

# Reengineering the Impeller

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**Have you ever experienced this? The pump that you purchased for one specific performance is placed in service and operates at another point that is completely different from its original design point or BEP. Here's one way to resolve this problem.**

The problem above is all too common. In addition to being very inefficient, when you operate the pump away from the original design point or best efficiency point (BEP), it causes a multitude of other issues, including excessive noise and vibration, shaft oscillation, cavitation, premature wear, and failure of mechanical seals, bearings, rings, sleeves and impellers.

In extreme cases, the shaft will break right behind the impeller from the excessive radial forces that occur when you operate a pump away from the original design point. Damage to these pump internals and poor reliability are a real and direct result of such operation.

These problems can be resolved by reengineering the impeller to operate at the new system design point so that the BEP will be the true operating point in the plant or ship system. This will improve both the efficiency and the reliability of the pump.

Operating a pump away from the BEP has a detrimental effect on pump efficiency and wastes a tremendous amount of money, since 85 percent of the total cost of owning a pump is

**An impeller that uses traditional metallic technology.**

**A reengineered impeller that uses a graphite combination-fiber reinforced composite material with phenolic resin.**

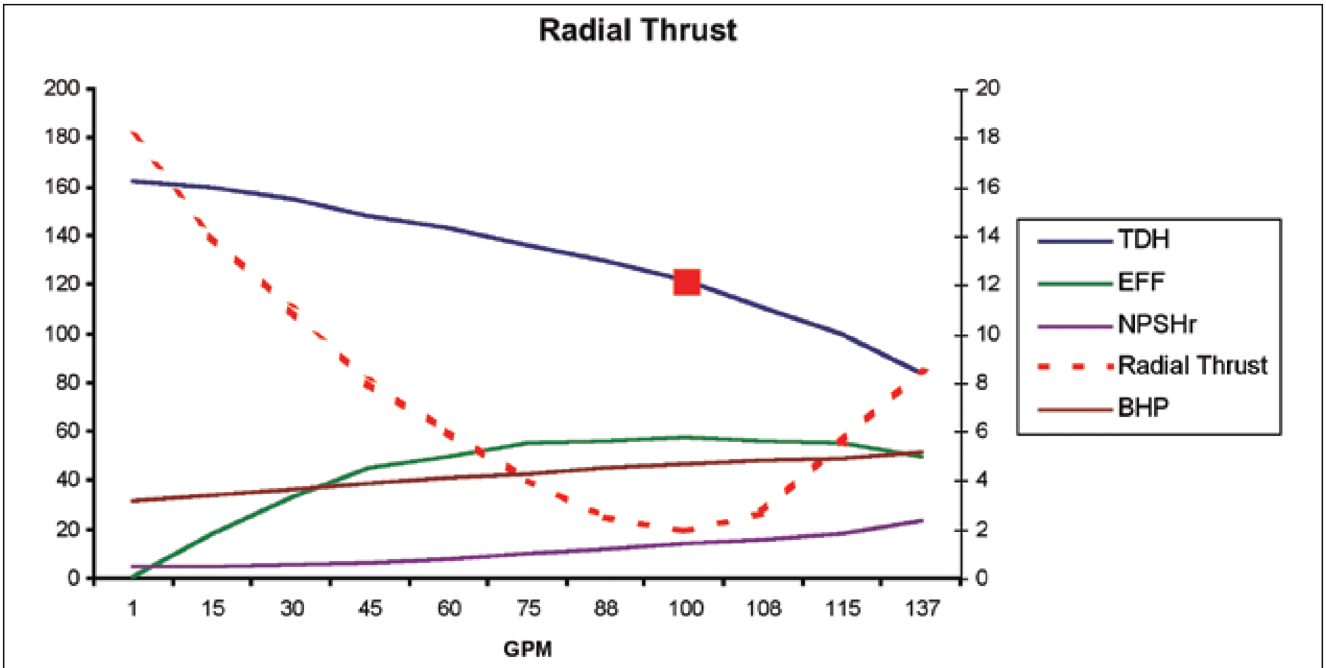

**Figure 1. Radial Thrust**

the operational cost (maintenance cost plus the cost of energy). The larger the pump, the more energy is wasted when a pump operates off the original design point.

