ELECTRIC SUBMERSIBLE PROGRESSING CAVITY PUMP THE SYSTEM—A TUTORIAL

David L. Olson, Centrilift

ABSTRACT

This tutorial describes the components of the electric submersible progressing cavity pump system. The intended audience is familiar with electric submersible pumping systems used in petroleum production. While the electrical parts of any electric submersible system are important, this material emphasizes descriptions of the progressing cavity pump and its unique mechanical drive components.

INTRODUCTION

Often it is advantageous to abstract a system to gain insight into its characteristics. In this paper the Electric Submersible Progressing Cavity Pump **(ESPCP)** system is abstracted by dividing the system into the following elements: controller, cable, motor, gear reducer, thrust bearing, coupling, and progressing cavity pump. All current ESPCP systems have these elements. In this tutorial, the focus will be on the unique mechanical elements in the progressing cavity pump system which include the gear, thrust bearing, coupling and progressing cavity pump.

PROGRESSING CAVITY PUMP

Rene Moineau developed the progressing cavity concept in the late **1920's** while designing an aircraft engine supercharger. He used this concept in **1936** when he designed a progressing cavity pump. Moineau's principle is used in many industries in a wide variety of applications. It has been used for fluid transfer in the petroleum industry for over 50 years. During the **1950's** the concept was applied to hydraulic motor applications. By reversing the function of the progressing cavity, the mechanism is driven by the fluid rather than driving the fluid. By driving the pump elements with drilling mud or other fluids, it became the prime mover for drill motors. Moineau's principle is now widely used in the petroleum drilling industry. **In** early **1980,** the progressive cavity pump was first offered **as** an alternative artificial lift method. In this method the pump stator is attached to the tubing which is deployed downhole. The rotor is attached to the bottom of the rod string and landed in the stator. A wellhead drive supports and rotates both the rod string and rotor, thus producing fluid up the tubing.

During the 90's the ESPCP was introduced. In this method, the pump elements are assembled with a seal, thrust bearing, gear reducer, and an electric motor then deployed on tubing.

An ESPCP offers the potential to lower well operating costs in difficult applications. A progressing cavity pump is capable of producing viscous and solids laden fluids, it reduces emulsion creation, and it can be reversed for backflushing of tubing and pump. An ESPCP eliminates rod and tubing failures, it eliminates stuffing box leaks on the surface, and it can be operated in horizontal or deviated wells. An ESPCP eliminates frictional losses between tubing and rods, thus the efficient operation of a progressing cavity pump is enhanced by an ESPCP. An ESPCP combines the advantages of a progressing cavity pump and an electric submersible motor.

The simplest design of the progressing cavity pump consists of a single external helix that revolves eccentrically within an internal double helix. The internal helix has the same minor diameter and twice the pitch length of the external helix. The eccentricity is the locus of the rotor axis as its geometry rotates against the geometry of the stator. For oil field applications, the rotor is metal and the stator an elastomer that is injection molded within tubing. The rotor and stator are assembled with a compression fit. When the stator and rotor are assembled a series of cavities are formed. The cavities are sealed by the fit comprised of two lines on the rotor 180° apart. As the rotor turns the cavities spiral (progress) along the pump axis so that as one cavity diminishes, the following cavity increases. The fluid cross section is unchanged throughout the length of the stator, regardless of rotor position, resulting in a pulsation-free, positive axial flow.

A Progressing cavity pump can also consist of a multiple helix rotor and corresponding stator—a multi-lobe pump. These are the preferred elements for the drilling mud motors. Multiple helix designs can have any number of helices as long as there is one more helix in the stator than on its mating rotor. For pumps, the most affordable and practical multi-lobe pump design is a double helix rotor with a triple helix stator.

There is no inherent directionality in the progressing cavity pump elements. There is no top or bottom until other equipment is attached. Though the helices of a pump *are* conventionally right hand, there is nothing between pump elements that dictate the direction of rotation. If a stator is constrained on a horizontally on a bench, the pump maybe assembled by inserting the rotor in one end then rotating it clockwise into the stator. The rotor is backed out with counterclockwise rotation. In operation, both rotor and stator are held against axial movement. If the rotor is rotated clockwise, the fluid moves toward the viewer and the thrust away. If counterclockwise, the fluid moves away from the viewer and the thrust opposite. Most of the power driving a progressing cavity pump is converted to thrust since the liquid moves along the same axis as the rotating parts.

