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The Shock Dyno Graphs and how they are created

We have all been looking at shock graphs for about a thousand years but I am still amazed that a true understanding of just how they are created, where the data comes from and how to identify what is happening is still not wide spread. We hope to change that with this paper.

Motion: Let's begin by understanding the motion. A crank type dyno converts rotary motion of the motor output shaft into linear motion to push and pull on the damper, shock or fork. It does this by using a (*) scotch-yoke mechanism. It begins with an AC motor that goes through a gear reduction of some sorts, could be a gearbox or a series of belts and pulleys to reduce the motor's RPM to a range that is usable to test the shock, that is connected to a crank head that is rotating at a given frequency. The scotch-yoke converts the bolt in the crank face going around and around into motion that goes up and down.

- https://en.wikipedia.org/wiki/Scotch_yoke

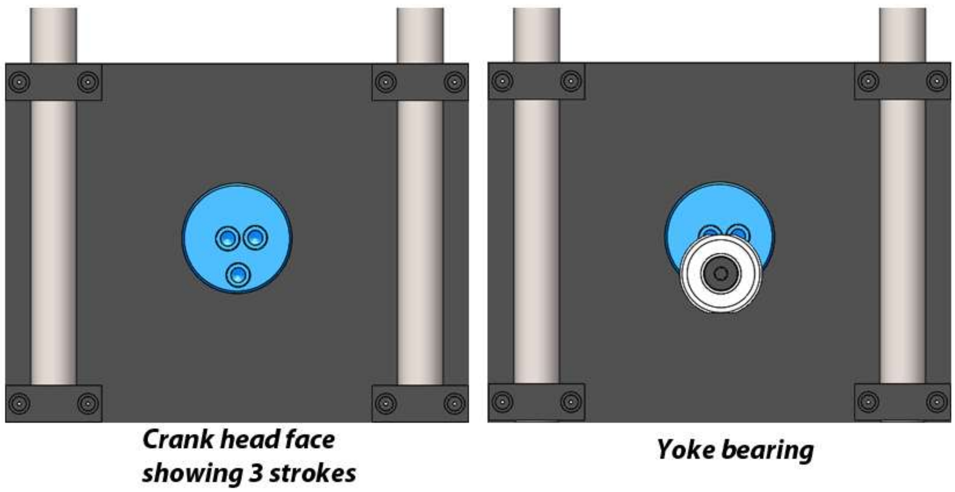

Figure #1: The crank head face and the yoke bearing

One full rotation, 360 degrees is 1 cycle: the time it takes to complete one cycle is called the frequency. When you build a Test in the software, you tell it to run at a given velocity (or several even). When you chose 10 in/sec, it is important to understand that it does not run at a constant 10 in/sec but instead it accelerates and de-accelerates from zero to 10 and back to zero. That is what happens when you convert rotary motion to linear. Believe it or not, the crank shaft is turning at a constant frequency for a given "test speed", however, the actuator pushing and pulling your damper is not constant.

- When we think of a CVP at 10 in/sec, we really mean an accelerating and de-accelerating test from zero to 10 to zero in compression and then zero to 10 and back to zero in rebound. This breaks down into 4 distinct events for every cycle. Roehrig called these CO – Compression Open, CC – Compression Closed, RO – Rebound Open and RC – Rebound Closed. The "open" and "closed" referred to the shims / valves on the piston.
- CTW Automation would like to advance this concept to a more accurate: CA – Compression Accelerating, CD – Compression De-accelerating, RA – Rebound Accelerating and RD – Rebound De-accelerating.