When a centrifugal pump operates to the left of the originally designed BEP or to the right of the BEP, many bad things happen. First, *radial thrust* grows exponentially (see Figure 1), resulting in significant shaft deflections and oscillations that lead to premature mechanical seal failures, bearing failures, excessive bushing, ring, and sleeve wear and even shaft failure (breakage).


**In the case of suction recirculation cavitation (shown on the left), coatings are ineffective against cavitation damage. On the right is an example of discharge recirculation cavitation.**

Also, a hydraulic phenomenon called *rotating stall* sets-in, which is essentially a back-flow that leaves the impeller eye and progresses backwards. This can result in violent piping vibrations, pressure pulsations, and premature wear of the components.

Another very common hydraulic problem that occurs when the pump operates at a performance which is different from the original design point is an occurrence called *recirculation cavitation*. When two flow paths within a fluid are moving in opposite directions and they are in close proximity to each other, vortices form between the two directions of flow causing high fluid velocities and turbulence, resulting in pockets of low pressure where cavitation occurs.

*Suction recirculation cavitation* occurs when fluid entering the pump suction is reversed, resulting in high velocity vortexes in or near the impeller eye. These high velocities produce low localized pressures at the center of the vortex, resulting in cavitation damage which occurs in the impeller eye in-between the impeller vanes, on the pressure side of the inlet vanes near the impeller eye. This recirculation cavitation damage increases the farther away from the BEP that the pump operates.

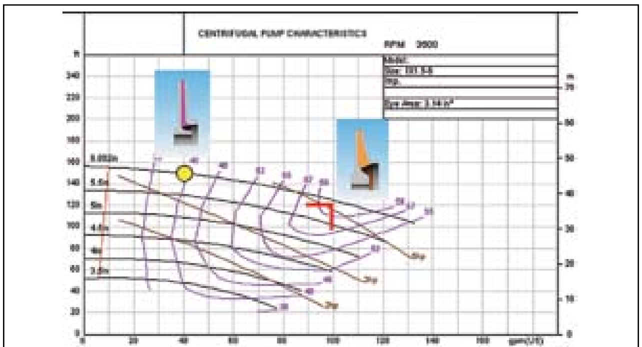
**Figure 2. Original hydraulic curve for a 1 x 1.5-6 pump.**

*Discharge recirculation cavitation* occurs when fluids leaving the impeller discharge may be reversed, causing high velocity vortexes between the two flow directions, in turn causing low-pressure areas. Cavitation occurs when these low-pressure areas drop below the vapor pressure of the fluid being pumped. Discharge recirculation cavitation occurs on the discharge side of the impeller. This damage increases the farther away from the BEP that the pump operates.

The problem intensifies when a hydraulic parameter called suction specific speed (NSS) is high. *Suction specific speed* is the geometric relationship between the impeller eye diameter, the impeller outside diameter, and the NPSHR. It is an indirect indication of the impeller eye being too large, but it also depends on several other factors related to design, installation and application.

There are certain engineering rules and principles related to minimum allowable flow: as a function of pump energy, specific speed (NS), suction specific speed (NSS), and other factors. When violated, these rules and principles can cause trouble and problems.

