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**INFLUENCE OF DAMPER DEGRADATION ON THE SUSPENSION
FREQUENCY SPECTRUM
26TH COBEM**

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Abstract. A damper is responsible for energy dissipation of a vehicle suspension, and, like any mechanical component, it is prone to wear. This paper addresses the analysis of a vehicle suspension frequency response along the lifespan of dampers. The data considered in the proposed analysis was acquired using an accelerometer, which was installed in the car damper fixation. A set of tests have been conducted using two different dampers from the same model, but with different mileages: a brand-new one and an end-of-lifespan damper. Tests results show that worn dampers present higher amplitudes at natural frequency, as well as show a tendency of non-progressive behavior, which can compromise the vehicle stability.

Keywords: Vibration analysis, shock absorber, lifespan, automotive, suspension.

1. INTRODUCTION

The first self-propelled vehicle is dated from 1886, a three-wheeled Otto engine-based vehicle designed by Karl Benz. 135 years have passed, and many automotive technologies, such as auto-blocking brakes, traction control, airbags, blind-spot detectors, components that can detect the integrity of brake pads, tire pressure sensors have been developed, targeted not only for driver safety but to promote a better driving experience (Jardine Motors Group, 2020), been said the automotive industry is pushing for more integration with smart guided hardware that is capable not only to promote driver comfort but its safety.

The entire car mass can store kinetic energy, the suspensions springs can store the potential energy from road excitations, but during suspension vibrations is easy to observe the movement fading through time, and that it is because of the damper (Reza N. Jazar, 2014). This component is responsible for energy dissipation of the vehicle suspension, and, like any mechanical component, it is prone to degradation trough time.

The damping ratio is a dimensionless parameter that describes, for a system, how their oscillations decay after a disturbance. It characterizes the frequency response of a second-order ordinary differential equation for a damped harmonic oscillator with mass m , damping coefficient c , and spring constant k . Commonly, systems are classified as: overdamped with higher damping ratios ($\xi > 1$), underdamped systems ($\xi < 1$), and critically damped ($\xi = 1$). Figure 01 shows an underdamped system, obtained through an analytic model of spring-mass damper system, this system was used to study the characteristics of vehicle vibrations.

The damping coefficient of a damper, or the ability to perform energy dissipation, is compromised by the wear of its internal components, such as rubber seals, internal springs, and even the oil. Damper wear is an issue of concern since this device plays a major role in controlling wheel forces. If it does not work properly, wheel force variations can impact the adhesion between tire and road surface and lead to a vehicle behavior different from the expected. (Dobaj, K, 2015).

This paper is a piece of a broader work involving the study of damper lifespan focused on the goal of understanding how a car reacts to the damper wear through time. With these studies, the authors can expect to create a series of parameters to have a more detailed and quantitative measurements technique, to indicate the end of the damper lifespan. This way, it is expected to provide a more accurate set of parameters to define the more suitable moment for a damper replacement when compared to the damper millage change that's used today.

