Damper tuning at the shop and at the track

In the previous issue, the basic theory behind dampers was introduced. We discussed the two degree of freedom spring-mass-damper system used to model a shock, the way a damper generates force, the method this force is measured and briefly went over how the valving and adjustability affect the handling of a car. This article travels more deeply into the testing and tuning of a damper for a race car both at the shop and at the track.

First, I would like to talk about the many variables that will affect the ride and handling of a car. There are several components that need to be properly setup to ensure that damper tuning is enhancing the performance of the vehicle rather than covering up other problems inherent to the suspension. These variables include the alignment and corner weights, the springs, anti-roll bars, tires and suspension geometry. A good suspension setup will take each of these into account in order to optimize the handling, and a good shock design needs to account for each of these variables in order to achieve the maximum performance. For this discussion we will assume that each of these variables has been properly designed and selected. This process deserves a separate article of its own and will follow in the future.

In order to initially tune a damper at the shop, there must be an understanding of how much damping force is desired throughout the range of shaft velocities. This involves modeling and calculations based on the variables previously mentioned. Using the installed spring rate, the spring rate of the tire and the sprung and unsprung masses, natural frequencies of the suspension can be determined. From these frequencies the critical damping coefficient can be calculated.

From this point on, modeling and experience are the best tools. Modeling a damper is a very good way to predict the way it will affect the ride and handling of the car. This can be done using several different software programs. These programs can either be specifically designed suspension programs or blank slates that will allow you to design any type of model you can imagine. Of course, you can not forget about the use of spreadsheet programs, like Microsoft Excel, which is a very valuable tool when working on the design of the suspension system.

Along with Excel, I have been using The Math Works, Inc. Simulink, which is the blank slate type that does a very good job of modeling dynamic systems. The model is a four-corner lumped mass model that I designed last year with the help of another member of the Virginia Tech Formula SAE Team. It is fully customizable and expandable to account for many variables. It has inputs for Roehrig Shock6.0 dyno data, braking, acceleration, roll, and road profile. The example seen in Figure 1 illustrates the damper velocity and displacement for a 1g turn followed by a large bump in the road. Models like this and the data they provide are very important in estimating the operating characteristics of the damper.

