Performance measurements on chassis dynamometers

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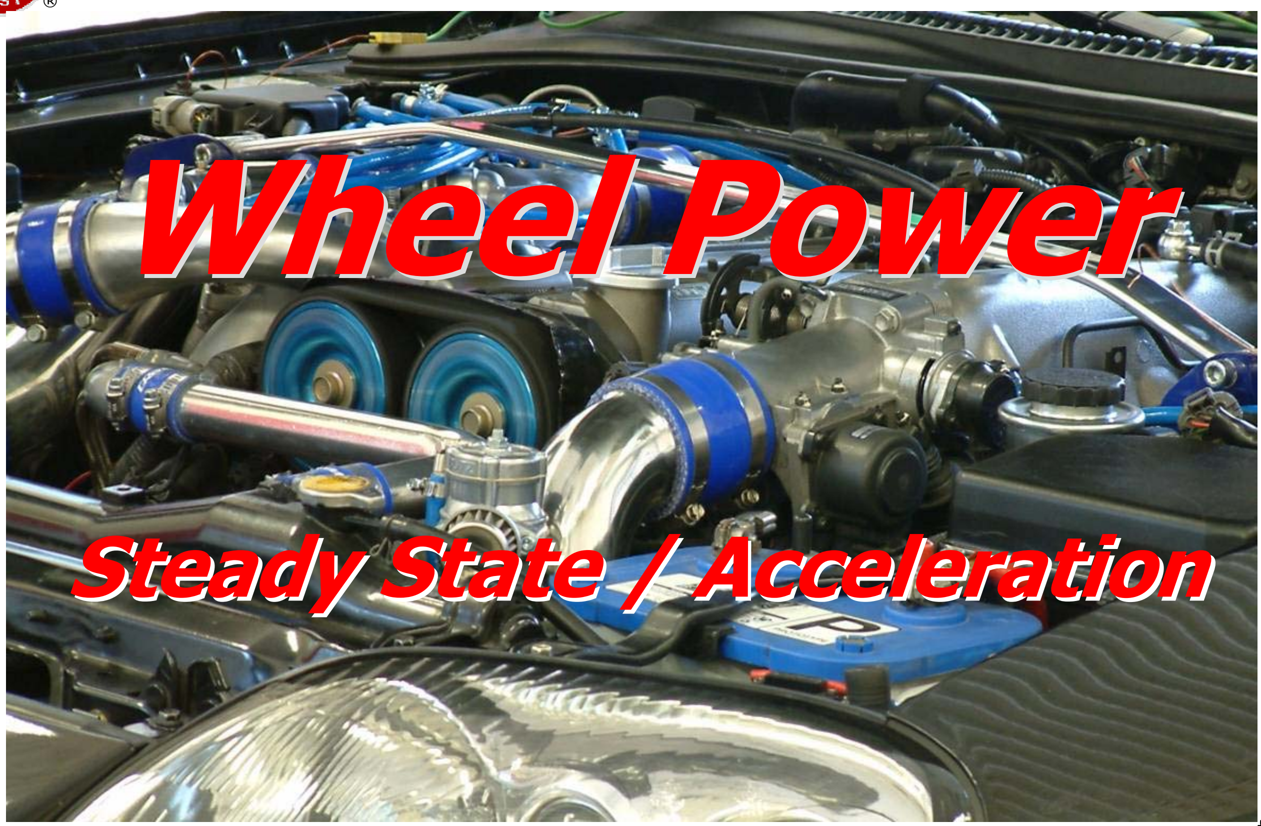

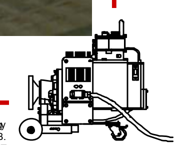

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Performance measurements on chassis dynamometers

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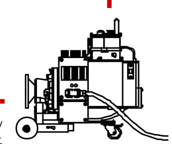

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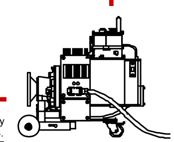
History

- James Watt (1736-1819), Scotland
- Tuned steam engines to replace horses for coal transports
- Invented the unit horsepower



James Watt was an engineer and inventor from Scotland (1736-1819) and you could say the first engine tuner. He improved the design of the steam engines and raised the efficiency. His aim was to replace horses in the coalmines.
Horses were used to lift the coal up to the ground. However, he had to convince the owners they would make more money if they went to his steam engines.

