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# PERFORMANCE OF HARD DISK DRIVES IN HIGH NOISE ENVIRONMENTS

Trinoy Dutta
*Michigan Technological University*, trinoyd@mtu.edu

# PERFORMANCE OF HARD DISK DRIVES IN HIGH NOISE ENVIRONMENTS

By

Trinoy Dutta

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Department of Mechanical Engineering – Engineering Mechanics

Report Advisor:     *Andrew R. Barnard*

Committee Member:     *Charles D. Van Karsen*

Committee Member:     *Jason R. Blough*

Department Chair:     *William W. Predebon*

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# ABSTRACT

Digital information stored in rotational media, such as Hard Disk Drives (HDD) needs to be reliable and readily accessible. Various studies have been performed on the modal analysis of HDDs and the noise emitted during operation. Analysis performed by Siemens Corporation, IBM and Tyco Fire Protection Products show that HDDs are sensitive to noise. This report initially focusses on identifying the critical frequency ranges and the levels of noise where the performance of the drives reduces. A series of tests have been performed using pink noise at one-third octave frequency bands at sound pressure levels ranging from 80 dB to 130 dB (re 20 µPa) in an anechoic chamber. A detailed description on the test set-up along with the methodology of testing has been provided. Read/write speeds have been used to measure HDD performance. A completely random read/write workload with varied data packet size has been incorporated through a custom LabVIEW program. Serial Advanced Technology Attachment (SATA) drives have been used for the analysis. General trends in performance curves of Enterprise HDD, Laptop drives, Helium filled HDD and Non-Helium filled HDDs are shown. HDD performance is shown to be sensitive to sound pressure levels as low as 85 dB (re 20 µPa) at some frequencies. Depending on the type of the HDD, noise at a frequency range of 2 kHz – 8 kHz beyond certain SPL affect the HDD's performance up to the point of temporary and even permanent failure. Speculating the observed frequency content to be the resonant frequencies of the internal parts such as the platter and head gimbal assembly, the modal analysis has been performed. The report later focusses on impact test and measurement of the response using non-contact methods on the HDDs platter and head gimbal assembly. A detailed analysis on the test set-up and measurement parameters has been laid out. The modal parameters obtained, provide an insight to the causal for the HDD's performance reduction and help establish a relation with the results obtained from acoustic experiments. The modal parameters and the response obtained has been validated using Finite Element Analysis. A comprehensive analysis on the failure of HDDs due to modal parameters has been presented.

# 1. Introduction

The research has been presented in the form of two chapters. The second chapter titled "Acoustic performance of hard disk drives in high noise environment" discusses the Hard Disk Drives (HDDs), read and write performance in high noise environment. A robust method to test the HDDs performance has been laid out. The test-set-up has been discussed. A quantitative analysis on the read and write performance has been performed on a set of 14 HDDs. This chapter has been presented as a journal article which contains an introduction, methods, results and discussion and conclusion along with acknowledgement and references.

The results obtained from the above analysis led to the speculation of the cause behind the performance degradation of the HDDs and so, a modal analysis of the head gimbal assembly and platter of a HDD was performed. This analysis was performed with Siddharth Parmar, a graduate student of Mechanical Engineering – Engineering Mechanics Department of Michigan Technological University as part of a course project for Analytical and Experimental Modal Analysis (MEEM 4701) under the guidance of Prof. Charles D. Van Karsen and Dr. Andrew R. Barnard. The modal frequencies obtained have been compared with the acoustic performance of the HDD which has been presented in chapter 3 titled as "Evaluation of hard disk drive modal parameters with respect to acoustic drive failures". Trinoy Dutta and Siddharth Parmar performed this analysis together where Trinoy took the lead in the experimental analysis of the modal parameters and compared the results with the acoustic performance of the HDD. Siddharth took the lead on validating the results through Finite Element Analysis. This section has been presented as an extended research to the original objective. The HDD used in this analysis was provided by Tyco Fire Protection Productions and all other resources for the analysis was provided by Michigan Technological University.

# 2. Performance of hard disk drives in high noise environments

## 2.1 INTRODUCTION

Due to our reliance on digital data, particularly on remote servers, it is of vital importance that the information in the Hard Drive (HDD) storage media be reliably accessed. Noise can affect the performance of HDDs and has been observed in a case study presented by Siemens Corporation [1]. They mentioned that the damage can range from automatic shutting down of HDDs to permanent loss of information due to damage in the HDDs, up to the extent that the HDDs need to be removed from the storage array and replaced [1].

Data centers, in general, are an environment where high noise levels can occur. In the event of fire in a data center, inert gas fire suppression systems are often used to protect data on the hard drives because they do not release agents that could damage the drives. However, the noise generated due to the fire suppression system can be a factor in the performance degradation and failure of hard drives. The two main sources of noise during the operation are the acoustical alarm system, used to warn people, and the noise produced during discharge of the inert gas through the distribution nozzles. The inert gas fire suppression system, along with the warning alarm, produces high noise levels, with sound pressure levels (SPL) ranging from 90 dB to in excess of 130 dB (re 20 µPa) [2]. The frequency content is broadband, from hundreds of hertz to 20+ kHz, and contains tonal content that varies with the nozzle design and flow rate [2].

In an attempt to understand hard drive failures in data centers during inert gas fire suppression, Siemens Corporation, investigated the effect of overpressure generated in the room due to the release of large amounts of extinguishing agent. They concluded that quasi-static

pressure and pressure gradient does not affect the hard drives' performance [2]. They also found that the room temperature change is very small (only a few degrees Celsius) and does not affect hard drive performance [2].

Siemens Corporation, in their case study, performed performance testing on hard drives using pink noise of third-octave frequencies between 353 Hz to 10kHz and a broad band noise in the frequency range from 500 Hz to 10 kHz [1]. They concluded that HDDs are not sensitive to noise below 500 Hz; whereas, high noise levels, typically above 120 dB (re 20 µPa), in the frequency range of 500 Hz to 12.5 kHz cause faults and failures in hard drives. They found the frequency range from 1.6 kHz to 8 kHz to be most sensitive to noise. At certain frequencies they observed that HDDs are sensitive to noise below 110 dB (re 20 µPa) [2]. They derived the conclusions by testing 4 HDDs which is generally not enough to define the sensitivity to noise of the entire population of commercially available HDDs.

Nickerson, et al, compared the performance degradation of hard drives when exposed to tones, broadband noise with tones, and broadband signals. They employed a 100 % read workload with a data packet size of 16 KB which is a very small workload [3]. Generally, HDDs are subjected to random read and write workload of varying packet sizes. So, a proper workload with both random reads and writes of different packet size would reproduce something close to a regular work load of a HDD. They also compared the performance of Enterprise HDDs to previous generation of rotational drives, such as 2.5" Laptop drives, when exposed to acoustic noise. They concluded that each of the hard drives are sensitive to different tones [4]. This is expected because the structural acoustic modal frequencies for each different HDD will vary depending on internal and casing design. They concluded that the performance of HDDs reduced to a greater extent when exposed to tones overlaid on broadband noise compared to broadband noise with no tones overlaid.

They also concluded that swept sine signals from 1kHz to 16 kHz have a high probability of affecting the drives in a data center. The frequencies of the modes of the HDD system, were overlaid on the performance curve and it was observed that the performance drops at the frequencies where the system has modes of vibration, as expected.

Researchers have studied extensively the noise generated by a Hard Disk Drive (HDD). Fah, et al. provided measures for active noise control of airborne noise from HDDs [5]. Hu, et al. analyzed the effects of airborne noise due to speakers inside a notebook. They studied the acoustic force-induced vibrational displacement as frequency response on the Hard Drive, along with the effects of stiffness and damping ratios of the supports [6]. Min, et al. performed modal analysis on a head gimbal assembly of an HDD and presented a method for active control of flow-induced vibration on the head gimbal assembly [7]. The literature abounds with studies on HDDs as sources of noise and as receivers on sound from nearby information technology (IT) devices. However, very little work exists that describes the performance degradation and outright failure of HDDs due to exposure to high noise level transient events, such as with some fire alarm and inert gas fire suppression system discharges.

In this paper, an analysis has been performed on the HDD performance due to one-third-octave (OTO) filtered pink noise at different amplitudes. To replicate a typical read/write workload, a random read/write workload with varying data packet size was implemented. In order to avoid human error, a completely autonomous test procedure was designed using a custom National Instruments (NI) LabVIEW software program which measures the HDD performance at different test conditions. A total of 14 HDDs were tested from different generations of rotational media such as 2.5" Laptop drives and 3.5" Enterprise Serial Advanced Technology Attachment (SATA) drives. Helium filled and Non-Helium filled drives were also tested.

## 2.2 METHODS

The sound produced by the inert gas fire suppression system is broadband in nature. The autopower spectrum of the noise produced during the extinguishing event is shown in Fig. 2.1. The spectrum has been normalized to show the relative contributions of OTO bands in the frequency range of 500 Hz to 20 kHz. To understand the critical frequencies and sound pressure levels that affect HDDs, pink noise filtered into one-third octave (OTO) bands was used to excite the HDDs at successively increasing SPLs. The HDD performance was monitored through a custom LabVIEW program. The data packets used were 131 KB, 262 KB, 393 KB, 524 KB, 655 KB, 1 MB, 2 MB, 4.2 MB and 8.4 MB in a random order. The random read and write workload was used with a total memory size of 1 GB. The time taken to read/write the total 1GB memory size consisting of smaller randomly sized data packets was measured and used to calculate the total read/write speed. Each read and write test was performed 9 times, starting with the write test followed by the read test to obtain an adequate number of averages of read and write speed. A Sabrent USB 3.0 to SATA/IDE 2.5/3.5/5.25 – INCH Hard Drive Converter with Power Supply (USB DSC9) was used to connect the HDDs to the chassis (NI PXIe-1078). The read/write speed test data were normalized to a baseline average without added sound to account for variations in absolute read/write speeds due to the USB 3.0 connector wires.
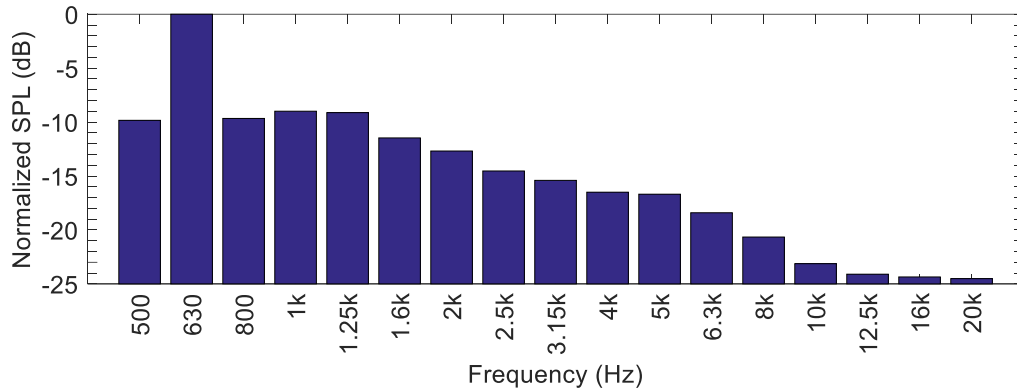
*Fig 2.1: The normalized autopower spectrum of the sound produced during the extinguishing event through an inert gas fire suppression system*

The HDDs were tested in an anechoic chamber at Michigan Technological University [8]. The HDDs were placed on a Medium Density Fiberboard (MDF) to increase the SPL at the hard drive by approximately 6dB due to reflective interference, which reduced the required load on the compression drivers. A surface mount microphone (PCB 130B40) was mounted onto the top surface of the HDDs to measure the SPL at the drive in OTO bands. Two B&C Speakers DE 1085TN compression drivers were placed 0.5 m above from the HDDs, facing downward.

An NI PXI-Express system was used to generate the OTO pink noise, measure the SPL from the microphone and perform the HDD read/write test. A NI PXIe-8840 controller was used with a NI PXIe-1078 chassis. A NI PXI-6733 signal generator was used to generate OTO band pink noise. The generated signal was input to an amplifier (Behringer NU 10000 DSP) which sent the signal to the two horn (B&C ME60) loaded compression drivers. A current probe (Fluke 80I-110s AC/DC) was used to measure the electrical current sent to the speakers throughout the test. An NI 4497 dynamic signal analyzer was used to measure the sound pressure from the microphone and electrical current from the current probe. Fig. 2.2 shows the block diagram of the test set-up. Fig. 2.3 shows photographs from the actual test-setup.
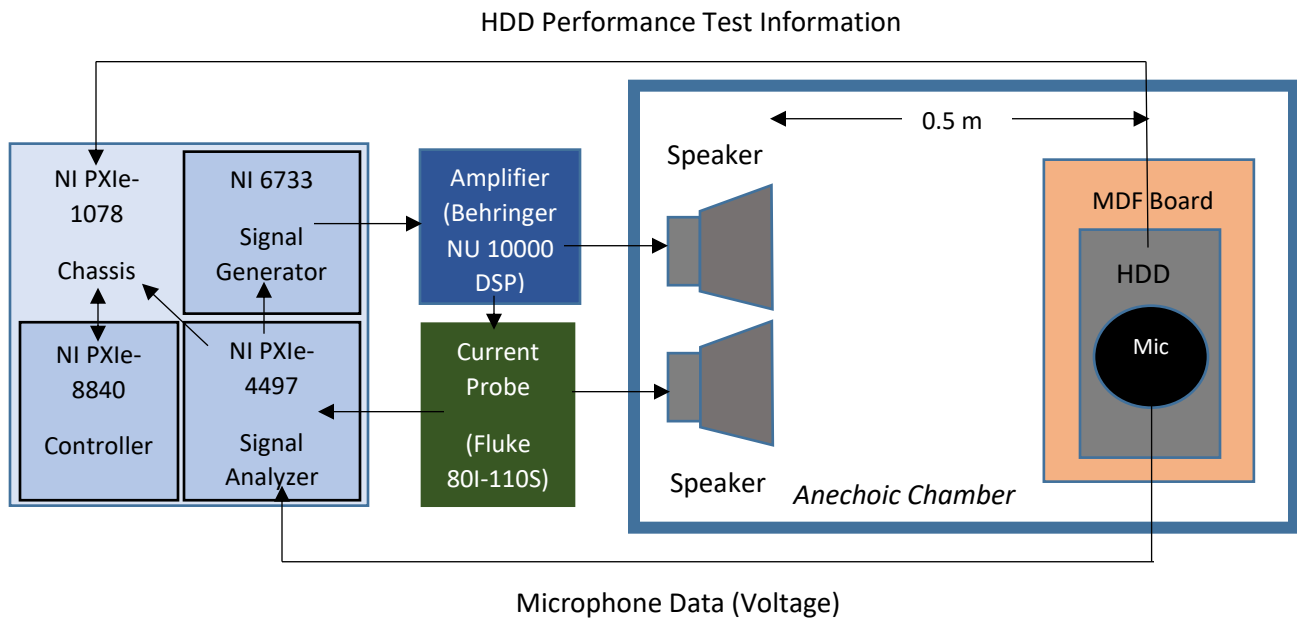
*Fig 2.2: Block diagram of the test set-up. The HDDs were placed in an anechoic chamber and were exposed to sound produced through the speakers by the signal generator.*
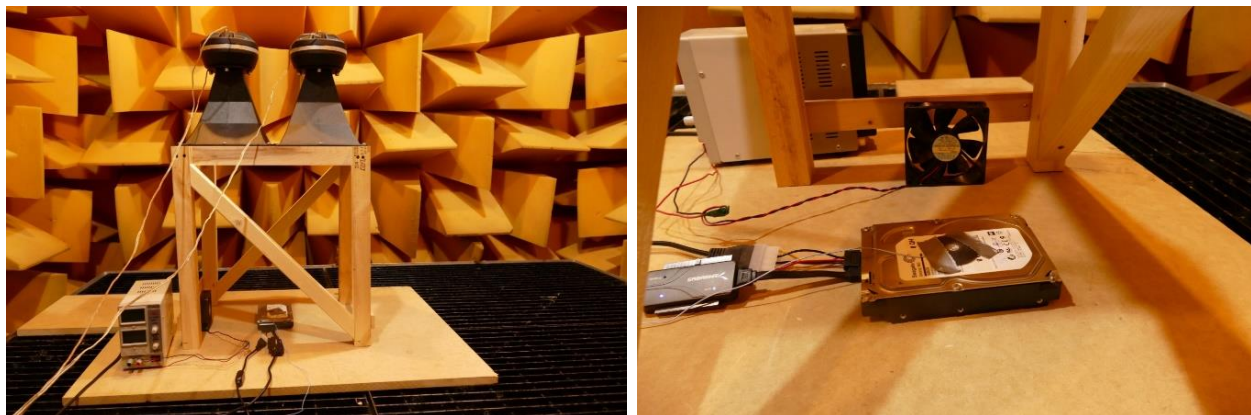


*Fig 2.3: The test set-up showing the HDD on a reflective MDF board in the anechoic chamber at Michigan Technological University with the speakers placed 0.5 m above the HDD (left). The surface mount microphone, a fan used for cooling the HDD and the USB 3.0-to-SATA cables used for the performance test (right).*

A custom LabVIEW program was designed to generate the pink noise, to be sent to the compression drivers at one-third octave frequencies bands. The LabVIEW program also measured the SPL from the microphone and performed random read/write tests for the performance analysis of the HDDs. The data size for each read or write test was roughly 1 GB with packets of smaller data ranging from 100 KB to 8 MB sent or received in a random sequence. The speed of the read or write test was assessed by measuring the central processing unit (CPU) time taken to complete the process. The HDD performance test involved a write test followed by the read test. For each performance evaluation, the process repeated 9 times for read operations and 9 times for write operations and an average speed was calculated.

The initial read and write speeds were measured at least 3 times per HDD to create a baseline performance in a quiet environment (46 dBA). Some HDDs were found to be sensitive to ambient temperature and so a fan was used to cool the drives. The OTO and overall SPL, or $L_{eq}$, of the background noise is shown in Fig. 2.4. An average of the baseline speeds was used as the default performance of each HDD. Then the HDDs were tested over the frequency range from 500 Hz to 10k Hz in OTO frequency bands and successively increasing SPLs. Three HDDs were tested up to 20 kHz to understand the effects of high frequency content. At each OTO frequency band, the SPL was successively increased by 5 dB until the performance of the HDDs were reduced by 50% from the baseline condition. The range between 80 dB (re 20 µPa) and 130 dB (re 20 µPa) was evaluated in this study. The 50% performance metric was chosen as a stop condition because it was observed early-on that the performance of the HDDs dropped dramatically after reaching a 50% performance reduction from the default value. Fig. 2.5 shows a representative example of the dramatic reduction in performance of the HDDs at SPLs above the 50% performance reduction point. This stop condition helped to avoid permanent damage to the HDDs during the test. Once

the HDD performance reduced to 50% or an SPL of 130 dB (re 20 µPa) was measured, the program moved on to the next OTO frequency band and started the process again. The HDDs were re-tested in the quiet environment condition several times throughout the testing process to ensure no permanent damage was induced.
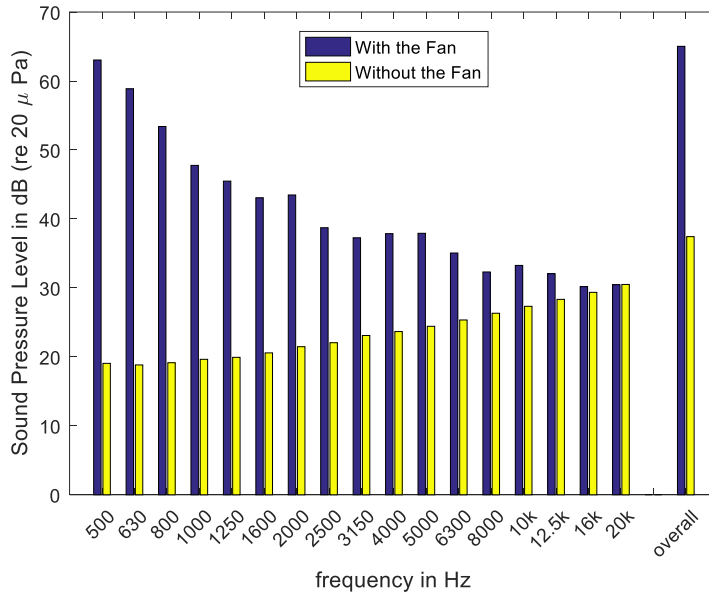


*Fig 2.4: The OTO band spectrum of the background noise with and without the fan inside the anechoic chamber at Michigan Technological University. Notice the background noise is more than 10 dB below the starting condition of the tests (80 dB), giving adequate signal-to-noise ratio even with the cooling fan running.*

A total of 14 HDDs were tested with different memory sizes ranging from 120 GB to 10 TB from different manufacturers of 2.5" and 3.5" HDDs. The tested HDD details are shown in Table 2.1.

*Table 2.1 - Details of the HDDs tested in this study*

| Manufacturer | Memory Size | Model No | Size (in) | RPM | Interface | Helium Filled |
|---|---|---|---|---|---|---|
| Western Digital | 320 GB | WD3200BEKX | 2.5 | 7200 | SATA | No |
| Hitachi | 120 GB | HTS541612J9SA00 | 2.5 | 5400 | SATA | No |
| Hitachi | 320 GB | HCS5C1032CLA382 | 3.5 | 7200 | SATA | No |
| Hitachi | 2 TB | HUA723020ALA640 | 3.5 | 7200 | SATA | No |
| Hitachi | 1 TB | HDE721010SLA330 (0A38028) | 3.5 | 7200 | SATA | No |
| Seagate | 500 GB | ST3500514NS | 3.5 | 7200 | SATA | No |
| Seagate | 500 GB | ST500DM002 | 3.5 | 7200 | SATA | No |
| Toshiba | 6 TB | MG04ACA600E | 3.5 | 7200 | SATA | No |
| Toshiba | 6 TB | MG04ACA600E | 3.5 | 7200 | SATA | No |
| Western Digital | 6 TB | WD6001FSYZ | 3.5 | 7200 | SATA | No |
| Western Digital | 6TB | WD6001F4PZ | 3.5 | 7200 | SATA | No |
| HGST | 8 TB | 0F23267 | 3.5 | 7200 | SATA | Yes |
| Seagate | 10 TB | ST10000NM0016 | 3.5 | 7200 | SATA | Yes |
| Western Digital | 10 TB | WD101KRYZ | 3.5 | 7200 | SATA | Yes |

**Hard Drive Performance Sensitivity to Sound**
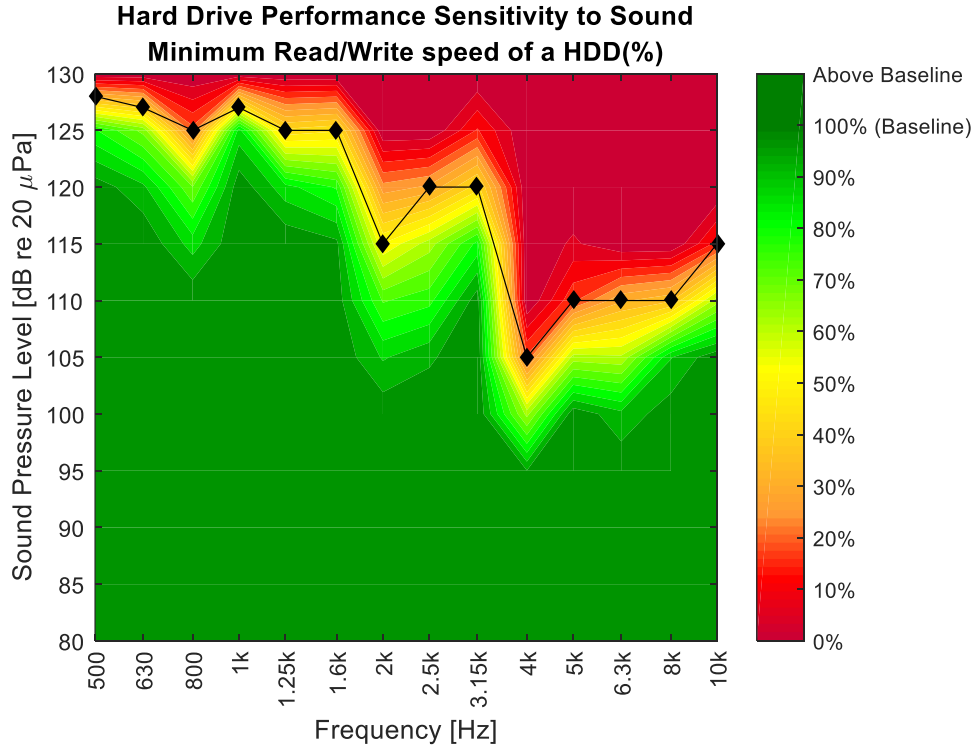
*Fig 2.5: The minimum of the read and write speeds as percentage of the respective baseline values shown in OTO frequency bands for a single hard drive. The performance of the HDD drops dramatically after reaching the 50% curve, shown by the black line with black diamond data points. The steep reduction in performance after the 50% point in these data are representative of the entire population of HDDs tested in this study.*

## 2.3 RESULTS AND DISCUSSION

In this paper the results are grouped based on the type of HDDs. The results of the two Laptop drives that have a 2.5" disk, are shown in Fig. 2.6. The Enterprise drives have a 3.5" disk. Enterprise drives may or may not be Helium filled, so results showing both the Helium filled and non-Helium filled Enterprise drives are shown in Fig. 2.6 and Fig. 2.7, respectively. It should be noted that out of the 14 HDDs, only 4 of them (one helium filled Enterprise drive and 3 non-helium filled Enterprise drives) were tested for the OTO frequency band of 12.5 kHz, 16 kHz and 20 kHz.

