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Calibration of Hollow Operating Shaft Natural Frequency by Non-Contact Impulse Method

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Abstract: *In this study, experimental and theoretical results carried out on a cantilever hollow operating shaft, in order to determine the natural frequency of hollow operating shaft and in experimentally aims to provide a non-contact electromagnetic impulse. In this experimental work, to creating impulse on a hollow operating shaft electromagnet was use. To analyze time domain signal of static hollow shaft with an impulse effect, in order to measure natural frequency of hollow shaft. To analyze time domain signal of a hollow operating shaft without an impulse effect, in order to measure natural frequency of hollow shaft. To analyze time domain signal of a hollow operating shaft with an impulse effect, in order to measure the natural frequency of a hollow operating shaft. The time domain converted into frequency domain by using fast Fourier transform (FFT). Frequency measurement of hollow operating shaft could be one such parameter and in general it is difficult to determine natural frequency of hollow operating shaft. In this project an effort is made to determine the natural frequency of hollow operating shaft by non-contact impulse method, a new approach is made use of. And the results obtained by experimental and theoretical methods correlated well.*
Keywords: *Eddy current proximity probe, Electromagnet, NV Gate software, S-Type load cell.*

1. Introduction

The application of an external load on a hollow rotating shaft causes an excessive stress, noise, friction between the shaft and bearing which leads to complete or partial failure of machine parts. There are different types of load applied on a hollow rotating shaft such as concentrated load, uniformly distributed load and uniformly varying load. Due to application of these loads the shaft may come into surface contact with loads, which leads to increases friction, wear and reduces shaft life. Hence for these defects hollow rotating shaft is not performed very well. So it is very difficult to determine natural frequency of hollow rotating shaft. To resolve this problem, use new approach non-contact impulse method, in order to determine natural frequency of hollow rotating shaft by using non – contact impulse technique. Static hollow shaft with an impulse effect, hollow rotating shaft without an impulse effect and hollow rotating shaft with an impulse effect.

In these three cases to analyze signal in time domain and to measure natural frequency in frequency domain. The time domain is converted into frequency domain by Fast Fourier Transform (FFT) and NV Gate software used for measuring noise and vibration.

2. Literature review

Surendra N. Ganeriwala, brian schwarz and mark h. Richardson are demonstrated the use of the operational deflection shape of a rotating machine as a means of detecting unbalance in its rotating components. The results of this work provide a new method for detecting machinery unbalance and offer a simplified approach for on-line fault detection in operating machinery.

3. Experimental setup

Fig. 1 Experimental setup front view

Fig. 2 Experimental setup top view

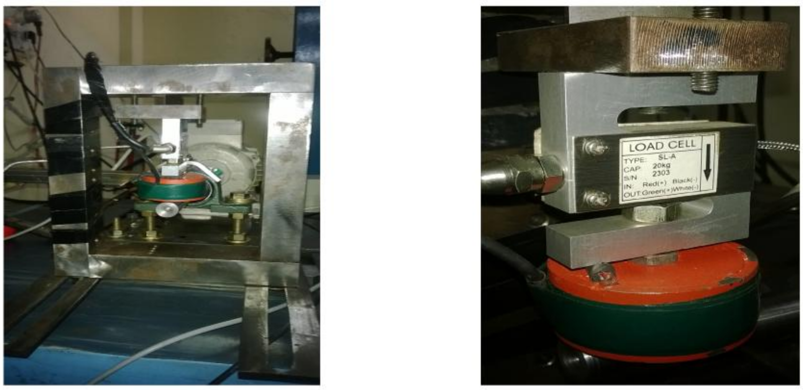


Fig. 3 Experimental setup side view

a) An electric motor having capacity of 1hp is used to rotate the shaft with certain speed (max. Sp. 3600 rpm).
b) An electromagnet (13 kg capacity) is used to give impulse on a hollow static or operating shaft and then load capacity of hollow operating shaft is measured using load cell.
c) Load cell having capacity of 20 kg is used to convert the load acting on it into analog electric signal. This analog electric signal is converted into digital signal which is displayed on data acquisition system.
d) Eddy current proximity probe is used to sense the displacement of a static or rotating hollow shaft without physical contact and the response signals shown in time domain is converted into frequency domain with the help of fast Fourier transform.
e) In case of static shaft with impulse effect, two frequencies are measured. In case of a hollow operating shaft with or without impulse effect, three frequencies are measured
f) **NV Gate software** is used for the analysis signals and measuring different frequencies.

