

Session Two:  
**Increasing Reliability and Life of Vertical, Multistage  
Pumps Using Focused Repair Process**

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## **Abstract**

Life expectancy of a vertical pump between overhauls greatly depends upon the proper understanding of various assembly requirements and their influence on the reliability during refurbishment. Proper attention and implementation to these details can improve the pump life three to four times between repairs.

## **1. Introduction**

Typical vertical pump types include turbine, mixed and axial flow. The Hydraulic Institute classifies these pumps as VS (vertically suspended). These pumps typically have the pumping element (impeller, diffuser, column pipe and pump shaft) submerged in the pumping media. Design can be of single stage to multiple stages depending upon the application.

The vertical pump is versatile, both in construction style and hydraulic capabilities ranging from 1500 through 10000 specific speeds (US units). It is used effectively in many industries such as Nuclear power, Fossil power, oil and gas, mining, Municipal general industrial and agricultural markets.

Pump life and reliability depends upon the material selection, its operation in the system, repair process installation. While material selection and system design is finalized during the project stage, repair and installation is as an ongoing process during the pump life.

Reliability and pump life of a multistage vertical pump depends on the straightness of Rotor and Stator components. To keep the cost down, this aspect is often overlooked by the Original Equipment manufacturer (OEM). A typical life for a vertical pump is about 3 to 5 years. Often the pump rebuild is focused on bringing back the limits and tolerances to OEM standard. Thus, expected pump life remains the same as supplied by OEM between overhauls.

This paper deals with the focused repair process and upgrading of the design. One that can improve the life of a pump up to three to four times, increase reliability and provide an attractive return on investment.

## **2. Vertical Pump Construction**

a vertical pump typically comprises of Rotor and stator.

Rotor consists of impellers, shafts and line shaft couplings.

Stator (or static parts) consists of bellmouth, Bowls, vertical columns, discharge head, bush bearings and main thrust bearings. Fig 1 shows the typical construction of single stage and multistage pumps.

### 3. Design and Repair Philosophy

One of the main reasons for pump life reduction is the increased Vibration. This influences the bearing clearance affecting the reduction in damping. This goes in a vicious cycle as shown in Fig 2.

Following factors influences the Vibration, hence the pump life.

- 3.1. Non Straightness of Rotor Bundle
- 3.2. Non straightness of stator bundle
- 3.3. Rotor Imbalance
- 3.4. Rotor to Stator misalignment.
- 3.5. Vertical installation inaccuracies

these factors should be eliminated or reduced to the extent possible.

### 4. Repair / upgrade Concept

Following Process is the overriding factors to improve the pump reliability and life.

- 4.1. Establish true centerline compatibility between the rotor and stator at the motor to discharge head flange location.
- 4.2. Ensure that the maximum relative radial displacement of stator to the rotor at any point for the entire length of the pump, does not exceed the maximum clearance of the closest running
- 4.3. The challenge is that there exists many individual components ( Fig 1 ), where the theoretical worst case stack up of manufacturing tolerances can be very large. Standard practice by OEM is to follow the close running (H7/g6) fit to the components for ease of assembly. This may lead to worst misalignment depending upon the number of stages and loose components.  
Similarly, the allowable face parallel run out tolerance (usually 0.03 to 0.05 mm) may result into the worst case stack up.  
Stack up tolerance on these components can create the eccentricity “e” as shown in Fig 3 for stator and rotor resulting into excessive centerline misalignment between stator and rotor.  
This causes excessive bearing load resulting into premature increase in bearing clearance followed by high vibration and cycle sets on as shown in fig 2.
- 4.4. In order to prolong the pump life, the essential build criteria is that total sum of eccentricity + perpendicularity + fit up + straightness tolerances should be less than the  $\frac{1}{2}$  of the bearing clearance as shown in Fig 4.

### 5. Focused Repair

It should be realized that it is difficult to reduce the component tolerance in general manufacturing Environment by OEM due to practical limitation on achievable tolerances during mass production of components. However, it is possible to minimize the eccentricity by focusing on tighter tolerance criteria on individual component at each joint during repair process.

Following points may be considered during repair process.

- Concentricity of Integral and mating Bores
- Clearance between spigot diameters.
- Non Parallelism of integral and mating flanges

- Shaft run out (TIR)
- Pitch diameter compatibility of threaded components i.e. threads coupling and columns.

Usually, the limits on these components can be reduced to half or even better than allowed by OEM depending upon the number of fitting components. Limits had to be tighter for multi joint design (usually multistage pumps or many columns) compared to single stage.

## **5.1. Rotor Straightness**

Following points may be focused on Rotor during repair process

### **5.1.1. Shaft Straightness**

Tighter limits on shaft run out is necessary in order to achieve the rebuild concept as mentioned in Para 4.4. Again allowable run out to half of that allowed by OEM is achievable through proper manufacturing process.