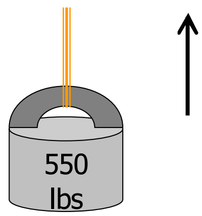
Performance measurements on chassis dynamometers

He made measurements on several horses and calculated the performance of an average horse. This was the performance it could manage during a whole days work. Watt gave it the unit ´horsepower´. Later it has been named bhp (brake horsepower) and imp hp (imperial horsepower). Now he could tell the mine owners how many horses they could replace with one of his steam engines and also easily calculate the profits.

History

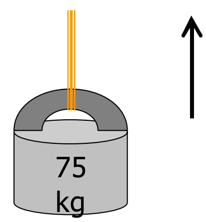
Imperial horsepower

- One average horse managed to lift 550 lbs to a height of 10 feet in 10 seconds.
- Units [bhp], [imp hp]



Metric horsepower

- Lift of 75 kg to a height of 10 meters in 10 seconds.
- Units [met hp], [PS], [ch], [CV],

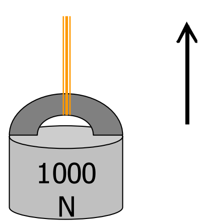


The original horsepower-unit was based on imperial units, i.e. pounds and feet. The rest of Europe wanted a definition based on metric units. It is nearly, but not exactly, the same. An imperial Hp converted to metric Hp shows a 1.5% higher number. Today all definitions are using SI-units, i.e. Newton, meters and seconds. The standard unit for power was named ´Watt´.

History

ISO power - Watt

- Lift of 1000N (98.1 kg) to a height of 10 meters in 10 seconds.
- Unit [kW]

