Low Volume Pumping Systems with Alternative Power Sources

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ABSTRACT

Problem! How does one de-water gas wells in both a cost effective and eco friendly way? One solution follows. Two West Texas pumping gas wells were equipped with belt drive high efficiency C-25-30-58 pumping units, small diameter fiberglass sucker rods, and small diameter downhole pumps set between 2500 and 3300 feet. To determine the exact power requirements for sizing alternative energy sources originally one hp 460-volt AC electric motors were utilized. Two sources of alternative electrical energy are being tested or evaluated, one is solar and the other is a thermoelectric generator system burning wellhead gas. The experience gained will provide technology to go to deeper depths and larger volumes. These alternative power sources and related equipment offer advantages over the traditional gas engine for dewatering remote location gas wells.

THE GOAL OF THIS PROJECT

The goal of this project was to achieve experience with alternative power systems, learn about the costs of such, and achieve a reliable low volume pumping system that typical oil field technicians and personnel can service.

BACKGROUND

Small diameter fiberglass rods have been utilized in a West Texas Oil Field since the early 1980s to provide lightweight artificial lift for marginal production pumping oil and gas wells. A design nominally called the 90-10 design (about 90 % of the rod string length made up of fiberglass rods and the remainder made up of steel sinker bars), utilizing a relatively small pumping unit with a longer than normal stroke length, was employed to reduce the capital expenditure for a complete lift package, reduce the electrical power requirements and to reduce well failures with the potentially better performance of the fiberglass rods.

When oil prices fell in the mid to late 1980s, many businesses folded, many personnel lost or changed jobs, and many products once available disappeared off of the market. One of these products was the small diameter fiberglass rod. Much later, in the early 2000s, a small diameter fiberglass rod again appeared on the market and the staff of the Waddell Ranch again began to employ that rod and its associated peripheral technology.

The objective of the reintroduction of small diameter fiberglass rods was to achieve light weight rod strings so that small conventional pumping units already on hand could be put to work to lift larger volumes of water than the same unit could lift with steel rods. This was done and several marginal high water cut wells were economically returned to production, then other applications for small pumping units and fiberglass rods were sought.

During the capital workover season in 2007 a few new pumping units had to be purchased. It was thought that a slightly smaller unit equipped with fiber glass rods could help cut the cost of capital lift equipment for workover wells and provide a step forward in the realm of reducing electric power consumption. Permission was obtained to pursue several small C 80 pumping units and fiberglass rods. Normally, these wells would have received C 114s or C 160s, but pumping unit prices were climbing and the lower cost per unit of the smaller units became attractive since it was now known that with light weight rods the wells could be produced without overloading the equipment. However, during the course of this effort interest in “micro” pumping units, such as C 25s, arose among the staff.

An inherent problem exists for small pumping units where in they are equipped with fiberglass rods; that is, rod stretch. A unit equipped with small diameter fiberglass rods must have a stroke of sufficient length to lift the pump plunger after it is set at depth and the well’s liquids have filled the tubing annulus. The net stroke of the pump must be long enough to attain the desired production. That said, a beam balanced unit was designed and provided that was the equivalent of a C 25 gearbox torque rating, 3000 lb. beam rating, and had a 58 inch stroke. Two gas wells were “targeted,” both were about 3300 feet deep.

The first well selected was from the 2007 Capital Program, a McElroy gas well, for which lift equipment had not yet been acquired. An AFE existed that provided funds, but the AFE lift plan was for a C 114 and steel rods. It appeared an opportunity could be realized if a Low Volume Pumping System could be obtained at a lower capital cost but one that could achieve the same production results, preventing the expenditure for the "conventional API" lift system.

The second well was an old pumping gas well already equipped with old ¾" fiberglass rods and a M 160 pumping unit (both 1983 vintage). This well was down with a tubing leak with presented an opportunity to modify its existing jointed fiberglass rod design with a ¾" diameter pump; plans also included swapping the unit for the new small unit. The oversized unit was then sent to another well to be used more optimally.

Well 1025 – Solar Power

Eventually, well Waddell et al 1025 was selected for a small pumping unit and a light weight fiberglass rod string. Its production was tested to be about 20 bwpd and 550 mcfpd flowing, later its production fell to 3 bwpd and 500 mcfpd. Efforts were made to design a low volume pumping system that could be serviced with the existing infrastructure. The well is a Sandhills (McElroy) gas well, it is plugged back at 2700 feet deep. It was equipped with 2 3/8" J-55 tubing, its seating nipple at 2559 ft, the rod string was 63 - 3/4" coupled fiberglass rods, 6 – 7/8" grade D sucker rods for sinker bars, and a top discharge 1-1/16" insert pump. The seating nipple was set well below the bottom perforation, though a poor-boy design gas separator was also used. The tubing was anchored five joints above the pump seat.

