International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 12, December-2020

Experimental Study of Free Vibration on the Comparison of 304 Structural Steel and 316 Structural Steel for Vibro-Acoustic Properties

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***Abstract*:-Vibro-acoustic materials play very important role in modern engineering applications. The structural steels are widely used now a days in aerospace and industrial applications. Modal analysis test is conducted for the steel and structural properties are found, the properties like logarithmic decrement, frequency and amplitude are the properties found by impact hammer test. In the Forced vibration system, the properties of the material structural steel304 and structural steel316 are found by the tests for forced vibration conditions. The base metal, and 304steel with Damping material and porous material have different properties and structural steel316 with Damping material and Porous presents different vibro-acoustic properties. The structural applications of the materials for different composition give the magnitude spectrum and frequency domain. Under damped condition the material shows resonant behavior and characteristics. Experimental Modal Analysis (EMA) is used for Frequency Response Functions (FRFs) obtained by measuring both output measurements and input forces of the experiment. In the present trend, there has been development of output-only Operational Modal Analysis (OMA) methods that do not require the measurement of input forces under strict assumptions in terms of the nature of excitation forces.**

Keywords: Vibro-acoustic materials, frequency, amplitude, logarithmic decrement and damping factor.

1. INTRODUCTION:

The technology of protecting metals and alloys from the damage by the surrounding medium in the contest of present field is an extremely important. The study of vibro-acoustic materials is an important task as there is a necessity for the low vibrating and enough working environment. The machine designers are now focusing on the use of the materials for this purpose for which the behavior of the materials leading for low cycled conditions for low cost and effective design works. The applications of vibro-acoustic materials are ranging from aerospace to various structural engineering designs. The experimental evaluation includes material behavior investigation and characterization. The material testing includes traditional and non-traditional methods. The vibro-acoustic modulation technique, ultrasonic methods, harmonic analysis etc. have been considered in the evaluation of the material properties. The characterization helps to reveal the material properties viz., mechanical and damping.

In the present paper the experimental results with impact hammer test with the boundary condition in vibration test, vibro-acoustic properties are determined.

2. METHODLOGY:

2.1 Experimental modal analysis

To focus on the vibro-acoustic materials an experimental setup is developed to measure the data which is used to find out the natural frequency of the material. The provisions are made in the experimental setup to incorporate the different testing conditions namely impact hammer test. The different vibro-acoustic material specimens are prepared and are used in the above experiment. The data corresponding to the mechanical behavior of the vibro-acoustic materials for structural applications are evolved.

Figure 1 Experimental setup

2.2 IMPACT HAMMER TEST:

The most common exciters are the impact hammer and the shaker. Impact hammers are convenient and relatively inexpensive compared to other actuators hence impact hammer test is conducted. In addition, because they are not attached to the test object, they do not change its dynamics. The impact hammer (Impulse hammer) resembles an ordinary hammer, but it has a specially designed tip that contains a sensor for measuring the impact force and is interpreted in terms of frequency. If the test object struck crisply with the hammer, the applied force is a pulse that resembles an impulse. This is the advantage of using an impact hammer because an impulse, simplifies the analysis while exciting all of the test materials into natural frequencies. By adding specially designed weights to the hammer and by using tips with different hardness, one can adjust the applied force and the duration of pulse. A harder tip generates a force having higher frequency content but it transfers less energy to the test object.

