Laser Doppler Vibrometer – Brake Disc Modal Analysis

Krishnadas Pachery Chandradas[1]

[1]*Mr Krishnadas Pachery Chandradas, 2105959 Motorcycle Engineering,* University of Wales Trinity Saint David

Abstract – This experimental research was performed to evaluate the application of a laser doppler vibrometer as a method for analyzing the vibration velocity and displacement in a brake disc with the help of data processing. The brake disc is positioned stationary and agitated by a solenoid actuator at a constant point until the scan is complete across all scan points. The vibration data was examined in both the time and frequency domains. Multiple frequency of higher vibrations was obtained due to inaccurate excitation of the solenoid with variable amplitude due to improper mounting which resulted in a fluctuated indentation frequency and data which are the key challenges while obtaining a displacement scan report. External vibrations have significant role in disturbing the environment whereas torsional surface vibrations are found out in selected bandwidth.

APPARATUS

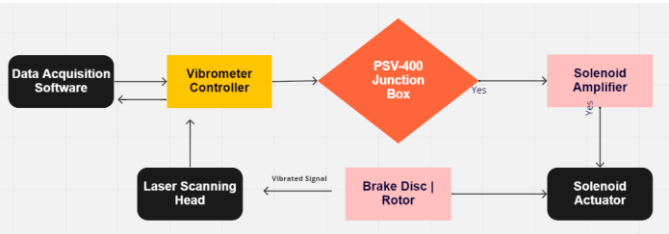


Figure 1 : Apparatus setup of Polytec LDV

A Laser Doppler Vibrometer (LDV) setup consists of a range of apparatus which works on the principle of signal transmission which is controlled over a data acquisition software.

A vibrometer controller system works on two principles. It obtains the vibration velocity and displacement at a fixed point of the surface of the component from the scanning head and direct the feedback on the acquisition software. The output is connected to the PSV-400 junction box to generator outputs to synchronize the indentation timing with the velocity displacement on the surface of the component. The velocity output from the laser scanning head is in the nature of an analog signal directed towards the controller.

Figure 2 : Polytec OFV-5000 Vibrometer controller

Figure 3 : Polytec PSV-400 Junction Box

An analog input from the junction box is send to a solenoid actuator that creates an indentation force on the component which can be positioned according to the nature of the component or type of results. Different point of indentation gives a different resonant frequency and it is directly proportional to the amplified indentation of the solenoid actuator.

Figure 4 : Solenoid actuation frequency controller

A laser Doppler vibrometer consists of a scanning head with a laser beam which will be reflected back from the component to the detector through Bragg cell. The frequency shift of the reflected light is stored instantaneously by the acquisition software when it generates an analog signal for the hit by solenoid actuator.

Figure 5 : Polytec PSV-400 Scanning Head

A solenoid actuator creates a hit generated by the generator every finite second that can be set manually on PSV acquisition software where an analog signal is transferred. The test component used for the experimental analysis is a brake disc of an automobile which is subjected to friction by the compression of the caliper assembly where strong sliding indentation of brake pads disturbs the frequency generating vibration of component. An analysis into brake rotor gives an understanding of how the material act for the desired braking force applied by the driver as a matter of application.

Figure 6 : Solenoid Actuator and mounted brake disc

1. INTRODUCTION

In recent decades, limiting the vibration and vibration analysis of automotive components has become a significant task in quality control. Brake rotors are frequently quite complex in terms of material performance, design, and regulatory relations. Design specifications and mechanical characteristics of automotive braking components are often selected to meet performance and scalability objectives. This can be achieved by optimizing the vibrations acting on the rotor while braking, which is transferred to the chassis and have severe impact on driver handling comfort. Lack of ability of directly mounting vibration reduction calipers or other dampening factors to the component, research into the behavior of vibration and noise transmission is important. Hence change in its design must be thoroughly considered from all perspectives in order to obtain the optimal transfer between different standards.

LDV is comprised of three scan heads that can measure motions in horizontal and vertical planes to acquire clear knowledge about three-dimensional movements. The LDV concept of operation is that it is used to comprehend vibration velocity and displacement at a given position.

