Dynamometer Card Interpretation by Visual Inspection

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In this day of high costs and high speed of operation in the petroleum industry, it has become necessary that every person in the industry have an exceptional set of data and information to exercise his best wisdom. It used to be that a man had to have a lot of experience to exercise wisdom. But in this hustle and bustle of high speed economy an employee does not have time to obtain the necessary experience in this fast changing industry. Many of you have learned a procedure of some sort and remember that in a year or two this procedure has been replaced by new theories, much to ones disappointments or confusion. The person who can use other people's experience for basis of his wisdom is the one who will advance more rapidly.

Fortunately the dynamometer is a tool, and/or an instrument with years of experience which may be used to improve your wisdom. Of course, from time to time mathematics or theories may be changed to give a new concept of the dynamometer card interpretations, never-the-less, the card is drawn by forces applied to the pumping system. Therefore, the object of taking a dynamometer card on a pumping well is to gather recorded stresses for analysis in an effort to operate the pumping equipment at its highest efficiency for the salable fluid produced.

The interpretation of the recorded stresses or dynamometer card is broken down into two phases. The initial, or visual, interpretation and the mathematical interpretation. This paper will deal with the visual interpretation. The reason being that from 50 to 80% of the cards could be interpreted by visual inspection, and immediate improvement of the pumping operations could be instigated. The balance of cards would be on very troublesome wells, where visual inspection could help, but may not be the complete answer, and mathematical interpretation would be necessary.

It is not the thought of the writer that this paper will cover every phase of visual interpretation, but the purpose of the paper is to indicate paths of thought which one may travel for certain types of indications on the cards. The care and accuracy exercised in the procedure of taking a card on a pumping well is of basic importance in the visual interpretation.

To do a good job of taking dynamometer cards, it is necessary to have a set of complete data on equipment installed in and on the well. It is recommended to have a list completed before going to the well, and to have an idea of why the tests are taken.

The list mentioned could be somewhat as follows:

<u>Sub-Surface Equipment</u>

1. Casing size
2. Setting depth
3. Tubing size
4. Tubing depth
5. Is tubing anchored to casing
6. Type of sucker rods
7. Length of rods
   (different size and length)
8. Pump type
9. Plunger size

<u>Well and Pumping Conditions</u>

1. Daily Production - Water
2. Daily production - Oil
3. Allowable
4. Hours pumped/day and what hours
5. Length and S.P.M.
6. Volumetric Pump eff.

<u>Calculated Data</u>

Calculated Polished Rod load
Dead Weight of rods in air
Theoretical Weight of rods in fluid
Weight of Fluid on Plunger (avoirdupois)
Fluid level: Static ___ Pumping ___ Date ___
B.H.P. : Static ___ Pumping ___ Date ___
Production Index (P.I.)
GOR
Agitator or Pumper
Lead Line Pressure
Casing Pressure
Sand, Paraffin, Gyp, Corrosion, etc.

One may obtain printed data sheets for this purpose to facilitate the work.

With this information available and knowing the reasons for taking the test, the person operating the instrument or dynamometer is now ready to go to the well.

There is very little to be said about the installation of the dynamometer except to say that it should be done properly. The important thing is to operate the dynamometer and pumping system so that accurate information is gathered. A lot can be gained by letting the well pump until it becomes stabilized, or to say, as it was before the unit was shut down for installation of the dynamometer. Some wells will stabilize in a few minutes, while in others it may takes hours to get back to normal pumping after being shut down for only a few minutes. While the well is pumping to become stable, cards should be taken regularly. These cards often give bits of information which are useful in analysis.

Cards should be taken to show maximum load and the minimum loads in relation to the zero line and reference lines on the cards.

A check should be run to see if the traveling valve and/or plunger is leaking. These checks also give weight of the rods plus the weight of the fluid on the plunger, as well as the weight of the rods submerged in that amount of fluid in the tubing (S.V. check). These checks should be repeated a number of times to see if they repeat themselves. Extreme care should be exercised, too, in the manipulation of the unit so that the brake is applied while the rods are moving their slowest during the up or down stroke.

If a repeat recording is not obtained in these tests it can be attributed to lack of patience in taking this part of the test, or that the well conditions are such that accurate tests cannot be taken. Sand or other foreign material may be holding the balls and seats in such a position as to lead to poor decisions in making the tests. Also, flowing of the well may affect the test.

