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**ABSTRACT**

In the present scenario, Energy demand is increasing day by day. To meet that demand, the production or extraction of crude oil, natural gas and other energy resources is done with the help of various pumps. Pumps are the second largest used machinery in world and plays a vital role. In this paper, we have done analysis on centrifugal pump categorised as overhung pump (OH2). It is commonly known that vibration problems on centrifugal pumps can result from multitude of possible parameters which are not easily identified. Due to deviation of pumps from best efficiency point (BEP), their service life is reduced and vibration can be a root cause of this problem. The unwanted vibration especially in overhung pump effect the performance of centrifugal pump and its mechanical characteristics. In the present paper, we had done an analysis by changing the design of pump feet. During mathematical and experimental analysis (using FFT analyser) it was observed that frequency of vibration is reduced to certain amount which result in enhancing service life.

**Keywords:** Overhung pump, vibration, BEP, FFT

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**INTRODUCTION**

Pumps are classified as Centrifugal Pumps and Positive displacement pumps. Centrifugal pumps are further classified, overhung types lies in this category [1]

**Classification of pumps**

*Dynamic pumps*

- End suction centrifugal
- Split case
- Vertical turbine
- Special effect pumps

*Displacement pump*

- Reciprocating
- Rotary [2]

**Classification of Centrifugal pumps**

- Overhung Type
- Between Bearing
- Vertically suspended

*Classification of overhung type pump*

- OH1 : Overhung Flexibly coupled horizontal foot mounted
- OH2 : Overhung Flexibly coupled horizontal centreline mounted
- OH3 : Overhung Flexibly coupled vertical inline bearing frame
- OH4 : overhung rigidly coupled vertical inline

- OH5 : Overhung Closed coupled vertical in line
- OH6: Overhung closed coupled high speed integral gear

**Classification of between bearings**

- BB1 : Between bearing 1&2 stage axially split
- BB2 : Between bearing 1&2 stage radially split
- BB3 : Between bearing multistage axially split
- BB4 : Between bearing multistage radially split single casing
- BB5 : Between bearing multistage radially split double casing

**Classification of vertically suspended**

- VS1 : Vertically suspended single casing discharge through column diffuser casing
- VS2 : Vertically suspended single casing discharge through column volute casing
- VS3 : Vertically suspended single casing discharge through column axial flow
- VS4 : Vertically suspended single casing separate discharge line shaft
- VS5 : Vertically suspended single casing separate discharge cantilever
- VS6 : Vertically suspended double casing diffuser
- VS7 : Vertically suspended double casing volute [3]

**Application of Overhung Pumps**

- Thermal power plants
- Nuclear power plants
- Oil and gas industry
- Petrochemical plants
- Marine industry
- Food industry
- Agriculture purpose
- Desalination industry
- Offshore engineering
- Refineries

**Source of vibration****1. Mechanical causes of vibration**

- Unbalance rotating components like damaged impellers and non-concentric shaft sleeves
- Pipe strain :Either by design or as a result of thermal growth
- The area & mass of pump base is too small
- Misalignment : Pump and driver
- Worn or loose parts like bolts and bearings
- Harmonic vibration from nearby equipment

**2. Process/ hydraulic causes of pump vibration**

- Low NPSHA : cause cavitation
- Turbulence in the system like eddy's formation
- Water hammer
- Piping system vibration
- Operating off of the pump best efficiency point (BEF)
- Insufficient lubrication results 36% of pump failure

**LITERATURE REVIEW**

Birajder et al., studied about the sources and diagnosis method to control vibration & noise in centrifugal pumps. They studied about the ill effects of vibration and concluded that during the operation of boiler feed pump exact diagnosis of vibration and noise sources is very difficult in centrifugal pump as this may be generated due to system or equipment itself. Hence they addressed only some of the issues. [4]

Elemer Mackay studied about the problem encountered in boiler feed pump operation and classified them into hydraulic and dynamic instabilities. He studied the interaction between hydraulically induced forces and bearing design parameters and their influence on rotor vibration characteristics. Friction induced in partial frequency modes were also discussed in his investigation.[5]

Lutfii SARI BULUT *et al.*, 2013 Fourier transform can be used to detect, classify and analyse PQ (Power Quality) disturbances with certain accuracy. An exhaustive review of Fourier transform in power quality issues is performed to provide clear understanding on their application. Most power quality analysers also use FFT based algorithm to identify the harmonics of the measured signals. This paper presents the fundamental of Fourier series, Fourier transform, discrete Fourier transform and fast Fourier. With simple examples and review of Fourier transform to provide a clear understanding of its application in power quality issues.[6]

