An Assessment on Design Parameters and Vibration Characteristics of Boiler Feed Pump for Auxiliary Power Consumption

Nikhil Abraham
UG Student
Department Of Mechanical Engineering
Saintgits College of Engineering, Kottukulam Hills, Pathamuttom P. O, Kottayam-686532, Kerala, India

Sachin Chacko
UG Student
Department Of Mechanical Engineering
Saintgits College of Engineering, Kottukulam Hills, Pathamuttom P. O, Kottayam-686532, Kerala, India

Sethu Sathyan
UG Student
Department Of Mechanical Engineering
Saintgits College of Engineering, Kottukulam Hills, Pathamuttom P. O, Kottayam-686532, Kerala, India

Sreenath K G
UG Student
Department Of Mechanical Engineering
Saintgits College of Engineering, Kottukulam Hills, Pathamuttom P. O, Kottayam-686532, Kerala, India

Parvathy Venugopal
Assistant Professor
Department Of Mechanical Engineering
Saintgits College of Engineering, Kottukulam Hills, Pathamuttom P. O, Kottayam-686532, Kerala, India

Abstract

High pressure boiler feed pump is a six stage horizontal centrifugal pump of barrel design casing. At RGCCPP, Boiler feed pump (BFP) takes water from the feed water system i.e. from the deaerator and provide this water to the boiler system, to generate steam which is responsible for rolling the Turbine to generate electricity. Normally Feed water pumped to the boiler is pumped to the Boiler's Drum where at the top point of the boiler, so we have to provide a pump that can handle huge pressure with high discharge to the boiler. BFP is usually rotate with 5000 rpm, 150 bar and can provide about 265 T/H. The HPBFP discharge pressure was around 160 kg/cm2, whereas HP Drum pressure (i.e. working pressure) is around 80 kg/cm2. So there was a large difference in pressure in HP Drum and HPBFP discharge, which should be the same. Various methods suggested for controlling HPBFP discharge pressure are,a) Throttling, b) Fluid coupling, c) Impeller trimming, d) Variable frequency drive, e) Replacement of HPBFP gear box with modified gear box, f) Magnadrive Among these Replacement of HPBFP gear box with modified gear box is the accepted solution by the industry. Modifying the gear ratio reduces output speed of BFP. As speed reduces, discharge pressure also reduces. Our aim was to reduce discharge pressure of BFP, thereby finding the most efficient method of reduced power consumption, which increases the efficiency of the plant. As the gearbox is getting replaced, it is essential to study vibration behavior of the pump. Hence experimental and numerical analysis of vibration characteristics is analyzed.

Keywords: High Pressure boiler Feed Pump; Deaertor; Boiler Drum

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I. INTRODUCTION

Eighty Percentage 80% of thermal power plants has boiler feed pump, that takes the water from the feed water system i.e. from the deaerator and provide this water to the boiler system, to generate steam which is responsible for rolling the Turbine to generate electricity. Normally Feed water pumped to the boiler is pumped to the Boiler's Drum where at the top point of the boiler, so we have to provide big pump that can handle big pressure with great flow to the boiler.

Boiler Feed Pump is one of the most sophisticated equipment in a thermal power station. This equipment is responsible for uninterrupted supply of feed water to the boiler under all operating conditions and therefore its reliability is of paramount importance. Furthermore, this being the highest speed rotating element in the whole combined Cycle, its efficient and reliable operation plays a major part in the reliability of the set which in turn depends upon the sizing criterion adopted along with design and manufacturing aspects.. It has got significant role in the operation of boilers. Boiler feed pump is used to feed water to steam generator boiler drum at desired pressure and temperature. As the water is fed to the steam generator it has to be at the temperature & pressure that of the steam generator. Boiler feed pump extract water from de-aerator and feed it to the boiler drum via economizer.

