

# Laser Doppler Vibrometer

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## **Abstract**

This experiment we attempt to find the vibrational modes of a brake disc using a laser doppler vibrometer, the Polytec PSV-400. The laser doppler vibrometer is used throughout industry in order to perform non-contact measurements on moving parts of which the properties measured may be affected by the addition of mass to the system. Whilst this experiment is performed on a static component which would normally be moving, it identifies has allowed the identification of the vibrational modes and the shape of these modes. This has allowed for the identification of frequencies which are best avoided in use as operation near these frequencies will cause a significant increase in the rate of degradation of the component.

The primary mode of vibration of the brake disc was found to occur at 671.875Hz and is characterised by the wave moving around the brake disc. There is a secondary shape to the vibration which is a consequence of the setup and characterised by a wobbling back induced by the solenoid tapping the brake disk on the back, this mode occurs at 81.25Hz.

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## 1 Apparatus

- Laser Doppler Vibrometer (Polytec PSV-400) + Computer
- Vice
- Solenoid
- Brake Disc

## 2 Introduction

In this experiment a Laser Doppler Vibrometer (LDV) is used to measure the vibration in a brake disc when it is tapped. A solenoid is used to tap the brake disc, exciting it and causing it to vibrate at its natural frequency. It is important that a tap is used, with sufficient time for the vibrations to decay, so as to not induce a forced vibration and to allow the LDV to measure the frequency. The LDV uses the Doppler effect in order to detect the minute movements in a object caused by the vibrations. The Doppler effect is characterised by the changing in wavelength of light emitted from an object when it is moving. With a red-shift observed when it is moved away and the wavelength is stretched and a blue-shift when the emitting object is moving towards the detector. The LDV emits a laser of known frequency to an object, this then reflects back to a detector on LDV which compares the frequency of the incoming reflection with that of the outgoing laser. Due to how this works it is important that the surface has a sufficiently smooth finish, otherwise there are scattering effects. There is a setting in the LDV's software to account for scattering effects however, it is best avoided for high quality data. In order to find the natural oscillating frequency of the brake disc we must observe it for sufficient amount of time in order to have the correct resolution. The software package for the LDV allows you to pick a frequency to measure to and it will select a detection period with sufficient resolution to do so, for this experiment we are using 20,000Hz as this allows sufficient time for the measurement of the vibrational modes of the component..

### 2.1 LDV Use in Automotive Industry

The laser doppler vibrometer has many uses in the automotive industry as there is a significant amount of improvements to efficiency and noise which can be made by measuring and gaining an understanding out the acoustics of car panels, break discs, tyres and drive trains. Polytec, the manufacturer of the LDV used in this experiment provides the following examples for uses of the LDV in automotive industries: Tire acoustics, drive train, aero acoustics, electronics EV, model validation, NVH testing, body-in-white and brake acoustics [1]. Comfort is an area of significant

importance in automotive developments as strong vibrations in the vehicle will lead to discomfort. Additionally, the excitation of panels, the tyres and the brakes can result in loud noises which can damage hearing and reduce the overall enjoyment of the drive. Simultaneously it is important to reduce noise for bystanders as the amount of noise a vehicle can produce is strictly regulated. The tyre noise from a vehicle is related to the tyre blocks hitting the road surface [], as such understanding this allows the production of quieter vehicles as it can be minimised in future tyre production. Efficiency of the vehicles can be significantly improved by using vibrometers as they can perform non contact observations and tests. This allows you to see if there are imperfections, such as manufacturing errors, in the setup without adding weight to the moving parts which would affect the results. Furthermore, identifying the vibrational modes of a component informs the designer of what frequencies should be avoided as to reduce fatigue damage to a component. For example a car panel being excited by aerodynamic effects in driving should not vibrate at its natural frequency or else it will experience more extreme changes in amplitude, accelerating the speed of the natural fatigue which will occur in use, reducing the lifetime of the part and exacerbating any defects that may have occurred during manufacturing.