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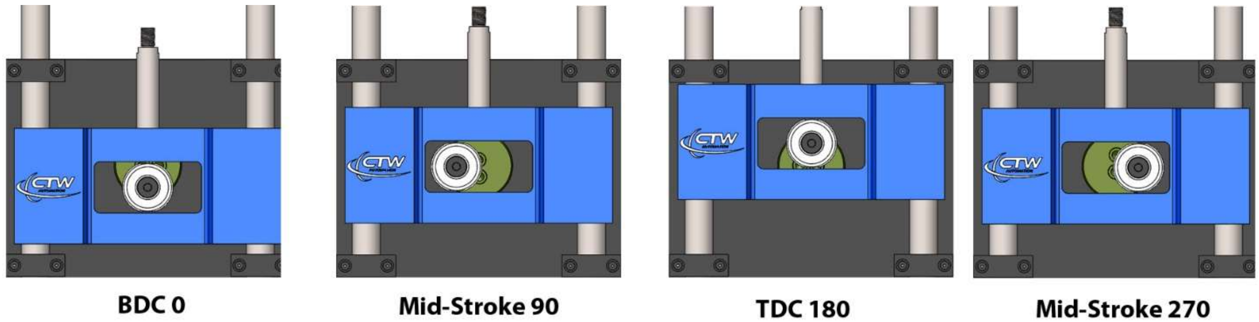

Figure 2: the scotch-yoke movement thru 1 cycle

One cycle – starting at BDC (Bottom Dead Center). It goes from a standing start, zero velocity, and accelerates to peak velocity which occurs at 90 degrees of rotation. Think "the middle" or as we refer to it as mid-stroke. Manufactures call it zero displacement. From there it de-accelerates back to zero velocity until it arrives at TDC (Top Dead Center). All of this motion has come in the compression direction or visually the actuator moves up to the top of the stroke.

From there, the same thing happens but in the "down" direction or extension / rebound. Again, accelerating out to mid-stroke, 270 degrees, to a peak velocity and then deaccelerate back to zero velocity at BDC. It all sounds simple but many people do not stop to think about these 4 areas of motion and they help us break down the damper and the graph into something we can understand. We also start to learn about accelerating effects on the damper because the dyno must accelerate differently if you run a test at 5 in/sec and a test at 10 in/sec. And this can be seen in your data and graphs. Figure 3 is a visual for the motion.

