Reprinted from the June Issue of:

PUMPS AND SYSTEMS

THE MAGAZINE FOR PUMP USERS

June 1996

Applying the NPSHR Standard to Progressing Cavity Pumps

Take NPSHR values into consideration to ensure proper continuous operation.

By: Michael Dillon and Klaus Vüllings

Applying the NPSHR Standard to Progressing Cavity Pumps

Take NPSHR values into consideration to ensure proper continuous operation.

By Michael Dillon and Klaus Vüllings

Progressing cavity pumps have characteristics unique to their class. These include high suction lift capabilities and the ability to transfer multi-phase fluids. Their ability to handle vapors or gaseous materials, however, complicates the application of traditional NPSH values. To make full use of any pump's capabilities, it is crucial to take into account NPSH - Net Positive Suction Head. This acronym, which originated in the United States, is used internationally in pump engineering as a standard term for designating the net energy level in the pump inlet cross-section. Even though, due to their construction, progressing cavity pumps do not suffer immediate damage in the area where cavitation occurs, there will still be negative long-term effects caused by the reduction in flow and by pressure variations. Possible product damage, as well as a degradation of a pump's continuous operating capability, are inevitable if $NPSH_R$ values are not taken into consideration.

NPSH

In simple terms, this acronym signifies:

- the internal pressure loss of a pump, designated as the $NPSH_R$ or NPSH required of the pump, and
- the inlet pressure available to the pump – that is, the pressure at the end of the suction line reduced by the fluid vapor pressure, designated as the $NPSH_A$ or NPSH available from the system.

With this definition of the $NPSH_R$ value, cavitation will be within acceptable limits if pump inlet pressure exceeds the fluid vapor pressure and the internal pressure loss (the $NPSH_R$). The following formula must hold:

$$NPSH_A > NPSH_R$$

When planning pump systems, a safety margin, of 0.5 m (1.6') should be taken into account, to accommodate variances within individual parameters such as pump speed, fluid temperature, vapor pressure or inlet pressure. Moreover, a safety factor should be allowed for system changes over time, such as solids settling in the inlet pipe or erosion of the pumping components and a resulting degradation of the pump's $NPSH_R$ capabilities. These changes will not immediately cause an operational fault but can certainly cause problems later. To define the $NPSH_R$ as a pure pump characteristic, $NPSH_R$ is generally stated in the "meters" or "feet" as the level of fluid (water) head in absolute terms.

The existing $NPSH_A$ is defined by the pump installation and calculated by

$$NPSH_A = (p_i + p_b - p_D / d^* g) + (v_i^2/2g) + H_{1,geo} - H_j$$

where

- p_i pressure in the inlet cross-section of the system, fluid level
- p_b atmospheric pressure
- p_D vapor pressure
- d density
- g acceleration due to gravity
- v_i velocity in the inlet cross-section of the system
- $H_{1,geo}$ geodetic level
- H_j loss level

As reference level, the horizontal level (Z_1) will be defined as – in deviation from the definition for rotary pumps (e.g., ISO 2548 or DIN 24260) – passing through the center of the pump inlet cross-section. This avoids the influence of an additional reference height.

PROGRESSING CAVITY PUMPS

As is generally known, the progressing cavity pump was invented by Dr. René Moineau, following World War I, as a supercharger for an airplane engine. Due to the multiphase and high suction capability of the pump and its ability to convey large quantities of air, vapor or gas in a fluid, that may also contain solids, this pump is not usually used in the same way or considered to be the same as other rotary positive displacement pumps.

The progressing cavity pump was designed to be a rotary and piston pump combination. It integrates the advantages of both types of pump constructions, such as high pumping flow rates, high pressure capabilities, minimal pulsation, valveless operation and excellent pressure stability.

The progressing cavity pump distinguishes itself from other rotary pump types, in particular, by the fact that the external housing – in addition to its sealing function – is also the pumping element.

This static pumping element, an elastomeric stator, is preferably designed with a compression fit for containing the rotating pumping element, the metallic rotor.