## 2.2 Risk Assessment

The Laser Doppler Vibrometer uses a high energy laser in order to measure vibration. The laser on the LDV cannot directly cause burns however, it can cause damage to the eyes, especially from prolonged exposure. In order to reduce the risk the LDV serves the LDV is pointed at an opaque surface and when the LDV is not being used to perform the setup or data collection the hatch on it must remain closed.

## 2.3 Methodology

In order to observe the acoustics of the brake disc the brake disc was clamped into a vice. In order to reduce damping on the brake disc and allow for as close to the natural frequency of the brake disc as possible with our setup. The LDV was placed 1 metre away from the brake disc and this information was put into the program. All settings used on the Polytec data acquisition program are listed in the Appendix. Figure 1 shows pictures of the setup.



Figure 1: Setup

The next step is to use the automatic focusing capability of the LDV software and begin the 2D alignment. 2D Alignment is performed by maneuvering the laser into a position on the object being observed and then clicking on this position. This process allows the operator to confirm that the returning laser being detected would be of high quality, generating more accurate results. Once this process has been completed we can set up the scan points on the brake disc. The LDV has a built in camera and you can either manually select individual positions to collect data from, or create a

shape which will be filled with scan point using settings you decide. A polygon was created, covering the visible flat outer surface of the brake disc. It is from here the data was collected.



Figure 2: Solenoid setup

The LDV will attempt to scan each position three times to make sure the data collected is of high quality, as such making sure there is sufficient contact between the solenoid and the brake disc is important. To do this we maneuvered the solenoid into the position shown in Figure 2 and set the LDV software to turn the generator on, when a loud ringing noise was heard we kept the solenoid in that position and turned it off before we collected results. The loud ringing noise means that the brake disc is oscillating significantly and should allow quality data collection.

The software was set to collect the data, which it performs automatically, by scanning each individual point from the scan point setup. Once it finishes collecting data you can opening the LDV's analysis program. In the analysis program the first step is to select where the peaks in the data are. This process is simple and just requires you to drag a box around each peak in the frequency bands and the program will find the value of the peak and set the frequency modes. Once this process is completed you can view the acoustics of the brake disc.

### 3 Results and Discussion

Two experiments were performed with more care and with more scan points being selected. being put into the setup of the second experiment Figure 3 shows the shapes of the vibration modes and Figure 4 shows the frequencies at which these modes occur in the first experiment.

Each mode occurs at one of the peaks shown in Figure 4, the modes shown in Figure 3 are ordered in ascending frequencies. Figure 5 shows the modes from the second experiment and screenshots of the modes have been placed in the appendix as they do not provide much visual information due to the angle they were taken at.

Significantly more frequency modes were detected during the second experiment, which is likely due to greater care being taken in the setup and data collection. This shows that despite the ease of use of the equipment without due care and attention being taken towards the experiment the accuracy can be affected. Additionally, the frequency modes occur in different but similar positions in each experiment. This is most likely due to the small differences in the set up of the clamp and brake disc.

The modes we see in Figure 3 can be split into two types of movement; The back and forth wobble of the disc in the clamp visible in the third picture and the vibration travelling around the disc making a flapping effect. This vibration is the primary mode of vibration for the disc, the magnitude of which increases with distance to centre of the disc. These shapes are the same on the second experiment however due to the higher quality data collection more peaks in the frequency are visible. The frequency with the highest magnitude in the second experiment was 671.875Hz, which

