# Artificial Lift

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## Lecture-23 Sucker Rod Pump (SRP)-Part-2

So, let's draw a sucker rod pump first. A sucker rod pump looks like this: I have a walking beam, and the walking beam will have a horse head. I mentioned that it would be like an arc. It will also have my Samson post. This is a simplified drawing. I'm drawing the Samson post, and there will be a tail pin. The tail pin is connected to my pitman arm, the pitman arm to my crank. The crank will be connected to one big mass called the counterbalance mass. This is the counterbalance mass, and there will be one pin also. There will be one gearbox and one pulley here, at the back, a sheave. So, the sheave will be connected to your motor sheave. This sheave will be connected to your motor sheave. So, here one motor will be. The motor here will be connected to a sheave. This will be a V belt, usually. I will explain later what a V belt is and why it is used for our industry application. There will be one gearbox, and this is called the crank. This is called the counterbalance mass. This is the pitman's arm. This is the tail pin. This is the walking beam. This is the saddle bearing. This is the horse head, and the horse head will be connected to the bridle or wireline. The wireline will be connected to your polished rod. The polished rod will go into the wellbore, and there will be one stuffing box. A stuffing box, a stuffing box, and there will be one T section. There will also be a gas venting pipe in the T section. This is going to the wellbore, and this is the sucker rod pump. The sucker rod pump is here, and this is the sucker rod. This is the tubing, and casing will be here. The casing is like this. So, this is how you can draw the whole sucker rod pump system.

Now, I've selected three types: conventional, Mark 2, and air balance systems. But if you search Google, here I have given one link also, if you see there, there are several other types of sucker rod pumping systems also available. The most common ones are Dupe pins and Weatherford. They manufacture these three types of systems.

So, one is the conventional system, the conventional sucker rod pump, and another is called Mark 2. What is Mark 2? Mark 2 is like this: I have one working beam and a Samson post. I have a Samson post here, and I have a beam here. The horse head is here, and my pump is here, and my power will be given here. Mass is here, and power will be given from here.

So, you can see both are the same; only the motor's location is changed. The motor's location changes from one end to in between your saddle point and horse head. This is Mark 2, and one company, Luftkien, they made this Mark 2 sucker rod pump.

Another is called the air balance unit. The air balance unit will be similar to Mark 2, but then you have it like this. Instead of a counterbalance, you are using an air compression system. This is an air compression system, so counterbalancing.

This is called an air balance unit, so you see the three systems' differences. Many companies are trying to develop long-stroke sucker pumps also. In that case, sometimes they are using a linear generator-type thing, sometimes they are using some gear mechanism. Instead of the whole beam, this Samson post, everything they are replacing and making it directly long-stroke like this. Maybe they will have one gear mechanism, and the rack is like this. If you rotate this gear continuously in positive and negative directions, the rack will be moving up and down, continuously up and down. The rack means this is one straight beam, and it will have lots of gear teeth. I will explain later what those gear teeth are.

If you give rotation to this pinion, the rack will be moving up and down. So, an average sucker pump stroke length will be 74 inches, 40 inches, or 50 inches, but this type of linear stroke-based system has stroke lengths like 25 feet, 20 feet, so very long strokes they create. They say these are better because you can run slowly, and with a very long stroke, many problems will be resolved. Many other types of sucker pumps may also be available or already in use, so please go through the link provided in the slide.

Now, I mentioned that the sucker pump or beam pump can be run by one motor or an IC engine, which is called a prime mover. So, what is a motor? A motor is an electrical system. The motor will have one magnetic coil plus a magnet. When both act together, they will give torque to a shaft. The shaft's torque will be transferred to your sheave or small pulley.

The small pulley will be connected to your V belt and attached to a more oversized V belt on a bigger sheave. You reduce speed when the bigger sheave is connected to the gearbox system. Normally, this motor's speed will be around 700 or 1400 RPM, so a very high-speed motor is there relative to your sucker pump stroke. The sucker pump stroke will be 6 to 20 strokes per minute (SPM), so 6 to 20 SPM means 6 to 20 rotations of the crank. The crank looks like this: the crank and pitman arm, pitman arm to your beam pump, sorry, walking beam. So, this rotation, N, and this horse head SPM, RPM, will be the same. So, one rotation means one stroke per minute, two strokes, one stroke up, one stroke down, and two strokes. So, if you want to achieve a stroke rate of 6 to 20 strokes per minute, your crank rotation must also be reduced accordingly. From 700 to 20 or 40 rotations, you have to reduce it. So, when you reduce the rotation so drastically, you cannot do it in one go; you must go in multiple steps to gradually reduce the speed. These days, variable frequency drives (VFDs) are also available. If you use a VFD or variable frequency drive, you can reduce or increase the speed as required.