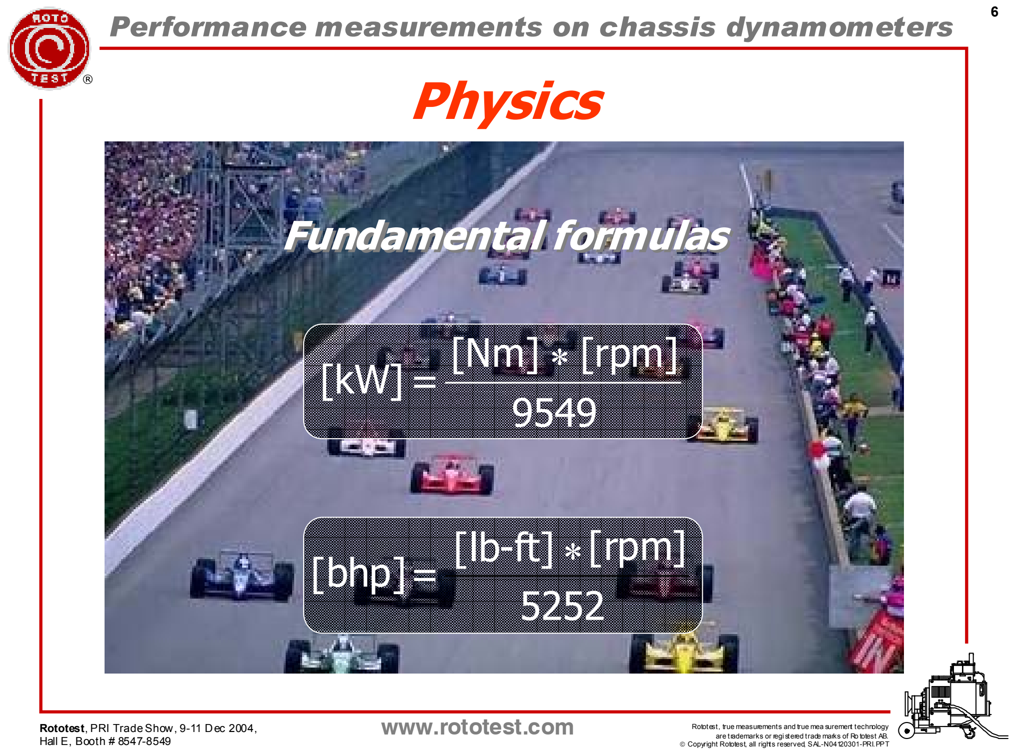


Conversions

- 1 kW ≈ 1.34 imp. Hp
- 1 kW ≈ 1.36 met. Hp
- 1 imp Hp ≈ 1.015 met Hp
- 1 lb-ft ≈ 1.36 Nm

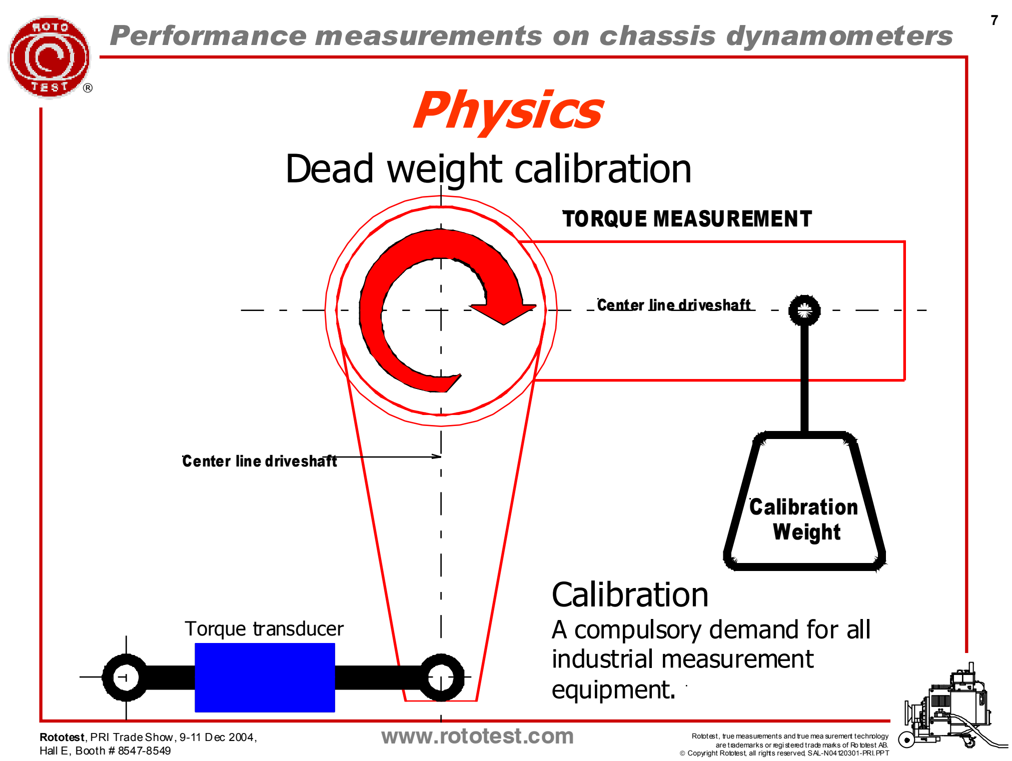
Performance measurements on chassis dynamometers

The performance of an engine is normally described by the power output. If the engine is used over a wide range of speed, like in a car, it is equally important to know the torque output. The torque is actually what you feel when driving a car. Power and torque are related. Maybe the most described formula in car magazines is the relation between ´bhp´ and ´lb-ft´. If you plot them using the same scales they will cross at 5252 rpm. If you plot with ´kW´ and ´Nm´ the crossing will be at 9549 rpm.



