

Investigation into the Characteristics of Dampers Through Data Acquisition of a Sport Prototype Race car



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General Abstract

In motorsport, the most important measuring tool is the stopwatch. It all comes down to who can produce the fastest lap time or who can cover the most distance within a given time frame. This is all down to the performance of the vehicle and the driver, therefore every aspect of activity needs to be measured for those abilities to be worked on, that's where data acquisition comes into play (Segers, 2014). The purpose of this paper is to get an understanding of how dampers work and what effect they have on a vehicle by looking at different aspects of their characteristics, using data acquisition. Understanding dampers can be very difficult, as Kasprzak (2014) describes that they are known as a 'black art' and that there is some magic involved when setting them (Kasprzak, 2014). This is why data acquisition is such an important tool that motorsport engineers use when tuning their dampers therefore, different ways of gathering the information is included in this report and

what use they have when practically adopting them to a race car.

Technical Abstract

"Different tracks will require different shock adjustments" (Smith, 1978) – this is the reason why motorsport engineers have such a demanding job as the team will race on many different tracks per annum, making damper adjustments the key to success. Hence why this report will discuss how dampers work and what impact they have on the balance of a race car, precisely looking at the Sports 2000 Prototype vehicle. The Penske and Quantum dampers will be compared by using the damper dynamometer to test them through a series of sweeps because the car used to be fitted with Quantum's but now has Penske's. By doing these tests both dampers' strengths and weaknesses can be compared, and the Penske damper data can be combined with the on-board data logger on the car to see if its compatible enough to enhance the balance of the vehicle in question.

The on-board logging system will be used by analysing the latest information gathered by the MCR race team from Silverstone.

Introduction

In a motorsport context a suspension system has two main roles that are different to road cars. These two roles are very important factors on the behaviour of the vehicle and the lap times, controlling the weight transfer and control the impacts from bumps and kerbs. The potential performance of dampers can be unlocked by finding the optimal combination of settings and components for the specific track and conditions (DemonTweeks, 2014). Therefore, the best combination of dampers and suspension geometry is key to a successful car out on track.

The vehicle in question is a Sports 2000 Prototype Race Car which is equipped with a pushrod style suspension system which, according to Parry (2018), has an advantage on other systems due to its flexible nature of design that can be shaped to benefit overall vehicular performance (Parry, 2018). Its

equipment consists of Penske 8300 series dampers which are two way adjustable, these replaced the old dampers which were Quantum single adjustment.

Before any testing commences, the first part of this project is to physically measure suspension parameters such as the motion ratio, spring rates front and rear and the un-sprung and sprung masses.

This report will begin by discussing what dampers are used for and how they practically work, it will then move onto what different dampers there are and what advantages and disadvantages they have against each other. This will give an understanding of why the Penske dampers replaced the Quantums on the race car in question. To add to this, both dampers will be physically tested on the university damper dyno to assess the ability of both through a number of sweeps.

After this practical test, data sets will be collected from the car's on-board logging system to assess the damper behaviour around the Silverstone circuit at different stiffness settings.

The data collected from the track can be analysed using data acquisition techniques on the Motec I2 Pro software.

Data acquisition provides the engineers with information in order to improve the performance of the car and the driver, there are a few things more important within a race team (Santos, 2014).

With the on-board data collected and the damper dynamometer tests completed, the project will then investigate the possibility of combining both results to enhance the vehicle performance and balance.

Suspension systems

Spring mass damper system

Below is a damped spring and mass system which has three forces governing the dynamic behaviour. Although there is a small amount of damping in the tire (2% approx), the damper must do the majority of damping in this system (Kasprzak, 2014).

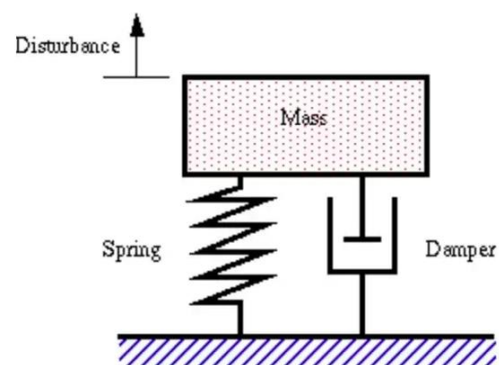


Figure 1 - Spring mass damper system
(Abhijeet Pandey)

Where Spring = K , Mass = M and Damper = C

Inertial force is created due to accelerating the mass which is a function of the mass and acceleration (Milliken, 1995).