The dynamometer is far more sensitive than most people understand, therefore the recordings are accurate, but, one must know what is being recorded to use the cards successfully.

It appears in discussion that the dynamometer card or graph should be a rectangular shape. With a very slow speed it would probably approach such a shape, however, the constant velocity of the crank does not produce a constant velocity of the polished rod. For example, assume that the crank does move in a constant angular velocity. The pitman is connected to the crank in an effort to cause the beam to move up and down.

Beginning then, with the crank pin at zero degrees at its uppermost position, the vertical movement accelerates until the crank has moved 90 deg. As the crank pin moves beyond the 90 deg. point the vertical motion is said to decelerate, till the point of 180 deg. is reached, at which time the vertical motion actually stops.

Now this acceleration and deceleration repeats on the down stroke. So as a result, instead of a card shaped as shown in Fig. 1

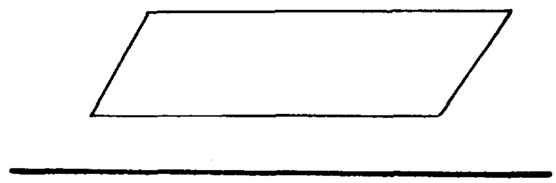


Figure 1

we obtain a card such as shown in Figure 2.

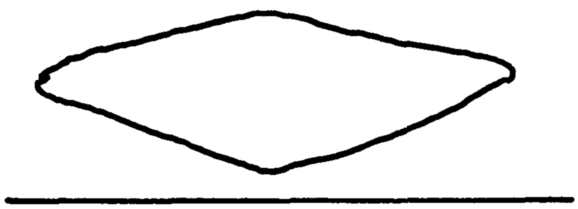


Figure 2

The flexibility of the rods and tubing, effected by loads and speed, result in all kinds of fancy shapes and designs. It is these fancy shapes that are the tattletale we must interpret.

In the "Sucker Rod Handbook" published by Bethlehem Steel Company, is shown, a card and with the explanation of celerity and the elasticity of the sucker rods in relation to a dynamometer card. (Fig. 3)

The explanation is as follows: "Point "A" represents the end of the upstroke and the beginning of the down stroke. As the polished rod starts down there is an immediate decrease in load. This shows the fluid load has been transferred from the sucker rod string to the tubing and means that the traveling valve in the pump opened at the beginning of the downstroke. This is characteristic in most wells where the apparent volumetric efficiency is 75 per cent or over. In the cases of semi-flowing or agitating wells, the shape of the load curve is continuously changing and an average card is not obtainable.

"Point "B" represents the minimum load, or the lowest point on the dynamometer card. In this case it occurs a little past the center of the down stroke. From "B" to "C" the polished rod is going down yet the polished rod load is increasing. This is perhaps one of the most difficult facts to visualize for one not familiar with dynamometer cards. When the motion of the polished rod is considered, it is seen that its speed on the down stroke accelerates until it reaches a maximum velocity near the center of the downstroke. It then decelerates until it comes to an instantaneous stop at the end of the downstroke. For this well pumping 20 spm, 8800 pounds of sucker rods, which have been traveling at the rate of 7.1 fps are brought to a stop in three-fourths of a second. The total instantaneous force as measured at the polished rod at point "C" has then reached 16,000 lb. Point "C" is the end of the down stroke and the beginning of the upstroke. As the polished rod reverses its direction the sucker rod string acts as a spring and further elongates. An increasing load is produced at the polished rod, which reaches its peak at point "D".

From point "D" to point "E" the recoil of spring action of the sucker rod string gives back some of the energy, which was stored up when the rod string was stretched at the end of the downstroke. From point "D" to "E" the polished rod is going up at an increasing speed, moving not only the sucker rod string, but also the weight of the fluid. Yet the energy given back to the system by the spring is sufficient to cause a decreasing load between these points.

The load curve from "E" to "F" represents a continuation of the upstroke. The load is increasing as the fluid and sucker rod string are moved at an increasing velocity. Point "F" represents the maximum load, which is reached at the approximate center of the upstroke.

From point "F" to point "A" the polished rod is decelerating, which accounts for the decreasing load in this part of the upstroke. This completes the plotting of the load curve during one pumping stroke."

The preceding show how the elasticity and celerity are effecting the shapes of the cards. This article is considering beam type pumping units, however many factors will apply to hydraulic long stroke pumping.

