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Engineering Pump Solutions™

WHITE PAPER
Optimal Centrifugal Pump Selection & Operation

Guide to Understanding the Tradeoffs in Initial, Operating and Lifetime Costs

There is much discussion within the pump industry around the optimization of pump system design. Defining optimization varies between applications and encompasses a number of variables.

Optimization is Not One-Size-Fits-All

Pumps operate on a simple premise, using mechanical energy to create a pressure differential that causes gas or fluid to flow from lower pressure to higher pressure. Despite their simplicity, pumps play a critical role in the modern world. Almost every product manufactured, processed or treated includes pumps as part of its lifecycle.

Pump optimization can refer to any of the following qualities:

a. The pump with the lowest initial cost
b. The pump with the lowest energy consumption
c. The pump with the lowest lifetime maintenance
d. The pump with the longest service life

Each is a worthy goal; the more of these achieved, the more 'optimized' the pump. Unfortunately, these goals do not often align in real-world applications. Alignment is more readily achieved in clean fluid applications. In applications involving fluids other than water or those containing solids or entrained air, achieving this alignment is more difficult. Before pump selection can be optimized, the design goals and processes of the entire system must be understood. It is common for users to blame manufacturing or quality following a failure, but the reality is more complex.

There are very few bad pump designs. Pump and mechanical seal failures are rarely the result of poor design. The vast majority of premature failures result from:

a. Improper pump selection for a given system
b. Improper operation of the system (outside original intent)
c. Improper installation

Defining Optimal Pump Operation

Pump manufacturers determine efficiency through performance testing. This point is called the Best Efficiency Point (BEP) and should be stated on all centrifugal pump curves. At BEP, the least amount of fluid is bypassed back to the suction side. The pump runs the smoothest, flow is cleanest, and radial loading on bearings is minimized.

During normal operation, the Hydraulic Institute recommends operating centrifugal pumps between 70% and 120% of BEP. This range is based on design physics and assures the highest efficiency and reliable operation, with the lowest bearing loads, turbulence, and vibration.

If flow is reduced by system restrictions, a low-pressure area develops past the cutwater in the casing. This results in a force that deflects the impeller and shaft (approximately 300 degrees from top dead center).

Conversely, if too little restriction is present, a low-pressure zone forms before the cutwater, causing shaft and impeller deflection (approximately 120 degrees from top dead center).

Neither condition is beneficial for pump or mechanical seal health. Figure 1 is a representative depiction of the resultant pressure differential inside a casing in these conditions. This pressure differential causes increased shaft deflection, vibration and bearing load. Figure 2 illustrates the amount of this potentially damaging radial load and shaft deflection relative to a performance curve, with the lowest radial load near the pump’s BEP.

Selecting a pump exactly at BEP assumes a system never fluctuates. In reality, pump systems are variable and often operate outside controlled test conditions. This variation is frequently not fully accounted for.

With a pump selected at BEP, flow fluctuations can result in operation well outside the recommended BEP range. It takes only about 20% deviation to move too far on the curve, introducing the risk of cavitation and increased radial loads.

For this reason, many designers target around 85% of BEP. This allows system fluctuations to the right and left without moving outside the acceptable 70-120% window.

In Figure 3, the optimal range of operation on the pump curve is shown. The area in green encompasses that 70-120% window, with pump operation becoming more unstable as you move out into the red on either end of the curve. Note the short distance past BEP before entering into potentially problematic operation.

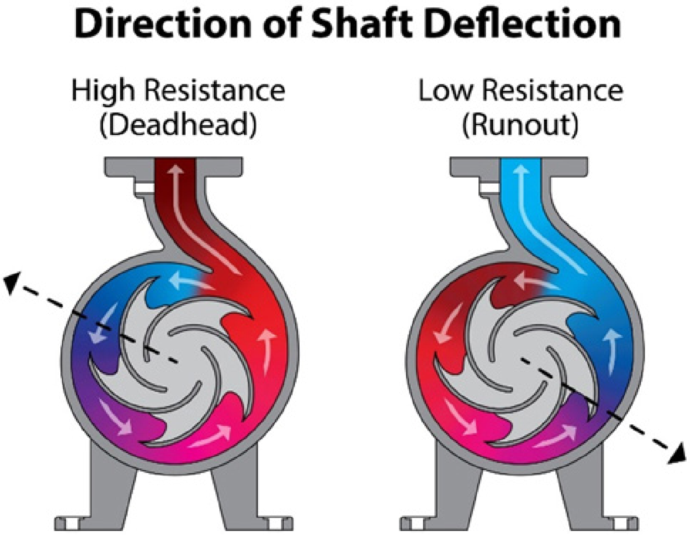

Figure 1: Effects of flow resistance on shaft deflection and operating temperature

Selecting the Optimal Pump for a System

Selecting an optimized pump requires consideration of the full operating range, not just a single flow and head point. A centrifugal pump has no sensors or process controls. It moves as much fluid as system resistance, pump capacity, and inlet conditions allow.