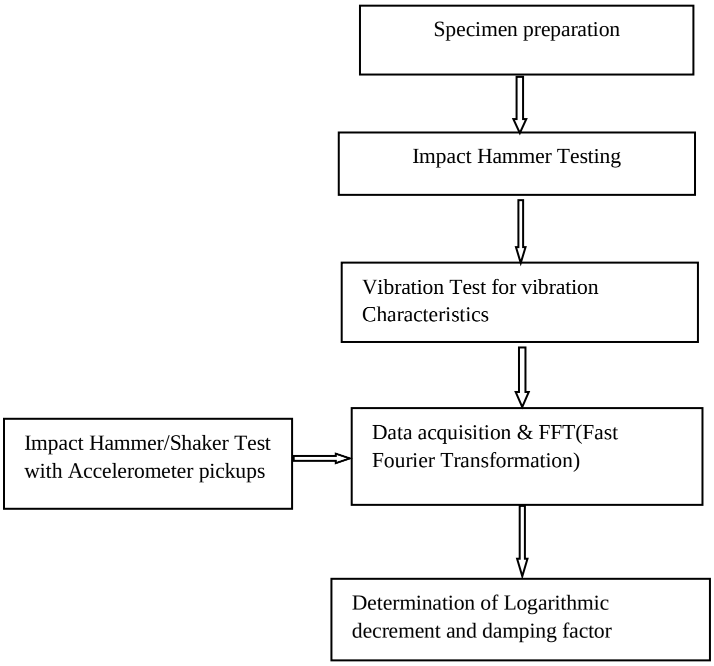

Figure 2: Flow chart showing experimental analysis

Table 1 The details of Material 304 Structural steel and boundary conditions

Material condition	Composition			Boundary condition	
	Length (mm)	Breadth (mm)	Thickness (mm)	Specimen tested for Forced vibration cantilever	Specimen tested for Forced vibration fixed-fixed
304	170	150	3	1	1
304+D	170	150	3+4.5	1	1
304+P	170	150	3+7.5	1	1
304+D+P	170	150	3+4.5+7.5	1	1

Table 2 Details of the Material 316 Structural steel and boundary condition

Material condition	composition			Boundary condition	
	Length (mm)	Breadth (mm)	Thickness (mm)	Specimen tested for Forced vibration cantilever	Specimen tested for Forced vibration fixed-fixed
316	170	150	3	1	1
316+D	170	150	3+4.5	1	1
316+P	170	150	3+7.5	1	1
316+D+P	170	150	3+4.5+7.5	1	1

IMAGES OF SPECIMENS

Fig.3: Structural Steel 316

Figure 4: Structural Steel 304

4. RESULTS AND DISCUSSIONS:

Type 1 : FREE VIBRATION CANTILEVER BOUNDARY CONDITION

MATERIAL STRUCTURAL STEEL 304

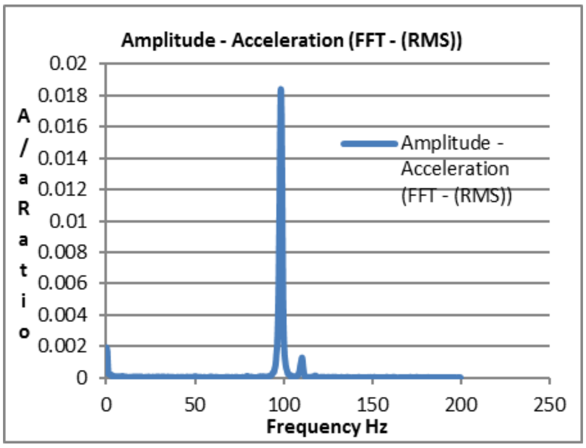

Figure 4.1 Amplitude acceleration curve for Free vibration cantilever 304 base metal

Difference in frequency=110-98.5=11.5 Hz

Difference in Amplitudes=0.0183999-0.00101607=0.01738383 metre

Logarithmic decrement, δ= $ln\frac{x0}{xn}$=ln($\frac{0.0183}{0.0010}$) = -4.0

(negative because of amplitude decreases)

$\zeta=\frac{\delta}{\sqrt{4\pi2+\delta2}}$ =-0.537=Damping factor

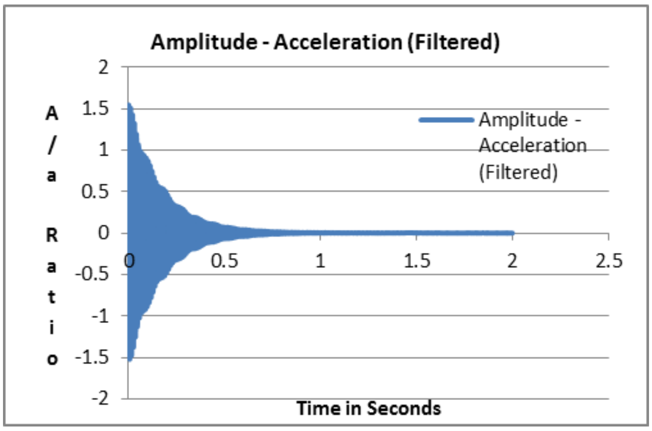

Figure 4.2 Amplitude acceleration filtered curve, free vibration cantilever 304 base metal –Time Domain (TD)

Difference in time=0.02062-0.00023=0.02039 sec,

Difference in Amplitudes=1.48-1.40=0.08 metre δ= $ln\frac{x0}{xn}$=ln($\frac{1.40}{1.48}$) = 0.227 (positive value because of amplitude increases)