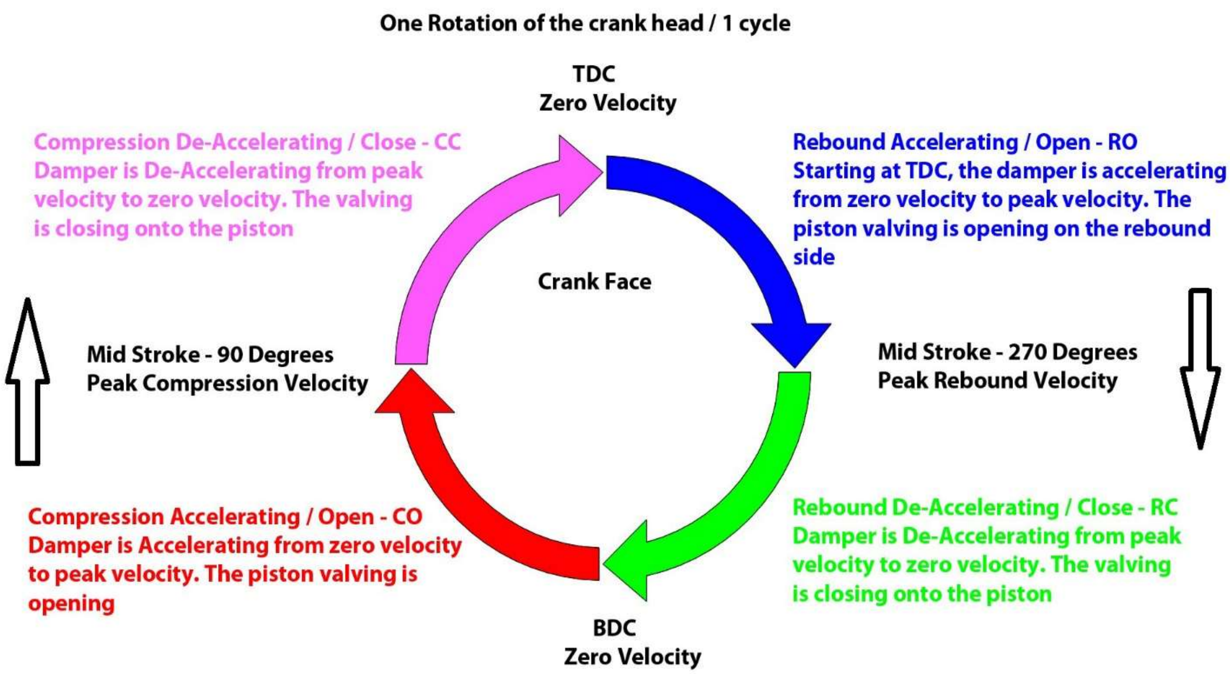

Figure 3: One cycle or rotation of the crank

Data: Now we need to understand what is collected during this motion. We collect sensor data while the machine is moving and this is used to create a graph or report. Displacement, Force, Velocity and Temperature are the standard signals collected. In the world of the "Geek" programmer, these signals are collected on a time scale and are later displayed based on what the User wants to see. In the Figure #4 we see what the sensor data looks like vs time. One cycle is shown.

Note: Many crank type dynos run more than one cycle for each speed. The machine needs time to get to speed, then time to stabilize and collect good data. As we saw in the PVP paper we published a few weeks ago, these cycles are important and which one you use and which one the software uses all matter. But in the end, we have a long table of data for each signal and a time column to work from to begin making graphs.

Now that we understand that the damper is constantly going through motions in compression and extension, while accelerating and de-accelerating to the Test specified peak velocity, we can better begin to examine the damper and data in terms of when it is happening.

The figures all use color coded lines to show the results that match the location of the crank head movement. "Red" is the compression accelerating out to a peak velocity and the "purple" is de-accelerating back to zero velocity as it moves to TDC. The same can be seen in the rebound phase using the blue and the green.

Figure #4 shows our signals plotted out vs. Time. They are all labeled and the colors match back to the original crank movement. This is where your graphs come from! (If you struggle reading a Force v Displacement graph just think, you could be looking at this.)

(History lesson) The very early pieces of test equipment for shock absorbers used a very simple system. As the yoke went up and down, it was connected to a drum (think round cylinder) that rotated back and forth based on the position of the yoke. Then a beam type strain gauge was connected to a pen that deflected based on the force pulling on the gauge by the damper. This was moving up and down drawing a line on the can that was rotating back and forth. And hence, what was created was a Force vs Displacement graph or as many call it, the 'football" or "potato" graph. I have seen these in action and it is like watching old race cars, history, except not as much fun.

