How a Chassis Dynamometer Works and why to take "HP to the ground" with a grain of salt.

Let's take a look at how a chassis dyno works, to try to clear up some misunderstandings. Feel free to ignore the math, It's just there to show that the numbers do work in reality.

Note: We will talk about torque and power. Torque can be measured directly. Power, specifically horsepower or Kilowatts, can be calculated from torque and rotational speed or force and linear speed. Power is most relevant, since you can change torque by changing gear ratios, but horsepower should remain the same through the drivetrain, other than mechanical losses. If a gear ratio is doubled, (2:1 in to out) torque is doubled but rotational speed is halved so power remains the same. This will be demonstrated by comparing dyno power to engine power.

A chassis dyno generally has one or more rollers the vehicle sits on. A 2WD dyno may have a single large roller or a pair (or set) of smaller rollers.

A single roller dyno may have a 24" or larger roller. Here's one for a motorcycle, a car dyno would look the same only it may have two rollers next to each other, or a single large roller.

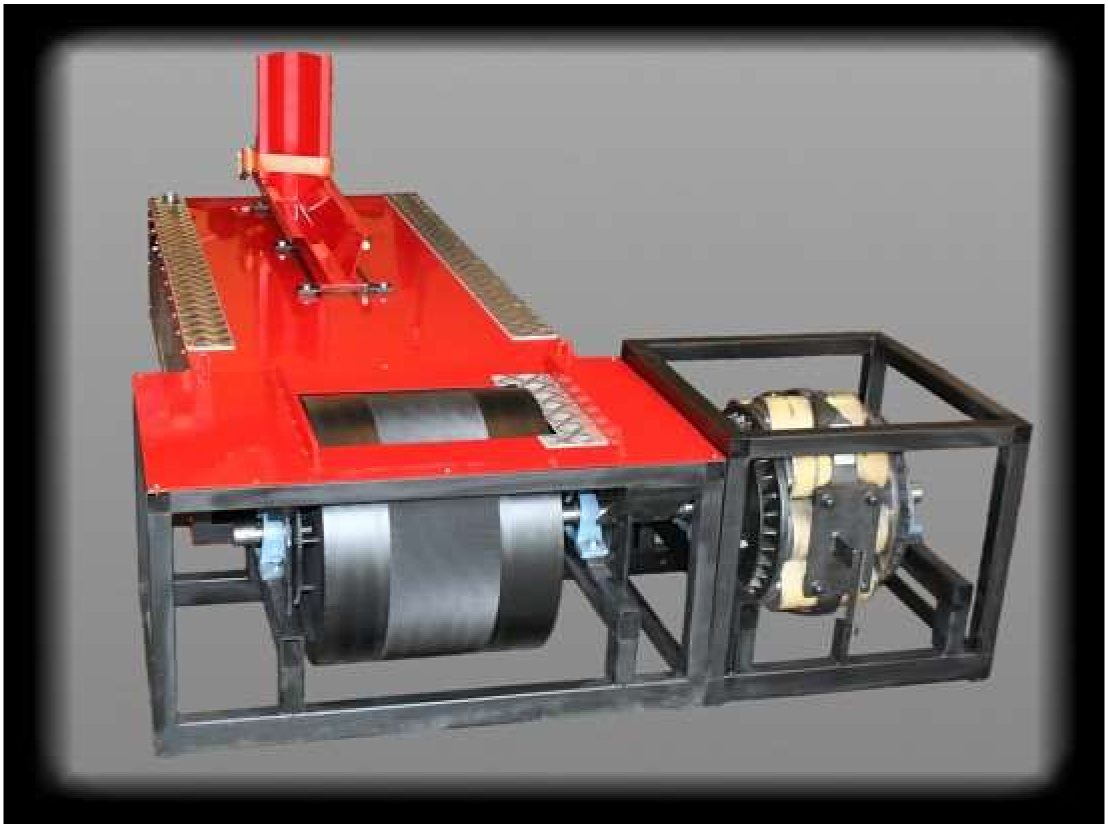


Figure 1 Motorcycle single roller dyno with no load cell

Also shown in the above photo is the PAU (right). That is essentially a combination generator and motor. The generator generates electricity which is then fed back to the motor portion. The motor is used to RESIST the rotation. By regulating the amount of electricity fed from the generator to the motor the amount of resistance generated can be changed by the controller software.