This was because the compression drivers ran into failure conditions at the high amplitude test conditions at these higher frequencies.
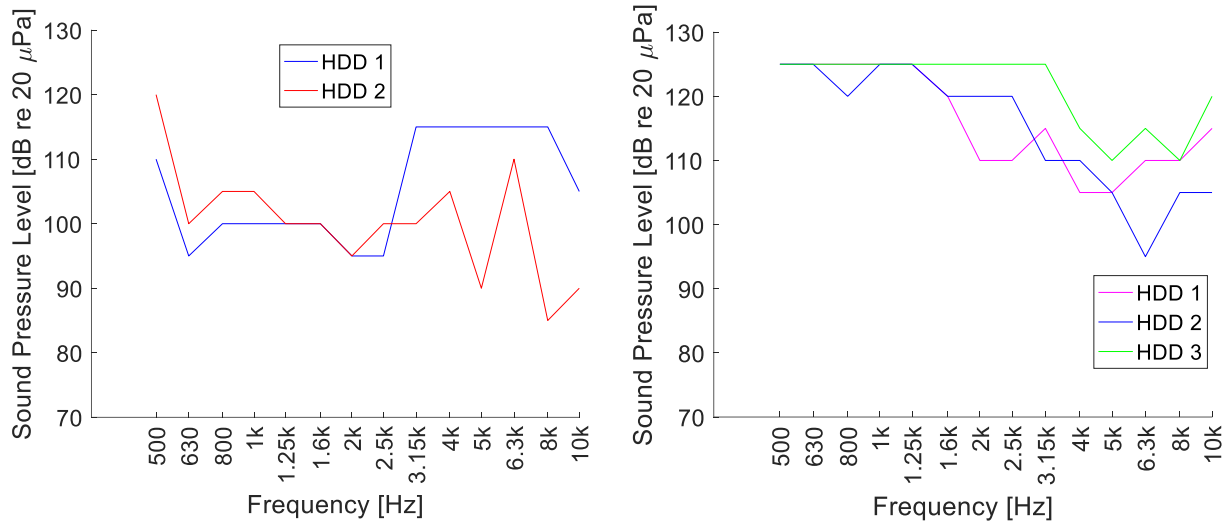


*Fig 2.6: The SPL at OTO frequency bands where the performance reduced by 50 % from the baseline values for the Laptop Drives (left) and the Helium Enterprise drives (right).*

It can be observed that the Laptop drives are more sensitive to noise in the OTO frequency bands from 630 Hz to 2.5 kHz and SPLs as low as 85 dB (re 20 µPa) can cause adverse effects on the HDDs performance. The helium filled Enterprise drives are more sensitive to noise at higher frequencies, ranging from 4 kHz to 10 kHz. It was observed that helium filled Enterprise HDDs were more robust than the Laptop drives and required higher levels of SPLs to cause a performance reduction. The non-helium Enterprise drives were also found to be sensitive to noise at lower frequencies, ranging from 630 Hz to 2.5 kHz similar to the Laptop drives.
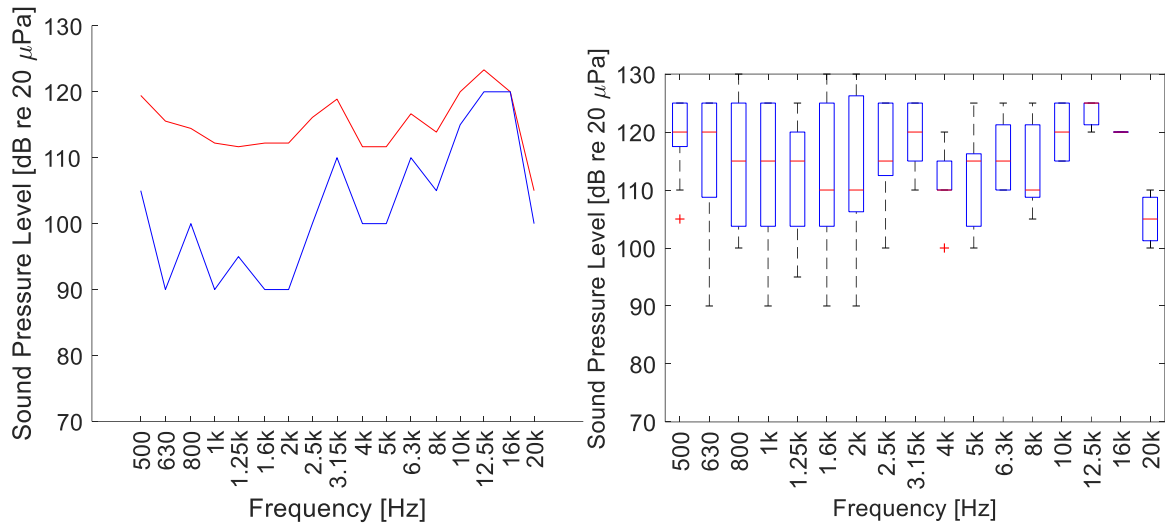
*Fig 2.7: The SPL at OTO frequency bands where the performance reduced by 50 % from the baseline values for the Non-Helium Enterprise drives (left). The curve in the red represents the average of the 50 % data points and the blue curve represents the minimum of the data. Box plot representation of the 50 % curve data points (right).*
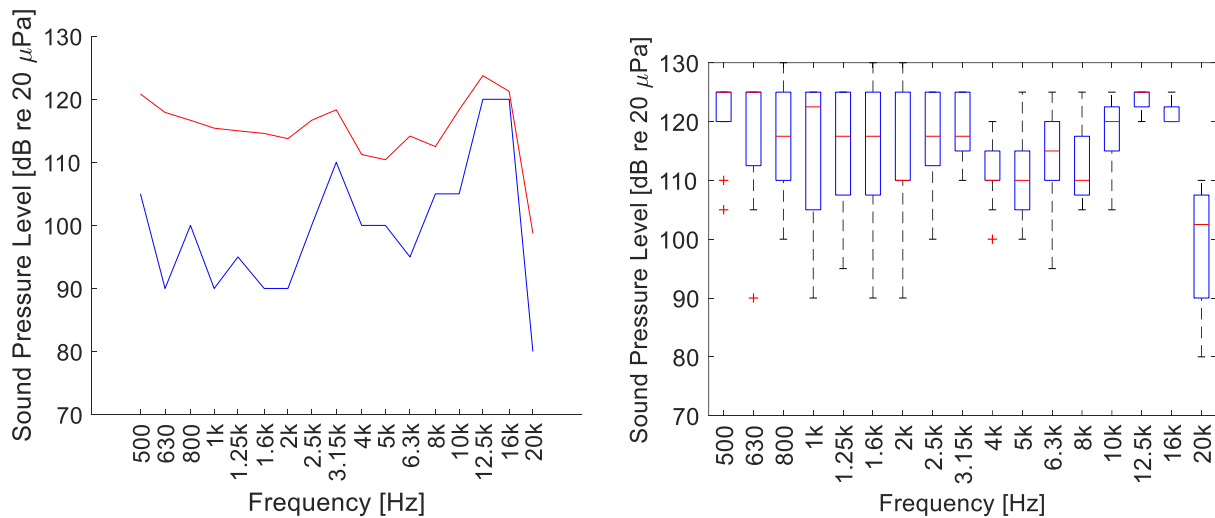


*Fig 2.8: The SPL at OTO frequency bands where the performance reduced by 50 % from the baseline values for all the Enterprise Drives (left). The curve in the red represents the average of the 50 % data points and the blue curve represents the minimum of the data. Box plot representation of the 50 % curve data points (right).*

The results for all the Enterprise drives are shown in Fig. 2.8. It contains both the helium as well as non-helium filled drives. It should be noted that out of the 4 HDDs, which were tested for the OTO frequency band from 12.5 kHz to 20 kHz, one particular drive was found to be very sensitive to noise at 20 kHz at 80 dB (re 20 µPa) SPL. Fig. 2.9 shows the results for the 11 non-helium HDDs which contains both the Laptop as well as Enterprise drives. Fig. 2.10 shows the results of all the 14 HDDs. It is shown that an SPL above 90 dB (re 20 µPa) in the frequency range from 500 Hz to 20 kHz can affect the HDDs performance depending on the HDDs in use.
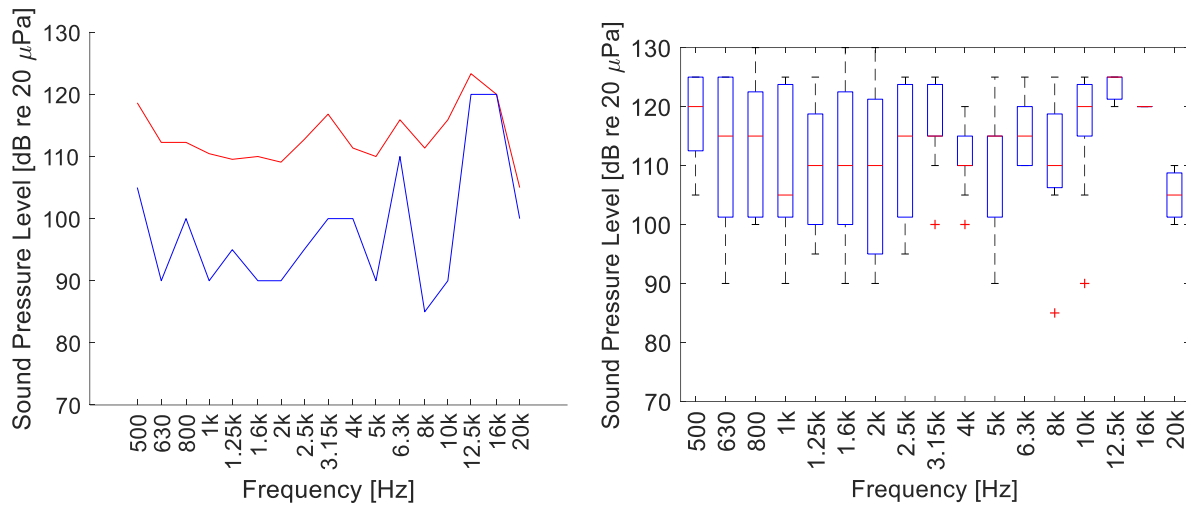


*Fig 2.9: The SPL at OTO frequency bands where the performance reduced by 50 % from the baseline values for the 11 non helium filled HDDs (left). The curve in the red represents the average of the 50 % data points and the blue curve represents the minimum of the data. Box plot representation of the 50 % curve data points (right).*
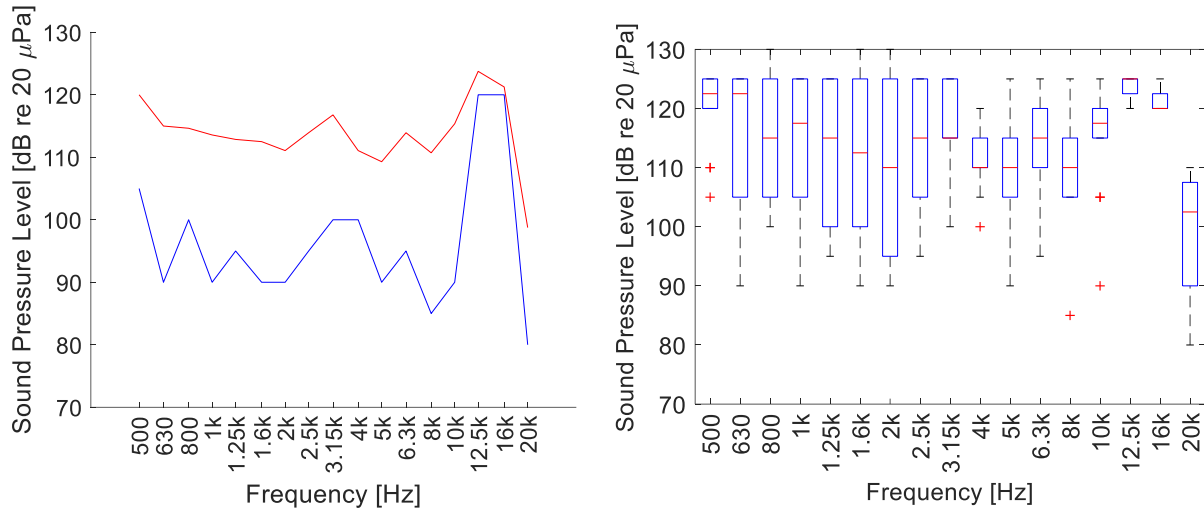
*Fig 2.10: The SPL at OTO frequency bands where the performance reduced by 50 %
from the baseline values for all the HDDs tested (left). The curve in the red represents the
average of the 50 % data points and the blue curve represents the minimum of the data. Box plot
representation of the 50 % curve data points (right).*

Two identical non-helium Enterprise drives manufactured by the same company and having the same model number were tested separately to check the drive-to-drive variation. The results of the 50 % curves obtained are shown in Fig. 2.11. It can be seen that the performance of a particular model of HDD remains consistent to within one 5 dB test increment, for the two samples tested. Some HDDs in this study were also tested multiple times for repeatability. No change was seen in the 50% performance reduction curves during the repeatability testing. In the analysis the write speed test was performed first followed by the read speed test and it was observed that the HDDs during the write speed test showed greater sensitivity to noise compared to read.
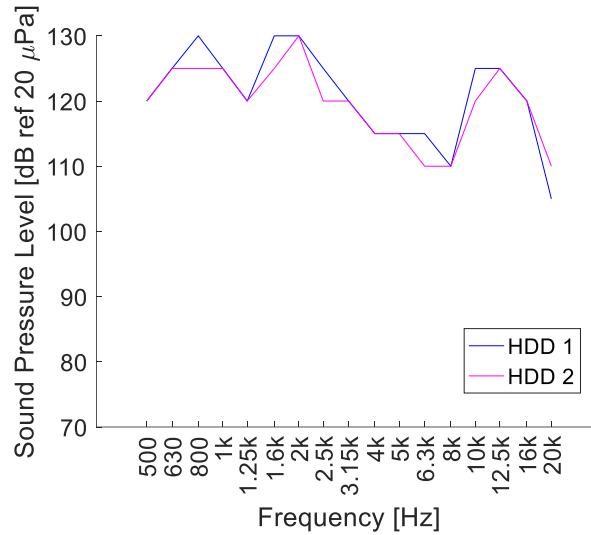
*Fig 2.11: Comparison of the SPL at OTO frequency bands where the performance reduced by 50 % from the baseline values for two identical non-helium filled Enterprise HDDs.*

Several additional anecdotal observations were made during these tests and are presented here as motivation for future study. Certain HDDs proved to be highly sensitive to the ambient temperature inside the anechoic chamber. As the temperature exceeded 20 – 25 ℃, the performance dropped drastically and caused the storage controller to stop the HDD due to over-heating. In this study, these situations were identified and the tests were repeated multiple times to obtain a consistent set of 50 % curve data points. Additionally, on repeated testing of a HDD (4 to 5 full cycles), some baseline read and write speeds changed from the initially measured baseline value (before the first run). After repeated testing, reduction in the baseline values compared to those of a new HDDs was noticed. Observations were also made of dramatic increases in the baseline value of the HDDs (up to 100% increase) after multiple tests immediately followed by a permanent failure on the next run. This may indicate that HDDs are sensitive to prolonged exposure to high amplitude noise and can cause detrimental effects on the HDDs performance over time, even if a single, high amplitude noise event doesn't immediately damage a disk.

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## 2.4 CONCLUSION

It is very critical during the manufacturing of inert gas fire suppression systems to consider the noise emissions from the source. HDDs are found to be sensitive to noise and an analysis of the frequencies and SPLs that affect the HDDs performance has been performed.

A test procedure has been laid out along with the measured data on the effect of noise on HDDs performance. A controlled environment was used by testing the HDDs in an anechoic chamber and a rigorous and random read and write speed test was performed. The random read and write work load consisted of data packets varying from 100 KB to 8 MB. As the performance test results were normalized to the baseline values it eliminates any overall performance reduction due to the hardware used in this test setup. The 50 % HDD performance curve is shown to be a good indicator of the HDDs performance.

Noise affects the HDDs during reading as well writing data on the drive. The frequency range from 4 kHz to 10 kHz has been found to be the most sensitive to HDDs performance. HDDs in the frequency range from 10 kHz to 20 kHz has been found to be less sensitive to noise. In the frequency range from 500 Hz to 3150 Hz, non-helium filled Enterprise HDDs were found to be very sensitive to noise at SPLs as low as 90 dB (re 20 μPa) while helium filled HDDs were found to have no reduction in performance below a SPL of 120 dB (re 20 μPa). The performance of the HDDs at lower frequencies, below 500 Hz, was not analyzed in this study but could be analyzed to obtain the performance parameters of the HDDs in the entire noise spectrum. These lower frequencies are less commonly associated with inert gas fire protection systems.

Many avenues of future exploration exist in this field. The HDDs are sensitive to ambient temperature and measures should be taken to maintain an ambient temperature below 18 ºC at the HDDs location to avoid performance reduction due to thermal load. An analysis of the HDDs

performance in a temperature controlled environment would provide the insight on thermal loading and measures could be taken to improve the HDDs performance. HDDs respond adversely to prolonged exposure to noise which was anecdotally observed during the test. A noise-dose-like calculation could be performed to analyze this phenomenon. A proper analysis of the modes of vibration of the platter and the head gimbals assembly would allow us to identify the reasons of failure at certain frequency. This would allow the inert gas fire suppression system to be designed such that it avoids the critical modal frequencies of the HDDs. Experiments could be performed by mounting the HDDs in racks as in Data Centers to acknowledge any effects on the HDDs performance due to the coupling of sound with the structural mounts.

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# 3. Evaluation of hard disk drive modal parameters with respect to acoustic drive failures

## 3.1 Introduction

Hard Disk Drives are an important part of today's society to store digital information. Servers store digital information in Hard Disk Drives (HDD) in Data Centers. The data centers are equipped with inert gas fire suppression system. The inert gas fire suppression system produces broad band noise during its operation. Fig 3.1 shows the autopower spectrum of the noise produced during its operation. It is normalized to the maximum value at 630 Hz one-third octave center frequency band.
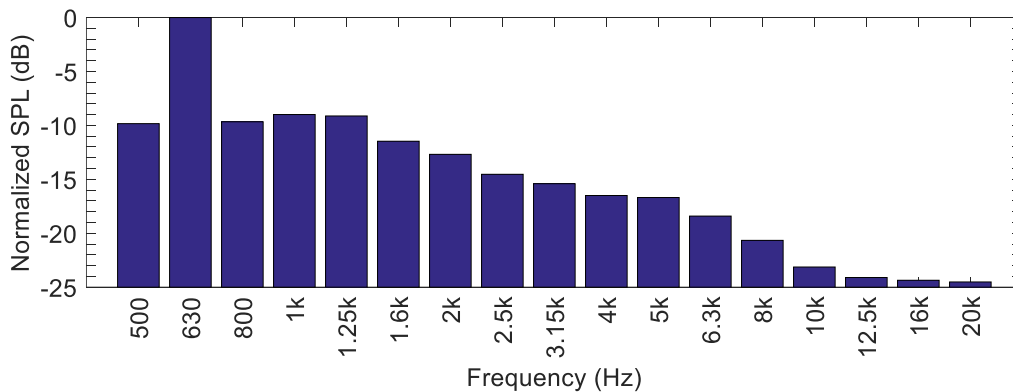


*Fig 3.1: The autopower spectrum of the sound produced during the extinguishing event through*

*an inert gas fire suppression system normalized to the maximum value at 630 Hz OTO*

*Frequency Band*

Studies performed by Siemens Corporation and IBM show that HDDs are sensitive to noise. They observed that at frequencies between 2 kHz to 8 kHz, the read and write performance of HDDs were reduced when exposed to noisy environments (~80 dB – 130 dB re 20 µPa)

compared to the read and write values of the HDDs in background noise environment (~60 dB re 20 µPa) [1]. In order to investigate this phenomenon further experiments were performed in Michigan Technological University on a set of 14 HDDs. Pink noise at one-third octave frequencies were produced and the HDDs were exposed to that noise at Sound Pressure Levels ranging from 80 dB to 130 dB (re 20 µPa). Read and Write speed analysis of the HDDs in such noisy environments with frequencies ranging from 500 Hz to 20 kHz were performed in the Anechoic Chamber. The results showed that particular HDDs are sensitive to noise at different frequencies. Analysis by IBM show that HDDs are more sensitive to noise at frequencies which match the modal frequencies of the HDDs system [2].

The focus of this project is to obtain the modal frequencies of the platter and the head gimbal assembly of a HDDs and compare the results with the Acoustic Performance graph of that HDD. The mode shapes and the modal frequencies of the platter and the head gimbal assembly have been obtained through Impact Testing. The results have been validated by comparing the mode shapes and the modal frequencies with a Finite Element Model of the platter and the head gimbal assembly. The results have also been compared with the Acoustic Performance of HDDs. A detailed description of the Test Set-up and Modal Parameter estimation method has been discussed.

## 3.2 Methods and Test Set-up

The HDDs used for this analysis is a Western Digital 6TB 3.5" AE Datacenter Archive SATA III 64 MB Cache Enterprise Hard Drive (WD6001F4PZ). The material for the platter and the head gimbal assembly was considered as Aluminum [3]. Fig 3.2 shows the HDDs assembly on removing the cover plate.
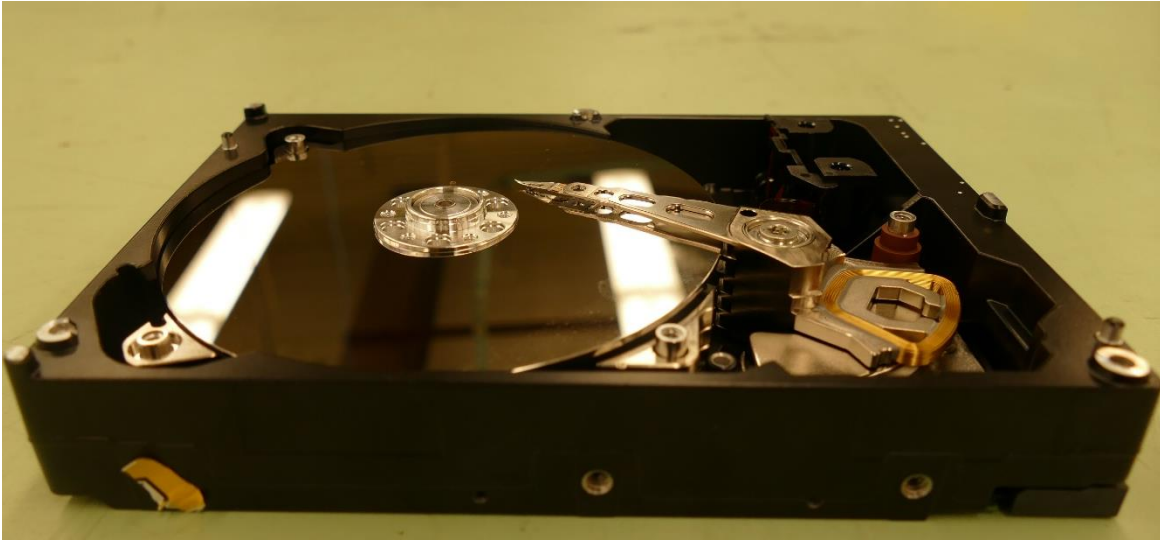
*Fig 3.2: HDD assembly on removing the cover plate of a WD 6TB 3.5" AE Datacenter Archive SATA III 64 MB Cache Enterprise Hard Drive (WD6001F4PZ). This model has 5 platters and 5 cantilever beams in the head gimbal assembly.*

Read and write performance analysis is performed by moving the head gimbal assembly on the platter. In order to investigate the modal parameters of the assembly, experiments were performed on the platter and the head gimbal assembly separately. LMS SCADAS was used to acquire all the data. LMS Test.Lab was used for post processing.