Simmons opened that vibration from their sources origin may be small but excite the resonant frequencies of the rotating parts such as rotor shaft and set up considerable extra dynamic load on bearings. The cause and effect reinforce each other and the machine progresses towards ultimate breakdown. As per Gyarmathy there are generally two situations in which vibration measurements are taken. One is surveillance mode to check the health of machinery on routine basis. The second analysis is during an analysis process where the ultimate goal is to lag the problem. In the later case, vibration measurements are taken to understand the cause, so that an appropriate fix can be undertaken. [7]

Ravindra A.Tarle *et al.*, studied that all rotating machine produce vibrations that are a function of the machine dynamics such as the misalignment and balance of rotating parts. A study completed in this project by data collection shows that FFT of intrinsic mode functions in helbert huang transform is useful tool in finding out all possible root causes and predict root causes based on systematic study. At present the major failures in bearings like inner race crack, outer race crack, etc are analysed by using FFT analyser amplitude at BPFO is higher than BPFI and BSF. Amplitude at BPFI is less than BPFO and BSF.[8]

Babu *et al.*, did condition monitoring and vibration analysis of boiler feed pump. During their investigation they found that for the boiler feed pump the vibration reading shows that values are more than normal readings and found that mass unbalance in vanes. It was corrected based on phase analysis and vibration reading were observed after modification which gives the value within normal range. It eliminates unnecessary opening of equipment with considerable saving in personnel resources.[9]

K. Bialas \* in this work there are presented basic methods of reverse task of active and passive mechanical systems realization. The method of polar graph and their relationship with structural numbers were used in order to derive equations determining the values of amplitudes of force generated by active elements. Comparison of active and passive reduction of vibrations of mechanical system was shown, that active elements give better results than passive elements. On diagrams of amplitude is visible that using too reduction of vibration active elements give completely effects however passive elements give partially.[9]

YOUNG KUEN CHO *et al.*, the purpose of this study was to examine the efficiency of the DoE and response surfaces with stiffness and damping coefficient in 3 D model of motor pump and spring. In the present paper, experimental test for the moment of inertia were investigated by micro-indentation. The response surface could be generated by using 3D multibody analysis and DoE method. It shows that differences in contours of response surfaces were clearly found for particular area. This study suggested test techniques for vibration reduction of motor pumps in medical device. The combined method suggested in this study will greatly contribute to design of medical devices concerning vibration intervention.[10]

## **BASICS OF OH2 PUMP: DESIGN AND FEATURES**

In this overhung pump, the impeller(s) is mounted on the end of a shaft that is cantilevered or “overhung” from its bearing supports. These pumps are either close coupled, where the impeller is mounted directly on the driver shaft; or separately coupled, where the impeller is mounted on a separate pump shaft supported by its own bearings.

Type of OH2 pump: API 610

Description: Horizontal, Single Stage, Radial-Split, Heavy Duty Design, Axial Suction Nozzle, Radial Discharge Nozzle.

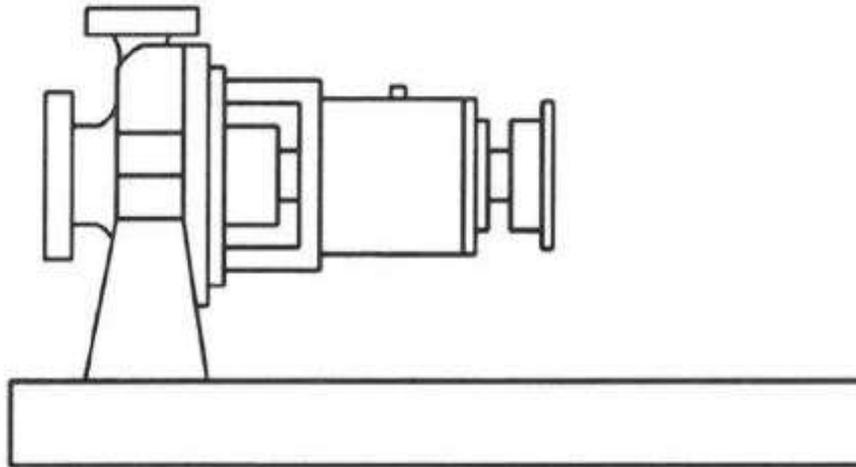
Material: Austenitic steel, 12%chromium steel.

Flanges: According to ASME 816.5 for class 300 or 600 lbs

Impeller: Stainless Steel, A 890 grade 4A (D42904)

Technical data

Temperature: Up to 450° C



*Fig 1. OH2 Type Pump*

### **Problem**

Overhung Pumps are widely used pumps in many industries .It is used in almost all food processing industries and refineries. For Overhung type Pumps, we were facing problem in performance of the pump and increase cost of servicing.