The pumping unit was of a new design and required a few adjustments after being set. The unit was a belt driven C 25 x 30 x 58 pumping unit. This first unit was equipped for only one stroke length, the 58 inch. It originally was equipped with a 480 volt, 1 horse power motor. The well as also equipped with a SAM POC and operated with A/C power for about 10 months. Eventually, all of the bugs in the system were worked out and a solar power system was installed replacing the 480 volt system. A solar array was statically mounted on a pole facing the southern sky; it was coupled with a bank of batteries, a 12 Volt DC/115 Volt A/C inverter, and a 115 Volt 1 horsepower high efficiency motor. Under solar power the well began operating late in December 2007.

Production capacity is estimated to be 20 bfpd, if operated 24 hours per day, but it has actually been running only 1.2 hours per day, lifting about 0.4 bfpd. Meanwhile, gas production has declined to 200 mcfpd, but the well is known to have all of the liquids pumped off the well's perforations.

Recent dynagraph analyses show the polished rod horse power to be 0.3 horsepower. The pumping speed is 3.6 spm. Downhole gross stroke length is 54 inches, rod loading is 12 % for the ¾" fiberglass and 6 % for the steel rods on bottom. Operating in a pumped off condition, the peak polished rod load was 2254 lbs and its minimum load was 964 lbs. The buoyant weight of the rod string was 1237 lbs. The unit's "gear box" torque, balanced, is estimated to be 19,000 in-lbs.

Well 1234 – TEG or Solar?

The new design pumping unit serial number 2 was installed at well Waddell et al 1234. This well was equipped with ¾" fiberglass rods in 1983 just after it was drilled and completed. Over the course of time, the well has become a marginal producer, and being an off-set to 1025, appeared to be a good candidate well bore for a second test application for a low volume pumping system. The current design uses 76 of the 1983 vintage ¾" fiberglass rods, 6 new ¾" fiberglass rods were also added (the well had been cleaned out and the seating nipple depth lowered during the tubing repair). The tubing was 2 7/8" J-55, with its seating nipple set at 3286 feet, a perforated nipple below the seat, and a TAC set 10 joints above the seat. The seating nipple was set about 10 feet below the bottom perforation. The rod string was equipped with 2-1.25" sinker bars and a shear tool. The pump was an insert design with a bottom discharge, a solid 3/4" plunger, and bottom hold down. This pump design was not readily available in the Permian Basin and was shipped in from Oklahoma City, where they are more commonplace.

The smaller pump diameter seemed to be a viable way of reducing the polished rod loads relative to the deeper depth of this well as compared to the first installation at well 1025. However, the now clean wellbore presented a new unknown, the new liquid production volume. Old well test data indicated this well produced no more than 6 bfpd with about 150 mcfpd, and these figures led to the selection of the small bore pump. The gas meter was accurate, but at the end of the repair new well tests were sought only to find out the test separator liquid dump meters had not worked in quite a while, so a ¾" in water well meter was added to the well head to measure liquid production. When the pumping system was started, it was found that the new liquid production rate was just shy of the system's lift capacity.

The second new design-pumping unit was equipped for two stroke lengths, and for this well the shorter 42 inch surface stroke was picked, knowing the well was a 800 feet deeper. It was set up to run a little faster than the first one at 4.1 spm. At startup the peak polished rod load was estimated at 2064 lbs, with its minimum load estimated to be 1040 lbs. The polished rod horsepower was 0.3. The buoyant rod weight was 1494 lbs, and the fluid load was 643 lbs (pumped off). Balanced, the "gear box" load was 10,000 in-lbs. The downhole stroke measured 34 inches, giving it a net displacement of 7 bfpd. The pump card shows no gas interference or compression. The well operates 20 hours per day, and cycles, so it is considered pumped off, but barely so.