While its mechanical efficiency is greater at higher speeds, a progressive cavity pump's life is extended when it is run at moderate speeds. Speeds between 250 and 400 rpm offer a good compromise between efficiency and life. Other factors affecting pump life are the compression fit, elastomer properties, pressure loading, pumped fluid properties, and ambient temperature.

The pressure capability of a progressive cavity pump is a function of the number of stages within the pump—the number of times the seal lines formed by the rotor and stator are repeated. A stage is defined as 1.0 to 1.5 times the pitch length of the stator. Each stage is usually designed to achieve 100 psi. The more stages a pump has, the more its pressure capability increases. As pressure increases the flow rate will decrease. The reduction in flow rate, or slip, is independent of speed, but dependent on the number of stages, fluid viscosity, and the compression fit.

The majority of stators are made with elastomers classified as nitrile rubbers. The nitrile rubber copolymers are acrylonitrile and butadiene. The properties of the rubber vary with composition of the rubber. The principal methods of altering the rubber properties are variation of acrylonitrile proportion or saturation of butadiene. Elastomer properties that are important for well service include: hardness, tensile strength, abrasive resistance, resilience and elasticity, heat resistance, oil resistance, and gas permeation resistance. Elastomer recipes are proprietary to each progressing cavity pump manufacturer.

A key progressing cavity pump application issue is the amount of stator swell anticipated in the well. The goal is to provide a pump with a compression fit that produces the well efficiently without sacrificing run time. The stator elastomer swell depends on the bottomhole temperature and the chemistry of the pumped fluid. Accurate prediction of swell is difficult. The fit of a pump is varied by changing the rotor size, so a common strategy in a new well is to start with an undersize rotor, run the pump for several days to allow the elastomer to swell, then evaluate the production performance. Using an oversize rotor resulting in a very tight fit after swell runs the risk of not being able to start the system or breaking a drive shaft. It is not uncommon to tolerate an underperforming well until the next good opportunity to change out the rotor. Closer prediction of stator swell in a new application is possible when elastomers are tested, at operating temperature, in the intended production fluid.

The essential operating characteristics of a progressing cavity pump that affect the other mechanical components of the system described below are the rotor eccentricity, high thrust, direction of rotation, positive flow, torque, and speed.

COUPLING

The coupling must convert concentric rotation of the motor and power train to the eccentric, rotating motion of the progressing cavity pump rotor. This must be accomplished in the power train after the thrust bearing that requires concentric motion. In addition, the thrust generated by the pump must be transmitted though the coupling to the thrust bearing shaft.

The axis of the pump rotor moves parallel to the axis of the motor and other drive components. This rotor moves in a pattern, within the limits of its eccentricity that is dependent on the number of lobes in the stator. The axis of the most common 1:2 design moves basically on a line—the 2:3 multi-lobe on a triangular pattern, and so forth. This eccentricity may be as much as 0.50 inches. Most machinery coupling schemes are intended to connect closely aligned shafts with little radial movement. However, there are few types of flexible couplings that can accommodate this range of movement. As a practical matter, given the thrust that must be transmitted and annular space available, two types of coupling accomplish the above objectives: paired universal joints or a flex shaft.

The universal joint is one the first forms of flexible coupling used to transmit power. Such joints can accommodate significant angular misalignment. The amount of angularity is dependent on the u-joint type. The most common kind of joint consists of two yokes attached to a cross. As one yoke turns it, the cross, while twisting within both yoke attachments to adjust for shaft misalignment, transmits torque to the other yoke. Yoke construction varies, as does the type of bearing used between the cross and the yokes. The design must consider the bearing life or wear of bearing journals as well as the possibility of cross breakage. The thrust transmission requirement implies that the joint be robust and that the angular play be limited. The joints must be lubricated and sealed from the well fluid. To transmit constant angular velocity, joints must be paired in correct alignment with an intermediate shaft between joints.

