Comparative Research of Methods for Performance Improvement of High Pressure Boiler Feed Pumps in Power Plants

Gopikrishna Balakrishnan, Rohan Mathew Philip, Aravind Sudev, Ruben Bijy Thomas
Department of Mechanical Engineering,
Mar Athanasius College of Engineering
Ernakulam, Kerala

***Abstract*— High Pressure Boiler Feed Pump (BFP) is an important component of any thermal power plant. Its function is to pump de-aerated water from the de-aerator to the boiler. These pumps are normally high pressure units that uses suction from condensate return system .It can be of centrifugal pump type or positive displacement type; for the purpose of this study we conducted this research on centrifugal pump. But the problem here is that "The HPBFP discharge pressure of the pump is around 160 kg/cm^2 whereas HP-drum pressure is around 80kg/cm^2. So there is huge loss of pressure in HP drum, hence huge loss of energy". This means that there is huge amount of throttling which is currently taking place to bring the pressure to 80 kg/cm^2 which ultimately leads to huge wastage of power and high maintenance to the throttling valve in the long run. So after extensive research four solutions were found and on further analysis and feasibility the best solution was found which could solve the problem.**

Keywords*— HPBFP; De-staging parts; Energy Losses; Retrofitting; Hydraulic Coupling; Speed Control; Throttling; Variable frequency drive

I. INTRODUCTION

For the system which is considered, it is observed that HPBFP discharge pressure is around 160 kg/cm^2, whereas HP drum pressure is less than 80 kg/cm^2. There is a huge throttling in pressure from high pressure (HP) pump to HP drum during normal base load operation and hence huge loss in energy. Further this also leads to erosion in feed regulatory system control valve (FRSCV) and HP desuperheater valve with the passage of time.

At present HPBFP design TDH is 1510 MLC corresponding to the flow of 265 M^3/hr. The HPBFP design TDH has been selected at maximum capability point (i.e.) Peak load, 28 ^{0}C ambient, 32 ^{0}C CWT, 3% make up. If we redesign HPBFP TDH/ Discharge pressure for naphtha firing base load operation the new TDH shall be 1360.99 MLC corresponding to the flow of 255 m^3/hr.

Considering the above facts the aim is to reduce the pressure/ flow in HPBFP to the extent possible without affecting the process requirements by suitably reducing the speed of pump. This will result in a reduction in power consumption of approx.400 kW (2 X 200 kW) which amounts power saving of approx. 3.5 MU per annum and reduction in valve internal erosion.

II. MATHEMATICAL MODEL OF PROBLEM DEFINITION

From Affinity Laws: All centrifugal pumps follow the Affinity laws which are given below

Q α N	Q α D
H α N^2	H α D^2
P α N^3	P α D^3

Where,

N is the speed of the pump, in rpm

D is the diameter of the impeller

- Pressure reduction from 1507.7 to 1360.99 mlc
- Speed reduction = (1507.7 /1360.99) = (4285)^2 / n_2^2
- n_2 = 4071.18
- Say 4072 rpm

Fig. 1. Depicts the variation in parameters for different speeds. Hence the required reduction in pressure can be obtained by speed reduction. So to solve this problem the best method is to be adopted such that the required reduction in pressure is obtained without sacrificing the performance of the system.

