R7 ARTIFICIAL LIFT HYDRAULIC PUMPING SYSTEM

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1. R7 DESCRIPTION & OVERVIEW

Bosch Rexroth is a manufacturer of hydraulic drive systems and components including power units, cylinders, and electronic controls. The R7 pumping unit is a specially designed hydraulic artificial lift system for crude oil pumping or natural gas dewatering applications. It can be used in applications with rod loads between 15,000-35,000 lbs, and stroke lengths up to 236 inches. It consists of a hydraulic power unit, which is driven by an electric motor, and a hydraulic cylinder, which stands vertically on top of the well head. The power unit also contains an electrical control cabinet with a PLC and an operator touchscreen to input control parameters to the system. Additionally, the power unit contains a mechanical flywheel, which is mounted directly on the shaft of the electric motor and is used to recover energy during the pumping process.

The advantages of a hydraulic system versus a mechanical system stem from Pascal’s Law which basically states that the pressure a fluid exerts will be equal in all directions. This concept means that a piston with a small surface area can drive a piston with a larger surface area because the pressure at one piston will be the same as at the other piston. This allows us to lift large loads with smaller amounts of force than a mechanical system, which needs a direct linkage to drive a system.

In a cylinder system, the lifting force the cylinder is able to exert is a function of the surface area of the piston for pushing applications or the annulus surface area of the cylinder (piston area minus rod area) for pulling/lifting applications times the hydraulic fluid pressure in the system. The speed of a system is determined as a function of the flow output of the hydraulic pump and either the piston or annulus surface area of the cylinder. In order to determine the horsepower required by the hydraulic system, the maximum system pressure needs to be multiplied by the maximum system flow. Of course, the volumetric and mechanical efficiencies need to be taken into consideration as well when sizing the prime mover.

2. R7 OPERATION

The hydraulic power unit portion of the R7 drive system has an electric motor with a flywheel attached to the back, which drives a variable displacement axial piston hydraulic pump. The displacement of the pump is varied by an internal control spring that controls the angle of a swashplate inside the pump, which increases or decreases the pumping displacement of each piston. The control spring is controlled hydraulically by a proportional valve attached to the pump. This proportional valve can vary the force on the control spring, which can infinitely vary the swashplate angle over its range of motion from positive full flow to negative full flow. The proportional valve gets its signal from the PLC, which is reading feedback devices in the system and make adjustments according to the desired set points and actual system feedback. The feedback devices include pressure transducers on either side of the hydraulic cylinder, which measure pressure on both sides of the piston. This pressure differential is used to calculate the cylinder load at any given moment in time. The other feedback device is either a linear position transducer in the hydraulic cylinder or limit switches at each end of the hydraulic cylinder. The position transducer can measure where the piston is at all times down to the micron, and by using this transducer, the stroke length of the cylinder can be varied infinitely over the entire stroke of the cylinder. If limit switches are used instead of a transducer, the system will only know when the cylinder has reached the end of its stroke on each end. In order to change the stroke length of the cylinder with limit switches, the switches need to be physically moved to their desired location.

During the lifting phase of the stroke, the flywheel is driving the hydraulic pump, which is sending pressure and flow to the cylinder in order to lift it at the desired speed and force. The flywheel can only provide a portion of the power required to drive the hydraulic pump, so the electric motor makes up the difference. Due to the physical laws of fluid power, the hydraulic pressure in the cylinder will only equal out to the exact amount needed to lift the cylinder and rod string assembly, no more, no less.

During the lowering phase of the stroke, the cylinder rod string assembly is gravity lowered by the weight of the rod string. This in turn causes the cylinder to push the hydraulic fluid back through the hydraulic system. The proportional valve on the hydraulic pump tells the pump to swivel its swashplate over center, which causes the flow to go in the opposite direction. As a result, the pump turns into a motor, and drives the flywheel, allowing it to store the energy as rotational inertia. Because the swashplate can swivel over center, the direction of rotation of the electric motor shaft does not need to change in order to change the direction of flow.

Along with the main pump to drive the cylinder, there are also two other small pumps attached to the back of the main pump. One of the small pumps is used for a filter/cooler loop, and the other is used as a charge pump to make up any flow deficiencies during the lowering stroke of the cylinder-rod assembly.

