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An Experimental Approach for Balancing a Vibratory System Considering Vibrational Characteristics

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Abstract

This paper presents the condition monitoring in terms of vibration of a static and dynamic balancing vibratory system which comprises a sturdy base unit, four flexible mounts, a steel shaft, low friction horizontal bearing, a set of four rotating masses where each masses contains a various circular insert. As for the rotating shaft, a signature of vibration has been identified due to mass imbalance which can be balanced by static or dynamic. For balancing the rotating mass system, the angular and longitudinal position of the 4th mass is settled to a perfect position for which fewer amount of vibration obtained in the base along with the vertical stands. A CSI 2140 machinery condition analyzer enumerates the vibrational data obtained at different angular spaces of the 4th mass at the rotating shaft and afterward, acquired data is compared with the ISO standard chart to identify the condition of the apparatus. It has been experienced that when the 4th mass is at an angular position of 338° in clockwise direction, the apparatus is in the perfect balanced position and the amplitude of vibration which has overall RMS value of 0.74770mm/s at accelerometer input A, 5.29330 mm/s at accelerometer input B and 1.32002 mm/s at accelerometer input C comparatively lower than any other angular position of the mass. Moreover, this paper includes the mathematical way for balancing the rotating system analytically.

Keywords: mass imbalance, condition monitoring, vibration analysis, static and dynamic balance..

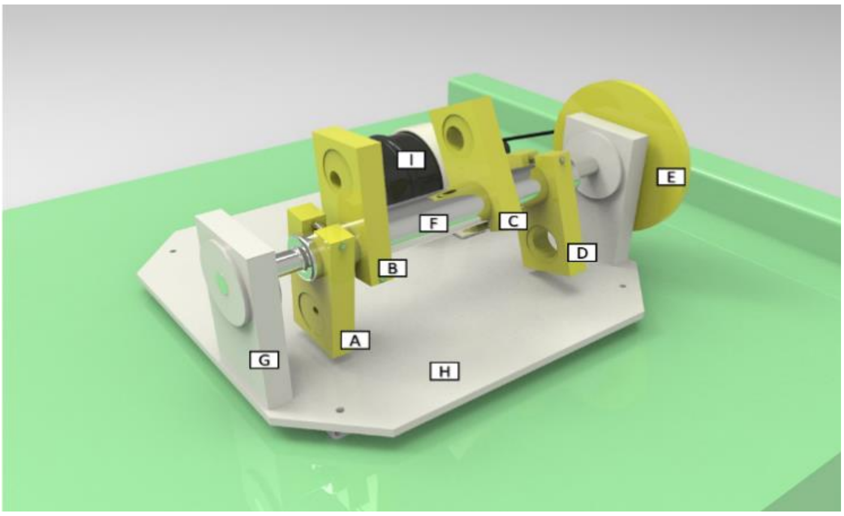
1. Introduction

Vibration is a familiar signature for rotating machinery which is developed by mass imbalance and the mass imbalance comprises static or forced imbalance and dynamic or quasi-static imbalance. If a rotor is supported by bearings which carries heavy spot at the mid-point between them, the static imbalance is formed and can be identified by the weight distribution axes which is parallel to the rotational axes. On the contrary, dynamic balancing aggregates static and couple imbalance which forms when the weight distribution and rotational axes don't intersect at all and it's a common phenomenon in rotating machinery. When vibrational parameters in rotating machinery exceeds the satisfactory level, it may cause severe damage to the machinery. That's why condition monitoring of the components of the machinery is much important which is performed in a regular scheduling to protect the machines. In case of fault diagnosis of rotating machineries a number of methods [1-7] have been developed such as statistical analysis, principal components analysis, model based diagnosis, oil/debris analysis, vibration analysis, temperature monitoring, acoustic emission monitoring etc.. Vibration based condition monitoring is must popular and well accepted in plants to meet this requirement because the machine vibration response is sensitive to any small structural or process parameter change [8]. According to Farrar and Doebling, the most nature and successful application of vibration based damage detection technology has been in the monitoring of rotating machinery [9]. The apparatus comprises a sturdy base unit with four flexible mounts with a rotating shaft including four different masses at different angular and longitudinal positions at the shaft which is driven by an electric motor. Additionally, two vertical stands support the circular shaft along with a base supports the entire setup. Furthermore, the first three masses are fixed at a particular angular and longitudinal position, only 4th mass can be operated to minimize the high level of vibration generating in the apparatus due to mass imbalance.