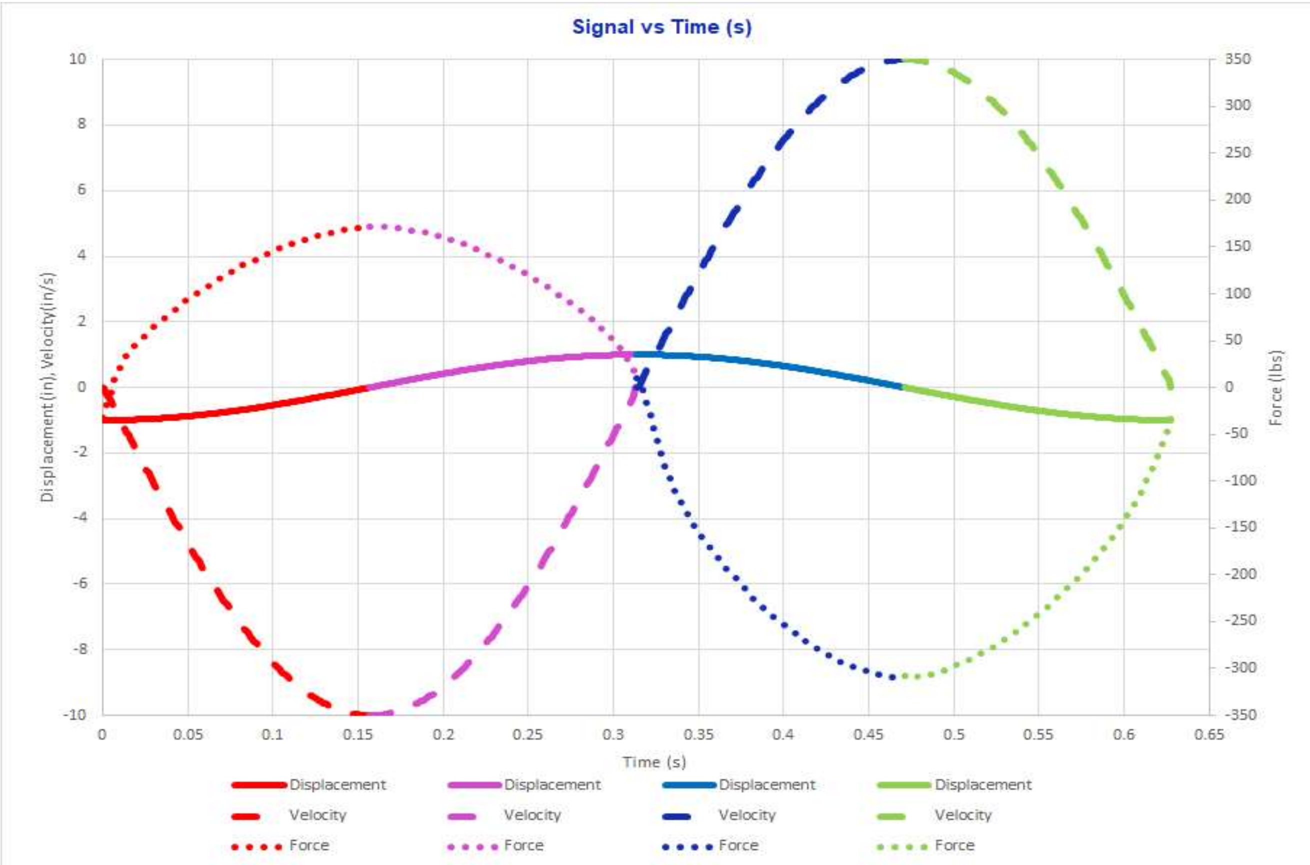

Figure #4: Sensor data for 1 cycle plotted vs time

This data is used to make all the graphs and reports that you use on a daily basis to decide what your damper is doing and what you need to change. You can use a Report format to just get the numbers. Since they are in a table (think Excel) aligned by Time, if you want the Force and Velocity data at every 0.5 in/sec, then the software looks at the Time table and then displays the Force at each Velocity you asked for. If instead you want to see a Force vs Displacement graph, then a plot is made using a position and force data point for an entire cycle. You can do the same thing in Excel, the CTW Probe software (or Roehrig Shock) simply does this for you. In figure #5 & #6 we show the typical graphs that are produced and used.