As the pump has to be transported again and again to the facility for servicing, the pump was working less than its actual claimed time and was performing to be less efficient then claimed

As the initial investment for a simple OH2 type pump is very less if taken with normal seal plan option. But customer hesitate to send it again for the service as it cost them a huge amount and also affect their production schedule

The pumps are manufactured with an assurance to work uninterrupted for many years and the companies purchasing them plan's their shutdown and maintenance accordingly so that they can optimize the shutdown cost and get maximum output from it by calculating all the factors involve like spare cost, transportation, service charge etc.

It was observed that the operational life of overhung type pump was reducing due to some factor and the pumps were not completing the service life claimed

As the company also faces loss if a pump returns to the facility within the warranty period.So, to detect and rectify the defect the analysis was carried out.

The overhung pump is a pump which is almost a cantilever type of body in which only the feet are in touch with the plates or base plate and rest of the portion hung up in the air so the tendency of vibration due to not having any rigid support increases

A deep study was carried out on an OH2 pump having a Flow, rated : 125.00 m<sup>3</sup>/h ,Differential head / pressure, rated: 19.00 kg/cm<sup>2</sup> to analyse the cause of poor service life

Many aspects were taken into consideration searching for the cause like balancing, flow, flanges, material etc.

The pump was tested to know the efficiency and it was noted that the vibration on the foot of the pump is on higher side of the prescribed limit.

It was noted that Vibration is also a major reason for the inefficiency of any machinery and the analysis was done on that to reduce the vibration.

As in overhung centreline mounted pump only the foot of the pump remain in contact with the base plate and the rest of the portion of the pump is hung in the air.

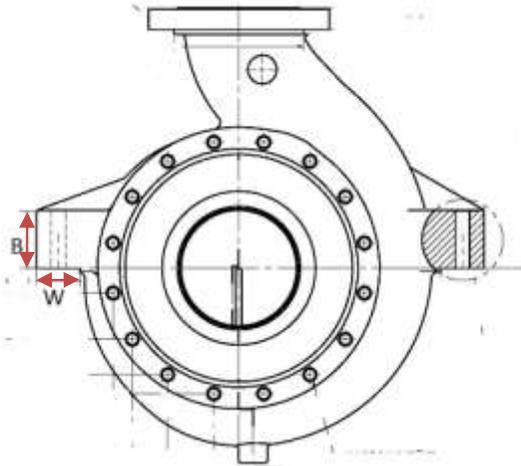
First of all it was evaluated that there should be no extra vibration on the other overhung parts of the pump and then an analysis was carried out on the design of the foot of the pump and how it help to transfer the vibration.

The analysis was done on the foot of the overhung pump having the dimensions;