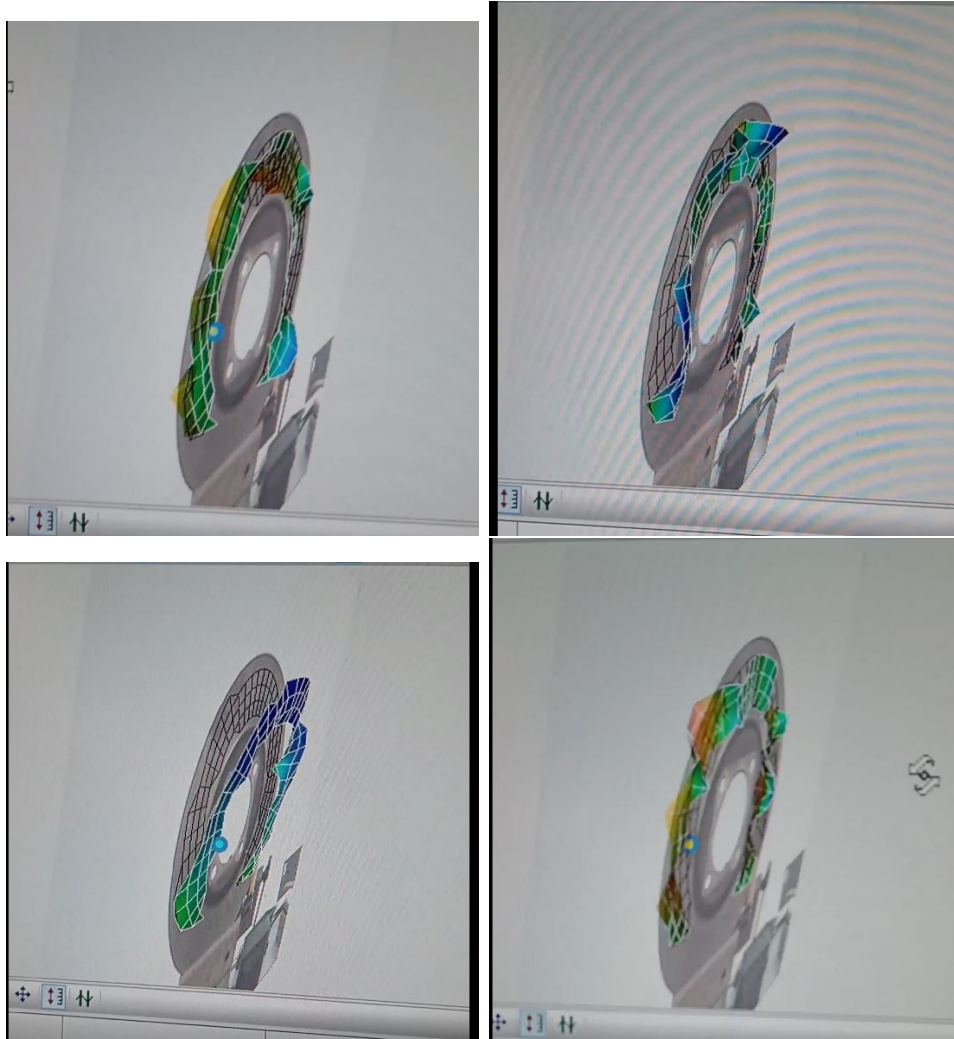


Figure 3: Shape of the vibration modes

is significantly higher than the frequency in the first experiment. Differences in the positioning of the solenoid, where the disk is clamped and the table the disc was on could be responsible for these results. Interestingly there is a significant amount of noise around the 50Hz area for which the electric network's background hum is responsible for as the UK's electric grid operates at 50Hz. This means any electrical equipment in the room, the computer, the LDV and the lights are all emitting this hum and inducing other objects to vibrate at this frequency. The lowest frequency identifiable peak occurred at 81.25Hz and the highest occurred at 2378.125Hz.

When doing these experiments we wanted to achieve as close to the natural frequency of the brake disc however, the set up we chose in the end is not representative of brake in use as it is clamped at the sides of the disc, this causes the setup's natural frequency to change to that of a coupled system of the clamp and brake disc, somewhat reminiscent of a brake disc with brakes applied. However, the clamp is significantly heavier than a brake assembly and is of a completely different shape, the way the system is held in place is also different as the clamp used in this experiment is just placed on a table and will thus the system will be affected by the natural frequency of the table, although to a lesser degree than the effect of the clamp. The clamp is also supporting the weight of the brake disc whereas normally on a vehicle the brake disc is attached to the axle. In order to be the best representative of a vehicle this experiment would best be performed on a brake disc attached to an axle or similarly. Additionally, in order to excite the natural frequency of the we tapped the brake disc on the rear. It would be interesting to analyse the effect of tapping different locations such as the sides of the disc and comparing the results. Furthermore, in order for the disc to be the best representation of a real life situation a spinning brake disc with a brake which can be applied would best show the acoustic effects that a driver will feel and hear and should be investigated in the future.