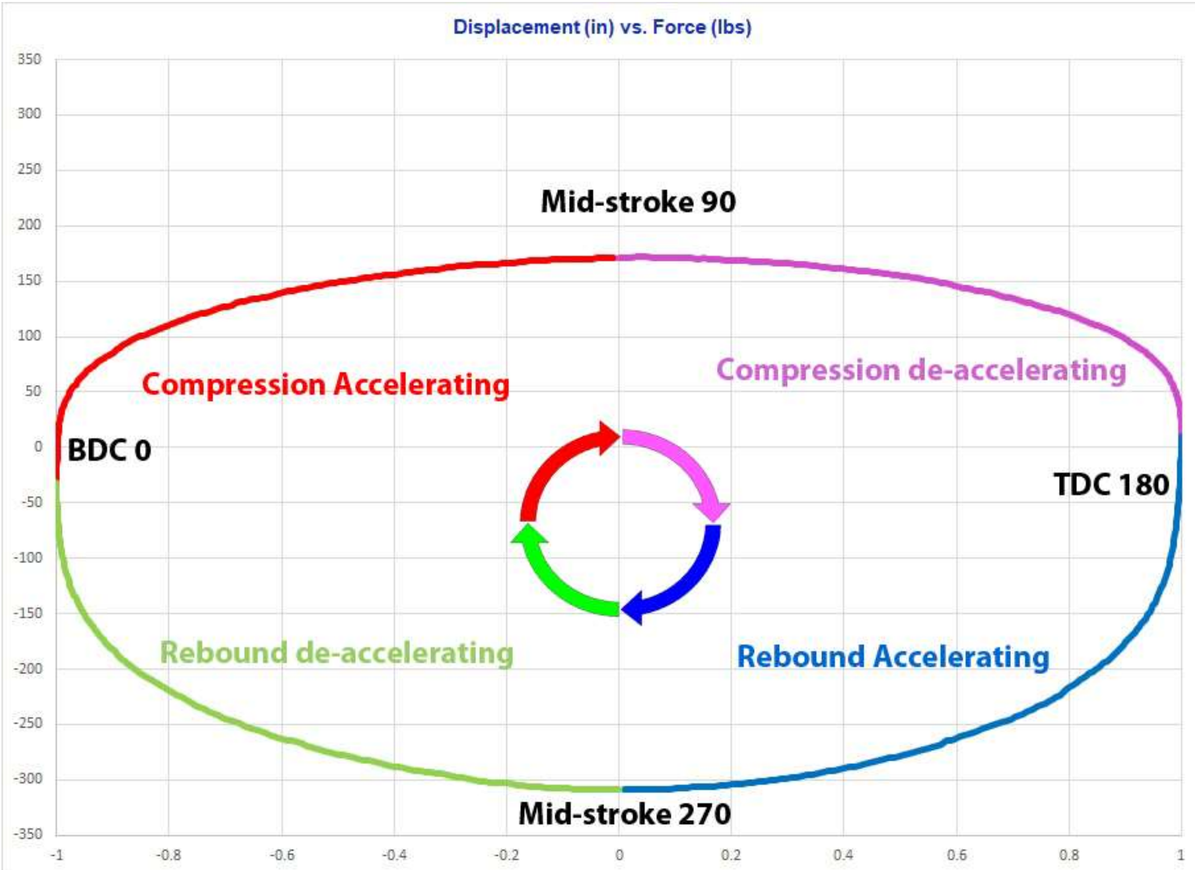

Figure 5: Force vs Displacement of one cycle

Figure #5 is a Force vs Displacement graph. It is 90 degrees out of phase compared to what we were viewing earlier. When looking at the dyno, displacement is going up and down but the Force v Displacement graph is plotted left to right. It is annotated and color coded to match the movements so you can always refer to the movements we are trying to teach. The X-axis is displacement ranging from -1.0” to 1.0” centered around zero (0). The zero is mid-stroke of the yoke movement. It is easy to understand, but for me, harder to interpret. What is often used in industry is looking for “lag”. A term used to talk about the Accelerating phases, be it compression or rebound, and referring to how the force reacts. It is often a very small difference and not easy to see. Many of these changes become magnified when we view the data on a Force vs Velocity graph. Figure #6 shows this type of graph.