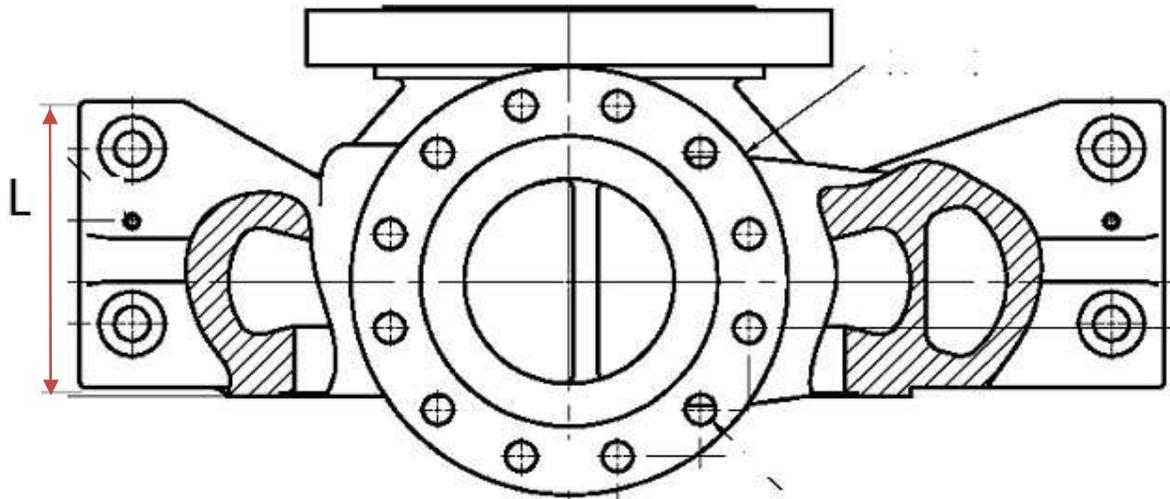
L = 212.34mm

W = 82.9 mm

B = 104.32mm



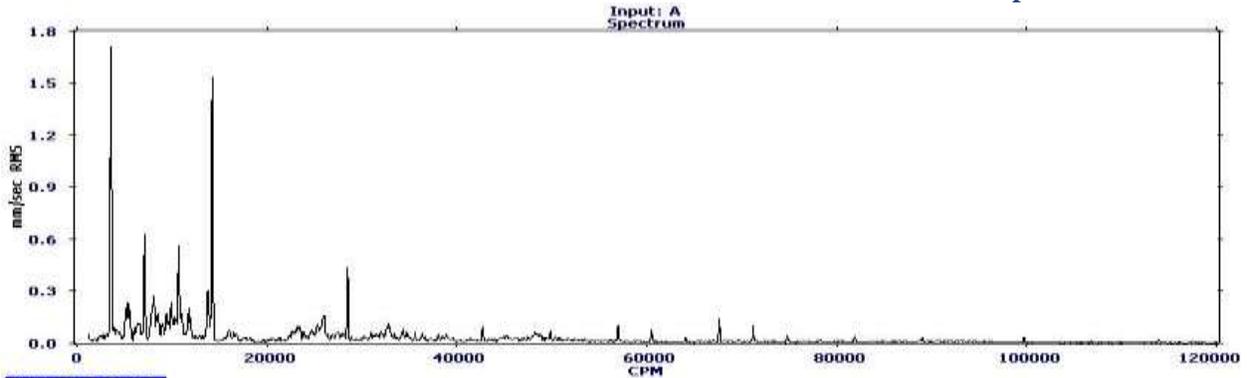
*Fig 2. Side view of OH2 pump*



*Fig 3. Top view of OH2 pump*

## RESULTS AND DISCUSSIONS

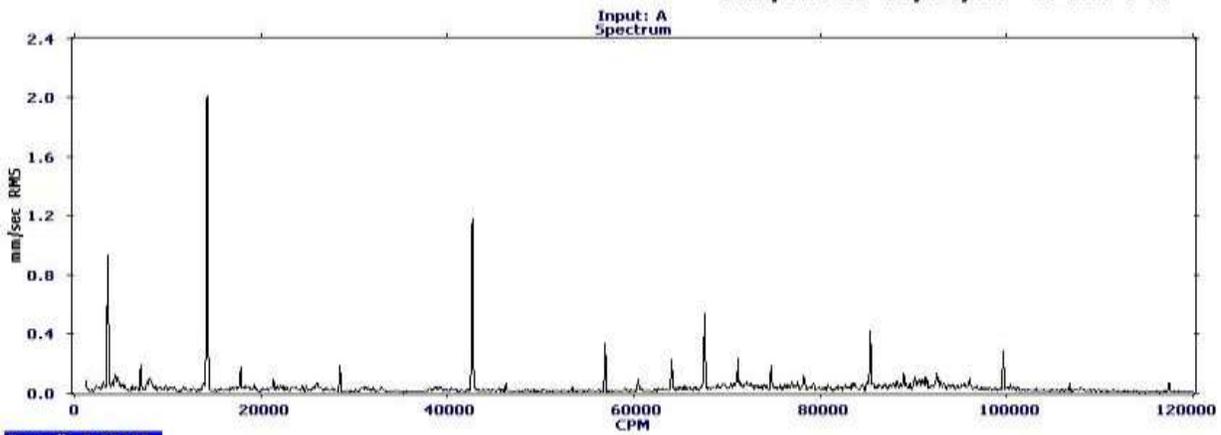
During the pump testing , vibration reading were taken using FFT Analyser and following were obtained in 1 hour testing



Overall: 3.02763

Frequency Data		Frequency Data		Frequency Data		Frequency Data	
395.2	0.21195	3556.1	1.90533	5230.0	0.2445	5494.7	0.23528
7113.6	0.62989	7910.8	0.21299	8062.3	0.32022	8362.4	0.17812
8444.5	0.19069	9417.3	0.19208	9880.2	0.24329	10307.8	0.17014
10668.6	0.58369	10895.7	0.20852	11755.2	0.20808	11897.5	0.15942
13764.5	0.3507	14223.1	1.66495	25986.0	0.18559	28446.3	0.45532