If a scientist makes a new discovery it will not be accepted until somebody else can repeat the same test and achieve the same result. This is a simple way of convincing others, and yourself (!), the results were correct. One of the corner stones in measurements is calibration. If a tool cannot be calibrated it is not a measurement tool. The normal way when calibrating a load cell is to use a rod and dead weights. Today's standard of high quality in all aspects demands that the calibration is traceable. This means that the weights themselves must have been measured on a calibrated scale.

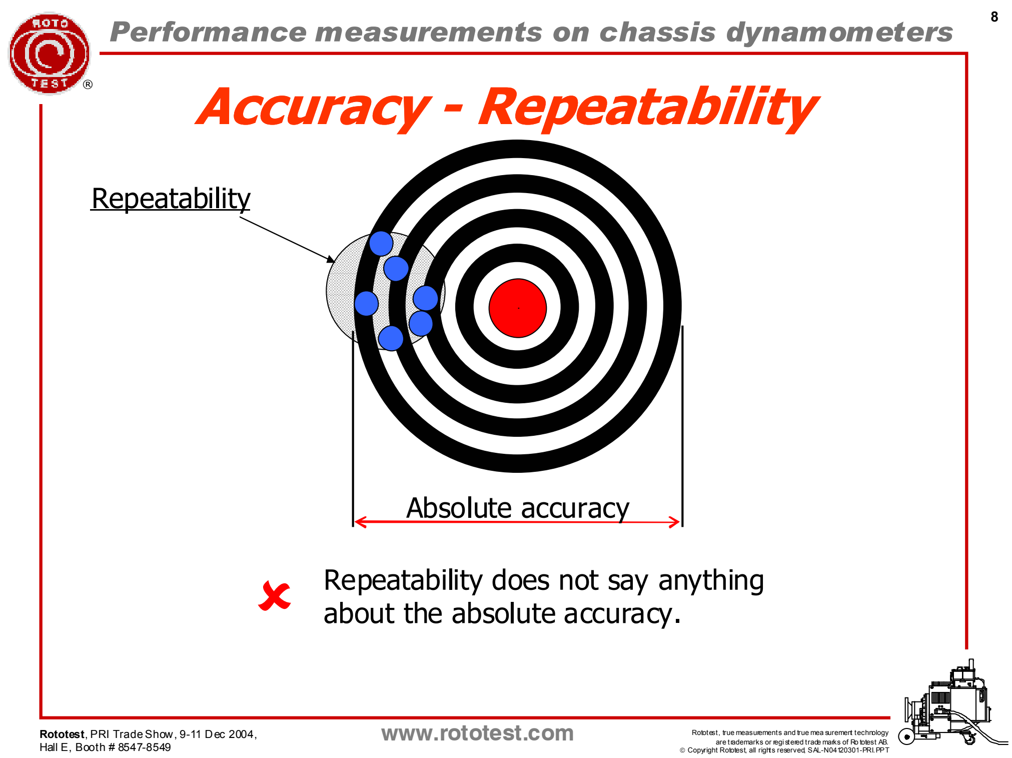
If you need to be extremely sure about the results a good way is to calibrate before the tests and check the calibration afterwards. Then you can be sure of the accuracy of the equipment during the tests.