4. Theoretical and experimental results discussions

4.1 Natural frequency calculation (theoretical method)

Given data
Consider hollow operating cantilever shaft with UDL
Length of shaft, L = 270 mm.
Outer diameter of shaft, D = 19 mm.
Inner diameter of shaft, d = 2 mm.
Modulus of elasticity of mild steel shaft, E = 210 GPa.
Mass of shaft, M = 0.660 Kg
Weight of shaft, F = 6.4746 N
Solution
F = W*L…….. (N/m)*(m)…N

Moment of inertia, $I = (\pi/64)*(D^4-d^{4)}$
$= (\pi/64)*(19^4-2^4)$
$= 6396.33\ mm^4$.

Deflection of shaft, $\delta = WL^4/8EI$
$= FL^3/8EI$
$= (6.4746*270^3) / (8*210*10^3*6396.33)$
$= 0.011859$ mm.

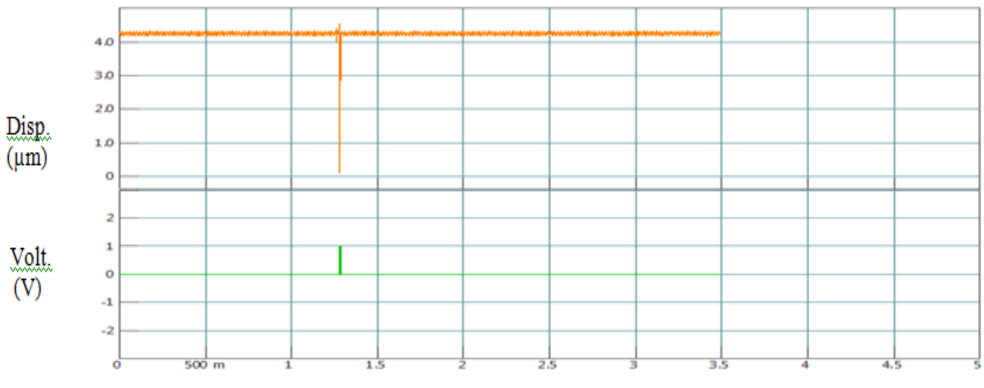
Shaft stiffness, $k = (8EI / L^3)$
$= (8*210*10^3*6396.33) / (270^3)$
$= 545.945$ KN.

Natural frequency of shaft, $\omega_n = (k/m)^{0.5}$
$= [(545.945*10^3) / (0.660)]^{0.5}$
$= 909.5$ rad/s

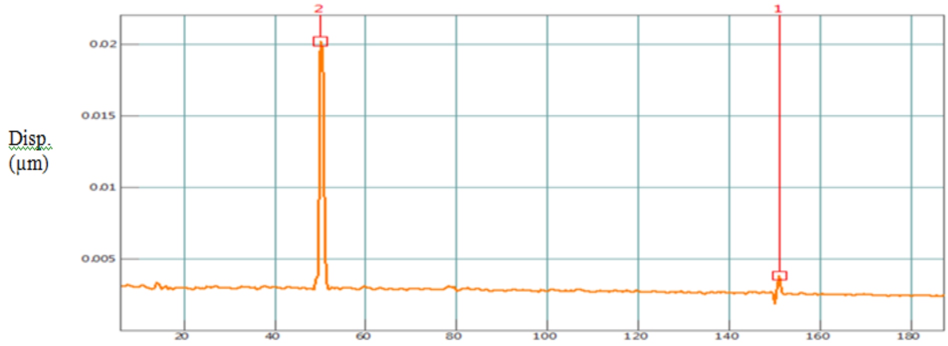
Natural frequency of hollow shaft = 144.7514 Hz

4.2 Experimental results: signal analysis of shaft vibrations for measurement of natural Frequency (shaft at different speed)