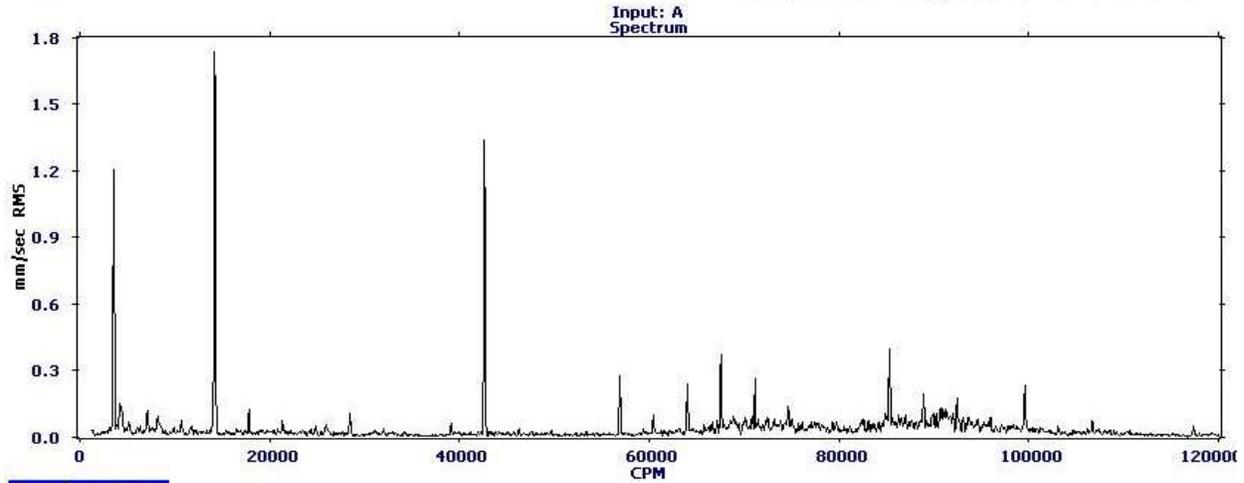
Graph 1



Overall: 3.25422

Frequency Data		Frequency Data		Frequency Data		Frequency Data	
1086.8	0.12481	3553.4	1.02424	4318.7	0.14568	7108.4	0.1982
8066.6	0.11822	14213.5	2.34432	17762.5	0.18007	28423.2	0.1868
42640.6	1.34428	56854.2	0.33473	63960.6	0.23106	67515.5	0.55529
71066.1	0.26614	74616.2	0.18963	78175.3	0.12759	85282.6	0.42529
88829.0	0.14671	91230.6	0.12194	92372.1	0.14378	99493.2	0.32242

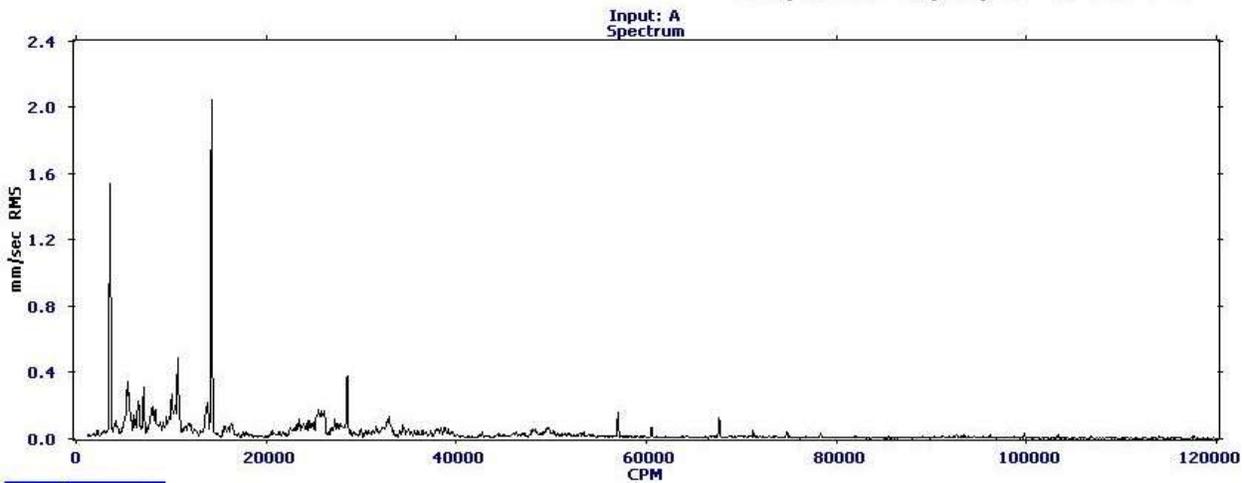
Graph 2



Overall: 3.08213

Frequency Data		Frequency Data		Frequency Data		Frequency Data	
3551.2	1.29871	4230.7	0.16624	4316.4	0.16131	7099.9	0.12576
14205.5	1.92947	17756.5	0.13196	42616.8	1.3751	56823.0	0.30096
63923.0	0.2555	67475.9	0.39782	71028.8	0.26311	74571.8	0.14758
85233.5	0.44979	88767.5	0.22025	89814.3	0.12411	90565.4	0.14977
90855.0	0.13694	91230.1	0.13849	92313.7	0.18026	99435.1	0.23871