The maximum load in a card indicates the degree of load on the sucker rods, beam, gears, a-frame (sampson post), and etc. The best way to determine if it is near the right amount of load is to have theoretical calculations ready for comparison. In this manner it is a simple deduction to see if the load is too high, too low, or just about the correct amount for the size of the equipment used. If the loading is too high, then it must be considered if overloading is caused by excessive plunger size, unanchored tubing, or if speed

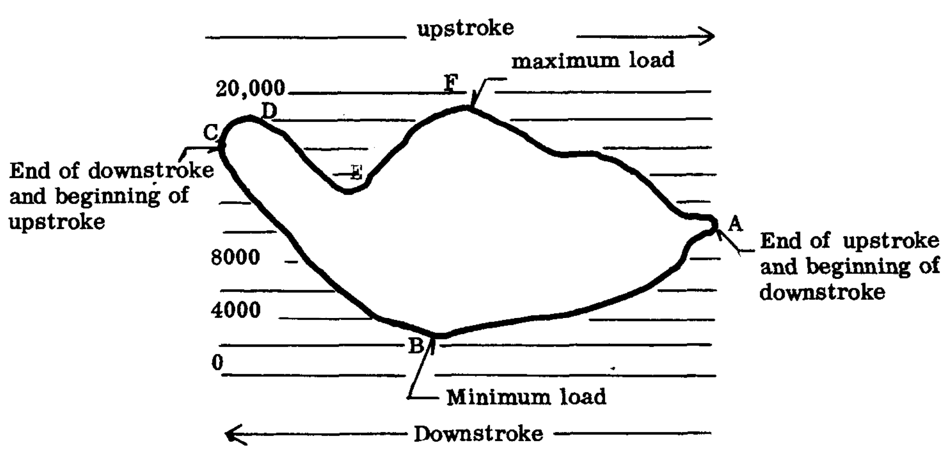


Figure 3

is the cause, and etc. If the load is too small according to the calculations, then the well could be flowing, rods broken, plunger unscrewed, or balls and seats cut out, and/or etc.

The load difference between the minimum and maximum is called the range of load. This load difference in connection with the maximum load is a determining factor in the life of the sucker rod string. It is also a determining factor in the torque load on gears, belts, and prime mover. The simple ways to reduce range of loads is to reduce speed, reduce length of stroke, or the diameter of the plunger, or any combination of the three. Excessive range is the most destructive effect on rods. Often times it becomes necessary to abuse the rods to produce sufficient oil for the operation to be a profitable one. Reducing the range of load ordinarily will increase the life of sucker rods.

The card area represents polished rod horse power. In other words, a card which had a large area should produce a large volume of fluid, and, conversely, a small area card represents a small amount of fluid produced.

Here is a list of equipment and associated items and troubles that may be analyzed:

Counter balance	Foundations	Pump	Formation
Belts	Structure	Rods	P.I.
Engines	Reducers or gears	Tubing	
Clutches			

Counter balance is probably the most important adjustment for economical operation of all the list above. Counter balance is also the most abused part of a pumping system. It seems that as long as the unit will rotate without too much noise, then everyone is satisfied.

An engine which is running too slowly will indicate an impulse of load on each explosion. This is shown in Figure 4.

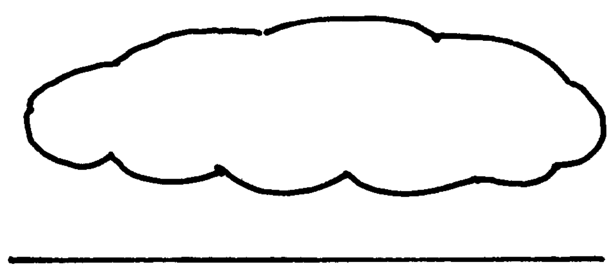


Figure 4

The inertia of the flywheel is not enough due to lack of speed. The increase in engine speed will smooth out the card something like that shown in Fig. 5.

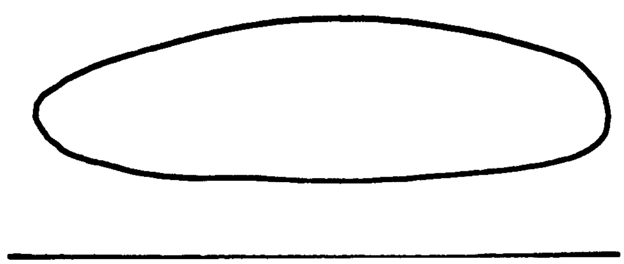


Figure 5

A great reduction of abuse to all the equipment is now effective.