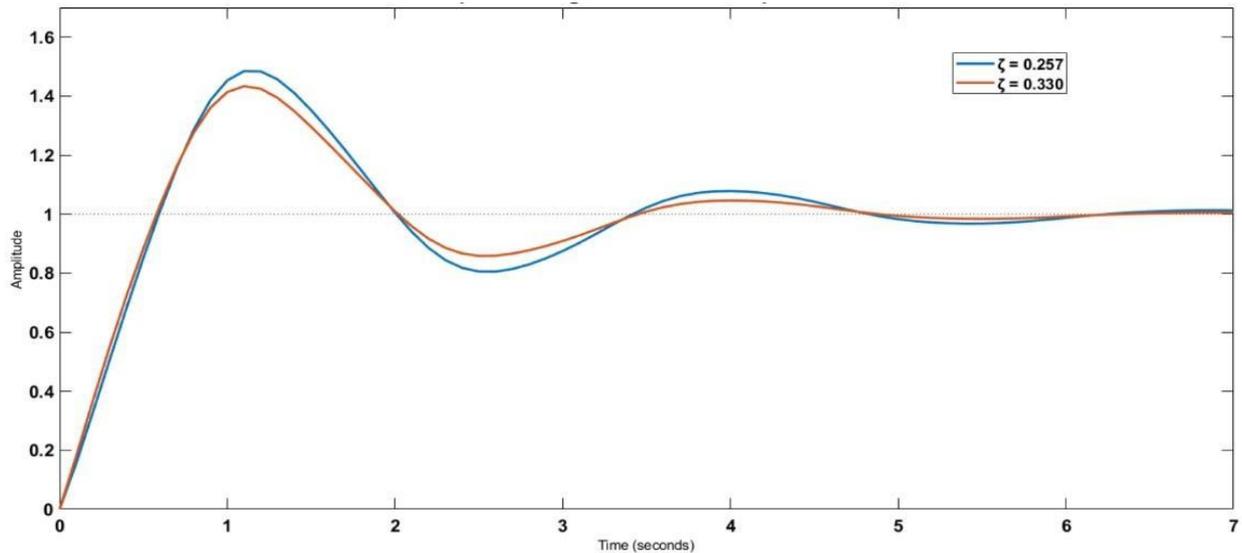


Figure 01. Energy dissipation of a vehicle suspension simulated for two damping coefficients.

2. METHODOLOGY

The methodology adopted in this work consists in measuring the vertical acceleration of a passenger vehicle, with this data it is possible to generate the vehicle suspension frequency spectrum. Data acquisition was performed by a microcontroller-based data logger, developed by the authors. This data logger was placed at the front damper mount of the vehicle. A set of tests have been conducted, using two different dampers: a brand-new one and an end-of-lifespan damper (mileage: 82000 km).

Accordingly, with (Felipe L. Mrad, et al 2018), for a broader acceptance of the acquired data, one must set a standard for the tests and attend to every detail, since they are responsible for the data reliability. The following procedures were adopted to ensure this goal:

- All the tests we conducted at monitored speeds;
- Tire Pressure was recorded before each test, as show at Table 1;
- Measurements of the data logger location were taken to ensure its position, as shown in Figure 02;
- Each test was repeated ten times to assure data convergence.

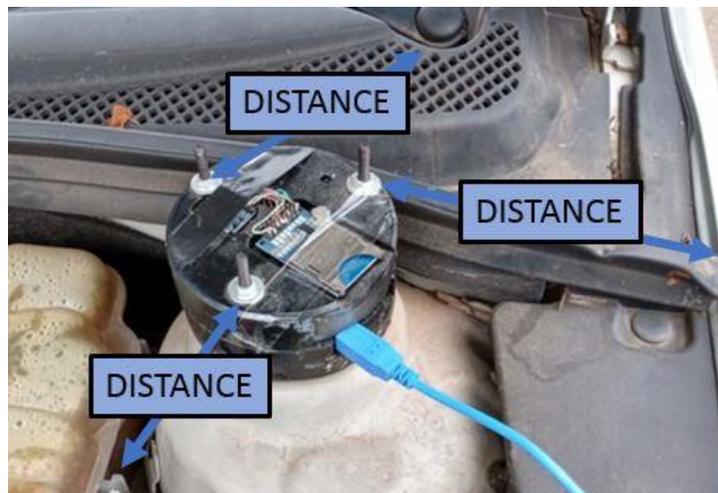


Figure 02. Data logger placement and monitored distances.

The distances illustrated in Figure 02 have been checked at the beginning and at the end of each test run. A displacement up to 0.4 millimeters were considered acceptable. If the data logger displacement exceeds this limit after a test run, the acquired data was discarded, and the data logger position adjusted. Only 2 out of 30 test runs presented this excessive displacement, assuring the fixation reliability.

Table 1. Tire pressure before each test run (Units in psi).

Test	Run									
	A	B	C	D	E	F	G	H	I	J
01	32	31	32	32	31.8	32	32	31	32.1	32
02	32	32	32	32	32	31	32	32	32	32
03	32.1	32	32.2	32	32	32	31	32	32	31

The car used in the tests was a 2012 Chevrolet Cruze with original equipment manufacturer (OEM) dampers. The maintenance record of the tested vehicle has been considered in order to assure that it was running accordingly to the manufacturer's specifications since worn elements such as bushings, damaged bearings, worn brake pads or unbalanced wheels would compromise the acquired data. Table 2 describes the more relevant maintenance records of this car regarding elements directly related to vehicle vibrations. The current mileage of this car is 82,000 km.

Table 2. Maintenance record of the vehicle considered in the test runs.