Graph 3



Overall: 3.21542

Frequency Data		Frequency Data		Frequency Data		Frequency Data	
3559.5	1.76304	5420.5	0.36563	5516.8	0.31489	6096.7	0.15323
6491.0	0.26047	7113.4	0.3132	7994.6	0.21755	8289.4	0.19987
9790.9	0.15208	10026.1	0.28527	10394.3	0.22884	10669.8	0.51178
13827.5	0.23525	14232.1	2.11643	25310.5	0.16549	25467.7	0.19701
25750.2	0.18142	26067.1	0.18655	28463.3	0.43694	56929.8	0.16073

Graph 4

As the vibration is coming more than the prescribed limit of 3.0mm/Sec RMS so we started optimising the result theoretically to lower the value of vibration

The pump foot was noticed as the major cause of vibration in pump so we performed a theoretical analysis on that to optimise the value. The iterations were done on the pump feet by changing its L,W & B to reach the optimised solution. The mathematical calculations are given below;

### MATHEMATICAL CALCULATION

We have noticed that natural frequency of excitation can be calculated as:

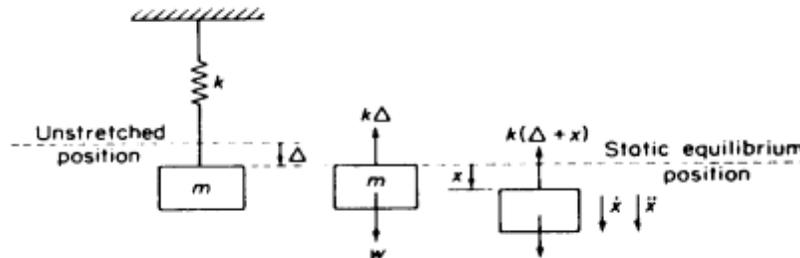


Fig 4. Spring Mass System

$$F = -kx$$

$$m\ddot{x} + kx = 0$$

But general equation is

$$\ddot{x} + \omega^2 x = 0 \quad (1)$$

$$\ddot{x} + \frac{kx}{m} = 0 \quad (2)$$

On comparing (1) and (2)

$$\omega = \sqrt{\frac{k}{m}} \quad (3)$$

Where k = stiffness coefficient of spring

$\omega$  = angular frequency of the system

m = mass of system

But in case of pump (rigid) stiffness is analogues to rigidity

$$F = kx$$

$$\frac{F}{x} = k \quad (4)$$

$x$  = deflection

We know that,

$$x = FL/AE \quad (5)$$

From (4) and (5)

$$k = AE/L \quad (6)$$

Consider figure 2 and 3

The whole analysis of k is done on pump feet of OH2 pump which is shown in figure. Hence its dimension are as follows:

For stainless steel

E = 200 Gpa

L = 212.34mm

W = 82.9 mm

B = 104.32mm

A = B \* W

= 104.32 \* 82.9

= 8648.128 mm<sup>2</sup>

Using equation (6)

k = 8145547.707 N/mm

m = mass of the system

m = 250 kg

$$\omega = 5708.078 \text{ rad/sec}$$

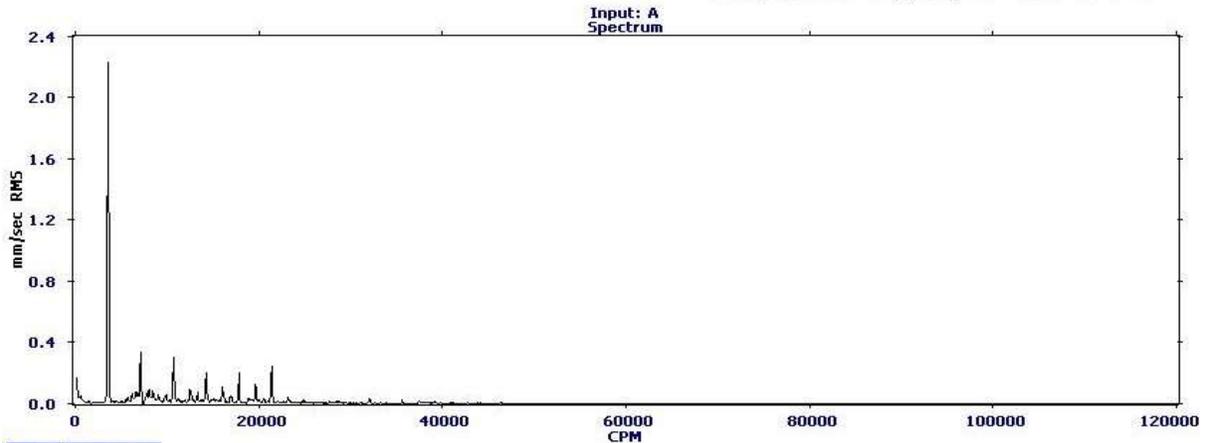
**Table: Variation of  $\omega$  on varying L and m**

