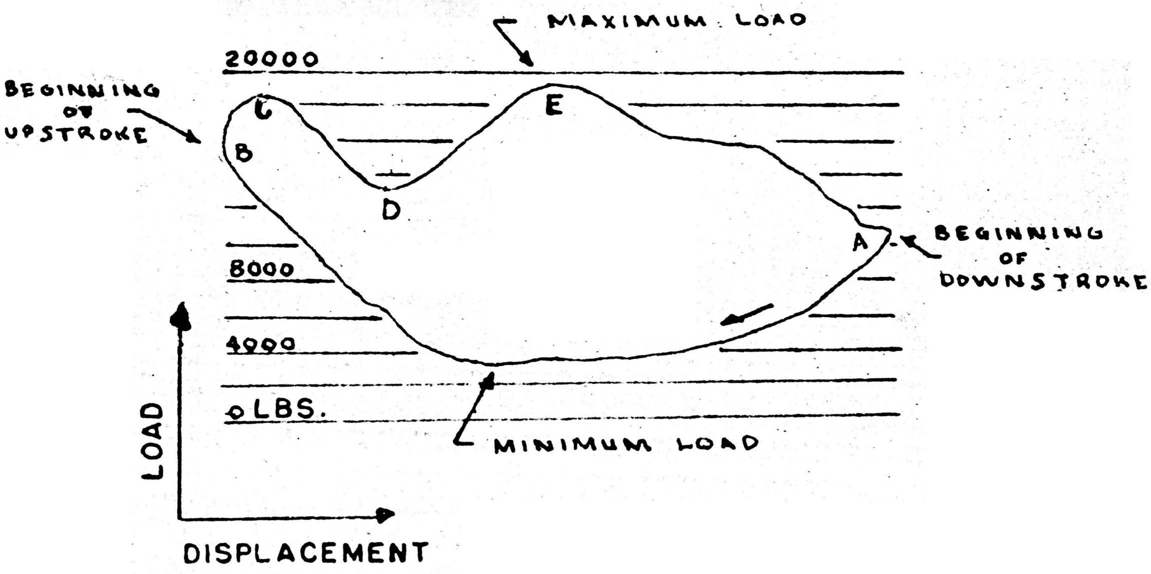
Point A represents the end of the upstroke and the beginning of the downstroke. As the polished rod starts down there is an immediate decrease in load. This shows that the traveling valve in the pump opened at the beginning of the downstroke and the weight of the fluid is now supported by the tubing.

The minimum load occurs a little past the center of the downstroke, and beyond this point the load increases to point B. Note that in this range, the pump is still in its downstroke, but the load increases

---

(3) Bethlehem Steel Company, Sucker Rod Handbook, No. 336, pp. 145, 1953.

FIGURE ONE
TYPICAL DYNAMOMETER CARD



considerably. This phenomenon is due to acceleration forces. The rod string reaches its maximum velocity somewhere near the center of the downstroke, then deaccelerates to a zero veloctiy at point B. The inertia forces due to acceleration are the reason for an increase in load while still in the downstroke region. At the instant of direction reversal, the rods have an inertial force causing them to elongate (overtravel) which explains the continuing increase of load from point B to C. From point C to D the recoil action of the sucker rod string returns some of the energy, which was stored up during the previous elongation of the string. This causes the decrease in load from points C to D. The load begins to increase as the pump continues on the upward stroke and the weight of the fluid acts on the traveling valve which closed at the beginning of the upstroke. Point E represents the maximum load and is usually reached about the middle of the upstroke. The decreasing load from that point to the end of the upstroke is caused by the inertia forces acting opposite the direction of acceleration. This completes the cycle and the pump again starts the downstroke.

It is impossible to define what is generally referred to as a "normal" card. Actually all cards are normal for the conditions under which they are taken, assuming complete accuracy has been used in obtaining the card. However, there are typical characteristics which can be associated with a particular well condition.

Analysis of the four basic influencing factors may determine whether the dynamometer card taken is typical or at least somewhere close to what should be expected as to shape, and maximum and minimum loads.(4)

In order to simplify the discussion, factors influencing the basic shape of the card will be taken in order of their importance.

1. Speed and Pumping Depth

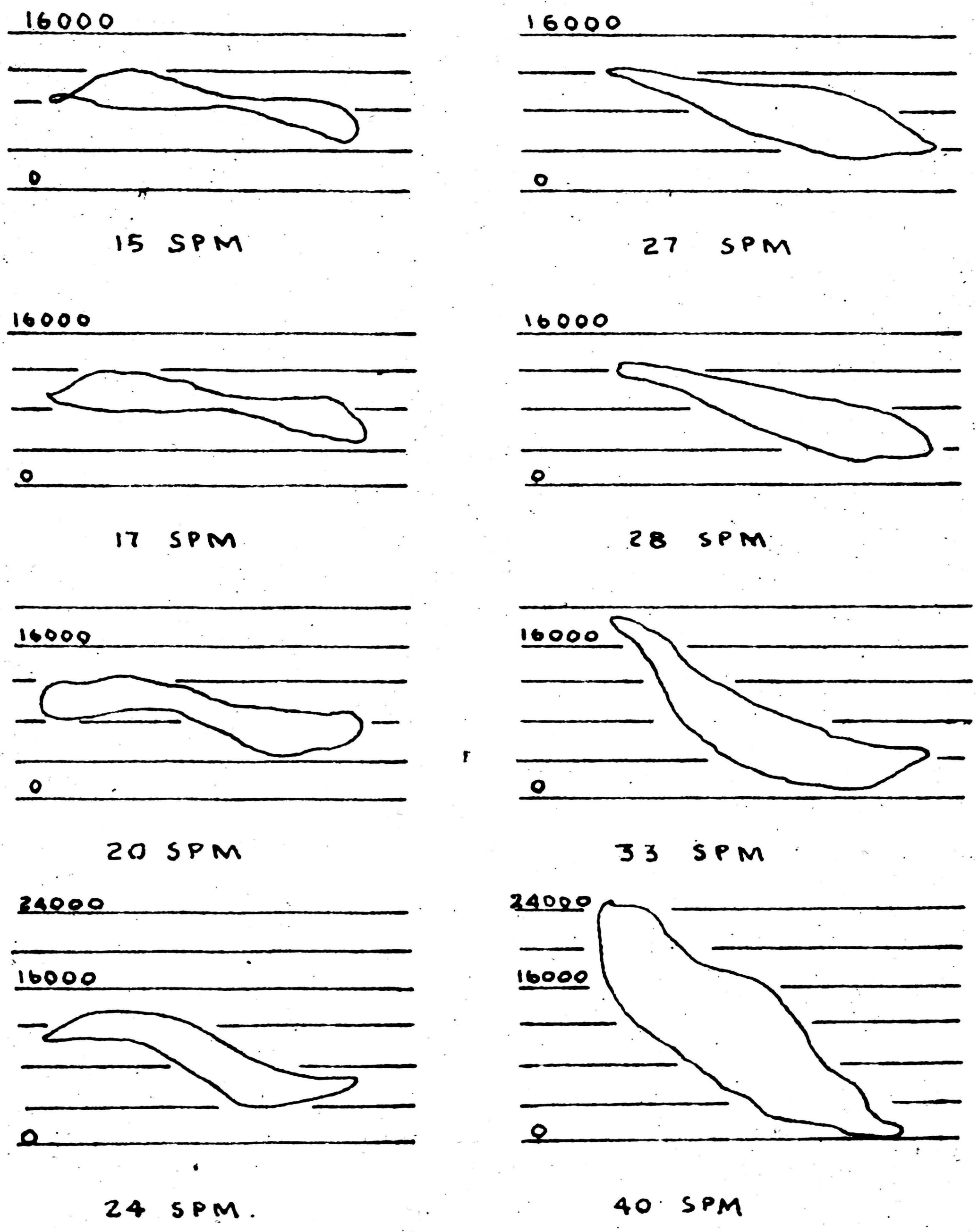
In a well which is pumping and has an apparent volumetric efficiency of 75% or over, the speed of operation and pumping depth should determine the general shape of the dynamometer card. The forces due to vibration and acceleration are affected by the speed change. Figure #2 illustrates speed changes on the same well on the same day.