Most of the time, a bent shaft is the result of improper machining process and non compliance to stress relieving during shaft manufacturing. It is common observance that a straight shaft put in the service comes out bent during strip and assessment due to the result of surfaces stress being relieved during operation. Shaft gets bent very early in operation as stress relieving cycle is faster due to dynamic condition of shaft in operation. This results in setting up of vicious cycle at an early stage as shown in fig 2.

A proper manufacturing process may be followed for shaft in case of new shaft machining. This depends upon the material used. Vertical Stress relieving is must before final machining to produce a stable shaft.

Austenitic and Duplex shaft may need a low temperature stress relieve whereas Martensitic and Alloy steel may be subjected to Vertical stress relieve as per the material standard.

### **5.1.2. Parallelism and Concentricity of adjoining shafts faces.**

This is important for the shaft having the threaded coupling design. Face the ends of the shaft true to its centerline. Relieve the centre of the shafts ends by at least 0.4 mm deep to reduce the face contact. It is best to manufacture the new shaft coupling in one continuous operation. Ensure pitch diameter compatible with shaft.

### **5.1.3. Shaft Couplings**

Proper selection of shaft coupling design is an important decision for rotor staginess and ease of maintenance over the long term. A cheapest coupling need not be the cheapest solution for long term maintenance.

Following types couplings are commonly used in the pump with their relative advantages and disadvantage.

#### **5.1.3.1. Threaded Coupling**

Threaded coupling is the most common coupling used in the industry being the cheapest cost option. But, it is often difficult to maintain the shaft straightness after few overhauls due to wear out on the threads making the joint eccentric upon tightening. Ref Fig5.

#### 5.1.3.2. **Sleeve Coupling**

It is better to upgrade the threaded coupling to Sleeve coupling as shown in Fig 6. This is the medium cost option. Design ensures the concentricity of the two shafts and is unaffected by number of overhauls. Maximum size depends upon the ease of handling (weight) and machining capability to maintain acceptable bore concentricity and straightness. As a guideline, sleeve coupling may be used up to 130 mm dia with length to dia ratio of 3. Beyond this the muff split coupling is the preferred option.

#### 5.1.3.3. **Muff Coupling (Split)**

Maintaining bore concentricity of a long sleeve coupling becomes difficult during machining at times. It gets difficult to disassemble risking seizure. Also, removal of sleeve coupling becomes an issue under the corrosive or silt application (i.e Sea water). Fig 6C shows a typical example of Coupling seizure .

It is best to upgrade the coupling to Split Muff coupling design (Fig 7) if above situation is faced. Split Muff Coupling is easiest to assemble and disassemble. There is no risk of damage to shaft or the coupling though initial cost is high.

Most of the cases, Muff coupling can be designed replacing the sleeve coupling within the same coupling outside diameter. Otherwise a minor increase in outside diameter might be necessary without affecting the pump performance.

#### 5.1.4. **Keys**

Most of the manufacturers use the rectangular key in the shaft being the cheapest option. The design is acceptable below 3000 rpm as rotor balance is not so critical. It is recommended to use the Full rounded keys (Fig 8) for the machine operating at 3000 rpm or above. This helps in rotor balancing to higher degree.

### 5.2. **Stator Straightness**

Stator straightness requires close attention to achieving spigot fits, flange perpendicularity and concentricity of all bores to the centre axis within the acceptable criteria. Generally, values could be half or made better of that specified by the OEM to help in achieving the straightness criteria specified in para 4.4.

Some of the important components requiring focused attention are as follows

#### 5.2.1. **Discharge Head**

Main area of attention on discharge head is motor flange, stuffing box support flange and top column flange attachment flange .Typical areas of attention is shown in fig 9.

#### 5.2.2. **Columns**

Typical areas of attention for column are concentricity of spigots diameter and spider bore. Perpendicularity of flange faces is an important requirement. It is best practice to make the bearing spider integral to the column to mitigate the eccentricity accumulation.

### 5.3. Rotor Balancing

International standard (ISO 1940) used for allowable rotor unbalance is based on the average acceptable pump life in the industry. However it is recommended to balance the rotor to tighter tolerance as specified in API 610 or EPRI. It is possible to achieve these tolerances with focused repair and helps in improving the pump life. A comparison of various balance standards is shown in fig 10.

### 5.4. Pump Assembly

Most of the vertical pumps are assembled horizontally in the shop floor. Centre of each bowl ( or stator component) keep shifting down relative to previous component by the amount of radial clearance between spigot fits as assembly progresses. This can result into the stator centre line being displaced relative to the rotor centre line by the cumulative radial clearance at each spigot fits. Ref Fig 11-A

The best practice is to Jack Up the alternate static component during assembly. This helps to reduce the effect of accumulated eccentricity to only half of the Spigot radial clearance. Thereby greatly improving the rotor to stator axis alignment. Fig 11B shows the effect of staggered assembly.