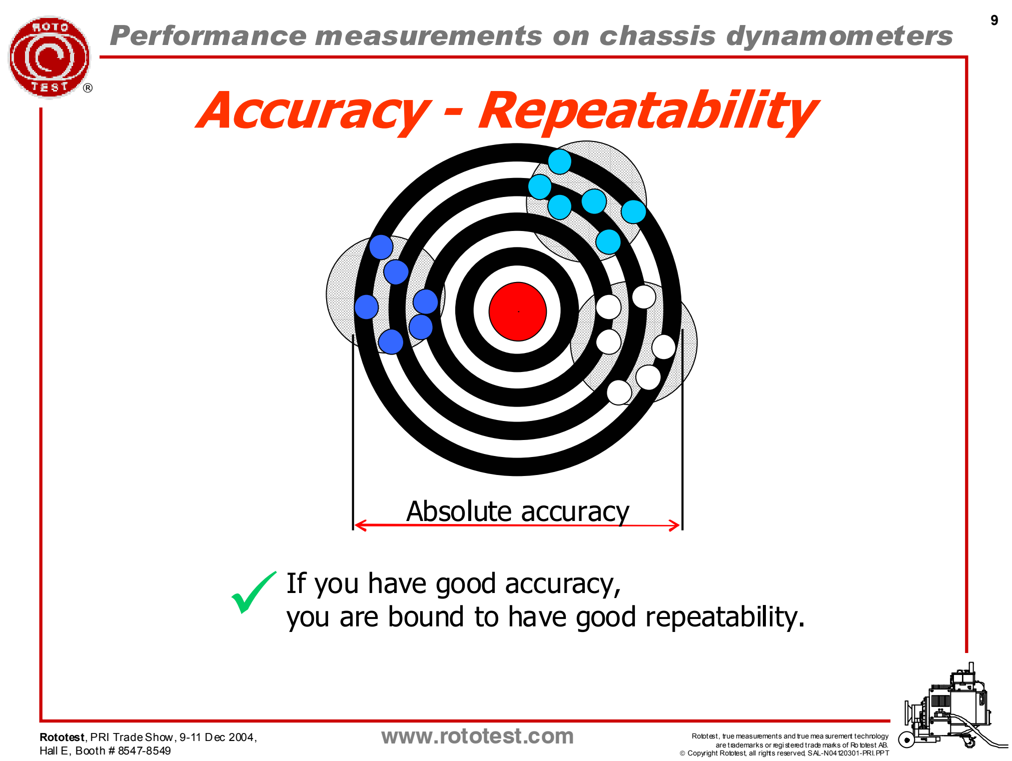
Performance measurements on chassis dynamometers

Accuracy and repeatability are always present when it comes to measurements. In most cases only one of them are mentioned and they are often misunderstood. It is very common to hear that you don't need the accuracy, only a good repeatability. This statement could mean it is ok to present false values as long as you do it all the time…