This paper gives an experimental examination of the vibration velocity and displacement of the brake disc caused by a constant frequency external force that stimulates the material to resonate in order to acquire frequency at different contact points.

2. LITERATURE REVIEW

Laser vibrometer is an effective non-destruction technique method for measuring vibration on a wide range of materials. Modal analysis is the study of a linear structure's acoustic properties, such as natural frequencies, mode shapes, and modal damping ratios (Ewins, 2000) A laser Doppler vibrometer, one of the most precise and dependable vibration measuring equipment, can detect the surface velocity of a spot on a material along its laser beam path (S. Rothberg, 2017).

2.1 Working principle of a Laser doppler vibrometer.

The LDV generates a laser beam that is focused on a vibrating surface and reflected off the oscillating surface. A laser vibrometer can be equipped with a scanner that includes a series of orthogonal mirrors to optimize measurement efficiency (D.M. Chen, 2016). The vibrometer's laser light may constantly move across a predetermined path on a material to detect its surface velocity via spinning mirrors controlled by a controller.

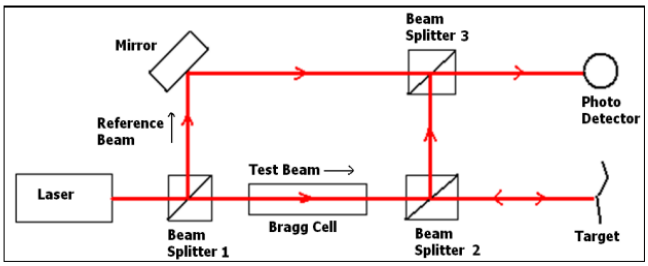


Figure 7 : Components of a Laser Doppler Vibrometer (VENKATARAO, 2014)

To determine the frequency and amplitude of the vibrating target, the Doppler shift of the reflected laser beam frequency is utilised. The apparent difference between the frequency at which sound or light waves leave a source and that at which they reach an observer caused by relative motion of the observer and the wave source is known as the Doppler effect. The LDV is a continuous analogue voltage that is proportional to the vibrating target's velocity. Helium-neon lasers are used primarily in LDV devices.

The laser beam that is focused on the target, i.e., the vibrating surface, is first separated into reference and test beams by beam splitter 1 with an initial frequency of (fo), as illustrated in Figure 7. The reference beam travels vertically towards the mirror, where it is reflected to the beam splitter3 and finally to the photo detector. (VENKATARAO, 2014). The test beam travels through the Bragg cell, which adds frequency shift (fb) to the target beam. This beam has a frequency (fo + fb) and is aimed at a vibrating body (Target). The velocity of the vibrating body (target) causes a Doppler shift in the beam.

The principle behind the working of a Laser doppler vibrometer is Doppler effect. The frequency of the light wave exhibited by the LDV is directly proportional to the speed of light in the laser beam which can be calculated by using equation 1.

Frequency = Speed of light in laser beam / wavelength

Equation 1 : Frequency of the light

2.2 Applications of LDV on automotive industry

According to the recent research using laser doppler vibrometer in automotive applications on damping properties of hybrid flax/carbon fiber-reinforced composites, (Fairlie G, 2020) concluded that the addition of an exterior flax layer to an epoxy/carbon fibre-reinforced composite raised its damping ratio by 53.6 percent, while the addition of two layers increased it by 94 percent. (El Abdi, 2019) concluded that relative displacements between sensor components in contact in three space directions for different vibration frequencies for a Top Dead Centre sensor. Displacement measurements at crimping zones of the sensor needs to widely analysed. (Luca Pagano, 2017) concluded by experimenting a modal analysis on the carbon fibre reinforced swingarm that the compared results of finite element analysis and laser doppler vibrometer is close where LDV is accurately perfect with respect to the values obtained after analysis. All of the application in this experiment demonstrates how the LDV enables for realistic findings on dynamic properties under simulated operational situations. (P. Castellini, 2002) compared the simulation results with LDV and proposed a new solution. The sidewall of a tyre during rotation in a conventional drum test-bench is the first component examined. in order to meet the

accuracy standards established by the tyre manufacturer, an optimised version of the TLDV was built for the specific purpose, including a trajectory evaluation tool based on image analysis.