This well, too, was considered a candidate for solar power, but as of yet it has not been so equipped. Alternatively, due to its long runtime per day consideration for a thermo electric generator was made. Such a device could provide constant power, through a battery and an inverter to transform DC power into AC and finishing the system with a low cost 120 volt electric motor. However, this well's gas was found to contain 3 percent hydrogen sulfide, and an economical filtering media has not yet been defined to remove the H2S, so this power source has not yet been resolved. However, the technology has merit for low power requirement applications.

Thermo Electric Generator Power

During the testing of both Well 1025 and Well 1234 a second form of alternative power came to mind. The alternative power would utilized a well's own produced gas, convert it to electricity using a thermal electric generator (TEG), and through batteries and an inverter, power a 115 volt motor (1 horse power) to operate the new style pumping unit.

This next passage is an edited excerpt from the Global TEG, Inc. web page: A thermoelectric generator (TEG) converts heat directly into electricity. As heat moves from a gas burner through a thermoelectric module, it causes an electrical current to flow.
The module is a hermetically sealed thermo electric module, called a thermopile. This contains an array of semiconductor elements. The durable module provides a chemically stable environment for the thermoelectric material and ensures a long service life. A burner maintains a high temperature on the hot side while cooling fins keep the other side cool. The temperature difference across the thermopile creates steady DC electricity with no moving parts. Individual generators range in output size from 15 to 550 Watts, and are ideal for applications requiring power up to 5,000 Watts.

A REVIEW OF THE PHYSICS OF BEAM LIFT POWER CONSUMPTION

The amount of work that a beam lift system does come down to barrels of fluid lifted from a depth. That is foot-pounds of work in a 24 hour time period because production is measured in barrels per day. A barrel of fresh water (42 gallons) weights approximately 350 pounds. One horsepower is defined as 33,000 ft-lbs. in 1 minute, or 746 watts in 1 minute or 746 volt-amps in 1 minute.

Example;

A well produces 10 barrels of fresh water per day from 3000 feet.
The work done is: 10 bpd x 350 lbs/bbl x 3000 feet or 10,500,000 ft-lbs per day,

Translating into horse power: 10,500,000 ft-lbs/day / 24 hr/day / 60 min/hr = 7,300 ft-lbs/min = 0.22 hp.

One kilowatt = 1.341 hp, thus if 0.22 hp is applied, 0.29 kilowatts are needed to lift 10 bfpd, not including losses.

The installed horsepower will be some multiple of this due to losses in the pumping system. (In the two wells equipped the actual depths of 2559 and 3286 feet resulted in the estimates of 0.188 hp and 0.241 hp, respectively)

Measuring the running power consumption of Well 1025 with the 480 volt AC motor, the RMS amps were averaging 1.2 during a series of pumping cycles, this translated into a power usage of 550 watts or about 0.75 hp. If the system ran for a period of 24 hours, 7 days per week it would consume 92.4 kilowatts of power. Or, if it ran less, say the system ran about 20 percent of the time it would consume about 18.5 kilowatts per day. Thus the system power efficiency was about 25 %. This sounds low, but in fact is very good, all things considered. Thus, confidence was established that a solar system would work, one designed with a one horse power motor, an affordable alternative power source, and considering West Texas sunshine no more than a stored energy supply of 72 hours.

Power Generation Costs

The cost of conventional power can be expensive if an infrastructure is not already provided. Even the cost of the “extension cord” from that infrastructure to a well can be very expensive. And, given an electric infrastructure is readily at had, the monthly power bills will continue for the life of the well.

Meanwhile, the cost of solar power, or other alternative power, can be very high per horse power. It appears to be a preventative cost unless the power supply is remote from the application sit. However, if the power demand can be reduced then the power investment cost for the system can be reduced.

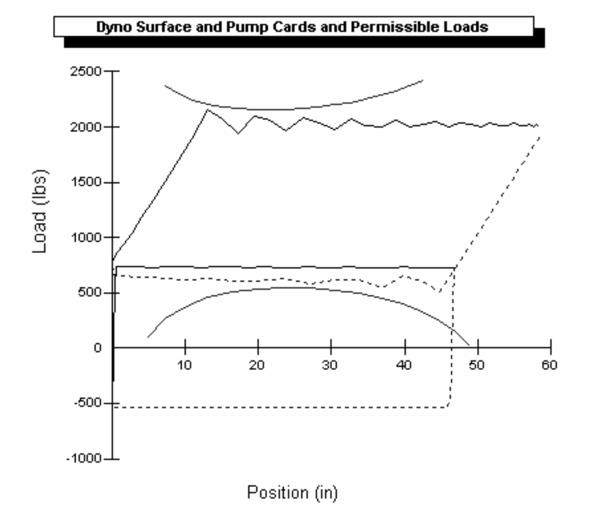
Power generation from a solar array varies greatly from day to day. The factors that affect the efficiency of the solar array are weather conditions, altitude, latitude, the day of the year, and the tracking system of the array. The array must be oversized to offset the efficiency of the batteries, the losses of the inverter, and the days (or hours) of autonomy that you want designed into the system. Solar systems have a high capital cost, about $20,000 dollars per installed horsepower, but cost can go up rapidly.