$\zeta=\frac{\delta}{\sqrt{4\pi 2+\delta 2}}$ =0.036=Damping factor

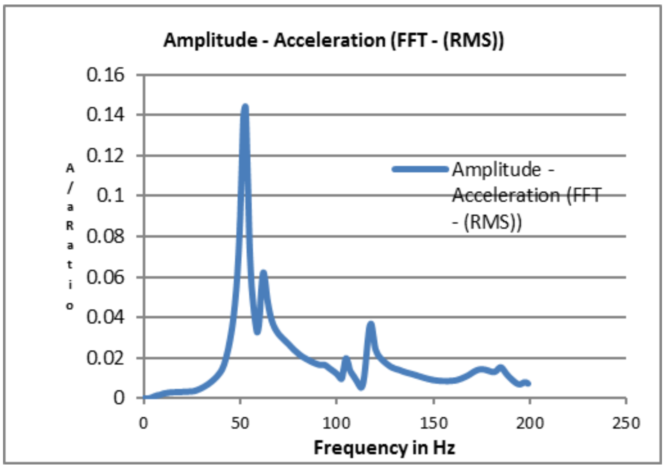

Figure 4.3 Free vibration cantilevers 304 with damping material

Figure 4.3 shows frequency domain plot for free vibration with Cantilever type boundary condition, for 304 steel base material with damping material. The time domain is an expression of amplitude and individual amplitudes.

Difference in frequency=61.96-52.82=9.14 Hz,

Difference in Amplitudes=0.14425-0.0624=0.08185 metres

δ= $ln\frac{x0}{xn}$=ln($\frac{0.0624}{0.14425}$) = -0.8379 (negative value because of amplitude decreases)

$\zeta=\frac{\delta}{\sqrt{4\pi 2+\delta 2}}$ =-0.132=Damping factor

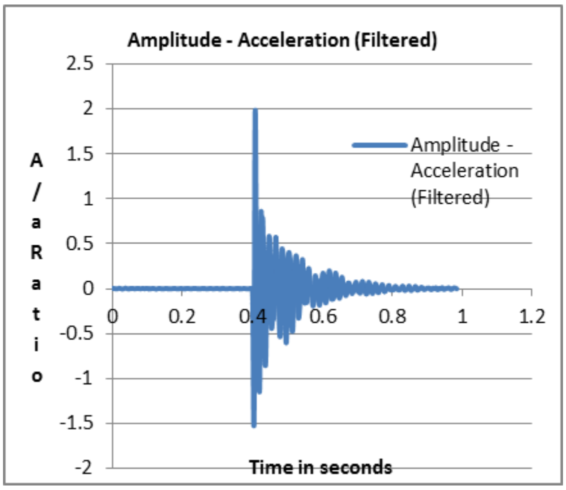

Figure 4.4 Amplitude acceleration filtered curve, free vibration cantilever 304+Damping-TD

Figure 4.4 Shows Time domain plot free vibration with Cantilever type boundary condition, for steel 304+Damping. The time domain is an expression of amplitude and individual amplitudes.

Difference in Time=0.4243-0.4080=0.0163 sec,

Difference in Amplitudes=1.96-0.82=1.14 Hz

δ= $ln\frac{x0}{xn}$=ln$\left(\frac{0.82}{1.96}\right)$ = −0.10 (negative value because of amplitude decreases).

$\zeta=\frac{\delta}{\sqrt{4\pi 2+\delta 2}}$ =-0.16=Damping factor.

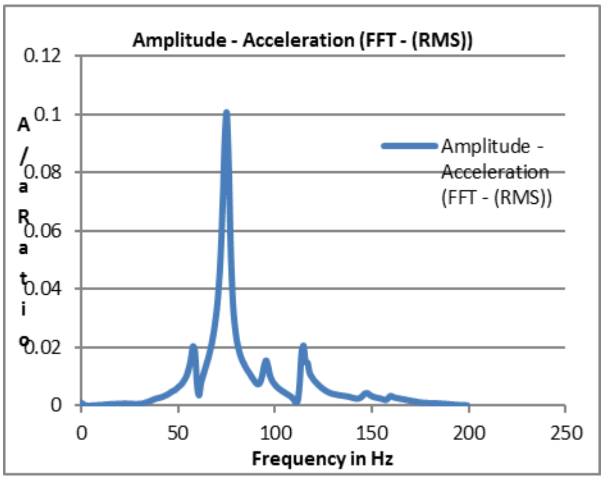

Figure 4.5 Free vibration cantilever 304+Porous-FFT

Figure 4.5 Shows frequency domain plot for free vibration with cantilever type boundary condition, for 304+Porous-FFT. The frequency domain is an expression of amplitude and individual amplitudes.