The total weight of the fluid depends partially on the depth of the well; therefore, a larger volume of fluid above the plunger will cause a greater maximum load. Figure #7 shows the effect of depth change on wells of the same pump size and operating at the same speed. These are representative shapes.

---

(4) Bethlehem Steel Company, op. cit., p. 145.

FIGURE TWO
SPEED CHANGE



15 SPM

27 SPM

17 SPM

28 SPM

20 SPM

33 SPM

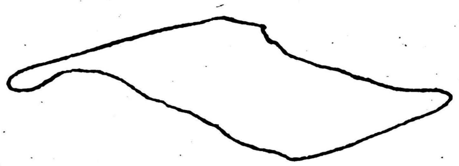
24 SPM.

40 SPM

FACTORS THAT INFLUENCE THE SHAPE
OF THE DYNAMOMETER CARD

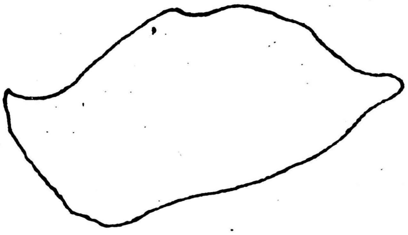
FIGURE THREE
WATER INFLUX

1 st. Year



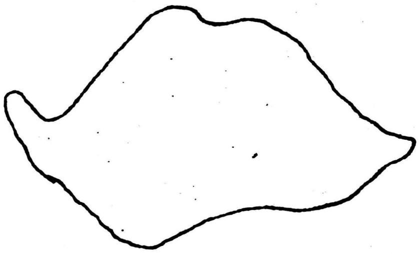
MAX. LOAD 12800 LB
OIL 453 BPD
WATER 0 BPD

2 nd. Year



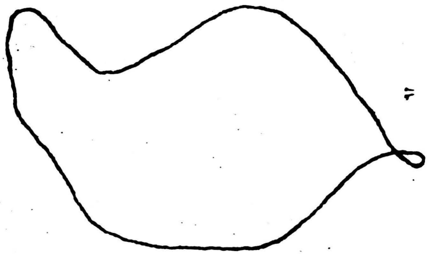
MAX. LOAD 18600 LB
OIL 189 BPD
WATER 199 BPD

3 rd. Year



MAX. LOAD 18900 LB
OIL 152 BPD
WATER 205 BPD

4 th Year



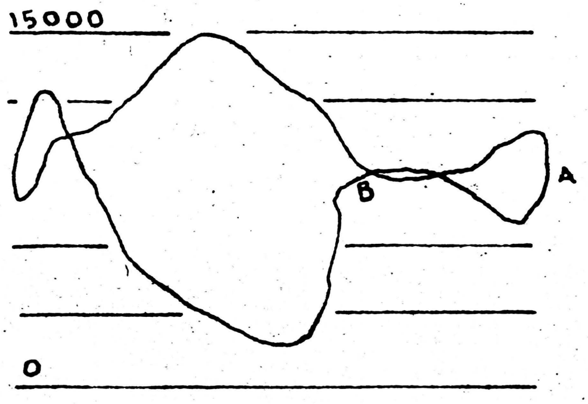
MAX LOAD 18900
OIL 129 BPD
WATER 205 BPD

The influence of water influx on dynamometer over a peroid of four years - note the increased horsepower.

FACTORS THAT INFLUENCE THE SHAPE OF THE DYNAMOMETER CARD

FIGURE FOUR

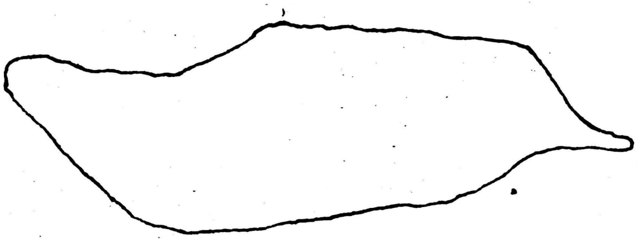
FLUID POUND



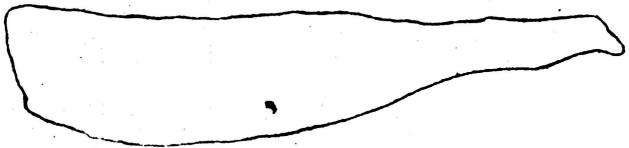
NOTE: In moving from A to B
the rod string is in compression

FACTORS THAT INFLUENCE THE SHAPE OF THE DYNAMOMETER CARD

FIGURE FIVE
FLOWING



NORMAL LOAD

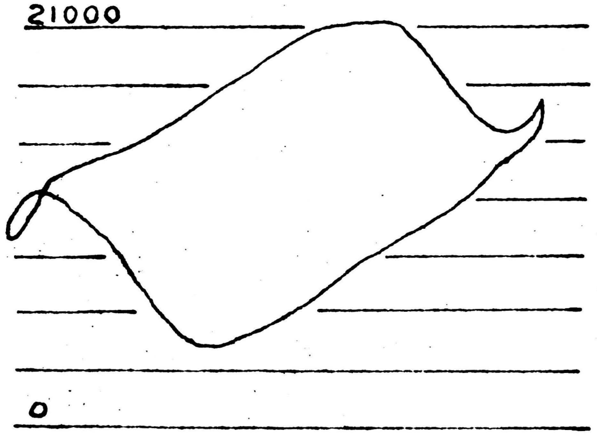


SOME AGITATION AND FLOWING

FLOWING

FACTORS THAT INFLUENCE THE SHAPE OF THE DYNAMOMETER CARD

FIGURE SIX
FRICTION

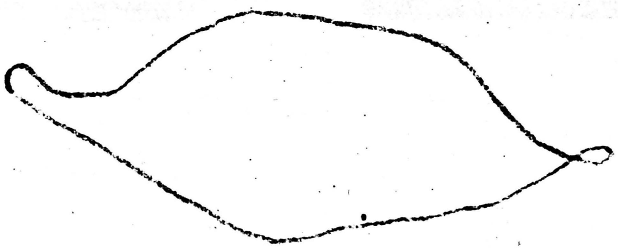


Note the undertravel due to friction

FACTORS THAT INFLUENCE THE SHAPE OF THE DYNAMOMETER CARD

FIGURE SEVEN
DEPTH CHANGE

DEPTH 2275' MAX. LOAD 6800#



DEPTH 5050' MAX. LOAD 23,600#

FACTORS THAT INFLUENCE THE SHAPE OF THE DYNAMOMETER CARD

2. Fluid Characteristics

Fluid characteristics may greatly influence the shape of the dynamometer card. Two such conditions would be the production of large amounts of water, and a well that is semi-flowing with large amounts of gas present. In producing large amounts of water, which has a higher specific gravity than oil, the maximum load on the rods will be greater. Conversely, if the production fluid is gaseous, it will require less force to lift it to the surface. In the case of a semi-flowing well, the reservoir pressure helps lift the oil and also decreases the required force to lift the oil. Figures #3 and #5 illustrate these conditions. One should notice the changes in maximum and minimum loads and polished rod horsepower.

3. Fluid Pound

Fluid pound will always show on a dynamometer card. In order to visualize more easily what happens when a well is pounding, figure #4 is given as an illustration.

"The polished rod travels from A to B before the traveling valve in the pump opens. This means the approximate top third of the pump barrel is filled with gaseous fluid, which must be compressed to a pressure in excess of the fluid weight above the traveling valve before the traveling valve will open. In this case (3500 feet pumping depth) the pressure amounts to about 1400 psi. At point B the pressure below the traveling valve must exceed 1400 psi. When the traveling valve is opened the fluid load is instantly transferred from the sucker rod string to the tubing. The fluid weight is now supported by the standing valve instead of the traveling valve. In this case we have a sudden reduction in load amounting to 8950 lb."

"In moving from A to B the sucker rods in the lower part of the string are subjected to a compression load, which causes a buckling action. When the traveling valve opens at B the sucker rod string is snapped straight in a very short interval of time. This action is commonly termed bending and flexing of the rod string."(5)

4. Friction Factors

In areas where there are a great many very crooked holes, almost any shaped card can be obtained. Both loads and horsepower requirements are generally higher than the theoretical. Figure #6 shows such a well, which has a maximum deviation from the vertical of 32°. A definite undertravel is evident on these cards.