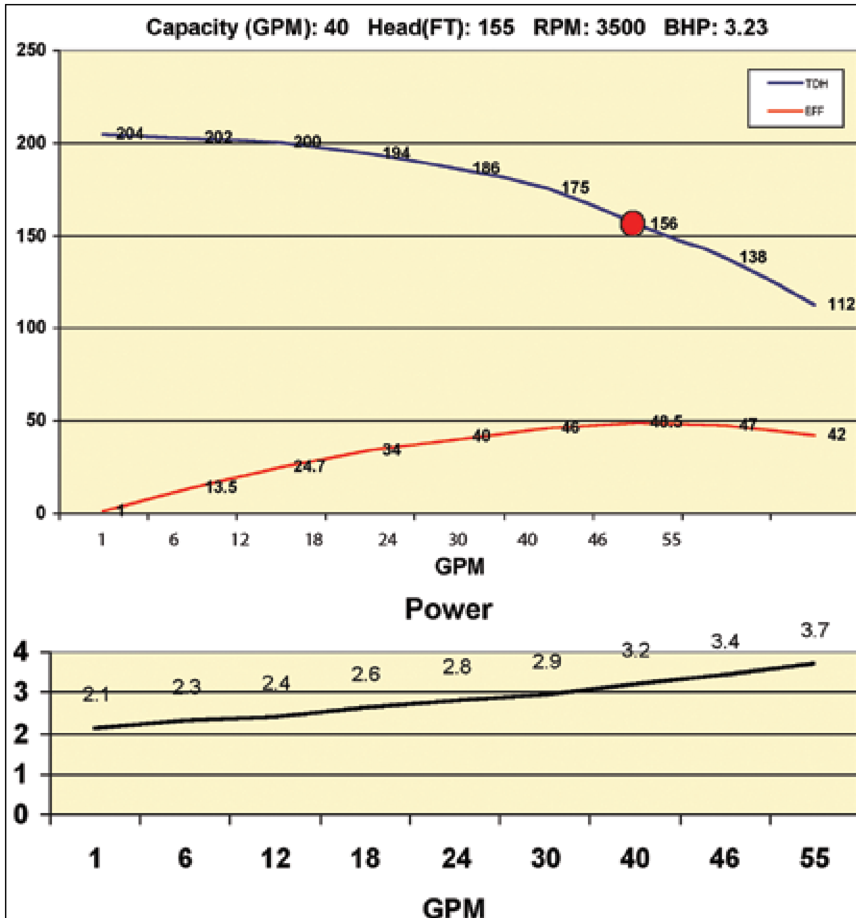

**Figure 3. The performance curve of the 1 x 1.5-6 pump using a reengineered impeller.**

## Example 1: A Small Pump

Let's consider a relatively small pump that needs to produce 40-gpm at 140-ft of head. A 1x1.5-6 pump size (with an approximately 6-in impeller diameter) may be selected from hydraulic curves. The pump will work, but unfortunately will not be operating at its optimum design point or BEP.

As is evident from the hydraulic curve for this pump size (see Figure 2), this pump will have 40 percent efficiency (yellow circle). However, the optimum design point or BEP (red angle) is at 58 percent efficiency. The result is that the pump operates to the left of its BEP for the impeller diameter required to achieve the desired head. This will result in radial thrust, vibrations, and premature wear.

What effect will this have on energy consumption? Note that the horsepower line (see Figure 2) that passes near the operating point is approximately at 4-hp, which is roughly 3-kW. How much does it cost to operate this pump if it is running continuously, 365 days per year at, say, $0.10 per kilowatt-hour? It is 3 x 24 x 360 x $0.10 = $2,592.

Now, what would it cost if the efficiency were somehow improved to the 48 percent efficiency that this pump would

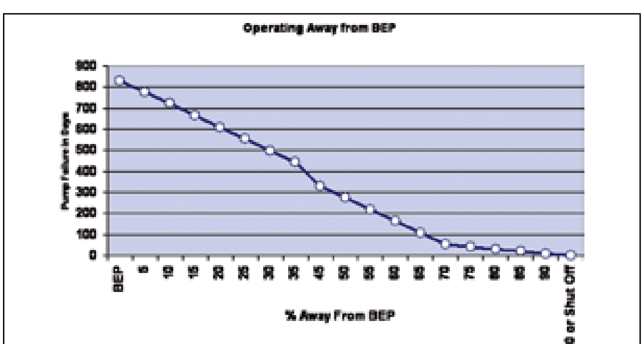

**Figure 4. *Operating away from the design point.* This chart represents an average failure mode based on information compiled of pumps operating away from their design point.**

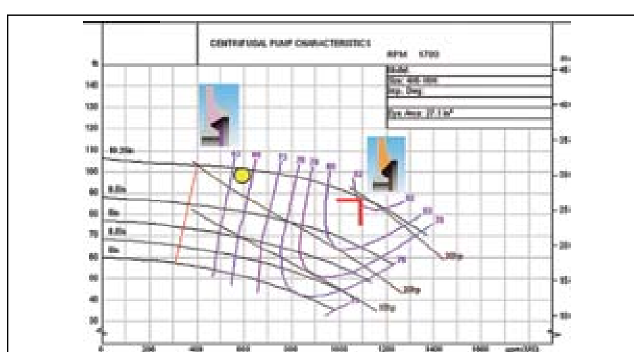

**Figure 5. Original hydraulic curve for a 4 x 6-10 pump.**

enjoy if the system operating point were to become the best efficiency or design point by redesigning the impeller? See Figure 3. Obviously, if a pump runs more efficiently, it will take less power. In fact, the power (and thus cost) would be inversely proportional to efficiency: \$2,592 x (40/48) = \$2,160. The net *electrical* savings would thus be \$2,592 – \$2,160 = \$432 per year, which is 17 percent less.