### 3.2.1 Experimental Test Set-up

**Platter**

The platter is an annular disk with a thickness of 1.3 mm, inner diameter of 25 mm and outer diameter of 95 mm. Impact test was performed on the platter using a Miniature Instrumented Impulse Hammer (PCB SN 086E80). The nominal sensitivity of the hammer is 22.5 mV/N and has a mass of 4.8 gm. The platter assembly consists of 5 platters. In order to study its behavior,

one platter was considered. The boundary conditions were fixed at inner edge and free at outer edge. To obtain the same boundary conditions in the test set-up, the platter was fixed using the same cover plate to screw it down. The platter was placed on top of the spacer ring. Efforts were taken to ensure that the platter has the same type of boundary condition as in its operating condition. The response was taken using a Probe Microphone (PCB 377B26) with a probe length of 20 mm with a probe diameter of 1.3 mm. The nominal sensitivity of the probe microphone is 2.15 mV/Pa. The diameter of the microphone is ¼". The range of operation is from 2 Hz to 20 kHz. Non-contact method was used as the transducers such as accelerometer mass loaded the structure. Fig 3.3 shows the mass loading due to an accelerometer mounted at location E1 and impact at location A1. Fig 3.4 shows the set-up used to perform modal analysis of the platter.
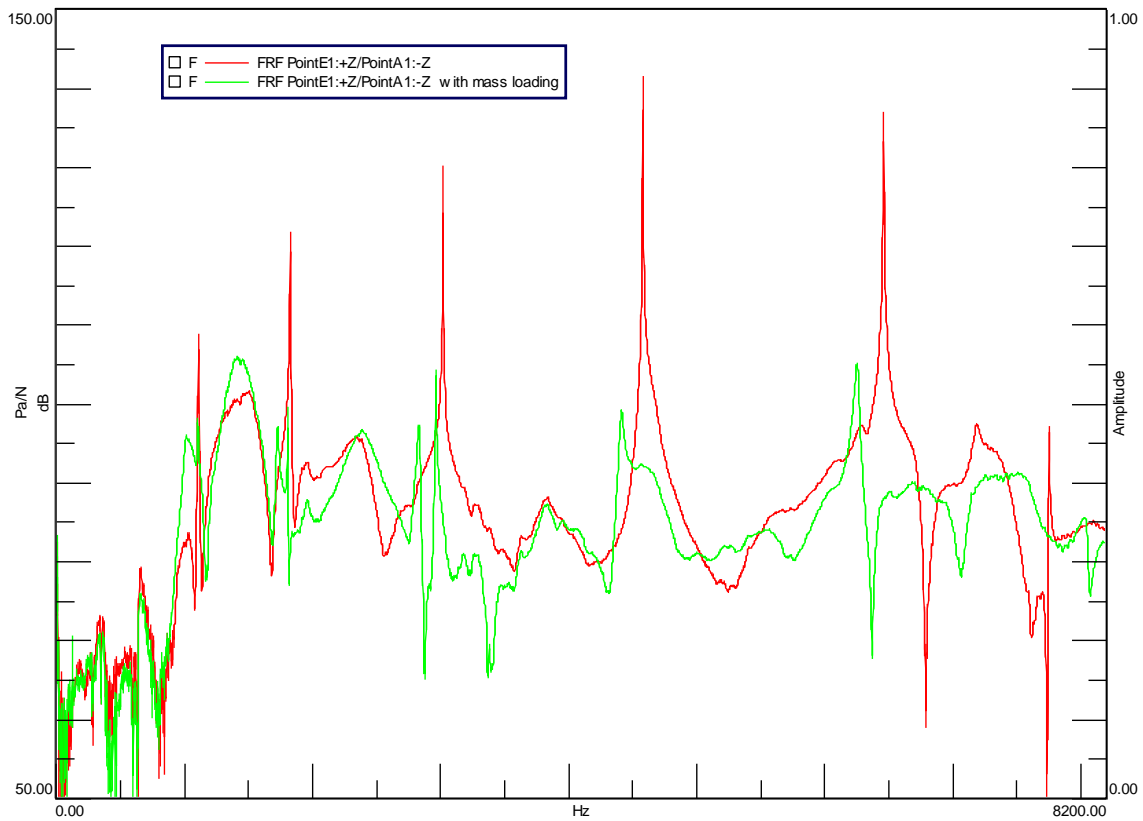


*Fig 3.3: Shows the FRF with mass loading effect on mounting an accelerometer on the platter*

*Fig 3.4: The test set-up of the platter used to perform modal analysis. The points from the outer radius to inner radius is named as point 1 to point 4.*

In Fig 3.3 it can be observed that due to the mass of the accelerometer the resonance of the structure moves towards left as frequency of the resonance is inversely proportional to its local mass. A total of 48 response locations were taken at every 30º at radiuses of 21 mm, 28 mm, 36 mm and 44 mm from the center on the platter. The impact hammer was used to excite the structure at A1. Responses were measured at all the response locations. The higher modal resolution was taken to differentiate between different mode shapes. The platter was screwed on the spindle of the HDD chassis. The chassis was clamped onto a wooded platform of a table using C-clamps.

**Head Gimbal Assembly**

The head gimbal assembly is used to seek data stored at various locations of the HDD. It consists of 5 cantilever beams which are equally spaced. One end of the beam is fixed and the other end is free. Impact Test was performed on the head gimbal assembly using the Miniature

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Instrumented Impulse Hammer (PCB SN 086E80). The nominal sensitivity of the hammer is 22.5 mV/N and has a mass of 4.8 gm. To obtain the response of one cantilever beam of the head gimbal assembly, the response of the other cantilever was damped using a highly damped material between the two cantilever beams. The response was taken using a Probe Microphone (PCB 377B26) with a probe length of 20 mm. The nominal sensitivity of the probe microphone is 2.15 mV/Pa. The diameter of the microphone is ¼". The range of operation is from 2 Hz to 20 kHz. Non-contact method was used as the transducers such as accelerometer mass loaded the structure. Fig 3.5 shows the set-up of the cantilever beam of the head gimbal assembly used to perform modal analysis.
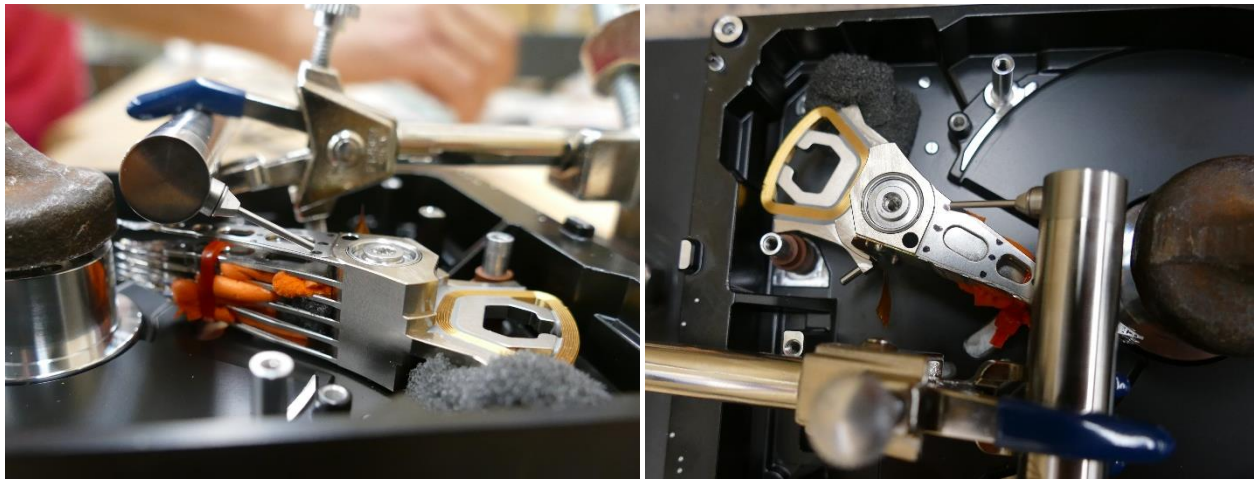


*Fig 3.5: Shows the test set-up of the cantilever of the head gimbal assembly used to perform modal analysis. Ear plugs were used to damp the response of the remaining cantilevers.*
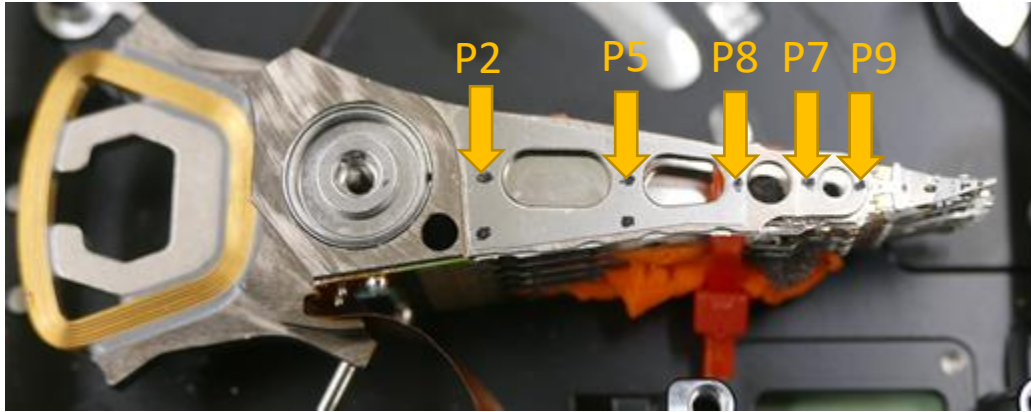
*Fig 3.6: The response and reference locations of the cantilever beam of the head gimbal*

*assembly*

A total of 5 response locations were selected on its center line shown in Fig 3.6. The probe microphone was used to measure the response. The impact hammer was used to excite the structure at location Point 8. Responses were measured at all the five locations.

## 3.2.2 Calibration

The probe microphone (PCB 377B26) with a probe length of 20 mm was used to measure the responses due to the impact. The microphone was calibrated using the CAL 200 at 94 dB at 1000 Hz. The sensitivity obtained was 2.13 mV/Pa. The response of the microphone due to the probe is flat up to 8 kHz and -1 dB from 8 kHz to 10 kHz. So, the correction due to the probe has been considered in the frequency band of interest.

Miniature Instrumented Impulse Hammer (PCB SN 086E80) was calibrated using the hanging mass method where an accelerometer of known sensitivity was mounted on the back of a mass of known weight. The accelerometer value due to the impact of the hammer was measured along with the response of the hammer due to the hit. The following equation was used calculate the sensitivity:

(F X Default Sensitivity)/ Actual Sensitivity = Mass X Accelerometer reading / Sensitivity of the accelerometer. The mass used for calibration is PCB TMS 9961005A (498 g including the weight of the bolts and the accelerometer). The accelerometer PCB 356A13 was calibrated using the calibration tab in LMS Test.Lab using a Handheld Shaker with 1 g rms as input at 159.2 Hz.

The calibrated values were obtained as shown in Table 3.1.

*Table 3.1: Sensitivity and serial number of the transducers used in the experiment*

| Sensitivity values obtained after Calibration | | | |
|---|---|---|---|
| **Transducer Type** | Microphone | Accelerometer | Impact Hammer |
| **Model No.** | PCB 377B26 | PCB 356A13 | PCB SN 086E80 |
| **Sensitivity** | 2.12 mV/Pa | 4.99 mV/g | 22.13 mV/N |

## 3.2.3 Post Processing of Experimental Data

The data acquired from the impact test of the platter and the head gimbal assembly was analyzed using LMS Test.Lab. Trigger values were set as appropriate along with the pre-trigger. The bandwidth was selected based on the autopower spectrum of input using rubber and steel tip. The autopower spectrum of the force input on platter and cantilever is shown in Fig 3.7 and 3.8. It can be seen that the rubber tip gives a bandwidth of 2700 Hz and the steel tip excites the structure up to 8192 Hz for the platter. A bandwidth of 8192 Hz with a frequency resolution of 1 Hz was selected due to the impact using steel tip for the platter. In Fig 3.8, it can be seen that both the rubber and the steel tip excites the structure up to 615 Hz.
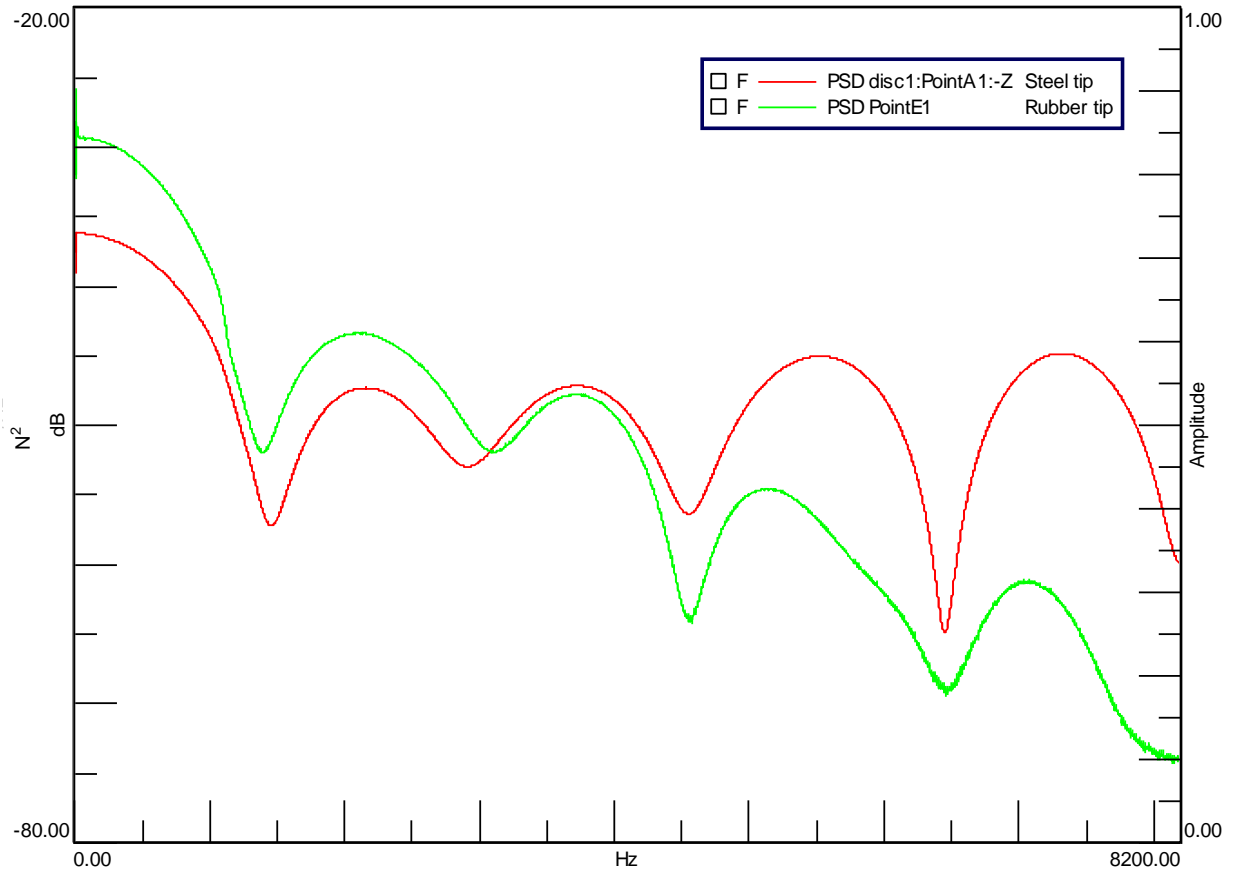
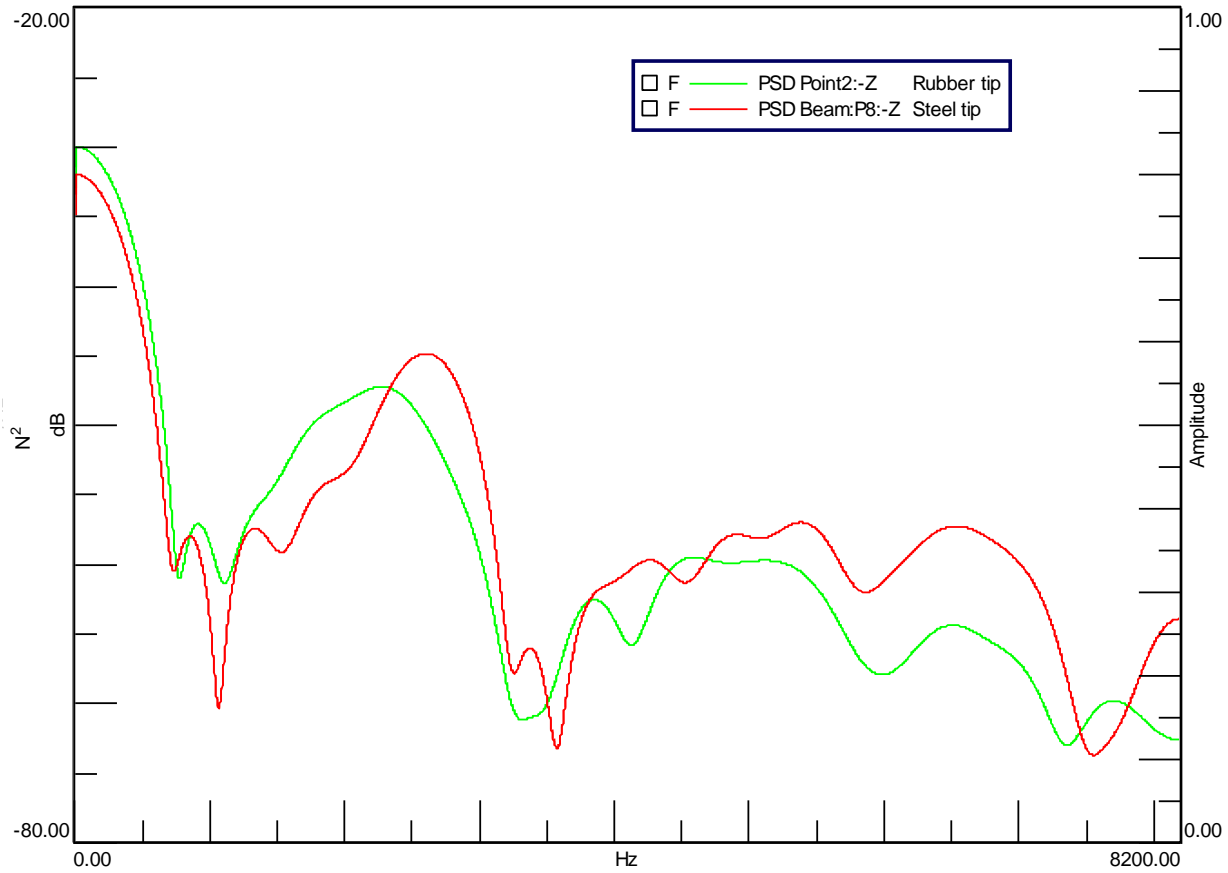*Fig 3.7: Autopower spectrum of the force impact using rubber tip and steel tip on the platter.*

*Fig 3.8: Autopower spectrum of the force impact using rubber tip and steel tip on the cantilever.*

Force exponential window was applied on the reference channel and exponential window on the response channel. Initially the reciprocity check was performed. The platter was excited at location A1 and response was taken at location E1 and vice versa. The cantilever was excited at location Point 8 and response was measured at Point 5 and vice versa. Fig 3.9 and 3.10 shows the reciprocity check of the platter and the cantilever. This shows that the structures behave linearly. The reciprocity measurement for the cantilever is not very accurate as it may be due to the difference in background noise and non-linearity due to the support material glued to the beam.