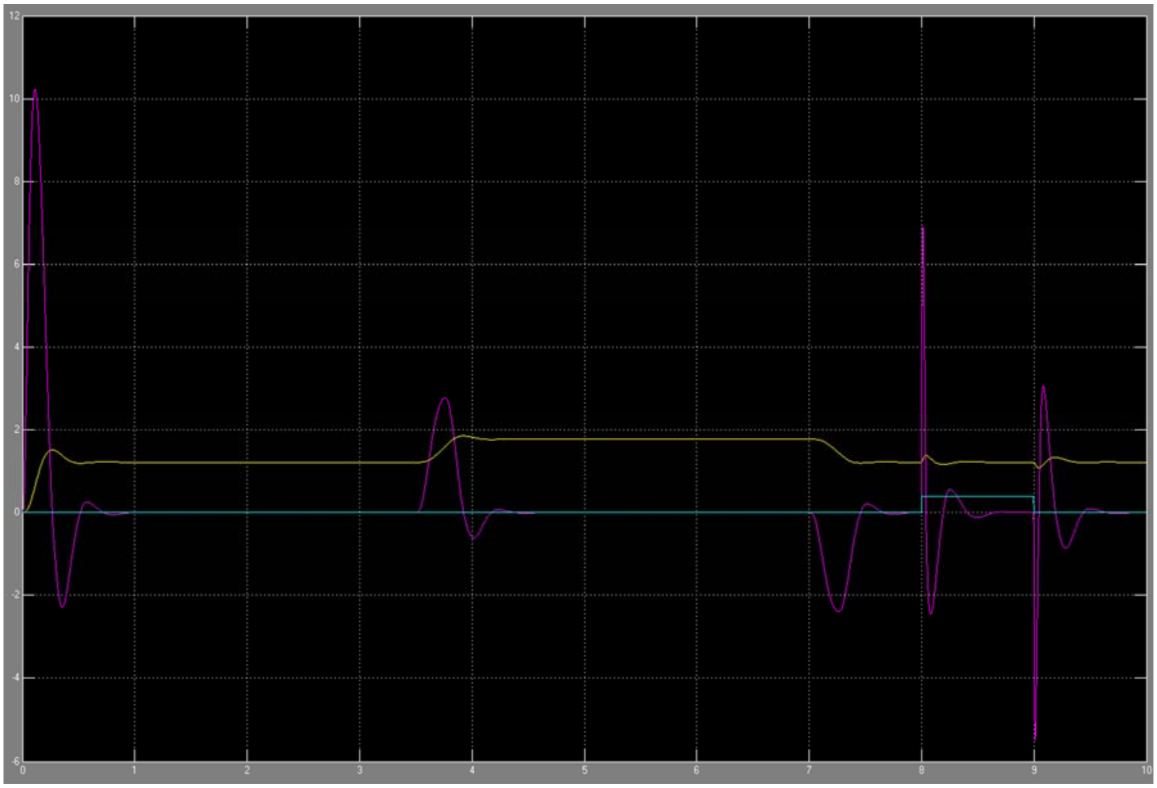

Figure 1. The light blue line is the road profile, the purple line is the damper velocity and the yellow line is the displacement of the damper. The first section of the graph can be ignored because it is representative of putting the car on the ground. The middle of the plot shows the effects of the 1g turn. The last section of the graph shows what happens when the car hits a bump. Compression velocities are positive, and displacement increases as the shock compresses. From this data, the estimated operating velocities of the damper for given conditions can be determined, as well as expected displacements. Based on this data, the damper seems to operate well in the low speed range, but the high speed damping is high and will cause a very harsh ride.

Experience is something that comes with time. After working with a car for a while you begin to learn what works and what does not. This will allow for a quicker initial design phase and a more concise iteration period when tuning the suspension. Different tracks and conditions will also call for different valving, whether this means adjustment or revalving, the process becomes much easier with more practice. Another factor is SWAG or a scientific wild ass guess. From what I have learned from my NASCAR friends, SWAG is justifiable as long as 50% of the time, you are right all the time.

When tuning a damper at the shop, your final tool is a shock dyno, such as the one seen in Figure 2. A shock dyno measures the amount of force generated by a shock at different velocities. The shock is cycled based on desired input displacement characteristics. These inputs determine the velocity and acceleration of the test. For the simpler, crank type dynos, the input displacement curve is always a sine wave. There are higher end dynos that allow for inputs of other general types of curves and more complex, custom curves.