So, if it is running without any load, a motor will give a very high speed. Now, when you load it, some speed will be reduced. The amount of speed reduction can be calculated using slip calculation, denoted as motor slip. The slip (S) is calculated as,

$$S = \left(\frac{N_s - N_F}{N_s}\right) * 100$$

where $N_S$ represents synchronous speed, and $N_F$ is nominal full-load speed. This calculation yields the motor slip.

If there is no load, the speed will be very high. You can measure the speed using a tachometer, a speed sensor, or a speedometer. A tachometer functions by emitting a light signal onto a reflector glass attached to a shaft. When the shaft rotates, it reflects light, and the tachometer senses the reflection rate. The number of reflections per unit of time provides the speed measurement. Handheld devices for this purpose are available in the market.

Initially, without any load, you can check the synchronous speed. Then, load the motor and observe how much the speed is reduced; this reduction is referred to as slip. You can determine the motor's speed range based on the slip measurement. You can decide whether to use a higher or lower-power motor if you need a specific stroke per minute.

For example, consider a problem where an induction motor has an initial speed of 1200 rpm. After loading or connecting it to your sucker rod pumping system, the tachometer reads 1000 rpm. To calculate the slip, use the formula:

$$S = \left(\frac{N_s - N_F}{N_s}\right) * 100$$

Slip = (1200 - 1000) / 1200 = 12.5 percent when multiplied by 100.

This represents the amount of slip.

Now, let's discuss IC engines. In surface units, motors are commonly used for power, provided an electric connection is available. However, if electric connectivity is unavailable, you have to resort to using an IC engine, which stands for internal combustion engine. An internal combustion engine can operate on diesel, petrol, or even the gas obtained from the wellbore.

Choosing between an IC engine and a motor depends on accessibility. Using a motor is a good option if you have easy access to electricity.

So, what exactly are two-stroke and four-stroke engines? A two-stroke engine can deliver high power but tends to produce higher levels of pollution. On the other hand, a four-stroke engine provides slightly lower power but is known for its lower pollution emissions. I will explain later how these two-stroke and four-stroke engines work.

Typically, two-stroke engines have speeds of 750 rpm, whereas four-stroke engines can reach 2000 rpm, especially in multi-cylinder engines. Fuel engines with power outputs ranging from 15 to 325 horsepower are readily available for oil and gas industry applications.

To adjust the speed, you would need to go through a V-belt pulley system or sheave system, followed by a gear mechanism, pitman arm, working beam, horse head, middle and polish rod, ultimately connecting to the sucker rod. The sucker rod then transfers power to your pumping system or down-hole system.

Now, what is a V-belt drive? In this picture, you can see that a V-belt connects one pulley, known as a sheave, to a larger pulley. It's somewhat akin to a bicycle, where you have a smaller sprocket or wheel connected by a chain to a larger one. Why the difference in sizes? Well, it's precisely because of this difference in size that you can change the speed. For example, let's say you're pedaling at a rate of 10 rpm. By altering the diameter, such as $d_1$ and $d_2$, and having a ratio of $d_1$ to $d_2$ at 2:1, where $d_1$ is twice the size of $d_2$, you can effectively increase your speed to 20 rpm.

Similarly, in bicycles, you have small sprockets connected to larger tires. This connection to larger tires allows you to achieve higher speeds. Nowadays, bicycles often come equipped with multiple gears so that you can change speeds. If you examine a multi-gear or geared bicycle, you'll notice various-sized gears at the back, enabling speed adjustments.

That's the idea behind small and large gears—different types of gears are available, and by changing the gear, you're effectively altering your speed. This change in speed is achieved by adjusting the $d_1$ and $d_2$ ratio, where $d_1$ remains nearly fixed for all cycles, but $d_2$ varies. Changing $d_2$ will modify your cycle's speed, even though you might have to exert more effort because power remains constant.

Remember, when you change speed using a gear mechanism, we assume minimal or negligible power losses occur during power transfer from a large wheel to a small one. The power remains the same, but only the torque or rotational speed, represented by omega, changes.