Sr. No.	L( in mm)	m ( in Kg)	$\omega$ (rad/sec)
1.	212	250	5708.078
2.	225	264	5396.1327
3.	232	272	5235.372
4.	240	285	5028.5906
5.	250	299	4810.26704

$$\% \text{ change in } \omega = (5708.078 - 4810.26704) / (5708.078) = 15.72\%$$

**Experiment calculation using FFT analyser**

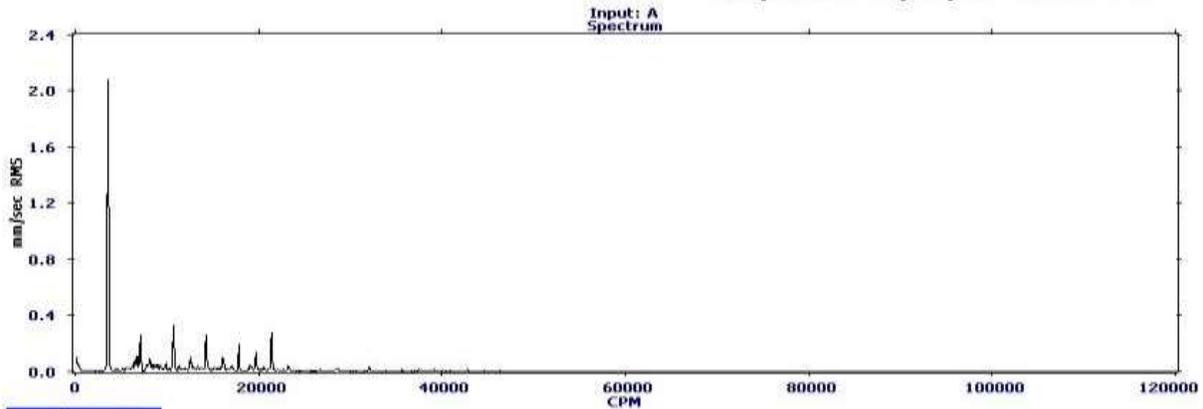
To verify the theoretical calculation, again readings of pump feet vibration are taken by FFT analyser with change in design and following graphs were obtained



Overall: 2.67286

Frequency Data		Frequency Data		Frequency Data		Frequency Data	
565.8	0.05287	3559.6	2.55938	6165.0	0.06974	6564.8	0.09116
6775.9	0.08383	7119.3	0.3396	7771.8	0.07396	7993.9	0.0991
8426.9	0.08737	9083.8	0.06054	9867.5	0.06427	10676.3	0.32565
12482.7	0.10456	13290.8	0.07364	14237.4	0.20637	16040.3	0.11286
16904.0	0.05204	17797.1	0.21083	19600.6	0.13257	21357.8	0.24911

