TECHNICAL BULLETIN

PROGRESSING CAVITY PUMPS | LS-TB-019

LIFTING SOLUTIONS

BULLETIN	TOPIC	ISSUE DATE	ISSUED BY
LS-TB-019	PCP SIZING METHODOLOGY	JULY 20, 2020	ENGINEERING

BACKGROUND

In a progressing cavity (PC) pump the fit between the rotor and stator is as critical to pump operation and longevity as the more commonly discussed pump geometry and elastomer materials. The pump fit impacts the sealing of the cavities by the rotor and as a result the associated fluid slippage (leakage), volumetric efficiency and pressure capability of the pump. But the fit also dictates the deformation of the elastomer which in turn impacts other critical pump characteristics including elastomer fatigue, rotor and stator wear and pump friction. It is also important to consider that the fit for a given pump is not static and can change as a function of the pumps interaction with the downhole environmental conditions over time. Specifically the elastomer material has a high thermal expansion coefficient and contracts and expands with temperature changing the internal stator dimensions. The elastomer is also prone to swell by various produced fluids and in some cases the fluids can remove elastomer constituents resulting in shrinkage. Lastly the progressive wear of the rotor and stator as a result of operation also change the nature of the pump fit. Pump sizing practices, including adjustments for anticipated downhole environment conditions, vary across the industry often with limited technical insight into the rationale or process. This Technical Bulletin provides an overview of the process used by Lifting Solutions Inc. (LSI) to size its PC pumps.

PUMP SIZING THROUGH PUMP TESTING:

Often pump sizing is used interchangeably with pump testing completed via a standard pump test process at one or more reference speeds and usually with water at one of several reference temperatures. Pump testing for downhole PC pumps originated when PC pumps were first being used and the rotor and in particular stator components had large variations due to the manufacturing process and where stator dimensions could not be measured non-destructively. So pump testing was used as means to ensure that a given combination of rotor and stator could pump fluids before they were installed in a well. Over time through experience correlations were made by pump suppliers and users between pump testing results and performance in given applications resulting in the development of target ranges for volumetric efficiency at pump rated pressure. As an example if the fluids were expected to swell the elastomer or downhole temperatures were elevated then low efficiency ranges would be specified to ensure a loose pump fit. Conversely if high levels of component wear were anticipated due to solids then a high efficiency range would be selected for a tight fit.

Pump sizing through pump testing can be effective but it has its limitations. First of all it is highly dependent on the pump elastomer which varies between different suppliers thus limiting the transferability of pump sizing targets between suppliers. Secondly it relies on operational experience necessitating an iterative process which is time consuming and costly. Lastly, and most importantly, because pump testing focusses on the pressure sealing element and associated volumetric efficiency it neglects other pump sizing considerations that may be important to performance and longevity. Further complicating the situation is the potential for multiple different physical pump sizing combinations to generate similar efficiency profiles. So while pump testing can be an important component of pump sizing it is most effectively used in combination with other supporting processes.

PUMP SIZING GEOMETRICAL CONSIDERATIONS:

Pump sizing implies the physical fit between the outside of the rotor profile and the inner stator elastomeric profile. The PC pump geometry creates cavities which are bounded by seal lines between the rotor and stator. These cavities progress due to the motion of the rotor within the stator which in turn implies that the rotor and stator fit is dynamic in nature. The majority of the length of the cavity seal occurs along the flat sides of the stator which is contacted by the round rotor profile. This is the minor seal and the difference between the minor diameter of the rotor and stator is the minor interference. The ends of the cavity seal occur when the rotor moves into the circular ends of the stator resulting in a seal formed by two circular sections. This is the major seal and the major interference is a function of the stator major diameter, rotor minor diameter and pump eccentricity. The sealing region between the minor seal and major seal is typically referred to as the flank. Figures 1a and 1b show the interference areas on the minor, major and flanks.