Mileage	Addressed components
60.000 km	Wheel Balancing, Brake pads and damper top rubber.
80.000km	Wheel Balancing, Brake pads All front suspension bushings

Local streets from Juiz de Fora, containing irregularities such as potholes, speed bumps, deformities caused by manufacturing limitations or by degradation, were selected to emulate the daily use of passenger cars. Three different paths were considered for the test runs, as depicted in Figure 04. Ten test runs were conducted for each path, as shown in Figure 05, assuring data convergence, if any data set displayed irregularities compared to the others it was deleted from the analysis and the test of that set is repeated. Also, a standard speed of 20 km/h, measured by the car cruise control and GPS, has been imposed on the car during all the tests. After a test run, recorded data was download from the data logger and analyzed using mathematical software. Low-pass filter and fast Fourier transform (FFT) algorithms were used for data processing and vibration analysis.



Figure 04. Paths used for vehicle testing.

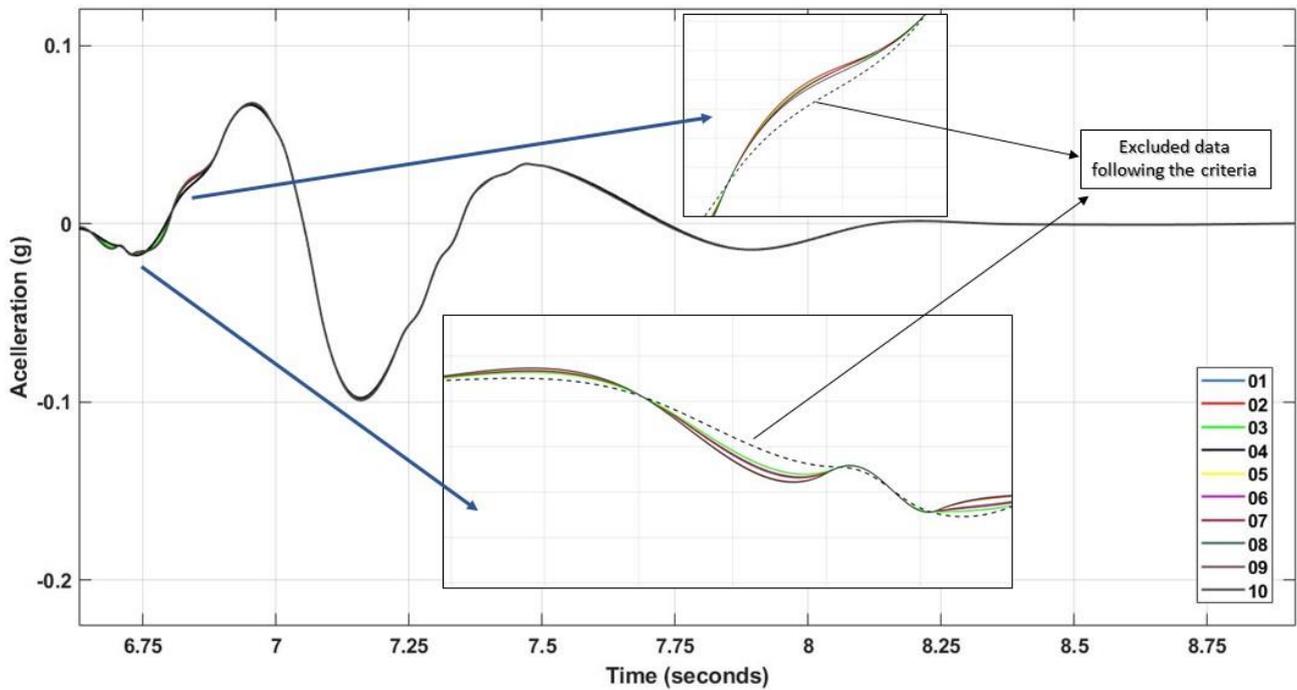


Figure 05. Example of the test convergence.

2.1 Data logger

The data logger was designed to be safely mounted on the vehicle chassis employing a magnet. It propitiates flexibility to the device since it can be installed in any part of the vehicle. This device can record the vehicle vibrations and store the measured data in an SD card for later processing. Data logger sampling frequency was set as 800 Hz, which is suitable to measure the vibration related to a vehicle suspension since it produces oscillation signals in the frequency range from 0 to 24 Hz 24Hz (GILLESPIE, 1992). Table 03 shows an overview of the components of the data logger.