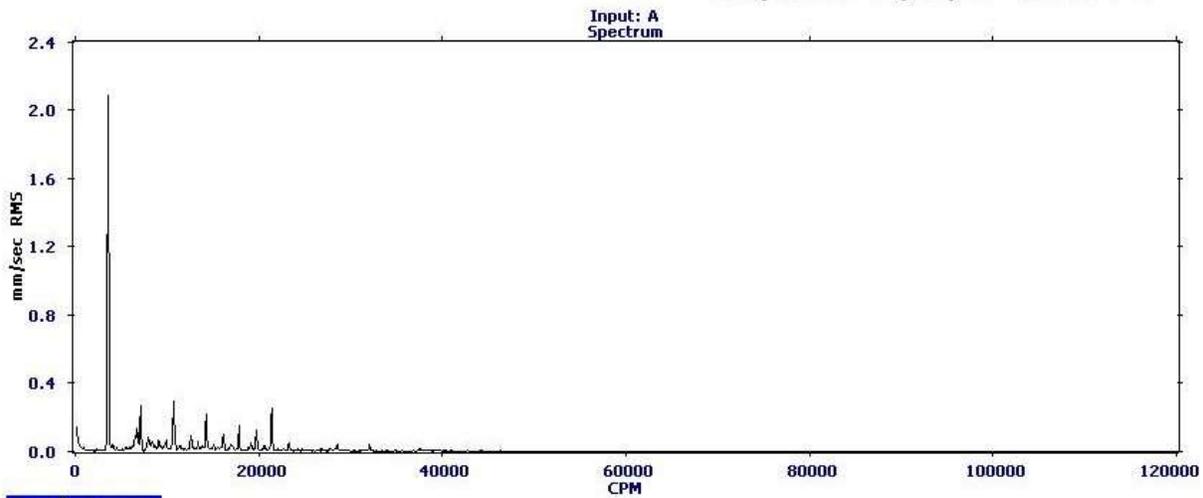
**Graph 5**



Overall: 2.51333

Frequency Data		Frequency Data		Frequency Data		Frequency Data	
348.8	0.06012	3560.0	2.39287	6428.8	0.08734	6789.3	0.12882
7119.1	0.25925	7776.2	0.05714	8079.0	0.09541	8433.9	0.05648
8825.9	0.05264	9101.0	0.05056	9882.6	0.06382	10679.4	0.36166
12535.6	0.0982	12639.6	0.07151	13308.7	0.05218	14240.5	0.26321
16083.9	0.11087	17800.7	0.20469	19640.0	0.1329	21359.1	0.28933

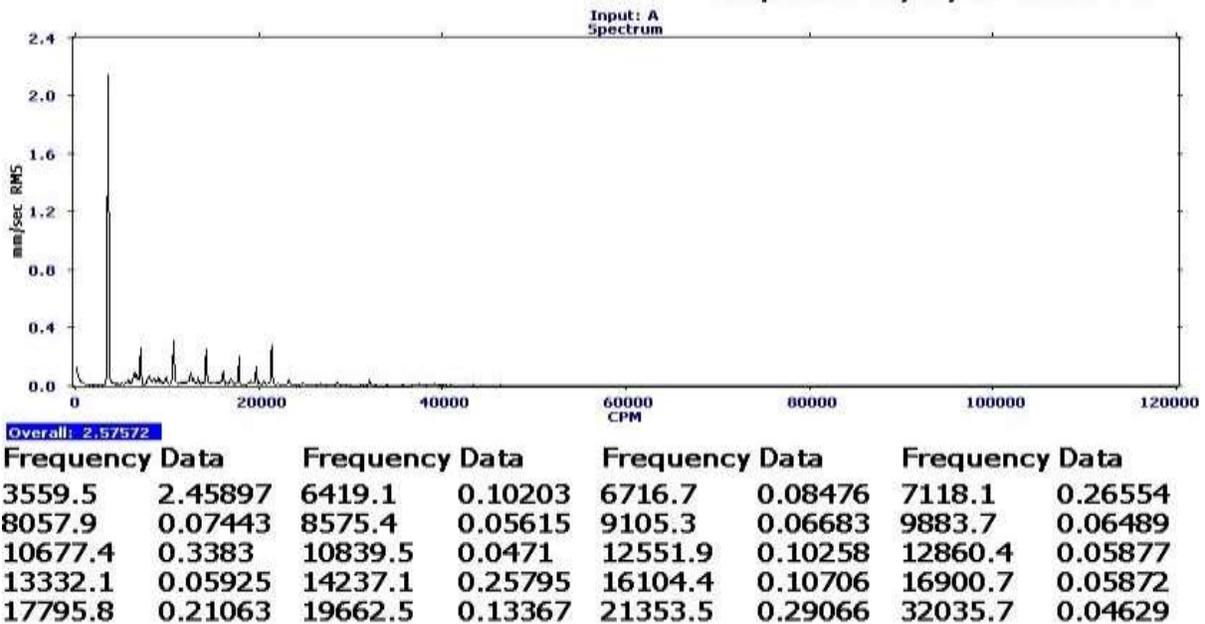
Graph 5



Overall: 2.49885

Frequency Data		Frequency Data		Frequency Data		Frequency Data	
3559.5	2.38548	6472.9	0.09935	6707.9	0.15094	7119.9	0.2655
7931.1	0.08717	8358.2	0.06291	9107.3	0.07213	9886.4	0.06913
10678.6	0.3238	12558.2	0.1024	13338.5	0.06276	14237.9	0.22423
15043.7	0.0485	16112.7	0.10263	16904.5	0.04812	17795.7	0.15449
19105.7	0.0496	19674.1	0.13604	21354.9	0.26662	23231.3	0.04822

Graph 6



Graph 8

By doing all these calculations we achieved a result for the most appropriate value of the pump foot

Initially average frequency without change in design = 3.14485

Average frequency after change in design = 2.49969

% change in experimental frequency = 20%

The pump casing was designed again with the modified foot area and was installed for testing.

The practical value coming out for the vibration was justifying the theoretical value.

It was noted that the pump overall vibration was reduced due to the change in the design of the pump foot and increasing the service life of the pump.

## CONCLUSION

Based on detailed study it can be claimed as a new design of pump feet because it considerably reduces vibration up to 15%. This will lead to the increase in the life of pump and won't hamper the productivity. This leads to an increase in service life of the pump 2 to 3 years and a low maintenance cost of the pump, more efficient and increased productivity.

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