Clutch trouble is usually caused by overloading the assembly. When a unit is out of counter balance the engine speeds up and slows down due to the misadjustment of the weights. These sudden reversals of speed tend to overload the clutch and often burn it up or break the shaft. The same action is causing a lot of straining on the V-belts and has caused many to burn out.

The foundation is often cracked and the cause is set as poor concrete, etc. Really in most cases it is due to the improper counter balance of the well. These improper forces created by improper counter balance have a tendency to buckle the unit foundation up and down in the center section with each complete stroke. This often causes cracking or base-I-beam fatigue, and results in expensive maintenance.

Power consumption is usually attributed to lack of counter balance. This is probably not true on a lease which is electrified as a group, with only one metering point. In such a case, the units would generate and consume power and balance out economically. However, on engine operated units or on single-well-metered electricity it is imperative that the unit be balanced to prevent abnormal consumption of power in one part of the stroke.

It might be well to explain the proper positioning of the forces on a card to indicate good counter balance. Many refer to the counter balance line drawn on the card and falls 1/2 way between the maximum load and minimum, if they are near the center of the stroke. If the card is irregular, that is to say the peak is away from the center, then an instrument should be used to determine the areas above and below the counter balance line. The areas should be approximately equal for the unit to be in balance.

This is shown in Fig. 6.

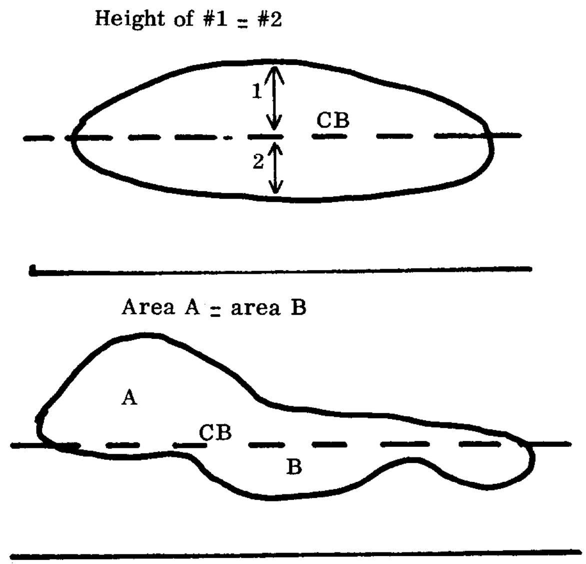


Figure 6

Ordinarily, any time a load line on the dynamometer card crosses the counter balance line we have back-lashing of gears. This is detrimental if it occurs with much force. Any time you feel, see, or hear back-lashing in the gear train - you no doubt have an improper counter balance.

Often you will find a card that cannot be counterbalanced to smooth out the flow of power. In these instances the shape of the card must be changed. This is accomplished by either a change of speed, stroke length, or plunger diameter, or a combination of two or more of these conditions.

The mathematical approach to the card analysis starts from accuracy of the Traveling Valve check, and also the Standing Valve check. They are also a visible check to see if the pump is malfunctioning. If the traveling valve is leaking or the plunger and liner seal are leaking, the load will become light as the pumping unit is stopped on the up stroke and the styles actuated to indicate a place of reading. If the Standing Valve is leaking and the unit is stopped on the down stroke, and the styles actuated by the string, then the line would show a gain of weight on the rods as the fluid leaked away from under it.

The distance the two lines are apart, to begin with, indicates the load on the plunger. The Standing Valve check at the start indicates the weight of the rods submerged in the fluid in the tubing. If the pump was really new, and had not had time to wear, then a loss of load on the rods when checking the traveling valve would indicate leaky tubing.

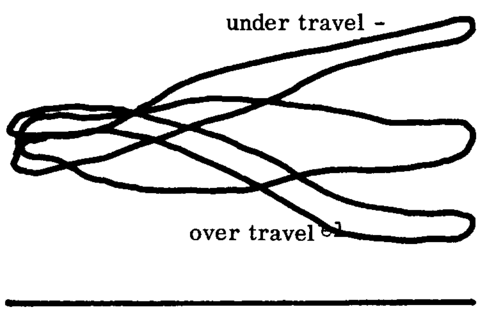
With a bad leak and solid fluid the leak can actually be calculated.