4.2.1 Static hollow shaft with impulse and 3.34 mm gap between shaft and electromagnet.



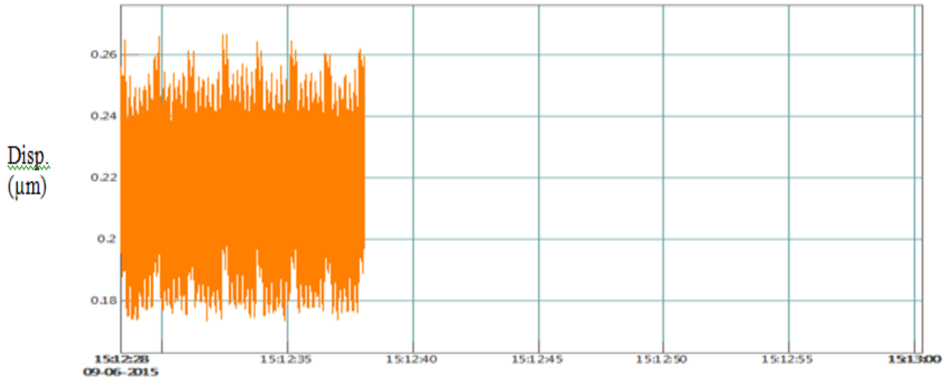
Time (s)
Fig 4 – Time domain for static shaft with impulse



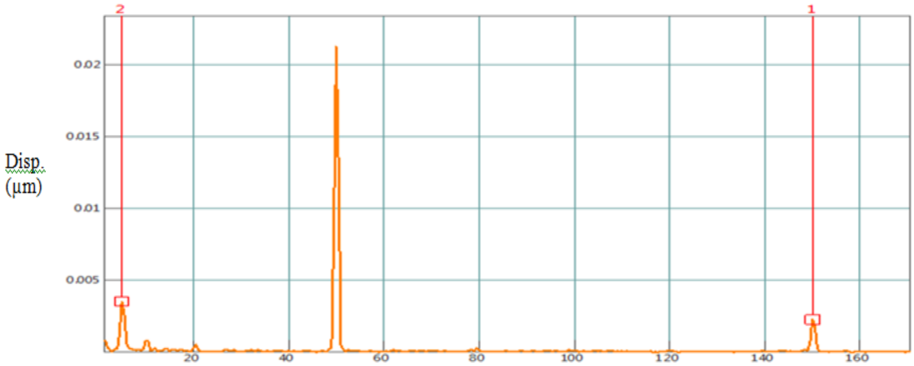
Frequency (Hz)
Fig 5 – Frequency domain for static shaft with impulse

From fig 5 – Fast Fourier Transform (FFT): average spectrum **natural frequency of hollow shaft 150 Hz** along with displacement is 0.00383 µm and ac main phase frequency 50 Hz along with displacement is 0.02361 µm.

4.2.2 Hollow shaft rotating at 300 rpm without impulse and 3.34 mm gap between shaft and electromagnet.



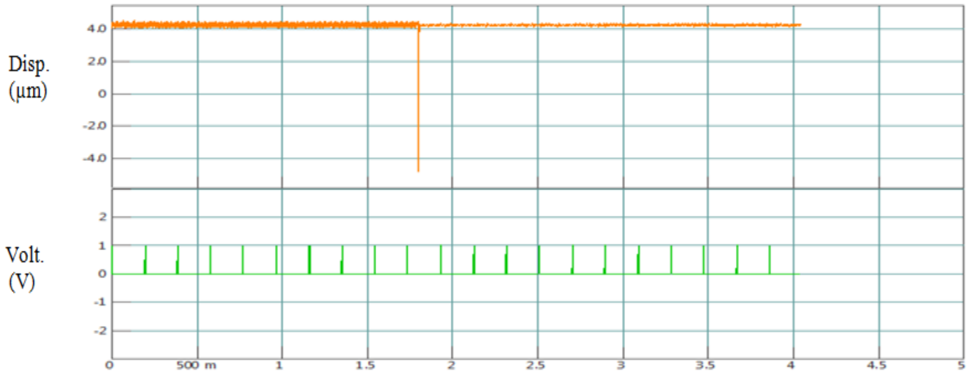
Time (s)
Fig 6 – time domain for hollow operating shaft without impulse