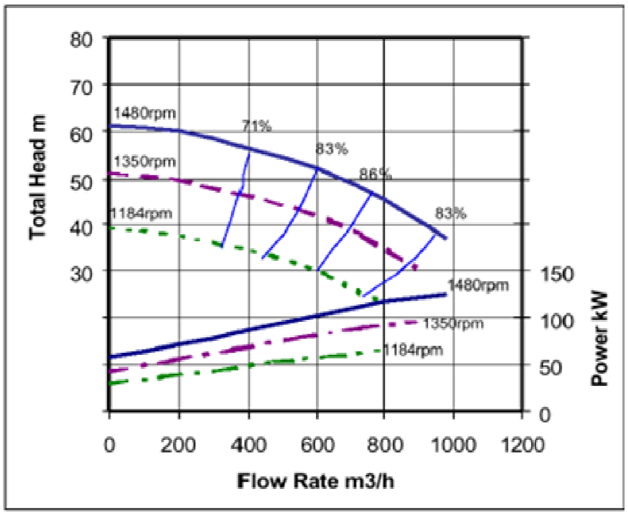

Fig. 1. Speed variation affecting centrifugal pump performance

III. PROPOSED SOLUTIONS

A. Changing Gear Box Internals

Here we reduce the speed by varying the gear ratio, which is the ratio of number of teeth of driven gear to the driving gear. We can reduce the speed by increasing the gear ratio and can increase the speed by reducing the gear ratio.

B. De-Staging of HPBFP

Destaging is a method of reducing the differential pressure of multistage pump by deactivating one, or more, of its stages. Stage deactivation is done by taking out an impeller and replacing it with destaging parts.

C. Retrofitting of Hydraulic Coupling

A fluid coupling is a hydrokinetic transmission that performs like a centrifugal pump and a hydraulic turbine. The input drive (e.g. electric motor or Diesel engine) is connected to the pump/impeller Mechanical energy is conveyed via the pump/impeller to the oil in the coupling.

The oil moves by centrifugal force across the blades of the turbine towards the outside of the coupling. The turbine absorbs the kinetic energy and develops a torque which is always equal to input torque, thus causing rotation of the output shaft. The wear is practically zero since there are no mechanical connections. The efficiency is influenced only by the speed difference (slip) between pump and turbine, i.e. fluid level.

slip %=((input speed - out speed) / input speed) x 100

D. Retrofitting of VFD (Variable Frequency Drive)

A variable-frequency drive (VFD) (also termed adjustable-frequency drive, variable-speed drive, AC drive, micro drive or inverter drive) is a type of adjustable-speed drive used in electro-mechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage.

IV. CALCULATIONS

A. High Pressure Boiler Feed Pump

To find the losses in the HPBFP we have to find out the actual, theoretical and overall efficiency of the pump and for that we collected the experimental values and made the required calculations.

Design Point

Capacity	=	265 m^3/hr
Head	=	1409 mlc
Temperature	=	150^0c
Specific gravity	=	0.9169
Efficiency	=	80%
Power	=	1166 kW
Speed	=	4285 rpm
NPSHR	=	16 mlc

Design Calculation

Discharge , Q	=	265 m^3/hr = 0.0736 m^3/s
Head in m of water , H	=	1409 m of water
Output power in kW = $\frac{\rho g Q H}{1000}$	=	932.78 kW
Input power	=	1166 kW
Efficiency of BFP	=	$\frac{932.78}{1166} = 79.99\%$

BOOSTER PUMP

Design Point

Suction Temperature	=	150^0c
Specific gravity	=	916.9 kg/cm^2
Dynamic Head	=	106 m of water
Flow rate	=	265 m^3/hr
Input Power	=	100 kW
Speed of Pump	=	1485 rpm

Design Calculation

Discharge , Q	=	265 m^3/hr =0.0736 m^3/s
Head in m of water ,H	=	106 m of water
Output power in kW = $\frac{\rho g Q H}{1000}$	=	$\frac{0.9169*1000*9.81*106*0.0736}{1000}$
Input power	=	70.17 kW
	=	100 kW
Efficiency of Booster pump	=	$\frac{70.17}{100} = 70.17\%$

Combined Efficiency of BFP & Booster Pump

Input =1266 kW,

Output =1002.95 kW

Combined Efficiency = $\frac{Output}{Input} = \frac{1002.95}{1266} = 79.22\%$

Overall Efficiency

$\eta_{overall} = \eta_{pump} \times \eta_{motor}$

Motor Input = 1318.75 kW

Motor Output =1266 kW

$\eta_{overall} = \eta_{pump} \times \eta_{motor}$ = 79.22% x 96%

=> $\eta_{overall}$ = 76.05%

Actual Calculation (from table)