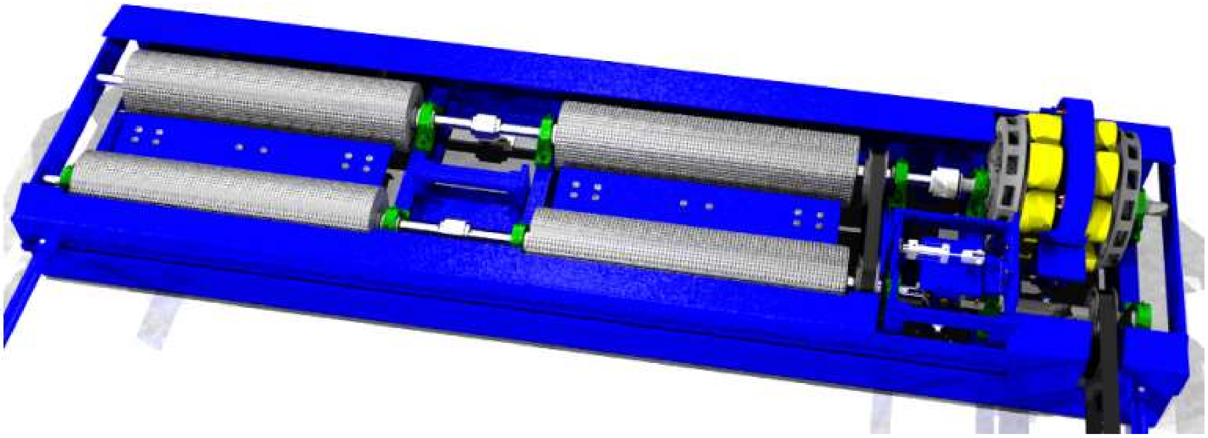


Figure 2 Mustang Dyno with four rollers and PAU

Above is Mustang MD150, which is what we have. Four rollers that all move in unison because of the common shafts and belt connection. The tires sit on both pairs of rollers. The PAU (Power Amplifying Unit) is shown on the right with cast iron vented end plates and yellow coils.

A 4WD dyno is shown below with the covers off, the front rollers are often driven as well.