The damping force is a function of the velocity across the damper including the damper coefficient, this is expressed in terms of force/unit velocity. Finally, the spring force is a function of the spring displacement and the spring rate, which is expressed in terms of force/unit displacement (Milliken, 1995)

Critical Damping

“Amount of damping required to stop movement as quickly as possible” (Tudor, 2019). Using the mathematical terms, K, M and C from the damped spring and mass system, the critical damping coefficient can be explained. This is when the mass is given a step displacement then the damping level that allows that mass to return to steady-state position quickest with no overshoot, is the critical damping.

Critical damping coefficient expressed mathematically is;

$$C_{crit} = 2\sqrt{KM} \quad (\text{Milliken, 1995})$$

Suspension Frequencies

This is how fast the suspension travels up and then back down to the same point when the vehicle drives over a bump. The suspension frequency can be very useful to determine the handling and balance of a vehicle, including how it will react to driver inputs. Before choosing the spring stiffness the first step is to choose the ideal frequency for the front and the rear of the vehicle. The higher the frequency, the stiffer the ride (Routley, 2017). Concluding this statement, Giaraffa (2016) states that lower frequencies produce a softer suspension with more mechanical grip, however drivers will report a ‘lack of support’ due to a slower response, which is opposite to the higher frequency (stiffer suspension) (Giaraffa, 2016).

Here are some examples of ballpark figures for different applications;

- 0.5 - 1.0 Hz – Passenger cars
- 1.5 – 2.0 Hz – Rally cars

- 2.5 – 3.0 Hz – Moderate downforce race cars with up to 50% total weight in max downforce capability.

To calculate the suspension frequency of a corner the mass and spring rate is needed, as shown in the equation below; (Routley, 2017)

$$F = 1/(2\pi)\sqrt{(K/M)}$$

Motion Ratio

This is defined as the ratio of the damper displacement to the wheel displacement. Simply put, if the wheel travels up an inch and the damper compresses by 0.6 inches then the motion ratio would 0.6 (Performancetrends, 2016).

Therefore, the calculation for the motion ratio is;

$$MR = \frac{\text{Damper Displacement}}{\text{Wheel Displacement}}$$

(Tudor, 2019)

Spring Rates

Spring rate is, as expressed by Acxess spring (2019), the constant rate of force expelled by a spring per millimetre of travel once a force is applied to compress it (AcxessSpring, 2019).

Wheel Rate

From here, the wheel rates can be calculated by using the spring rates and motion ratio for each corner as can be seen in the formula below;

$$WR = SR \times (MR)^2 \text{ (Schermerhorn, 2013)}$$

Dampers

Kasprzak (2014) states dampers are the most misunderstood components of a race car and that there is some 'magic' to developing and tuning them, hence they are known as the black art of race car engineering. A damper will damp the motion of both the sprung mass, which is the body and chassis of the vehicle, and the un-sprung mass which consists of components such as the wheel, brake calliper, a proportion of the suspension arms and the hub.

Springs and anti-roll bars produce forces based on their deflection whereas dampers, produce forces based on their velocity (Kasprzak, 2014).

Monotube and Twin Tube Dampers

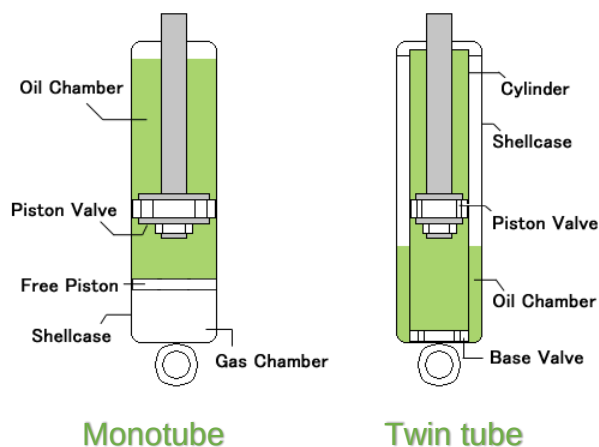


Figure 2 - Monotube and Twintube dampers (www.tein.co.jp)