A. Layout of Boiler Feed Pump:

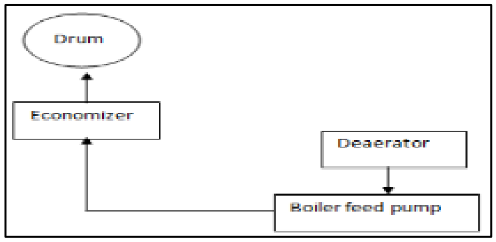


Fig. 1: Layout of boiler feed pump

The HPBFP is designed to give a discharge pressure of 160 kg/sq.cm. ie; when turbine runs at peak load. But it is not necessary for the turbine to run at peak load and it results in various damages. So the HPBFP is over designed. The discharge pressure of BFP can be reduced to required pressure I.E, 80 kg/sq.cm,When the steam turbine runs at base load. The project is concentrated on design parameters of a boiler feed pump, which is the most important feed pump in steam turbine plant of NTPC. The project includes vibration characteristics of the system also. The final effort is to reduce the power consumption and increase overall efficiency of the system.

Table -1:
Showing specification of BFP in NTPC, kayamkulam

Pump type	*FK6D30 (Horizontal centrifugal multi stage pump)*
No. of stages	*6*
Direction of rotation	*Anticlockwise*
Suction temperature in (°C)	*150*
Specific weight (kg/cum)	*916.9*
Design flow in (m^3/hr)	*265*
Dynamic head (m)	*1409*
Efficiency %	*80*
Speed rpm	*4285*
Input power kW	*1166*
Medium	*Water at 150 deg c*
Rating kW (Drive motor)	*1500*
Speed (motor)	*1493 rpm*
Electrical supply	*6.6kV, 3 phase, 50Hz*

B. Nomenclature:

A	Cross sectional area (m2)
a	Acceleration (m/s2)
c	Centre distance (mm)
D	Equivalent diameter of pipe (m)
f	Coefficient of friction (dimensionless)
F	Frequency (Hz)
l	Equivalent length of pipe (m)
T	Temperature (°C)
t	Time (s)
v	Velocity (m/s)
ρ	Density (kg/m3)
hf	Head loss due to friction (kg/cm2)
P	Pressure (N/m2)
N	Speed (rpm)
W	Angular speed (rad/s)
p	Power (kW)
G	Gear ratio (Dimensionless)
φ	Helix angle (Degree)

C. Subscripts:

b	Booster pump
bfp	Boiler feed pump
e	Exit
f	Coefficient of friction
g	Gear box
s	Suction
m	Motor
1	Refers to pinion gear
2	Refers to main gear

II. METHODOLOGY

Reduction in discharge pressure can be attained implementing any of the following 6 methods,

- Variable frequency drive
- Magna drive
- Impeller trimming
- Throttling
- Fluid coupling
- Replacement of HPBFP gear box with modified gear box

Among the six methods, Replacement of HPBFP gear box with modified gear box is the accepted solution by the industry. Modifying the gear ratio reduces output speed of BFP. As speed reduces, discharge pressure also reduces. Our aim was to reduce discharge pressure of BFP, thereby finding the most efficient method of reduced power consumption, which increases the efficiency of the plant.

III. MAIN WORK

A. Calculation for Finding Optimum Value of Discharge Pressure:

- Equivalent length of pipe (HPBFP to deaerator), l = 40m
- Equivalent diameter of pipe, D = 0.130m

1) *Velocity of Flow through Pipe:*

- Mass flow rate, m $= \rho A v$
- velocity, v $= \frac{m}{\rho A}$
- Discharge ρ = 187 T/hr
- Velocity of flow, v $= \frac{187*10^3*4}{1000*\pi*0.130^2*3600}$
  = 3.91m/s
- Coefficient of friction, f = 0.14
- Head loss due to friction, $h_f = \frac{4flv^2}{2gd}$
  $= \frac{4*.14*40*3.91^2}{2*9.81*0.130}$
  = 134.26 m
  = 13.426 kg/cm^2