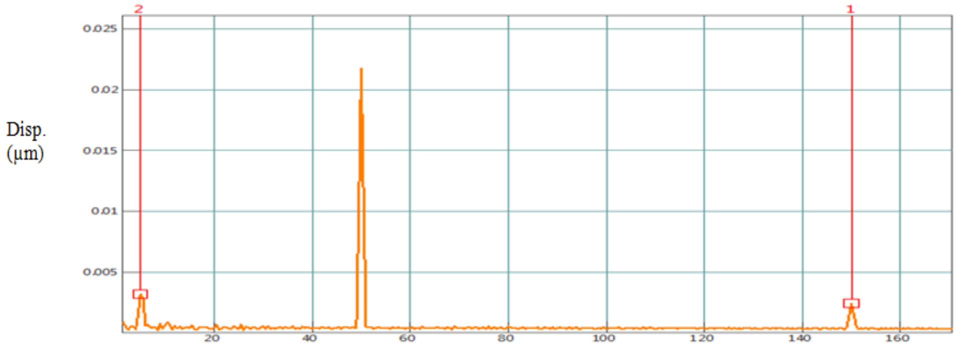
Frequency (Hz)
Fig 7 – frequency domain for hollow operating shaft without impulse

From fig 7 – Fast Fourier Transform (FFT) : average spectrum **natural frequency of hollow shaft 150 Hz** along with displacement is 0.002266 µm, ac main phase frequency 50 Hz along with displacement is 0.02126 µm and hollow shaft rotational frequency is 5 Hz along with displacement is 0.00351 µm.

4.2.3 Hollow shaft rotating at 300 rpm with impulse and 3.34 mm gap between shaft and electromagnet.



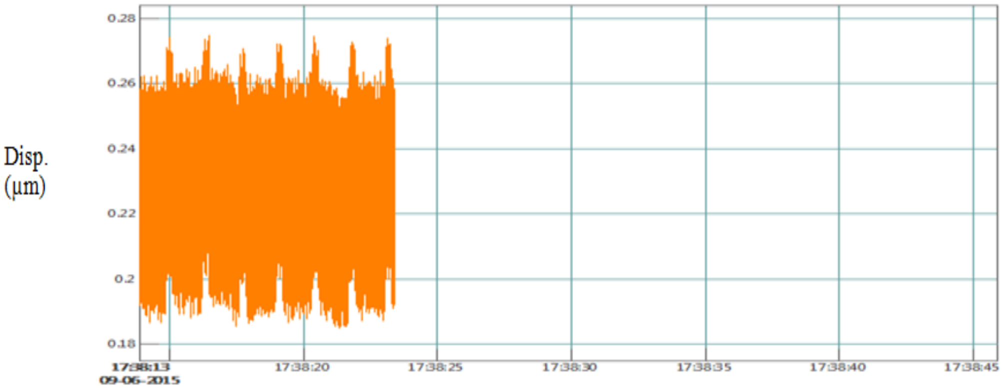
Time (s)
Fig 8 – time domain for hollow rotating shaft with impulse



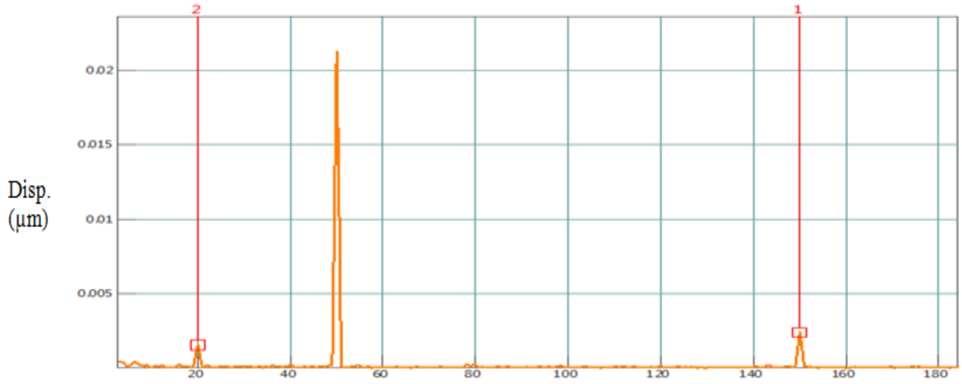
Frequency (Hz)
Fig 9 – frequency domain for hollow rotating shaft with impulse

From fig 9 – Fast Fourier Transform (FFT): average spectrum **natural frequency of hollow shaft 150 Hz** along with displacement is 0.00401 µm, ac main phase frequency 50 Hz along with displacement is 0.03090 µm and hollow shaft rotational frequency 5 Hz with displacement is 0.00381 µm.