As can be seen in the figure above, the Twin tube has a separate gas chamber that is controlled by a valve at the bottom of the damper whereas the monotube is all in one with the gas chamber controlled by a free piston. The monotube damper is known to have a better ride quality, as mentioned by StrutMasters (2015), because the free piston separates the gas and the oil, making the monotube damper less likely to experience foaming. StrutMaster (2015) also

suggests that the monotube offers better response properties than the twin tube, this is due to the monotube being controlled by a single needle valve whereas the twin tube is equipped with several valves on the piston (StrutMasters, 2015).

Damper construction

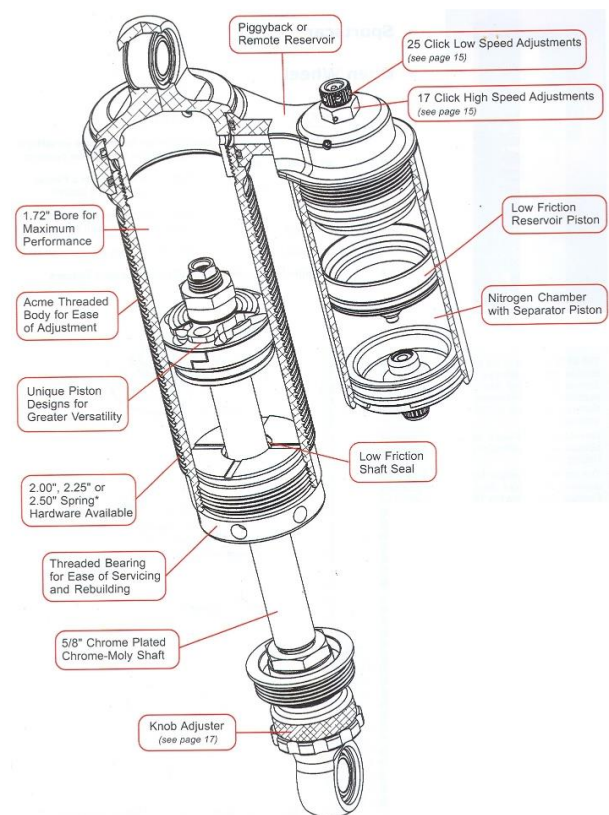


Figure 3 - Cut out diagram of a Penske 8300 series damper (Penskeshocks.com)

The dampers that are currently used on the sports 2000 prototype race car are Penske 8300 series which are double adjustable, as can be seen in figure 3.

This type of damper is a simple, high quality and performance damper that can be used for many different applications (Penske, 2006).

It is equipped with a single rebound bleed style adjuster and a twenty click linear stepped compression adjuster situated on the reservoir (Penske, 2006). Refer to appendix 1.A for the outside labelled diagram of the same damper with a separate cannister rather than the piggy back one, which is figure 3.

Piston Variety and Shim Stacks

As can be seen in figure 4, the different piston types have a big impact on how the damper reacts to different inputs. This variety of pistons will allow the technician to change the output force characteristics of the damper by fitting different pistons for a variety of applications such a driver preference and track demand. Another major component to the performance of the damper are the shim stacks, as the damper velocity increases the same amount of fluid is to be passed through at a higher rate.

This creates high pressure that force the shims to flex and open a new fluid circuit through the piston.