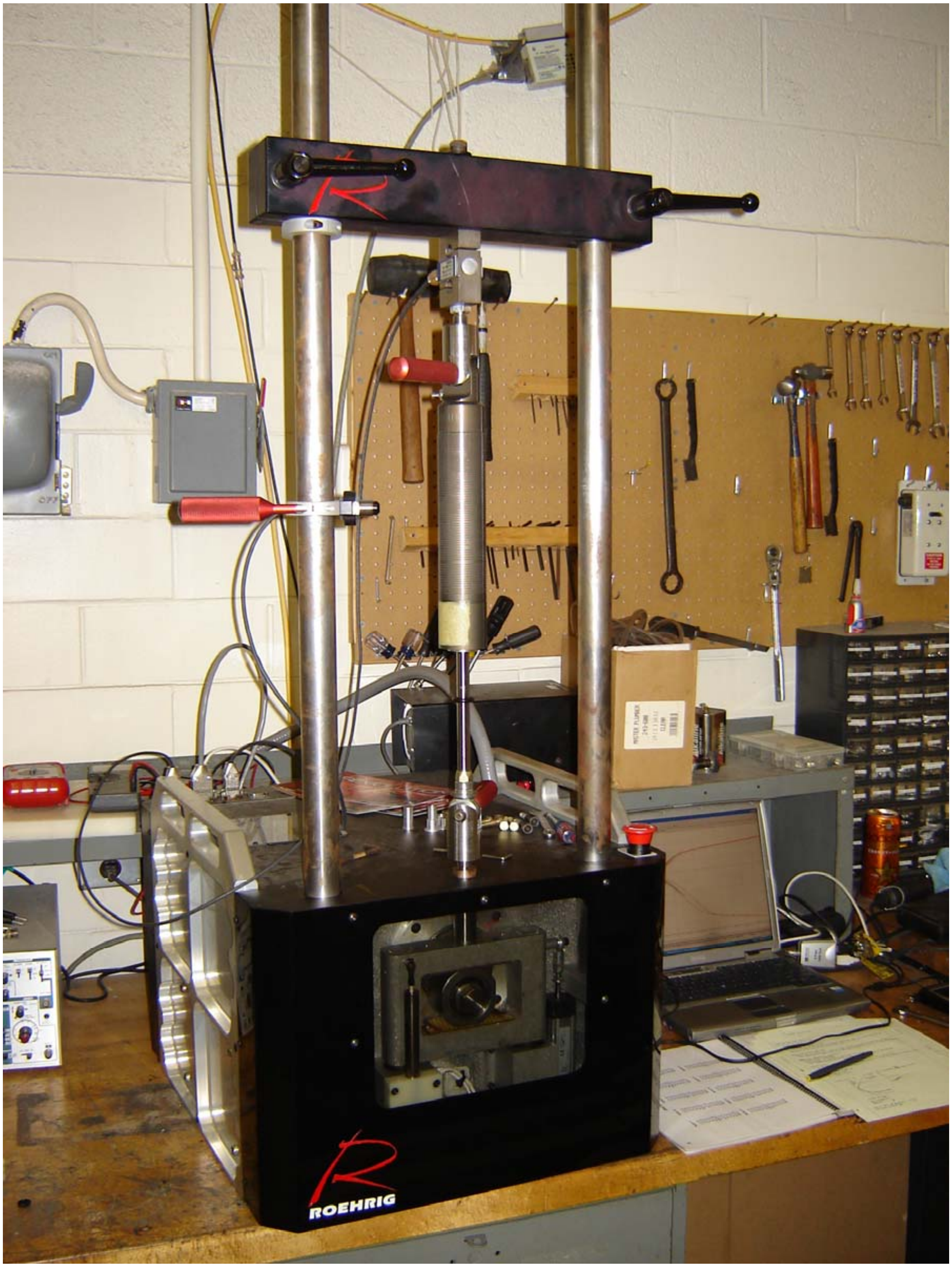

Figure 2. Fine tuning one of the Bilstein dampers used in the TIP Engineering Spring Damper System for the Mk3 Supra on a Roehrig 2VS Shock Dyno.

In the previous issue, the shock dyno plot and characteristic curve were introduced. There are several different types of dyno plots. There are peak velocity plots

(PVP) which test the damper at several different speeds and then plot only the peak velocity and connect the points with straight lines. These plots look very choppy and are the type of plots that are usually provided by manufacturers with their shocks. These plots are virtually worthless when trying to determine the true performance of a damper. In most cases, they only use 8-12 data points and fail to truly model the behavior of the damper.

Another main type of plot is a constant velocity plot (CVP). These plots will run a shock through a range of speeds and capture the force generated at very small intervals. More than 2000 data points are used in the creation of each plot. These plots will also illustrate the effects of hysteresis and cavitation, which are very important when building a damper. Hysteresis is a history effect that causes damper to generate a higher force when it is slowing down versus accelerating. This can be an effect of the internal friction in the damper or internal pressure buildup inconsistencies. Cavitation is an effect of the fluid involving the pressure on the low side dropping below the vapor pressure of the fluid creating a vacuum and causing the fluid to create air bubbles. This means that the damper will not work correctly because the necessary pressure differential is no longer present.

Constant velocity plots are useful in examining the different phases of a damper. Because CVP uses a sine wave displacement input, there are four distinct regions that can be seen on the dyno. There is a compression open line, compression closed line, rebound open line and rebound closed line. These lines describe different scenarios involving the displacement and acceleration of the damper shaft. For example, the compression open line occurs when the damper is compressing and accelerating to its peak velocity while the compression closed line also occurs when the damping is compressing but the shock is decelerating down to a velocity of zero inches per second.

For basic shock design and tuning, CVPs are more than sufficient, but sometimes there are other effects that need to be looked at. Several companies manufacture and sell dynos that have the capabilities of non-sine displacement inputs. This will allow such types of input curves as triangle waves, square waves and any type of custom designed displacement curve that can be imagined. These types of curves allow for such testing as constant velocity and constant acceleration testing. This is used for higher level testing, for example, basic damper theory states that for a constant velocity a constant force will be produced. So when you run a square wave displacement input, the velocity curve will be a constant velocity. Running a test like this on a standard damper will illustrate any of the displacement sensitive effects due to the construction of the damper, but ideally the curve should be a straight line when looking at a force versus displacement plot of the data. This type of testing is more than most people need to worry about at this point.