A CSI 2140 machinery health analyzer has been used to measure the vibrational parameters of the apparatus at different angular positions of the 4th mass using static and dynamic balancing. This paper aims to focus on the effects of mass imbalance that causes heavy signature of vibration in addition to damages or failure of the rotating machineries. This minimization of the imbalance due to mass has been done by static and dynamic balancing procedure. It has been seen that when the apparatus is balanced at 338° angular position of the 4th mass, the amplitude displayed in the analyzer is minimum than other angular positions of the 4th mass.

2. Mathematical modelling and methodology

In static and dynamic balancing apparatus, an electric motor is used to power the test assembly in which the shaft is turned electrically for dynamic balancing. During dynamic balancing test, the assembly undergoes vibration which is allowed by the flexible mount in order to show mass imbalance. For static balancing, the shaft is kept static at any angular position which is done by removing the belt.
The electrical power given to the motor drives it which further drives the shaft by a pulley arrangement where a round belt connects both of the pulley. Four masses with different weight and angular and longitudinal positions are placed around the shaft. The shaft starts rotating in accordance with the rotation of the electrical motor which also causes rotation of the four different masses in anticlockwise. A signature of vibration occurs as a result of mass imbalance which is taken in the machinery analyzer in terms of amplitude where frequency is displayed within the abscissa. When steep vibration occurs due to the imbalance, the apparatus can be balanced by static and dynamic balancing by fixing the 4th mass considering its angular position. The schematic of the apparatus is given below in the following figure.



Annotations: A. 1st mass B. 2nd mass C. 3rd mass D.4th mass E. Large pulley F. Shaft G. Vertical Stand H. Base I. Motor

Figure 1**:** Static and Dynamic Balancing Apparatus

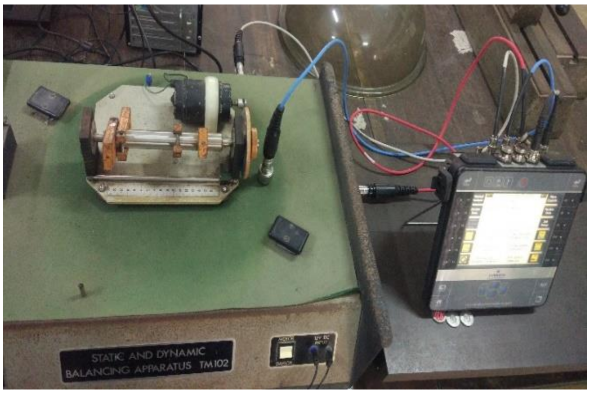


Figure 2: Static and dynamic balancing apparatus with Measurement of vibration at base.

Figure 3: Static and dynamic balancing apparatus With measurement of vibration at vertical stand

The magnitude and direction of the 4th mass for static and dynamic balance have been obtained analytically.

<u>Magnitude and direction for static balance:</u>

The moment tending to turn the shaft due to out of balance are:

Table 1: Moments with direction of the masses

Mass	**Moment**	**Direction**
1	$w_1r_1\cos\alpha_1$	Clockwise
2	$w_2r_2\cos\alpha_2$	Clockwise
3	$w_3r_3\cos\alpha_3$	Clockwise
4	$w_4r_4\cos\alpha_4$	Clockwise

For static balance, it is known that,

$$w_1r_1\cos\alpha_1 = w_2r_2\cos\alpha_{2+}\ w_3r_3\cos\alpha_{3+}\ w_4r_4\cos\alpha_4 \qquad \text{........................ (1)}$$

$$w_1r_1\sin\alpha_1 = w_2r_2\sin\alpha_{2+}\ w_3r_3\sin\alpha_{3+}\ w_4r_4\sin\alpha_4 \qquad \text{........................... (2)}$$

Where, w_1, w_2, w_3, w_4= Distributing masses in the shaft
r_1, r_2, r_3, r_4 = Distance from the axes of the rotating shaft
α_1, α_2, α_3, α_4= angles of these mass with horizontal axes respectively

<u>Magnitude and direction for dynamic balance:</u>
All of the masses placed in the shaft are subjected to centrifugal forces when the shaft is rotating. There are two conditions which must be satisfied if the shaft is not to vibrate at the time of rotating at high speed. The conditions are:

(a) Out of balance centrifugal forces trying to deflect the shaft must not be presented while rotating the shaft.
(b) Out of balance moment or couple trying to twist the shaft must be avoided.