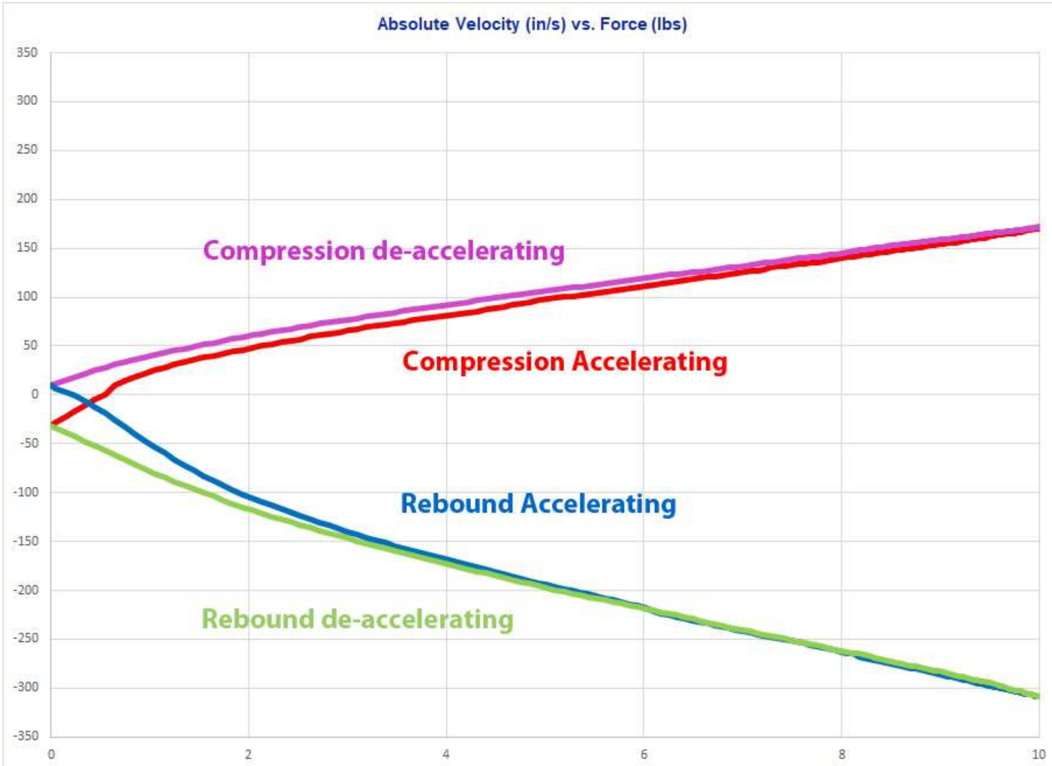

Figure 6: Force vs Absolute Velocity of one cycle

Figure #6 shows a graph we should all be used to seeing, FvsAbsVel. CTW Probe (and Roehrig Shock) use this data to present (4) ways to look at this.

Force vs Velocity – this shows velocity in the positive and negative values. This is the true way to think of the damper as it forces the User to see it moving in both positive and negative velocity directions.

Force vs Absolute Velocity - this makes all velocities positive and affectively simply folds the graph over along the Y-Axis. I can tell you that from the moment we did this at Roehrig, in many ways we regretted it. The terms "knee" and "offset' and "X" come from doing this and they are all visual anomalies that have lead to more confusion rather than a better understanding. But in the early 90's it helped us maximize the small screens we were all using.

Force vs Velocity - Compression Open / Rebound Closed – now that we know there are (4) sections and the cycle covers 360 degrees, we can take the FvVel graph and cut it in half by showing just half of the rotation, 180 degrees. The history for Roehrig again was due to screen size in the 90's as well as the idea that we were very interested in the CO / RC areas. It was our method of understanding the movement of the damper and spring on the car. The CO or as we now refer to it, the Compression Accelerating is what the damper does when the wheel hits a bump or an event and we wanted to focus on that. The RC (rebound de-accelerating) part was how we felt the wheel was being allowed to return to the ground after and event. In today's world, I think these two graphs hide too much information and should not be used.

Force vs Velocity - Compression Closed / Rebound Open – this is the other part of the 360 degrees circle. Again, because it only shows half of the cycle, you could easily miss a problem that occurred outside of this area.

Note: if your damper body had a dent on the inside of the tube that caused a force spike when the piston passed over it and this happened late in the compression stroke (compression de-accelerating) and all you were looking at was the comp-accel / rebound-decel (CO/RC) then you would never know there was a problem. This happened and I never used these "half" graphs again.

And that is the long explanation of the Graphs and the Data and where they come from.

For future discussion: When you start to think of the damper accelerating and de-accelerating you begin to see why when you run different speeds in your test that you see different results. On your race car or motorcycle, in the real world, is not running a velocity; it is being accelerated and de-accelerated all the time. It might be reaching a peak velocity but the only way it got there was by accelerating from one speed to another. Whether this was from zero to 5 in/sec or from 2 in/sec to 15 in/sec no of this as at a constant velocity but rather at an acceleration!

Let's do a thought experiment. If you are running a 2.0" stroke on your dyno and you run to a peak velocity of 10 in/sec, then the shock is accelerated from zero to 10 in/sec. in the distance from BDC out to mid-stroke. If you then change the speed to 3 in/sec then the damper is not accelerated as quickly because in the same distance it only need to get to 3 in/sec instead of 10. Your damper will react differently under these different accelerations. And since most of the important vehicle events happen in the lower velocity ranges, this becomes very important to us.

Why does the damper react like this and what is happening? Stay tuned.