Last month we discussed the cause of shaft deflection and identified the fact that in an end suction, overhung centrifugal pump with a single volute casing, there exists the potential for unbalanced radial forces to cause excessive shaft deflection if the pump is run away from the best efficiency point (BEP). So Let’s Get Practical. How do we combat that problem in the field?

About 20 years ago, a concept called the Shaft Slenderness Ratio was introduced. It compares the diameter (D) of the shaft under the shaft sleeve, with the distance (L) between the impeller and radial bearing centerlines.

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\text{Slenderness Ratio} = \frac{L}{D^4}
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While most mathematicians can relate the slenderness ratio with a simplification of the complex formula given in last month’s column, it is fairly obvious that the amount of movement at the end of the shaft depends on the diameter of the shaft and the length of the overhang.

It is important to note that a shaft sleeve does not help in the rigidity of the shaft unless the sleeve is shrunk onto the shaft. As this is not a common practice on end suction process pumps, the diameter of the shaft under the sleeve must be measured to establish the slenderness ratio.

Accordingly, as the shaft diameter increases and/or the length decreases, the slenderness ratio will decrease, and the shaft will become more resistant to deflection. In contrast, a higher value reveals a shaft that is less resistant. Consequently, it will deflect more easily. Stronger shafts rarely exhibit any real shaft deflection problems and, therefore, seals and packing operate without any difficulty, resulting in a very reliable pump. This reliability is almost regardless of the operating conditions.

Pumps with shafts having higher levels of slenderness ratio can also display high levels of reliability, but only when they are operating at, or close to, their BEP. If the operating point on these pumps moves away from the BEP, the radial loads can increase beyond the point that can be effectively resisted by the weaker shaft, and excessive shaft deflection can take place.

Many pumps in the chemical process industry (and others) are subjected to excessive and inappropriate hydraulic conditions, such as fluctuating pressures or repeated cavitation or recirculation problems. When faced with such conditions the pump shafts are susceptible to a degree of deflection (and frequently, vibration) that is sufficient to cause repetitive seal and packing failure. As a result, any pump that displays the symptoms of premature and repeated failures of the mechanical seal is exhibiting the classical symptom of excessive shaft deflection.

Considering all practical options to overcome this condition, the simplest and most effective modification is to remove the shaft sleeve and increase the shaft diameter to the same size as the original sleeve. In some cases, this will cut the slenderness ratio almost in half, thus making the shaft twice as capable of resisting deflection.
It should also be noted that this will require a non-fretting mechanical seal, but this seems to be a small price to pay for increased pump reliability in the most practical sense.

Vertical Pumps

Owing to the distance from the impeller to the first bearing on a vertical pump, the validity of the slenderness ratio has been brought into question. This will depend on the type of vertical pump being considered. For example, a vertical turbine pump utilizes axial diffuser vanes in the bowl assembly that minimize any consequential radial loads. Hence, the slenderness ratio is not a factor.

On a vertical inline pump that uses a single volute casing, however, the slenderness ratio becomes a consideration as the radial loads will still be imposed at right angles to the pump shaft. It is of particular concern for the older inline pump designs shown in Figure 3. These older designs don’t incorporate a bearing in the pump, but merely secure the impeller to an extension of the motor shaft. In some cases, this will create an increased distance from the bearing centerline to the impeller centerline, resulting in a higher value of the slenderness ratio. This makes the shaft more susceptible to deflection. This problem has been addressed by newer inline pump designs, where a bearing housing has been built into the pump in a manner similar to that of the horizontal process pump.

Weight of Impeller and Shaft

It also has been suggested that the weight of the impeller and shaft might be a factor, but it is evident from Figure 1 that the bulk of the resultant out-of-balance radial force created in a horizontal pump is acting upwards and will be opposing the weight of the impeller and shaft. So, a lighter impeller, such as what might be found in a non-metallic pump, may even be detrimental to the resulting condition. To a lesser degree, this will also be the case in a vertical shaft pump, where the physical weight of the impeller and shaft is negated.

An Excellent Tool

The slenderness ratio is an excellent tool to consider when excessively repetitive seal failures are evident—but where it has been clearly established that these failures are not an actual seal problem. This is a relatively safe consideration if a variety of seal styles and types are exhibiting a similar failure pattern on the same pump.

The classic failure pattern is when all the different seals that have been installed in the pump fail within the same approximate time period. There is also the wear pattern on the seal that can be repeated, but this one depends on the actual design of the seal, where the barrel of the seal is within the closest proximity of the bore of the stuffing box. Under these conditions, the shaft deflection brings that part of the seal into touch with the stuffing box bore, which creates a rubbing mark all round the diameter of the seal.

So Let’s Get Practical, again. The Shaft Slenderness Ratio should not be considered in isolation to the operating condition of the pump. It only becomes a factor when the pump is not running at its BEP. On the other hand, how many pumping applications can boast that luxury?

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