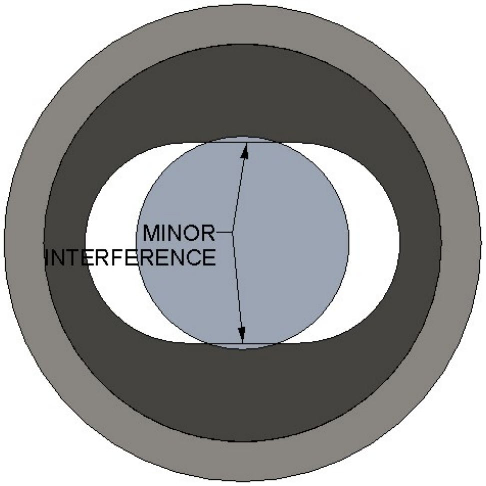

Figure 1a: Minor Interference (curved rotor on flat stator)

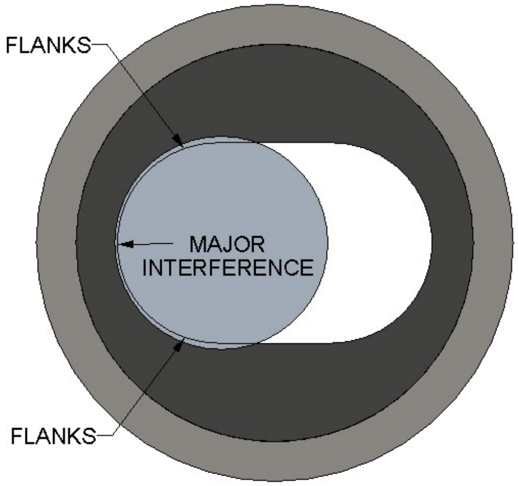

Figure 1b: Major Interference (curved rotor on curved stator)

Pump sizing starts with the stator internal profile which in turn is controlled by the mold used to make the stator and the associated stator manufacturing process. The manufacturing process is important in that the final stator size is different than the mold side due to shrinkage of the elastomer. This shrinkage can vary along the length of a stator due to the manufacturing process but also between stators due to changes in the process or variations in the raw elastomer.

LSI uses fit-for purpose CNC rotor core machining equipment along with a specialized process to produce its stator molds for each model. Dimensions are controlled to +/- 0.002" along the length and verified at multiple locations using laser coordinate measurement (CMM) equipment. Once the mold is produced no modifications such as polishing or coating are made to the core to avoid compromising its shape from its originally highly precise machined profile. As a result the mold surface and corresponding stator internal surface exhibits a "snake-skinned" appearance reflective of the machining process.

As part of the LSI development process for each model, prototype stators have their internal profile size/shape verified using laser CMM equipment. When required the manufacturing processes adjusted to achieve the desired profile and if that is not possible then a new mold is produced with an adjusted shape. In most cases the target stator profile has flat sides similar to a "hockey rink" as opposed to being oval shaped like an egg or compressed in the center like a peanut. Examples of these stator profiles measured by the CMM equipment and compared against the theoretical flat profile are shown in Figure 2.

Once the stator profile has been confirmed various rotor sizes are designed to target a range of pump performance characteristics which are confirmed through pump testing. LSI uses a balanced compression fit methodology as described in LSI Technical Bulletin LSI-TB-002. This methodology transforms the minor and major diametric interference values to percentage compression fits based on the associated elastomer thicknesses. Because the elastomer thickness on the stator minor is several times that on the major, the balanced compression fit methodology employed by LSI uses higher levels of minor interference than major interference. Although this results in low major interference fit values there is still minimal slippage/leakage due to the favorable nature of the seal geometry. It is important to note that the compression fit required to produce a given pump test efficiency varies by the pump configuration – specifically the geometry and the elastomer.