## 6. Pump Installation

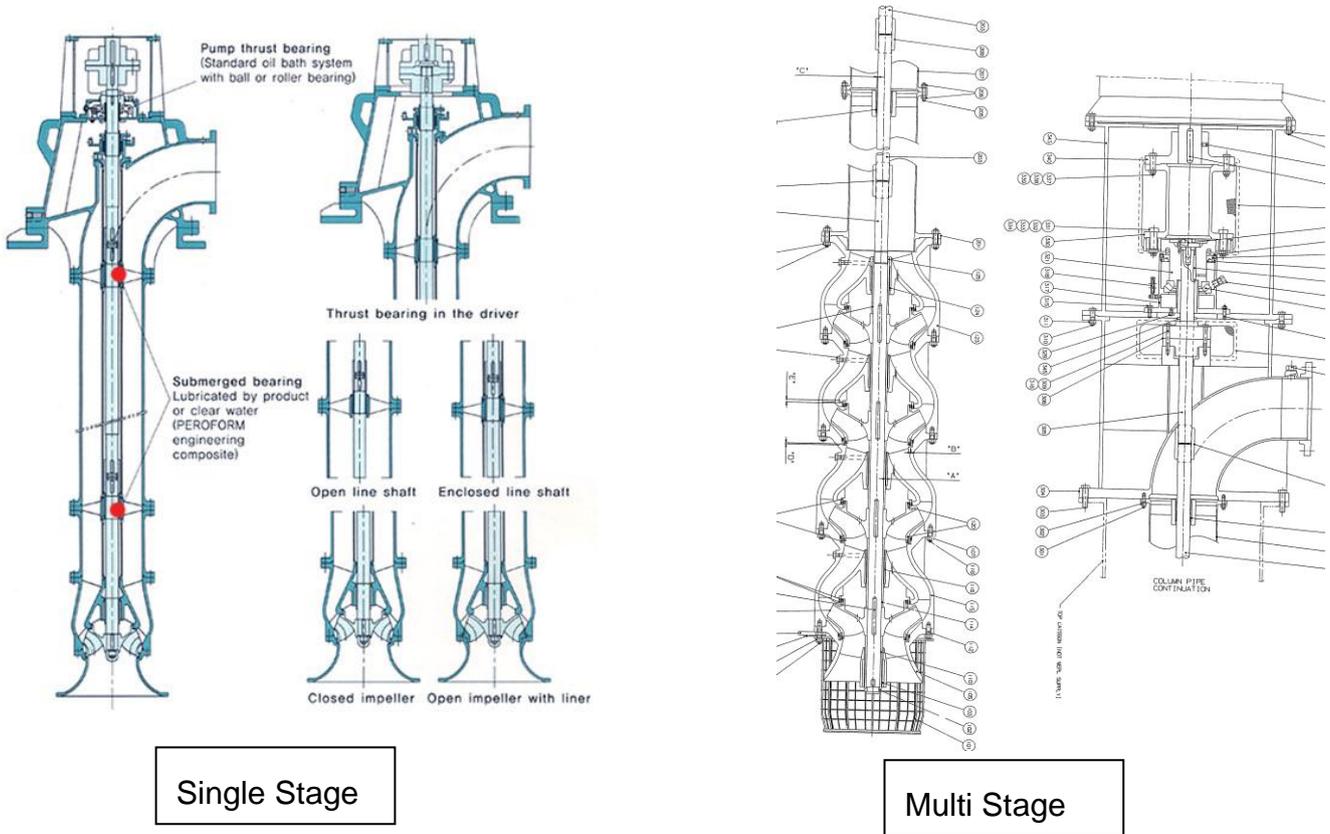
It is important to install the pump perfectly vertical. Any vertical misalignment in the installation at support plate results into an excessive increase in eccentric loading of pump bottom bearing resulting into onset of eccentric wear and premature bearing failure. The effect gets propagated in the upper bearings as the wear in the bottom bearings increases.

A horizontal level tolerance of 0.025 /300 mm may be used as guidelines for installation.

Effect of poor installation is shown in fig 12.

## 7. Conclusion

- 7.1. Mean time between repairs (MTBR) on the vertical pumps can be increased three to four times by applying tighter repair criteria (as described in para 4.4) and focused attention to the details during refurbishment.
- 7.2. It is possible to repair the pumps with half (or better) the allowable tolerance by OEM.
- 7.3. Upgrading the threaded coupling into Sleeve coupling is better long term option for improving pump life and help with maintenance. Similarly sleeve coupling can be upgraded to Split muff design if a difficulty is experienced during disassembly and assembly risking seizure.
- 7.4. First time upgrade cost for tighter tolerance and focused repair may be marginally higher than OEM standard repair. But, it is easily offset by increased MTBR of about 3 times.