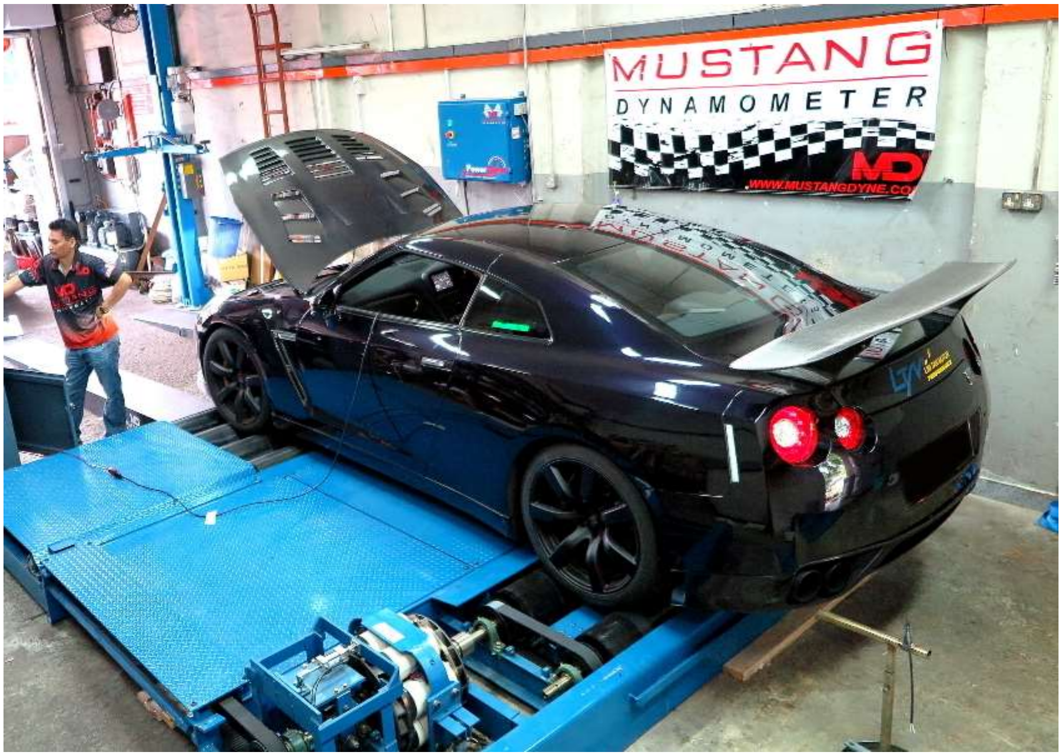


Figure 3 Mustang 4WD dyo with PAU and belt covers removed

The PAU assembly is on the same shaft as one of the rollers, so it's armature rotates at the same speed as the rollers. The only thing keeping the ENTIRE PAU from rotating is the connection to the frame. In the photo that connection is a metal bar, but when in use, that is replaced by a load cell…essentially an electronic scale that can be loaded in tension or compression, so readings can be taken regardless of which direction the vehicle is pointing.

Since the PAU is otherwise free to rotate, if data is collected from the load cell, torque can be directly read. If the load cell is placed 12" from the central axis, the output (measured in pounds) is multiplied by length of the lever arm (12" =1 foot) to determine torque generated by the PAU. If the load cell reads 150 lbs, then the torque is 150 ft-lbs. If the lever arm were increased to 18" (1.5 feet), such as in the case of our Mustang Dyno, the load cell would read 100 lbs, and torque would be 150ft-lbs. The PAU is shown below with load cell, and the load cell is shown separately.

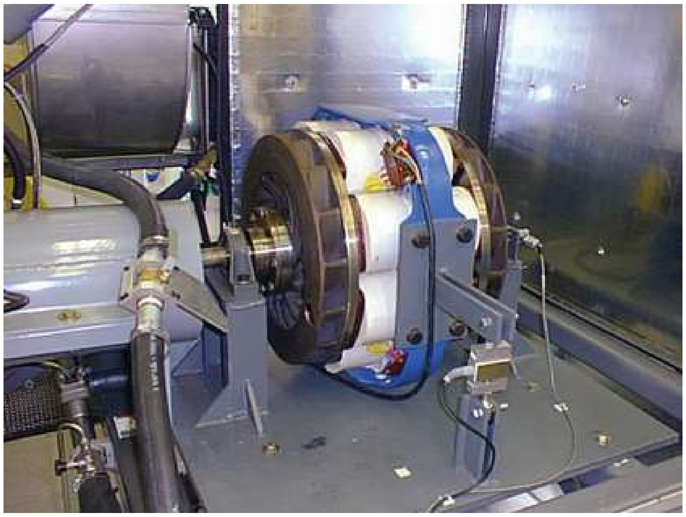


Figure 4 PAU with "S" style load cell

Figure 5 "S" Style load cell

The second aspect of the dyno is the inertia section. The roller, rotating portion of the PAU and, in many cases, a flywheel have a known moment of inertia. The rollers have a known diameter, in the case of a mustang dyno that's 10.7".

Imagine a vehicle in a vacuum, weighing 3000 lbs, accelerating at 0.2G (1/5 the force of gravity, 6.44 feet per second squared, or 4.4 mph per second). That requires a force of 600 lbs (mass times acceleration). Let's assume this is the case for this specific vehicle at full throttle in 3rd gear and is constant from 3000-6000 RPMs.