Difference in frequency=77.17-57.90=19.27 Seconds,

Difference in Amplitudes=0.100-0.0206=0.0794 meters

δ= $ln\frac{x0}{xn}$=ln($\frac{0.02}{0.10}$) = -39.12(negative value because of amplitude decreases)

$\zeta=\frac{\delta}{\sqrt{4\pi 2+\delta 2}}$ =-0.98=Damping factor

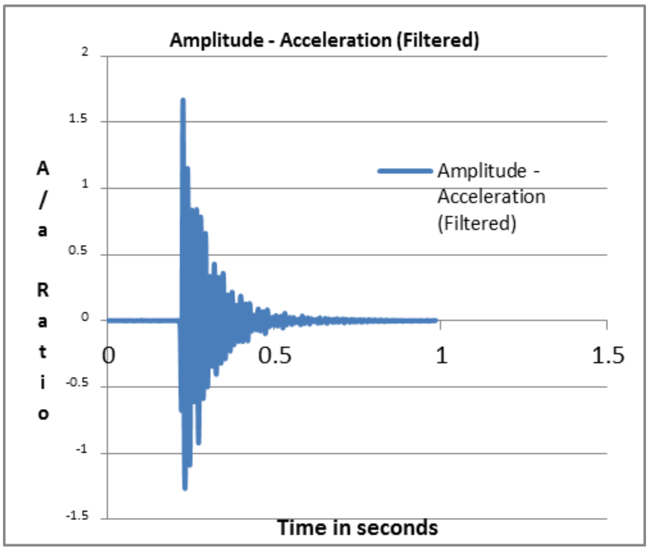

Figure 4.6 Amplitude acceleration filtered curve for Free vibration condition with cantilever boundary condition steel 304+ Porous material

Figure 4.6 shows Time domain plot of free vibration with Cantilever type boundary condition, for steel 304 with Porous material. The time domain is an expression of amplitude and individual amplitudes.

Difference in Time=0.2252-0.2242=0.001sec,

Difference in Amplitudes=1.62-1.12=0.5 metre

$\delta = ln\frac{x0}{xn} = \ln\left(\frac{1.12}{1.62}\right) = 0.07$(positive value because of amplitude increases)

$\zeta = \frac{\delta}{\sqrt{4\pi 2+\delta 2}}$ =0.01=Damping factor.

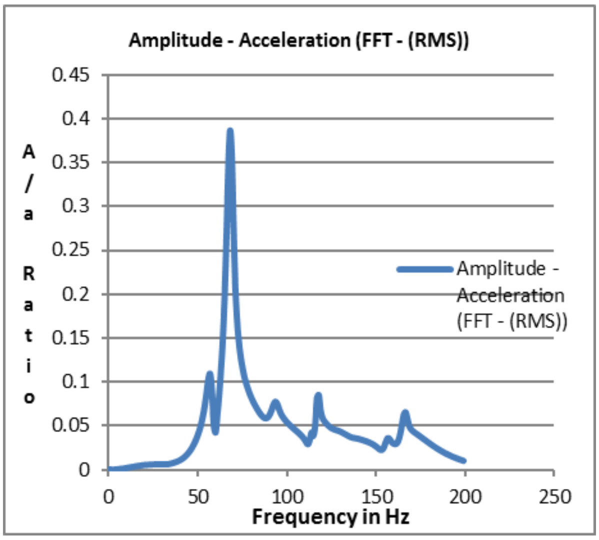

Figure 4.7 Free vibration cantilever for 304 with Porous and Damping material

Figure 4.7 Shows frequency domain plot of free vibration with Cantilever type boundary condition, of 304+Porous+Damping-FFT. From the graph we can find the following value, the time domain is an expression of amplitude and individual amplitudes.

Difference in Time=0.2252-0.2242=0.001 Sec,

Difference in Amplitudes=1.62-1.12=0.5 metre.