For example, a system with a filter may see a 40’ TDH pressure drop between clean and dirty conditions. In a system designed for 70’ TDH, this swing is significant.

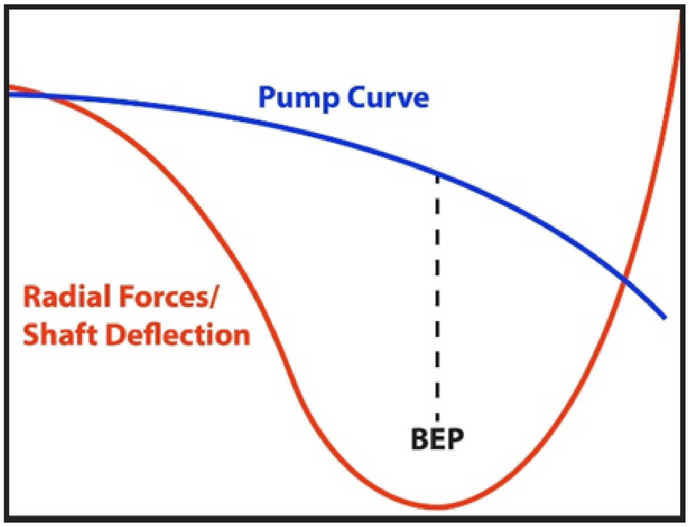

Figure 2: Amount of radial load and shaft deflection relative to the BEP on a performance curve

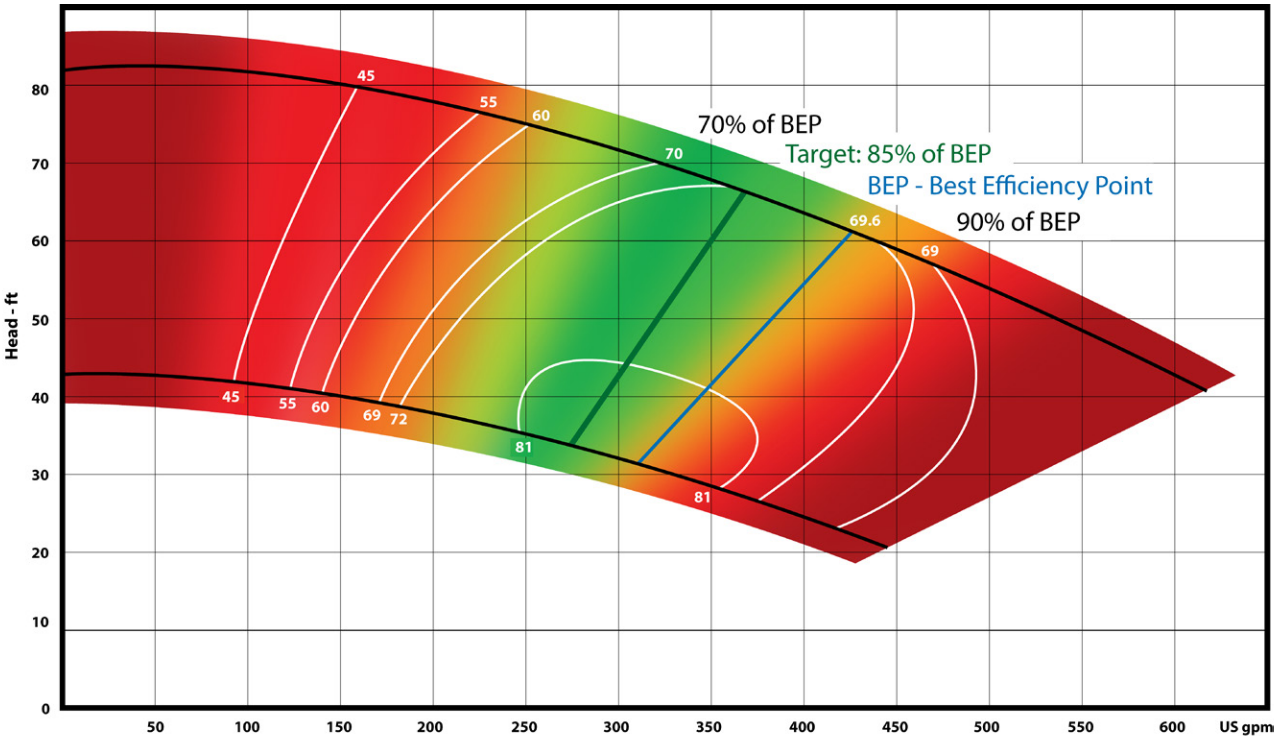

Figure 3: Recommended operating zone on a pump curve relative to BEP

If an application requires 100 GPM, the pump must overcome all system losses, including a dirty filter. With losses of 40 feet (clean) and 70 feet (dirty), the pump must handle both conditions. The pump must be sized for both scenarios: 100 GPM at 40’ TDH and 100 GPM at 70’ TDH.