Once the initial design and dyno testing have been accomplished, now the adjustments must be made. Depending on the construction of the shock, adjustments can either be made internally or externally. With internal adjustments, the shock can be adjusted in any way desired by adjusting shim thickness and diameter, bleed orifice area and piston design. Externally adjustable dampers can adjust from just rebound to high and low speed rebound and compression.

When tuning on the dyno, the idea is to adjust the curve to match your initial estimates for how the damper should be performing. Another important task is matching the dampers on an axle so they perform the same way. This tuning ties in each of the previously mentioned tools. The curve and, essentially, the damper must be broken down into sections. Rebound and compression should be decoupled and with a decent damper this is usually not a problem. Some dampers have a lot of crosstalk which occurs when one adjuster, for example the rebound adjuster, also affects the other side of the curve, in this case compression. There are also shocks out there that are designed to adjust both compression and rebound at the same time, which makes it very hard to get the shock dialed in correctly.

If rebound and compression are decoupled, the speed ranges of the damper need to be determined. The low speed region, transition and high speed region need to be estimated. Usually the low speed region is capped somewhere between three and five inches per second. There is then a small transition range where the knee of the curve appears. The high speed range is everything above the transition range. The low speed regions will be different for rebound and compression, as will the location of the knee. Figure 3 shows the breakdown of the speed ranges for both rebound and compression.