Through mathematical means the bottom hole pressure is calculated from the Traveling Valve and Standing Valve checks along with the weight of rods, etc.

The position of the force lines on a dynamometer card are indicative of many things about the equipment. For example, if the forces are more or less horizontal, the first thought is about the plunger travel in reference to polished-rod-travel. Here the two travel a comparable distance in most instances.

Now if the forces of the load on the card travel to the right and upward, this would indicate under travel of the plunger.

If the forces on the card travel to the right and downwardly, this indicates over travel of the plunger. Drawings of these three shaped cards, and some of the causes of these general shapes are shown are shown in Fig. 7.



Over Travel	Under Travel
Over design of rods	Under design of rod string
Under design of pump	Over design of pump
Pump unseated	Speed
Plunger unscrewed	Paraffin
Rods parted low	Cup or Ring plunger
Leaky tubing	Fiction in pump
Pump stuck in upper 1/2	(T.A.
Ball & Seat leaking,	Crooked tubing (Packer.
or stuck open	(Bottomed.
Flowing, etc.	Pump stuck in lower 1/2, etc.

Figure 7

There are other causes you will find which will also indicate shape similar to those above. It must be remembered that a number of things could be wrong with the well. Therefore, it is necessary to do some elimination to determine what the causes are. As each becomes more proficient, more causes will be added to the lists above.

The greatest cause of trouble which prevents full production in West Texas seems to be gas interference. This is sometimes called gas lock, but it really never quite becomes a gas lock. A gas lock would be when no fluid entered the pump due to gas pressure in the pump.

A card taken on a certain West Texas well went through three stages; pumping, gas interference and gas lock. (Fig. 8, 9 & 10)

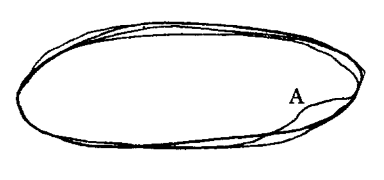


Figure 8. 7 minutes pumping before gas began to interfere as at point A.

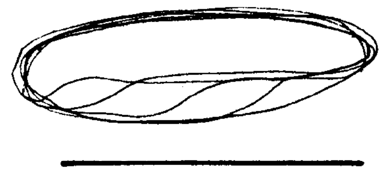


Figure 9. In 3 minutes gas had interfered with the fill of the pump.

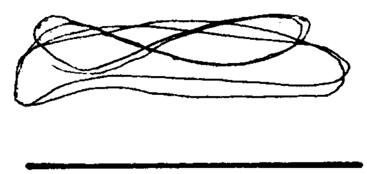


Figure 10. The figure eight at the top part of the card is caused by a complete gas lock. The areas cancel out showing no work being done.

The cause of this was due to the plunger being spaced too far off the bottom, in which case the plunger could not compress the gas enough to push the gas through the traveling valve.

Elimination of gas interference must be done by gas separation below the pump. Many articles have been written on this subject, and must be studied to succeed in more efficient pumping.

The difference between fluid pound and gas interference is easy to determine on a card, as shown in Fig. 11.

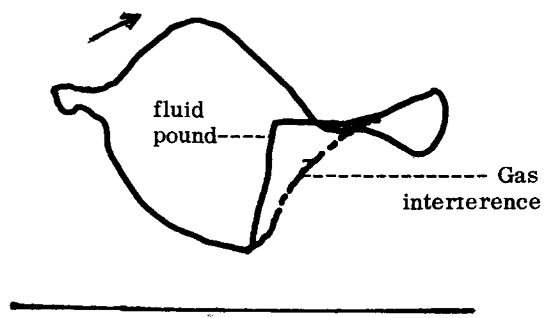


Figure 11

The slope of the line from fluid pound to gas interference indicates the amount of gas interference or the expansion of gas drawn, or the drawing of gas out of solution.

Other things might cause a card as above, such as plugged perforations, caving around the tubing or sand in the mud anchor and perhaps other, which would indicate a starved condition.