For no out of balance force, sum of horizontal components and sum of vertical components of centrifugal force must be zero. i.e.

$$\sum Fx = 0 \quad \text{and} \quad \sum Fy = 0$$

$$\Rightarrow \frac{w1}{g}\,\omega^2 r_1\cos\alpha_1 = \frac{w2}{g}\,\omega^2 r_2\cos\alpha_2 + \frac{w3}{g}\,\omega^2 r_3\cos\alpha_3 + \frac{w4}{g}\,\omega^2 r_4\cos\alpha_4$$

$$\Rightarrow w_1r_1\cos\alpha_1 = w_2r_2\cos\alpha_{2+}\ w_3r_3\cos\alpha_{3+}\ w_4r_4\cos\alpha_4$$

This is actually the same result obtained for static balance. Thus it can be said that if the shaft is statically balanced then it will also be dynamically balanced.

Table 2: Data for the statically and dynamically balanced Shaft

Mass no.	Angle(°), α	Distance (mm), r	Mass weight (gm), W
01	0	5	190
02	150	105	180
03	190	25	170
04	337.94≅338	145	160

In order to determine the values of r4 and α4, it can be written from equation (i),
$190\times5\cos90° = (180\times105\cos150°) + (170\times25\cos190°) + (160\times r_4\cos\alpha_4)$
$\Rightarrow r_4\cos\alpha_4 = 134.4$
Similarly from equation (ii),

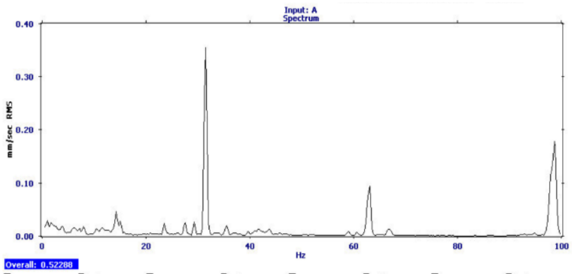
$$r_4\sin\alpha_4 = 54.45$$

$$\text{So, } \frac{r4\cos\alpha4}{r4\sin\alpha4} = \frac{134.4}{54.45}$$

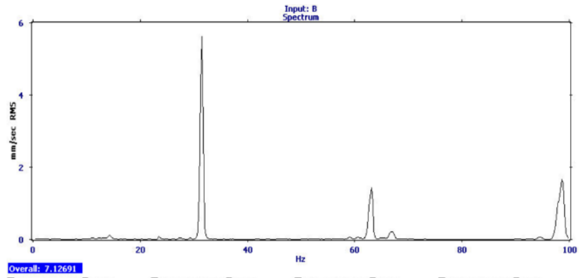
$$\Rightarrow \alpha_4 = 337.94° \text{ and } r_4 = 145 \text{ mm}$$

3. Result and discussion

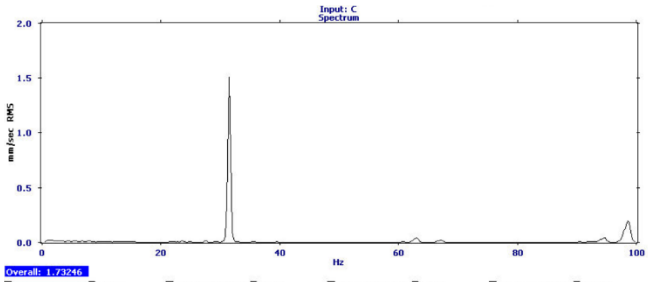
This experiment has been aimed to achieve a stable system depending on the ISO standard from an unstable system. Due to mass imbalance in the static and dynamic balancing apparatus, vibration data is recorded which signifies the different levels of vibration at the sturdy bas and the vertical stands which supports the shaft for different angular position of the 4th mass. Here, the vibrational data is obtained by the use of CSI 2140 machinery health analyzer which consists of three accelerometer which placed at right angle to each other. For making possible of dynamic balancing of the apparatus, the angular position of the 4th mass has been calculated by analytical method. After calculating the angle and longitudinal direction of the 4th mass from the left vertical stand which supports the steel shaft, the vibration data in terms of amplitude has been taken from the analyzer by performing spectrum analysis. Now, whether the angular position of the 4th mass is ok not, can been proved experimentally by taking vibrational data for other angular position of the 4th mass. Here the angle is 338° and longitudinal distance is 145 mm of the 4th mass for perfectly balanced position of the apparatus. And vibrational data has been taken for angle of 333°, 338°, 343° of the 4th mass rotating at anticlockwise direction and vibrational data has been measured. A comparison of sensitiveness of the apparatus to vibration of different angular position which is measured at the base and at the vertical stands has been showed below presenting the spectrum analysis and a bar chart.