Now imagine instead that the same force is applied to a 10.7" roller it generates a torque on the roller shaft of 268 ft-lbs.

The speed of the roller can be measured in RPMs and then the surface speed can be calculated in miles per hour. With the above radius, 1000 RPMs is 31.8 mph, 3000 RPMs is 95.4mph etc. Accelerating the vehicle at 0.2G would mean speed is increased 4.4 miles per hour per second, so after 1 second the speed would be 36.2 mph or 1138 RPMs, and each second the roller would gain 138 RPMs as speed increased by 4.4 mph per second.

As you may know, F=MA and T= Iα where T is torque (ft-lbf), I is the moment of inertia and α is the angular acceleration, in radians per second squared. Since we know T (268 ft-lbf) and a (9.55 RPM=1 rps, radians per second, or 138 RPM/second=14.5 rps^2 so we can determine I is 18.5 ft-lb/s^2, since radians are unitless.

So now we know all we need to know to calculate torque and horsepower.

Ignoring the PAU, this vehicle generates 268 ft-lb of torque on the rollers. Let's assume it does this at 3000 RPMs roller speed, that means horsepower is 153 HP, since HP=T*RPM/5252.

Knowing all of the above, if we measure roller acceleration, we can calculate torque required for that acceleration and also horsepower as there is a linear relationship. We care about HP at the ENGINE so if we know the ENGINE RPMs we can calculate NET Engine HP. In this case if the overall gear ratio for the drivetrain is 4:1 and tire diameter is 26.8, the ratio of tire speed to roller speed is 2.5 and the ratio of engine speed to roller speed is 1.6 so engine speed is 4800. That means that HP at the crank is ???

Well…we know we have 600 LBF at the roller/tire interface. The RADIUS of the tire is 13.4" so torque at the axle is 669 ft-lb. With an overall drivetrain ratio of 4:1 we have torque at the engine of 167 ft-lb. at 4800 RPMs of 153 HP. That assumes no losses between the engine and the dyno and that the dyno shafts/bearings/etc are frictionless. We also know that the ratio of dyno roller speed to engine speed is 4800/3000=1.6.

OK, if the dyno is inertia based only, we know that an acceleration of 138 RPM/sec requires 153 HP so if we measure the acceleration of the dyno rollers we can calculate Torque at the rollers, for an increase of each RPM/Second a torque of 1.94 ft-lbs is required. Note that torque is linear with angular acceleration, but force is not, since force is torque TIMES angular speed. If torque is constant from 3000-6000 rpms, then force increases linearly and doubles from 3000 to 6000 RPMs. That's what's known as a "flat torque curve".

The PAU acts as an additional torque resisting acceleration.

Let's take the same car and the same 167 ft-lbf torque on the rollers, but now let's exactly oppose acceleration by generating 167 ft-lbf with the PAU. In this case there will be no acceleration. If we put 83.5 ft-lbf then the acceleration would be half that of the rate with no PAU (7.25 rad/s^2). If the PAU torque was greater than 167 ft-lbf then the rollers would decelerate.

Since torque is directly measured at the PAU, and acceleration is also measured, the PAU can be dynamically regulated to give a desired acceleration, and the acceleration and PAU torque can be used to determine total torque and power.