3. HYDRAULIC CYLINDER MOUNTING OPTIONS

There are a few different ways to mount the hydraulic cylinder to the well. It can either be attached directly to the top of the well head, slightly above the top of the well head, or at least a stroke length's distance above the well head. If it is mounted directly on the well head, then the cylinder rod acts as the polished rod and no stuffing box is required. This saves space and parts, but it makes it more difficult to detach the cylinder from the rod string when needed and all the loads of the rod are transferred through the well head. To alleviate the problem of detaching the cylinder, it can be mounted a few feet above the well head, so that there is a big enough gap to get access to the coupling between the hydraulic cylinder rod end and the rod string. In this situation, the cylinder rod would act as the polished rod, but a stuffing box would be required and a platform would need to be built to mount the hydraulic cylinder. The platform could either be attached to the well head, which would still transfer the rod string load through the well head or secured to the ground. The third alternative is to build a taller platform that is secured to the ground. This gets the hydraulic cylinder rod completely out of the crude oil, so a polished rod would be required. The platform also has to be high enough so that when the cylinder is fully extended, it is still a few feet above the stuffing box.

4. R7 VELOCITY PROFILE ADJUSTIBILITY FOR INCREASED SPEED

One of the main advantages of a hydraulic system is the ability to manipulate the velocity profile of the rod string to whatever is desired. With a mechanical system, the velocity profile is fixed as a sinusoidal wave. The period (stroke time) of the wave can be modified by changing the amplitude (speed); however, the profile will always stay in the form of a sinusoidal wave. On the other hand, because a hydraulic system is not rotating like a mechanical system, it is just moving up and down in one dimension of movement, the profile can easily be modified. The picture above illustrates this concept. A hydraulic system can ramp up to the desired speed immediately, while the mechanical system must slowly accelerate to a peak speed because of the sinusoidal wave properties. Additionally, a hydraulic system can maintain that desired velocity over virtually the entire stroke of the cylinder; whereas, a mechanical system only momentarily reaches its peak velocity before it has to decelerate again. Consequently, the hydraulic system can increase the strokes per minute of the rod string assembly while actually travelling at a lower maximum velocity than the peak velocity of a mechanical system. On the other hand, if an increase in speed does not have any value for a particular well, the velocity profile can be configured in such a way that either the lifting or lowering speeds are decreased while still being able to maintain the same strokes per minute. For example, if a slower lowering speed is desired without sacrificing the overall strokes per minute, then the velocity profile can be adjusted to increase the lifting speed and decrease the lowering speed as depicted in the picture.

5. OVERLOAD PROTECTION & CONDITION MONITORING

Another advantage of a hydraulic system is in an overload situation. If the rod string gets stuck during either the lifting or lowering phase, the hydraulic system will immediately recognize that the cylinder is not moving. The hydraulic system will only allow the pressure to build to a maximum set point, making sure that the rod string is never over loaded. With a mechanical system, the system would continue to try to rotate until the weakest point of the system failed. Overload switches on a mechanical system can help prevent that, but even with switches, once the overload is reached, there is still mechanical inertia which can exert adverse loads on the rod string assembly. Once the hydraulic system recognizes that the movement has slowed or stopped, it will then change the direction of the movement. The cylinder will go back to its starting position and attempt to complete the stroke again assuming it is still possible to move the rod string at that point. If it is possible to move the rod string back to its starting position, that means that the hydraulic system will be able to continue to pump crude oil, albeit over a shorter stoke, even when there is something preventing the rod string from completing an entire stroke. At best the mechanical system would shut down for a period of time. At worst, it would break something.

There is also a built in pressure relief valve in the hydraulic system, which would be set at the desired maximum pressure set point. Should pressure in the cylinder build to that set point, the additional hydraulic fluid would then be relieved over that valve making sure that the pressure in the system never goes over the maximum set point. Additionally, it is imperative that the polished rod and string assembly be able to handle the additional force exerted by the cylinder when maximum system pressure is reached.

In addition to the velocity profile and overload protection advantages, the hydraulic system is able to do condition monitoring as well. With the pressure transducers and the linear position transducer on the cylinder, the system knows exactly what the force on the rod string is at any given stroke position. Therefore, it is easy for the system to produce to data necessary for a dynometer graph.