When transferring power from a motor to your pitman arm or sucker rod pump, you typically use a V-belt, although it can also be a chain. The key difference between a chain and a V-belt lies in their composition. As shown in the picture, a chain is entirely metallic, composed of interlinked metal pieces. It lacks flexibility but also has minimal friction. In contrast, a V-belt has a V-shaped cross-section, with grooves in the pulley or sheave shaped to match. Typically, V-belts come in odd numbers, like 3, 5, or 7, and they are arranged to maximize friction. This design, combined with soft materials like rubber or cotton, provides excellent grip and minimizes sliding. The continuous bending action these softer materials undergo prevents failure during continuous rotation.

Certainly, chain drives can also be used, but chains tend to be heavier. For high-speed and long-duration applications, chain maintenance can become quite challenging. In contrast, V-belts are much lighter and can handle very high speeds with less maintenance. V-belts offer flexibility, high load-carrying capacity, and safe operation. They can extend and slide in case of blockages within the machinery system.

Regarding gear systems, belts, gears, and chains all serve as power transmission systems, facilitating power transfer from the motor to the pitman's arm. Here's how it works: the motor's shaft is connected to a sheave, and this sheave links to a V-belt. The V-belt, in turn, connects to another larger sheave. The shaft of this larger sheave is connected to a gearbox, which is then linked to a crank.

The primary purpose of using a V-belt in this setup is to transmit power while simultaneously reducing speed. In the case of a bicycle, for example, when you pedal, the gear connected to the pedals has a larger diameter, while the gear attached to the back wheel has a smaller diameter. This difference in diameter results in speed reduction. Similarly, in the motor-to-gearbox connection, the smaller-sized gear is on the motor side, while the larger sheave is on the gearbox side. This configuration effectively reduces speed. If you were to change the diameters $D_1$ and $D_2$ by doubling $D_1$, your speed would be halved.

Certainly, when two shafts are positioned very close together, it's common to use a gear mechanism instead of a belt or chain. Gears have very high efficiency, resulting in minimal power losses. However, it's crucial to ensure proper lubrication to keep friction low, as gears have surfaces that can generate friction. Lubrication is essential in all these cases where friction is involved.

When drawing a gear, you can create its shape as follows: first, draw an initial circle, then add curves and flats alternately. The gear teeth should have this curved, flat, curved pattern. This process is typically done manually, which can lead to variations, as you can see in the drawing.

Gears consist of teeth or gear wheels. When two gears mesh, their teeth should have the same shape and size. The teeth on both gears must match precisely. If the teeth are different in size or shape, the gears won't be able to rotate together properly. For example, if one gear has larger teeth and the other has smaller teeth, the gap between them may not be sufficient for the larger teeth to fit, preventing them from meshing effectively.

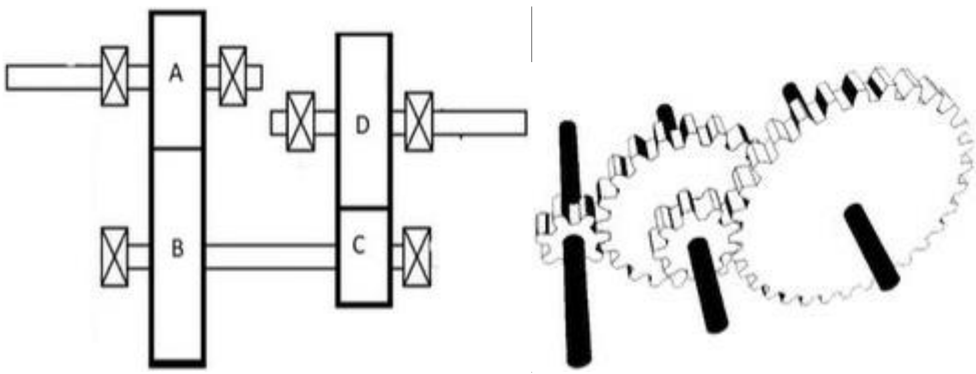


Fig.1. A sample gearbox assembly.

If there's a big gap on one gear and a small gap on the other, the small gear will mesh with the big gap, but the reverse won't work. When gears rotate, they must mesh properly to function correctly. Therefore, both gears must have the same shape and size for proper meshing. The power transmission between big and small gears is achieved by changing the number of teeth, not the shape and size. The number of teeth changes along with the diameter, but the ratio of diameter to teeth remains the same. So, the larger diameter gear will have more teeth, while the smaller diameter gear will have fewer teeth, but the shape and size of the teeth must remain consistent.

In gear systems, one gear is called the driving gear, and the other gear that receives power from it is called the driven gear. When power is applied to the driving gear, it results in rotation in the driven gear. This rotation is typically in the opposite direction, meaning if the driving gear turns clockwise, the driven gear will turn counterclockwise, and vice versa.