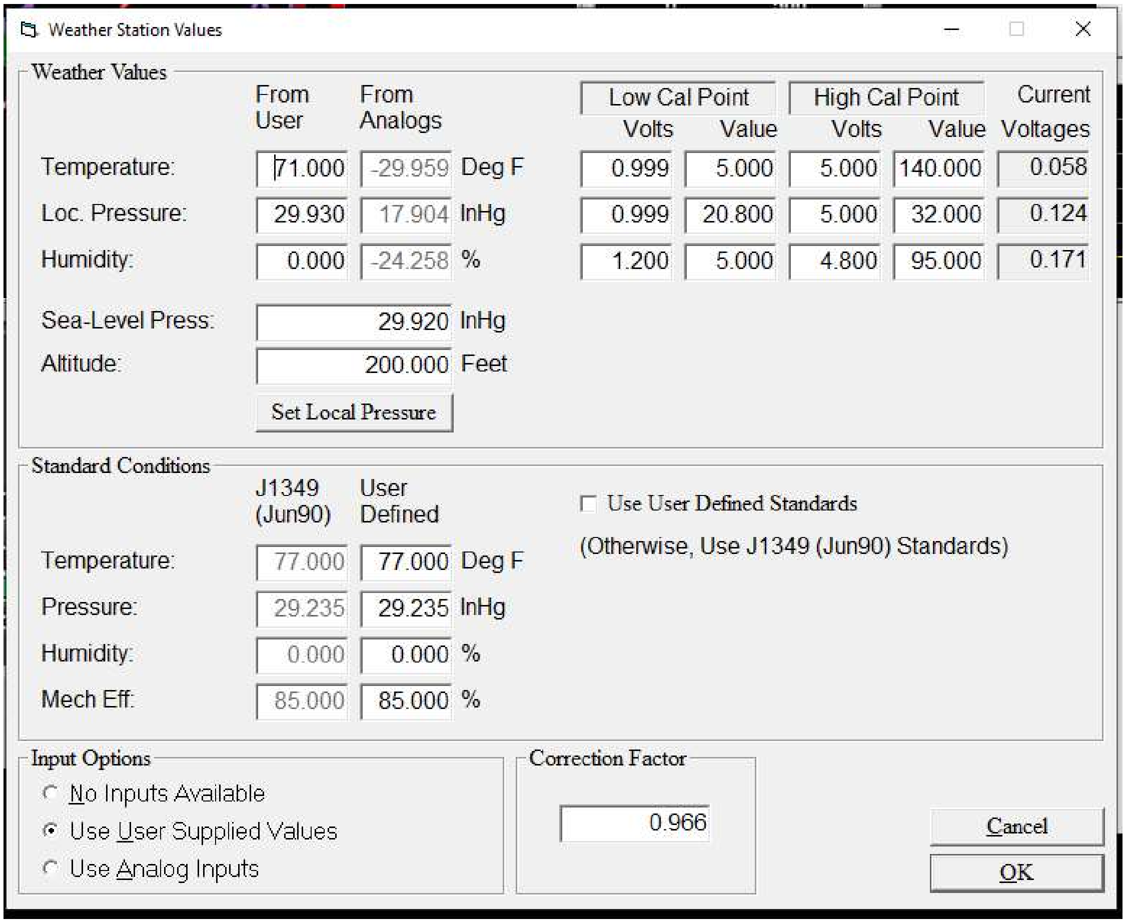
So we determined that at 4800 RPMs and 2.0 G accelleration for a 3000 lbs car requires 153HP "to the ground", i.e. at the tire-roller (or road) interface. That assumes there are no losses between the engine and the tire. Most cars lose 15-25% of the power between the rear of the engine (flywheel) and the tire surface. A Porsche 911 loses about 20% in the drivetrain and tires.

Most modern dynos, including mustang, try to display flywheel torque and HP by using this correction factor along with a correction factor that reflects losses due to friction in the dyno itself (mainly bearings) so let's say this adds another 2%. Where it's lost doesn't much matter, so lets say it's 22% total.

$$HP_{fw} = 153/(1-0.22) = 153/0.78 = 196 \text{ HP}.$$

The same losses apply to torque.

