Connecting Rod Capacity in a Rotoliptic Positive Displacement Pump

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1 Introduction

In PCP applications, particularly in those with difficult operating conditions, a rod string must be selected such that a safety threshold of $> 20\%$ is included for unanticipated torque increases and to prevent fatigue failures. The relationship between connecting rod diameter (D) and allowable stress can be derived from the equation relating stress due to torque on a circular shaft:

$$Stress = \frac{Tr}{J}, \tag{1}$$

$$Stress \propto \frac{1}{D^3}. \tag{2}$$

Using Equation 2 we can see that a 20% decrease in the diameter of the rod can account for a nearly 100% increase in rod stress, and therefore a 50% reduction in load capacity of the rod. Applications in directional oil wells further increase the stresses on the rod due to cyclic bending acting at the frequency of the pump rotation; in a non-corrosive environment, the endurance of the steel connecting rods is determined by these stresses, and therefore increasing the diameter and therefore durability of these connecting rods is an extremely important factor to consider when designing a PCP system. Additionally, when pumps are connected in series the limit on the diameter of the connecting rod is the maximum diameter that can fit through the stator. The RTI geometry allows for a larger diameter connecting rod to fit through the stator than a comparable PCP.

2 Application

The size and grade of the connecting rods is chosen so that it can withstand the following forces:

- Axial tension,
- Torque loading.

These loading components can be split by the location that the force is applied to, where forces applied to the rod string at the pump include the pump's hydraulic torque and axial load, and forces applied to the length of the rod string that include the resistive torque and rod weight. Special consideration for the connecting rod design is required when connecting pumps in series with the desire to maximize the connecting rod capacity.

2.1 Connecting Pumps

Connecting pumps in parallel or in series can provide benefits in the form of a multi-pump system with additional head or lift, rather than one larger sized pump with these head/lift values. These benefits can be in the form of increased flow, lower requirements for energy input, better durability with regards to wear, or a smaller wellbore. When connecting pumps in series, at the same flow rate the head of the pumps is additive; this means that each pump in the series is operating at a lower cost, requires less power, and is potentially more reliable in terms of wear than 1 larger diameter pump that produces the same head as the total of the two in series. The limiting factor when connecting pumps in series like this is the connecting rod, which must withstand the axial forces acting on it and transmit torque between the motor and the pump.

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2.2 Hollow Rods

Another interesting application for a larger diameter rod is from the recent development of hollow rods and the benefits associated with these, including decreasing the magnitude of tubing wear, and the possibility to inject fluids inside the rod such as viscosity reduction or chemical corrosion inhibitors. RTI does not currently have plans for trials that use hollow connecting rods, however it is worth mentioning that a larger diameter connecting rod will allow for more choice when operators select the connecting rods for the system.

3 RTI vs. PCP

In the event that the connecting or drive rod is sent through the stator, in series coupled pumps for example, the maximum size of the connecting rod is determined by the size of the through-bore hole in the pump's stator. There there is a trade-off between the rod's size and strength and the width of the maximum diameter; from a pump system design perspective, it is important to select a rotor and stator coupling that allows for minimum wear and therefore maximum lifetime of all involved components, which results in minimum operating expenditure due to maintenance downtime.

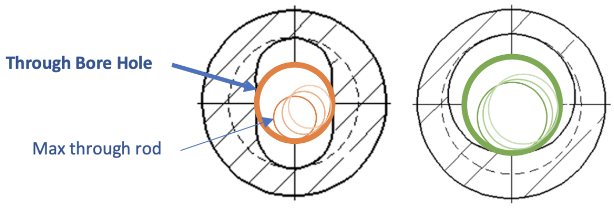

Figure 1: Comparison of the through-bore holes between a PCP (left) and RTI (right)

From $Fig.$1. we can see the difference in the size of the through-bore hole for a PCP and for the RTI pump; it is also possible to see the how the pump's eccentricity requires the connecting rod to have extra room to orbit as the pump operates. The relationships between the eccentricity and other key geometric parameters and the size of the through-bore holes will be defined in the following section.