Frequency	Data	Frequency	Data	Frequency	Data	Frequency	Data
0.93	0.03162	1.86	0.02763	3.86	0.02023	6.13	0.01805
7.15	0.01588	8.05	0.01826	10.6	0.01497	11.6	0.01733
14.29	0.04714	14.94	0.02912	23.49	0.0241	27.4	0.02732
29.26	0.02597	31.43	0.371	35.42	0.02074	41.62	0.0153
43.63	0.01395	62.9	0.10434	66.86	0.01427	98.61	0.20371

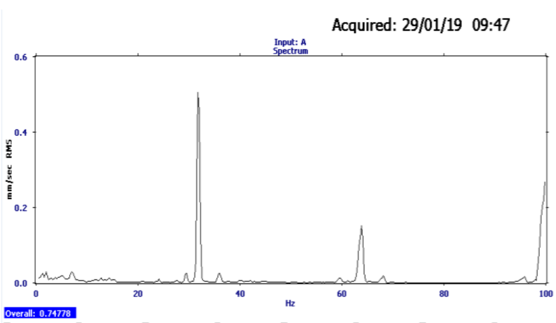


Frequency	Data	Frequency	Data	Frequency	Data	Frequency	Data
11.1	0.04133	12.37	0.03846	14.28	0.12783	23.49	0.07649
27.41	0.054	29.27	0.03398	31.43	5.90593	46.6	0.02345
52.84	0.02441	54.92	0.02451	58.9	0.06119	60.59	0.06495
62.91	1.5627	64.87	0.04708	66.87	0.24561	69.1	0.02227
69.4	0.02183	92.65	0.02929	94.38	0.07126	98.61	1.8942

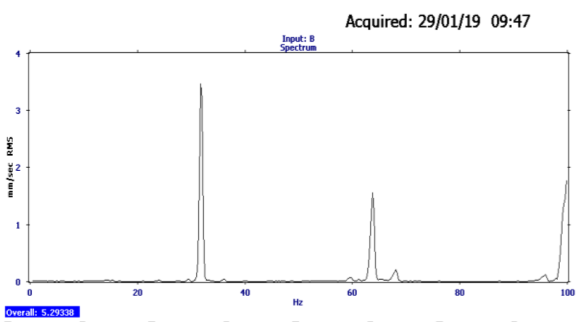


Frequency	Data	Frequency	Data	Frequency	Data	Frequency	Data
1.12	0.02574	2.38	0.01782	3.16	0.01789	4.42	0.01549
5.61	0.01838	6.86	0.01219	7.94	0.01557	10.43	0.00929
13.1	0.00839	14.3	0.01045	15.09	0.0095	23.48	0.01588
27.45	0.01679	29.28	0.00865	31.43	1.588	62.9	0.046
66.89	0.01997	92.65	0.00812	94.62	0.0473	98.62	0.2232

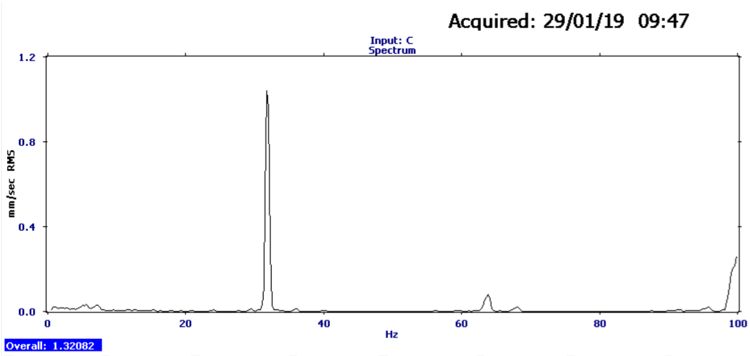
Figure 4: Frequency and amplitude for Input A, B, C for Angle 328° considering the base at unbalanced condition



Frequency	Data	Frequency	Data	Frequency	Data	Frequency	Data
1.15	0.02758	1.91	0.03064	2.91	0.01453	3.68	0.01446
4.37	0.01758	5.1	0.02105	6.9	0.03206	11.64	0.00962
12.66	0.01333	14.35	0.01374	15.14	0.01038	24.04	0.0111
29.39	0.02901	31.86	0.56606	35.9	0.02796	59.6	0.01343
63.67	0.16195	67.93	0.01898	95.67	0.01715	97.83	0.00987



Frequency	Data	Frequency	Data	Frequency	Data	Frequency	Data
12.63	0.02163	13.35	0.02293	14.38	0.02607	15.15	0.02523
23.62	0.02136	24.03	0.03322	29.38	0.0418	31.86	3.91844
35.9	0.04077	55.13	0.02306	59.6	0.08139	61.05	0.04327
62.07	0.03525	63.83	1.65387	65.39	0.05271	66.13	0.03204
67.92	0.22893	94.11	0.02998	95.67	0.12756	97.83	0.06534