3. METHODOLOGY

3.1. 2D alignment and Laser signal.

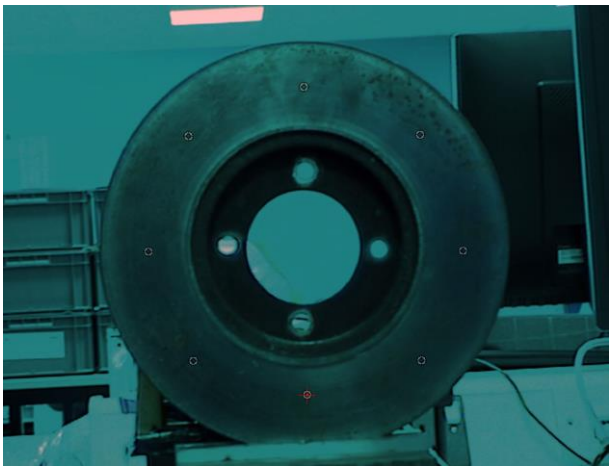


Figure 8 : 2D alignment

A brake disc is assembled on a fixed jack parallel to the scanning head within a range of 1.2 meters. PSV data acquisition software is opened and the function 2D alignment under setup is done. The scan points are defined on the component at 8 different points as illustrated in figure 7. The scan points are positioned using a toolbar that navigates the direction of the laser beam throughout the surface of the brake disc as illustrated in figure 8.

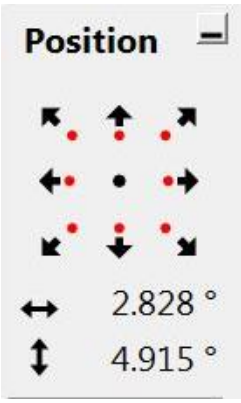


Figure 9 : Toolbar used for positioning 2D scan points

The 2D alignment directed by the laser is completed once by using the auto focus toolbar as illustrated in figure 9 which concludes that a signal is being obtained from the surface of the component subjected to excitation. Once the feedback of the signal level is obtained the scan points are preset for experimentation.

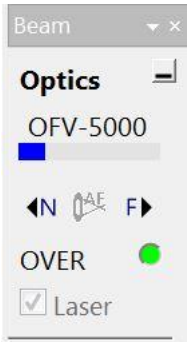


Figure 10 : Auto focus and signal feedback

3.2 Component Scan and analysis

As the scan requires a wide analysis of data throughout the surface of the circular component for the definition of scan points for obtaining the velocity displacement on the component surface, a polygon surface profile is used as illustrated on figure 10. The circular grid property defined with the density properties allocates the scan points constrained between the polygon shape defined throughout the brake disc. A final scan grid is obtained as illustrated in figure 10.

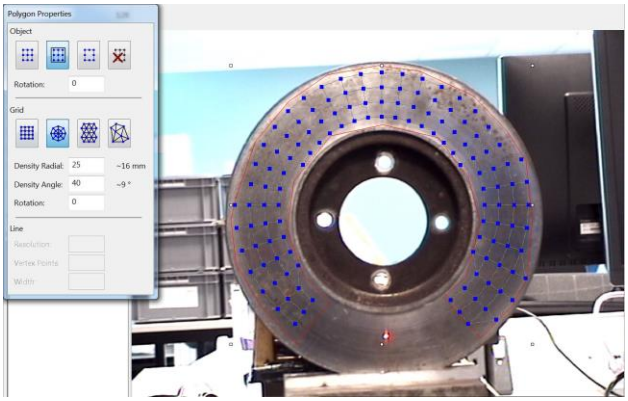


Figure 11 : Scan grid properties

The scan is initiated by saving the scan report under a filename which is later analyzed using a PSV data analysis software. The scan is initiated through all

predefined points where the laser is positioned to obtain the data for vibration velocity and displacement at the time of excitation. Figure 11 and 12 illustrates the half scan and full scan of the operation which is saved in the source file as results of the experimentation.