Single Stage

Multi Stage

Fig 1 - Vertical Pump Constructional Arrangement



Fig 2 - Life reduction Process Cycle

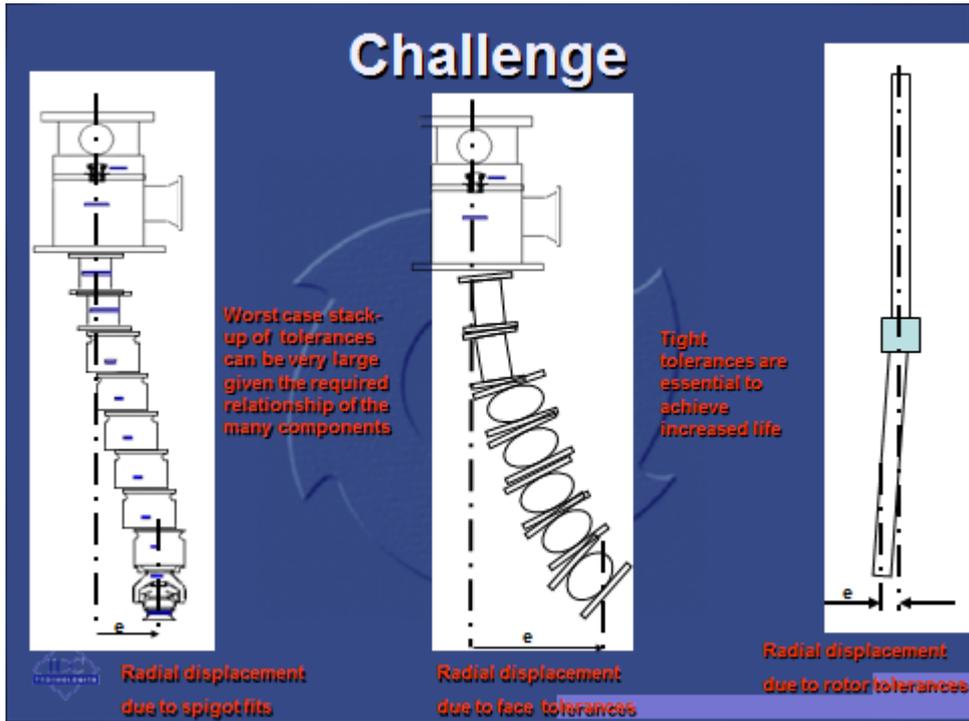


Fig 3(a)

Fig 3(b)

Fig 3(c)

Figure 3 - Stator and Rotor Misalignment due to stack up of various manufacturing tolerances

Fig 3(a) –the resultant eccentricity between rotor and stator caused by loose fits between the bowls and columns .

Fig 3(b) – The resultant eccentricity caused by a lack of parallelism between mating faces .

Fig 3(c) – The resultant rotor eccentricities caused by loose fit by threaded coupling

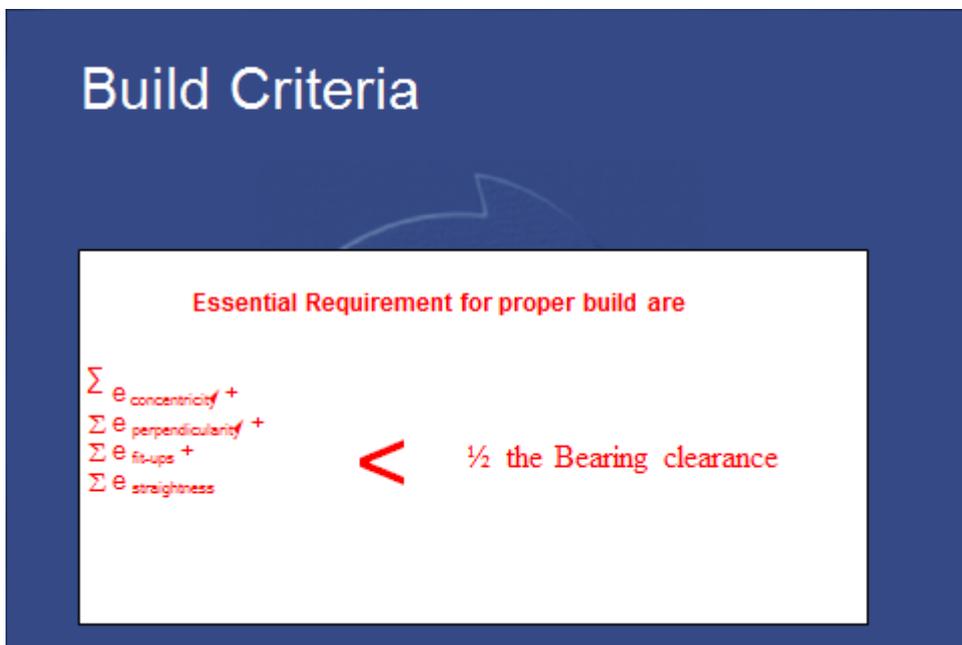


Figure 4 - Vertical Pump Build Criteria for Extended Life.