Thermo-electric generators have a higher capital cost, but no moving parts and maybe suited to more extended operational hours per day given a well can generate sufficient sweet natural gas to feed the generator. Roughly, a TEG will require about $45,000 per installed horsepower. A one horsepower system will consume a little less than 3 mcf per day, depending upon the BTU content of the source gas. Well 1234’s gas contains 3.0 mole percent hydrogen sulfide, to clean the gas an additional $20,000 would be required: roughly $10,000 for a low working pressure vessel, $6500 for a dry media, and some installation costs. The media would need to be changed about every 5 months.

Meanwhile, shallow, low volume wells use very little power which makes the concept of remote conventional power sources uneconomic and the use of alternative power attractive. Solar power and TEG power can, thus, be an economical alternative to conventional power, where in conventional power supply must be built to location. It does not take a lot of distance for the construction of conventional power to mount until the alternative sources describe become viable.

DEFINING THE PUMPING UNIT

Although many unit designs could be adapted, the use of fiberglass rods encourages the idea that a highly efficient small unit would be the best selection. The design of the surface pumping unit should be improved to get the best mechanical efficiency possible. The surface dynamometer card for shallow low volume beam pumping tends to be a trapezoid. This type of cards needs constant counterbalance, not a sinusoidal wave that would come from a crank balanced unit. A beam balanced unit has a permissible load diagram the fits this trapezoid surface card quite well.



PREDICTING SYSTEM PERFORMANCE

As with any artificial rod lift system installation, it is desirable to be able to predict how the system will perform after the installation of selected equipment. As such, the designers and developers of this system chose to use software that has a proven track record for this purpose. This software is commercially available industry wide. Only special input data files and minor modification to program input assumptions were needed to be able to accurately predict how our systems would perform. Actual data from our installations were compared to the predictive output. A very acceptable level of correlation was found that gave the team confidence with this software for future installations.

THE PUMPING UNIT

The function of a pumping unit is to change the rotating motion of the motor into a reciprocating motion that can rise and lower the rod string. To meet the specific requirements of this system concept, a pumping unit was specifically designed to meet the requirements for high efficiency, long stroke, serviceability and low cost.

The articulating inertia should be as small as possible. The use of fiberglass sucker rods not only lightens the rod string but also reduces the required counterbalance. And, the beam balanced unit can be improved by giving it a preferred direction of rotation. (Such as the MarkII or Baker Torquemaster)

The drive system selected, for high efficiency, was a hybrid system. First reduction was belt; second reduction is a planetary speed reducer with a belt drive for the high torque final reduction. To add to the unit's power efficiency, the number of bearings, bearing speed and windage has been minimized.

A special geometry was developed to have a very slow upstroke (where the loads are highest) to minimize the spiking power and torque requirements. The upstroke is achieved with 204 degrees of crank arm rotation with 156 degrees for the downstroke. This also reduces CBE and peak torque required. The API designation for our installations is 25-30-58. Generally speaking, this geometry limits the maximum speed to around 5 SPM, but because of the much longer stroke vs. torque rating, production requirements are met. This longer stroke also accommodates and handles the stretch of a high percentage fiberglass rod string. Units with shorter strokes at a higher SPM do not provide the efficiency levels required. The slow speed and long stroke also reduce downhole pump cycles, coupling to tubing wear and rod load cycles. Thus the long stroke and slow speed enhances downhole reliability

THE DESIGN OF THE POWER SUPPLY

The solar system consists of six-170 watt photovoltaic panels. The total rated output allows about a 70 % derating. The panels are wired to a combiner box that takes the unregulated voltage through a circuit breaker then to a charge controller. Because the panels can vary in voltage output, the charge controller is put in place to regulate the amount of voltage going to the batteries and to regulate when to charge and when not to charge. The batteries are 4 - 265 amp-hour 12 volt DC batteries wired in a series-parallel configuration resulting in a 24 volt DC output to the power inverter. The DC voltage is then routed to a 120 volt AC output inverter that provides power to both the pump off controller and the one hp single-phase high efficiency motor. Both the AC and DC power systems are protected by externally mounted circuit breakers and lightening arrestors. This system is more than adequate for Well 1025 power needs including up to 72 hours of autonomous power reserve. The basic design will handle Well 1234 if the final power system for it is decided to be solar power instead of TEG, but this well would need about 10 more panels and 10 more batteries to achieve the 72 hour reserve power.