Boiler Feed Pump

Discharge , Q = 193.93 T/hr

Head in m of water = $\frac{pressure\ in\ kg/cm^2}{specific\ gravity} x10\ m\ of\ water$

Pressure = 139.5 KSC

Specific gravity = 0.9252

Head, H = $\frac{139.5}{0.9252} x10 = 1507.78\ m\ of\ water$

Output power in kW $= \frac{\rho g Q H}{1000}$ = $\frac{0.9169*1000*9.81*1507.78*0.0736}{1000}$ =732.21 kW

Input power of main pump = 1370.67 kW

Efficiency of BFP $= \frac{output}{input}$ = 53.78%

Booster Pump

Discharge = 0.05387 m^3/s

Head, H= 105.92 m of water

Head = $\frac{pressure}{specific\ gravity}$x10 m of water

Pressure =9.8 KSC

Specific gravity = 0.9252

Output = $\frac{\rho g Q H}{1000} = 51.78\ KW$

Input = 100 kW

Efficiency = $\frac{output}{input} = \frac{51.78}{100} = 51.78\%$

3.2.4 Combined Efficiency of BFP& Booster Pump

Output =$Output_{BFP}$ + $Ouput_{BP}$ =737.21+51.78 = 788.99 kW

Input = $Input_{BFP}$ + $Input_{BP}$ =1370.67+100 = 1470.67 kW

Efficiency =$\frac{output}{input} = \frac{788.99}{1470.67} = 53.65\%$

$\eta_{overall} = \eta_{pump} \times \eta_{motor}$ = 53.65% x 96%

=> $\eta_{overall}$ = 51.50%

Corrected Value

Using affinity laws we have to correct these values.

Correction factor = $\frac{Actual\ speed\ of\ pump}{Design\ speed\ of\ pump} = \frac{4268.6}{4285} = 0.9946$

Capacity: $\frac{\mathbf{Capacity1}}{\mathbf{Capacity2}} = \frac{\mathbf{speed1}}{\mathbf{sped2}}$

Capacity2=$\frac{0.05387}{0.99617}$=**194.68**

Head: $\frac{\mathbf{Head1}}{\mathbf{Head2}} = \left(\frac{\mathbf{speed1}}{\mathbf{spped2}}\right)^2$

Head2=1519.39 m of water

Input: $\frac{\mathbf{Input1}}{\mathbf{Input2}} = \left(\frac{\mathbf{speed1}}{\mathbf{spped2}}\right)^3$

Input power=1386.54 kW

Efficiency=$\frac{\mathbf{output}}{\mathbf{Input}}$ =$\frac{745.74}{1386.54}$ =**53.78%**

Booster Pump

Capacity

Capacity 1/ capacity 2 =speed 1/ speed 2

Capacity 2 =194.68 T/hr

Head 1/ head 2 = (speed 1/ speed 2) ^{2}

Head 2 =106.736 m of water

Input 1 / Input 2 = (speed 1/ speed 2) ^{3}

Input power =101.1578

Efficiency = output / input = (52.379 /101.1578) * 100

= 51.78%

Combined efficiency = 53.6%

Efficiency from Graph

Discharge =194.68

From graph capacity, Q =195 T/hr

Efficiency = 66% (from efficiency vs. capacity graph)

Efficiency = 53.6 % (corrected to 4285 rpm)

Loss = Efficiency from graph – Efficiency (actual)