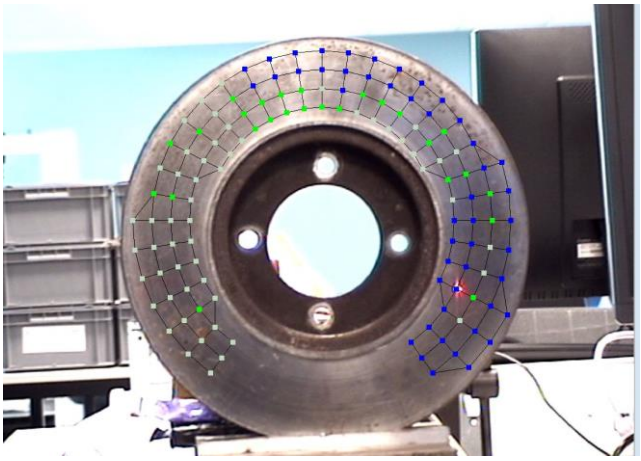


Figure 12 : Halfway scan and automated laser positioning

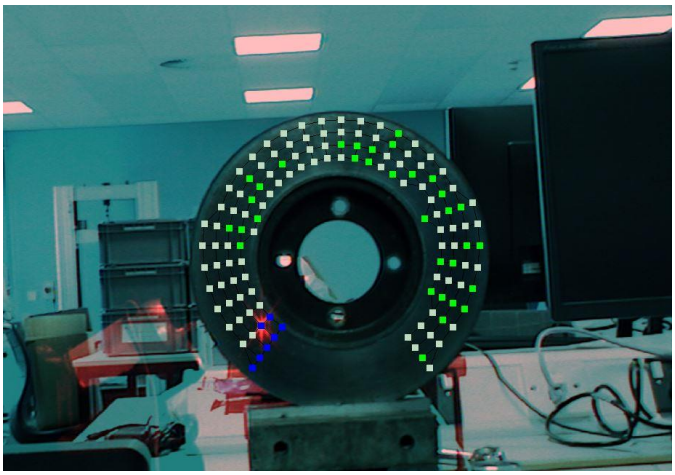


Figure 13 : Completed scan of the component surface

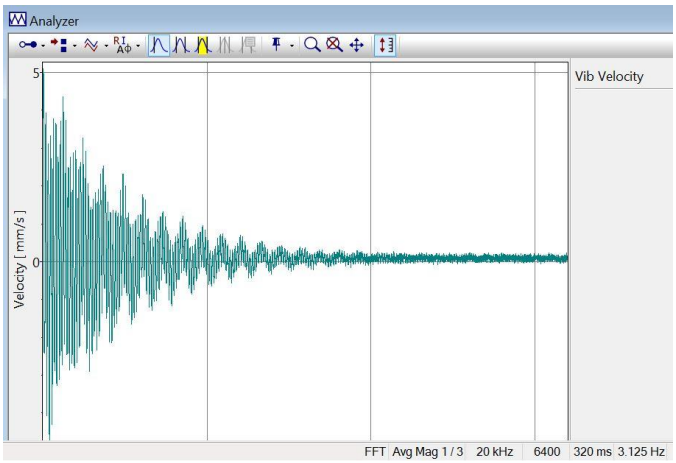
During the scan as illustrated in graph 1, a live data of the vibration velocity against time is shown in the FFT window to understand the importance of excitation and the decay of the signal. The vibration velocity is influenced by the positioning of the solenoid actuator

No	*Start*	*End*	*Peak*	*Bandwidth*	*Unit*
1	71.875	150	81.25	78.125	Hz
2	250	271.875	256.25	21.875	Hz
3	590.625	725	659.375	134.375	Hz
4	1093.75	1212.5	1153.125	118.75	Hz
5	1834.375	1878.125	1837.5	43.75	Hz
6	2340.625	2381.25	2362.5	40.625	Hz

which have to be positioned accurately where the excitation remains the same.