However, when the pump is operating at 40-gpm at 155-ft, instead of 100-gpm at 120-ft, the pump is operating in the danger zone, 60 percent away from BEP. At this point, the pump is subject to high radial loading, which causes tremendous noise and vibration and excessive shaft oscillation that leads to premature bearing, mechanical seal, and impeller failure.

Using the chart in Figure 4, you can see that when the pump operates 60 percent away from design point (40-gpm at 155-ft, such as the example in the pump curve above), the pump failure rate has increased drastically, by 5.2 times. In other words: 833 days/163 days = 5.2 times or 520 percent higher cost!

In other words, on average, this pump will have to be overhauled 5 times more than if it operated at BEP. With an estimated overhaul price of \$2500, the operational cost is approximately \$13,000 more than it should be! Redesigning the impeller and installing a new reengineered impeller will save electrical costs (\$432 savings per year per pump in this example) and, more importantly, operational costs (\$13,000 savings per pump in this example).

## Example 2: A Somewhat Larger Pump

Consider a 4x6-10 pump operating in a plant system at 600-gpm and producing 100-ft of head. Again, the pump is off the efficiency peak. It operates at approximately 65 percent, whereas its peak efficiency at that diameter (10.25-in) should be 82 percent at the original specified performance of 1100-gpm at 88-ft.



Now the energy dollars become more pronounced. Its power consumption is approximately 25-hp (19-kW), according to horsepower lines in the proximity of the operating point: 19 x 24 x 360 x $0.10 = $16,416. The electrical cost to operate the pump would be substantially less if efficiency were increased by redesigning the impeller to operate at the system requirements of 600-gpm at 100-ft, instead of 1100-gpm at 88-ft.

The efficiency at this new point would be increased to 78 percent: $16,416 x (65/78) = $13,680. The electrical savings would be: $16,416 – $13,680 = $2,736 per year, about 16 percent in this case.

This pump is operating in the system at 600-gpm at 100-ft, instead of 1100-gpm at 88-ft, which is approximately 45 percent away from the original design point (600/1100 = 55 percent – 100 = 45 percent away from design point). From Figure 4 we can determine that when this pump operates 45 percent away from the original design point (1100-gpm at 88-ft red arrow in Figure 5), the pump failure rate has increased drastically, by 2.56 times. In other words, 833/325 = 2.56 times or 256 percent higher cost!

This pump will have to be overhauled 2.5 times more than if it operated at BEP. With an estimated overhaul price of $5500, the operational cost is approximately $13,750 more than it should be.

Reengineering the impeller will save $2736 in electrical costs per year per pump, and save $13,750 in operational costs per pump.