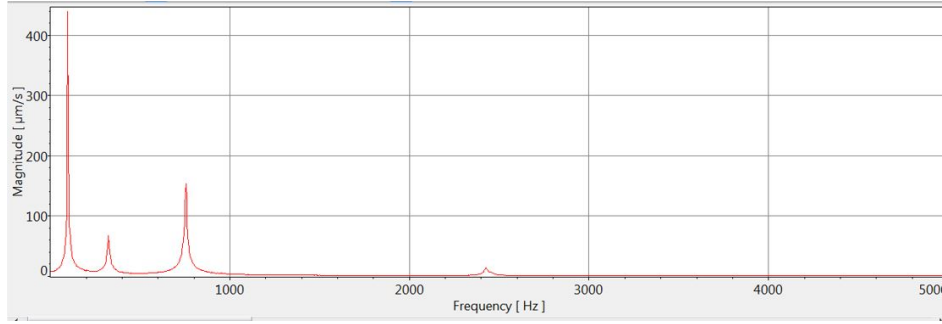


Figure 4: Graph of frequencies from first experiment.

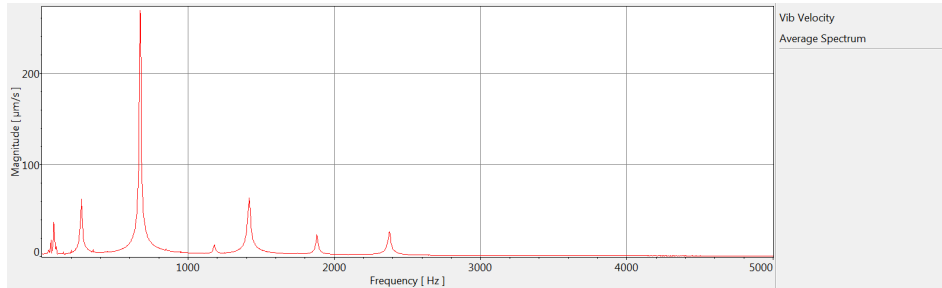


Figure 5: Graph of frequencies from second experiment.

## 4 Conclusion

The peak frequency we found in the experiment occurred at 671.875Hz and the shape of mode shows the vibrations traveling around the disc. The maximum amplitudes occurred at the edges of the brake disc and there was a significant movement caused by the clamp and brake disc wobbling on the desk. This analysis of the brake disc has been heavily affected by the clamp, changing its natural frequency, as is observable in the differences in peak amplitude frequencies in experiment one and two. The setup used is not representative of actual brake disc usage, this could be improved by using spacers the size of the brakes which normally would be applied to the disc however, this will still affect the natural frequency of the disc and is again, not representative of real life usage. An ideal situation to investigate would be a brake disc attached to an axle which can be rotated at different speeds with a brake assembly which can apply pressure to brake. Testing different combinations of brake pressure and rotation speed will provide a wide array of brake disc acoustic information which can be applied in order to improve the performance of the brake assembly and the decrease the noise of the brakes, improving comfort during driving through redesign of the brake disc or brake pads.

## References

- [1] magazine.polytec.com. (n.d.). Brake discs on the test station - Experimental modal test with laser vibrometers. [online] Available at: <https://magazine.polytec.com/uk/experimental-modal-test-with-laser-vibrometers> [Accessed 20 Jun. 2022].
- [ ] Galeazzi, S., Chiariotti, P., Martarelli, M. and Tomasini, E.P. (2018). 3D Digital Image Correlation for vibration measurement on rolling tire: procedure development and comparison with Laser Doppler Vibrometer. *Journal of Physics: Conference Series*, 1149(1), p.012010. doi:10.1088/1742-6596/1149/1/012010.