$\delta = ln\frac{x0}{xn} = \ln\left(\frac{1.12}{1.62}\right) = 0.07$(positive value because of amplitude increases)

$\zeta = \frac{\delta}{\sqrt{4\pi 2+\delta 2}}$ =0.01=Damping factor

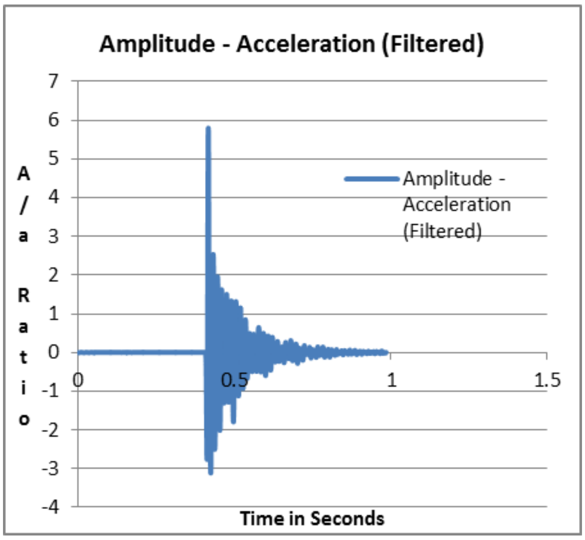

Figure 4.8 Amplitude acceleration filtered curve for Free vibration condition with cantilever boundary condition for steel304 with Porous Material and Damping-TD

Figure 4.8 Shows time domain plot for free vibration with Cantilever type boundary condition, for steel 304 with Porous material and Damping-TD. The time domain is an expression of amplitude and individual amplitudes.

Difference in Time=0.4178-0.4159=0.0019 sec,

Difference in Amplitudes=5.75-2.49=3.26 metres

$\delta = ln\frac{x0}{xn} = \ln\left(\frac{2.49}{5.75}\right) = 0.158$(positive value because of amplitude increases)

$\zeta = \frac{\delta}{\sqrt{4\pi 2+\delta 2}}$ =0.025=Damping factor.

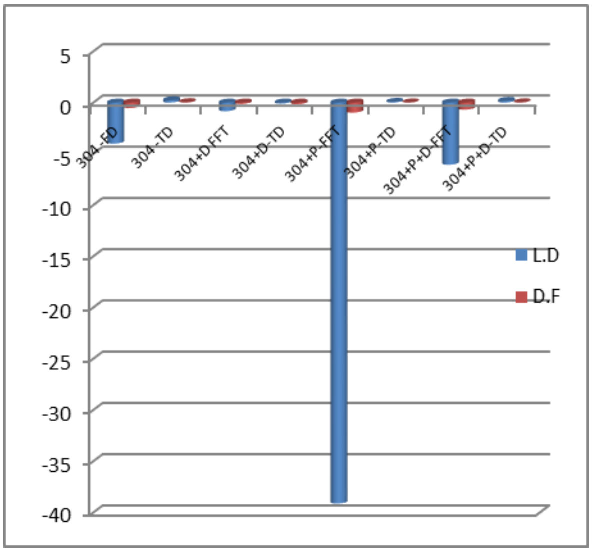

Figure 4.9 Trend of Logarithmic decrement and damping factor-Column diagram

Figure 4.9 shows the trend of the Logarithmic decrement and damping factor. From the above column figure, it clearly shows that the logarithm decrement and damping factor are negative value because for the base metal 304 both the values of logarithmic decrement and are coming negative because frequency is high for frequency domain plot, where as in time domain plot the amplitude is decreases continuously here the value is positive because it is under damped system. Where in 304+Damping-FFT it clearly shows negative value, here damping material PVDF objects the signals, so here it affects the natural frequency of the material, so it is neglected. In 304+Porous-FFT, here negative value are coming here porous material EOC, suppress the signal in frequency plot, but in 304+Porous-TD,number of amplitude is high so here positive values are coming due to amplitudes ,so it clearly shows it is under damped system. When 304+Porous+Damping-FFT here negative values are coming also logarithmic decrement decreases comparatively and damping factor are negative and the values are less.in304+Porous+Damping-TD are positive values and the values comparative slightly increases.

Type 2: FREE VIBRATION FIXED-FIXED BOUNDARY CONDITION MATERIAL STRUCTURAL STEEL 316

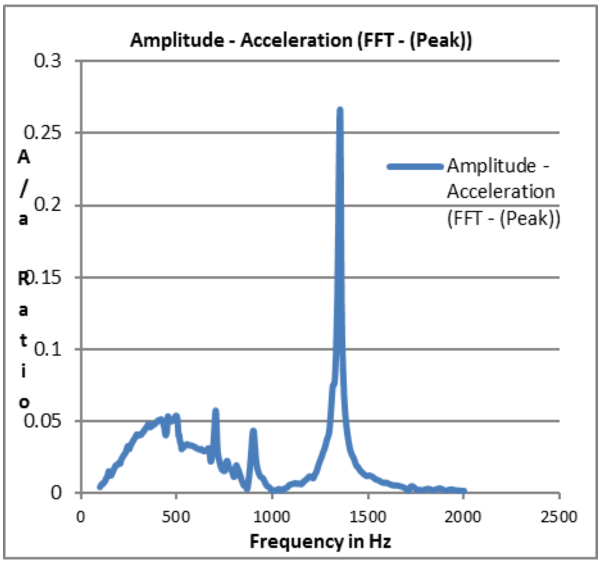

Fig 4.10 Amplitude acceleration curve for free vibration with fixed- fixed 316 FFT