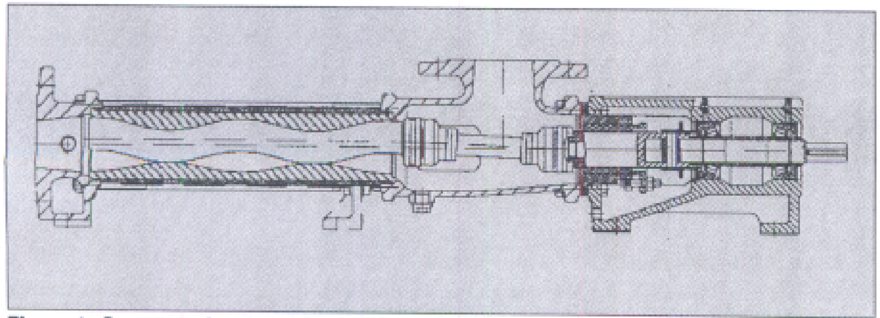

Figure 1. Cross-sectional view: progressing cavity pump of a modern modular type.

In this way, fluids with very low viscosity can be conveyed with very little internal fluid slippage. Most other rotary positive displacement pumps require pumping media with a much higher viscosity than that of water in order to produce slip-free performance between the rotating and stationary elements. Since tolerance fits are integral to their designs, the resultant gaps and the inherent slippage in other pumps produce volumetric efficiencies below those of progressing cavity pumps. This is particularly the case for applications with higher differential pressures and lower viscosity. In addition, the higher internal leakage will induce a cavitation "gap" condition. As in all rotary positive displacement pumps, the progressing cavity pump volume is directly proportional to the speed and shows only a slight degradation due to the pumping pressure.

In contrast to reciprocating pumps, as well as to gear pumps and peristaltic pumps, the progressing cavity pump has almost no pulsations. In this regard, $NPSH_R$ values in piston pumps show a particularly strong dependence on the mass forces of the pumping medium, originating from the pulsating flow. A periodic movement law, which is dependent on the displacement kinematics and the elastic characteristics of the pumping fluid, will be imparted to the liquid inside the pipes. The pressure pulsations thus generated in the pipe system must be taken into account. If low frequency pressure variations exceed the vapor pressure, cavitation will occur.

CAVITATION STANDARD

If the pressure in a flowing liquid decreases at any point below the level of the liquid vapor pressure, bubbles will form, and these bubbles will implode intermittently when they contact areas of the pumped fluid that are under higher pressures. Manufacturers can experimentally define a series of cavitation scenarios and, depending on the customer's application parameters, define operational and fluid condition limits that will not be exceeded at a predefined NPSH value. In general, practical engineering – looking for an economical and operationally safe system – is interested in solving problems such as the deterioration of pump performance by cavitation and the consequences of such cavitation – i.e., noise emission, pulsation, vibration and wear. Generally, the most common indication of cavitation is reduction of the pumping height or the pumping flow (X%, ΔH or ΔQ). When such conditions exist, the amount of cavitation must already be significant since there must already be a significant volume of bubbles forming for the resultant effect to be noticeable.

The standard procedures for measuring the cavitation sequence are designed to decrease the system-side NPSH value ($NPSH_A$). Depending on the regulatory standard to be met, the pump manufacturer will chose from one of the following methods:

- The inlet pressure of the fluid entering the pump will be controlled by means of a throttling valve.
- The pump will be fed by a vessel with an adjustable fluid level.
- In a closed circuit, system pressure or temperature (and thus vapor pressure) will be changed.

Taking into account the real measurement cross-section, the $NPSH_A$ value here is calculated in the same manner as NPSH:

$$NPSH_A = (p_1+p_b-p_D/d*g)+(v_l^2/2g)-H_l+-z_1$$

where

p_1 pressure in the measurement cross-section

v_1 velocity in the measurement cross-section

z_1 height level of measurement point in relation to the entry cross-section

$NPSH_R$ STANDARDS

Varying standards among international regulatory institutions regarding the definition and testing of NPSH values can cause confusion about the correct way to operate progressing cavity pumps in relation to their suction capability. The Hydraulic Institute recognizes the difference between the general classification of rotary positive displacement pumps and reciprocating pumps or centrifugal pumps. For this reason, a separate standard as well as a test procedure for the required pressure at the pump inlet (NPIP = Net Positive Inlet Pressure) has been provided. However, discrepancies between the institutions and even pump manufacturers arise when the percentage of the reduction is to be determined. The German VDMA (Verein Deutscher Maschinenbau – Anstalten-Association of German Engineering Institutions) states in VDMA 24284 "Testing of Positive Displacement Pumps" that there is to be a decrease of pumping flow by no more than 2%. This is the same standard set by the Hydraulic Institute for centrifugal and positive displacement pumps. Yet API (American Petroleum Institute) describes in API 676 "Positive Displacement Pumps - Rotary" a reduction by 3%. The Hydraulic Institute states additionally that the $NPIP_R$ for rotary positive displacement pumps is to be measured at a 5% reduction of the pumping flow. Users need to know which standard is being used by the pump manufacturer to calculate $NPSH_R$.