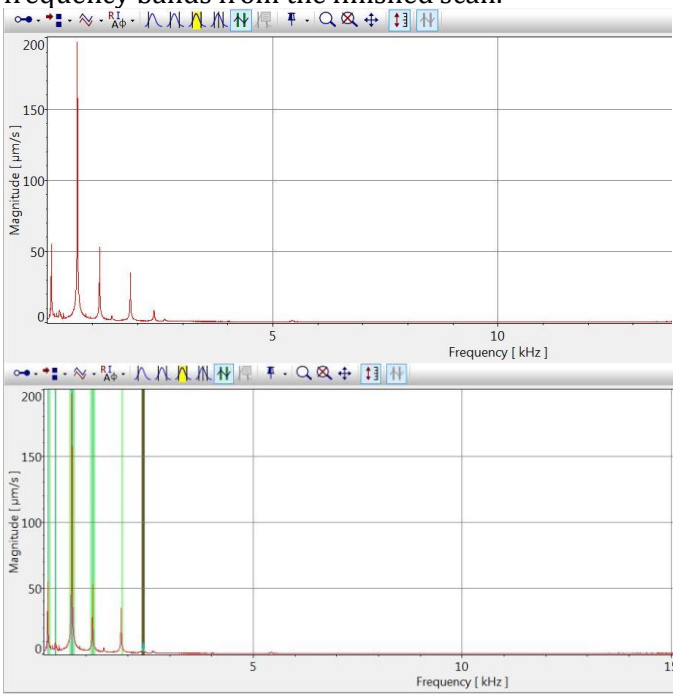
4. GRAPHS

The spectrum of the vibration signal measured live during simulation is presented in Graph 1. Using the analysis software,6 frequency bands of larger magnitude are extracted from the scanned data.



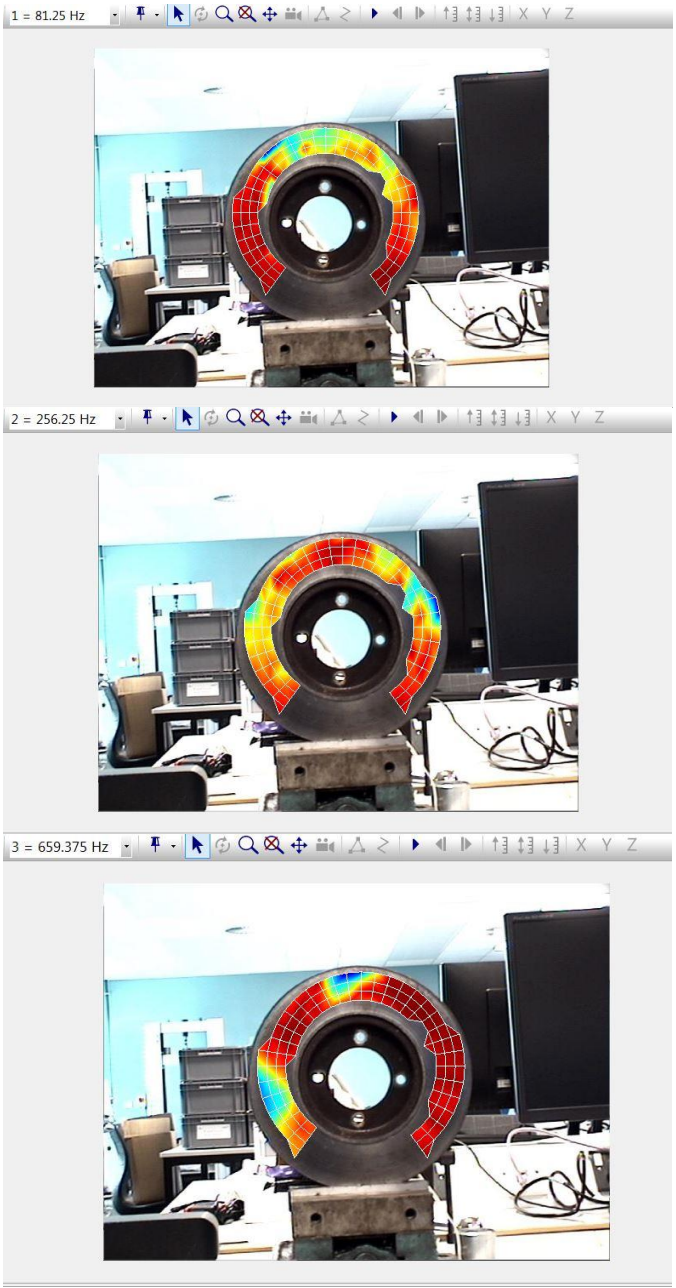
Graph 1 : Live capture

Graph 2 depicts the scaled data of the vibration velocity frequency bands from the finished scan.