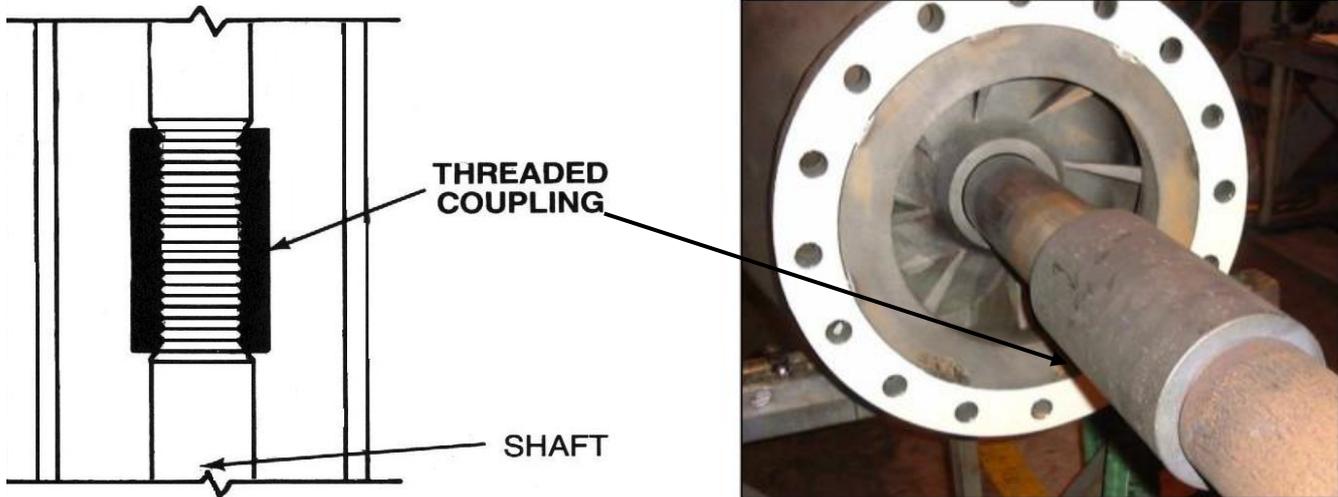


Fig 5 –Threaded Coupling - Hard to Align. Difficult to Disassemble.  
Replace with non Threaded Coupling

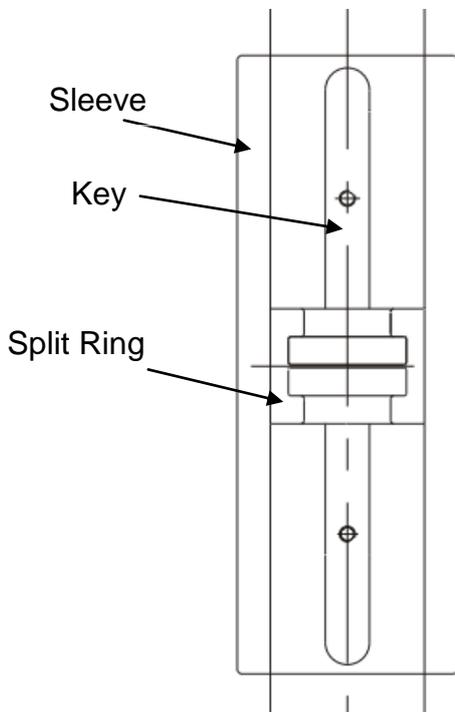


Fig 6(a)

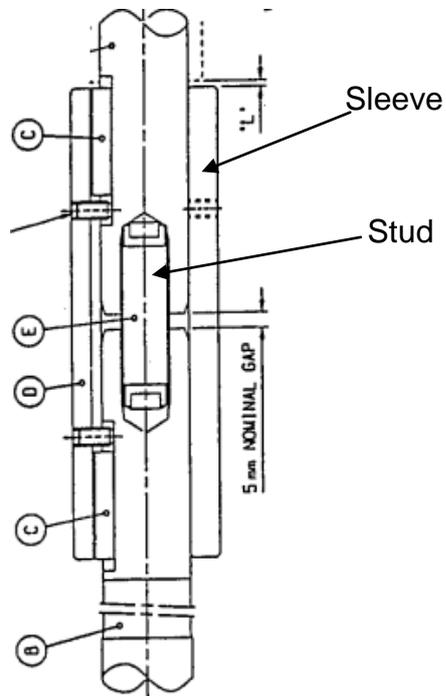


Fig (b)

Figure 6- Sleeve Coupling (Commonly used up to shaft diameter 130 mm and  $L/d = 3$ )

Fig 6(a) - Split ring design. Better Rigidity. Used for short length pumps with less number of joints. Shaft length cannot be adjusted.

Fig 6(b) - Stud design used for long pumps with multiple shafts. Gap between two shafts can be adjusted to maintain shaft stick.



Fig 6C-1



Fig 6C-2

Fig 6-C – Examples of Threaded type and Sleeve Type coupling Seizure .

Fig 6C-1 - Coupling being Cut to save the shaft damage .