ELECTRIC MOTOR SELECTION

Consideration was given to several different motor types. The system designers finally decided on a high efficiency, ¾ to 1 ½ hp, 120 volt AC, single phase, 1800 RPM motor. These motors are used when power is provided from alternative energy sources (Solar or TEG). The reason for this selection is high efficiency, availability and low cost. A similar motor is selected if conventional power is available.

THE PUMP

Rod conveyed bottom hold down insert pumps were selected for both wells. The initial installation a 1-1/16" diameter standard API traveling valve pump was selected. This pump was familiar to field personnel. The 1 1/16" pump has a bad reputation because the valve cage failures. They work fine at shallower depths (less than 5000') where fluid loads are much lower, but not as reliability in deeper wells.

For the second installation, a ¾" diameter, bottom discharge pump was selected. With a solid plunger it does not have a traveling valve or cage to cause failure issues. The bottom discharge washes solids from between the tubing and pump barrel, thus reducing pump sticking. Further, this pump is far more robust and durable then the 1-1/16" pump. The ¾" pump has been successfully installed in 15,000 foot wells and with over 500 pumps in service, its durability and reliability are well proven.

Other pump sizes of similar construction are being considered to meet specific applications. The 1-1/16" pump will be replaced with a ¾" pump at first opportunity in the first installation. However, the larger pump is more readily available at most pump shops.

LEARNING CURVE

The bugs in the system included the pumping units, which were serial numbers 1 and 2, both required a few adjustments.

The stuffing box and polished rod friction was tricky. A conventional rubber stuffing box was used and the personnel learned to not tighten it very much. If tightened too much the friction could cause the motor to draw too many amps (i.e., about 1.7) and trip the motor out. To address this issue, we are considering a "fluid seal" packing for retrofit and future installations.

Adjusting the counter balance was tricky as a few pounds needed to be added or removed depending upon the tubing gradient. Adjustments were made several times.

Friction in the pump, caused by salt precipitation, could not be "busted up" using brute forces as normal with conventional systems. So the well was "squeezed" with scale inhibitor and flushed with fresh water.

This project did give everyone involved a chance to cut their teeth on the logistics and handling of small production wells. The project did not use the other technologies other operators have used such as polyethylene lined tubing, or continuous fiberglass strings. The solar panels don't tract the sun. However, real progress was realized. Conventional fiberglass rods are lifting water off of a formation from about one half mile deep using less than one horsepower, from two wells, one solar powered.

It was of interest that the insert pump itself was almost as expensive as the rod string. The pumping unit didn't cost much more than the rod string and pump combined. And the alternative power was not much more expensive than all of the lift equipment combined, yet the total investment was much less than a conventional pumping unit without rods or motor or power, given a steel sucker rod design would have been used with it.

FUTURE

Work has begun on continuous fiberglass "rods" and longer stroke pumping units. Preliminary design work has been done for depths of 8000 feet, though larger motors and larger capacity power supplies would be required. Yet, at current oil and gas market prices, the future of dewatering low liquid volume gas wells, and equipping marginal low volume oil wells with an economical pumping system seems to have a bright future.

CONCLUSION

1. The first goal of the project was achieved, a reliable solar powered low volume pumping system. As of February 2008, Well 1025 has operated without interruption for several weeks, through the winter weather season thus far. The goal of achieving a thermoelectric generator powered well has not yet been achieved, but it appears to be a viable alternative given the gas content is sweet.

2. Given two wells requiring the same horse power requirements and considering the cost of the two alternative power sources, the solar system is better suited for shorter run times, or cyclic operation, and the TEG is the better design for long runtimes per day where recharging time is limited.

3. Light weight small diameter fiberglass rods, jointed in this case, coupled with small diameter rod pumps are the keys to successfully using small pumping systems to lift liquids off gas wells.