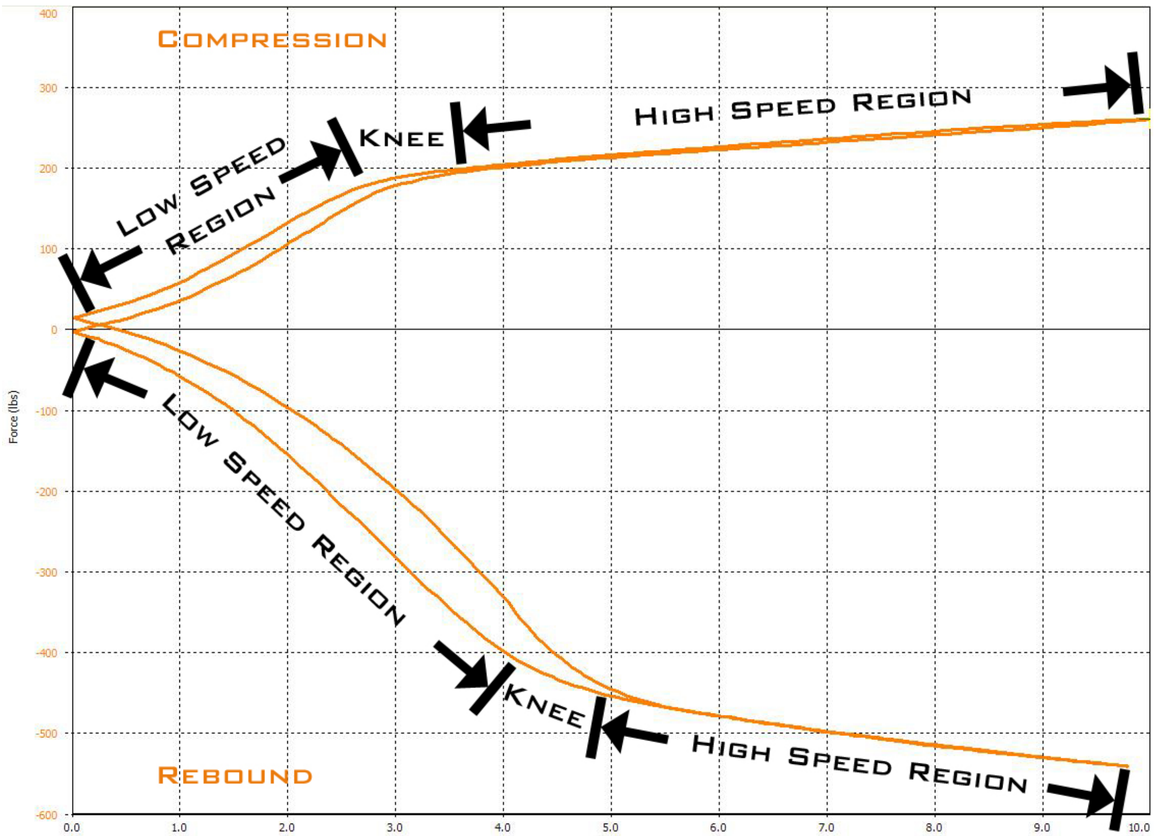

Figure 3. CVP of the TIP Supra Damper illustrating the different speed range breakdown for rebound and compression. In this plot, the hysteresis in the low speed range can also be seen, this effect is much greater when doing a higher speed test. For testing that remains in the low speed region the hysteresis is hardly noticeable.

In general the compression curve should be digressive, meaning that the slope of the curve starts off high in the low speed region and after the knee the slope falls off greatly. Having a compression curve like this allows for a stiffer low speed region and better control of the unsprung mass. With the high speed compression falling off, the rough roads, curbs and bumps will be absorbed by the suspension rather than transmitted to the chassis. The location of the knee should be at the end of the low speed range. A linear low speed range will keep consistent feel during the handling maneuvers. The best way to determine where the knee should be is data acquisition. This will show you what speeds the shocks are seeing during a race. Without data acquisition, an initial guess is the best way and can be changed after driving the car.

For rebound, a more linear curve or a digressive curve with the knee well past the low speed region is the most desirable. In most cases, high speed rebound is of much less concern than the other speed regions. Keep in mind that rebound forces oppose the spring forces, so with a linear spring close to linear damping is best used to control the energy stored in the spring.

If you look at Figure 3, it seems that compression is much softer than rebound, which is the case for the high speed regions. For the low speed range, the curves are very similar until the knee begins on the compression side. This knee begins around 3 inches per second (ips) while the rebound knee does not start until closer to 5ips. The rebound knee should be at a high enough speed to not negatively affect the feel of the car, although the final iteration of this damper will see the knee shifted a little further into the high speed range.

Adjusting the dampers on the dyno is a good way to get accustomed to how the adjusters work. You will also be able to determine if you have an adjuster that affects just rebound, or rebound and compression or just compression. Depending on the number of adjusters you have, there are a limited number of combinations available. The best method for the initial tuning on the dyno is to run the shock throughout its entire range of adjustment. Intervals can be used for adjusters with very fine increments. Once this is done, you will be able to see where the shock starts to build too much residual pressure and affects the hysteresis and pressure balance inside the damper. It will also help to know what adjustment level gives the desired shock curve and what damping ratio you will be seeing based on what the adjuster is set at. Knowing this contributes greatly to the experience factor. It will also allow you to go back and redo the calculations and reiterate your design much quicker and more efficiently than if each of these variables were unknown.

Another method of adjustment that requires a deeper understanding of how a shock generates force is internal valving adjustment. External adjusters are usually more than sufficient for obtaining the desired damping forces, but in some cases the curve design does not match up with what is desired. There is also the case where there is no external adjustment and the damper has to be disassembled and revalved in order to adjust the curve. Figure 4 shows the shim stack and piston used in the TIP Supra dampers. Each of these shims has a different effect on the force generated by the shock.

Figure 4. The upper set of plates is for the rebound side of the piston, while the lower set is for the compression side. Each shim performs a different function that influences the curve. The plates against the piston affect the preload on the whole stack, this will adjust the location of the knee of the curve. The plates with the slots are the bypass plates which determine the low speed forces. The large plate defines the overall magnitude of the curves. The last set of plates is for adjustment of the high speed region of the curve.

The culmination of tuning at the shop is the combination of the dyno tuning, the modeling and the calculation. This is an ongoing process that will allow the comparison of the actual measured dyno curve versus the theoretical curves. The actual curve can be compared to the critical curve or a theoretical curve based on the damping ratios determined from modeling. Figure 5 shows a working plot comparing these different curves.