Fig 6C-2 - Coupling Slit

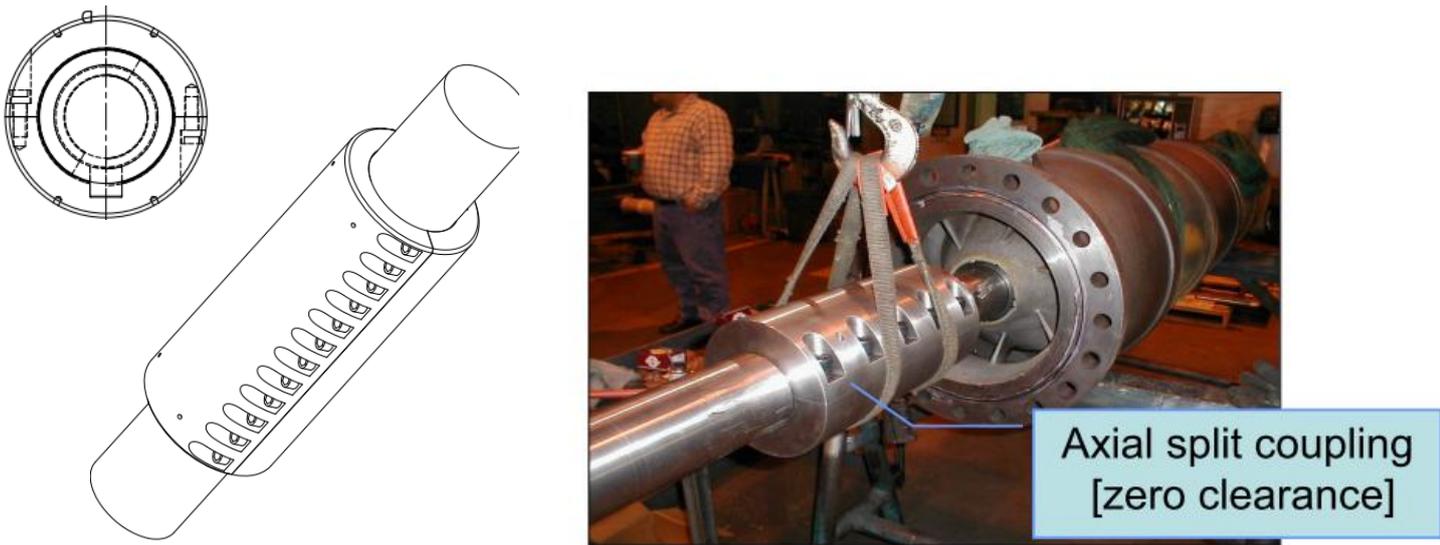


Fig 7 – Axial Split Muff Coupling (improved shaft alignment due to zero clearance. Ease to assemble and disassemble .No risk of damage to shaft or coupling. Commonly used above 120 mm shaft diameter.

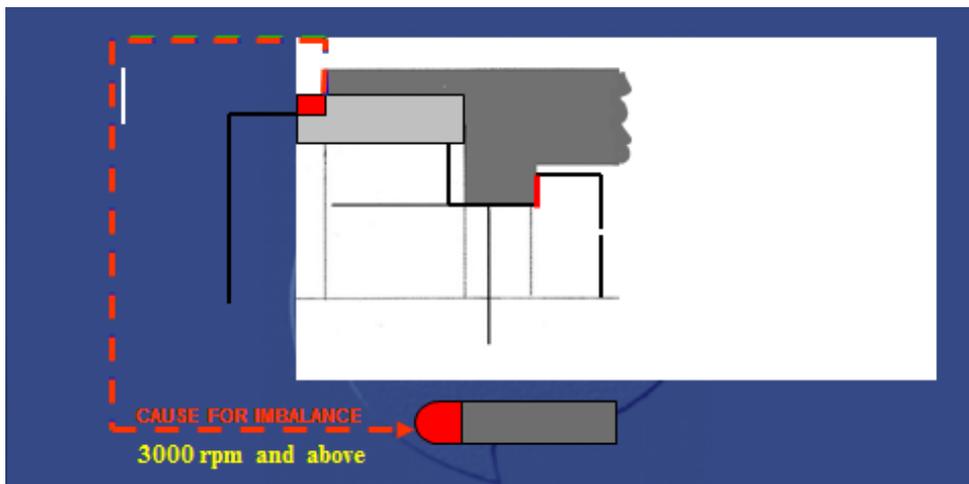


Figure 8 - Use Full rounded keys to fill up the key ways for machines 3000 rpm and above to mitigate cause for reduce unbalance