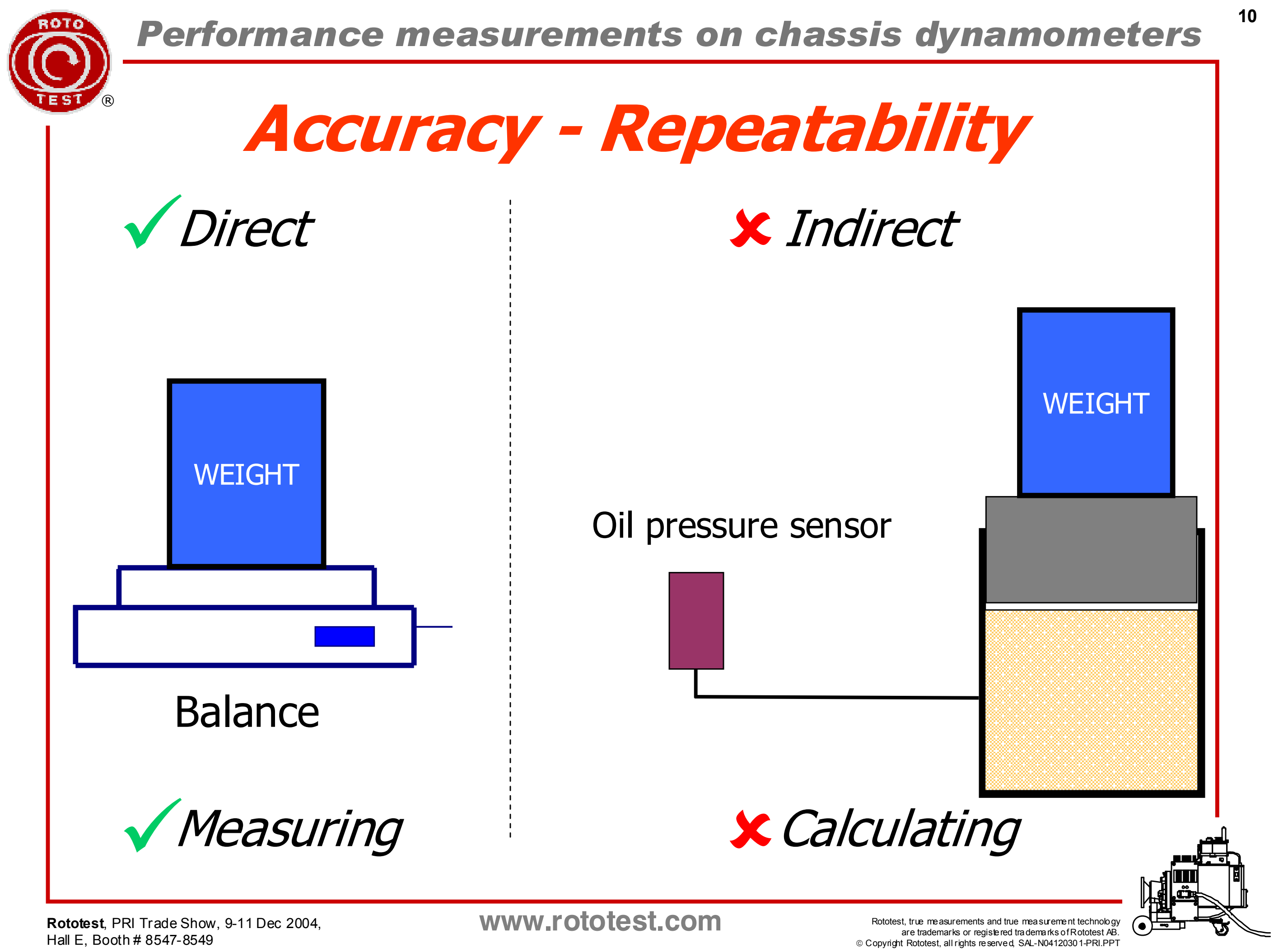
How can it be explained? Lets say you shoot 6 shots on a target. All of them hit the target but on the left side. They are fairly close to each other, which mean the repeatability seems to be fairly good. Although the repeatability itself does not say anything about the absolute accuracy!



Lets shoot two more rounds. It turns out each round have a fairly good repeatability. All together it seems the absolute accuracy is within target every time. The question is: How big is the target?
There is only one relation existing between accuracy and repeatability:
If you have good accuracy, you are bound to have good repeatability.