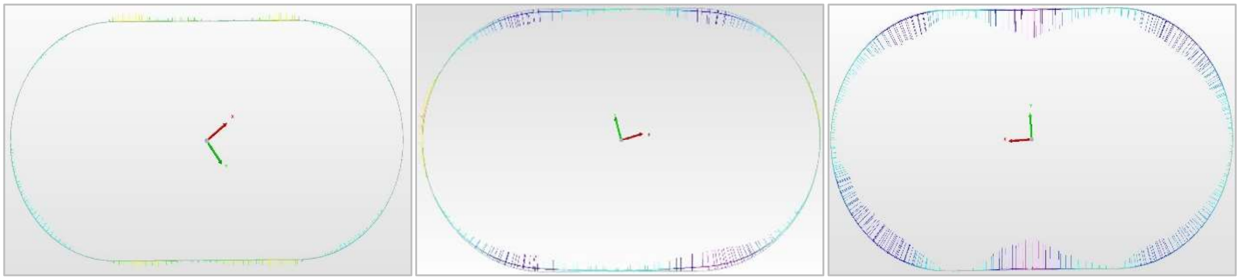

Figure 2: Examples of Stator Profiles (Flat, Egg, and Peanut)

The pump fit, as defined by the stator internal dimensions/profile and rotor dimensions, control other elements beyond the pressure sealing and associated efficiency. The rotor flexes the elastomer which due to the visco-elastic nature of the elastomer results in a small energy loss that manifests itself in the form of internal heat build-up in the elastomer but that also represents a mechanical inefficiency within the pump. More importantly the magnitude of the interference fit along with various other parameters, most notably the pump geometry and fluid lubricating conditions, determine the rolling and sliding friction between the rotor and stator which again represent another inefficiency. The fit also determines the elastomer displaced by the rotor which is a key determiner in the break-away torque that must be overcome within start-up. Excessive interference fit can result in break-away torque values that exceed the normal operating torque of a pump even when start-up conditions are at minimal differential pressure.

PUMP DIMENSIONAL AND PERFORMANCE VALIDATION:

LSI sizes its PC pumps using a balanced compression fit methodology combined with pump testing. Every stator manufactured has its minor diameter measured along the length and to be approved for use the average dimensions as well as the variation along the length within a narrow range. Because the dimensional variations in the stator are related to process shrinkage the thicker minor lobe associated with the minor diameter has significantly higher variation than the thinner major lobe associated with the major diameter. Consequently, stator major diameters are determined based on applying a shrinkage adjustment determined from the minor diameter. Rotor minor and major dimensions at multiple locations along the length are measured after machining and after the chrome coating operation.

During the development process LSI defines a series of rotor fits that correspond to standard pump test bench characteristics. Since the objective is to maintain consistent stator sizes, pump sizing variations are generated through variations in the rotor size. LSI designates its rotor sizing based on the percentage compression fit relative to the as-manufactured stator size at ambient (25C) temperature conditions. LSI also includes the average rotor minor and major diameters on its pump testing reports.

Standard pump testing is completed to verify the pump sizing and when specified that the performance efficiency target range is achieved. Additionally the pump test torque profile must fall within an acceptable torque range that has been established for each model and sizing configuration. This is a secondary check to ensure an acceptable level of friction.

PUMP SIZING FOR THE APPLICATION:

For practical reasons pump testing for sizing is typically completed at standard conditions that are not necessarily representative of the downhole conditions. Specifically, water is usually used as a test medium at a standard temperature and even when the temperature is adjusted the test is usually not run long enough to generate a thermally equalized condition.

Changing temperature conditions impact the pump performance through the thermal expansion of the stator elastomer and associated internal size changes combined with variations in the mechanical properties of the elastomer and associated stiffness changes. Estimates of these physical changes can be determined theoretically but establishing the impact on pump performance is more challenging. To support sizing for downhole temperature conditions LSI has characterized the performance characteristics of various models under thermally equalized conditions through a series of full-scale pump tests. Figure 3a shows volumetric efficiency and torque curves for a pump tested with a single rotor size at 150 rpm and 70°C with various warm up times indicating thermally equalized condition was achieved after 60mins warm up time. Figure 3b shows the results of the same pump tested at various temperatures after 90 mins warm up time, i.e. thermally equalized showing the effect of temperature.