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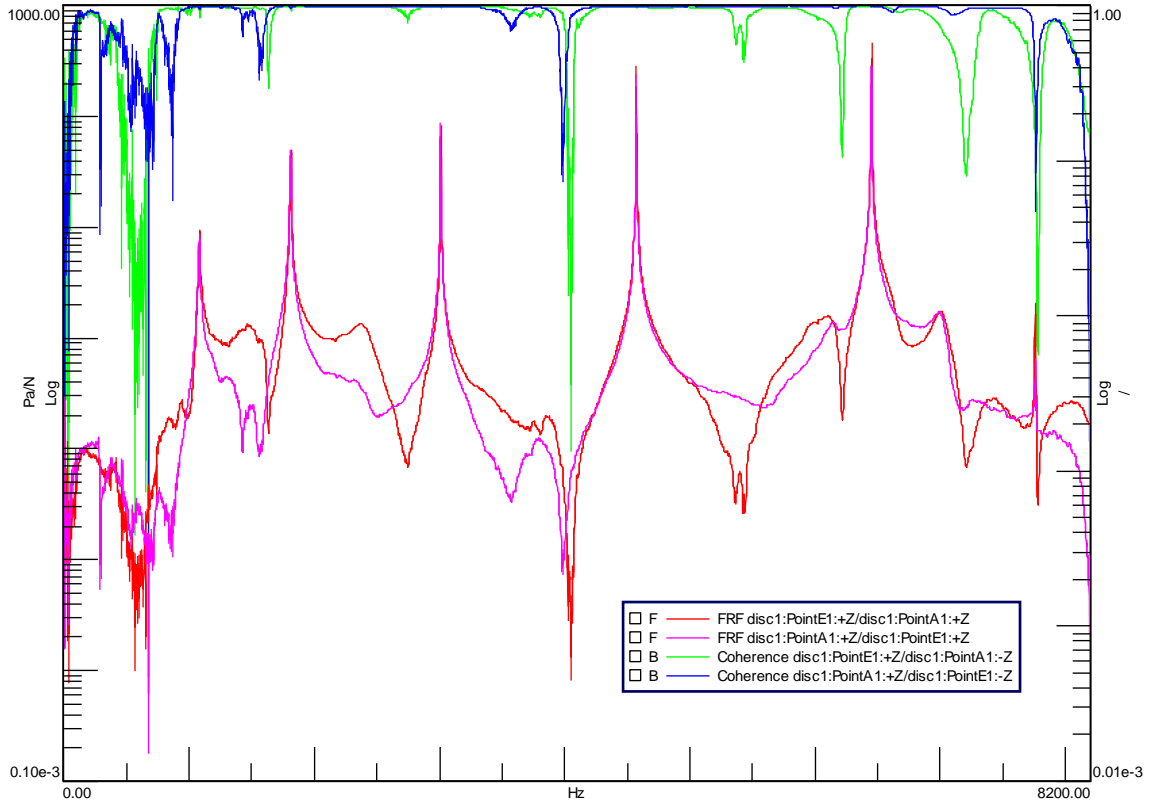
*Fig 3.9: The reciprocity checks for the platter along with its coherence. The response and reference locations are point A1 and point E1 and vice versa.*
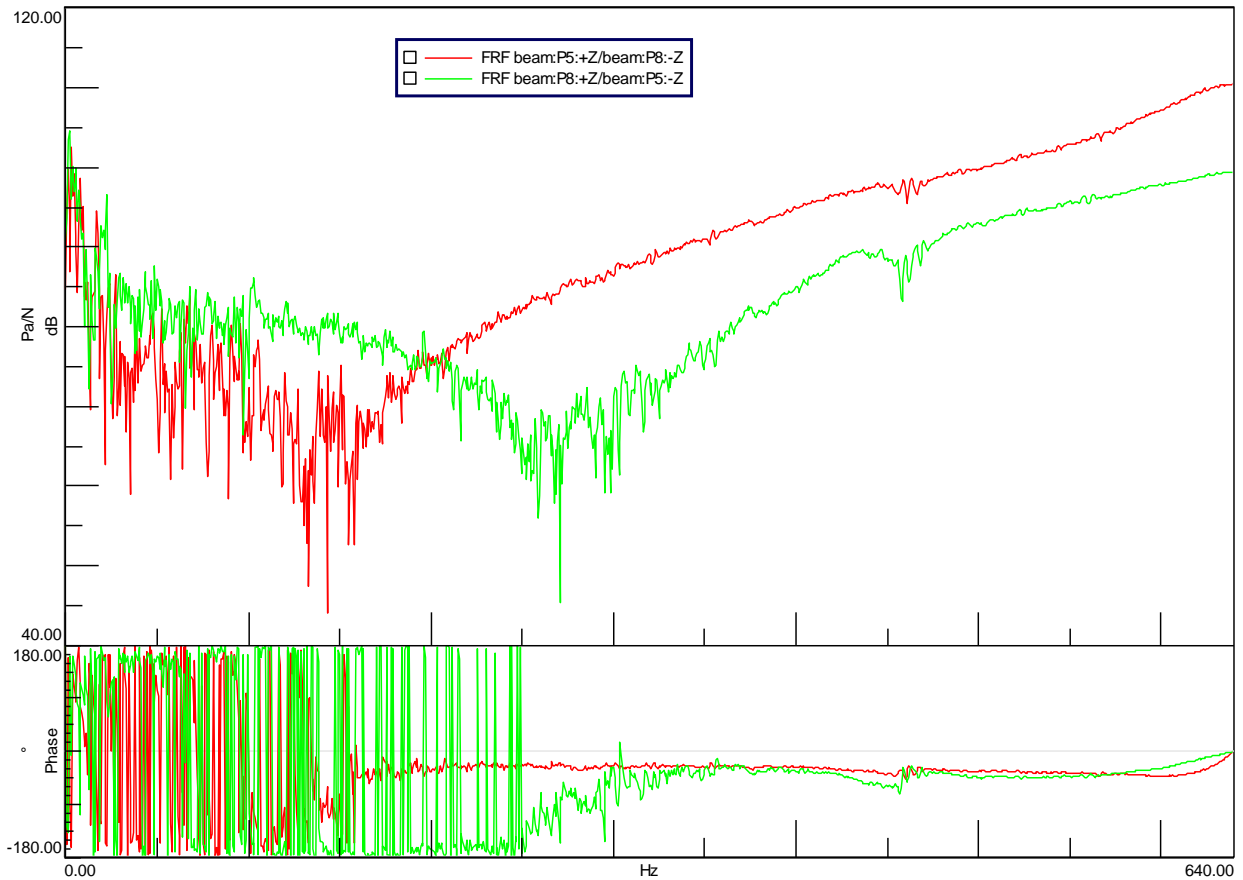
*Fig 3.10: The reciprocity checks for the cantilever along with its coherence. The response and reference locations are point 8 and point 5 and vice versa.*

The drive point measurements of the platter and the cantilever are shown in Fig 3.11 and 3.12 respectively. Drive points are required to scale the mode shape vectors. It can be seen that the driving point measurements have no saddle points. The cantilever has been observed to contain two sheets on top and bottom of the structure to damp its vibration response. The FRF measurements also show evidence of this damping. Also, the structure could not be excited above 615 Hz.
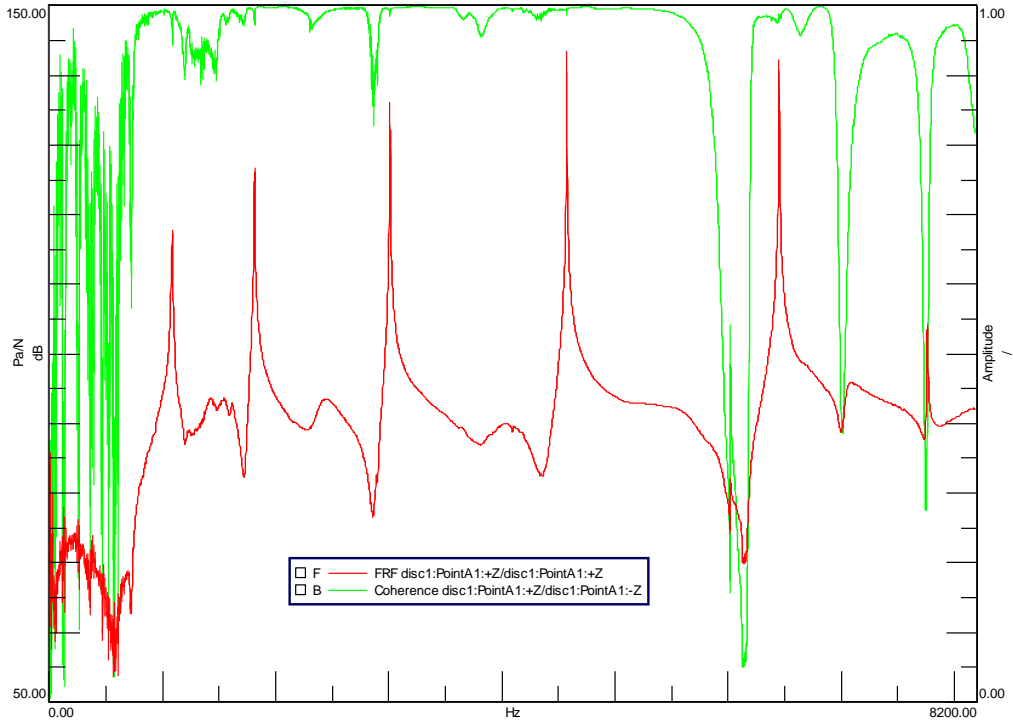
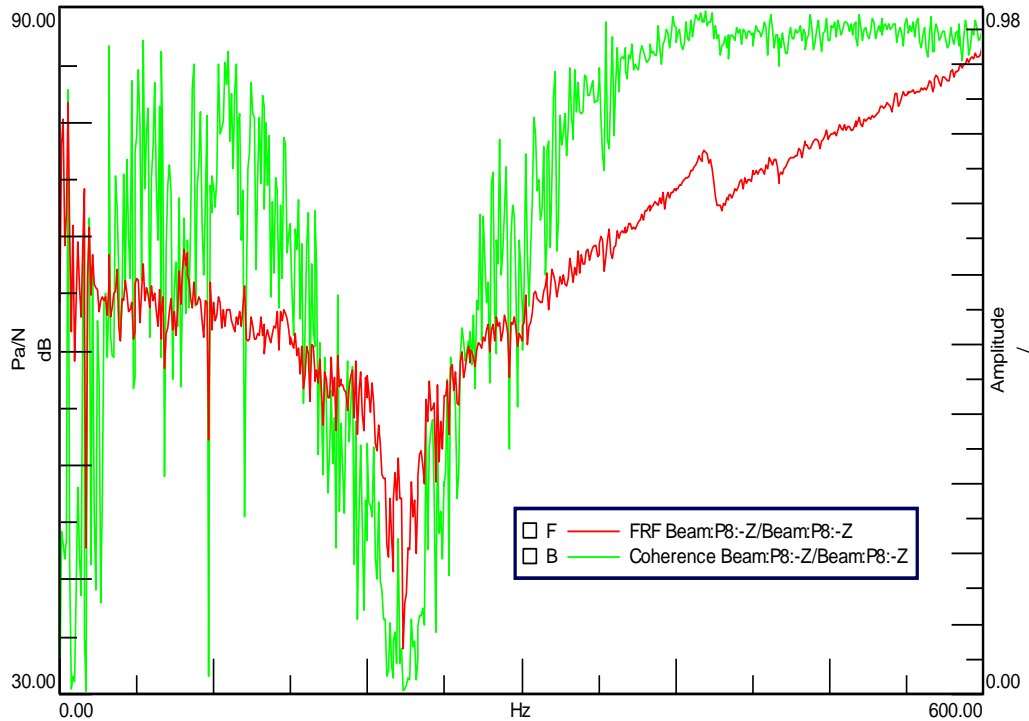*Fig 3.11: Drive point FRF of the platter due to response and reference at location point A1.*

*Fig 3.12: Drive point FRF of the cantilever due to response and reference at location point 6.*

The parameter estimation algorithm used is PolyMAX. A sample FRF of the platter and the cantilever is shown in Fig 3.13 and 3.14. It has been observed from Fig 3.13 that that platter shows high amplitude response at 5 certain frequencies. The stabilization diagram of the TMDOF and PolyMAX is shown in Fig 3.15 – 3.18. It can be seen that PolyMAX could identify the closely spaced poles and shows stable poles. TMDOF could not differentiate between closely spaced modes but it also shows stable poles at the frequencies of high amplitude response. The modes were selected based on the stabilization diagram of the PolyMAX. It should be noted that the system has many modes but only the modes with high response have been identified. Fig 3.19, 3.20 and 3.21 shows the FRF synthesis for the platter and the cantilever. Fig 3.22 shows the MAC between PolyMAX and TMDOF parameter estimated results.
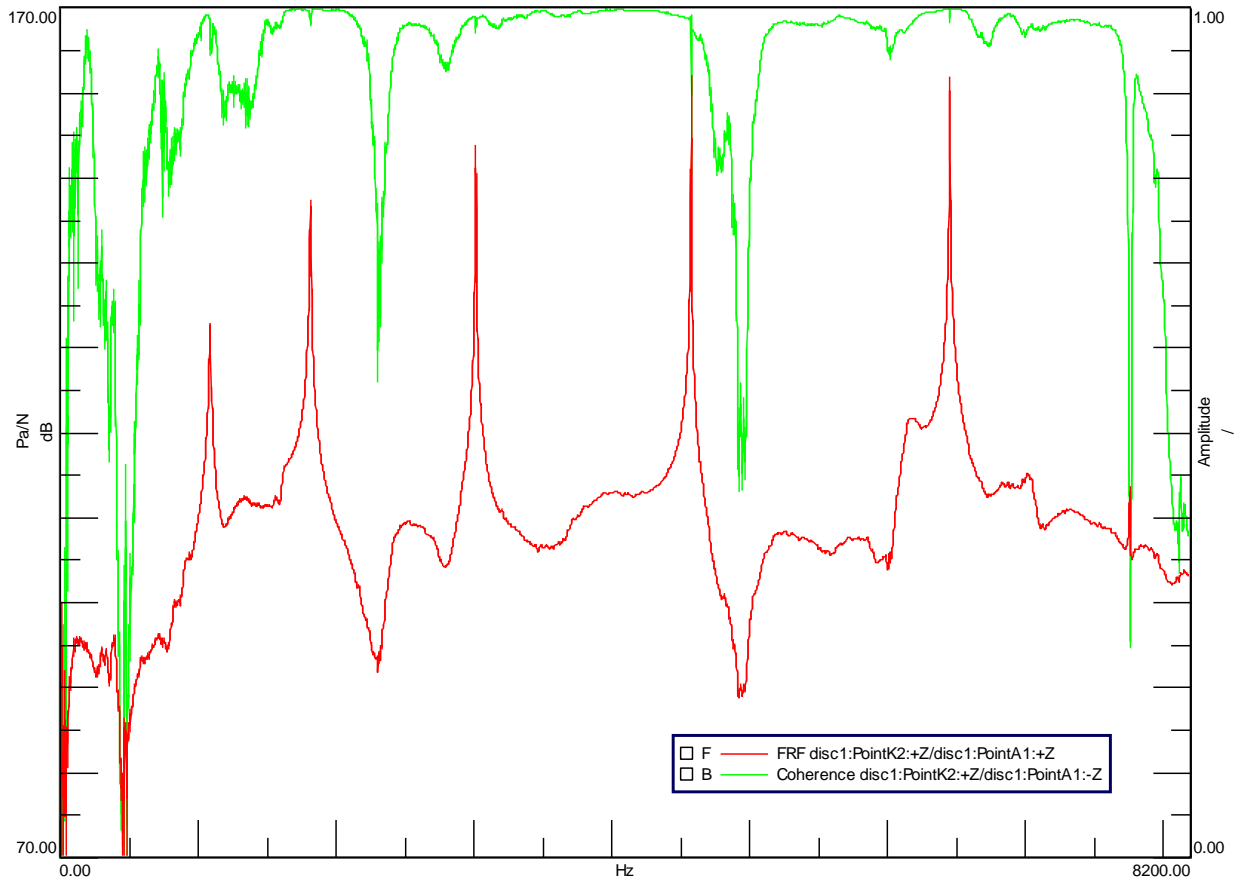
*Fig 3.13: FRF due to reference at Point A1 and response at Point K1 of the platter*
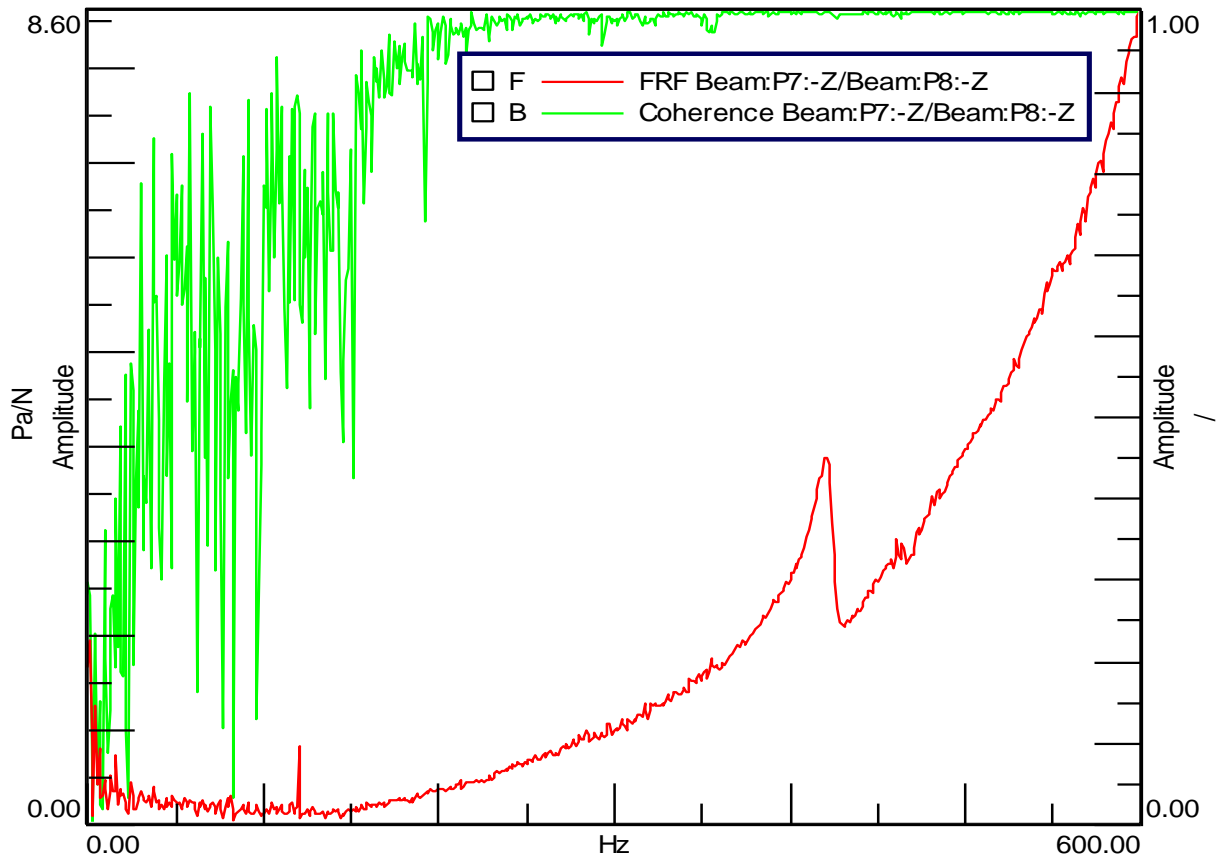
*Fig 3.14: FRF due to reference at Point 8 and response at Point 7 of the cantilever*

It can be observed from Fig 3.19 that the correlation between the synthesized FRF and the measured FRF at point J4 due to impact at A1 is 13.92%. This shows that the response of this location does not yield reliable results. The best correlation obtained between point A1 and E1 was 82.5%. The overall correlation is very small for the cantilever.

From Fig 3.22 it can be observed that the MAC between TMDOF and PolyMAX of the platter drops for the third and fourth mode due to the variance in calculation between the two methods.
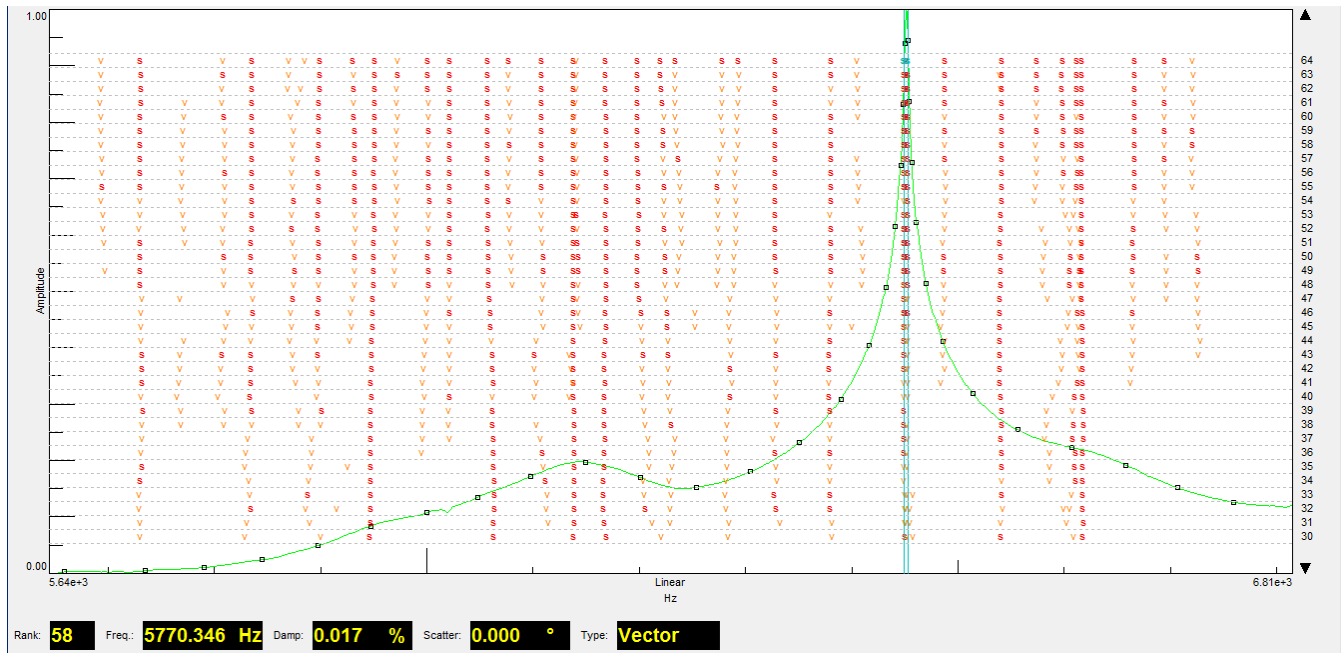
*Fig 3.15: Stabilization diagram of the platter using PolyMAX for the bandwidth 5400 Hz to 6700*
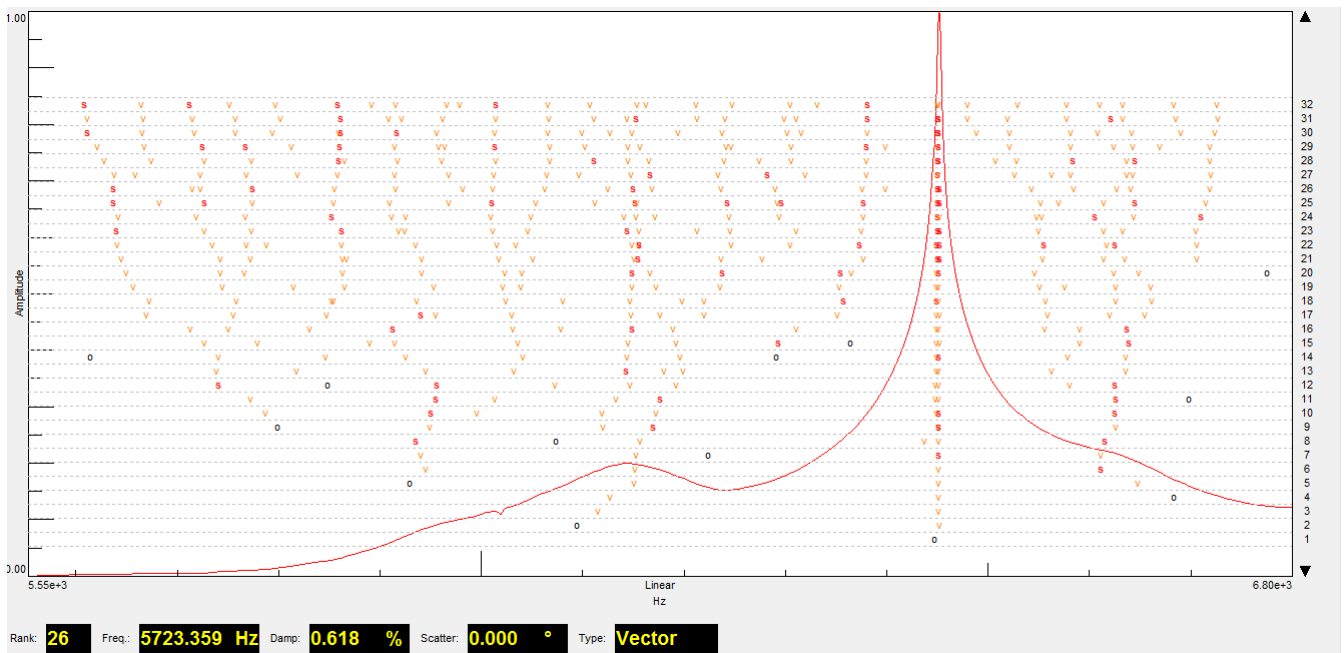
*Hz*



*Fig 3.16: Stabilization diagram of the platter using TMDOF for the bandwidth 5400 Hz to 6700*
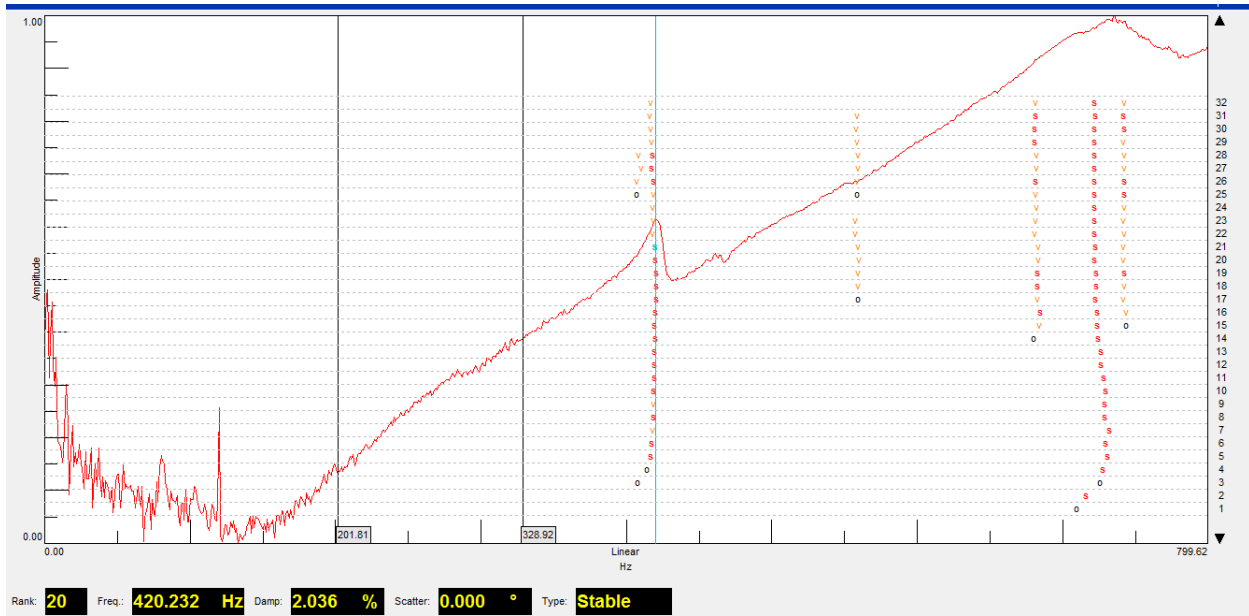
*Hz*