The flex shaft or torque shaft is a relatively long, slender shaft whose smallest cross section is sufficient to withstand the fatigue stress. This type of shaft also has a long history of use. The shaft must transmit the pump torque while being flexible enough to bend and accommodate the pump shaft offset. The length of the flex shaft is such that the eccentricity of the progressing cavity pump does not produce a significant angle of misalignment. If the shaft is driving the pump from the bottom, the pump thrust places the shaft in compression; hence this approach must proportion the shaft to account for column effects. There are no moving parts in this coupling. Lubrication is not required, and it can be exposed to the well fluid.

Some ESPCP systems are arranged in a way that permits installation in two parts. The intent is to allow installation or removal of the progressing cavity pump using a method other than a workover rig. In this type of system, the thrust bearing, gear reducer, and motor are deployed as usual on tubing—

only a connecting coupling and landing base are looking up. Using a wireline, for example, the progressing cavity pump and coupling are then lowered to engage the previously deployed equipment. A standard packoff and tubing stop are then set to complete the installation. Using wireline, coil tubing, or similar equipment, removal of the pump and coupling alone are now possible without disturbing the rest of the equipment.

THRUST BEARING

Unlike a floating impeller submersible pump, a progressing cavity pump transmits a significant thrust through shafting to a thrust bearing. To protect the gear and motor, the thrust bearing must be located between the coupling and the gear. Different thrust bearing designs include antifriction tapered roller bearings, antifriction tapered roller thrust bearings, antifriction spherical roller thrust bearings, and hydrodynamic film bearings. Even at the lower speeds of a progressing cavity pump, a plain, hydrodynamic film bearing will carry a significant axial load. Properly lubricated, such a bearing avoids the life limits of an antifriction bearing.

Any type of thrust bearing benefits from the lubricant required by the gear reducer. The surface stress considerations of the rolling contact in an antifriction bearing and the tribology and film formation considerations in a hydrodynamic film bearing are closely related to those used in gear rating calculations. The extreme pressure additives that make gear oil unique are used to advantage by either an antifriction or a hydrodynamic bearing.

GEAR REDUCER

A gear reducer is used since a progressing cavity pump operates best at speeds much lower than the usual electric submersible induction motors. The gear reducer converts the speed and power of the motor to the requirements of the pump. Gear manufacturing technology and gear unit design is very well developed. A gear reducer offers a reliable, efficient, and practical solution to matching disparate items of equipment. In a well however, the application becomes more challenging. Above ground, space and availability of lubricant systems allow more design options. Even automotive and aerospace applications seem less harsh. Certainly, refinery service is less demanding than many downhole conditions.

The gear reducing arrangement that provides the most compact, inline transmission of power is the simple planetary. A simple planetary reducer is an epicyclic gear drive where the sun gear drives a planet against a stationary, or fixed, ring gear. **As** the planet rotates and orbits, it drags around a planet carrier that rotates at a reduced speed. Multiple planets are used to increase the power capacity. The speed ratio is a function of the diameters of the ring gear and sun. Gearing proportions and diametral space limit the possible ratios in this application to a maximum of about 6.5:1. A two-pole induction motor running at 3500 rpm would require 10.8:1 ratio to meet the median best operating range of a progressing cavity pump. Thus, a two-pole motor requires a double reduction gear unit. In this arrangement, the carrier of the first gear set drives the sun of the second, and the exact overall ratio is determined by multiplying the reduction ratio of each set. A four-pole induction motor running at 1750 rpm would require a 5.4:1 ratio. Here a single reduction gear unit would suffice.

Not only does the gear reduce the speed, but also the torque is multiplied. The torque input to the gear is multiplied by the ratio—the very small power loss is ignored. This implies that the mechanical components between the gear and the pump have a design that is more robust than those normally encountered in electric submersible applications.