## 5 Appendix

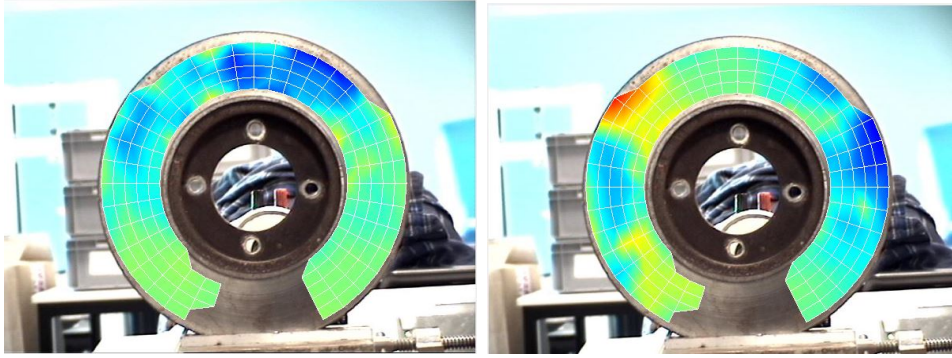


Figure 6: 81.25Hz and 271.875Hz

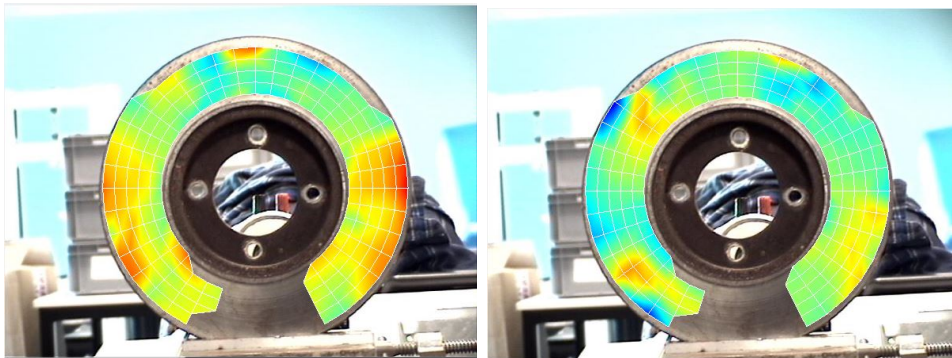


Figure 7: 671.875Hz and 1181.25Hz

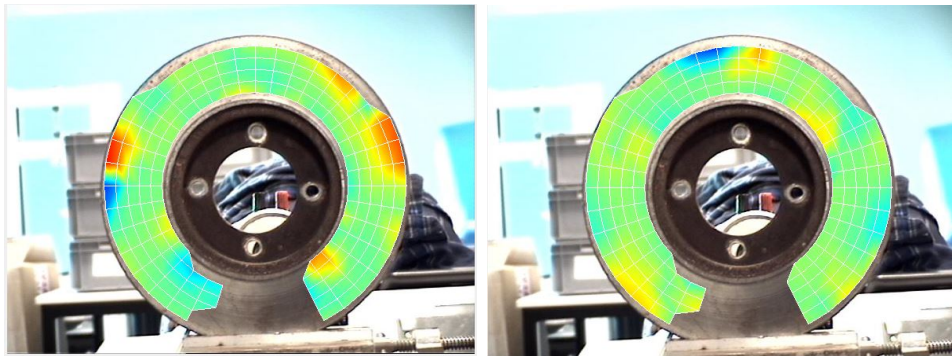


Figure 8: 1418.75Hz and 1881.25Hz

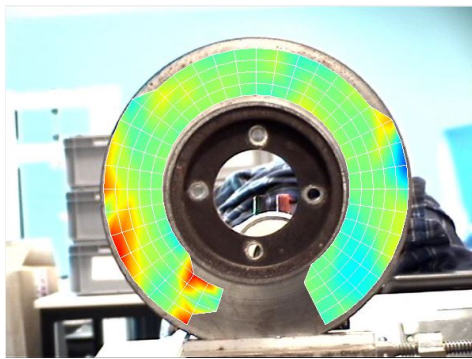


Figure 9: 2378.125Hz