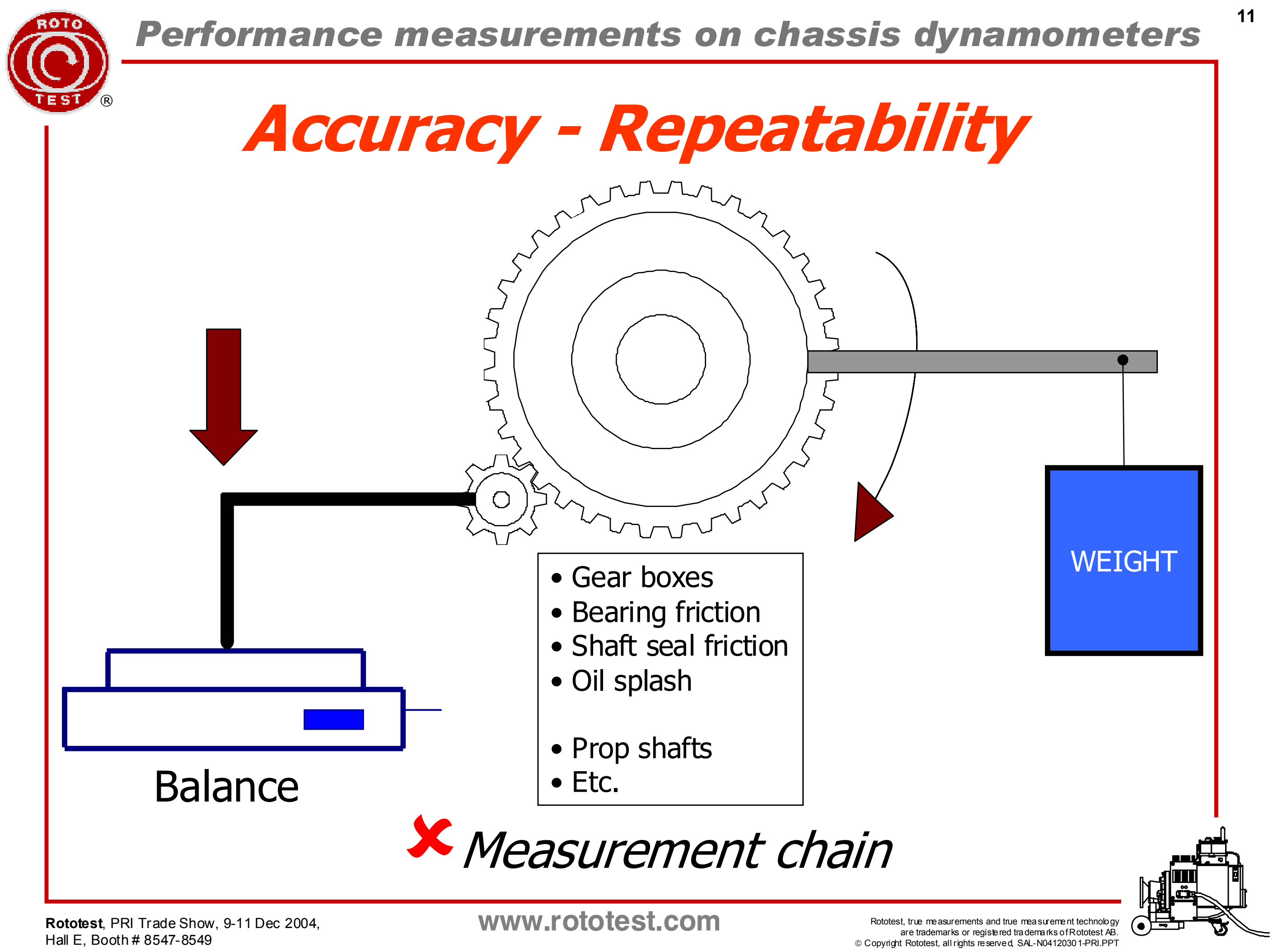
Performance measurements on chassis dynamometers



All measurements are estimates! The true value is never exactly known. It is always a measured value ± tolerance. High accuracy means small tolerances and vice versa. In other words, to be sure to have a good measurement you need to keep the tolerances to a minimum.

First step towards minimizing the tolerances is to have a direct measurement. This means that you measure the property directly, i.e. measuring the weight on a balance. An example of an indirect measurement would be if you set the weight on a hydraulic cylinder and measure the pressure of the fluid. The weight could then be calculated from the internal dimensions of the cylinder and the sensor value. However the total tolerances will include not only the size of the cylinder but also internal friction, temperature dependency etc, and also added the accuracy of the sensor itself.

Performance measurements on chassis dynamometers



Measuring the property directly does not automatically make it a good and accurate measurement. A measurement chain describes the way the forces have to take from the actual object to the sensor. In this picture the weight is measured directly but the force has to travel from the lever through the gearbox and then via another lever before it reaches the actual balance. The ideal solution is to have the object (weight) as close as possible to the sensor (balance). For every link in the measurement chain there will be an added tolerance.
Referring to dynos: High accuracy demands direct measurement of torque and speed and sensors close to the engine / car.