Fig4.10 shows frequency domain plot of free vibration with fixed-fixed type boundary condition, of 316 FFT. From the graph we can find the following value, the frequency domain is an expression of amplitude and individual frequencies.

Difference in frequency=1332-897=435 Hz,Difference in Amplitudes=0.2659-0.04159=0.22431metre

δ= $ln\frac{x0}{xn}$=ln$\left(\frac{0.04159}{0.2659}\right) = -11.94$(negative value because of amplitude decreases)

ζ=$\frac{\delta}{\sqrt{4\pi2+\delta2}}$ =-0.88=Damping factor.

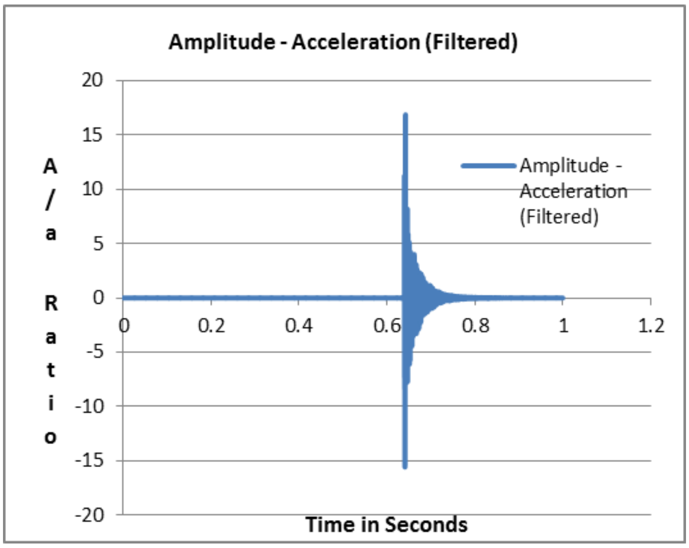

Fig 4.11 Amplitude acceleration curve for free vibration with fixed- fixed 316

Figure 4.11, shows time domain plot of free vibration with fixed- fixed type boundary condition, of 316. From the graph we can find the following value, the time domain is an expression of amplitude and individual amplitudes.

Difference in frequency=0.6420-0.6398=0.0022 Hz, Difference in Amplitudes=16.86-11.24=5.62 metre

δ= $ln\frac{x0}{xn}$=ln($\frac{11.24}{16.86}$) $= 0.1435$ (positive value because of amplitude increases)

ζ=$\frac{\delta}{\sqrt{4\pi2+\delta2}}$ =0.0228=Damping factor

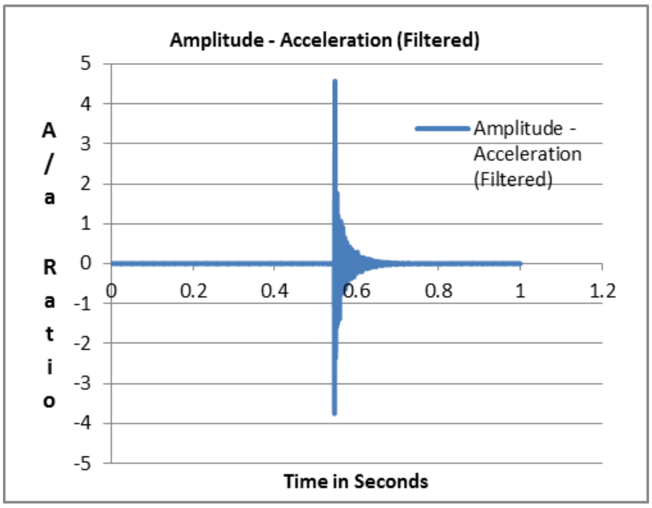

Fig 4.12 Amplitude acceleration curve for free vibration with fixed- fixed boundary condition for 316+Damping+Porous

Figure 4.12, shows time domain plot of free vibration with fixed- fixed type boundary condition, of 316+Damping+Porous. From the graph we can find the following value, the time domain is an expression of amplitude and individual amplitudes.