Graph 2 : Frequency of the recorded data

The 2-dimensional analysis of the vibration measurement throughout the scan point detected by the laser vibrometer is shown on the frequency bands selected on the recorded data. The peak frequency and the bandwidth of the interested values are described on table 1. Impact of the actuator on the rear assembly of the rotor resulted in the following selected peaks have the following values of 81.25 ,256.25, 659.375, 1153.125 ,1837.5, and 2362.5 Hz respectively as shown in table 1. As the frequency of the data gets higher as per figure 13, the torsional vibration of the brake disc is highly noticed during the analysis.



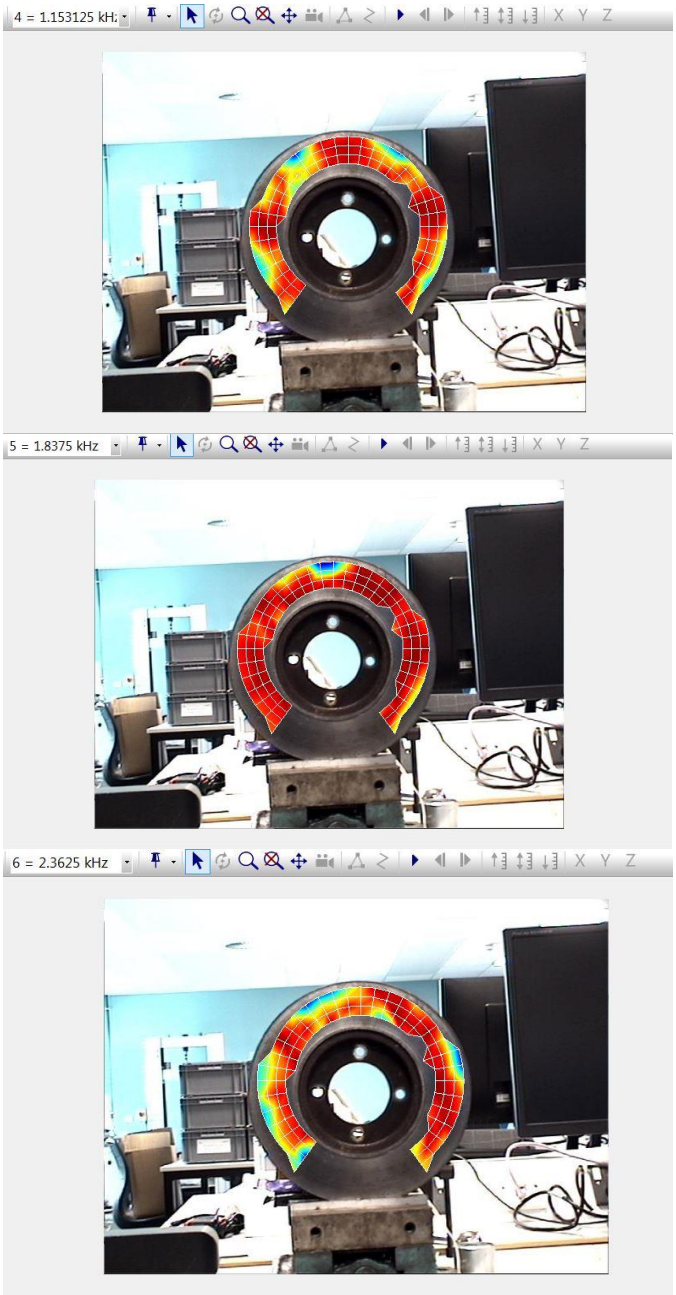


Figure 14: 2D frequency band

Bending modes of the surface illustrates different colors as a representation of the reflected wavelength of the laser beam. This is clear that the indentation of the solenoid actuator has resulted in a strong impact that vibrated the material in higher frequencies. The torsional modes of the modal analysis are represented between blue, yellow and red transition in the analysis software in both 2D and 3D views.