4. It has been proven that technology and know-how are now available for cost effective, reliable, alternative energy rod-pumping systems that make it viable to produce low volume wells, whether it be dewatering of gas or oil.

5. The results of this project have proven to be successful and that we are satisfied with the results and anticipate future applications.

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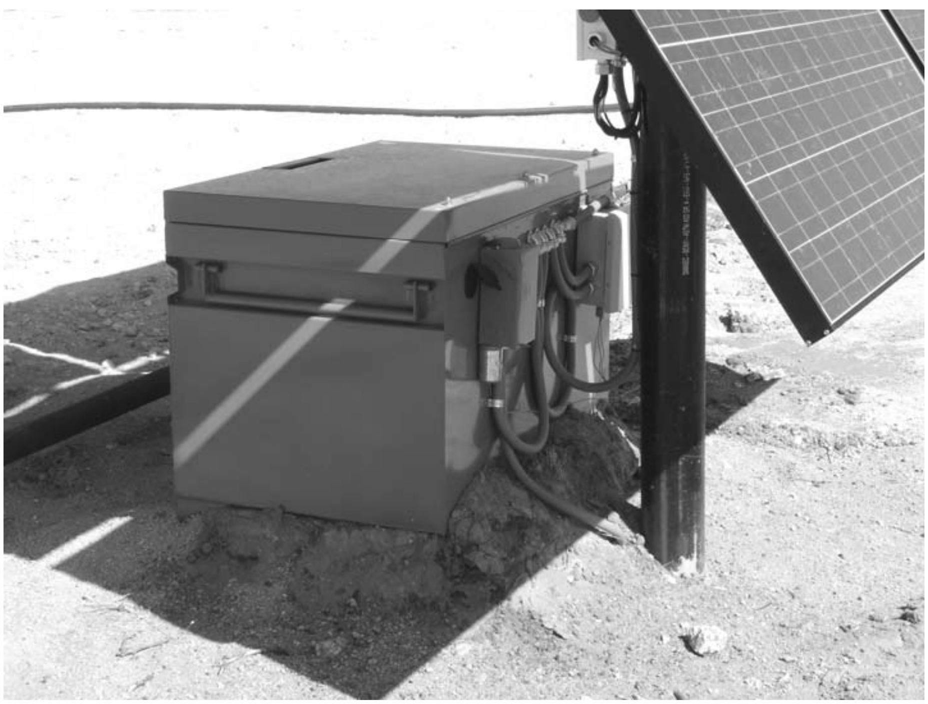

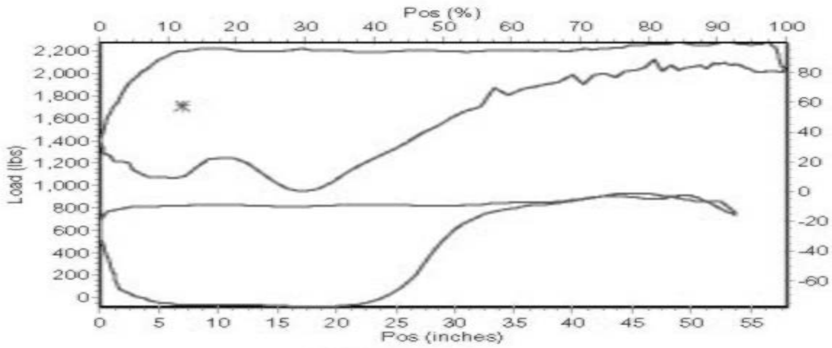

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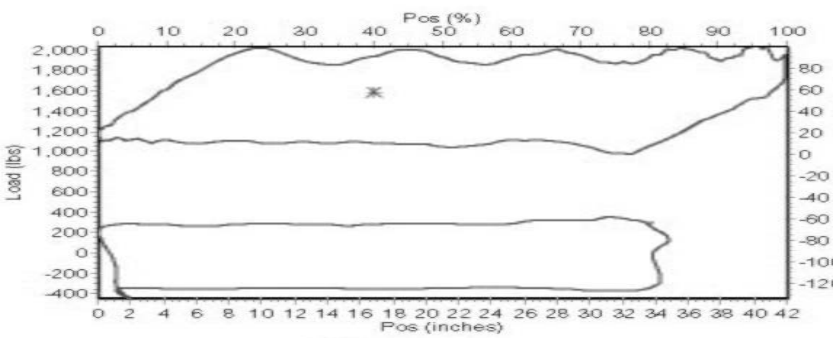

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