$NPSH_R$ CHARACTERISTICS

As described in the section on NPSH, the $NPSH_R$ value can be understood as the internal pressure loss of the pump, and this pressure loss can be read off directly from the Q-Ps characteristic curve.

This criterion is frequently used in connection with reciprocating pumps. The pressure loss will be determined experimentally, by measuring the pressure inside the pumping cavity. The NPSH value will then be calculated as follows:

$$NPSH = \Delta p / d^{*}g$$

The procedure described here can be used for progressing cavity pumps as well; however, the pressure measurement drilling that needs to be carried out does not permit any non-destructive testing of production pumps. By recording the pressure curves in the pumping chambers of a progressing cavity pump, any resulting cavitation phenomena can be analyzed.

When a new pumping chamber is created, rotation of the rotor within the stator will cause a sudden opening of the chamber on the suction side, accompanied by a strong decrease in the cavity pressure. Depending on the actual level of inlet pressure, speed or fluid viscosity, this pressure decrease may fall below the vapor pressure level for a defined time and thus determine the volume of the cavity filled with bubbles. If any bubbles implode in the area of higher pressure as early as this suction action, they will not affect the Q-Ps characteristic curve. However, with low viscosity fluids this situation leads to pressure variations. The resulting oscillating behavior and increase in noise can be considered as a first indication of cavitation, even though this phenomenon – when compared to other rotating positive displacement pumps – frequently is not as marked due to the damping acting of the elastomeric stator. If the bubbles remain intact while the pumping chamber is being created, the chamber will be formed and progress through the pump in a partially filled state, and this will decrease the flow. When the chamber opens on the pressure side of the pump, the bubbles will condense instantaneously. The consequent back-flow causes pulsations the strength of which is determined by the volume of vapor. The Q-Ps characteristic curve of a progressing cavity pump is dependent on both speed and fluid viscosity.

In the lower speed range there will be a relatively immediate transition from partial cavitation to full cavitation for highly fluid media. At higher speeds this transition is more gradual. For high viscosity fluids the transition will be progressive across the entire speed range, and will frequently begin as early as at the point of entry into the vacuum range. The onset of cavitation will also be influenced by the type and characteristics of the fluid. For instance, with mixtures such as hydraulic oils, cavitation will start slowly and then become amplified across a wide boiling or vapor phase range.