Difference in frequency=0.5473-0.5470=0.0003 Hz,
Difference in Amplitudes=4.57-1.75=2.82Metre

δ= $ln\frac{x0}{xn}$=ln($\frac{2.44}{2.97}$) $= 0.122$ (positive value because of amplitude increases)

ζ=$\frac{\delta}{\sqrt{4\pi2+\delta2}}$ =0.0194=Damping factor

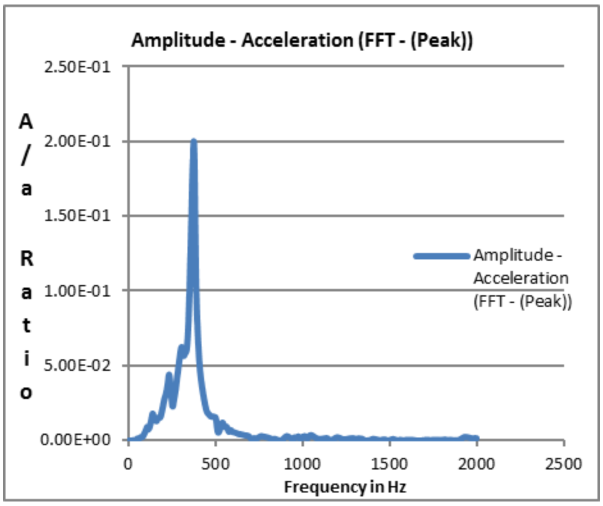

Figure 4.13 Amplitude acceleration curve for Free vibration with fixed- fixed 316+Porous FFT

Figure 4.13, shows frequency domain plot of fixed- fixed type boundary condition, for steel 304+Porous FFT. From the graph we can find the following value, the frequency domain is an expression of amplitude and individual frequencies.

Difference in frequency=1316-1255=61Hz,

Difference in Amplitudes=2.97-2.44=0.53Metre

$\delta = ln\frac{x0}{xn} = \ln\left(\frac{2.00E-01}{6.14E-02}\right) = 0.026X103$ (positive value because of amplitude increases)

$\zeta = \frac{\delta}{\sqrt{4\pi 2+\delta 2}}$ =0.97=Damping factor

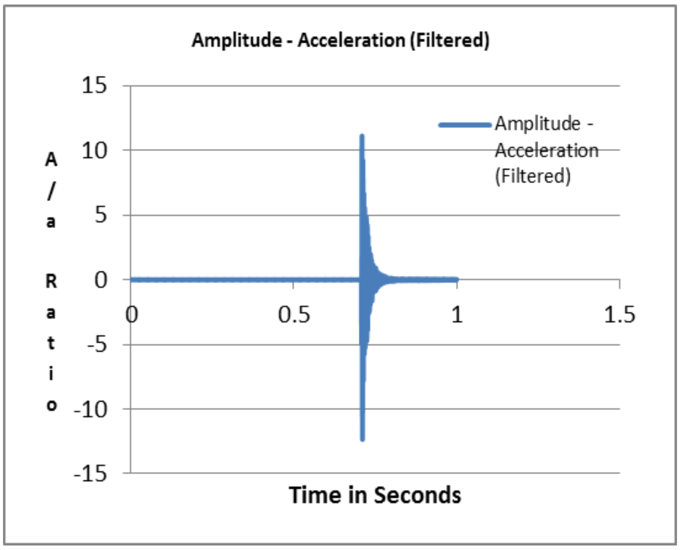

Figure 4.14 Amplitude acceleration curve for Free vibration with fixed- fixed 316+Damping

Figure 4.14 shows time domain plot of free vibration with fixed- fixed type boundary condition, of 316+Porous. From the graph we can find the following value, the time domain is an expression of amplitude and individual amplitudes.

Difference in frequency=0.7120-0.7091=0.0029 Hz,
Difference in Amplitudes=11.00-9.15=1.85 metre

$\delta = ln\frac{x0}{xn} = \ln\left(\frac{9.15}{11.00}\right) = 0.201$ (positive value because of amplitude increases)

$\zeta = \frac{\delta}{\sqrt{4\pi 2+\delta 2}}$ =0.032=Damping factor.