*Fig 3.17: Stabilization diagram of the cantilever using PolyMAX for the bandwidth 0 Hz to 800*
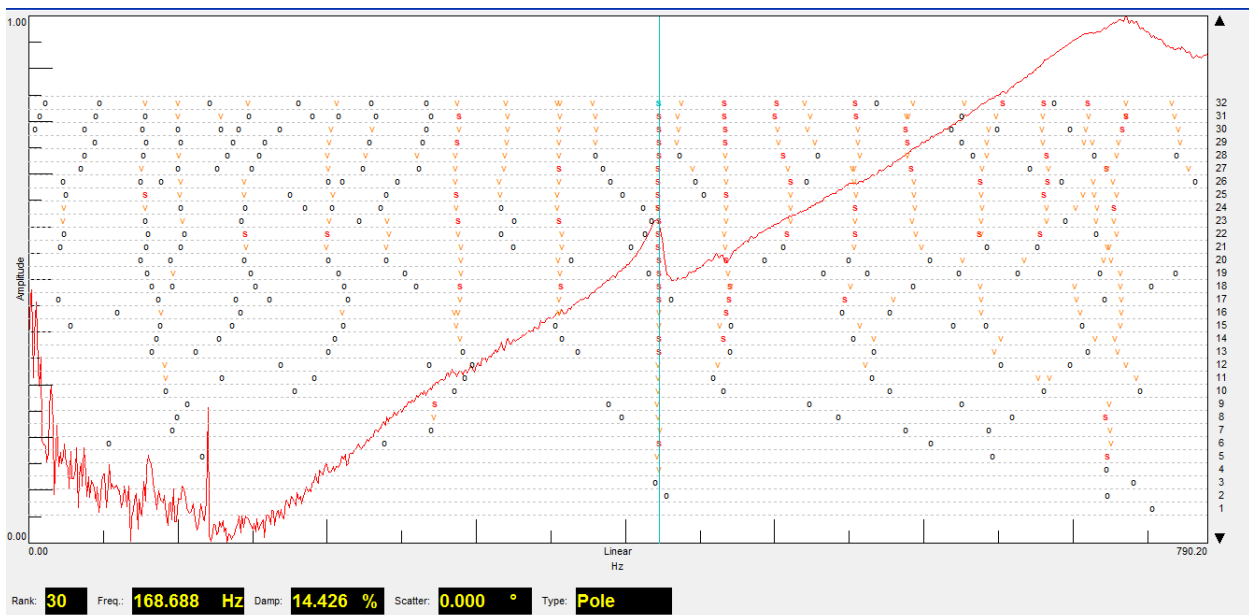
*Hz*



*Fig 3.18: Stabilization diagram of the cantilever using TMDOF for the bandwidth 0 Hz to 800*
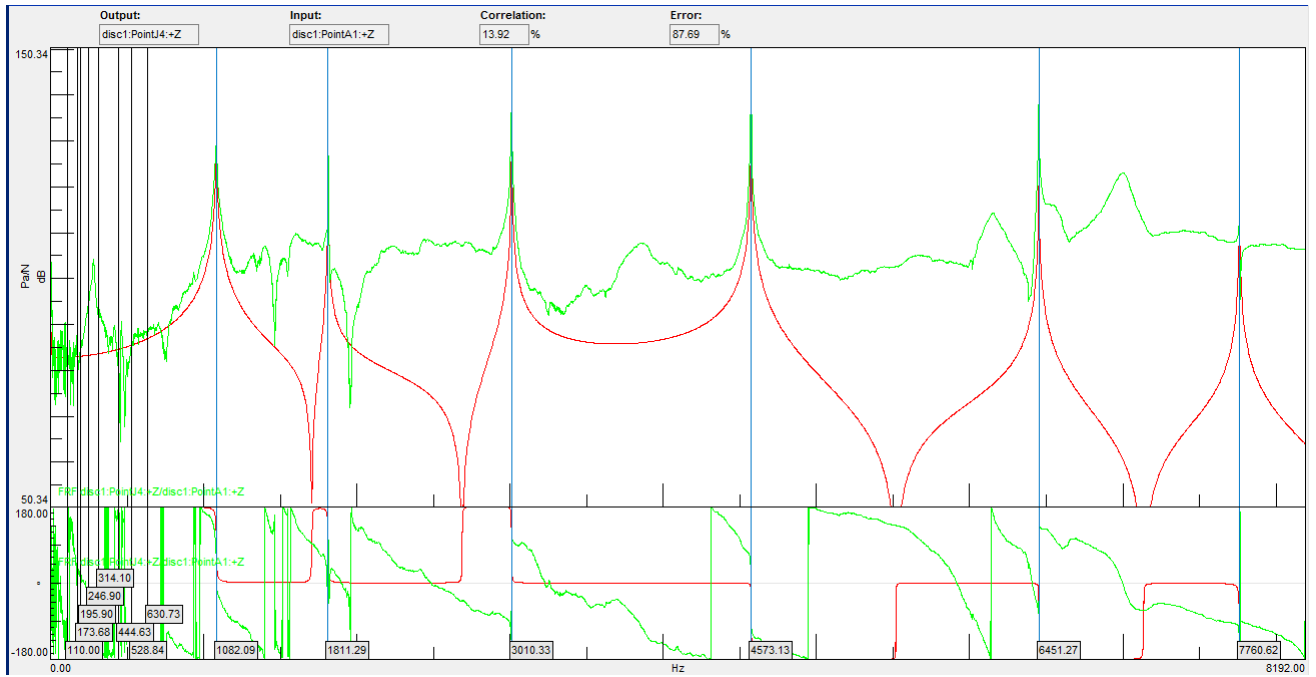
*Hz*

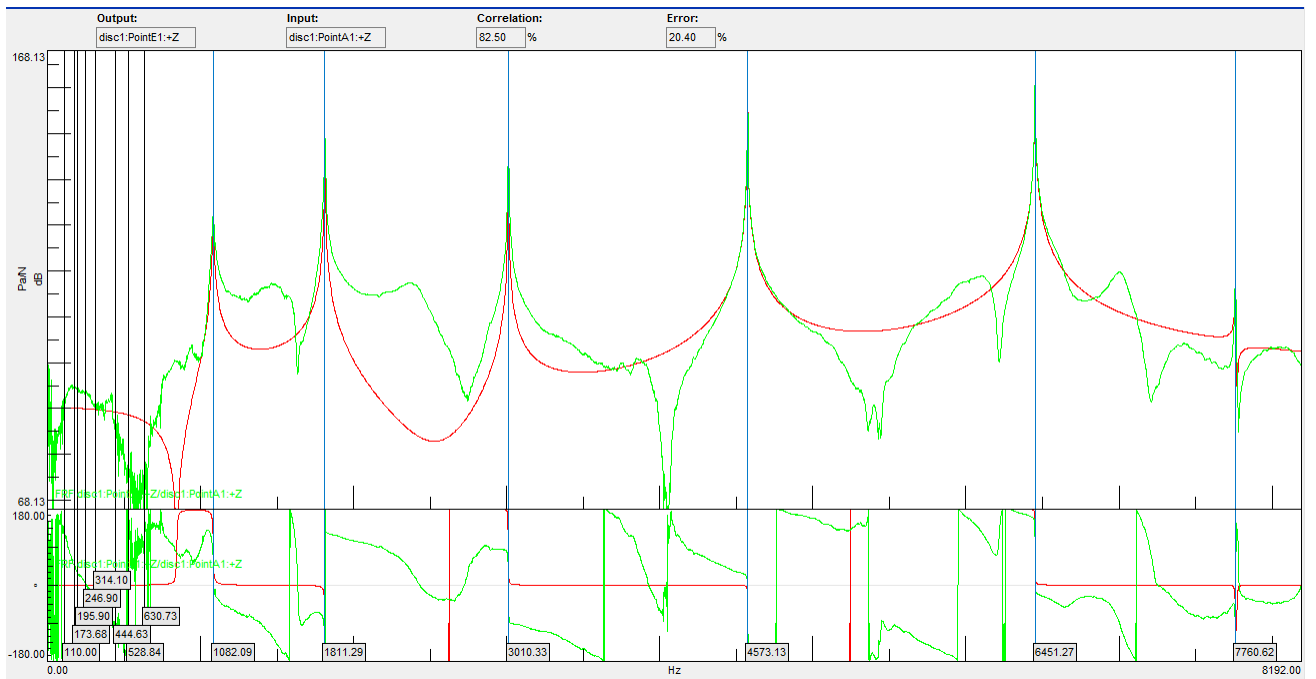*Fig 3.19: FRF synthesis with worst correlation (13.92 %) for the platter for the location J4*



*Fig 3.20: FRF synthesis with best correlation (82.5 %) for the platter for the location E1*
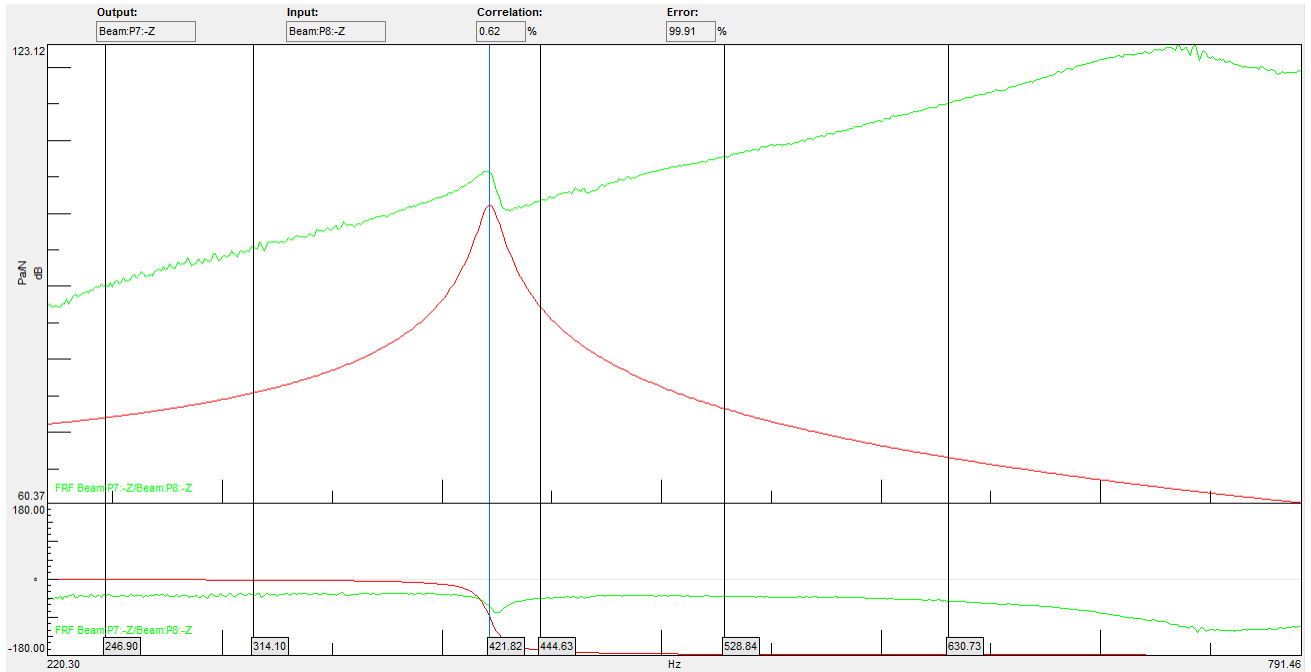
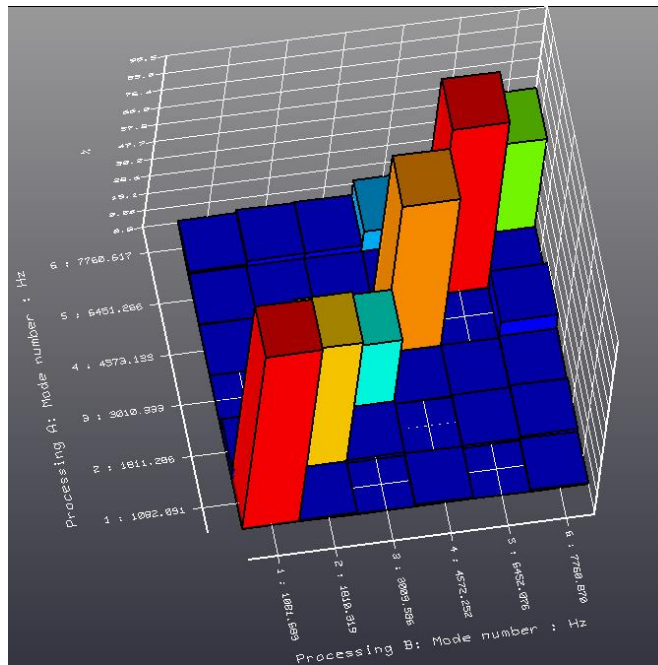*Fig 3.21: FRF synthesis correlation (0.62 %) for the cantilever for the location Point7*



*Fig 3.22: Shows the MAC between TMDOF and PolyMAX of the platter*

## 3.3 Finite Element Analysis of the Platter and the cantilever

The Finite Element Analysis of the platter and the cantilever was performed in NX. The material properties selected are shown in Table 3.2. The analysis was performed through 2D meshing of the structure with a thickness of 1.3 mm and the elements used were PShell of size 0.75 mm. The solver used is SOL103 Real Eigen Values. The model used for Finite Element Analysis is shown in Fig 3.23. The inner edge was fixed and the outer edge was free for the platter. One end of the cantilever was fixed and the other end was kept free.

*Table 3.2: The material properties of the structure used for the FEM analysis*

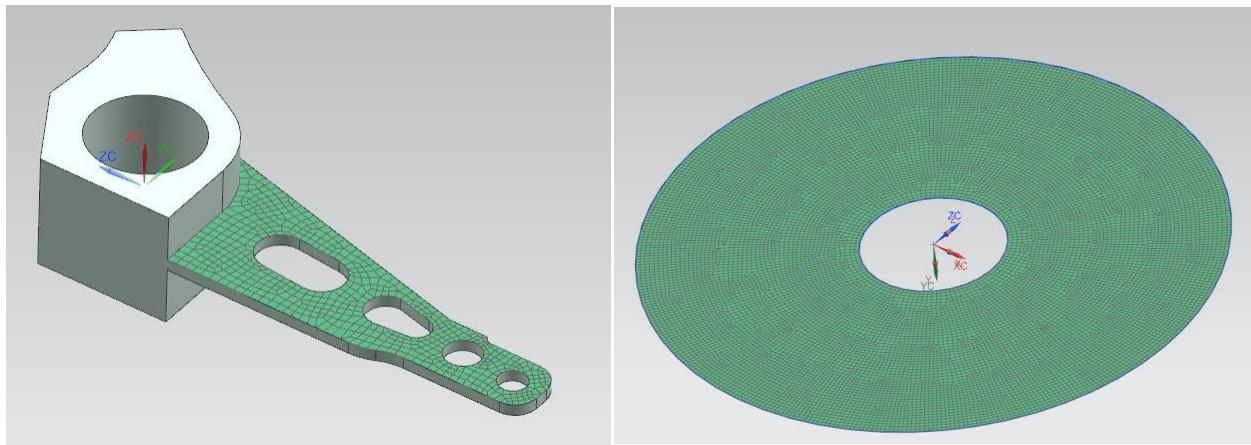| | |
|---|---|
| Young's Modulus | 80 G Pa |
| Poisson Ratio | 0.33 |
| Density | 2680 kg/m$^3$ |
| Material | Aluminum |



*Fig 3.23: The finite element model used to perform the Finite Element Analysis for mode shapes on the platter and the cantilever*

## 3.4 Results

The Modal parameters such as frequency, mode shape and damping values were obtained through Experimental Modal Analysis and FEM Analysis. The results obtained from FEM and Experimental Modal Analysis have been compared in Table 3.3.

*Table 3.3: Comparison of the modal frequencies obtained from experimental modal analysis and finite element analysis for the platter and the cantilever.*

| Part | Mode Number | FEM Results Frequency (Hz) | Experimental Results Damping Ratio (%) | Experimental Results Frequency (Hz) | Frequencies in OTO (Hz) (center band frequency) |
|---|---|---|---|---|---|
| Platter | 1 | 779.55 | 0.3 | 1082.17 | 1000 |
| | 2 | 1693.35 | 0.12 | 1811.20 | 2000 |
| | 3 | 2961.37 | 0.03 | 3010.32 | 3150 |
| | 4 | 4539.19 | 0.01 | 4573.20 | 5000 |
| | 5 | 6414.44 | 0.01 | 6451.26 | 6300 |
| | 6 | 7462.5 | 0.04 | 7760.6 | 8000 |
| Cantilever | 1 | 422.18 | 1.14 | 419.65 | 400 |

The mode shapes of the cantilever and the platter obtained from Finite Element Analysis (FEA) and Experimental Modal Analysis (EMA) is shown in Table 3.4 and Table 3.5. It can be observed that the mode shapes obtained using the two methods match.

*Table 3.4: Comparison of the Mode Shapes obtained from FEA and EMA for the cantilever*
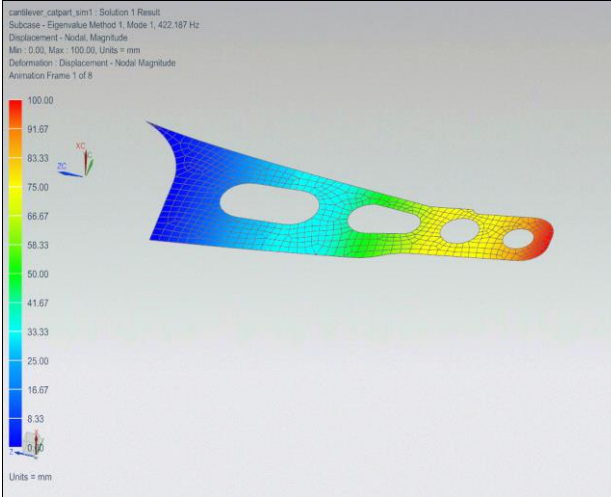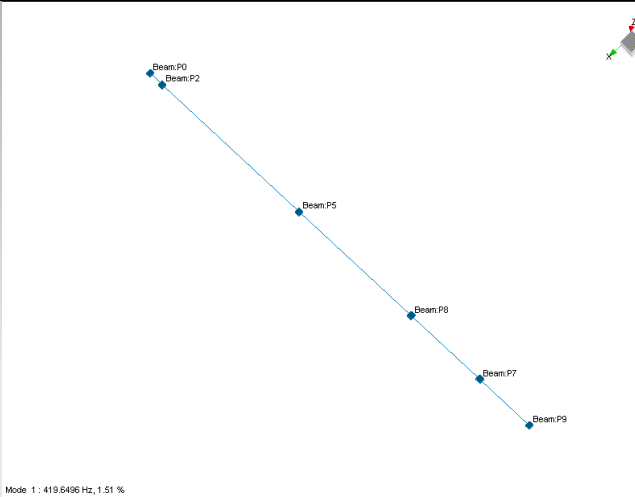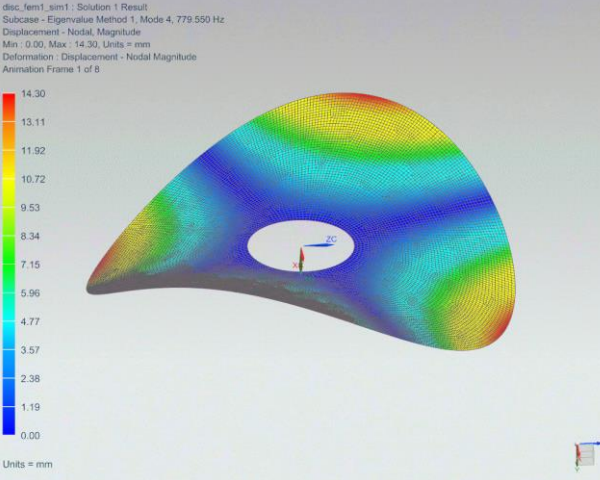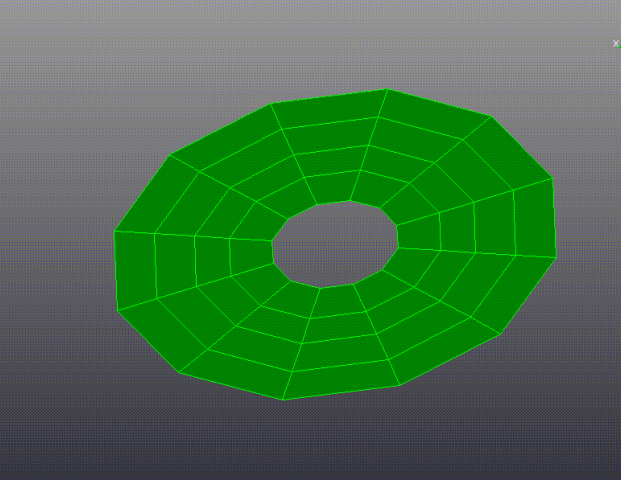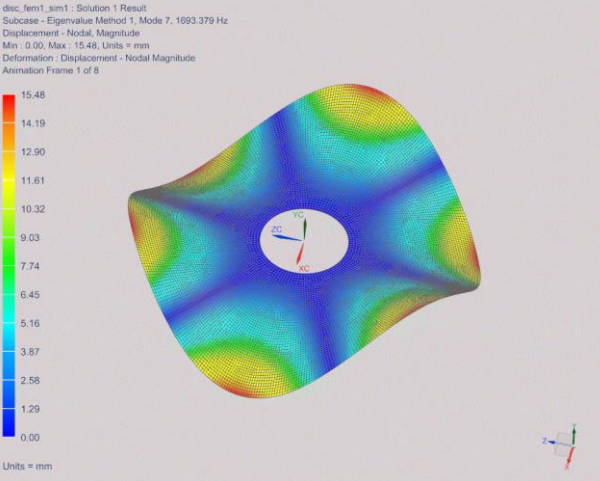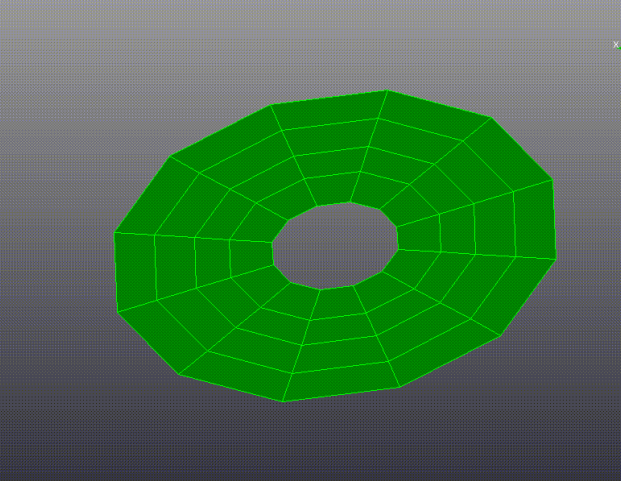
| Mode Shape from FEA | Mode Shape from EMA |
|---|---|
|  |  |
| Mode 1: Frequency 422.18 Hz | Mode 1: Frequency 419.65 Hz |