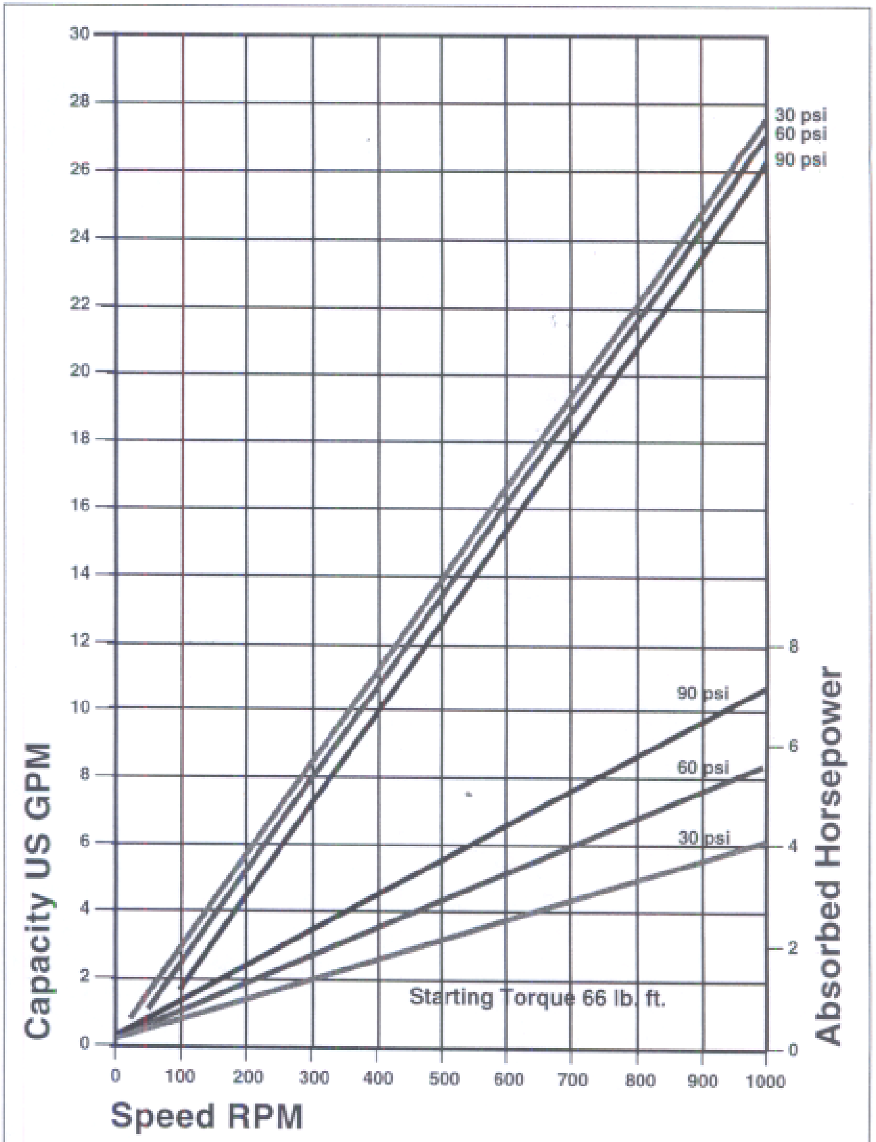

Figure 2. Characteristic curve of a progressing cavity pump

The Q-Ps characteristic curves of progressing cavity pump sizes have been recorded in comprehensive test runs. From the results it is possible to derive pump-specific coefficients that take into account the positive displacement geometry and the individual manufacturer's design of the suction components. For the normal direction of rotation, construction of a hydraulically favorable joint seal and the length and design of the suction casing are both important. Within the turbulent flow range, the NPSH value will be independent of the pumped fluid, and the pressure loss will be in proportion to the density. For each pump size, using the flow rate and this coefficient, it is possible to calculate an NPSHR value, as is shown on the curve in Figure 3.

REVERSE DIRECTION OF ROTATION

For applications in which the $NPSH_A$ value is very low, the performance of progressing cavity pumps rotating in reverse should be considered. The pumping medium flows into what is normally the high pressure side of the pump and is discharged from what is normally the low pressure side. The advantage of this is that shaft sealing will be on the pressure side, excluding any possibility of losing prime through the packing or a mechanical seal. A further advantage is that the NPSH value will be improved by the undisturbed suction conditions. This mode of operation eliminates the influence of the 90° angle inside the suction casing as well as the restrictions from the moving rotor joint on the inlet side of the pumping elements. The influence of the moving joint, in particular, represents the primary restriction, as frequently a 90° angle must be installed in the pipeline to make it possible to run the pump in reverse.

CAVITATION DAMAGE

In long term studies we have made, progressing cavity pumps were subjected to many different cavitation conditions, and the pumps have proved themselves to be relatively insensitive to cavitation damage. In addition to the pump-specific cavitation phenomenon, minimization of damage is essentially due to the combination of materials in the pumping elements and the effect of the elastomeric stator. The stator acts as a shock absorber. Pressure surges caused by bubble implosion are better absorbed in this design than by a pump made from an inelastic metal or synthetic materials. Moreover, the smooth injection-molded stator surface provides a poor working surface for the currents that occur during cavitation. If casing walls are rough, these "microjets" shoot into fine grooves and cracks. By selecting an appropriately low strength elastomer quality, damage as a consequence of cavitation could be confined to the first third of the stator pitch - when viewed from the suction side. Cracks in the elastomer will appear, and these, in connection with the mechanical load due to squeezing, will cause - in part - material to peel off across a wide surface area. Photo 1 shows this cavitation damage across three phases. A total blocking of the suction line will cause damage in the entire area, and this will be similar to the damage generated by running the pump dry. In contrast to dry run following overpressure, however, the stator end will keep the original form. In addition to a temperature rise in the entire pump area, extreme cavitation will increase the power consumption of the drive due to temperature-dependent material expansions. Photo 2 shows a typical dry run which - in contrast to cavitation damage - starts from the center.