2) *Head Loss in Economizer:*

- Mass per tube, m $= \frac{187*10^3}{3600*920}$
  = 0.056 kg/s
- velocity, v = 0.07 m/s
- $h_f = \frac{4flv^2}{2gd}$
  $= \frac{4*0.14*18*0.072}{2*9.81*0.032}$
  = 0.078 m/tube
- For 920 tubes hf = 0.072*920
  h_f = 7.237 kg/cm^2

- Minor losses = 0.5 kg/cm^2
- Static head loss = 2.91 kg/cm^2
- Total head loss = 13.426+7.237+0.5+2.91
  = 24.073 kg/cm^2
- Pressure inside the Boiler drum = 82 kg/cm^2

1) Flow margin - 10% when operating at maximum capability corresponding to peaking capacity of the module.
2) Pump head - be computed at frequency 47.5 Hz when the last SV of the drum is blowing at the max capability point

- Margin on friction pressure loss shall be = 20%
- Required pressure to be developed by HPBFP = 82+24.037+margin
  =127.244 kg/cm^2

B. New Speed Calculation for Required Pressure Using Affinity Law:

$$\frac{P_s}{P_e} = \frac{N_m^2}{N_g^2}$$

- Where, P_s = pressure at suction
- P_e= pressure at exit
- N_m=speed of the motor
- N_g=speed of the gear

$$\frac{20}{127} = \frac{1493^2}{N_g^2}$$

N_g = 3762.24 rpm

1) *Power Calculation*

$$\frac{p_b}{p_{bfp}} = \frac{N_m^3}{N_g^3}$$

Where, $P_{b=}$ Power at booster pump
P_{bfp} = Power at HPBFP

$$\frac{70}{P_{bfp}} = \frac{1493^3}{3762^3}$$

- P_{bfp} =1119.8 kW
- Power at HPBFP before replacing the gear = 1305 kW
- Difference in power = 1305- 1119.8
- Power saved = 185.2 kW

Therefore, Auxiliary power consumption of the boiler feed pump is reduced by 10%

C. Gear Design Calculation;

Terminology of helical gears is

1) Helix angle: it is the angle at which the teeth are inclined to the axis of a gear.
2) Circular pitch: it is the distance between corresponding points on adjacent teeth measured on the pitch circle
3) Normal circular pitch: it is the shortest distance measured along the normal to helix between corresponding points on the adjacent teeth.

- New speed N_g = 3962 rpm
- Therefore the gear ratio is, G = $\frac{N_g}{N_m} = \frac{3962}{1493}$ = 2.71
- Helix angle,φ_1 is 35° and φ_2 is 30°
- Centre distance ,d = 300 mm
- Normal pitch , P_n =14 mm
- Let T_1 = Number of teeth on pinion gear
- T_2 = Number of teeth on main gear
- Gear ratio= $\frac{T_2}{T_1}$ = 2.71
- Therefore $T_{2\,=}$ 2.71 T_1
- Since centre distance, c = $\frac{P_n}{2\pi}\left[\frac{T_1}{\cos 35°} + \frac{T_2}{\cos 30°}\right]$
- 300= $\frac{14}{2\pi}\left[\frac{T_1}{0.81} + \frac{2.71\,T_1}{0.86}\right]$
- T_1 =30

– T_2 =79

As the gearbox is getting replaced, it is essential to study vibration behavior of the pump. Due to faulty replacement there is unbalance in the system which causes excessive and unpleasant stresses in rotating system because of vibration. The vibration causes rapid wear of machine part such as bearings and gears.

When the natural frequency of the system coincides with the external forcing frequency, it is called resonance. The speed at which resonance occurs is called critical speed or whipping speed. So it is important to find frequency of system to avoid the occurrence of critical speed, which may result in excessive noise and its breakage into pieces. Present case system has frequency around 50Hz, so after the replacement of HPBFP gears box the frequency of system should within the limit.