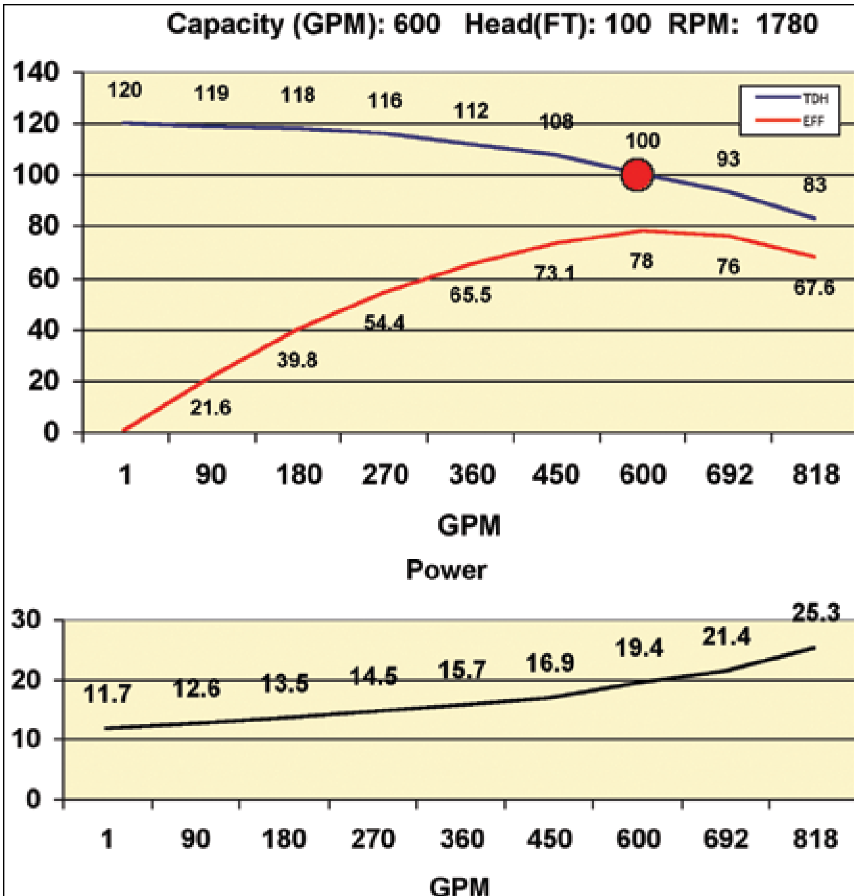


Figure 6. The performance curve of the 4 x 6-10 pump using a reengineered impeller.

## Example 3: An Even Larger Pump

Assume an 8 x 10-17 pump operates at 2000-gpm (280-ft head) instead of a peak point of 4000-gpm at 240-ft of head. The efficiency at the actual operating point is only 70 percent, rather than the potentially achievable 83 percent by this pump.

The horsepower at the operating point is roughly 225-hp (168-kW), and the yearly energy bill is: 168 x 24 x 360 x $0.10 = $145,152. The electrical cost to operate the pump would be substantially less if efficiency were increased by redesigning the impeller to operate at the system requirements

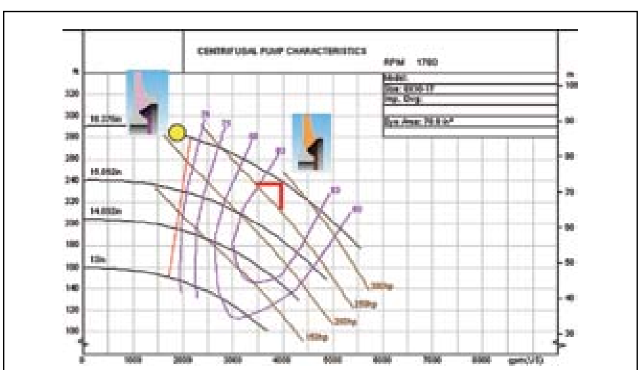

Figure 7. Original hydraulic curve for an 8 x 10-17 pump.

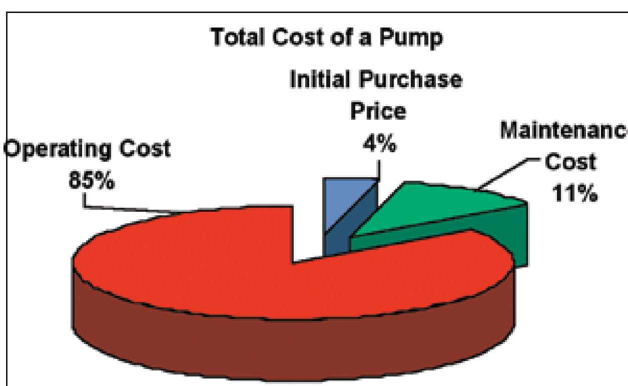


Figure 9. Total cost of a pump.

of 2000-gpm at 280-ft instead of 4000-gpm at 240-ft. The efficiency at this new point would be increased to 81 percent: $145,152 x (70/81) = $125,440. The electrical savings would be: $145,152 – $125,152 = $20,000 per year, or about 13.8 percent in this case.

This pump is operating in the system at 2000-gpm at 280-ft instead of 4000-gpm at 240-ft, which is approximately 45 percent away from the original design point (2000/4000 = 50 percent – 100 = 50 percent away from design point). From Figure 4 we can determine that when this pump operates 50 percent away from the original design point (4000-gpm at 240-ft red arrow in Figure 7), the pump failure rate has increased drastically by 2.78 times. In other words, 833/300 = 2.78 times or 278 percent higher cost!

This pump will have to be overhauled 2.78 times more than if it operated at BEP. With an estimated overhaul price of $10,000, the operational cost is approximately $27,800 more than it should be. Reengineering the impeller will save $20,000 in electrical costs per year per pump, and save $27,850 in operational costs per pump.