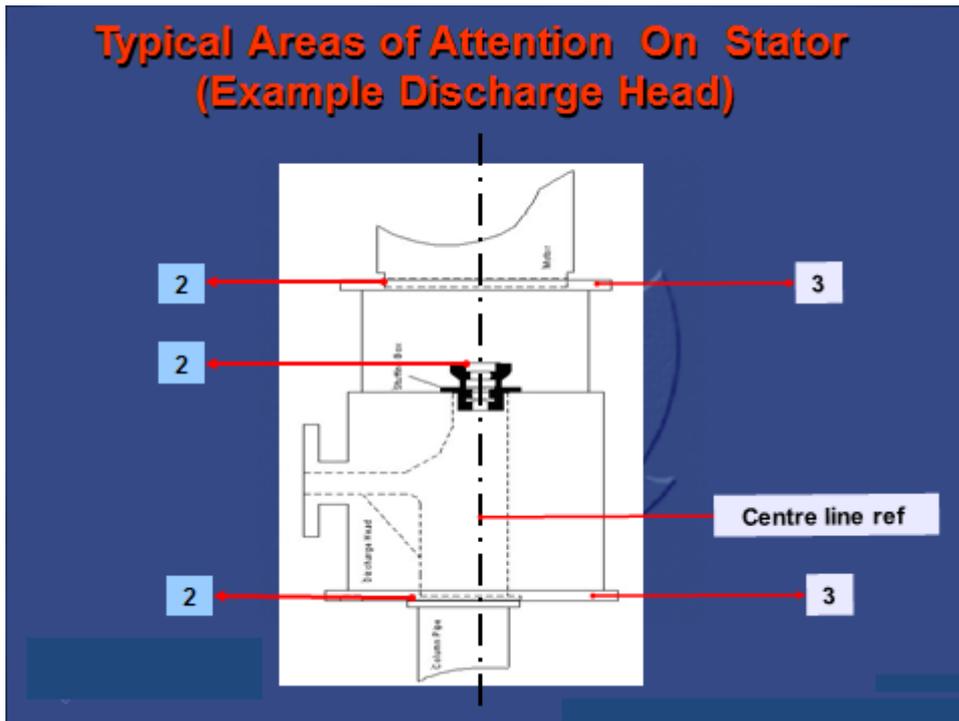


Fig 9 – Typical Area of Attention in Stator.  
Example Discharge Head.

Balance Standard	Unbalance (oz-in)	Unbalance (gm-cm)
ISO Grade 2.5	15 W/N	2300 M/N
ISO Grade 1.0	6 W/N	920 M/N
API 610	4 W/N	610 M/N
EPRI Standard	4W/N	610 M/N

Example: 1500 lb ( 680 kg) Rotor @ 3600 RPM		
Balance Standard	Unbalance (oz-in)	Unbalance (gm-cm)
ISO Grade 2.5	6.30	434.4
ISO Grade 1.0	2.52	173.8
API 610	1.67	115.2
EPRI Standard	1.67	115.2

Fig 10 -Rotor Balance Standard Comparison

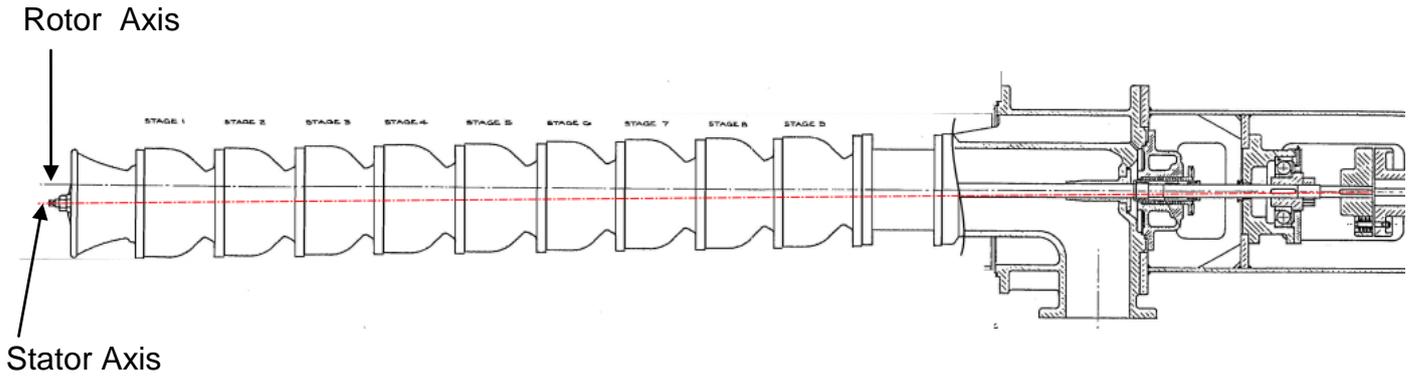


Fig- 11A Pump assembly Conventional Method  
Stator eccentricity due to cumulative effect of spigot clearance .