The 2% dyno losses are not constant. They are weakly dependant atmospheric conditions. If the dyno is calibrated for 77F and 0% humidity and sea level standard pressure, but the actual temperature is 71F and 0% humidity and elevation is 200 feet, the correction factor is 0.966, so that means actual HP is 96.6 percent of that read by the dyno, i.e. if the dyno calculates 100 HP reality is that only 96.6 is the actual value. This should allow the dyno to calculate the same HP independent of changes in weather if the atmospheric conditions are accurately input. This can be done by a weather station connected to the dyno computer or by the operator gathering measurements and inputting them (see below)



Weather Values

	From User	From Analogs		Low Cal Point Volts	Low Cal Point Value	High Cal Point Volts	High Cal Point Value	Current Voltages
Temperature:	71.000	-29.959	Deg F	0.999	5.000	5.000	140.000	0.058
Loc. Pressure:	29.930	17.904	InHg	0.999	20.800	5.000	32.000	0.124
Humidity:	0.000	-24.258	%	1.200	5.000	4.800	95.000	0.171

Sea-Level Press: 29.920 InHg
Altitude: 200.000 Feet

Standard Conditions

	J1349 (Jun90)	User Defined	
Temperature:	77.000	77.000	Deg F
Pressure:	29.235	29.235	InHg
Humidity:	0.000	0.000	%
Mech Eff:	85.000	85.000	%

☐ Use User Defined Standards
(Otherwise, Use J1349 (Jun90) Standards)

Input Options
○ No Inputs Available
● Use User Supplied Values
○ Use Analog Inputs

Correction Factor
0.966

Figure 6 Weather station configuration

How the correction factor is determined is up to the dyno/software manufacturer. I know this because I neglected to change the setting from "Use Analogs" to "User Specified" and the correction factor at NEGATIVE 29.95 degrees F and a humidity of -24.3% was used and the correction factor was 1.53. The correction factor is applied to overall losses so instead of 22% losses it was using 34% loss and correspondingly giving HP readings much higher than reality. In the above case the "Engine HP" would be calculated at 230 HP instead of 196, about 18% too high.

So here's the point:

A person takes their car to be tuned, let's say it's a Porsche 911 with a 3.6 liter 1998 engine. The tuner has a chassis dyno and gives the owner a "Dyno Sheet". That dyno sheet says the car makes a maximum of 300 HP – SAE corrected. The chassis dyno reads power at the tire, which is referred to as "to the ground". That does not mean that the engine is producing 300HP plus 66HP drivetrain losses = 366 HP at the flywheel, the "corrected" HP term already includes losses. In this case the power to the ground (measured at the tire) is actually 234 HP. The dyno operator can access this number if they choose to, but most do not…mainly because it's confusing to the customer.

The dyno operator can also tweak HP readings by using different atmospheric conditions, or calibrations, or by varying the PAU loading. It turns out that by increasing PAU loading, the vehicle accelerates less but the engine has more time to react to varying conditions so the HP readings may be higher (or at least that's what my Mustang Dyno software says).

Make sure you know what you are looking at. What's important is to see changes in HP from a tune, not what number you are given. If you a have normally aspirated stock engine, and the tuner says he added 15% HP from a tune, realize that this is highly unlikely, because all they can change is fuel mixture and ignition timing (and perhaps cam timing if the car is newer, though most tuners do not) so 5% is reasonable optimizing for higher octane fuel and sacrificing some fuel economy, but unless the manufacturer has seriously missed the mark on the stock tune, that's about all that's there….and it's there on purpose to provide a safety margin for variations in fuel quality. On an engine we built we were able to get 10 more horsepower by going from 93 octane to 100 octane race unleaded. That's because we could run more ignition advance. That tune would cause damage to the engine with 93 octane fuel or the power would be reduced by safely measures like reducing ignition timing when knock is detected.

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  Run# License   Owner    Acquired          Test Comments
     1 028M170   Cortina  09/17 14:35       5TH GEAR RUN1
     2
     3
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                         Min                 Max                 Avg
Channel / Run            1     2     3       1     2     3       1     2     3
Speed (MPH)              47.2                148.6               96.1
Wheel Torque T WC (Ft-   69                  515                 423
Wheel Power T WC (HP)    27                  558                 359
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Figure 7 Random dyno chart