*Table 3.5: Comparison of the Mode Shapes obtained from FEA and EMA for the platter*

| Mode Shape from FEA | Mode Shape from EMA |
|---|---|
|  Mode 1: Frequency 779.55 Hz |  Mode 1: Frequency 1082.17 Hz |
|  Mode 2: Frequency 1693.35 Hz |  Mode 2: Frequency 1811.20 Hz |
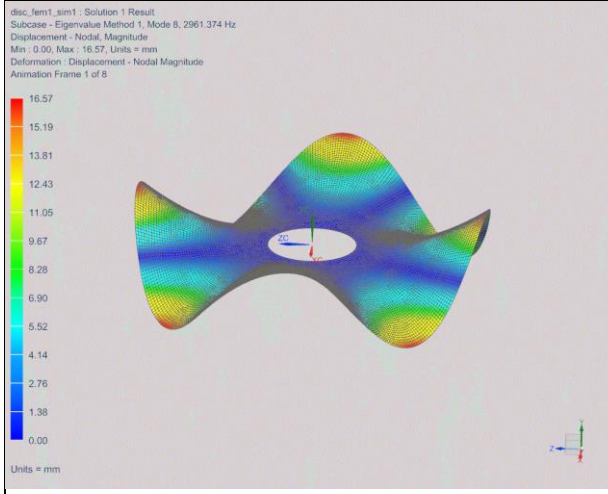
Mode 3: Frequency 2961.37 Hz
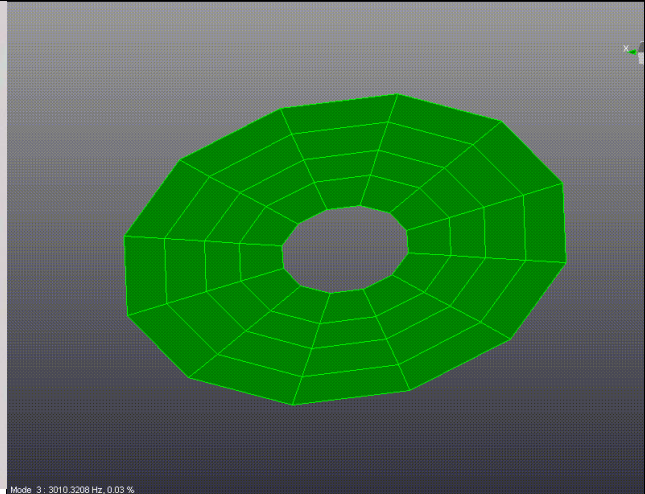


Mode 3: Frequency 3010.32 Hz
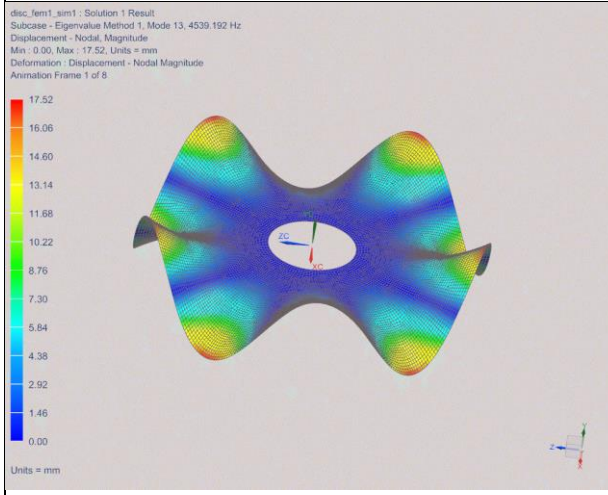


Mode 4: Frequency 4539.19 Hz
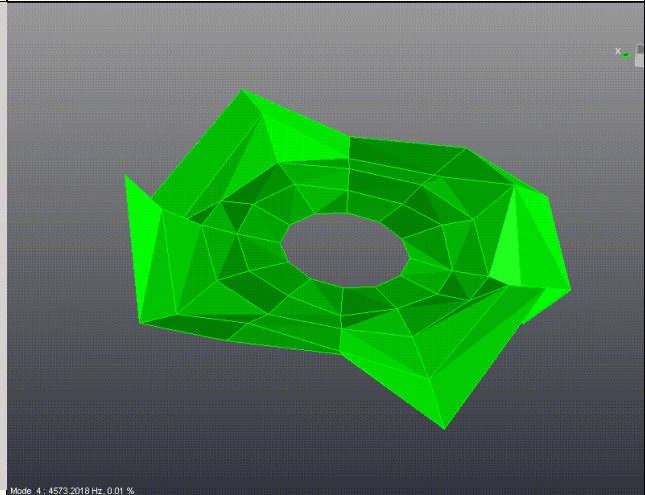


Mode 4: Frequency 4573.20 Hz
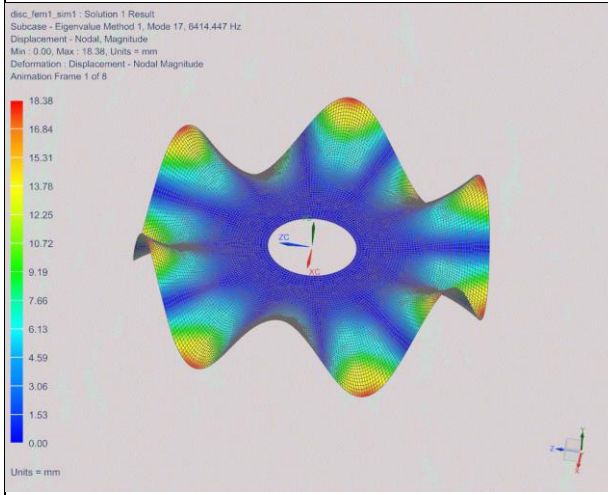


Mode 5: Frequency 6414.44 Hz
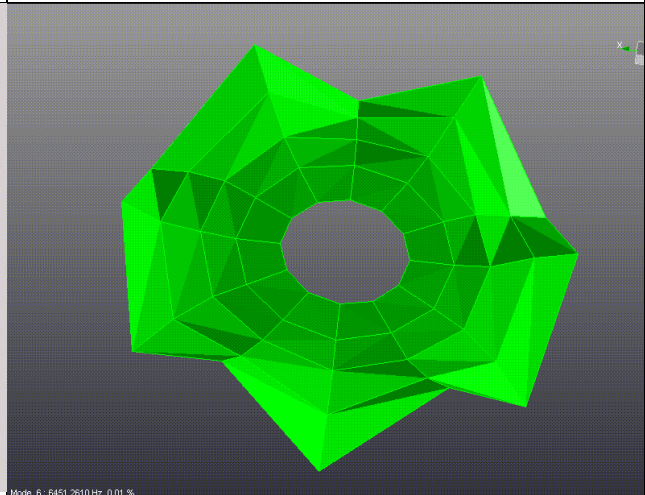


Mode 5: Frequency 6451.26 Hz

| Mode 6: Frequency 7462.5 Hz | Mode 6: Frequency 7760.6 Hz |
|---|---|
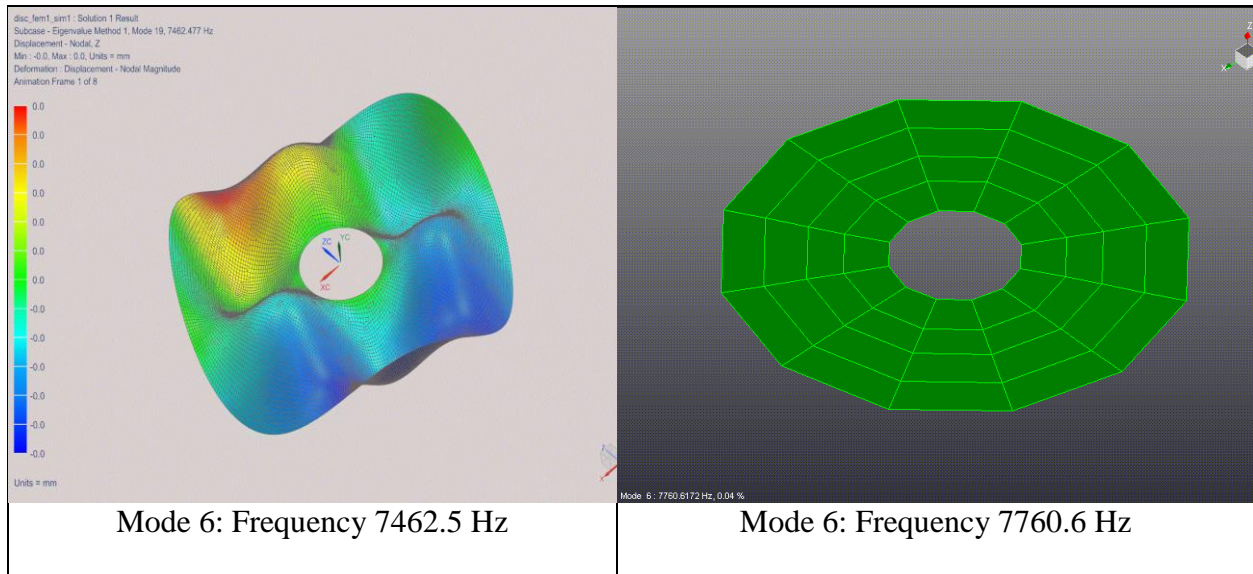
## 3.4.1 Comparing with the Acoustic Performance of HDD graph

The modal frequencies obtained from EMA have been compared with the bandwidth of the one third octave frequency bands to obtain the where that frequency lies in the one-third octave frequency bands. Fig 3.24 shows the acoustic performance of the HDD along with the modal frequencies obtained.

The HDDs were tested for read and write speeds with just the background noise and a baseline value was created. The color plot shows the minimum of the read and write speeds at the indicated frequency and Sound Pressure Level. The fifty percent curve (shown in blue) indicates the data point at which the read speed or write speed or both have reduced by 50% from the baseline. In the Fig 3.24, the region in green indicates good read and write performance of the HDD.

The frequencies of the 6 fundamental modes of the platter are shown using the dashed line. The solid vertical black lines indicate the one-third octave center frequencies where the modal frequencies lie.
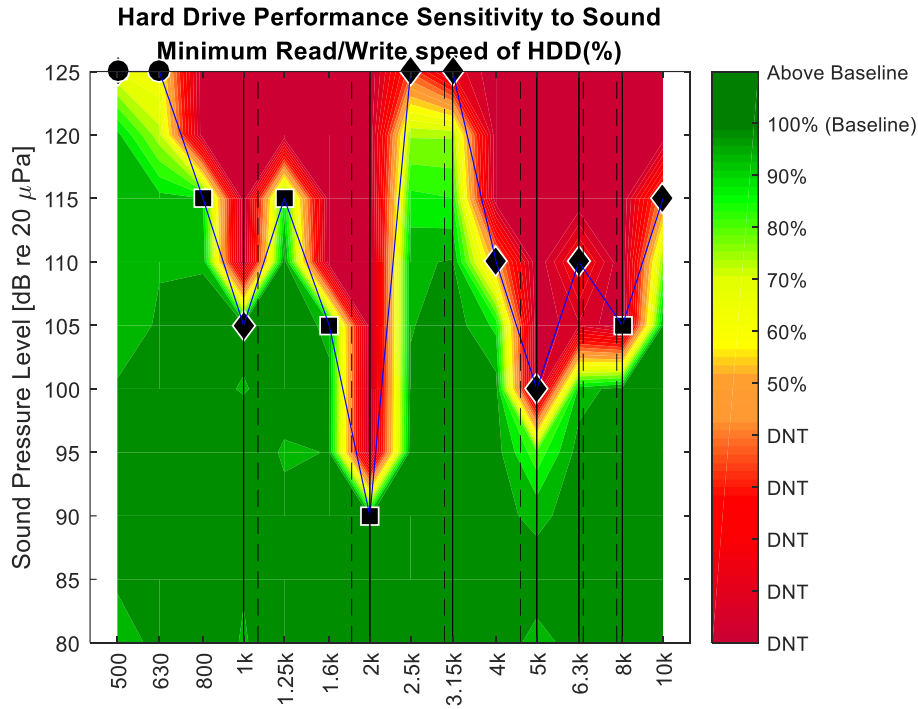


*Fig 3.24: Read and write performance of the HDD in noisy environment with the modal frequencies. The dashed lines show the frequencies of the modes and the solid lines indicate the modes in one-third octave frequencies.*

Fig 3.25 shows the 50 % curve of the HDD along with the modal frequencies of the platter (shown as dashed lines) and the modal frequencies of the platter on one-third octave frequencies (solid black lines). It can be seen that the read and write performance of the HDDs drop at those third-octave frequencies where the fundamental modal frequencies lie. The modes of the cantilever could be measured only up to 615 Hz and only one mode was observed at 420 Hz. The acoustic

performance data of the HDDs is not available at frequencies below 500 Hz center frequency one-third octave.
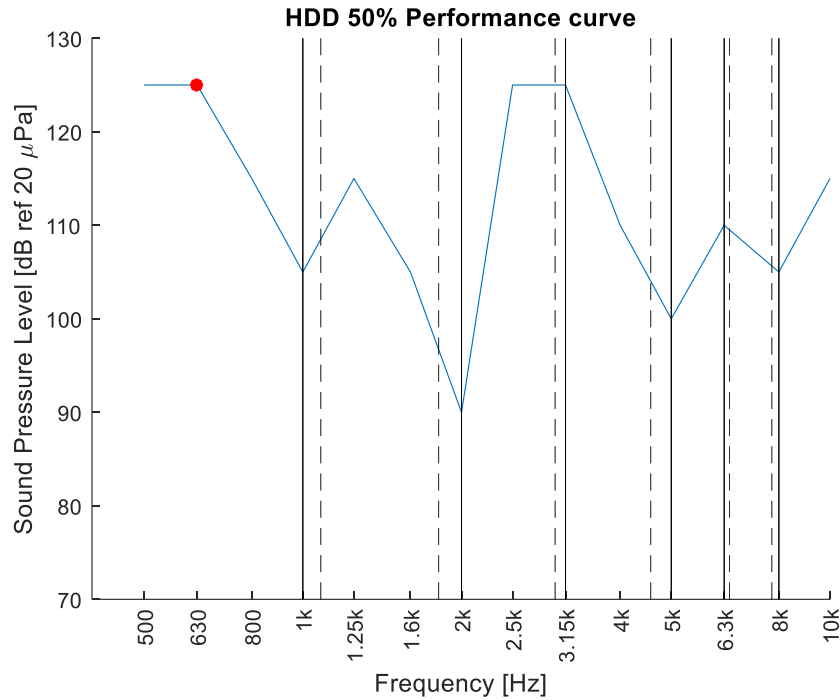


*Fig 3.25: 50 % performance curve of the HDD along with the modal frequencies of the platter. The dashed lines show the frequencies of the modes and the solid lines indicate the modes in one-third octave frequencies.*

## 3.5 Conclusion

The study shows that the HDDs are more sensitive to noise at those frequencies which matches the fundamental modes of vibration of the platter. The FRF of the platter due to impact testing at some location and response at some other location show that the 6 fundamental modes have very high amplitude. All other modes of the platter are within the noise floor of the measurement. In this study, it has been observed that both PolyMAX and TMDOF parameter

estimation method shows stable poles at the 6 fundamental frequencies. At other frequencies, the PolyMAX could identify other modes of vibration.

The cantilever could not be excited at frequencies above 615 Hz and only 1 mode of the structure was identified. Better excitation methods are required to test the structure at higher frequency range. The FEM analysis shows good correlation with the experimental data. Better modeling of the boundary condition is required to match the boundary condition of the experimental model.

The modes of vibration of the platter in one-third octave frequencies match exactly at those frequencies where read and write performance reduction has been observed. At 3150 Hz third octave center frequency, although a mode was identified for the platter, no appreciable performance drop was noticed for the HDD. To identify the reason for this behavior, the cantilever needs to be excited to that frequency range. The reason may be due to the cantilever and the platter moving in phase with each other. The path for the flow of energy during excitation needs to be studied.

The analysis can be taken further and can be tested at other HDDs. The Modal Test and the Acoustic Performance Test can be performed under the same boundary condition to identify the effects of mounting. A repeatability study can be performed. A mechanism to excite the structure through the miniature hammer can be designed, so that the structure can be excited with same energy throughout the bandwidth. Finer modal resolution can be used to analyze the lateral mode shapes of the cantilever and its effect on the performance of the HDD.

## 3.6 Acknowledgement

## 3.7 References

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2. Nickerson, Matthew L. and Kent Green. "Tonal Noise Sensitivity In Hard Drives". *The Journal of the Acoustical Society of America* 134.5 (2013): 4222-4222. Web.

3. "Platter Substrate Materials". Pcguide.com. N.p., 2016. Web. 14 Dec. 2016.

# 4. APPENDIX

**MATLAB CODE for PROCESSING the DATA from the LabVIEW program of 1 HDD**

```matlab
clear;
clc;
% Saving the data obtained from LabVIEW program
HGSTLV = csvread('HGSTharddriveperformance_revised.csv');
save HGSTLV
load('HGSTLV.mat');
load('Color','Color');

% Baseline Values
Baselinewrite=[172,179.6666667,178,179,178,177.6666667,179.6666667,176.333333
3,176.6666667,]*1000000;
Baselineread=[166.6666667    182.6666667 183.6666667 183 183.6666667
183.6666667 183.6666667 183.6666667 183.3333333
]*1000000;

% Parsing the data
for ii=0:length(HGSTLV)/9-1
Freq(ii+1,1)=HGSTLV(1+9*ii,1);
SPL(ii+1,1)=HGSTLV(2+9*ii,1);
Time(ii+1,1)=HGSTLV(3+9*ii,1);
end
AvgTime=mean(Time);

for ii=1:length(HGSTLV)/9
Blocksizes(ii,1)=HGSTLV(ii,2);
end

for ii=0:length(HGSTLV)/9-1
    for jj=1:9
    readspeed(ii+1,jj)=HGSTLV(ii*9+jj,4)/Baselineread(jj);
    writespeed(ii+1,jj)=HGSTLV(ii*9+jj,3)/Baselinewrite(jj);
    end
end

% Calculating the read and write speed (normalized)
for ii=1:length(HGSTLV)/9
    read(ii,1)=mean(readspeed(ii),2);
    write(ii,1)=mean(writespeed(ii),2);
end

% Storing the data systematically
for ii=1:length(HGSTLV)/9
    HGSTLVResults(ii,1)=Freq(ii,1);
    HGSTLVResults(ii,2)=SPL(ii,1);
    HGSTLVResults(ii,3)=Time(ii,1);
    HGSTLVResults(ii,4)=read(ii,1);
    HGSTLVResults(ii,5)=write(ii,1);
end
```

```matlab
% Sorting the rows
HGSTResults=sortrows(HGSTLVResults);
HGSTResults(isnan(HGSTResults)) =0;

% Total no of unique freq and SPL
frequency= unique(HGSTResults(:,1));
dB= unique(HGSTResults(:,2));

% Organizing the normalized data
for i=1 : length(frequency)
    c=0;
    for j = 1:length(HGSTResults)

        if  frequency(i) == HGSTResults(j,1);
            c=c+1;
            TimeTaken(c,i) = HGSTResults(j,3)/AvgTime;
            readaverage(c,i) = HGSTResults(j,4);
            writeaverage(c,i) = HGSTResults(j,5);
        end
     end

end

for ii=1:length(dB)
    for jj=1:length(frequency)
    sensitivity_r_w(ii,jj)=min(readaverage(ii,jj),writeaverage(ii,jj));
    end
end

% Center frequencies in one-third octave
centerfreq=[500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000,
6300, 8000, 10000, 12500, 16000, 20000];
for ii=1:17
    centerf(ii)=log10(centerfreq(ii));
end


% Dangerous Write frequencies with SPL
A=[2000,110;2500,110;4000,105;5000,105;6300,110;500,125;630,125;800,125;1250,
125;1600,120;3150,115;8000,110;10000,115];
A=sortrows(A);

% Dangerous Read frequencies with SPL
B=[20000,80;5000,105;6300,110;800,125];
B=sortrows(B);
A1=log10(A(:,1));
A2=A(:,2);
B1=log10(B(:,1));
B2=B(:,2);

% Less than 50 % performnace loss data frequencies
C=[1000,125;12500,125;16000,125];

% Compiling the data
Bad=[A;B;C];
```

```matlab
Bad1=log10(Bad(:,1));
Bad2=Bad(:,2);
Badline=sortrows(Bad);
Badlinex=log10(Badline(:,1));
Badliney=Badline(:,2);

% Plots

% Time Taken

figure('units','normalized')
axes('units','normalized','position',[.1,.1,.75,.8]);
contourf(centerf,dB,TimeTaken,20,'edgecolor','none');
hold on;
group= [0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19];
kk1 = gscatter(Bad1,Bad2,group,[],'dddddddddddssssssooo',[10],'off');
set(kk1,'MarkerFaceColor', [0 0 0]);
set(kk1,'MarkerEdgeColor', [1 1 1]);
hold on;
line(Badlinex,Badliney,'Color',[0 0 0]);
hold off;
set(gca,'ylim',[80 125]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k','1.6k'
,'2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12k','16k','20k'},'XTickLab
elRotation',90);
colormap(gca,Color);
caxis([0,1])
colorbar('ylim',[0,4],'ytick',[0,0.8,1,3],'yticklabel',{'DNT','Normal','Basel
ine','Above Baseline'});
xlabel('Frequency [Hz]');
ylabel('Sound Pressure Level [dB ref 20 \muPa]');
title({'Hard Drive Performance Sensitivity to Sound','Time Taken for each run
of HDD 12(%)'});

% Read Speed

figure('units','normalized')
axes('units','normalized','position',[.1,.1,.75,.8]);
contourf(centerf,dB,readaverage,20,'edgecolor','none');
hold on;
group= [0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19];
kk1 = gscatter(Bad1,Bad2,group,[],'dddddddddddssssssooo',[10],'off');
set(kk1,'MarkerFaceColor', [0 0 0]);
set(kk1,'MarkerEdgeColor', [1 1 1]);
hold on;
line(Badlinex,Badliney,'Color',[0 0 0]);
hold off;
set(gca,'ylim',[80 125]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k','1.6k'
,'2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12k','16k','20k'},'XTickLab
elRotation',90);
colormap(gca,Color);
caxis([0,1])
colorbar('ylim',[0,1.1],'ytick',[0:.1:1.1],'yticklabel',{'DNT','DNT','DNT','D
NT','DNT','50%','60%','70%','80%','90%','100% (Baseline)','Above Baseline'});
xlabel('Frequency [Hz]');
```

```matlab
ylabel('Sound Pressure Level [dB ref 20 \muPa]');
title({'Hard Drive Performance Sensitivity to Sound','Read Speed of HDD
12(%)'});

% Write Speed

figure('units','normalized')
axes('units','normalized','position',[.1,.1,.75,.8]);
contourf(centerf,dB,writeaverage,20,'edgecolor','none');
hold on;
group= [0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19];
kk1 = gscatter(Bad1,Bad2,group,[],'dddddddddddssssssooo',[10],'off');
set(kk1,'MarkerFaceColor', [0 0 0]);
set(kk1,'MarkerEdgeColor', [1 1 1]);
hold on;
line(Badlinex,Badliney,'Color',[0 0 0]);
hold off;
set(gca,'ylim',[80 125]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k','1.6k'
,'2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12k','16k','20k'},'XTickLab
elRotation',90);
colormap(gca,Color);
caxis([0,1])
colorbar('ylim',[0,1.1],'ytick',[0:.1:1.1],'yticklabel',{'DNT','DNT','DNT','D
NT','DNT','50%','60%','70%','80%','90%','100% (Baseline)','Above Baseline'});
xlabel('Frequency [Hz]');
ylabel('Sound Pressure Level [dB ref 20 \muPa]');
title({'Hard Drive Performance Sensitivity to Sound','Write Speed of HDD
12(%)'});

% Minimum of the read and write speed

figure('units','normalized')
axes('units','normalized','position',[.1,.1,.75,.8]);
pos=[0.15 0.21 0.7 0.75];
set(gca, 'Position', pos);
contourf(centerf,dB,sensitivity_r_w,20,'edgecolor','none');
hold on;
group= [0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19];
kk1 = gscatter(Bad1,Bad2,group,[],'dddddddddddssssssooo',[10],'off');
set(kk1,'MarkerFaceColor', [0 0 0]);
set(kk1,'MarkerEdgeColor', [1 1 1]);
hold on;
line(Badlinex,Badliney,'Color',[0 0 0]);
hold off;
set(gca,'ylim',[80 125]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k','1.6k'
,'2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'XTickL
abelRotation',90,'fontsize',16);
colormap(gca,Color);
caxis([0,1])
colorbar('ylim',[0,1.1],'ytick',[0:.1:1.1],'yticklabel',{'DNT','DNT','DNT','D
NT','DNT','50%','60%','70%','80%','90%','100% (Baseline)','Above
Baseline'},'fontsize',10);
xlabel('Frequency [Hz]','fontsize',16);
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
```

```matlab
title({'Hard Drive Performance Sensitivity to Sound','Minimum Read/Write
speed of HDD 12(%)'});

% Storing the data to use it for overall trends

Final_HGST_LV={sensitivity_r_w,readaverage,writeaverage,Badlinex,Badliney};
save Final_HGST_LV;

% 50% curve SPL at one-third octave frequencies
New=[125    125 125 125 125 120 110 110 115 105 105 110 110 115 125 125 80];
figure()
line(centerf,New);
hold on;
scatter(log10([1000, 12500, 16000]),[125, 125 125],'r','filled');
xlabel('Frequency [Hz]');
ylabel('Sound Pressure Level [dB ref 20 \muPa]');
title('HDD 12 50% Performance curve');
set(gca,'ylim',[70 130]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90);
```