Table 03. Logger configurations.

Component	Code	Specifications
Microcontroller	ATMEGA328P	8-bit AVR microcontroller Clock frequency: 16 MHz Operating voltage: 2.7 V to 5.5 V 14 I/O digital ports 6 analog ports
Accelerometer	ADXL3	Accuracy: $\pm 0.0015g$ $< 0.005g$ of noise
SD Card	Micro SD SDHC	Operating voltage: 5V Records up to 1300 Hz

2.2 Engine interference

Before each test, it was assured that there was no vibration produced by the engine that may have any effect upon the data recorded on the test. For this test the logger was placed in its original mount “Figure 02” and the car was revved up to 3000 rotations per minute, which is the maximum rotation that the car experiences within the tests. With this test is assured that there’s no noise coming from the engine. Figure 06 is a plot of one of these interference tests.

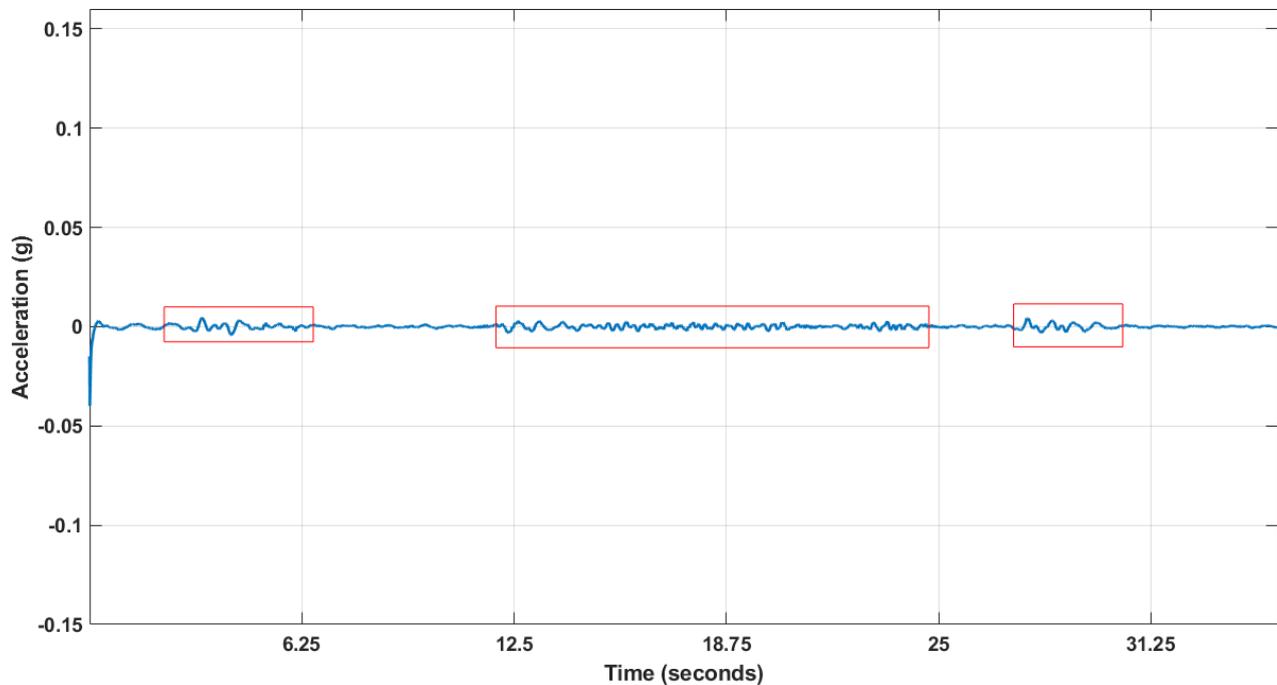


Figure 06. Engine interference test.

It can be observed in the above figure (red demarcations) that exist some ranges of interference, but they were on the order of 0.006 g, which is near to the lower range capacity of the accelerometer, so it’s easy to assume that the vibrations from the engine would not trouble our measures.

2.3 Low pass filter and Fourier Transform

To exclude unwanted measurement noise, a digital Butterworth low-pass filter with a cut-off frequency of 120 Hz was implemented. Felipe L. Mrad, *et al* (2018) achieved good results using this kind of filter for damper measurements..