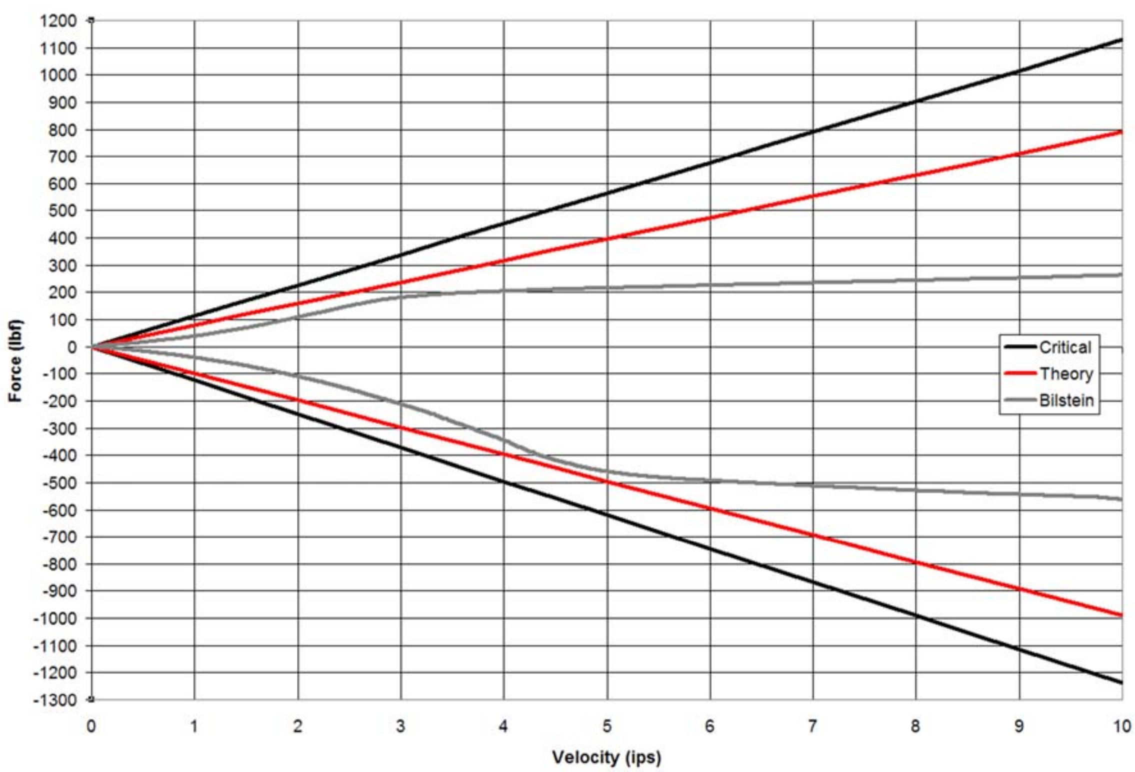

Figure 5. Plot from Excel spreadsheet comparing the critical, theoretical and actual curves. This spreadsheet combined with the dyno and the models have been an extremely valuable tool in determining the desired forces for each damper. This is an ongoing process that involves much iteration through both tuning at the shop and tuning at the track.

While tuning at the shop is very important, it is many times out of reach for people to do. Access to a good shock dyno is a very important part of that tuning and is not an inexpensive piece of machinery. Although it seems like there may be a trend starting for companies to provide more information on their damper. If other companies do not do it, I plan on dynoing everything I can get my hands on as soon as possible. If more companies were to make dyno plots available, it would be much easier to get a better idea of what adjustment you should try or at least help you to better understand how your dampers are working with your car. But until this happens tuning at the track will be much more important; all the tools should be available for track tuning. They are a well setup car in terms of the rest of the suspension and a knowledgeable driver.

Tuning at the track is similar to tuning at the shop in terms of the methodology. The movements of the car need to be separated from each other in order to best analyze the performance of the car. Since we are assuming that the rest of the suspension is dialed in, we can ignore the steady-state sections of the course. These sections are the parts of the course where weight is not being transferred. For analysis, these types of sections exist, but in real life, the shock is always moving.