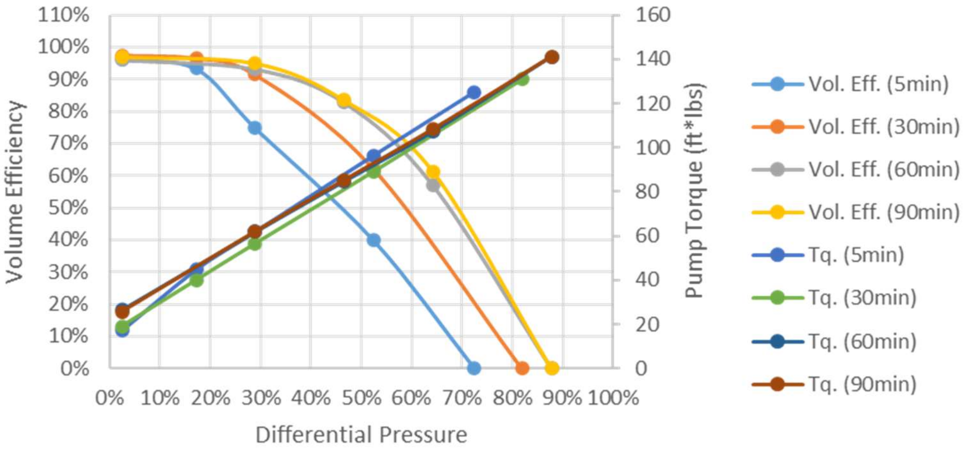

Figure 3a: Efficiency and Torque curves showing the effect of warm up time.

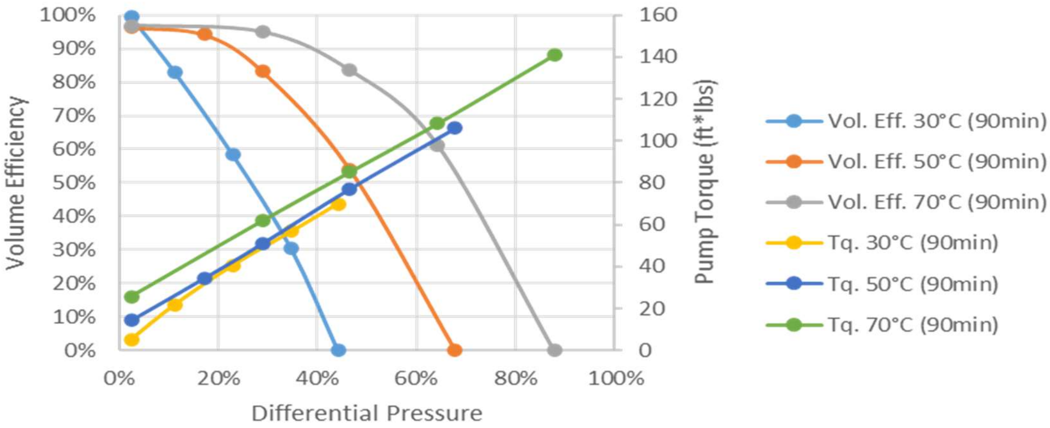

Figure 3b: Efficiency and Torque curves showing the effect of test temperature under thermally equalized condition.