D. Theoretical Calculation for Finding Frequency of Hpbfp:

The following data is obtained using lab view software

- Velocity, v = 0.005m/s
- Displacement, d = $1.5 * 10^{-5}$ m
- Therefore time, t $= \frac{d}{v} = 0.003$s
- Acceleration, a $= \frac{v}{t} = 1.66$
- Since, acceleration, a $= w^2 d$
- i.e. angular speed, w = 332.66 rad/s
- Thus, frequency, F = 51Hz

E. Analysis of Frequency of System Using Ansys 12.1:

Components of layout are booster pump, motor, gear box and boiler feed pump. Mass of each component is different so the frequency of vibration of entire system should be within the limit. So it is important to study the vibration characteristics of the layout after the replacement of gear box.

Table -2:
Arrangement of components

NUMBER	*COMPONENT*
1	*SUPPORT*
2	*BOOSTER PUMP*
3	*MOTOR*
4	*GEAR BOX*
5	*BOILER FEED PUMP*
6	*SUPPORT*

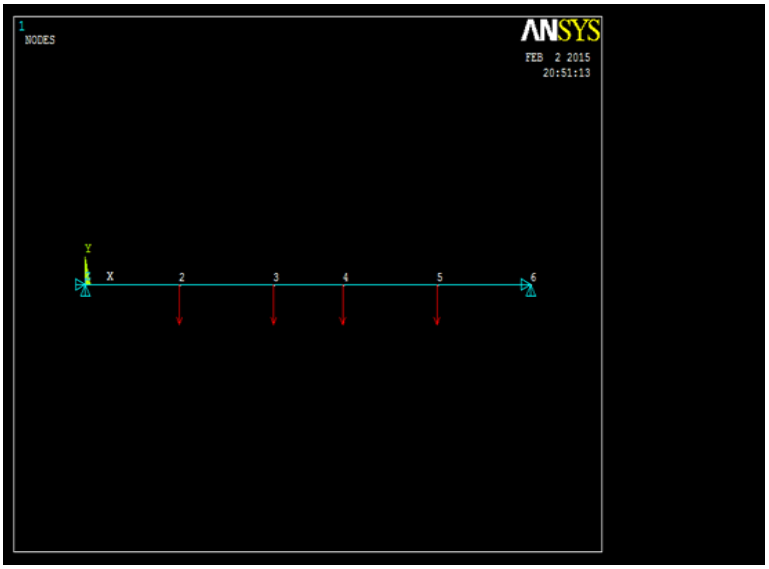