Loss = 66-53.78 = 12.22 %

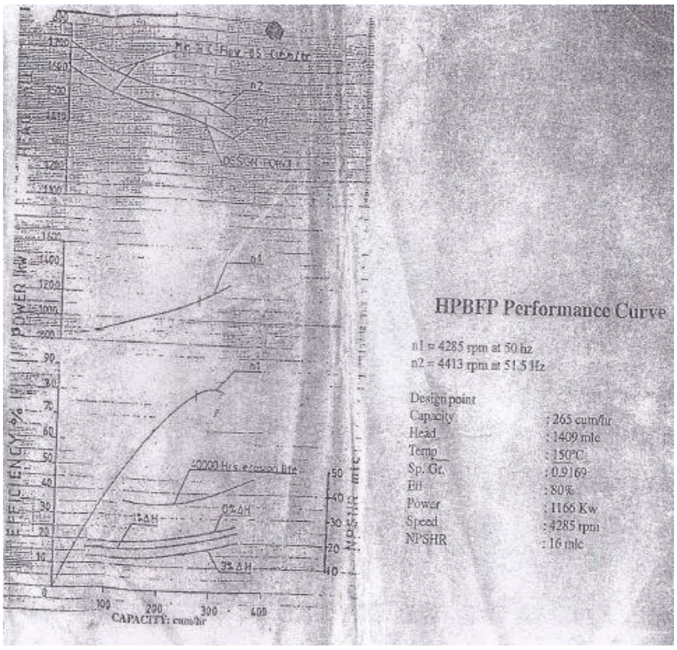

Fig. 2 HPBFP Performance Curve

V. COMPARISON & SELECTION FROM THE PROPOSED SOLUTIONS

By tabulating and outlining comparison of the above methods as shown in Table 1 and listing the merits and demerits of the applications of each proposed solutions in rectifying the speed control or controlling the pressure head of water discharge in the High pressure Boiler Feed Pumps to HP-Boiler drum a holistic comparison was obtained.

Table 1. Comparison of Proposed solutions

Installation of VFD		*Pump De-staging*	
Merits	Demerits	Merits	**Demerits**
VFDs provides most Energy Efficient means of capacity control, it can hit the peak loads & also work on part loads accordingly	Initial investments are quite high	Discharge ,pressure head & power consumption is reduced	**Pressure head & Discharge cannot be varied**
VFDs have the lowest starting current of any starter type	Space Allocation is more because installation of a control panel is needed	Total investment is very less compared to variable speed drives	**Initial Best Efficiency Point/Peak load conditions cannot be retrieved**
VFDs installation is as simple as connecting power supply to the VFD	Savings in Power consumption is negligible compared to cost of installation	Thermal & Mechanical Stresses in FRS CV , RC valve, motor winding, Economizer are reduced	**Efficiency of cycle is reduced considerably**
VFDs with Active Front Tech. can meet even the most stringent harmonic standards	Need More Payback period/cost per unit charge compared to others	Life of Feed-water supply components are enhanced(Reduced maintenance cost)	
VFDs provide High power factor(pf),eliminating the need for external pf correction capacitors		Energy Saving & payback period are favourable to the plant	
Cycle components life is enhanced ,Maintenance cost is reduced			
VFD needs comparatively less maintenance			

Dynamic Hydraulic coupling		*Gear box retrofitting*	
Merits	Demerits	Merits	**Demerits**
At less loads motor power consumption is less than those with fixed rpm	Cannot transmit 100% power from motor to BFP Slip occurs	Discharge ,Pressure Head & Power consumption is reduced	**Pressure head & Discharge cannot be varied**
Wear free , (maintenance is less)	In step less fluid couplings stall speed is limited. hence working range is narrow	Total investment is very less compared to variable speed drives	**Initial Best Efficiency Point/Peak load conditions cannot be retrieved**
Smooth start-up & operation(fluid dampens vibrations 0& rapid actions)	Motor Power is dissipated as a result of turbulence (in form of heat)	Thermal & Mechanical Stresses in FRS CV , RC valve, motor winding, Economizer are reduced	**Efficiency of cycle may be reduced**
Unlike electronic variable speed drive systems, no additional investments are needed over the entire lifetime.	Prolonged application of heavy loads upsets efficiency and may damage coupling & motors from overheating	Life of Feed-water supply components are enhanced(Reduced maintenance cost)	
Operating cost is less	Expensive Step-circuit couplings may be used with initial investments like furnace brazing etc.	Energy Saving & payback period are favourable to the plant	
Saves space & money	Additional cooling systems are required for heavy uses		