Both components rotate in the same direction in pulley systems, such as the cycle sprocket and chain drive. For example, if you pedal clockwise, the wheel also rotates clockwise. However, in gear systems, the direction of rotation changes along with the change in speed. Some arrangements involve cross-belt configurations, where one pulley is linked to another with a belt, resulting in opposite rotation directions. In applications like sucker rod pumps, a straight arrangement is typically used, changing the speed but not the direction of rotation.

If it is a single reduction gearbox, it will involve only one gear driving and one being driven. However, if multiple gears are arranged sequentially, with one driving the next, it becomes a double or triple reduction system. These gears are enclosed within a box called a gearbox, which is essential for smooth operation. Gearboxes require proper lubrication to minimize friction between the gears. Friction can lead to excessive heat generation, reduced component lifespan, and potential system failure. Lubrication ensures lower friction and longer equipment life.

Sucker rod pumps and Progressive Cavity Pumps (PCP) used in various surface and downhole applications, not only in the oil industry but also in other sectors such as trucking, buses, trains, and bicycles, make extensive use of gears, chain drives, or belt drives. In the case of SRPs, double-reduction gearboxes are commonly employed. These gearboxes are enclosed within a box and filled with a lubricating fluid, typically a high-viscosity oil like Mobil Oil or engine oil. Different companies produce varying qualities of lubricating oils, and the choice of lubricant may depend on factors such as temperature and operating conditions.

Now, let's delve into how the double reduction gearbox works. It consists of a single box with an input shaft that transfers power to gear A. Gear A's rotation drives gear B, which is directly linked to shaft C. Shaft C's rotation is transmitted to shaft D, which serves as the final driven output shaft. In essence, the input shaft provides rotation and torque to gear A, which, in turn, drives gear B. Since gear B is connected to shaft C, both C and D rotate accordingly. When shaft D rotates, it produces the desired output of shaft rotation and torque.

To visualize this arrangement, you can consider the following labeling: A for gear A, B for gear B, C for shaft C, and D for the final output shaft. Remember that these components' sizes may vary, as depicted in the top image. Alternatively, you can imagine a sequence of gears with varying sizes, where a smaller gear drives a slightly larger one, which, in turn, drives a larger gear, ultimately connected to a smaller gear representing D.

Now, let's explore how the double reduction gearbox operates. It consists of four main components: A, B, C, and D. A represents the input shaft, while D is the output shaft. The gears in between are responsible for transferring power and adjusting the speed.

When A rotates, it drives B, and since B and C are directly connected, they rotate at the same speed. Therefore, if B and C both have a speed of 100 RPM, D will have a lower speed, such as 400 RPM, while A will have a higher speed, perhaps 1000 RPM.

Herein lies the challenge: A has 7 teeth, B has 21 teeth, C has 9 teeth, and D has 30 teeth. The gear ratios are crucial. The first gear ratio is 7:21 (A to B), and the second gear ratio is 9:30 (C to D). If we input 700 RPM to A, we can calculate the resulting speeds for B, C, and D based on these ratios.

B's RPM will be,

700 * (7/21) = 233.33 RPM,

and C's RPM will also be 233.33 RPM.

Then, for D, which is further connected to C, the RPM becomes,

233.33 * (9/30) = 70 RPM.

Therefore, starting with an initial RPM of 700, the final output RPM is 70.

This illustrates how a double-reduction gearbox functions. However, with a triple reduction gearbox, you can introduce more gears with varying teeth counts or diameter ratios to further adjust the speed. It's important to note that while power remains constant, torque can vary. Additionally, the direction of rotation can change as gears interact, such as A rotating clockwise and B rotating anticlockwise.

In many applications, people can choose between a differential gearbox or a standard gearbox. The standard gearbox can come in various configurations, such as double reduction, triple reduction, or single reduction. Let's consider the scenario where we want to switch from a double reduction gearbox to a single decrease one with a gear ratio of 7:10. To achieve this, we need to calculate the necessary gear ratio, which is 700 RPM (input) divided by 70 RPM (output), resulting in a required gear ratio of 10. Assuming we have a small gear with a diameter of 10 centimeters, we must pair it with a larger gear with a diameter of 100 centimeters to achieve the 10:1 gear ratio.

However, it's worth noting that using a single reduction gearbox might pose space constraints, as it requires accommodating both a small and a significantly larger gear. Opting for a double or triple reduction gearbox can be more practical in situations where space is limited. These gearboxes offer a more compact design with integrated lubrication systems, making them easier to handle. Nevertheless, if the required speed reduction is not substantial, a single reduction gearbox can still be viable.