Design of Pumping Installations

Aside from determining various abnormal conditions from the shape of the dynamometer card, several important quanitative results may be obtained from the

---

(5) Bethlehem Steel Company, op. cit., p. 149.

dynamometer.(6) These are peak loads, peak torque, and horsepower requirements in conjunction with the design and selection of a pumping unit.

In the selection and design of a new pumping installation, attention must be given to the following factors:(7)

1. Load
    a. Static
    b. Dynamic
2. Speed
3. Torque
4. Horsepower
5. Efficiency

Several of these factors may be calculated theoretically, but sometimes a better method is the determination of these factors on similiar wells using the dynamometer.

Load (Static). The static or dead weight of sucker rods is the simplest factor to measure in making a dynamometer study. The dead weight of the rods in fluid may be checked with the dynamometer by stopping the motion on the downstroke so the full fluid column is supported by the standing valve and tubing.

This is also a check of the standing valve's operation. If the standing valve is leaking, the dead

---

(6) Johnson, D. O., Pumping Well Problem in Focus, World Oil, Jan. 1956

(7) Ibid.

weight of the rods in fluid will change materially over a short period of time, due to the transfer of fluid weight back to the rod string.

Load (Dynamic). Dynamic load is the load actually recorded by the dynamometer consisting of all the component forces acting on the polished rod. Simple calculations of peak load and minimum load serve to indicate whether the recorded load is in line with expectations. When the load is greater or possibly less, there is an indication of some undesirable forces acting on the system. Unknown friction forces can make measured loads considerably above the calculated loads and can alter the position of the peak load on the pumping cycle. Figure #6 shows an example of high friction caused by such factors as crooked holes, paraffin, heavy viscous fluid and slack in tubing.

Speed. The effect of speed, especially high speed, may produce many undesirable factors. One should remember that the strokes per minute at which a pump operates determines the number of major reversals of stress on the rod string. This is the greatest single factor in consideration of fatigue failures. Everything else being equal, increased speed means increased peak load, and increased horsepower requirements.

Speed can cause undue friction and also has an effect on counterbalance and pump efficiency. Speed should be controlled to avoid these undesirable effects.

Torque and Horsepower. Mathematically expressed, torque is the product of the tangential force on the crank multiplied by the perpendicular distance from this force vector to the center of rotation. This changes continually in the operation of the pumping unit and reaches two peaks, one on the upstroke and one on the downstroke.

"It was formally recognized by the American Petroleum Institute that pumping units should be rated on a peak torque basis, but no attempt was made to define just how this peak torque should actually be measured in the field."(8)

A method has been devised using the dynamometer, together with a tachometer and a timing cycle curve to determine both the instantaneous torque and horsepower. This is a long and intricate calculation and will not be taken up in this discussion. The important thing is that the determination of actual, instantaneous torque and horsepower is possible using the dynamometer.

The horsepower calculations are useful in determining the requirements of the prime mover, and the

---

(8) Johnson, op. cit., p. 9.

mechanical efficiency of the entire pumping system. The theoretical horsepower can be compared to the actual horsepower to determine mechanical efficiency.

Efficiency. The dynamometer may be used to evaluate the downhole pump efficiency. "The term "apparent volumetric efficiency" was first proposed by Marsh, and designates the ratio of the actual displacement of fluid at the surface in barrels per day to the total volume in barrels per day displaced by the full area of the pump plunger, assuming that the plunger travel is the same as the polished rod travel."(9)

If the apparent volumetric efficiency is less than 75%, the downhole pump is probably not operating properly. From the shape of the dynamometer card, the cause of this defectiveness may be determined. Overtravel and undertravel of the plunger will cause a low efficiency. (See figure #6) Also any defects in the mechanisms of the downhole pump will lower the output of the well.

---

(9) Bethlehem Steel Company, op. cit., p. 98.

EQUIPMENT

Strain Gages

The strain gage method of measuring dynamic load is nothing new, but is in common practice in many industries because it is accurate and yet simple to use. The load is determined by first measuring the strain.

The gage is a short length of wire which is firmly fixed to the test specimen. When the specimen is elongated or compressed the length of the wire changes accordingly, resulting in a change of the electrical resistance of the wire. If this wire is used as one leg of a properly balanced wheatstone bridge, the change of resistance will cause an unbalance and the resulting voltage signal can be recorded. In the ordinary minute ranges of strain, this signal will be very small and large amplification is needed in order that the voltage change is made large enough to be recorded. The gages will accurately measure a strain as small as one micro inch per inch.

Amplifier and Recorder

The amplifier and recorder are standard equipment which will take any voltage signal from a transducer and record it. The transducer could measure strain, temperature, pressure, velocity, or acceleration. This fact may add to the usefulness of the equipment aside from recording polished rod loads.

The amplifier used was a Brush Universal Amplifier which is both a high gain carrier amplifier and a medium gain D. C. amplifier. The amplifier receives the voltage signal from the strain gage. This signal has a maximum magnitude of about 100 micro-volts and is amplified to about 1 volt, which is the required voltage to operate the oscillograph. Also included in the amplifier is a wheatstone bridge. This bridge is so constructed that the strain gages may be included as arms of the bridge and the bridge balanced.

The recorder is a Brush single pen direct writing oscillograph with a frequency response up to 100 cps. The oscillograph has a magnetic galvanometer which receives the voltage signal and activates the ink pen. There are three paper speeds: 5 mm/sec., 25 mm/sec., and 125 mm/sec.

Mechanical Dynamometer

The dynamometer used was a Johnson-Fagg ring type dynamometer. This type dynamometer is in frequent use in the oil industry. The load is applied to a proving ring and recorded by a magnifying stylus on a waxed paper. (See figure #9B)

Pumping Installation

Closely associated with the primary purpose of the research, the use of strain gages on an oil well polished rod, was the installation of the simulated test well. In fact, this proved to be by far the most difficult and time-consuming portion of the project.

The simulated well consists of three basic parts: (1) the foundation and shaft; (2) the prime mover and pump; (3) the loading device and hydraulic equipment.

A thirteen foot shaft was sunk and reinforced concrete walls were poured to support the sides. The shaft accomodates the cylinder and hydraulic line. A six inch concrete slab together with the necessary foundation was installed to support the pumping unit.

The pumping unit is a Lufkin T7L3A unit with a maximum stroke of 36" and peak polished-rod load of 6000 lbs. The prime mover is a General Electric 10 horsepower motor with automatic timer controls.

All of the above mentioned equipment is stock equipment which is in general use in the oil industry. The problem that then presented itself was the method of applying a load to the pump. Certainly, it was not feasible to drill a well and install sucker rods. It was decided to use a cylinder and piston arrangement which would displace oil from the cylinder to a reservoir tank. As the cylinder displaces the oil, a load is imparted to the polished rod.

The cylinder is approximately 12 feet long with an inside diameter of 13 inches. It is placed vertically in the shaft and supported from the top by "I" beams across the shaft. The piston has three O-rings and is attached directly to the polished rod. With the fluid above the piston, the upward motion of the piston forces the fluid out of the cylinder into a reservoir tank. Air pressure is applied to the tank so that on the downstroke the fluid is forced back into the cylinder. It is possible to operate the system merely with air pressure in lieu of oil. The system is provided with a gate valve and air regulator to enable one to vary the load. The maximum peak polished rod load is easily attained with relatively small pressures. This is a closed system and retains the original fluid.

APPLICATION OF THE STRAIN GAGES

One of the most important steps in preparing for the test is the application of the strain gages. The strain readings will be erroneous if the gages are not securely glued to the polished rod. The surface to which the gage is to be applied must be absolutely clean and free from traces of oil and grease. This was accomplished by scrubbing the surface with carbon tetrachloride. Finally the surface was wiped clean with acetone and a liberal coat of SR4 13.41 cement was used to fix the gage to the rod. The gages should dry for at least twenty-four hours. The lead wires were soldered to the gage and then firmly taped to the rod. A neoprene coating was sprayed on the gages to waterproof them.

