

# Tech Talk

## Effects of Centrifugal Pump Hydraulics on Reliability

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### Introduction

Reliability of mechanical equipment has received considerable attention over the past ten years. Because of the large number of centrifugal pumps, and their relatively low reliability, they have been the focus of much of this attention in the process industries. Numerous articles have been written that address the application, installation, operation and maintenance aspects of reliability. We will discuss some critical application aspects from the point of view of the manufacturer. Relationships between pump design and application will be reviewed and a quantitative approach to selecting the most reliable pump for a given application will be proposed.

A properly selected pump is a necessary, but not sufficient condition for reliable pump operation. Critical installation parameters have been discussed extensively by others. It has been demonstrated that pump reliability can be improved when these parameters are followed, both for pumps that are well selected for the duty, as well as for pumps that are misapplied. Proper pump selection is the key to enhanced reliability.

### Pump Selection

Application issues may be divided into two categories; optimum selection of a pump size, and optimum selection of auxiliary equipment (i.e. mechanical seals, lubrication methods, bearings, couplings, etc.). In this article, we will focus on size selection when applied to pumps of a given design (i.e. from a single manufacturer) operating on a given service. We will not consider the effects of different services nor will we discuss selection of auxiliary equipment.

When selecting a pump one of the first things a user does is to determine the head and capacity required. After deciding on a supplier, and a product line, there is still a choice of a number of different size pumps that will handle the duty. As an example Figure 1 lists five ANSI pump sizes from a single manufacturer that could be selected to handle

Figure 1

SELECTED PUMPS						
PUMP	RPM	IMPELLER DIAMETER (INCHES)	TDH (FT)	HP	NPSHR (FT)	EFF %
2 x 3 - 8	3550	7.00	158	18.2	11.1	66
2 x 3 - 13	1750	12.63	153	18.5	5.6	62
2 x 3 - 10	3550	7.13	157	19.8	15.0	60
3 x 4 - 13	1750	12.50	153	19.8	4.6	58

a duty of 300 GPM at 150 FT. Review of the options indicate that the first pump, a 2x3-8 would probably be the least expensive due to its smaller size. Because it draws the least HP (18.2) it would have the lowest operating cost. Figure 1 does not provide any information regarding the relative reliability of the five selections.

This is an interesting situation since maintenance expense can be one of the major cost items in the life cycle cost of a pump. A number of surveys have shown that the average mean time between repair for an ANSI pump is 15 months. The average repair cost cited by users is \$2500 per repair. Since the average cost of a small ANSI pump is in the \$4000 range, the repair costs will exceed the initial cost in less than three years.

### Pump Selection Reliability Factors

From a reliability point of view there are three major factors that affect the selection; operating speed, impeller diameter, and flow rate. In this article a method of assigning a numerical value for each factor is proposed. This value allows ranking the relative reliability of alternate pumps on each factor. The numerical values range between zero and one, higher values indicating more reliable selections. Since a poor ranking on any one factor can significantly affect the reliability of the pump, an overall reliability index is formed by taking the product of the three individual factors. This product will be referred to as the Reliability Index (RI).

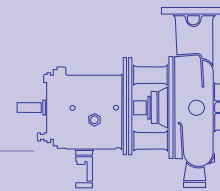
**RPM ( $F_R$ )** The operating speed affects reliability directly through; wear in rubbing contact surfaces (mechanical seals, and shaft seals), bearing life, heat generated by the bearings and lubricants and wear caused by abrasive in the pumpage. For most of these items the wear has a linear relationship to the pump RPM. Thus the RPM factor is taken as a

linear function of operating speed. The starting and ending points for the relationship are set as zero RPM and the maximum RPM for which the pump is designed since reliability is a function of the basic design.

A value of 0.2 is assigned to the RPM factor when application is at maximum design RPM. This value was arrived at by recognizing that the index is a comparative rating. The maximum and minimum values of the parameter affect how each parameter is weighted relative to the other parameters. Although the value of 0.2 is somewhat arbitrary, it does insure the RPM is weighted equally with the other parameters. It was also found that the final index values are not very sensitive to this value.

As an example, if a given pump was designed to operate at a maximum speed of 3500 RPM, an application at 3500 RPM would be assigned  $FR = 0.2$ . If the same pump was applied at 1750 RPM the value of FR would be assigned a value half way between 0.2 and 1.0, or 0.6 (the speed is one half the maximum).