Fig. 1: Analytical setup for vibration study

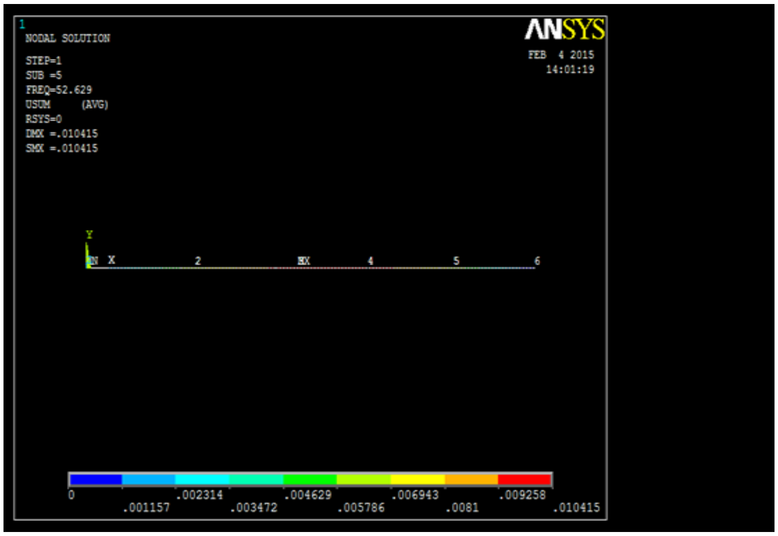


Fig. 2: Contour plot of the deformation obtained

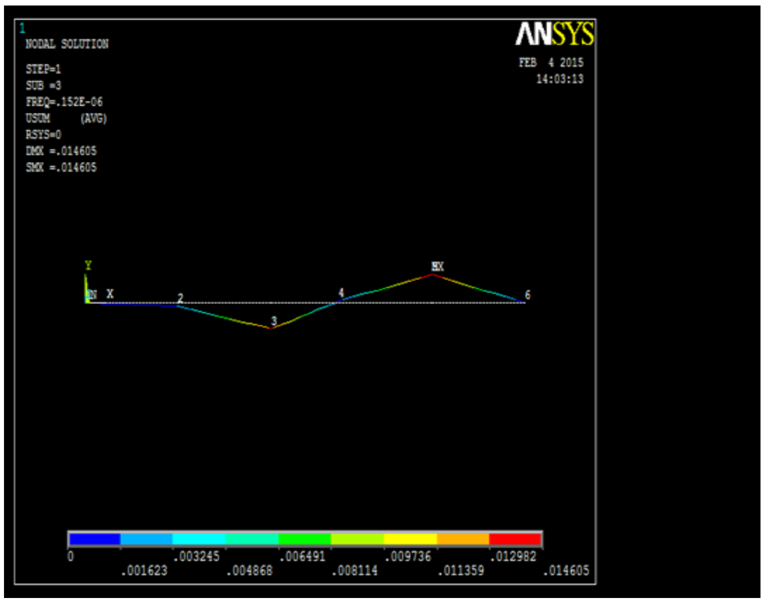
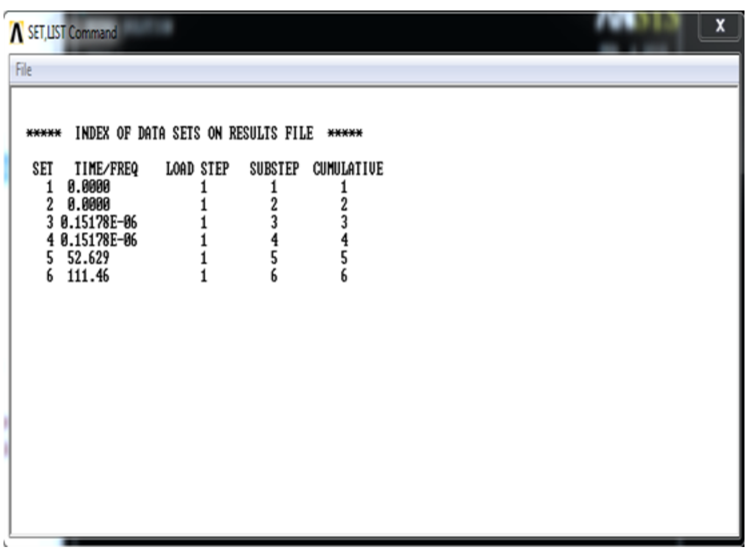


Fig. 3: Nodal solution



SET,LIST Command

File

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	0.0000	1	1	1
2	0.0000	1	2	2
3	0.15178E-06	1	3	3
4	0.15178E-06	1	4	4
5	52.629	1	5	5
6	111.46	1	6	6

Fig. 4: Result Summary

From the theoretical calculation, the value of frequency is found to be 51Hz. Before replacement of gear box the frequency of system is around 50Hz.After the replacement, the frequency of system (52Hz) is within the limit. The theoretically found values are also compared using ANSYS software .since the values are within the limit, whipping speed will never occur. Thus the system is free from the problem related to vibration.