Standard Baldwin-Lima A-3 strain gages with 120 ohms resistance were used. Two gages were fixed on opposite sides of the polished rod. (See figure #9A) The gages were positioned on the vertical axis to read tension or compression in the polished rod.

In testing the pumping cycle, the gages will always be in tension if we assume no bending moment is present. This seems to be a valid assumption, if one notes the manner in which the polished rod is connected to the horsehead. The hanger is supported by two vertical cables which are fastened to the horsehead. (See figure #9B) If the horsehead is directly above the hanger the cables cannot exert any horizontal force. With no horizontal force present, there will be no resulting bending moment.

If the unit is not properly aligned, causing a bending moment to be present, the arrangement of the strain gages and the method of connecting them to the bridge will nullify the signal. The output of the bridge circuit will be zero if two gages are connected in opposite arms of the bridge circuit and subjected to strains of equal magnitude and opposite sign. With a bending moment present, one gage will be in compression and the other in tension, causing the equal negative and positive signal to cancel, leaving only the strain signal due to the polished rod in pure tension. (See figure #8)

FIGURE EIGHT
CANCELLATION OF BENDING STRAIN

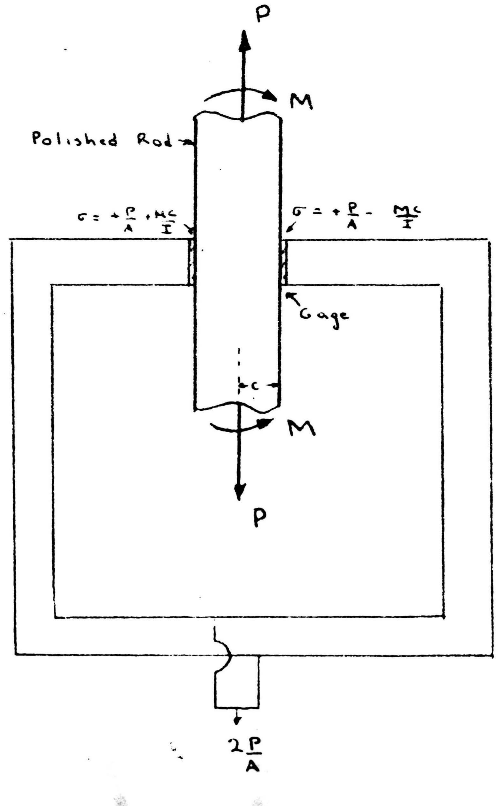
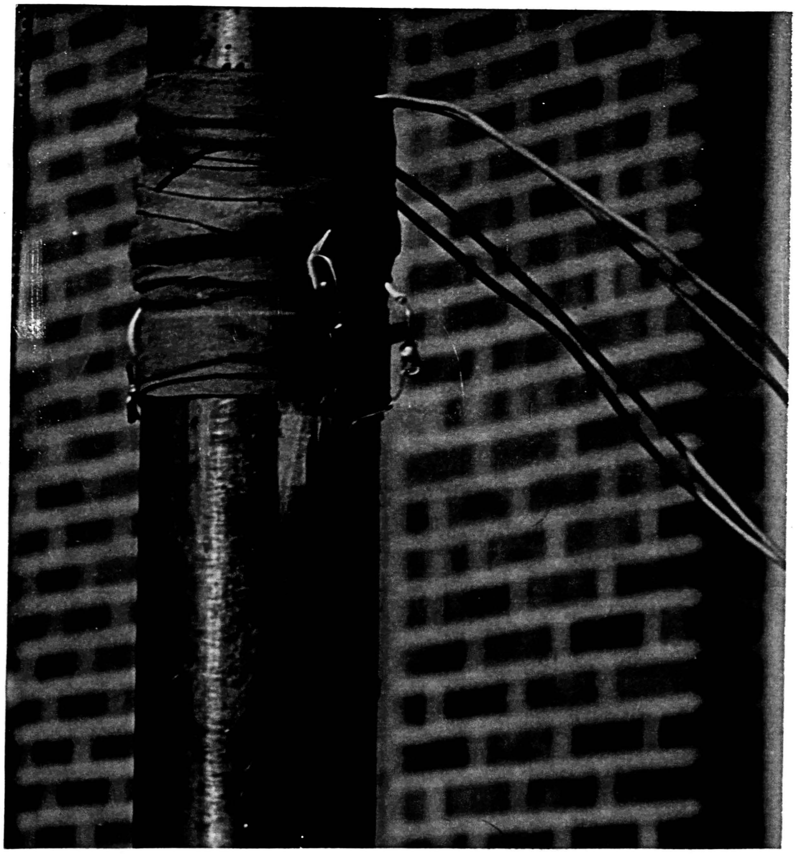
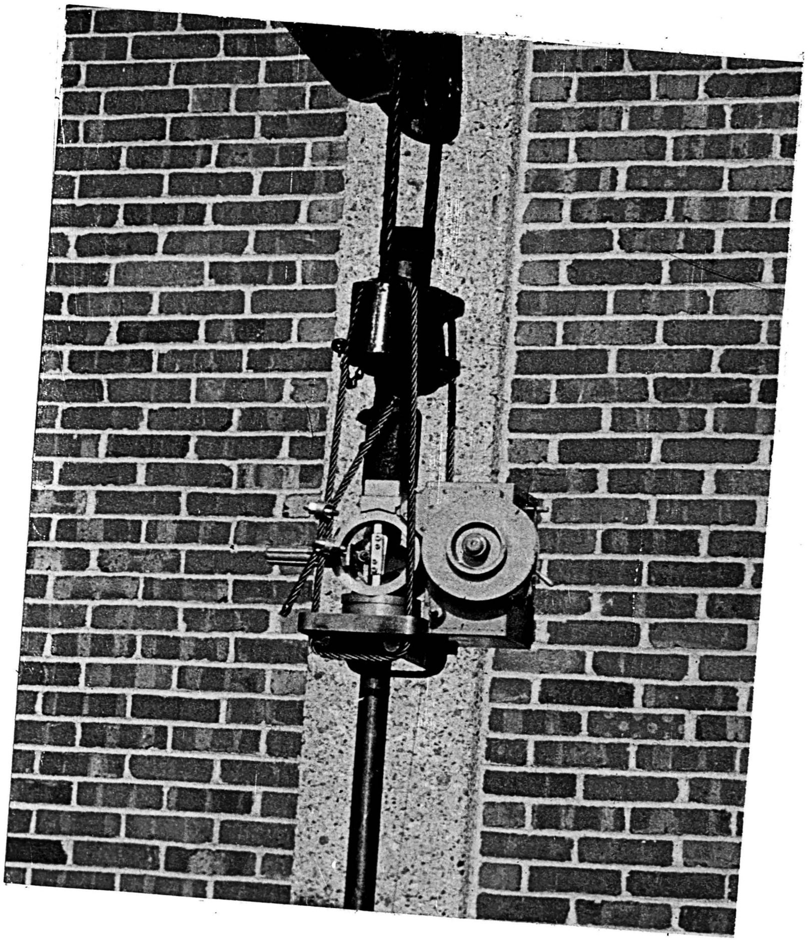