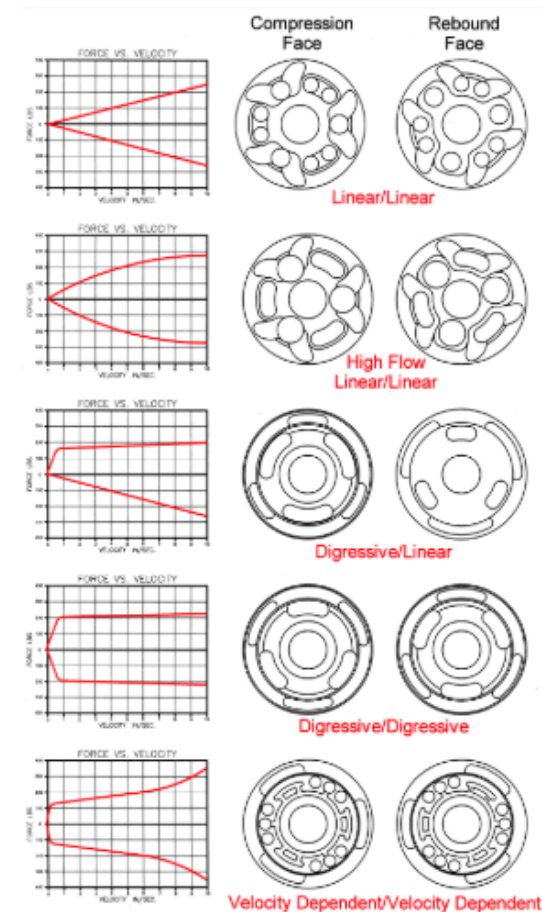


Figure 4 - Different types of pistons and their force vs velocity graphs (Penskeshocks.com)

Refer to appendix 1.B for an example of how the shim stacks work when the velocity of the damper changes from low speed to high speed in both compression and rebound.

Data Acquisition - Damper Speed Histograms

This is a characterization of the damper while it's on the car, giving an indication of how much time the damper is spending in each speed interval. This makes these histograms very useful to tune dampers because they produce evidence of the damper behaviour integrated into the vehicles suspension system (Segers, 2014), as agreed by Trevitt (2019), these are a very useful technique for suspension setup when out on track (Trevitt, 2019). To maximize the performance of a damper, adjustments to the setup should be made to get a symmetrical damper histogram (Segers, 2008). Refer to appendix 2.B for an example of a damper speed histogram explanation.

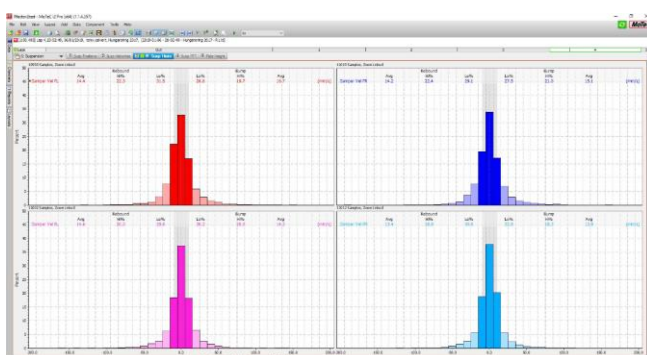


Figure 5 - Damper speed histogram example on Motec (Racedepartment.com)

Methods of Data Collection

The first step of data collection will be to use the damper dynamometer with both the Penske and Quantum dampers, testing different set-ups of the dampers. The on-board data collected from the vehicle is from Silverstone Circuit and was obtained from the data laptop of the MCR racing team. On top of the Silverstone data, the team will be doing some damper testing over the winter therefore, this can be collaborated with the other tests to emphasize on enhancing vehicle balance and performance.

Damper Dynamometer

All of the damper testing will be done in house in the workshop using the SPA damper dynamometer, this specialised equipment is widely used by many motorsport companies across the world (SPA, 2019). This dynamometer provides different types of data including force vs velocity graphs and force vs displacement graphs, refer to appendix 2.A for an example (Kasprzak, 2014).

Segers (2014) implies that the damper dynamometer is used to approach a more structured test which is an alternative to on-board data logging limitations, providing more concise answers to the characterisation of the suspension system (Segers, 2014).

Motec

Motec I2 pro is used by many motorsport teams across the world to organise and chart data in order to identify problems, trends and make improvements. The software system is used to review data from the on-board diagnostics system fitted to the vehicle, by doing this the vehicles damper behaviour can be analysed and improved.