IV. RESULTS AND DISCUSSIONS

A. Replacement of HPBFP Gear Box with Modified Gear Box:

1) *Present Case Of Speed Gear Box:*

- Let P_b be the discharge pressure of booster pump = 20 kg/cm^2
- P_{bfp} be the discharge pressure of Boiler feed pump = 160 kg/cm^2
- N_b be the speed of booster pump = 1493 rpm
- N_{bfp} be the speed of boiler feed pump = 4250 rpm

Gear ratio of the system is 2.88
Whereas HP drum pressure is around 80 kg/cm^2. So there is huge loss of pressure in HP drum, hence instead of 160 kg/cm^2 (present case), we need only 120 kg/cm^2 (Maximum).

2) *Modification:*

- Let P_b be the discharge pressure of booster pump= 20 kg/cm^2
- P_{bfp} be the discharge pressure of Boiler feed pump = 160 kg/cm^2
- N_b be the speed of booster pump = 1493 rpm
- N_{bfp} be the speed of boiler feed pump = x rpm

Gear ratio of the system is 2.71
To find x, According to the affinity laws,

$$\frac{P_b}{P_{bfp}} = \frac{N_b^2}{N_{bfp}^2}$$

- Therefore N_{bfp} =3762.24 rpm
- Power at HPBFP before replacing the gear = 1305 kW
- Difference in the value of power after the replacement of gear box = 185.2 Kw
- Modified Gear ratio of the system = 2.71

3) *Benefits of Replacing Gearbox:*

- Reduction in Power consumed by the pump is 225 kW / pump & ultimately APC by 0.25%.
- Annual saving is Rs 40 lakhs (considering 80% PLF & Rs. 1.3 as variable charge on gas)..
- It also resulted in reduction in HPBFP motor winding temp which normally goes up to alarm limit in peak summer.
- Reduced maintenance.
- No misalignment and vibration issues
- Less time and money spent aligning and maintaining equipment
- Longer equipment life

Table -3:
Specifications of BFP before and after replacing the gear box

PARAMETER	*BEFORE*	*AFTER*
Speed	*4250rpm*	*3762rpm*
Power	*1305Kw*	*1120kW*
Discharge	*187T/hr*	*187T/hr*
Frequency	*50Hz*	*51Hz*
Number teeth on pinion	*28*	*30*
Number teeth on main gear	*81*	*79*
Pressure	*160kg/sq.cm*	*128kg/sq.cm*
Gear ratio	*2.88*	*2.71*

V. CONCLUSIONS

The project is concentrated on design parameters of a boiler feed pump, which is the most important machinery in NTPC. The study includes vibration characteristics of the system also. The project has been made for the “Reduction in Auxiliary power consumption by the optimization of design parameters for Boiler Feed Pump**”.**

Our endeavor has been to ensure that the selection results in the most economical and optimum design for continuous operation throughout the life of the plant. Main aim was to reduce discharge pressure of BFP, thereby finding the most efficient method of reduced power consumption, which increases the efficiency of the plant. Detailed study about reducing discharge pressure of boiler feed pump and most efficient method of reduced power consumption shows that the Replacement of HPBFP gear box of gear ratio 2.88 with modified gear box of gear ratio 2.71 is the best solution for the present case. Selection is due to low cost of replacing gearbox and with minimum change in existing system. Present case system has frequency around 50Hz, after the replacement of HPBFP gear box the frequency of system is within the limit. Thus the replacement of gear box in the system is safe.

By replacing gearbox, auxiliary power consumption is reduced by 14 % and efficiency of the system is increased by 81.2%.Total cost of replacement is around 41 lakhs. Annual saving is Rs 40 lakhs. Reduction in Power consumed by the pump is 185 kW / pump. Reduced maintenance in RC valve, HRSG valves etc Due to dynamic nature of environment in which power plant operate, optimization of plant auxiliaries should be a continues process. This will help in better plant performance and also to increase the profit margin.

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