4.2.4 Hollow shaft rotating at 1200 rpm without impulse and 2.46 mm gap between shaft and electromagnet.



Time (s)
Fig 10 – time domain for hollow operating without impulse

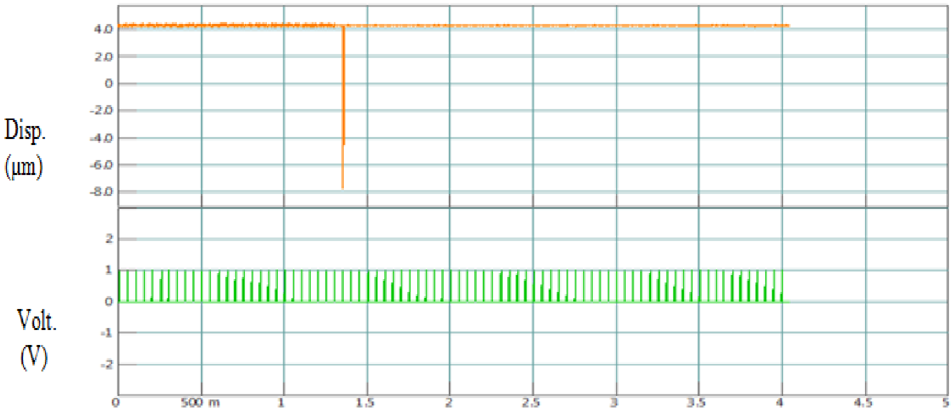


Frequency (Hz)

Fig 11 – Frequency domain for hollow operating shaft without impulse

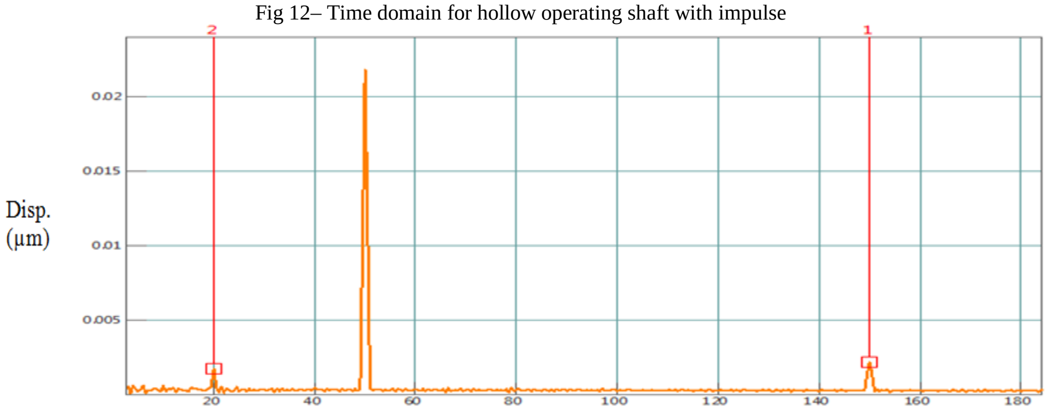
From fig 11 – Fast Fourier Transform (FFT): average spectrum **natural frequency of hollow shaft 150 Hz** along with displacement is 0.002943 µm, ac main phase frequency 50 Hz along with displacement is 0.02103 µm and hollow shaft rotational frequency is 20 Hz with displacement is 0.00141 µm.