Along with improving the balance and behaviour of the vehicle on track, Motec can also be used to develop drivers on different parts of the track by reviewing their performance using the vehicles behaviour. It can also be compared to other drivers that have logged data on the exact same vehicle (Motec, 2019).

Conclusion

Data acquisition is clearly one of the most important tools in the motorsport industry and is still being widely used in the amateur and professional levels, as Segers (2014) states that ten years ago this kind of technology only existed at professional level but has now spread to be used in nearly every discipline because sophisticated computers can be purchased much cheaper than back then (Segers, 2014).

The report clearly dictates that damper characterisation is an important part to be the fastest around the track which means that they are a very important component of the vehicle. Making them work on a race car requires a lot of different engineering implementations hence why the damper dynamometer is being used to understand their behaviour under different conditions of change.

The remainder of the project will carry on investigating different aspects of the damper and what outcome of results they will conclude. These outcomes will be investigated and combined with on-board track data from the vehicle to try and enhance the balance of the vehicle in different conditions. Therefore, more winter testing will be done to collect valuable data to fulfil the requests of the project.

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Appendices

1.A

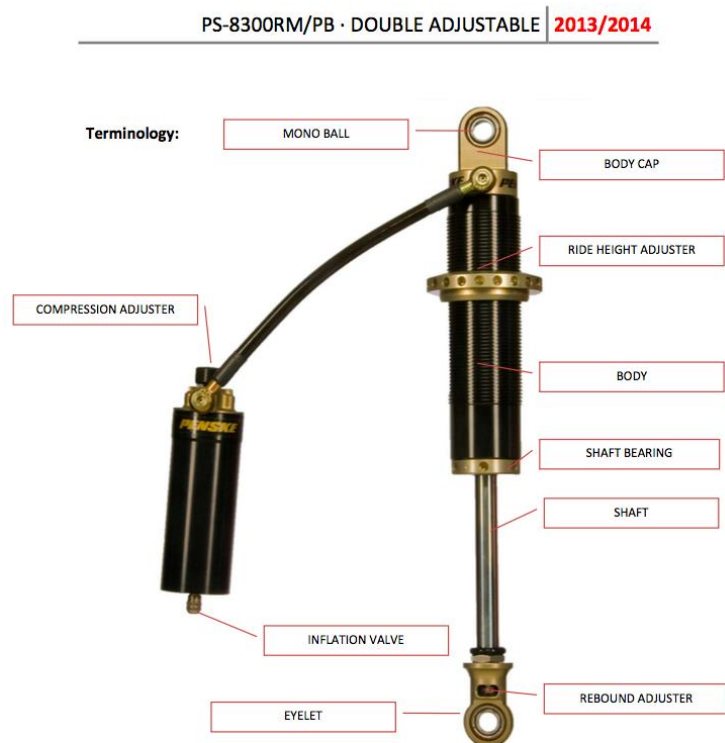


Figure 6 - Labelled diagram of a Penske 8300 damper (Penskeshocks.com)

1.B

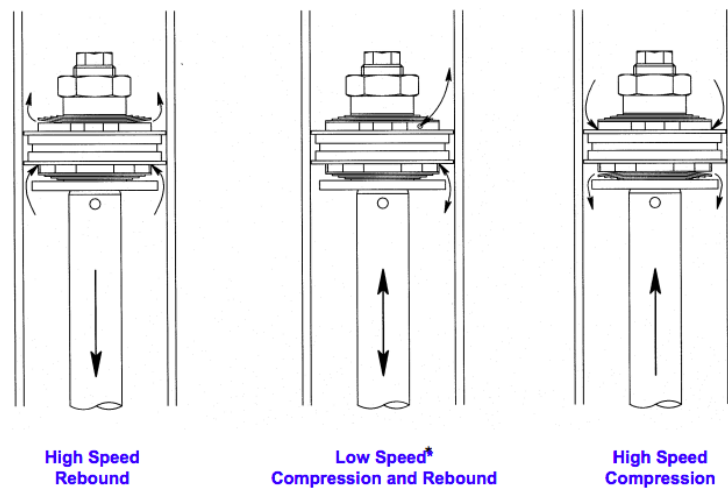


Figure 7 - Shim stacks and their purpose (Computrackboston.com)