Elastomer changes due to fluid exposure can influence both the stator internal dimensions and mechanical properties. While these changes can be measured in stators after operation they also can be evaluated in advance through laboratory elastomer testing. While a variety of different laboratory elastomer/fluid compatibility test methods exist, LSI uses the recommended practice from ISO 15136-1 Annex A. This involves exposing 2 mm elastomer samples to fluids at representative temperatures for a 168 hr period after which the changes in volume, mass and mechanical properties are measured. This thin sample specimen geometry was selected to accelerate the elastomer swell so as to provide comparative results in a practical timeframe. The laboratory elastomer volume change measurements due to not directly reflect the dimensional changes in stators due to differences in geometry. However through experience and lab sample versus full-scale stator testing correlations can be developed to transform lab results to stator dimensional changes. The impact of these dimensional changes on pump performance can then be estimated based on equivalent size/mechanical property changes from the thermal pump testing

LSI has and continues to conduct extensive laboratory testing with reference fluids including water, water with salts and ASTM reference oils and fuels. This testing is typically done with the 2 mm specimens over a range of temperatures and durations. Additionally LSI carries out on an ongoing basis elastomer compatibility testing using field fluid samples with a current test library of over 200 fluids. By relating the field fluid characteristics to fluid compatibility test results, estimates can be made for new fluids and associated applications when laboratory testing is not practical.

Using knowledge of the impact of temperature and fluid exposure on its PC pump characteristics, LSI can recommend sizing proactively in terms of dimensional values and associated rotor sizes. Additionally, it can estimate how the pump dimensional changes associated with downhole operating conditions, including changes that occur over time such as elastomer swell, impact the downhole pump performance characteristics. Figure 4 shows a pump sizing example where a standard test bench target is established taking into consideration the downhole operating conditions and anticipated fluid swell based on fluid compatability testing.

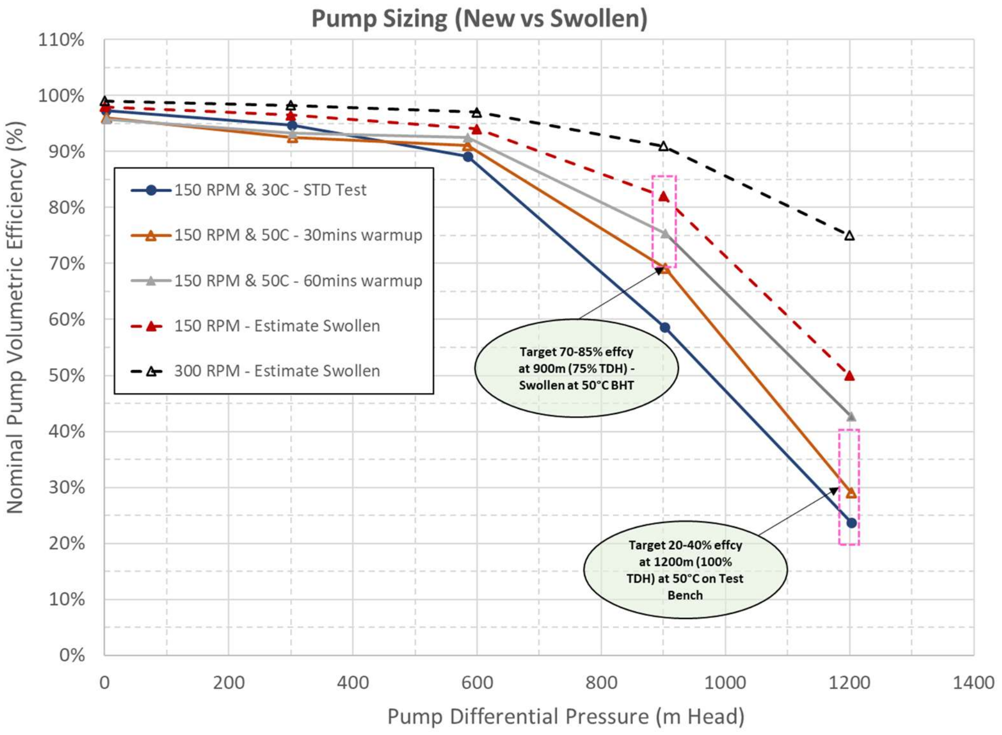

Figure 4: Establishing test bench target based on pump performance curves with varying conditions of warm up time, temperature fluid swell and operating speed.