A fast Fourier transform algorithm was then used to process the acquired data and to obtain the frequency spectrum of the suspension vibration

3. RESULTS AND DISCUSSION

After each test and proper data handling of the three paths, it was possible to plot the suspension frequency and compare it with the old and new damper. Figure 07 shows us the result.

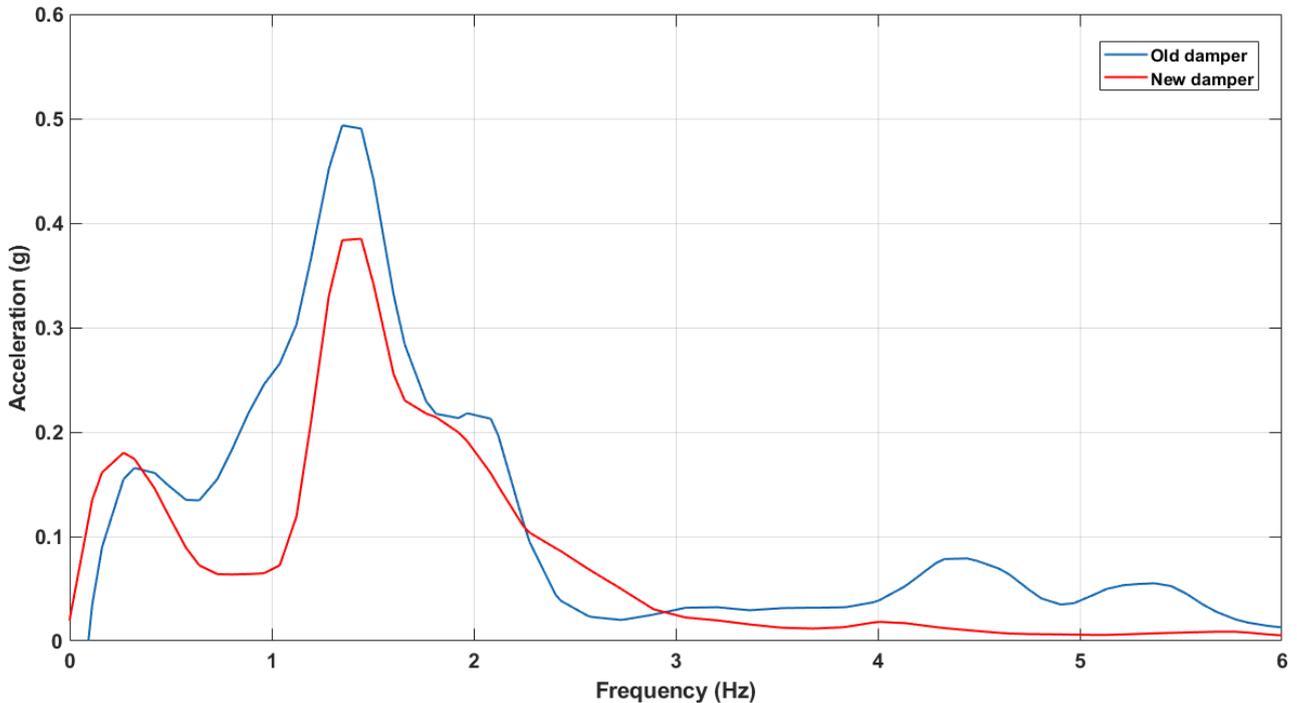


Figure 07. Vibration measures on the front damper fixation on the z axis.

In the lower frequency (0 to 1.6 Hz) it was possible to realize that the new damper has higher magnitudes than the older, this can be caused by manufactures' compromise of handling in prejudice of ride comfort. This scenario completely changes for most of the spectrum.

From 1.6 to 20 Hz, the old damper presented higher amplitudes than the new one, this is caused by the lack of energy dissipation, providing the bad ride control of the car. This can cause instability as it provokes different force loads in the wheels, altering the original and designed adhesion tire patch. In the range of 20 to 30 Hz, it can be observed a pattern that indicates the lack of ride control by the old damper. It can be noticed the abrupt changes, better displayed in Figure 08, taking into note that “handling is the quality of a vehicle, enabling it to be controlled by the driver in a safe and predictable manner...” (John C. Dixon *et al.*, 1999), so this change in damper amplitudes provoke the non-predictability of the vehicle, thus making it has bad handling capabilities..