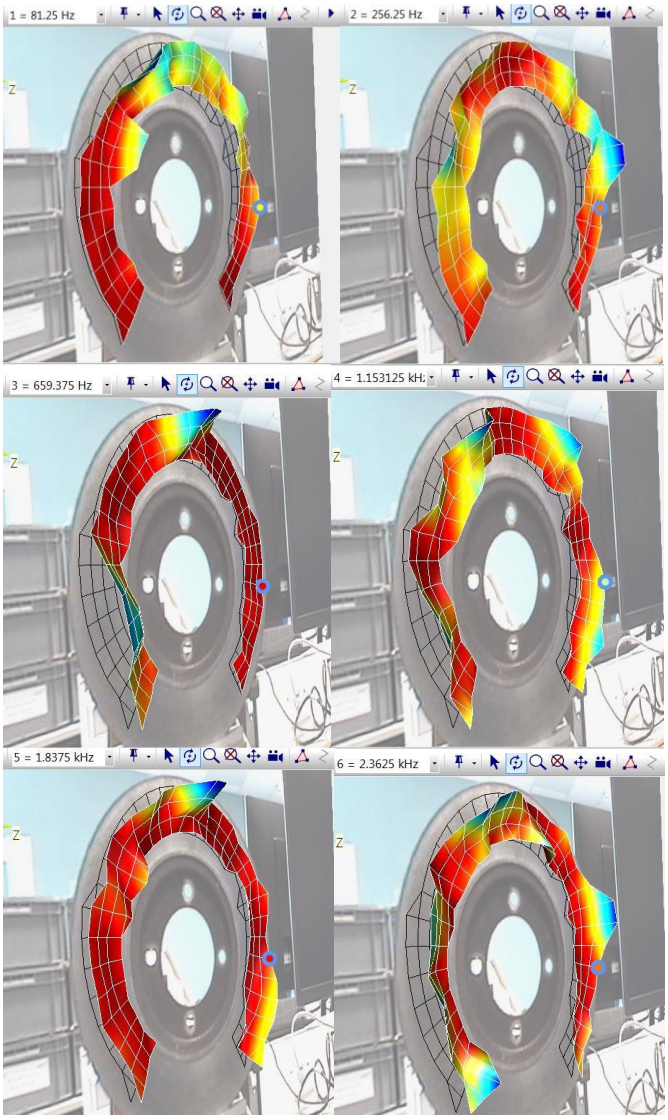


Figure 15 : 3D Frequency band

3-dimensional vibration analysis of the selected frequencies are mentioned in figure 14. The vibration of the surface is higher towards the edge of the component leading to torsion-oriented results throughout the component. This is because due to the constrained rotor with vertical mounting.

6.RESULTS AND DISCUSSIONS

The computational study of the dynamic behavior of a brake disc described here incorporates synchronized material behavior. A total number of 6 different frequency of vibration is obtained after the scan on the surface of the brake disc. The brake disc was excited vertically from the opposite side of the scan. The visual representation of the vibration of the component in 2D and 3D is illustrated in figure 14 and 15 respectively using the data analysis software. The highest peak of the selected bandwidth was higher for a frequency of 659.375 with a magnitude of vibration of over 200 micro meter per second. This resulted in torsional vibration of the component on horizontal axis towards the position of mounting.3D graph depicts a perfect illustration of the behavior of the component at different frequencies. Component vibration at 256.25 Hz have a uniform displacement throughout the component.

7.CONCLUSIONS

It is clear that the error percentage of the LDV setup is directly proportional to the mounting of the component and actuator which have influence on the vibrational frequencies. Modal analysis of the component is related to the shape, stiffness, and mass of the component. A clear analysis on the vibrational displacement and behavior of the material is understood and leads to an approach where design and development of brake disc have a strong influence on the reliability of steering mechanism and driver comfort. The study concludes that the environment under which the material should be tested must be a closed and not affected by an external disturbance. Efficiency of the results can only be attained if the excitation energy is well transferred through impact to the component. Uneven characteristics are more likely to discover through data if the mounting of the setup is not reliable.

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