2.A

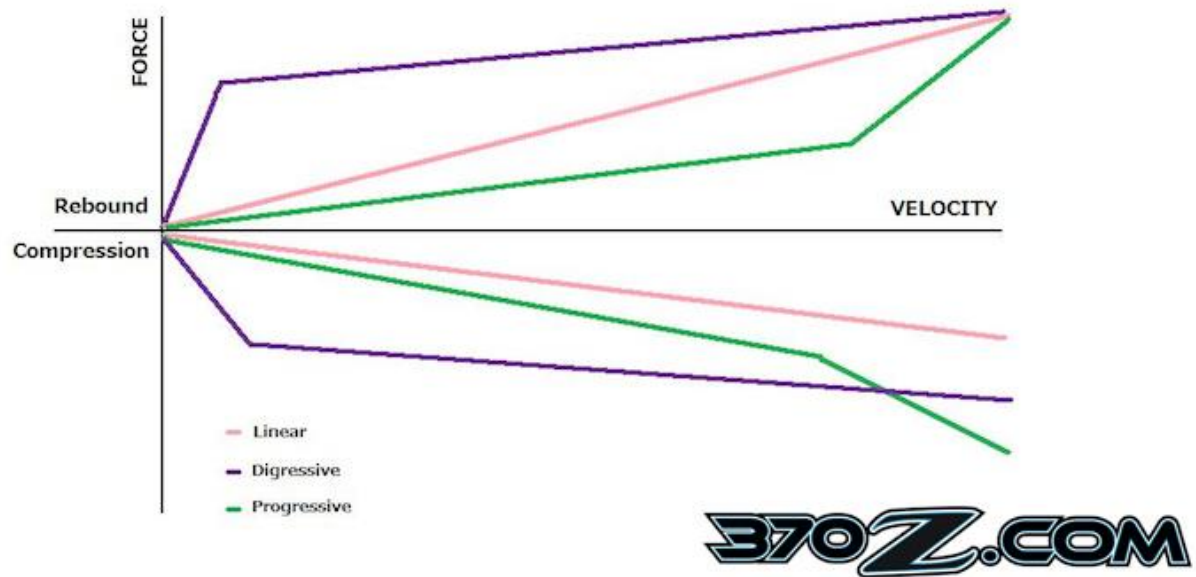


Figure 8 - Force vs velocity graph obtained on a damper dynamometer (370z.com)

2.B

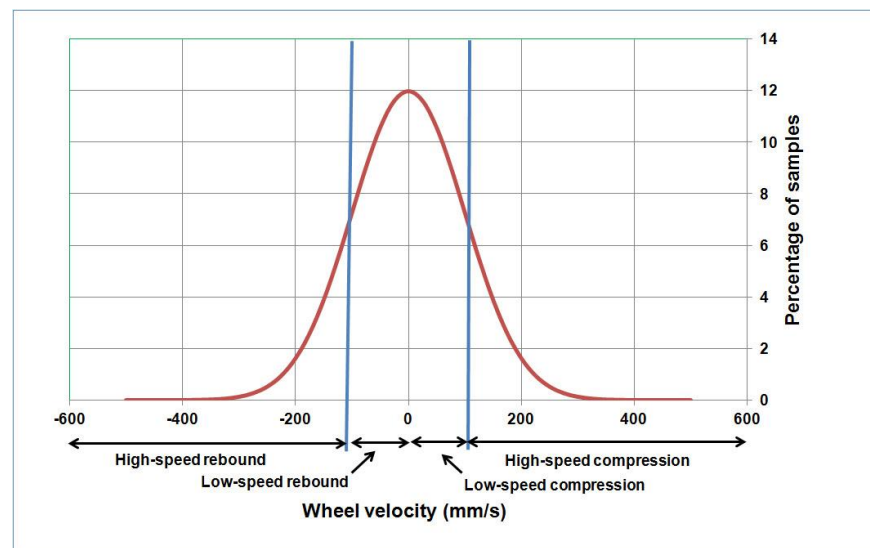


Figure 9 - Damper Speed Histogram showing high Kurtosis (Datamc.org)