Frequency	Data	Frequency	Data	Frequency	Data	Frequency	Data
0.9	0.02468	2.15	0.02092	2.64	0.01778	3.62	0.01542
5.1	0.03395	5.61	0.03648	7.13	0.03287	9.61	0.00753
11.63	0.00773	12.62	0.00766	15.2	0.00972	24.03	0.00959
29.39	0.01268	31.86	1.17823	32.88	0.01149	35.9	0.01336
63.66	0.08686	67.91	0.02244	91.59	0.00932	95.67	0.02137

Figure 5: Frequency and amplitude for Input A, B, C for Angle 338° considering the base at balanced condition

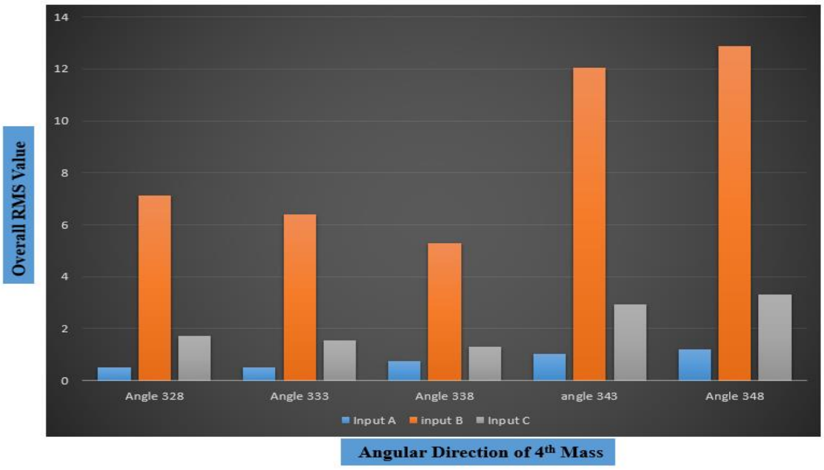


Figure 6: Comparative Illustration of the Overall RMS Value for Different Angular Position of the 4th Mass When Considering Vibration at Base

It can be seen from the bar chart that the overall RMS values has been reduced at base of the apparatus at angle of 338° as this angle is the perfect position for the 4th mass for static and dynamic balancing which has been measured analytically.

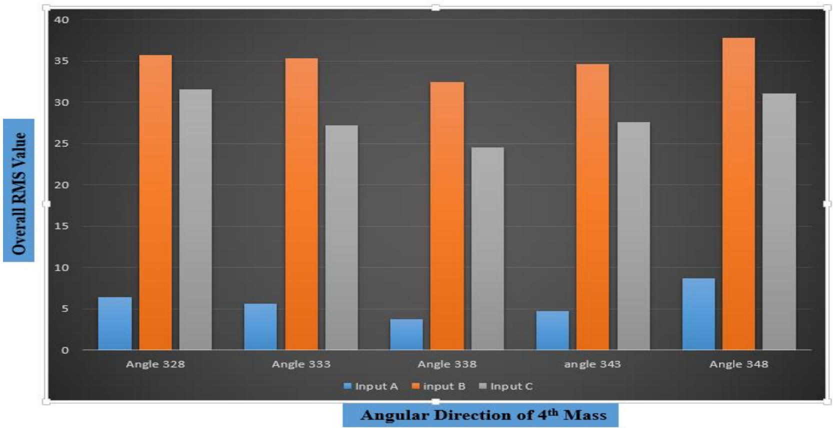


Figure 7**:** Comparative Illustration of the Overall RMS Value for Different Angular Position of the 4th Mass When Considering Vibration at Vertical Stand

It can be seen from the bar chart that the overall RMS values has been reduced at vertical stand of the apparatus at angle of 338° as this angle is the perfect position for the 4th mass for static and dynamic balancing which has been measured analytically.

4. Conclusion

The amount of vibration imposed in the static and dynamic balancing apparatus due to mass imbalance has been observed in this paper. Furthermore, the minimization of the vibration which is measured by using machinery health analyzer has been completed by static and dynamic balancing procedure. In case of rotation of a single mass with multiple masses in different planes, vibration often occurs when weight distribution axes and rotational axes don't coincide each other. Then the characteristics vibration undertaken generated a spectral plot which indicated that mass imbalance was mostly one of the causes for this signature. In accordance with, the angular and longitudinal position of the 4th mass has been calculated analytically which was 338° and 145 mm respectively in order to mitigate the additional vibrational generated by mass imbalance. Moreover, a comparison has also been shown in terms of vibration for different angular position of the 4th mass in this paper.

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