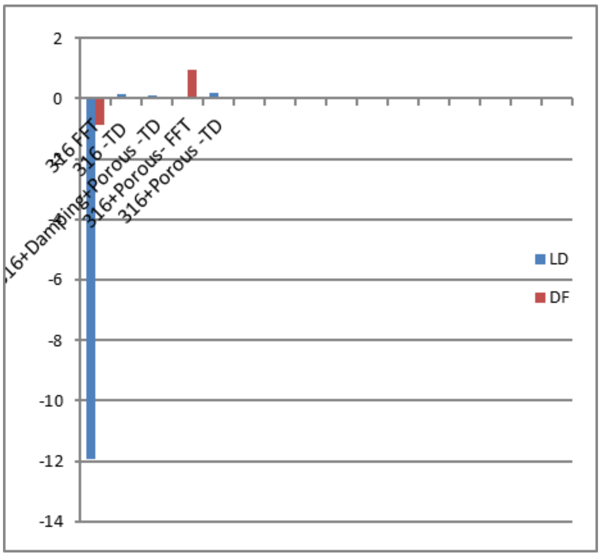

Figure 4.15 showing the trend of the Logarithmic decrement and damping factor-Vertical column diagram

Table 3: Damping factor for all materials with different boundary conditions.

Figure number	Type of composition	**Cantilever boundary condition Free vibration**	Damping Factor (ζ)
4.1	304 base metal -FD		-0.537
4.2	304 base metal -TD		0.036
4.3	304+ DampingFFT		-0.132
4.4	304+Damping-TD		-0.16
4.5	304+Porous-FFT		-0.98
4.6	304+Porous-TD		0.01
4.7	304+Porous+Damping-FFT		-0.69
4.8	304+Porous+Damping-TD		0.025
Figure number	Type of composition	**Fixed-Fixed boundary condition Free vibration**	Damping Factor (ζ)
4.10	316 FFT		-0.88
4.11	316 -TD		0.0228
4.12	316+Damping+ Porous -TD		0.0194
4.13	316+Porous- FFT		0.97
4.14	316+damping -TD		0.032

Figure 4.15 shows the trend of the Logarithmic decrement and damping factor. From the above figure, it clearly shows that the logarithm decrement and damping factor are positive value and negative value because forced vibration cantilever boundary condition .The base metal 316 FFT only have negative value both the values of logarithmic decrement and are coming negative because frequency is high for frequency domain plot, where as in time domain plot the amplitude is decreases continuously here the value is positive because it is under damped system. Where in 316+Damping-FFT it clearly shows positive value, here damping material PVDF objects the signals, so here it affects the natural frequency of the material. In 316+Porous-FFT, here positive value are coming here porous material EOC, suppress the signal in frequency plot, but in 316+Porous-FD,number of amplitude is high so here positive values are coming due to amplitudes ,so it clearly shows it is under damped system. When 304+Porous+Damping-FFT here positive values are coming also logarithmic decrement decreases comparatively and damping factor are positive and the values are less in 316+Porous+Damping-TD are positive values and the values comparatively increases.

CONCLUSION:

Table 3 shows the details of Material steel 304, under free vibration, with Cantilever boundary condition. From the above table, it clearly shows that the damping factor are negative value because for the base metal 304 has damping factor negative because frequency is high for frequency domain plot, where as in time domain plot the amplitude is decreases continuously here the value is positive because it is under damped system. Where in 304+Damping-FFT it clearly shows negative value, here damping material PVDF objects the signals, so here it affects the natural frequency of the material, so it is neglected. In 304+Porous-FFT, negative values are coming here for porous material EOC that suppress the signal in frequency plot, but in 304+ Porous-TD, number of amplitude is high so here positive values are coming due to amplitudes, so it clearly shows it is under damped system. When 304+Porous+Damping-FFT have negative values decreases comparatively and damping factor are negative and the values are less.In304+Porous+Damping-TD are positive values and the values comparative slightly increases.

In case of 316 material, it clearly shows that the damping factor are positive value and negative value because free vibration fixed-fixed boundary condition .The base metal 316 FFT only has damping factor negative value because frequency is high for frequency domain plot, where as in time domain plot the amplitude is decreases continuously here the value is positive because it is under damped system. Where in 316+Damping-FFT it clearly shows positive value, here damping material PVDF objects the signals, so here it affects the natural frequency of the material. In 316+Porous-FFT, has damping factor positive value.The porous material EOC, suppress the signal in frequency plot, but in 316+Porous-FD,number of amplitude is high so here positive values are coming due to amplitudes ,so it clearly shows it is under damped system. When 304+Porous+Damping-FFT here positive values are coming also logarithmic decrement decreases comparatively and damping factor are positive and the values are less.in316+Porous+Damping-TD are positive values and the values comparative slightly increases. From the above Table 3, the following observation, the 316+porous has 0.97 best damping factor.

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