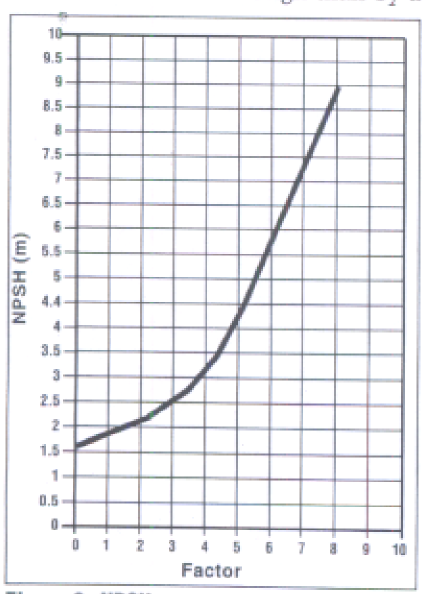

Figure 3. NPSH curve

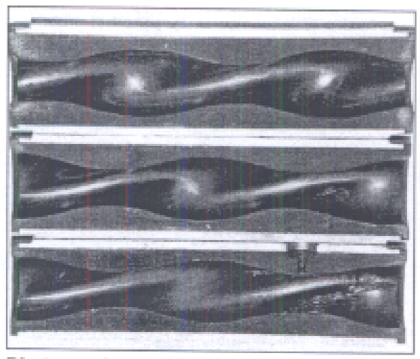
Photo 1. Cavitation damage sequence

During cavitation tests no damage to transmission components was found within the full cavitation range. Strong variations in pressure and the resulting thrust load shocks would normally damage universal joint connections. The design of the joint to absorb these loads is an important consideration if low $NPSH_A$ operation is likely. The use of high quality materials with sufficient cross section designs to avoid fracturing is essential. Designs that include thin locking keys, brass or bronze or cast iron components or flexible shafts represent increased risk.

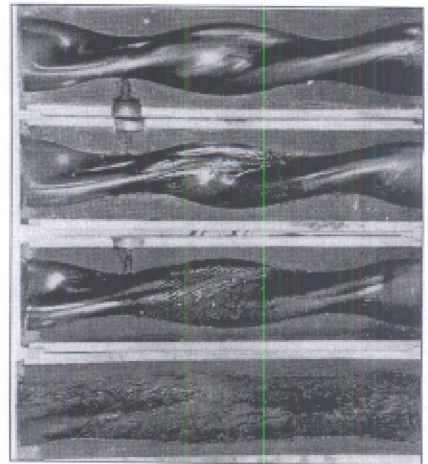
Photo 2. Dry run damage sequence

Earlier investigations have shown that progressing cavity pumps can continue to operate without damage to the elastomer when only 10% of the flow through the pump is really a fluid. In relation to the $NPSH_R$, this capability - when converted into a test standard - would allow a reduction in the pumping flow of around 90%. This standard could not be used for most other pump types, because of the destructive effect of cavitation on the internal components.

SUMMARY AND CONCLUSION

Progressing cavity pumps are a unique type of rotary positive displacement pump. In addition to their ability to pump very thin fluids, they can pump multiphase fluids with an extremely high vapor or gas content.

The typical standard of 2% or 3% reduction in pumping flow to determine the $NPSH_R$ may not be a prudent criterion for a decision against the use of a progressing cavity pump - if you consider that this type of pump can operate well below the listed $NPSH_R$ without suffering physical damage. Aside from the low speed operation, a progressing cavity pump incorporates specific design features and operational characteristics that minimize the damaging effects of cavitation.

While the consequences of cavitation may be acceptable far below the 2% or 3% criterion, it may be better to use criteria such as noise level or vibration, particularly for larger pumps, even when there is no visible reduction in flow or pressure. A general application of a criterion that allows for a 50% reduction in flow would mean that dramatic levels of pulsation, vibration, and noise must be accepted. For operators, this is not a good practice.

The extent to which cavitation can be allowed is mainly dependent on the oscillation behavior and the noise emission of the pump and plant system. However, it also depends on fluid characteristics, the loss of performance that is deemed acceptable, and whether this condition is intermittent or continuous.

LOOKING AHEAD

Currently, our lab is proceeding on systematic investigations for non-Newtonian fluids, whereby a criterion that is directly based on the inlet pressure loss of the pumps (as described earlier) is used. In the course of these investigations, new flow coefficients will be experimentally determined and optimized in relation to existing as well as newly developed pumping element geometries. ■

Michael Dillon is Vice President & General Manager of seepex, Inc. (Dayton, OH).

A graduate of Ohio University, he has more than 23 years of experience in research, marketing, sales and general management of progressing cavity pumps.

Klaus Vüllings is Director of Research and Standards, Seeberger GmbH + Co. (Bottrop, Germany). He has worked in the applications, research and development of progressing cavity pumps for 13 years.