## Conclusions

The net savings to be gained from reengineering depends upon how far away from the BEP the pump operates, a problem that exists in many pumps that were purchased and installed years ago that no longer operate at their originally intended hydraulic conditions.

As operating conditions change, the pump is simply throttled further and further away from the BEP, resulting in dollars that are literally "burned up," not to mention problems such as high loads, shaft breakage, premature rotating life wear, etc.

Obtaining a smaller pump may not be a good answer, because it may still not (and usually does not) have the hydraulics sized to hit the operating point "dead on." A smaller pump may help somewhat, but it is expensive and not as efficient. This limits the choice to the standard pump sizes available from

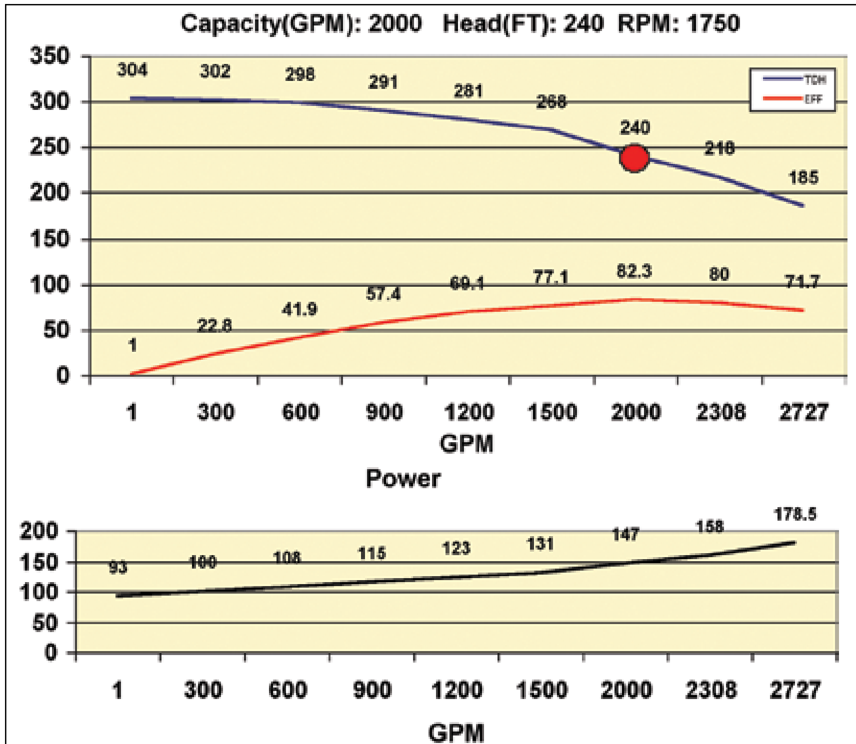


**Figure 8. The performance curve of the 8 x 10-17 pump using a reengineered impeller.**

the pump manufacturer's catalog. Even with a large number of sizes in the catalog, it is virtually impossible to cover each and every variation of the operating conditions. This could force the user to settle for the "second best," but not the optimum.

Even more important is the issue of economics and feasibility of piping changes to accommodate a proposed pump downsizing. Piping changes alone can often cost more than a pump.

**If a pump costs $15,000 and you increase its efficiency by 5 percent by installing a reengineered impeller, you will save $18,750 (more than the initial cost of the pump).**



An alternative solution is to install a custom-designed, reengineered impeller sized for the operating conditions. This can essentially "shift" or "slide" the pump performance to the exact BEP. The net losses and radial loading each become zero. This approach can be effective and the investment is minimal, with a payback less than one year and often only a few months.

Not only ANSI or single stage overhung-impeller pump designs can benefit from this approach. Split case and multistage pumps, vertical multistage, river intake pumps, condenser, circulating, etc. have all benefited greatly with improved impeller hydraulics. When a metal impeller is replaced with structural engineered composite impeller (often 85 percent lighter then metal), the combined effect of hydraulic fine-tuning with reduced weight (and thus load) can be dramatic and the rotor dynamic benefits are obvious.

When analyzing the total cost of a pump over its entire lifetime, you will find only 4 percent of the total cost is the initial purchase price. 85 percent of the total cost is the operational cost (including the cost of energy) and 11 percent of the total cost is maintenance cost (see Figure 9).

If a pump costs $15,000 and you increase its efficiency by 5 percent by installing a reengineered impeller, you will save $18,750 (more than the initial cost of the pump).

**P&S**

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