## MATLAB CODE for MAKING OVERALL PLOTS

```
clear;
clc;
% Loading Data
load('Color','Color');
load ('Final_WD64_LV','Final_WD64_LV');
load ('Final_HGST_LV','Final_HGST_LV');
load ('Final_WD128_LV','Final_WD128_LV');
load ('Final_WDHD15_LV','Final_WDHD15_LV');
load ('Final_Hitachi_320GB_LV','Final_Hitachi_320GB_LV');
load ('Final_HitachiHD12_LV','Final_HitachiHD12_LV');
load ('Final_HitachiHD17_LV','Final_HitachiHD17_LV');
load ('Final_HitachiHD19_LV','Final_HitachiHD19_LV');
load ('Final_SeagateHD11_LV','Final_SeagateHD11_LV');
load ('Final_SeagateHD14_LV','Final_SeagateHD14_LV');
load ('Final_Toshiba1_LV','Final_Toshiba1_LV');
load ('Final_Toshiba2_LV','Final_Toshiba2_LV');
load('Final_Seagate10TBnew1_LV','Final_Seagate10TBnew1_LV');
load('Final_WD10TBnew2_LV','Final_WD10TBnew2_LV');


Reduced_parameters=csvread('Reduced.csv');
load('MyColormaps','mycmap')
load('group','group');
load('Fiftypercent','Fiftypercent');
load('AllFreq','AllFreq');


% Finding the 50 % curve
reduced_WD64=[Final_WD64_LV{1,4}(:,1),Final_WD64_LV{1,5}(:,1)];
reduced_HGST=[Final_HGST_LV{1,4}(:,1),Final_HGST_LV{1,5}(:,1)];
reduced_WD128=[Final_WD128_LV{1,4}(:,1),Final_WD128_LV{1,5}(:,1)];
reduced_WDHD15=[Final_WDHD15_LV{1,4}(:,1),Final_WDHD15_LV{1,5}(:,1)];
reduced_Hitachi_320GB=[Final_Hitachi_320GB_LV{1,4}(:,1),Final_Hitachi_320GB_L
V{1,5}(:,1)];
reduced_HitachiHD12=[Final_HitachiHD12_LV{1,4}(:,1),Final_HitachiHD12_LV{1,5}
(:,1)];
reduced_HitachiHD17=[Final_HitachiHD17_LV{1,4}(:,1),Final_HitachiHD17_LV{1,5}
(:,1)];
reduced_HitachiHD19=[Final_HitachiHD19_LV{1,4}(:,1),Final_HitachiHD19_LV{1,5}
(:,1)];
reduced_SeagateHD11=[Final_SeagateHD11_LV{1,4}(:,1),Final_SeagateHD11_LV{1,5}
(:,1)];
reduced_SeagateHD14=[Final_SeagateHD14_LV{1,4}(:,1),Final_SeagateHD14_LV{1,5}
(:,1)];
reduced_Toshiba1=[Final_Toshiba1_LV{1,4}(:,1),Final_Toshiba1_LV{1,5}(:,1)];
reduced_Toshiba2=[Final_Toshiba2_LV{1,4}(:,1),Final_Toshiba2_LV{1,5}(:,1)];
reduced_Seagate10TBnew1=[Final_Seagate10TBnew1_LV{1,4}(:,1),Final_Seagate10TB
new1_LV{1,5}(:,1)];
reduced_WD10TBnew2=[Final_WD10TBnew2_LV{1,4}(:,1),Final_WD10TBnew2_LV{1,5}(:,
1)];
reducedx=[reduced_WD64(:,1);reduced_HGST(:,1);reduced_WD128(:,1);reduced_WDHD
15(:,1);reduced_Hitachi_320GB(:,1);...
    reduced_HitachiHD12(:,1);reduced_HitachiHD17(:,1);...

reduced_HitachiHD19(:,1);reduced_SeagateHD11(:,1);reduced_SeagateHD14(:,1);re
duced_Toshiba1(:,1);...
```

```matlab
reduced_Toshiba2(:,1);reduced_Seagate10TBnew1(:,1);reduced_WD10TBnew2(:,1)];
reducedy=[reduced_WD64(:,2);reduced_HGST(:,2);reduced_WD128(:,2);reduced_WDHD
15(:,2);...

reduced_Hitachi_320GB(:,2);reduced_HitachiHD12(:,2);reduced_HitachiHD17(:,2);
...

reduced_HitachiHD19(:,2);reduced_SeagateHD11(:,2);reduced_SeagateHD14(:,2);..
.

reduced_Toshiba1(:,2);reduced_Toshiba2(:,2);reduced_Seagate10TBnew1(:,2);redu
ced_WD10TBnew2(:,2)];
centerfreq=[500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000,
6300, 8000, 10000, 12500, 16000, 20000];
for ii=1:length(centerfreq)
    centerf(ii)=log10(centerfreq(ii));
end


%% NON HELIUM DRIVES (500 - 10kHz)

% Box Plot
A=Reduced_parameters(3:11,1:14);
A(A == 0) = NaN;
figure()
boxplot(A, 'PlotStyle','traditional');
set(gca,'ylim',[70 130],'fontsize',16);
set(gca,'XTick',1:17,'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);
xlabel('Frequency [Hz]','fontsize',16);
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
title({'Compilation of non-helium Enterprise HDD','50% performance curves(500
Hz to 10k Hz)'});

Averaged =mean((A(:,:)));

for ii=1:14
    Sensitivity(ii)=min(A(:,ii));
end

figure() % 50 % curves
line(centerf(1:14),Averaged,'Color',[1 0 0]);
hold on;
line(centerf(1:14),Sensitivity,'Color',[0 0 1]);
xlabel('Frequency [Hz]');
ylabel('Sound Pressure Level [dB re 20 \muPa]');
title({'Non-helium Enterprise Hard Drive Performance','Average 50% curve &
Minimum of the 50% curves(500 Hz to 10k Hz)'});
set(gca,'ylim',[70 130]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90);
```

```matlab
hold off;

% ALL THE DRIVES (500 - 10kHz)
Box Plot
A1=Reduced_parameters(1:14,1:14);
A1(A1 == 0) = NaN;
figure()
boxplot(A1, 'PlotStyle','traditional');
set(gca,'ylim',[70 130]);
set(gca,'XTick',1:17,'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'...
XTickLabelRotation',90);
xlabel('Frequency [Hz]');
ylabel('Sound Pressure Level [dB re 20 \muPa]');
title('Compilation of HDD 50% performance curves(500 Hz to 10k Hz)');


Averaged1=[120   115 114.6428571 113.5714286 112.8571429 112.5    111.0714286
113.9285714 116.7857143 111.0714286 109.2857143 113.9285714 110.7142857
115.3571429 123.75   121.25   98.75];
for ii=1:14
    Sensitivity1(ii)=min(A1(:,ii));
end

figure() % 50 % curves
line(centerf(1:14),Averaged1(1:14),'Color',[1 0 0]);
hold on;
line(centerf(1:14),Sensitivity1,'Color',[0 0 1]);
xlabel('Frequency [Hz]');
ylabel('Sound Pressure Level [dB re 20 \muPa]');
title({'Hard Drive Performance','Average 50% curve & minimum of the 50%
curves(500 Hz to 10k Hz)'});
legend('Average 50% curve','Minimum of the 50% curves','Location','north')
set(gca,'ylim',[70 130]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'...
XTickLabelRotation',90);
hold off;

% HELIUM DRIVES (500 to 10kHz)

% Box Plot
A2=Reduced_parameters(1:14,1:14);
B=[A2(1,:);A2(13,:);A2(14,:)];
B(B == 0) = NaN;

figure() % curves
line(centerf(1:14),B(1,:),'Color',[1,0,1]);
hold on;
line(centerf(1:14),B(2,:),'Color',[0 0 1]);
hold on;
line(centerf(1:14),B(3,:),'Color',[0 1 0]);
xlabel('Frequency [Hz]','fontsize',16);
```

```matlab
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
title({'Helium filled Hard Drive Performance','50% performnace curves(500 Hz
to 10k Hz)'});
legend('HDD 1','HDD 2','HDD 3','Location','north')
set(gca,'ylim',[70 130]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);

% Laptop Drives
A3=Reduced_parameters(1:14,1:14);
C=[A3(2,:);A3(12,:)];
C(C == 0) = NaN;

figure() % curves
line(centerf(1:14),C(1,:),'Color',[0 0 1]);
hold on;
line(centerf(1:14),C(2,:),'Color',[1,0,0]);
xlabel('Frequency [Hz]','fontsize',16);
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
title({'Laptop Hard Drive Performance','50% performnace curves(500 Hz to 10k
Hz)'});
legend('HDD 1','HDD 2','Location','north')
set(gca,'ylim',[70 130]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);


% ALL DRIVES (500 - 20kHz)
A5=Reduced_parameters(1:14,:);
A5(A5 == 0) = NaN;
figure()
boxplot(A5, 'PlotStyle','traditional');
set(gca,'ylim',[70 130]);
set(gca,'XTick',1:17,'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);
xlabel('Frequency [Hz]','fontsize',16);
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
title('Compilation of HDD 50% performance curves(500 Hz to 20k Hz)');


Averaged5=[120  115 114.6428571 113.5714286 112.8571429 112.5   111.0714286
113.9285714 116.7857143 111.0714286 109.2857143 113.9285714 110.7142857
115.3571429 123.75  121.25  98.75];
for ii=1:14
    Sensitivity5(ii)=min(A5(:,ii));
end
for ii=15:17
    Sensitivity5(ii)=min(nonzeros(A5(:,ii)));
end
figure() % 50 % curves
```

```matlab
line(centerf,Averaged5,'Color',[1 0 0]);
hold on;
line(centerf,Sensitivity5,'Color',[0 0 1]);
xlabel('Frequency [Hz]','fontsize',16);
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
title({'Hard Drive Performance','Average 50% curve & minimum of the 50%
curves(500 Hz to 20k Hz)'});
legend('Average 50% curve','Minimum of the 50% curves','Location','north')
set(gca,'ylim',[70 130]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);

% Enterprise Drives (500-20 kHz)

A6=Reduced_parameters(1:14,:);
A6=[A6(1,:);A6(3:11,:);A6(13:14,:)];
A6(A6 == 0) = NaN;
figure()
boxplot(A6, 'PlotStyle','traditional');
set(gca,'ylim',[70 130]);
set(gca,'XTick',1:17,'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);
xlabel('Frequency [Hz]','fontsize',16);
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
title('Enterprise HDD 50% performance curves(500 Hz to 20k Hz)');


Averaged6=[120.8333333  117.9166667 116.6666667 115.4166667 115 114.5833333
113.75  116.6666667 118.3333333 111.25  110.4166667 114.1666667 112.5
118.3333333 123.75  121.25  98.75];
for ii=1:14
    Sensitivity6(ii)=min(A6(:,ii));
end
for ii=15:17
    Sensitivity6(ii)=min(nonzeros(A6(:,ii)));
end
figure() % 50 % curves
line(centerf,Averaged6,'Color',[1 0 0]);
hold on;
line(centerf,Sensitivity6,'Color',[0 0 1]);
xlabel('Frequency [Hz]','fontsize',16);
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
title({'Enterprise Hard Drive Performance','Average 50% curve & minimum of
the 50% curves(500 Hz to 20k Hz)'});
legend('Average 50% curve','Minimum of the 50% curves','Location','north')
set(gca,'ylim',[70 130]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);
```

```matlab
% 500-10 kHz Enterprise Drives

A7=Reduced_parameters(1:14,1:14);
A7=[A7(1,:);A7(3:11,:);A7(13:14,:)];
A7(A7 == 0) = NaN;
figure()
boxplot(A7, 'PlotStyle','traditional');
set(gca,'ylim',[70 130]);
set(gca,'XTick',1:17,'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90);
xlabel('Frequency [Hz]');
ylabel('Sound Pressure Level [dB re 20 \muPa]');
title('Enterprise HDD 50% performance curves(500 Hz to 10k Hz)');

Averaged7 =mean((A7));

for ii=1:14
    Sensitivity7(ii)=min(A6(:,ii));
end

figure() % 50 % curves
line(centerf(1:14),Averaged7,'Color',[1 0 0]);
hold on;
line(centerf(1:14),Sensitivity7,'Color',[0 0 1]);
xlabel('Frequency [Hz]');
ylabel('Sound Pressure Level [dB re 20 \muPa]');
title({'Enterprise Hard Drive Performance','Average 50% curve & minimum of
the 50% curves(500 Hz to 10k Hz)'});
legend('Average 50% curve','Minimum of the 50% curves','Location','north')
set(gca,'ylim',[70 130]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90);

% NON HELIUM DRIVES (500 - 20kHz)
X=Reduced_parameters(3:11,:);
X(X == 0) = NaN;
figure()
boxplot(X, 'PlotStyle','traditional');
set(gca,'ylim',[70 130]);
set(gca,'XTick',1:17,'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);
xlabel('Frequency [Hz]','fontsize',16);
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
title({'Compilation of non-helium filled Enetrprise HDD','50% performance
curves(500 Hz to 20k Hz)'});
```

```matlab
Averaged4 =[119.4444444 115.5555556 114.4444444 112.2222222 111.6666667
112.2222222 112.2222222 116.1111111 118.8888889 111.6666667 111.6666667
116.6666667 113.8888889 120 123.3333333 120 105];
for ii=1:14
    Sensitivity4(ii)=min(X(:,ii));
end
for ii=15:17
    Sensitivity4(ii)=min(nonzeros(X(:,ii)));
end
figure() % 50 % curves
line(centerf,Averaged4,'Color',[1 0 0]);
hold on;
line(centerf,Sensitivity4,'Color',[0 0 1]);
xlabel('Frequency [Hz]','fontsize',16);
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
title({'Non-helium Enterprise Hard Drive Performance','Average 50% curves &
minimum of the 50% curves(500 Hz to 20k Hz)'});
legend('Average 50% curve','Minimum of the 50% curves','Location','north')
set(gca,'ylim',[70 130]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);


% Non Helium Enetrprise + Laptop (500 to 20kHz)

X1=Reduced_parameters(2:12,:);
X1(X1 == 0) = NaN;
figure()
boxplot(X1, 'PlotStyle','traditional');
set(gca,'ylim',[70 130]);
set(gca,'XTick',1:17,'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);
xlabel('Frequency [Hz]','fontsize',16);
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
title({'Compilation of non-helium filled HDD','50% performance curves(500 Hz
to 20k Hz)'});


Averaged5 =[118.6363636 112.2727273 112.2727273 110.4545455 109.5454545 110
109.0909091 112.7272727 116.8181818 111.3636364 110 115.9090909 111.3636364
115.9090909 123.3333333 120 105];
for ii=1:14
    Sensitivity7(ii)=min(X1(:,ii));
end
for ii=15:17
    Sensitivity7(ii)=min(nonzeros(X1(:,ii)));
end
figure() % 50 % curves
line(centerf,Averaged5,'Color',[1 0 0]);
hold on;
line(centerf,Sensitivity7,'Color',[0 0 1]);
xlabel('Frequency [Hz]','fontsize',16);
```

```matlab
ylabel('Sound Pressure Level [dB re 20 \muPa]','fontsize',16);
title({'Non-helium Hard Drive Performance','Average 50% curves & minimum of
the 50% curves(500 Hz to 20k Hz)'});
legend('Average 50% curve','Minimum of the 50% curves','Location','north')
set(gca,'ylim',[70 130]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);


% Comparison
New1=[120    125 125 125 120 125 130 120 120 115 115 110 110 120 125 120 110];
New=[120     125 130 125 120 130 130 125 120 115 115 115 110 125 125 120 105];
figure()
line(centerf,New,'Color',[0 0 1]);
hold on;
line(centerf,New1,'Color',[1 0 1]);
legend('HDD 1','HDD 2');
xlabel('Frequency [Hz]','fontsize',16);
ylabel('Sound Pressure Level [dB ref 20 \muPa]','fontsize',16);
title('Compariosn of two drives','50% Performance curve');
set(gca,'ylim',[70 130]);
set(gca,'XTick',[centerf],'XTickLabel',{'500','630','800','1k','1.25k',...

'1.6k','2k','2.5k','3.15k','4k','5k','6.3k','8k','10k','12.5k','16k','20k'},'
XTickLabelRotation',90,'fontsize',16);
```

**Minimum of the read and write performance of the HDDs as a percentage of the respective baseline values in one-third octave frequency bands, along with the 50 % curve**



a                                                                                  b

*Fig 4.1: The minimum of the read and write speeds as percentage of the respective baseline values shown in OTO frequency bands for HDD 13 and HDD 14 in (a) and (b). The black line indicates the 50 % curve. The diamonds and squares indicate that write speed and read speed reduced by 50 % from baseline values respectively. The circles indicate full test completion with no errors.*
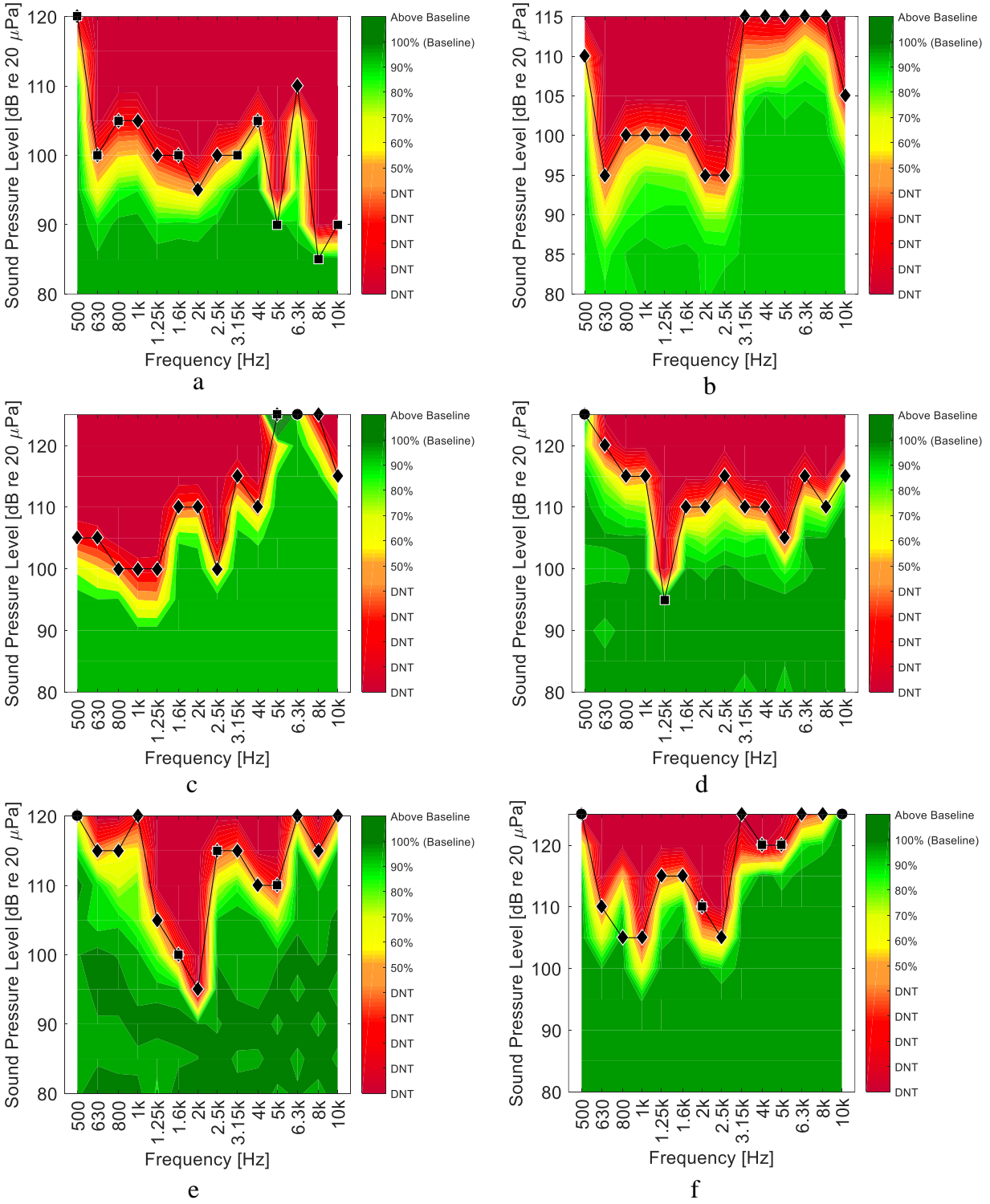
*Fig 4.2: The minimum of the read and write speeds as percentage of the respective baseline values shown in OTO frequency bands for HDD 1 to HDD 6 from (a) to (f). The black line indicates the 50 % curve. The diamonds and squares indicate that write speed and read speed reduced by 50 % from baseline values respectively. The circles indicate full test completion with no errors.*
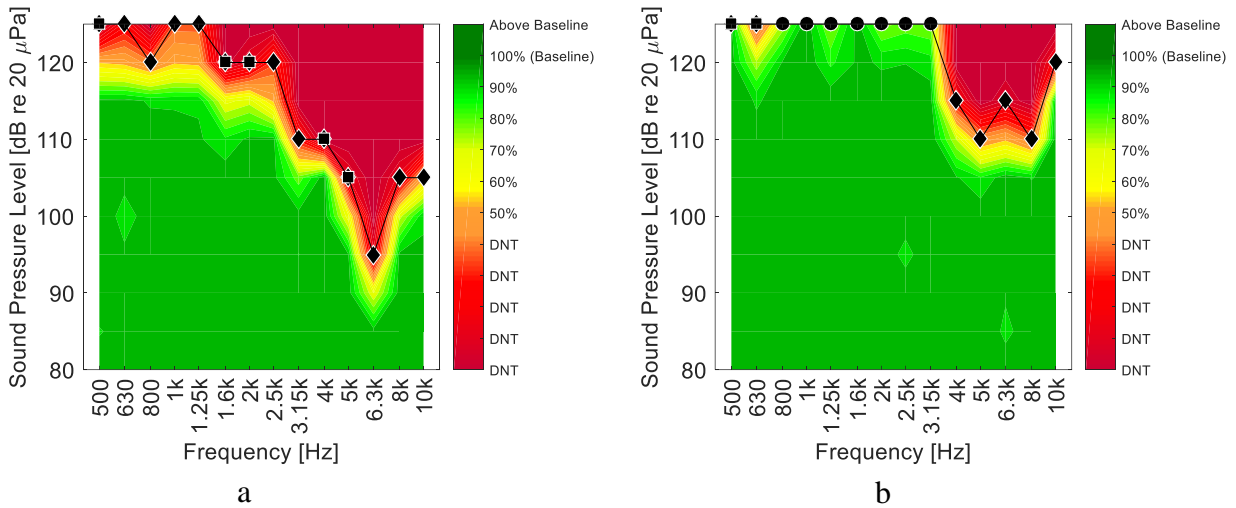
*Fig 4.3: The minimum of the read and write speeds as percentage of the respective baseline values shown in OTO frequency bands for HDD 7 to HDD 12 from (a) to (f). The black line indicates the 50 % curve. The diamonds and squares indicate that write speed and read speed reduced by 50 % from baseline values respectively. The circles indicate full test completion with no errors.*
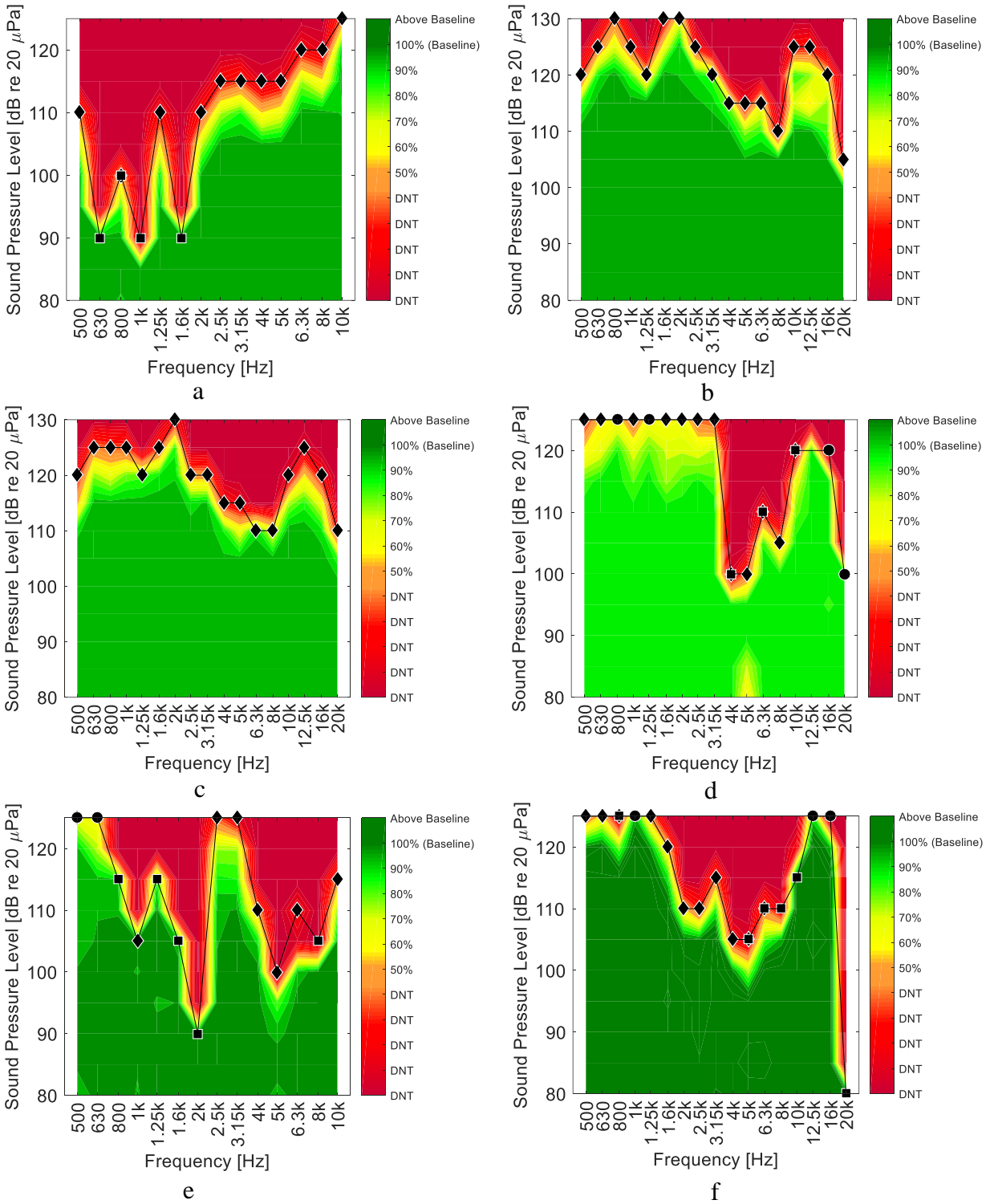
# INSTRUCTIONS for USING the VI for PERFORMANCE TEST and NOISE PRODUCTION in LABVIEW