The most important tool for track tuning is the driver. Having a driver that can feel what the car is doing is a huge benefit especially on a car without any type of data acquisition system. The driver will be the method of translation from the cars actions to the person who will be adjusting the suspension. It becomes necessary to really examine each corner and each section of a corner in order to best describe the way the car is handling. These descriptions need to break down the corner into entry, middle and exit sections, it needs to be observed if the driver is on the brakes or on the car or not giving any type of longitudinal input, steering angle and its rate of change also needs to be observed. Understeer, oversteer and stability needs to be analyzed based on these previous variables, but also driver inexperience or error needs to be considered.

For example, we will examine turn entry oversteer from a straight into a left hand turn. Even turn entry can be broken down into two stages, full braking and braking and turning. The driver needs to distinguish between these two phases in order to determine where oversteer is beginning. For the full braking stage, oversteer can begin based on the brakes, which although we're assuming as setup properly, I would like to mention them because many people forget how much they affect the handling. Too much front brake can lock up the fronts, but it can also unload the rear enough to make it slide if the front tires can generate enough force. Too much rear brake can also create an oversteer condition by locking up the rear brakes.

The shocks and the control of weight transfer can also make the car loose on entry. Compression damping in the front and rebound damping in the rear have the most effect on this situation. There are windows for each in which the car will perform as desired. With compression damping, if it is too soft, the front of the car can compress too far and bottom out creating an immediate understeer condition. If it is too stiff the front tires will lose grip very quickly and the ride will be overly rough. For rebound damping, too soft will make the rear of the car feel very floaty and weight transfer to the front will take longer. If rebound is too stiff, it can cause the initial loss of traction by lifting the inside wheel and can also lead to jacking down if the road surface before the turn in rough.

So in a situation like this, depending on the type of dampers you have on the car, there are a couple changes that can be made. Unlike shock tuning at the shop, rebound and compression need to be considered as working together in this case. An oversteer condition on turn entry would call for increase in compression damping in the front and a decrease in rebound damping in the rear. The change in rebound damping will be more important and the change in compression damping might not always be necessary.

This is only one situation that might be experienced. But I feel that it describes the method that should be taken to break down the course into sections of a corner. A good description of the way the car is handling provided by the driver is the most important and will allow the suspension tuner to adjust the car to account for these problems. It is important to not make too many changes during each stop. The reason for this is if a change is made that is detrimental to the cars performance it will be easier to undo that change. Another very important tool for tuning at the track is a good set of notes. These notes should include any relevant information on the car and the track, each change made should be written down as well as the reason for the change. Driver feedback after the changes is also very important and should be added to the notes. Keeping a set of notes like this is similar to running the shock on the dyno for different adjustments. It can be a very valuable reference tool in the future.

I understand that most people do not have a shock that is more than 1-way adjustable on their car. With a setup like this, there will always be compromises, more so if the damper adjusts both compression and rebound at the same time. With a damper that just adjusts rebound; the car should be able to be dialed in at least in terms of the body motion. The control of the unsprung mass will need to be accepted for whatever it is out of the box. The damper that has a lot of crosstalk will be more of a compromise because the chance that through adjustment rebound and compression will both be dialed in correctly is slim to none. Two, three and four way adjustable dampers greatly reduce the compromises used when tuning a single adjustable damper. This can also be said for a well designed custom valved non-adjustable damper. The only problem with that type of damper is if the track conditions change, adjustments are much harder to make.

Track tuning takes practice, in terms of both learning the principles behind these adjustments as well as learning what works well with the car, driver and track. This will take some time, but with a good idea of how each damper adjustment is supposed to affect the car this iteration phase will become much more streamlined. It would also be very beneficial to have a seasoned driver help initially dial in the car. This will allow a less experienced driver feel what the car is supposed to be doing and then minor changes can be made to better suit the new driver once he becomes comfortable enough.

The best way to tune a damper is to be ready. Make sure that the rest of the car is dialed in properly before adjusting the dampers, have your notes from past events with you and any notes from testing at the shop to use as a reference, be aware of the track conditions and any other outside variables and, most importantly, use common sense. It is also important to remember that damper tuning is an iterative process that will have you going back and forth between the shop and the track.

For more information or questions please check out www.theoryinpracticeengineering.com. The forum is the main source of information and contains updates on the progress of products and test cars as well as suspension discussions and resources that some may find very beneficial. So please take some time and look around. Also any questions or feedback on this article or any future articles would be greatly appreciated.

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