**Impeller Diameter ( $F_D$ )** The impeller affects reliability through the loads it imposes on the shaft and bearings. Impellers produce two types of loads; one that is relatively steady in both magnitude and direction, and a second which is variable in both magnitude and direction. The first is a result of non-uniform pressure distribution in the casing. It produces a shaft deflection in one direction (at a given capacity) which causes the mechanical seal faces to run off-center, but not wipe radially (for most seal designs). The second load is a result of the interaction between the impeller vanes and casing discharge, and produces a deflection as each vane passes the discharge. This second effect can be very damaging because it causes the seal faces to move radially relative to each other many times per



revolution. The magnitude of this movement may be greater than the steady deflection. Both loads are related to the impeller diameter in a cubic manner. Thus they decrease rapidly as the impeller diameter is reduced, and reliability increases equally rapidly. But, as the diameter is further reduced the possibility of encountering suction recirculation and resulting random loads increases. Since suction recirculation occurs at the pump inlet where fluid energy levels are lower than at the exit, the loads produced by recirculation are not as great as those produced by the impeller/discharge interaction. Consequently there is an optimum diameter which is closer to the maximum diameter than to the minimum which maximizes reliability. Since the loads produced by recirculation are less severe at lower RPM, FD is made a function of RPM. The optimum diameter is taken as 75% of the trim range (25% from maximum).

Thus a pump with an impeller diameter trim range of 10" to 6" would be assigned a value of  $FD = 1.0$  when trimmed to 9" at any speed. When trimmed to a maximum diameter (10")  $FD$  would be assigned a value of 0.0 if operation was at the maximum design RPM, and 0.5 when operated at one half of maximum RPM.

**Flow Rate ( $F_Q$ )** A centrifugal pump is designed to operate most reliably at one capacity for a given RPM and impeller diameter. This flow rate is called the best efficiency point (BEP). At this flow hydraulic loads imposed on the impeller are minimized and are steady. At flows greater than or less than the BEP the hydraulic loads increase in intensity and become unsteady due to turbulence in the casing and impeller. These unsteady loads have the same effect on reliability as the impeller/discharge loads discussed above. In order to measure the effect of these loads a series of tests were conducted on a pump. The tests involved varying the following parameters:

- RPM
- Impeller Diameter
- Flow Rate
- Pump shaft to motor shaft alignment
- NPSH Margin

Vibration at the bearings was selected as a convenient direct indication of the relative shaft motion. Vibration levels are averaged over the range of parameters as a function of

flow rate. Results show that the vibration at BEP is 60% of the level at 10% of BEP, and is 45% of the level at 120% of BEP. Thus if a reliability factor for flow is assigned a value of 1.0 at BEP, then values of .60 at 10% BEP and .45 at 120% of BEP are appropriate for this pump.

Experience with pumps of a variety of sizes has shown that smaller pumps vibrate less when throttled back on their curves than do larger pumps. This is probably a result of smaller pumps being more rugged relative to the imposed loads than larger pumps. Thus the reliability factor for flow rate was made dependent on BEP capacity.

A pump selected at BEP capacity is assigned  $FQ = 1$ . A small pump (BEP < 50 GPM) is assigned  $FQ = 0.5$  when operated near shutoff. A large pump (BEP > 3000 GPM) is assigned  $FQ = 0$  when operated near shutoff. For all pumps  $FQ$  is assigned a value of zero when applied at flows greater than 125% of BEP. This is done in recognition of rapidly increasing NPSHR as well as high impeller loading.

**Reliability Index ( $R_i$ )** The Reliability Index is formed as a product of the three individual factors:

$$RI = FR \times FD \times FQ$$

Values will range from zero to one with higher values indicating greater reliability. Because this factor does not take into account design characteristics it cannot be used to compare pumps of different designs. These design

characteristics can include single or double volute, number of impeller vanes, shaft overhang, relative frame loading, etc. The value of the Reliability Index is in assisting the selection of the most reliable pump of a given design in the same service.

An example of the use of the Reliability Index is given in Figure 2. This Figure lists the five pumps identified in Figure 1 which could be selected for a duty of 300 GPM at 150 FT. In Figure 2 these pumps are ranked using the Reliability Index. The fourth column lists RI for each pump. The 2x3-13 has the highest index value, primarily due to operation at less than its maximum design speed. The 2x3-10 has an RI of zero due to selection at 125% BEP. It can be seen in the next to last column that the NPSHR for this pump is considerably higher than the others.

This approach enables the user to have significant additional information available on which to base a selection. Reliability Index can be a reasonable indicator for judging the merits of a range of pump selections of a given manufacturer's design operating in the same service.

Figure 2

#### RELIABILITY OPTIMIZED PUMP SELECTION – #1

PUMP SIZE	IMPELLER DIAMETER	RPM	RI	FRPM	FD	FQ
2 x 3 - 8	7.0	3550	0.12	0.2	0.96	0.63
2 x 3 - 13	12.6	1750	0.47	0.6	0.79	1.00
2 x 3 - 10	7.1	3550	0.00	0.2	0.66	0.00
3 x 4 - 13	12.1	1750	0.17	0.2	0.96	0.87

#### RELIABILITY OPTIMIZED PUMP SELECTION – #2

PUMP SIZE	DIAMETER RATIO	Q/QBEP	COST FACTOR	ENERGY FACTOR	NPSHR FT	NPSHA FT
2 x 3 - 8	0.63	1.15	1.00	1.00	11.1	17
2 x 3 - 13	0.91	1.00	1.49	1.02	5.6	17
2 x 3 - 10	0.28	1.25	1.11	1.09	15.0	17
3 x 4 - 13	0.78	0.58	1.97	1.05	4.0	17