The LabVIEW program used produces pink noise at one-third octave frequencies. The power to be fed to the speakers to produce the desired sound pressure level (SPL) at the receiver location is done through this program. The desired SPL can be fed to the program through an CSV sheet.

The program is run in two stages. The first stage is the baseline value determination and the second is the read and write performance test of the Hard Disk Drive (HDD).

## Baseline Value Determination of Read and Write Speed

Initially the baseline values for read and write performance of the HDD need to be determined. Win32 Read Write Block Size Test.vi should be used to detrmine the basline values. Fig 4.4 shows the front panel of the VI.
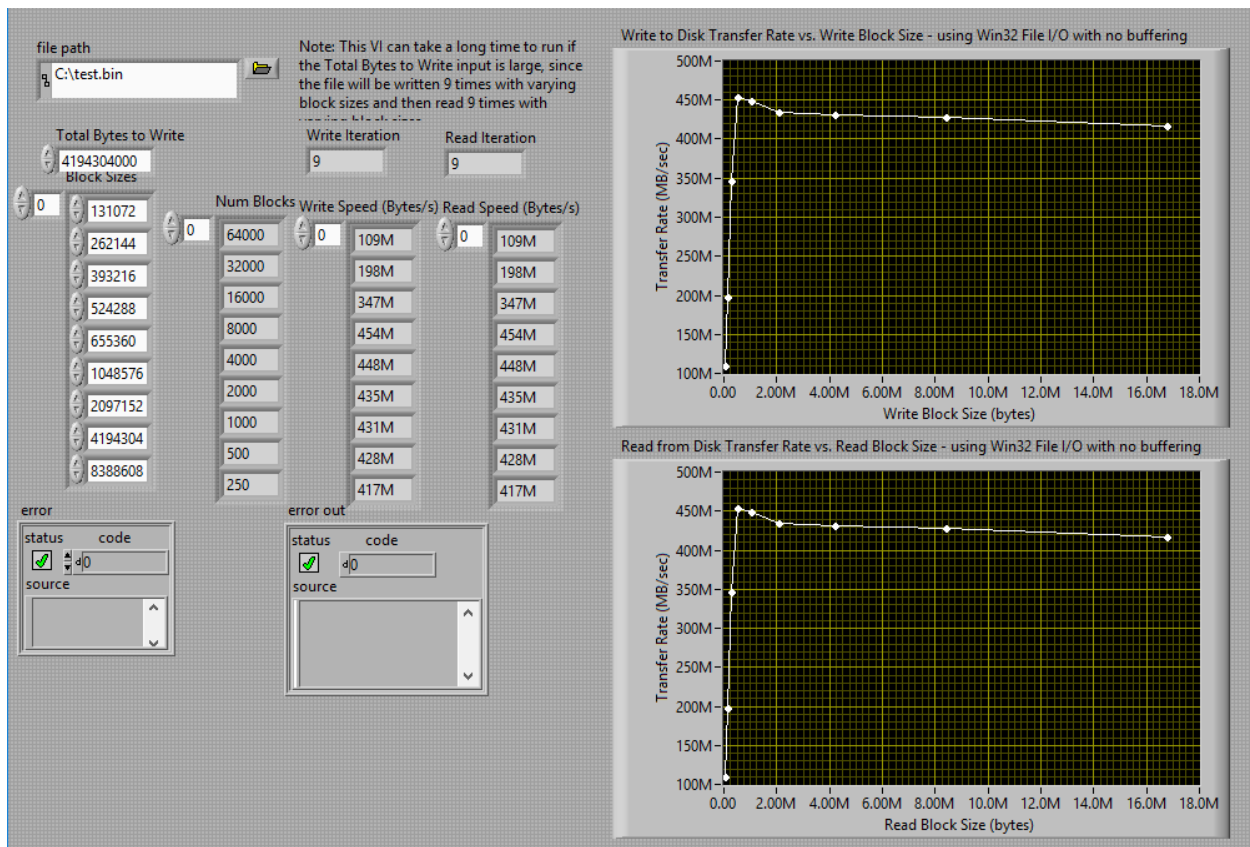


*Fig 4.4: Front panel of the Win32 Read Write Block Size Test.vi used for baseline measurements*

A file needs to be created in the drive as .txt format and should be selected in the file path option. The user inputs the number of times to perform read and write speed test (typically 9) in the Write Iterations and Read Iterations. The total bytes to write needs to be in the range of 1 GB so that it takes nearly 90 seconds to perform one cycle of read or write speed test (9 iterations of read and write speed test). The block size can be changed based on requirements. The write speed and read speed need to be noted down and the process needs to be repeated multiple time (3 to 5 times) to estimate the baseline values.

*NOTE: The baseline values should be measured with just the background noise at the start and end of every experiment and even during experiment. Baseline values should be measured 3 to 5 times before any experiment. Total bytes to write should be around 1 GB or such that it takes 90 second to perform 9 read and write iterations. If you obtain a value of infinity as the read and write speed, check your connections or re-connect the HDD. Infinity is obtained only when the LabVIEW program is unable to write/read any data in/from the HDD. The sensitivity of the microphone is set as 8.5 mV/Pa and dB ref is set to 20 µPa.*

## Read and Write Performance Test of the Hard Disk Drive

The read and write speed performance analysis of the HDD is performed using VI for performing test and Noise Production.vi. Fig 4.5 shows the front panel of the VI.
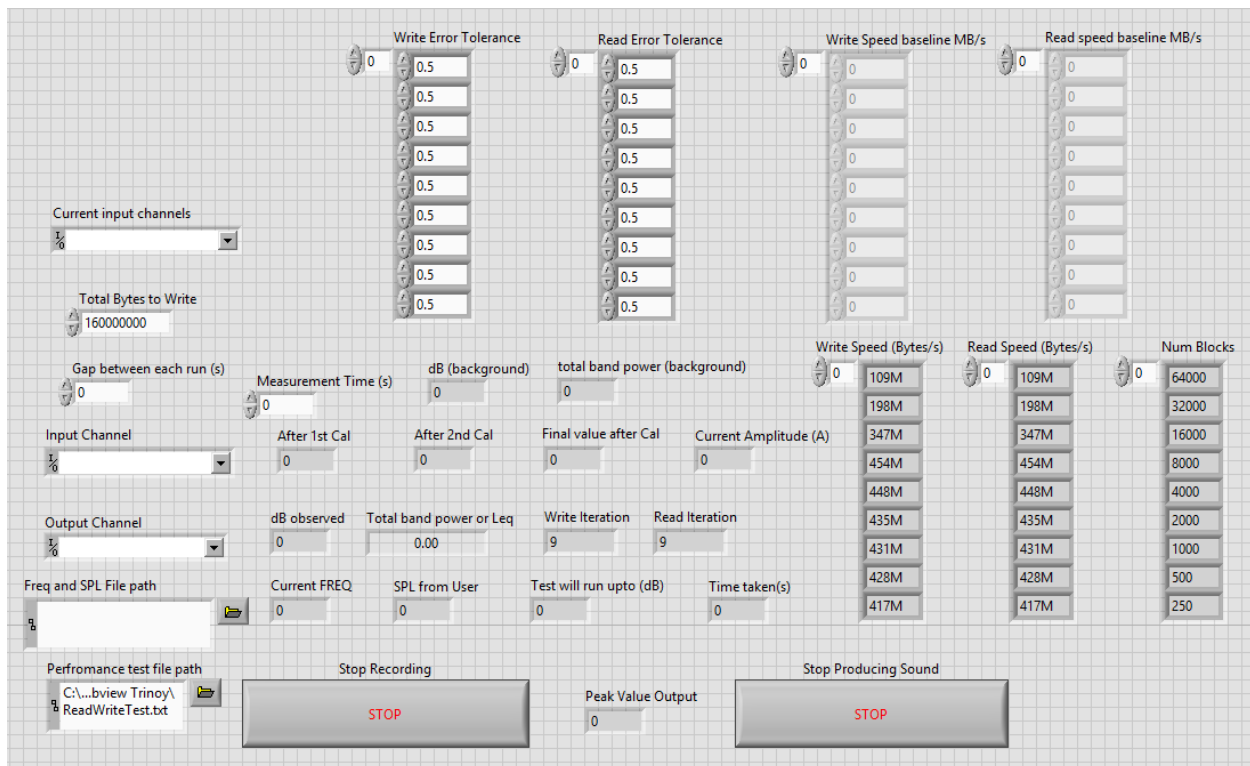


*Fig 4.5: Front panel of VI for performing test and Noise Production.vi used for read and write performance test of the Hard Disk Drive*

A file needs to be created in the drive as .txt format and should be selected in the Performance test file path option. The input channel for current signal, input channel from the microphone for the SPL measurement and output channel to send power to the speakers need to be set.

The Gap between each run indicates the time duration where it does not produce any sound during the calibration process. Calibration is done to produce the desired SPL which is fed using an CSV sheet in the Freq and SPL File path which will be explained later. Measurement Time is the duration of time when the Calibrator produces sound to achieve the desired SPL. The calibration process is done in three steps where it produces an arbitrary SPL of low intensity and the amplifier knob should be below the half way mark. Then it adjusts the voltage sent to the speakers and produces the desired SPL. It checks it one final time to make sure the SPL is the desired level and the current sent to the speakers are lower than 2.8 A and higher than 0.0005 A. These values are shown as After 1$^{st}$ Cal. After 2$^{nd}$ Cal and Final value after Cal. The current values measured using the current probe is displayed in Current Amplitude.

The total bytes to write needs to be in the range of 1 GB so that it takes nearly 90 seconds to perform one cycle of read or write speed test (9 iterations of read and write speed test). The block size can be changed based on requirements.

The Write Error Tolerance and Read Error Tolerance is the value (e.g. if you want 50% put 0.5) upto which the program will run when the performance value changes from the baseline value. The baseline values need to be fed in the Write Speed baseline MB/s and Read speed baseline MB/s in the same order as obtained from the Win32 Read Write Block Size Test.vi.

The read speed and write speed can be viewed in Write Speed (Bytes/s) and Read Speed (Bytes/s). The write speed and read speed are stored in the process as CSV files as name of the Freq and SPL File path + harddriveperformance. Fig 4.6 explains the harddriveperformance file. The program will also indictae the Frequencies and SPL where the performance of the HDD reduces by (Write/Read Error Tolerance value times 100) % of the baseline values as Freq and SPL File path + dangerous(read/write). It will also store the frequency and SPL values where the current sent to the speaker exceeds 2.8 A or is less than 0.0005 A to produce that sound as Freq and SPL File path + DangerousCurrent. Fig 4.7 explains the dangerous write/read speed files and the dangerous current file.
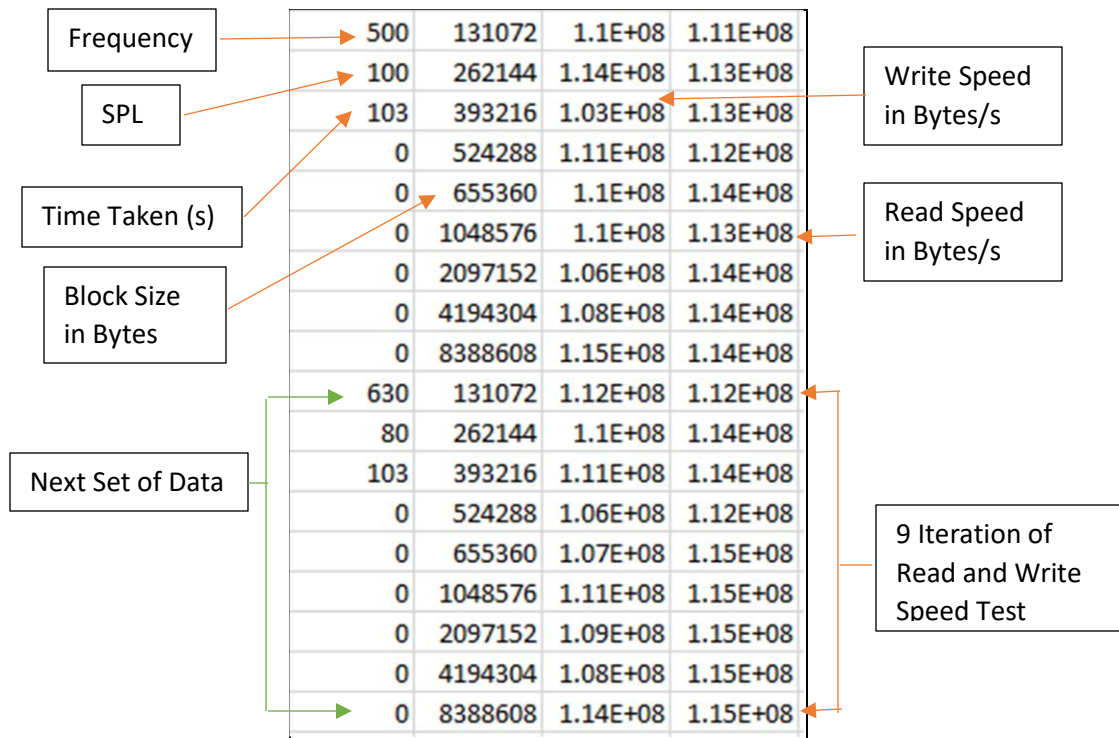
*Fig 4.6 Shows the harddriveperformance file. The 1$^{st}$ column is Frequency, SPL and Time Taken (s). Second column is Block Size, third column is write speed and 4$^{th}$ column is read speed. The new values append to the file*
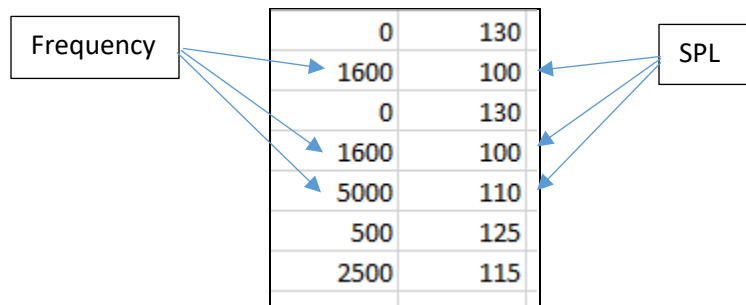


*Fig 4.7 Shows the dangerous read/write or current file. The 2$^{nd}$ column is the SPL and the 1$^{st}$ column is Frequency. The Value 0-130 repeats as it has been set as default value. The new values append to the file*

The real time write and read speed can be monitored through the graphs along with the output waveform sent to produce the sound. At any time the program can be stopped using the Stop Recording or Stop Producing Sound buttons.

The CSV file which contains the details of the Frequency and SPL need to have Frequency in 1$^{st}$ column, SPl in the second column and the third column contains the incremental value of SPL.

The incremental value is the (final SPl desired - second columns SPL-1 ). So, if the user wants to produce sound at 1000 Hz from 80 dB to 100 dB (re 20 µPa), the user needs to input 1000 in 1$^{st}$ column, 80 in the second column and 19 in the third column which is 100-80-1. This produces sound at 1000 Hz at SPL 80 dB (re 20 µPa), then it increments 5 dB and produces a SPL at 85 dB (re 20 µPa), then it again increments 5 dB and produces a SPL of 90 dB (re 20 µPa) untill it reaches a SPL of 100 dB (re 20 µPa). This is done so that the program does not have to calibrate itself a number of time to produce the desired sound. It is also employed as it was observed that 500 Hz to 800 Hz is not very critcal and so bigger range of SPLs can be tested unlike in the frequency range from 4000 Hz to 8000 Hz which is very critical. This is a safety measure employed by Trinoy Dutta based on experience. A sample document is shown in Table 4.1

*Table 4.1: Sample CSV file containing the Frequency, SPL and incremental value of SPL*

| | | |
|---|---|---|
| 500 | 80 | 19 |
| 630 | 80 | 19 |
| 800 | 80 | 19 |
| 1000 | 80 | 19 |
| 1250 | 80 | 19 |
| 1600 | 80 | 19 |
| 2000 | 80 | 19 |
| 2500 | 80 | 19 |
| 3150 | 80 | 19 |
| 4000 | 80 | 19 |
| 5000 | 80 | 19 |
| 6300 | 80 | 19 |
| 8000 | 80 | 19 |
| 10000 | 80 | 19 |
| 500 | 105 | 9 |
| 630 | 105 | 9 |
| 800 | 105 | 9 |
| 1000 | 105 | 9 |
| 1250 | 105 | 9 |
| 1600 | 105 | 9 |
| 2000 | 105 | 9 |
| 2500 | 105 | 4 |
| 3150 | 105 | 4 |
| 4000 | 105 | 4 |
| 5000 | 105 | 4 |
| 6300 | 105 | 4 |
| 8000 | 105 | 4 |
| 10000 | 105 | 4 |

| | | |
|---|---|---|
| 500 | 120 | 4 |
| 630 | 120 | 4 |
| 800 | 120 | 4 |
| 1000 | 120 | 4 |
| 1250 | 120 | 4 |
| 1600 | 120 | 4 |
| 2000 | 120 | 4 |
| 2500 | 115 | 9 |
| 3150 | 115 | 9 |
| 4000 | 115 | 9 |
| 5000 | 115 | 9 |
| 6300 | 115 | 9 |
| 8000 | 115 | 9 |
| 10000 | 115 | 9 |

The details about the sound produced such as frequency and SPL, the duration of each test cycle, the incremental value of SPL, background/observed noise SPL and background/observed Total band Power Level can be monitored along with the real time write or read test iteration value.

*Note: Amplifier knob should be below half mark during the start of experiment. The maximum value of current allowed to be sent to the speakers is set to 2.8 A and the minimum is 0.0005 A which can be changed in the Final Calibrator Sub VI and Sub VI Produces Sound. Total bytes to write should be around 1 GB or such that it takes 90 second to perform 9 read and write iterations. If you obtain a value of infinity as the read and write speed, check your connections or re-connect the HDD. Infinity is obtained only when the LabVIEW program is unable to write/read any data in/from the HDD. Check all connections properly if the desired output is not obtained. If the user needs to stop the test in between, the harddriveperformance file should be stored properly. The program is designed to append to the current file. The dangerous current, dangerous read and write values will be stored in the respective files which needs to be fed manually in the VI for performing test and Noise Production.vi in the top left portion of the file in the arrays in the format of frequency in 1st column and SPL in second. The initial value set as default in the program is 0 frequency at 130 dB (re 20 μPa). This value should not be altered. The new values should be put below that row. The dB reference is set to 20 μPa which can be changed in the program. The sensitivity of the microphone is set as 8.5 mV/Pa and dB ref is set to 20 μPa.*

## The SUB VIs used in the program and their description is shown below:

*Win32 Read Write Block Size Test*

This VI is used for baseline measurements of read and write speed of a HDD.

### VI for performance test and noise production

This is the main VI and all measuremenst are done using this VI. It measures the read and write performance of the HDD.

### Sub VI Calibrator

This is a SUB VI which is used to calibrate the voltage sent to the amplifier such that the desired SPL is produced. It sends out a very low arbitrary voltage initially which is equivalent to -20 dB (re 20 µPa). It also estimates the voltage needed to produce the desired SPL if not achived already from the microphone signal along with a prediction of the current value that will be sent to the speakers based on the input from the current probe.

### Final Calibrator Sub VI

A number of Sub VI Calibrator is put in this SUB VI to produce the desired SPL and implement it. It also stops itself if the predicted current value to be sent to the speaker is more than allowable which is 2.8 A or less than 0.0005 A in this file based on the signal from the current probe. It does the process thrice to make sure that the desired SPL is achieved.

### Record(SubVI)

This SUB VI measures the SPL at the receiver location from the microphone signal. It stops if current values are above 2.8 A or less than 0.0005 A. The sensitivity of the microphone is set as 8.5 mV/Pa and dB ref is set to 20 µPa.

### Sub VI Produces Sound

This SUB VI produces sound at desired one-third octave frequency and SPL.

### Sub VI HD performance

This SUB VI performs the read and write speed performance analysis of the HDD.

### SUB VI Per+Noise

This SUB VI contains the Sub VI Produces Sound and Sub VI HD performance. This SUB VI provides all the input to its SUB VIs and conatins come synchronization algorithm so that the program produces sound and measures the SPL at the correct instances and stops if anything goes wrong.

*FGVs*

The following FGVs are used to maintain the synchronization between the various tasks. The task it performs are mentioned in their title.

*FGV_End_Delay*

*FGV_StartData*

*SUB VI FGV stop input on error*

*SUB_WaitForOutput*

*SUB VI FGV*

*FGV Current Stoper*

*FGV Current Stopper*

*SUB_EndDelay*