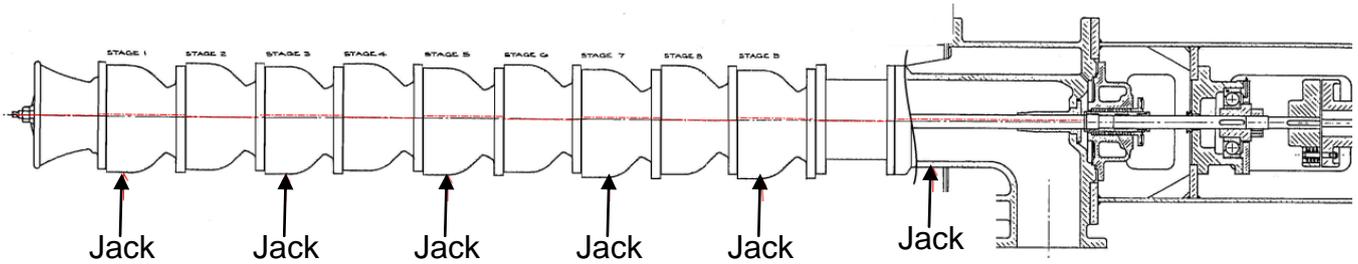


Fig-11A Pump assembly Improved Method.  
Jack the alternate static component during assembly. Maximum eccentricity can be controlled within spigot clearance. Greatly improves the alignment between rotor and stator Axis.

Fig -11- Pump Assembly Procedure  
Conventional v/s Proposed Method to improve Rotor to Stator alignment.

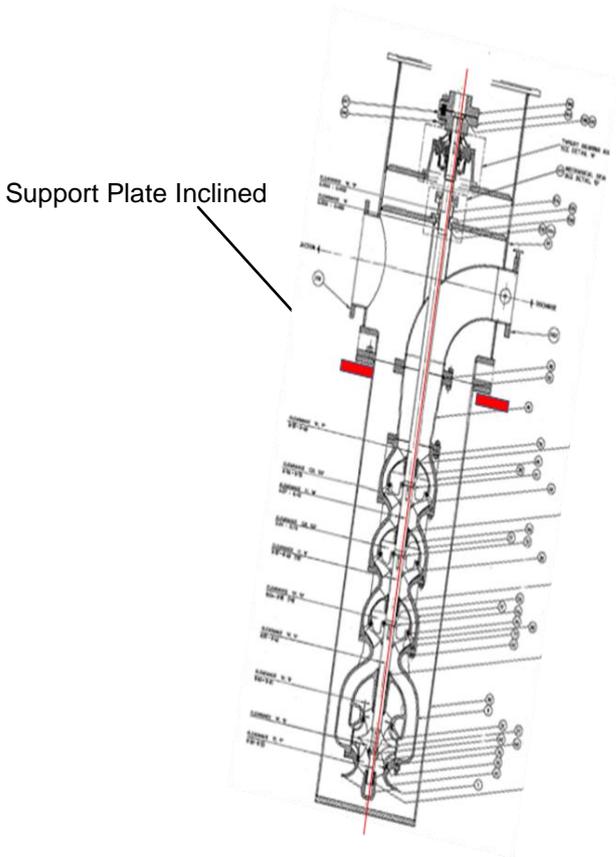


Fig 12(a) Inclined installation)

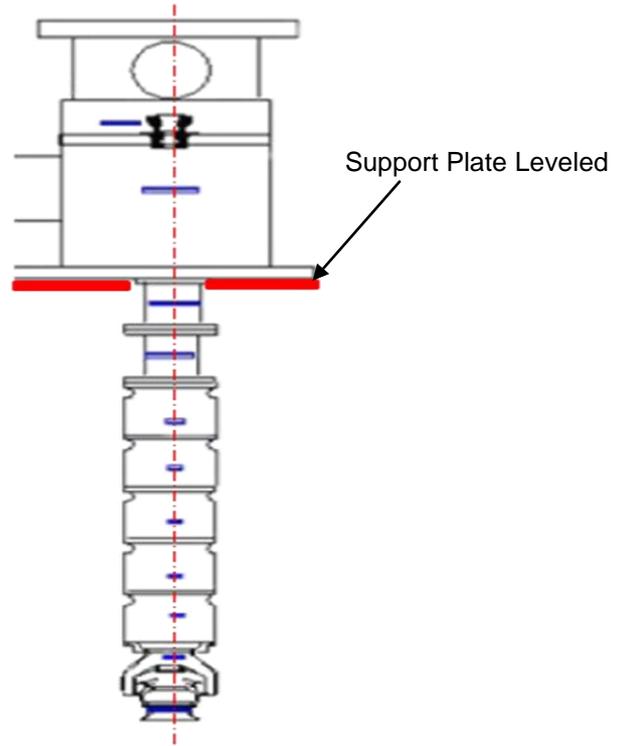


Fig 12(b) Proper installation

Fig 12 –Site Installation

Fig 12(a) –Pump with Inclined support base. Pump installed at an angle. Un-acceptable inclination results into premature bearing failure starting from bottom most bearing rub.

Fig 12 (b) proper installations where stator is perfectly vertical. 0.025 /300 mm may be considered as guideline during pump installation. Use Shims if required