A good check on gas lock of some cards other than # 11 may be done by measuring the down stroke weight to see if it is heavier than the weight of the rods immersed in fluid. For example, let us take the card of Fig. 12 which has a more

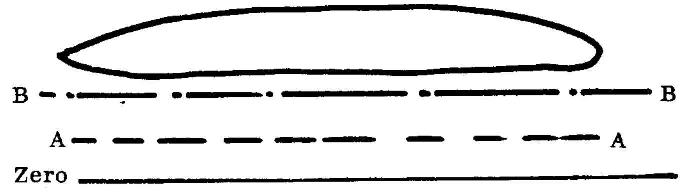


Figure 12

or less flat bottom or down stroke line. Theoretical calculations indicate the down stroke should be at "A". Also, the theoretical weight of rods immersed in fluid would be at "B" in static conditions. Therefore, the rods lose no weight of fluid on down stroke, meaning that the traveling valve stays closed on the down stroke as well as on the up stroke. Therefore, the pump must be gas locked, or the bottom of the pump is plugged, or the standing valve is open. A respacing of the plunger down till it just pecks the traveling valve, which jars open to allow the gas to move away, may start the well to pumping.

In a few instances we have come across dynamometer cards which indicate they are upside down. That is to say, the up stroke is the closest to the zero line. In one such instance it was calculated and found that about 10 feet too many rods were in the well. In another instance, it was calculated and found that the tubing was parted. However, the pump was stuck and the parted tubing was hanging on the rods.

These cards were similar as shown in Fig. 13.

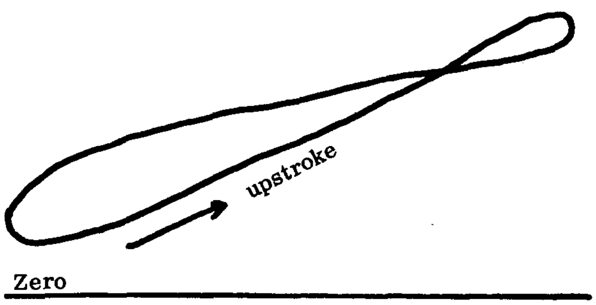


Figure 13

A suggestion for a quick appraisal of a dynamometer card can be done in a simple manner. When the operator goes to a well the theoretical calculation should be complete. The first card taken from the well may be placed on the magnetic drawing board, and the theoretical calculation be drawn there on the card also. In this case, we will have the well card and the theoretical card, as shown in Fig. 14.

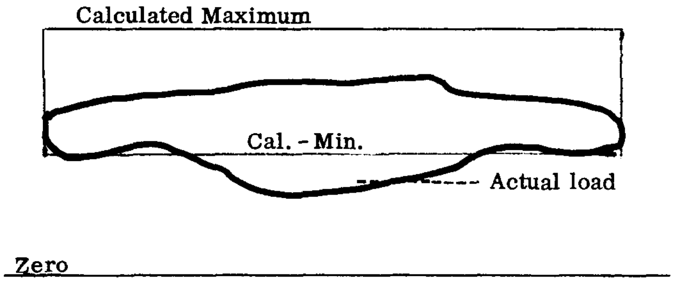


Figure 14

By looking at the card taken, as compared to what the minimum and maximum should be, it is easy to see that there is some difference. The theoretical shows a lot of load that is not produced. This might be caused by a number of things, such as high fluid level in well, flowing, worn plunger, etc.

If the cards were as in Fig. 15, it would be easy to see that there is a terrific overload on the equipment. This overload may be caused by crooked tubing, Paraffin, or the fact that the plunger is larger than recorded, etc.

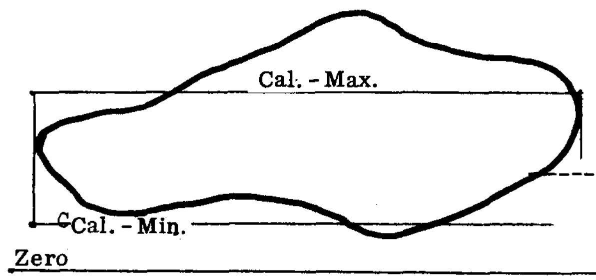


Figure 15

Here is a lot of experience that may be used. The nice part of it is that it will excite the thinking of many people who use dynamometers. As a result of this swapping of information and experience we can go ahead to grander thinking in problems of well production and operations.

Through this experience passed on to you, you now have it to balance out your wisdom and make a more efficient operator.