FIGURE 9A



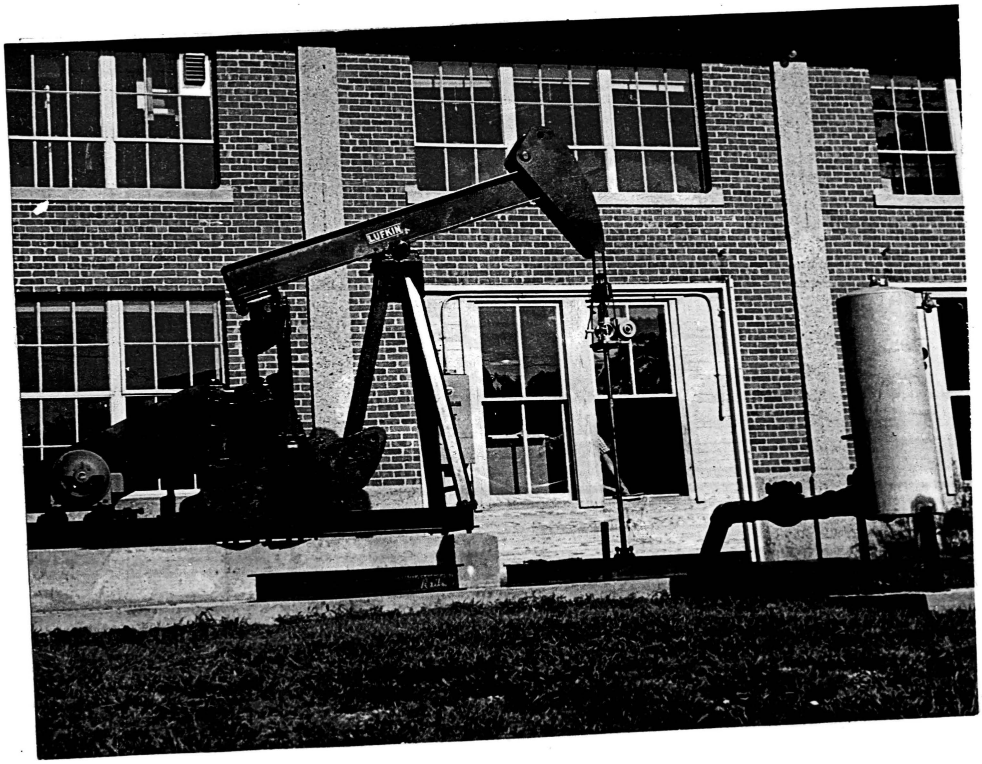
POLISHED ROD WITH ATTACHED STRAIN GAGES

FIGURE 9B



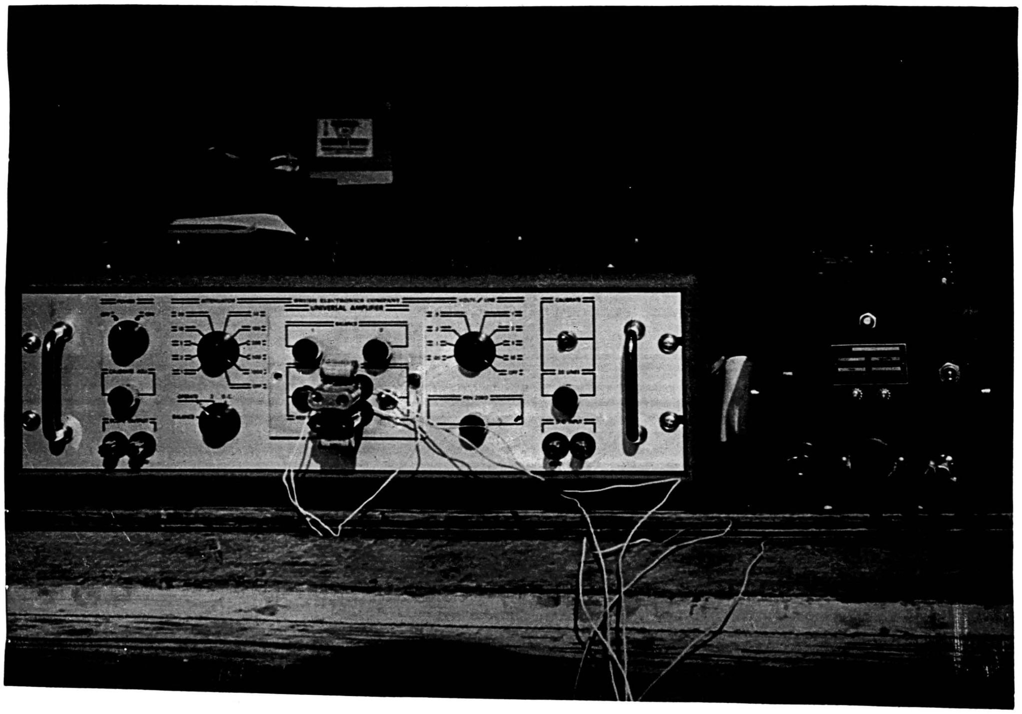
INSTALLATION OF THE JOHNSON-FAGG RING DYNAMOMETER

FIGURE 9C



SIMULATED OIL WELL INSTALLATION

FIGURE 9D



BRIDGE AMPLIFIER AND OSCILLOGRAPH

TESTING PROCEDURE

The actual testing of the equipment was divided into two phases, the first being the testing of the strain gages on the polished rod of the simulated oil well, M.S.M. #1. The second testing phase was done at the Teatman #1 well of the Texas Company, Illinois District. This was done in conjuction with a dynamometer test being conducted by a Texaco Engineer.

The Test on the Simulated Well

This first phase of testing had a multiple purpose. This was: the selection of the proper equipment to obtain the desired results; the proper method of installing the equipment; the calibration of the gages, amplifiers, and oscillograph; and obtaining a dynamometer card and a strain-time diagram simultaneously on an oil well.

The Selection of the Proper Equipment Several factors were considered in the selection of the equipment. These factors are not necessarily the ones to be considered by a company planning to use strain gages to measure polished rod loads, but were considered by the author as necessary to doing proper research on this problem.

Because of the limited funds available for research, cost was a very important item in obtaining equipment. It was determined that the Brush Amplifier and Oscillograph was the lowest priced recording apparatus that would meet the requirements. Many such recording devices are manufactured, but the Brush Instrument Company is one of the few that supplies a single channel unit (a single recording device which will accomodate only one signal). The cost of an oscillograph is directly proportional to the number of channels.

There are some disadvantages in this type of unit especially if it is to be used in the field. The amplifier and oscillograph are separate units which limits its portability. Also both units operate on a 110 AC voltage, which would practically exclude it from field use.

These limitations are small, and the author feels that a portable oscillograph-amplifier unit for this purpose could easily be developed.

The resistance strain gages are sold by the Baldwin-Lima-Hamilton Corporation of Waltham, Massachusetts. The selection of the proper gages for use in the field cannot be determined positively without extensive studies being made in a large field.

Approximately fifty types of gages are manufactured. The selection of one of these depends on: the magnitude of strains to be measured; the temperature to be encountered; environmental conditions; and the size of the space where the gage is to be attached. Standard 120 ohms, A-3, paper base gages were used in this experiment. The only disadvantage of this type of gage is that it will deteriorate under adverse weather conditions unless properly waterproofed.

A resistance gage which is covered with Bakelite is in use, but the material to which it is to be attached must be heated to an even temperature without a direct flame. This might prove impossible on an oil well polished rod. It is the authors belief that it would be better to use a paper base gage and replace it when necessary than to use a more expensive and inconvenient gage such as the Bakelite one. The A-3 gages used in this experiment were subjected to weather for three months without waterproofing and still functioned properly.

Installation of the Equipment. Once the equipment was selected, the installation was relatively simple.

The most important part of the installation is the mounting of the gages. The gages must be perfectly attached to the polished rod or the values of recorded strain will be in error. It is important that an even surface of glue be applied between the paper base and the polished rod and that there are no air bubbles trapped under the base of the gages. Especially in the oil field, one must be careful that the mounting surface is free from dirt, grease, oil, and wax. The surface should be roughed with a fine grade sand paper and a grease solvent liberally applied before applying the precoat. The precoat cement should dry for 15 minutes and then the gages applied with a liberal amount of glue. Some pressure should be applied to the gage while it is drying (about 1 lb.). The gage should dry for 24 hours.

A shielded cable must connect the gages to the amplifier. The cable should be taped to the polished rod and the leads soldered to the gages.

The entire section of rod where the gages are located should be covered with a waterproofing substance. This may be a petro-wax, or a convenient method is to spray on neoprene rubber coating. This is available in a pressurized can.

Calibration of the Equipment The amplifier has a calibration adjustment as an integral part of the unit and will automatically calibrate the oscillograph's pen deflection in terms of micro-inchs per inch of strain. If the calibration switch is depressed, a 390K ohm resistor is switched in parallel with the active gage. Depending on where the attenuator control is set the pen will deflect a specific number of divisions on the chart. For instance, if the attenuator control is set on 10, the deflection of the pen with the calibration switch depressed should be adjusted to 15 chart lines. This deflection is controlled by the calibration adjustment knob. After this calibration has been made for a specific setting, it should not be changed during the entire test. This will calibrate the oscillograph in micro-inches per inch of strain per chart line of pen deflection. A nomograph for determining the calibration factor for specific attenuator setting is included with the equipment.