The power capacity of gearing is determined by analyzing two kinds of stresses at each mesh: pitting resistance and bending strength. Pitting of gear teeth is a fatigue phenomenon at the surface of the teeth. The pitting resistance formula attempts to determine the load at which destructive pitting of the teeth does not occur. Bending strength of gear teeth is a fatigue phenomenon related to the resistance to cracking at the tooth root fillet in external gears. The intent of the bending strength formula is to determine the load that can be transmitted for the design life of the gear without tooth breakage. The mesh that has the least durability or strength rating determines the power rating of the gearing. There are other gearing design considerations, such as scuffing or overload strength, which may be considered. The general speed and loads encountered currently by ESPCP drives are met without pushing the limits of gear design. Well-configured, general-purpose gearing meets the speed and power requirements even within the downhole geometry constraints.

In a simple planetary, the sun and planets require bearings. The planet bearings are the more difficult design problem. Because of space, planet bearings tend to have small diameters. Needle bearings have the highest load capacity for a small annular space, and they are generally the bearing of choice. Slow surface speeds, high pressures, cost, and poor lubrication options constrain use of hydrodynamic bearings. The power rating of a gear reducer is determined by the least of all the design elements of the gear reducer. Bearing life is the limiting factor in this gear application.

For heat load purposes, the power loss of a simple planetary reducer is about 1.5% of rated power. Power is lost in the meshes, in bearings, and from oil churning. Speed is the overarching factor in power loss since the largest factor is oil shear due to mechanical sliding in the gear teeth, in the bearings, and passage of the rotating elements through the lubricant. The power loss is virtually independent of torque transmitted. Lost power is expressed as heat that must be lost to the fluid being pumped (this is the same as the motor). If these gear reducers were on the surface, they could be lubricated and cooled by an external system. Since they are self-contained in the well, the gear lubricant must be designed to operate at higher temperatures and over a greater viscosity range than commonly expected in gear design.

ELECTRIC SUBSYSTEM

The electric subsystem, which includes the controller, cable, and motor, provides the power that drives the pump. It is essentially the same as that used for an electric submersible pump. A variable speed drive is most often used. This type of drive is preferred for its soft start, ease of reversing rotation, and speed flexibility. An important consideration is that the electric system be adequately sized. It must provide enough power for normal pump operation, especially to start the pump after it has been stopped; however, it must not be so large that control over abnormal operation is compromised.

ISOLATION

Most of a progressing cavity pump system must be isolated from well fluids. At some point between the coupling and thrust bearing, where the shaft runs concentrically, the system must be sealed. Coupling joints that must be lubricated, located at least partially in the pump intake, are sealed separately. In a seal or protector, bag type expansion chambers are recommended since an ESPCP may possibly be landed horizontally. The size and redundancy of the sealing system are dependent on the well conditions and intended operation. Some systems use one seal above the thrust bearing and the same lubricant for the thrust bearing, gear, and motor. Other systems additionally isolate the gear and thrust bearing from the motor, thus using two seals and with this arrangement it is possible to use different lubricants for each part of the system.

SUMMARY

The progressing cavity pump has provided an alternative artificial lift method since the early 1980's. The ESPCP extends the value that this method previously provided in an efficient, reliable way. It is the solution to many difficult lift problems.

An ESPCP uses mechanical components that differ from other electric submersible pumping systems—notably, the coupling, thrust bearing, and gear reducer. The coupling converts concentric drive shaft motion to eccentric, rotary pump motion. The thrust bearing is often required to carry higher thrust loads at lower speeds than those of a floating impeller pump do. The gear reducer changes the higher speed of the induction motor to the lower speed used by the pump. Correctly applied these components offer reliable service in artificial lift applications.

ACKNOWLEDGMENTS

The author wishes to thank Bruce E. Proctor for his advice and comment on this paper.

BIBLIOGRAPHY

Dillon, Michael L. *Maximize the Performance of Progressive Cavity Pumps,* Pumps and Systems Magazine, AES Marketing, Fort Collins, CO, February 1999.

Mancuso, Jon R. *Couplings and Joints,* Marcel Dekker, Inc., New York, **1986.**

Revard, James M. *The Progressing Cavity Pump Handbook*, Pennwell Books, Tulsa, OK, 1995.

*AGMA/ANSI 6023-A88 Design Manual **for** Enclosed Epicyclic Gear Drives,* American Gear

Manufacturers Association, Alexandria, VA, 1990.