3.1 Design Parameters

The size and geometry of the rotor determines the maximum diameter of the connecting rods in both the PCP and RTI pumps; the derivation of this maximum size comes from a function of the eccentricity of the rotor e and radius of the stator's minor axis $R_{S,m}$, using the following equation:

$$R_{Rod,max} = R_{S,m} - e \tag{3}$$

where e is defined using the standard equation relating the major and minor diameters $R_{R,M}, R_{R,m}$ of the rotor:

$$e = \frac{R_{R,M} - R_{R,m}}{2}. \tag{4}$$

Although the geometries of the RTI and the PCP differ, equivalent sized designs can be compared in order to determine the equivalent maximum through-bore hole sizes and therefore the maximum size possible for a connecting rod.
Table 1 shows the design parameters of an equivalently sized theoretical PCP and an RTI subscale pump, such that displacement is equal in volume per revolution.

	RTI	PCP
Displacement (D)	0.0759	0.0759
Eccentricity (e)	0.26	0.34
Stator Major Diameter ($D_{S,M}$)	2.86	3.01
Stator Minor Diameter ($D_{S,m}$)	1.82	1.67
Rotor Major Diameter ($D_{R,M}$)	2.34	2.34
Rotor Minor Diameter ($D_{R,m}$)	1.30	1.00
Stator OD (S_{OD})	3.50	3.77
E/R	0.286	0.401

Table 1: Design parameters for equal displacement of a PCP and RTI pump

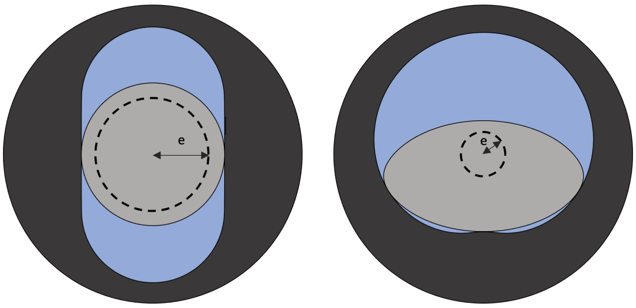

Figure 2: Relative sizes of PCP (left) and RTI (right)

3.2 RTI Maximum Connecting Rod Radius

Using the stator minor diameter and the eccentricity values for the RTI pump in *Table 1*, we are able to derive the following:

$$R_{Rod,Max} = \frac{D_{S,m}}{2} - e, \tag{5}$$

$$R_{Rod,Max} = 0.91 - 0.26 \tag{6}$$

$$R_{Rod,Max} = 0.65. \tag{7}$$

3.3 PCP Maximum Connecting Rod Radius

Using the equivalent values from *Table 1* for the we are able to derive for the PCP:

$$R_{Rod,Max} = \frac{D_{S,m}}{2} - e, \tag{8}$$

$$R_{Rod,Max} = 0.835 - 0.34 \tag{9}$$

$$R_{Rod,Max} = 0.495. \tag{10}$$

3.4 Resulting Rod Sizes

From the above two derivations it is clear that the allowable connecting rod diameter is larger for the RTI pump, with a total diameter of 1.3"($33.02mm$) vs. the equivalent PCP value of 0.995"($25.27mm$). Using Equation (2):

$$Stress \propto \frac{1}{D^3} \tag{11}$$

$$Stress_{PCP} \propto \frac{1}{(D_{PCP})^3} \tag{12}$$

$$Stress_{RTI} \propto \frac{1}{(D_{RTI})^3} \tag{13}$$

$$\frac{Stress_{PCP}}{Stress_{RTI}} = \frac{1.3^3}{0.995^3} \tag{14}$$

$$Stress_{PCP} = 2.23 \times Stress_{RTI} \tag{15}$$

showing that the decrease in diameter of the through-bore hole from the RTI pump to the PCP would result in a 2.23× higher stress on the PCP's rod.