4.2.5 Hollow shaft rotating at 1200 rpm with impulse and 2.46 mm gap between shaft and electromagnet.



Time (s)

Fig 12– Time domain for hollow operating shaft with impulse



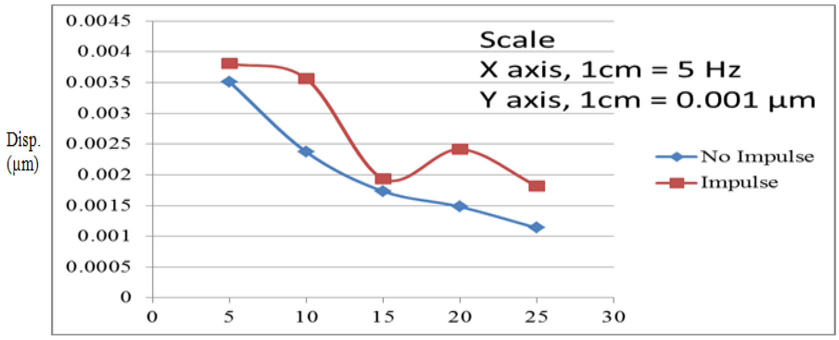
Frequency (Hz)

Fig 13 – Frequency domain for hollow operating shaft with impulse

From fig 13 – Fast Fourier Transform (FFT): average spectrum **natural frequency of hollow shaft 150 Hz** with displacement is 0.003963 µm, ac main phase frequency 50 Hz along with displacement is 0.03091 µm and shaft rotational frequency is 20 Hz with displacement is 0.002368 µm.

Experimental result summary

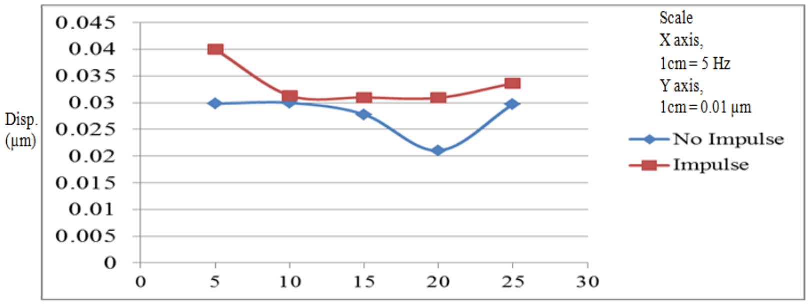
From above experimental results to draw the graphs displacement v/s rotational frequency when rotational speed, ac main phase frequency and natural frequency of shaft are constant



Rotational frequency (Hz)

Graph 1) characteristic curves for hollow operating shaft

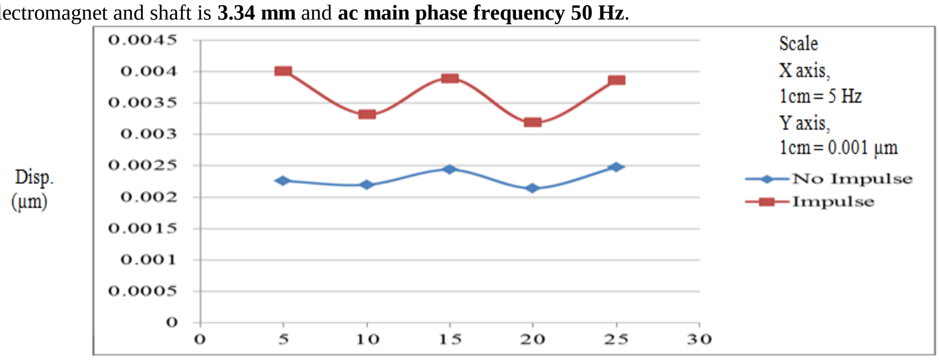
From graph 1 indicates that, the characteristic curve for hollow rotating shaft with impulse is larger than without impulse when constant gap between electromagnet and shaft is **3.34 mm**.



Rotational frequency (Hz)

Graph 2) characteristic curves for hollow operating shaft

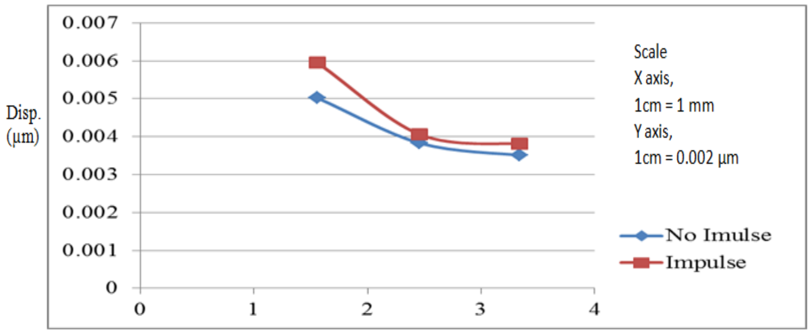
From graph 2 indicates that, the characteristic curve for hollow rotating shaft with an impulse is larger than without an impulse when constant gap between electromagnet and shaft is **3.34 mm** and **ac main phase frequency 50 Hz**.