In the determination of the load on the polished rod the chart lines may be calibrated directly in pounds because the load is directly proportional to the strain. To do this, one must introduce a multiplication factor depending on the polished rod material and the diameter of the polished rod. For example, if the polished rod is of steel, the strain recorded would be multiplied by 30×10^6, modulus of elasticity. This, of course, would be the stress in the rod and the load could be determined by multiplying the stress by the cross sectional area of the rod.

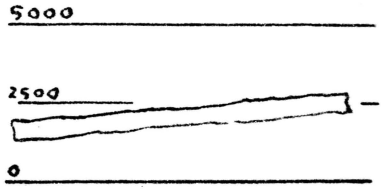
Load-Time Diagram on M.S.M. #1 In developing the equipment, many load-time diagrams were taken on the simulated well. After the proper method of obtaining a diagram was determined, a dynamometer card was taken simultaneously with the load-time diagram. (See figure 10)

This dynamometer card is an example of a pump operating under perfect conditions. In fact, it is too perfect, as no well could produce such a dynamometer card. The polished rod is loaded by the hydraulic system which will not produce any of the irregularities found in oil well dynamometer cards.

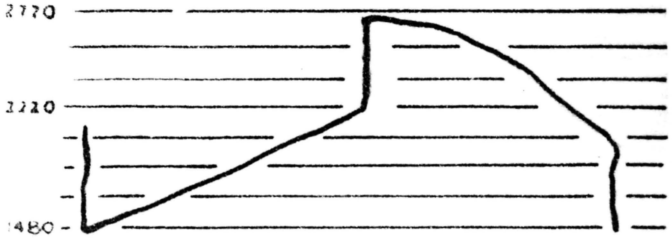
The only variable in the system is the peak polished rod load. The dynamometer card is shown in actual size and the peak load is about 2700 lbs. This would be approximately the load on a shallow well which is not a large fluid producer.

The strain-time diagram which was taken at the same time as the above dynamometer card is shown in comparison. The same data may be obtained from the load-time diagram as from the dynamometer card, but note how much more accurately the load recordings may be read. This is because the magnitude of the load recordings are limited only to the width of the recording paper. The strain recordings may be amplified to any desired amount depending on the peak load. Unlike this, the magnitude of the recordings on the dynamometer depend on the size of the proving rings which cannot be interchanged. This proposes a distinct

FIGURE TEN



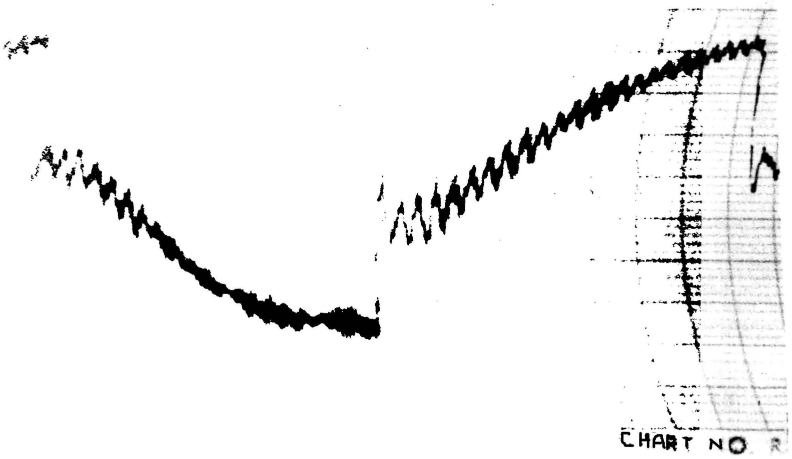
DYNAMOMETER CARD - ACTUAL SIZE



STRAIN-TIME DIAGRAM - ACTUAL SIZE

COMPARISON OF METHODS - M.S.M. #1

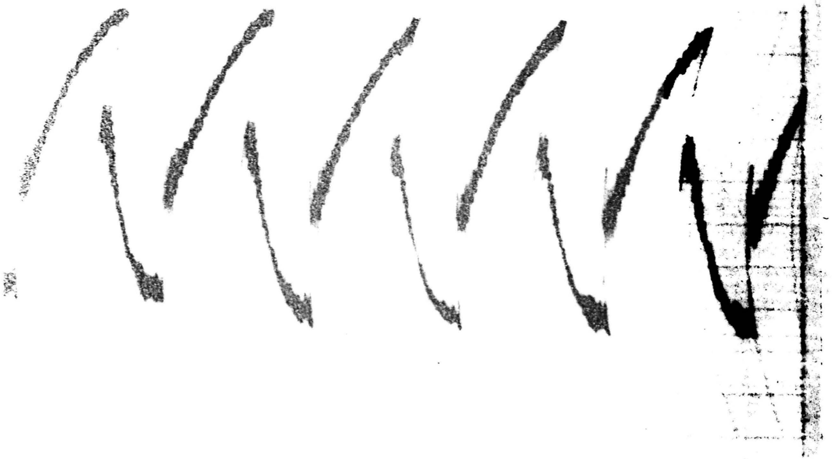
FIGURE ELEVEN
MSM NO. 1



SPEED - 25 mm per sec.
SCALE - 37 lbs per div.

L-T DIAGRAM - M.S.M. #1

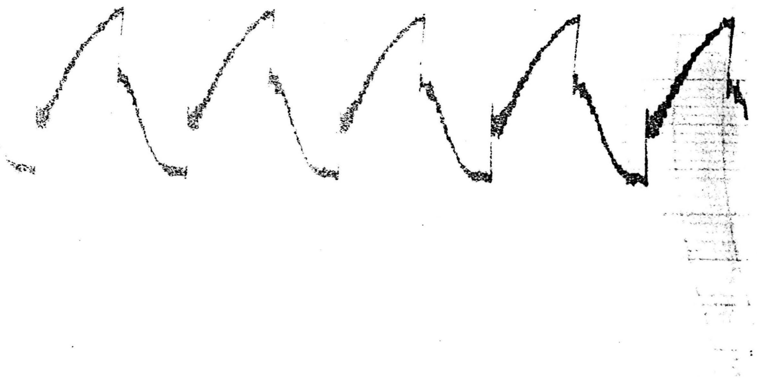
FIGURE TWELVE
MSM NO. 1



SPEED - 5 mm per sec.
SCALE - 37 lbs per div.

L-T DIAGRAM - M.S.M. #1

FIGURE THIRTEEN
MSM NO. 1



SPEED - 5 mm per sec
SCALE - 65 lbs per div.

L-T DIAGRAM - M.S.M. #1

advantage of the load-time diagram over the dynamometer card.

The outstanding difference between the two methods is that the dynamometer plots load versus displacement while the other plots load versus time. This will cause a difference in the distance between certain points on the cards because the polished rod is not moving at a constant velocity. The velocity is the greatest at the center of the upstroke and downstroke. There also may be a difference between the average upstroke and downstroke velocities. Note on the diagram, the difference in time interval for the upstroke and downstroke. This factor may cause some confusion in comparing L-T diagrams to dynamometer cards if one is not familiar with the method of obtaining such diagrams, This fact became more evident when the field test was made.

Because of the greater amplification, the strain gages will pick up smaller variances in load. These might be due to vibration, friction, or flow-line restrictions.

Another obvious advantage is that the pumping speed is automatically and accurately recorded. When taking a dynamometer study, the speed is usually taken by counting the approximate strokes in a minute using a watch. The oscillograph has three different speeds.

These are 5 millimeters per second, 25 millimeters per second, and 125 millimeters per second. The operator may choose which is best, or may change the speed during the test by merely pulling a lever. Figures 11, 12, and 13 illustrate different speeds and load scales during the same test on M.S.M. #1.

In this initial test, the versatility of the instrument became evident. This versatility proved to be one big advantage over the dynamometer.

Field Test on the Texas Company's Teatman #1 Well

The concluding portion of the research was the testing of the equipment under field conditions on an actual producing well.