VI. SELECTION BASED FROM THE COMPARISON STUDIES

- From Table 1. the 'Variable Speed Drives' such as 'Dynamic fluid couplings' and 'VFDs' are much superior, efficient and flexible to meet the energy demands of the power plant.
- For a fixed optimum working conditions we have seen that 'Constant Discharge Drives' such as 'Retrofitting of gear box integrals' and 'Pump-destaging' methods are suited.
- The economic advantage and space utilization of Constant Discharge Drives are may be greater than Variable Speed Drives, but the productive & flexible nature of the Variable speed drives outnumber the constant discharge drives

By a thorough inspection from the comparison based on the criteria's,

- Flexibility to meet varying energy demands efficiently.
- The production and maintenance are economical.

The Dynamic Fluid couplings are most preferred because of their simplicity & flexibility in working and low maintenance.

Table 2. Rating of Various Proposals

Methods Employed	Retrieves peak load after retrofit	Efficient in power generation	Economical	Saves Space	Less Maintenance
Retrofit on Gear box internals	✗	✓	✓✓	✓	✓
Replacing pump-drive with a VFD	✓	✓✓	✗✗	✗	✓
Retrofit with Dynamic fluid couplings	✓	✓✓	✓✓	✗✗	✓✓
De-staging of pump	✗✗	✗✗	✓✓	✓	✓

So the priorities should be in the order,

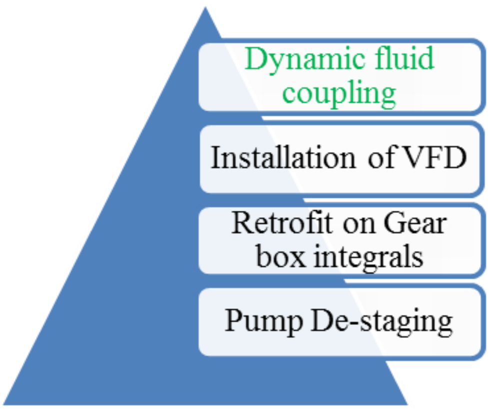

Fig 3. Priority of proposed solutions

VII. CONCLUSION

The study solved the basic problem which was to reduce the pressure from 160 kg/cm^2 to 80 kg/cm^2. After the initial part of the study a mathematical model was made to make this engineering problem more tangible. Hence from this mathematical model by incorporating affinity laws it was found that by reducing the speed this reduction of pressure could be achieved. Hence after extensive literature survey in this direction the four proposals were shortlisted which could solve this engineering problem.

Then after considering the technical as well as practical aspects of all these options a holistic rating process was carried out and the most feasible solution was found which was retrofitting of Hydraulic Coupling to the already existing system. Retrofitting refers to the addition of newer technology or features to older systems. In power plants retrofitting is used for improving power plant efficiency / increasing output / reducing emissions. Fig 3. Shows how the system would look like after incorporating hydraulic coupling in the system.

With significant improvement in technology and emergence of fields like mechatronics etc. the scope and application of the process of retrofitting has increased. The advantages of adopting this process were analysed in detail and have been cited in this report.

Hence the performance of the system was improved by retrofitting hydraulic coupling without any significant changes to the existing system.

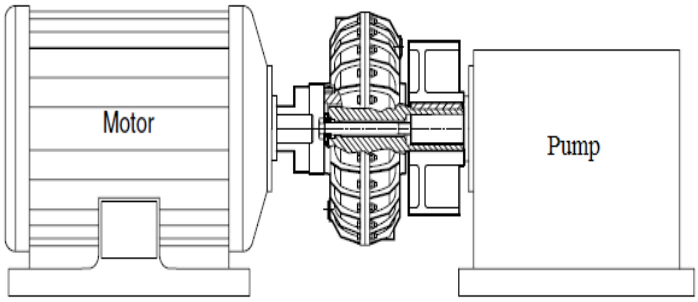

Fig 4 Schematic Representation after retrofitting of hydraulic coupling.

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