Rotational frequency (Hz)

Graph 3) characteristic curves for hollow operating shaft

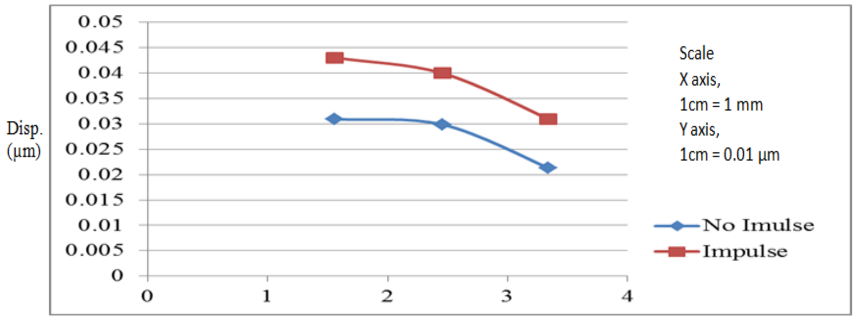
From graph 3 indicates that, the characteristic curve for hollow rotating shaft with impulse is larger than without impulse when constant gap between electromagnet and shaft is **3.34 mm** and **natural frequency of hollow operating shaft 150 Hz**.



Gap b/w electromagnet and shaft (mm)

Graph 4) characteristic curves for constant rotational frequency is 5 Hz

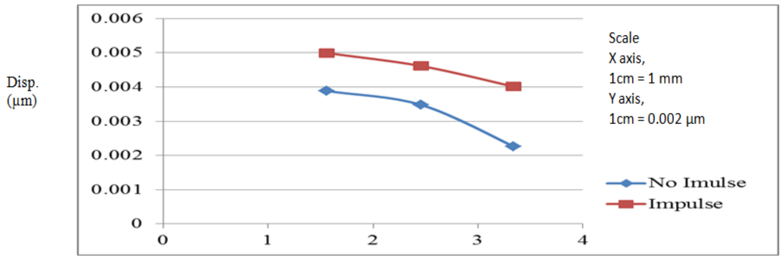
From graph 4 means that, the characteristic curve for hollow rotating shaft with an impulse is larger than without an impulse **when constant shaft rotational frequency 5 Hz.**



Gap b/w electromagnet and shaft (mm)

Graph 5) characteristic curves for constant rotational frequency is 5 Hz

From graph 5 means that, the characteristic curve for hollow rotating shaft with an impulse is larger than without an impulse **when constant ac main phase frequency 50 Hz and shaft rotational frequency 5 Hz.**



Gap b/w electromagnet and shaft (mm)

Graph 6) characteristic curves for constant natural frequency of shaft is 150 Hz

From graph 6 means that, the characteristic curve for hollow rotating shaft with an impulse is larger than without an impulse **when constant natural frequency of hollow shaft 150hz and shaft rotational frequency 5 Hz.**

Percentage error calculation

For experimental result, natural frequency of hollow shaft is **150 hz** and for theoretical method natural frequency of hollow shaft is **144.7513 Hz.**

$$= [(150-144.7514) / 150] * 100$$
$$=3.5\%$$

Conclusions

1) When the experiment is conducted on static hollow shaft with an impulse, we measured two frequencies. One of them is natural frequency and other is ac main phase frequency.
2) Hollow operating shaft without an impulse, we measured three frequencies. One is natural frequency, second is ac main phase frequency and third is rotational frequency of shaft.
3) Hollow operating shaft with an impulse, we measured three frequencies. One is natural frequency, second is ac main phase frequency and third is rotational frequency of shaft.
4) The above experiments are conducted with varied gap between hollow shaft and electromagnet and alsowith varied speed for the case when the hollow shaft is operating.
5) Natural frequency of the hollow shaft is calculated theoretically also.
6) The results obtained by experimental and theoretical methods correlated well.

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