The Texas Company, Oklahoma Division, kindly consented to allow the author to test the equipment on the Teatman Well #1 in their Illinois District. The Texas Company also made available the services of their engineering assistant to make a dynamometer study simultaneous with the testing of the strain-time apparatus.

On October 21 and 22, 1958, the author traveled to Salem, Illinois to make the above mentioned test. As was mentioned before, the existing apparatus is for use in a laboratory and the field test presented many problems. Because the equipment requires 110 volt AC power, a generator had to be taken to provide power at the well site. The apparatus is not very portable and care was taken in setting up the test at the well.

The well was about 2500 feet deep, and pumping with a peak polished rod load of approximately 3100 lbs. The pump unit was a Lufkin 10,000 pound polished rod load capacity. An interesting fact was that the well was "pounding". It was a policy of the Texas Company to keep such "stripper" wells "pounding".

Installation of Gages This well had a polished rod liner, so it was necessary to put the strain gages above the hanger. A liner is a hollow sleeve that fits over the polished rod between the hanger and first sucker rod to prevent excessive wear due to stuffing box friction.

The polished rod was scraped, sanded, and cleaned with solvent before the gages were attached. The gages were glued to the polished rod about two inches above the hanger. They were so arranged that the dynamometer rings would fit on each side of the rod where the gages were attached and a rod clamp could be fixed above the dynamometer. With this arrangement, the load was transmitted from the hanger through the dynamometer and to the polished rod.

Obtaining a Load-Time Diagram The first step in the test was balancing the bridge and obtaining a zero reference line. The resistance bridge balanced out very easily, but it was necessary to make some adjustment to balance the capacitance in the circuit. An .002 UFD capacitance was placed into the arm of the bridge adjacent to one of the active arms. This procedure was outlined in the operating instructions for the Brush Amplifiers. This allowed the system to be balanced and a zero reference was obtained.

The pump was then put into operation and a dynamometer card and strain-time diagram obtained simultaneously. (Figure #14) The proper amplification was chosen and two different paper speeds were used. (Figure #15)

As was to be expected, the two methods provided exactly the same information. Some care must be taken in examining the L-T diagram if one is only familiar with a dynamometer. Figure 16 provides an explanation of the important points on the diagram.

Point A is the beginning of the upstroke, and after a short hesitation the load begins to increase as the fluid is lifted. This short hesitation is from the slack in the rods being taken up. Point B is the maximum load and approximately the center of the upstroke. As stated before, one should realize the velocity of the rod is not constant, causing a non linear relationship on the time axis. The changes of load between B and C show up much clearer on the L-T diagram than on the dynamometer card and may be attributed either to friction or some obstruction in the flow line such as a pressure check valve. Point C is the beginning of the downstroke. Here is where the fluid pound is easily recognized. From C to D there is a very little decrease in load and then at D the first pound presents itself, followed by the second pound at E. Point F is the minimum load and at the end of the downstroke there is an increase in load due to acceleration factors.

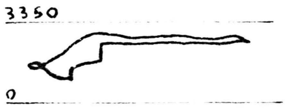
Economic Study

By actual measurements, it required ten minutes to obtain a strain-time diagram on this well. This did not include installation of the strain gages, as it was assumed they would be installed before hand and allowed to remain on the polished rod for many tests.

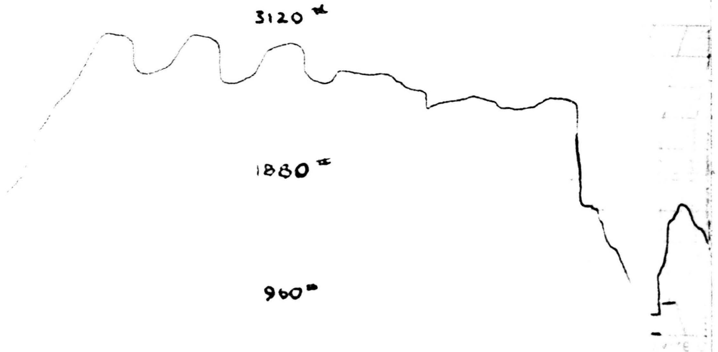
In a discussion with Texaco's well tester, who does the dynamometer studies throughout the entire Illinois District, it was found that it takes a minimum of one hour to obtain a dynamometer card. Also on larger wells, it could easily take an hour and one-half from the time he reached the well site until he left the lease.

FIGURE FOURTEEN

COMPARISON OF METHODS



DYNAMOMETER CARD - TEATMAN #1



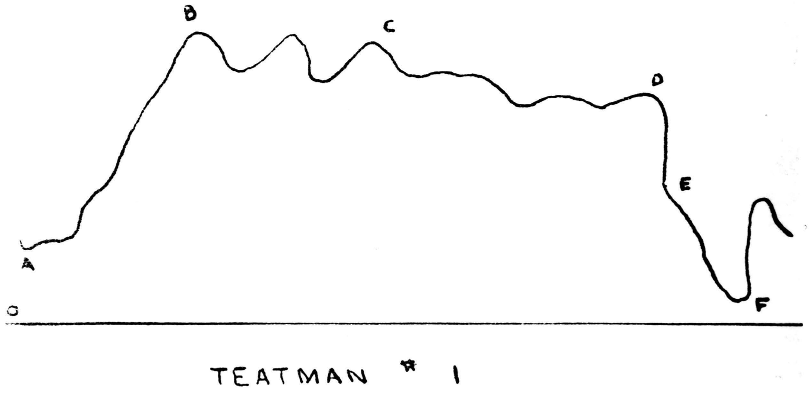
LOAD - TIME DIAGRAM TEATMAN #1
SPEED - 25 mm/sec SCALE - 48 lbs/div

FIGURE FIFTEEN
TEATMAN # 1

SPEED 5 mm/sec.
SCALE 51.5 lbs/div.

L-T DIAGRAM - TEATMAN #1

FIGURE SIXTEEN
TEATMAN * 1



L-T DIAGRAM - TEATMAN #1

DISCUSSION OF RESULTS

Before reaching a final conclusion, the following questions should be answered: (1) is the method of operation feasible, (2) can the same information be obtained from a strain-time study as is obtained from a dynamometer study, (3) is this information easier or more difficult to obtain, (4) and finally, is it economical to use a strain-time apparatus? From the following information it may be concluded that the research was successful and the method developed is beneficial.

Feasibility of Operation

As was discussed previously, the strain gages, amplifier, and oscillograph are standard equipment which are used extensively in many industries. This is particularly true in the aircraft and automobile industry where the apparatus has been subjected to rigorous tests and unusually violent enviromental conditions such as high temperature, high acceleration and large vibratory stresses. With this in view, it may be concluded that the strain gages, amplifier, and oscillograph will operate under nearly any field condition. Some of the specific types of equipment that were used in this investigation must be altered to increase their portability, but this will only entail the changing of the necessary power source from 110 AC to some feasible DC source.

With the few changes made in the equipment, it is felt the strain-time apparatus will operate properly under oil field conditions. The specific operator may wish to modify the equipment or procedure slightly to his particular need, but basically the apparatus is sound and efficient.

Comparison of the Information Obtained

With the comparison of the dynamometer cards to the load-time diagrams of the same wells, taken simultaneously, it will be proved that nearly the same information is obtained immediately. Also exactly the same information may be obtained with proper calculations.

Figure fourteen shows the comparison of the two methods. Each study was made simultaneously on the Texas Company Teatman #1 and recorded as shown. On the dynamometer card, the upstroke indicates a properly functioning well with a maximum peak polished rod load of approximately 3100 pounds. The load-time diagram provides the same information, but more accurately. Note how the variations of load during the last part of the upstroke are more prominent on the load-time diagram. Although it would be impossible to explain what causes this variation merely from the diagram, the fact is that this variation is much more pronounced and that the maximum load points may be more easily determined. On the downstroke of the well, a fluid pound is easily recognized on both diagrams, but again note how both the magnitude and position of this fluid pound could be determined more accurately from the load-time diagram than from the dynamometer card.

No matter how many tests were made, the same information would present itself because both instruments are doing the same job; only this information is presented differently, this difference being in whether the load is plotted versus time or displacement.