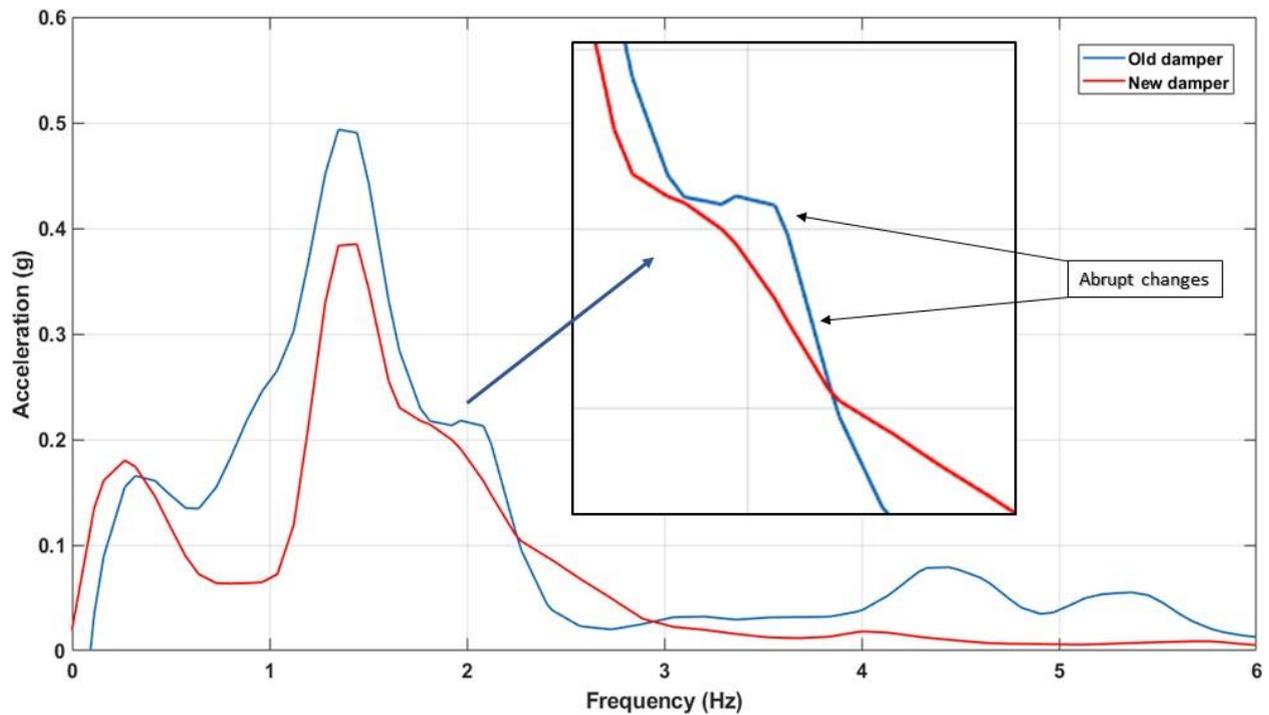


Figure 08. Abrupt changes shown by black arrows.

It can be also seen that in the values of 45 and 53Hz the old damper provides two concentration points of higher magnitudes, inferring that it also provides low ride control at the frequencies. This feature could be a key, to characterizing an old damper by the suspension frequency.

When analyzing the range of 20 to 70Hz, the new damper provides a predictable attenuation throughout all the spectrum, which the older damper is not capable of doing. The older damper makes an accentuated decrease in amplitude from the 20 to the 30Hz range, followed up by an increase in amplitude in the range of 30 to 40Hz, and as mentioned two concentrations of amplitude in high frequency.

4. CONCLUSIONS

With the worn of internal elements the damper, like any other mechanical component, losses its original capabilities of energy dissipation, leaving internal forces as friction to handle with dissipation. This causes poor ride control and vehicle instability.

For the adopted methodology and all the steps in the execution of the tests, and data handling, this paper was able to get a frequency spectrum that tells us the current behavior of the suspension and vehicle ride. This is a solid step in the process of creating the parameters for damper change, as mentioned before.

The experiencing of higher amplitudes in most of the suspension frequency spectrum and the creation of higher amplitudes in places where there should be an attenuation is a lead indicator that tells us that the damper is hitting the end of its life span. Suddenly erratic behavior, such as peaks and deep valleys in the spectrum can inform us as well that the component it's not performing as intended.

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