At lower head, the pump produces more flow, increasing friction losses. System losses must be recalculated at higher flow rates to estimate the higher flow operating point. Both condition points should remain within the 70-120% BEP window when possible.

Because real-world operating conditions cannot be fully predicted, designers often add safety margins. A requirement of 100 GPM may be increased to 120 GPM. Similarly, additional TDH may be added to account for known challenges.

If the system provides less resistance than expected, this padding may result in significantly more flow, causing the pump to operate well outside the desired efficiency window.

Operating a Pump for Optimal Performance

System variability often results in operation outside the recommended 70-120% BEP range. NPSHr and minimum submergence must be satisfied across all operating conditions.

When a pump operates outside this range, issues such as cavitation, excessive vibration and air entrainment occur, often simultaneously.

At flows greater than 120% of BEP, maintaining NPSH becomes more difficult as NPSHa decreases and NPSHr increases. Radial bearing loads also increase.

At flows less than 70% of BEP, system restriction forces recirculation from discharge to suction. This reverse flow creates excessive turbulence, vibration and increased bearing load.

These conditions often lead to premature failure of mechanical seals, shaft couplings, bearings and other components. Failures are typically driven by operating conditions, not component quality or initial selection.

Designing for Extreme Conditions

Pump selection involves trade-offs. In clear water applications, most centrifugal pumps operate at intended flow and pressure with minimal compromise.

In applications involving solids, entrained air or difficult suction conditions, standard centrifugal pumps may not be suitable. These systems often experience greater variability.

In such cases, design features such as strainers, choppers, hardened materials or rubber linings may be required, often reducing efficiency to achieve reliable operation. If extreme variability cannot be minimized, alternative pump designs may be required. Sealless pumps, vortex pumps, and variable speed drives are all options more forgiving of wide operating conditions.

Sealless Pumps

Mechanical seal failure is one of the most common reasons pumps are removed from service. The Hydraulic Institute places this at approximately 70% of pump repairs.

Mechanical seals are vulnerable to vibration, temperature swings, air entrainment and process buildup. Sealless pumps eliminate this problem component, instead using a specially designed throttle bushing to reduce leakage into the column to a negligible amount.

The sealless design improves reliability and significantly reduces maintenance costs and downtime. This meets the optimization goals of longest service life with lowest lifetime maintenance costs when compared to sealed pumps.

Vortex Pumps

Vortex pumps operate over a wider range than typical centrifugal pumps. Their design allows them to handle up to 30% entrained air and light solids while maintaining low radial loading under variable conditions.

However, there is a significant impact on efficiency, often 30% or more compared to typical pumps. In many cases, this loss is an acceptable trade-off for longer service life.

Variable Frequency Drives

Variable frequency drives (VFDs) provide operational flexibility by regulating pump speed. Speed adjustment can help maintain operation within the BEP range. In the example given on page 2, reduced speed maintains operation within the optimal range even under lower resistance and higher flow conditions of a clean filter.

VFDs do not solve all system issues but help mitigate the effects of changing conditions. In many applications, cost is justified by improved reliability.

Installation: The Often-Overlooked Element

Improper pump installation can create excessive vibration. Vibration can damage the housing, destroy the impeller, cause seal and bearing failure, increase power consumption, and reduce pressure or flow.

Pumps should be mounted securely on a level base (horizontal), or proper thickness mounting plate (vertical). Intake and discharge piping should be properly supported to avoid strain on the pump. All piping connections should be checked for axial and angular alignment. Inlet pipe should include a straight run of at least 5x the pipe diameter (horizontal). Distance from the bottom of the tank should be minimum 2x the diameter of the suction (vertical).

Conclusion

There is little consensus on what constitutes an optimized pump because it depends on application goals and operating conditions. A clear understanding of BEP and real-world variability allows alignment of initial cost, energy consumption, maintenance requirements and lifespan, resulting in a fully optimized pump for each installation.

As a family owned business supplying pumps for over 100 years, you can rely on Ruthman Companies to provide comprehensive support for the life of your pump. We custom manufacture a wide range of pump types to your specifications, assist you with installation, and provide service for the life of your pump.