The big advantage of the new method is that the strain gage is inherently more accurate than any type of mechanical measuring device including the dynamometer. On oil wells where the maximum load is low or the difference between the maximum and minimum is slight, the dynamometer card is difficult to interpret because the deflection of the stylus is small. Whereas in obtaining a load-time diagram on the same type of well the amptitude of the load scale may be set in any desired position.

As was indicated before, one of the most important uses of a dynamometer is trouble shooting. If the well is not operating properly, a dynamometer study is made and the shape of the card studied to see if it indicates any abnormal conditions. The card will take various shapes depending on the trouble that is being encountered, and these shapes are recognizable to one familiar with dynamometer studies. The load-time diagram will give the same information, but the shape of the diagram will differ considerable from the dynamometer card. Therefore, the shape of the load-time diagram will also indicate what trouble is present; but one not familiar with the new method may have difficulty in interpreting it. The proper interpretation of the load-time diagram will only take a knowledge of the method, and practice in comparing this diagram to the dynamometer card.

As further proof that the load-time diagram is equivalent to the dynamometer card, a load versus displacement diagram was plotted from the information obtained by the load-time diagram on the Teatman #1 well. The dynamometer card was enlarged to the same scale and super-imposed on the calculated load-displacement diagram as a comparison. (Seefigure #17) The method of calculating the load-displacement diagram from a load-time diagram is relatively easy if the well is properly counterbalanced. (In other words, the average upstroke velocity is equal to the average downstroke velocity.) This was true in the Teatman #1 well.

The method of calculation is to first write the displacement equation of the polished rod in terms of the time. If the well is properly counterbalanced, the rod will have simple harmonic motion and the equation will be:(10)

$$X = \frac{A}{2}(1-\cos\omega t)$$

X = displacement in feet
A = length of stroke in feet
ω = circular frequency
t = time in seconds

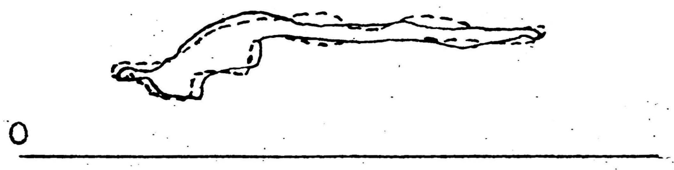
The load-time diagram for a cycle is divided into equal time intervals and the load determined at each interval. The displacement (X) is then calculated from the above equation by substituting in the various values for t. Now we have the necessary information to plot the load-displacement diagram. Figure #18 is the table of calculations for the displacements.

The calculated load-displacement diagram is very nearly the same shape as the dynamometer card. The difference between the shapes of the two diagrams is because the calculated diagram is more accurate on load (vertical) scale and less accurate on the displacement (horizontal) scale. This is because the load is

---

(10) Bethlehem Steel Company, Sucker Rod Handbook, No. 336, pp. 180-181, 1953.

FIGURE 17



L-T Diagram Superimposed on Dynamometer Card

Dynamometer Card ______

L-T Diagram ------

FIGURE EIGHTEEN

Load Lbs.	Time Sec.	Cosωt Ft.	Displacement Ft.
2118	0.08*	0.994	0.01
2166	0.28	0.930	0.105
2502	0.47	0.809	0.287
2958	0.68	0.614	0.588
3510	0.88	0.383	0.926
3750	1.08	0.127	1.310
3462	1.28	-0.140	1.710
3750	1.48	-0.397	2.096
3558	1.68	-0.626	2.439
3414	1.88	-0.810	2.715
3702	2.08	-0.936	2.904
3414	2.28	-0.996	2.994
3446	2.48	-0.984	2.976
3438	2.68	-0.945	2.918
3318	2.88	-0.771	2.656
3222	3.08	-0.561	2.341
3270	3.28	-0.321	1.980
3174	3.48	-0.062	1.510
3270	3.68	0.192	1.210
3270	3.88	0.460	0.810
2166	4.08	0.675	0.490
1686	4.28	0.845	0.233
2406	4.48	0.957	0.065

*Sample Calculation:

A= 3 feet

$\omega = \frac{2\pi}{42}$ radians

t= .08 sec.

$X= \frac{3}{2}(1-.994)$

X= .01 ft.

measured more accurately by the strain-time method, but the displacement is the calculated instantaneous displacement for successive time intervals.

Another important function of the dynamometer is to measure the counterbalance effects. To do this one must take the information from the card and make several calculations; but the load-time diagram will give the same information without any calculations. If the time intervals for the upstroke and downstroke are equal, the pump is properly counterbalanced. If the upstroke time interval is longer, the pump is under-counterbalanced; and if the downstroke time interval is longer, the pump is over-counterbalanced.

Because the strain-time equipment will immediately provide this information, the engineer may make the necessary adjustments of the counterweight without having to return to the office to make calculations. The positioning of the counterweight is a trial and error method, so the load-time diagram may save much time in properly counter-balancing a well.

It has been determined that the information obtained from each method is basicly the same; therefore, any calculation made from the dynamometer card may be made equally well from the load-time diagram. These calculations include: peak torque, horsepower, and efficiency.

If the same information is obtainable from each method, then what is the advantage of one method over the other? The advantage is that the strain-time method is easier and less costly.

The strain-time method is less costly because it takes the operator less time to obtain the information. In the field test, it took 10 minutes to obtain a strain-time diagram, while it took one hour and 30 minutes to obtain a dynamometer card. It is easy to realize that this saving of time is a great economical advantage. It should be understood that this 10 minutes does not include the time it takes to attach the gages. It is assumed that the gages are attached to each well before testing and are allowed to remain on the rod over the life of the well. The time required to make the test would then be only the time necessary for the operator to attach the lead wires, obtain a zero reference, and obtain a load cycle on the oscillograph.

In reviewing the entire research work, the author feels that the method developed is feasible, the information obtained is valid, and the operation is economical. Furthermore, it is believed that an oil company would profit by developing this method to replace the dynamometer.

CONCLUSIONS

The tests have proved that the information obtained by the strain-time apparatus is equilvalent to the information obtained by the dynamometer, and it is more economical to use the strain-time apparatus. Furthermore, the information is more accurate and in some cases provides a better method of presenting the information.

The use of the dynamometer has been curtailed because of the increased cost of labor necessary to make the study. It is believed that by using the method developed in this thesis, the oil industry may obtain accurate information about a pumping well and still maintain profitable production.

BIBLIOGRAPHY

1. Bethlehem Steel Company, Sucker rod handbook. No. 336, 1953. pp. 143-184.

2. Fagg, L. W., Dynamometer charts and well weighing. Petroleum Transactions, A.I.M.E., Vol. 189, (1950).

3. Johnson, D. O., Consider these factors for optimum pumping. World Oil, Dec. (1957).

4. Johnson, D. O., Pumping well problems in focus. World Oil, Jan. (1950).

5. Johnson, D. O., Ring dynamometer for pumping wells. World Oil, Nov. (1948).

6. Murray, W. M., Strain gage techniques. Massachusetts Institute of Technology, Vol. 1 and 2, 1956. p. 588.

7. Perry, C. C., and Lissner, H. R., The strain gage primer. McGraw-Hill, 1955. p. 278.

8. Philipp, E. R., Planned well weighing cuts operating costs. World Oil, Apr. (1957).

9. Russell, J. H., Jr., Interpretation of dynamometer cards. World Oil, July (1953).

VITA

Jerry B. Overton, son of Phillip M. Overton and Celina Overton, was born December 26, 1933 at Kansas City, Missouri. He received his elementary and high school education in this city.

He enrolled at the Kansas City Junior College in 1951 and completed one year of Pre-Engineering. The following year he enrolled at the Missouri School of Mines and Metallurgy in Petroleum Engineering and received his B. S. Degree in 1956.

Following graduation he accepted employment with the Texas Company as a Petroleum Engineer in Fairfield, Illinois. In September, 1956 he was appointed an Instructor in Mechanics at the Missouri School of Mines and Metallurgy in Rolla, Missouri. He also enrolled as a graduate student in the Petroleum Engineering Department. During the summers of 1957 and 1958 he was employed as a research engineer by the Marley Company and the U. S. Bureau of Mines, respectively.