6. FOOTPRINT & INSTALLATION

As the picture of the R7 unit illustrates, it is a very compact design with a much smaller footprint than a mechanical beam pump or other hydraulic systems. Its installation is quick and easy, and it can be easily transported from one location to another. Besides securing the cylinder to the well head or platform and securing the power unit to the ground, the only installation required on-site is the field piping required to connect the power unit to the system and field wiring to connect the linear transducer or position switches to the power unit and to connect electrical power to the power unit. In fact, because it has such a small footprint, it has been installed in offshore applications where it otherwise would not have been economical to build a platform for a different type of pumping system.

7. REMOTE CONTROL & MONITORING

Another feature available with the R7 is the ability to communicate with a remote location. Using an OPC server located in the electrical cabinet of the power unit, data or control functionality can be transferred over the web. Therefore, a person can input control parameters or monitor the function of the system from the comfort of a remote office. All they would need is a software visualization package to do so.

8. SUMMARY

All in all, the R7 has many advantages for pumping crude oil or getting liquids out of gas wells. Its compact design allow for easy installation and transportation. It can significantly increase crude oil production by going faster than a beam pump by virtue of a velocity profile that is neither fixed nor sinusoidal, or it can efficiently and effectively remove liquids from gas wells to increase the overall gas production. Because the depths and rod loads can be so high in certain dewatering applications, and the speeds required can be so slow, it might not be practical to use a mechanical type solution. This is the perfect application for a hydraulic solution because hydraulics can deliver a high force or torque very efficiently at low speeds. In fact, in hydraulic systems, force and speed are really two independent functions. It is just as easy for a hydraulic system to operate at low speeds as it is to operate at high speeds, and the same is true regarding pressure. In addition, the R7 stroke length and speed can easily be adjusted by entering different control parameters on a keypad, and it can reduce the risk of polished rod failures due to overload situations. Furthermore, it can operate more efficiently than other hydraulic systems because of the flywheel energy recovery design. With all of these advantages, the next generation in artificial lift has arrived.

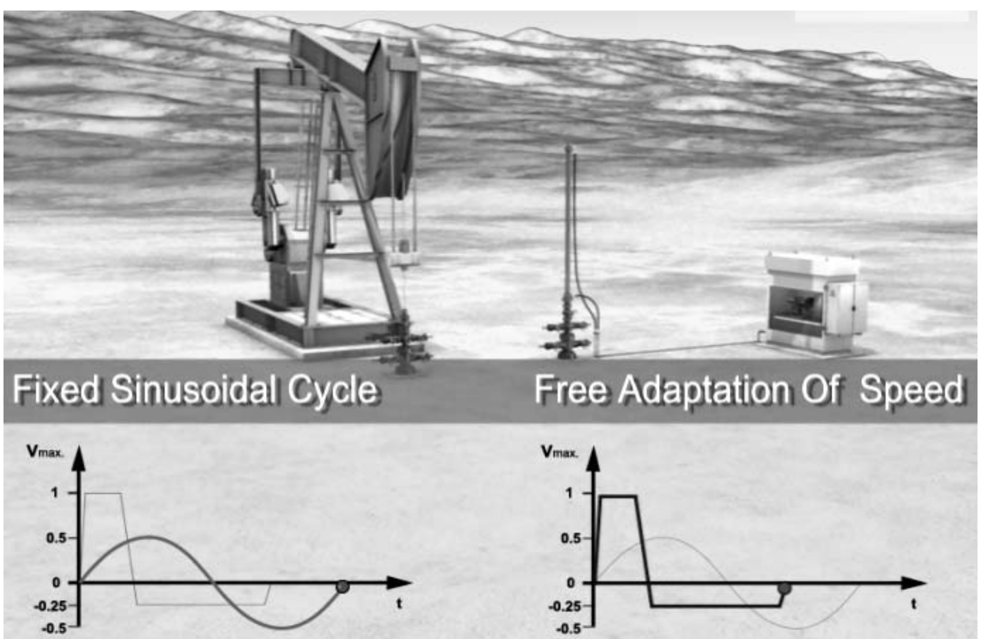

Figure 1 - Velocity Profile Comparison