Repeatability can be of different kinds.
• Short term can be measurements made close in time
• Long term can be measurements made in the beginning of the racing season compared to the middle of the same season.
• At different locations

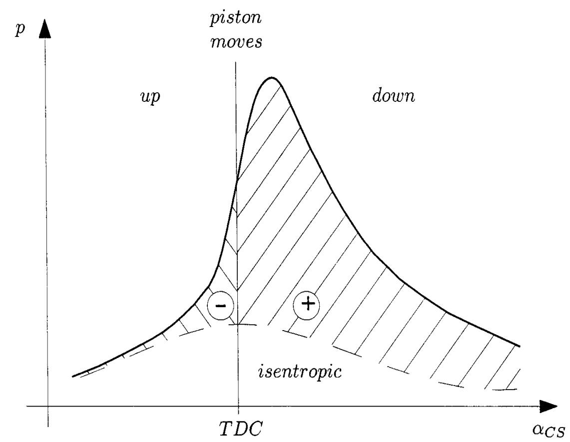
When it comes to the discussion about repeatability of dynos it is nearly always referring to the short-term situation described above. Mostly it consists of two measurements after one another on the same engine / car.

Performance measurements on chassis dynamometers

Real Life Repeatability

The picture describes the pressure acting on the piston inside the cylinder. The spark is fired before the piston reaches TDC. The pressure acting on the piston before TDC is producing negative work whereas after TDC it is positive. Optimum timing will be when the sum of the contributions is highest.

The pressure in the cylinder is producing both negative and positive contribution



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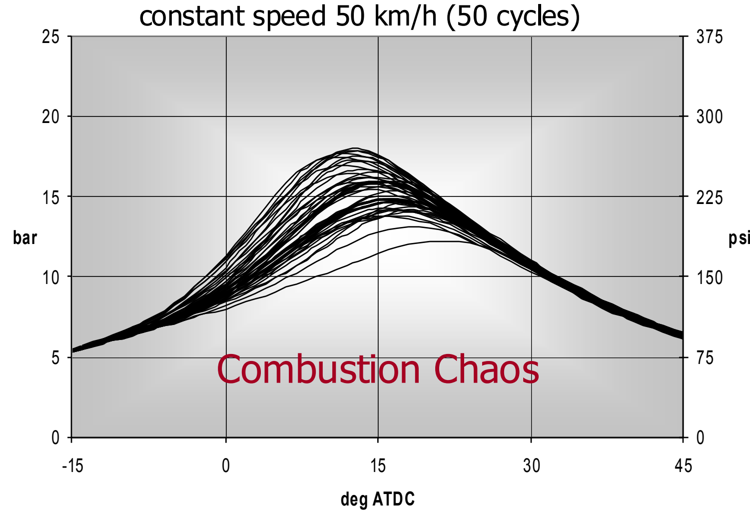
Real Life Repeatability

Measurements on a car with a modern four-valve engine cruising at 50 km/h show a big variation in the combustion process. The picture shows 50 combustions in a row from the same cylinder. Ignition timing is the same all the time. This is a typical result from an engine running on petrol.

Variation of cylinder pressure during constant speed 50 km/h (50 cycles)



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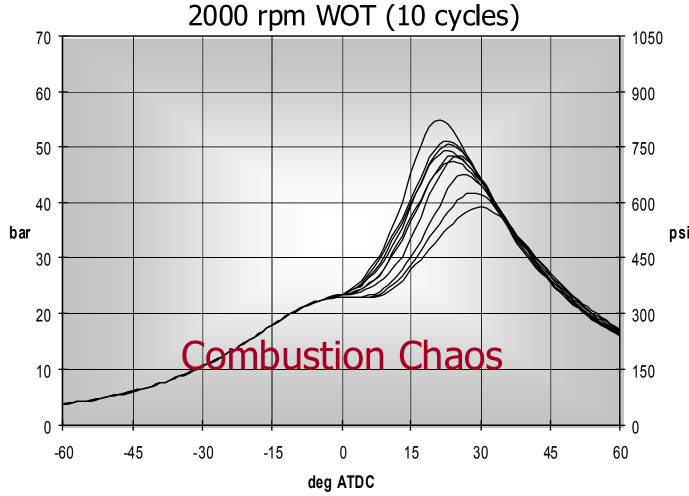
Here the same engine is running WOT at 2000 rpm. This is also a typical result. The combustions are quite unstable from cycle to cycle. Bottom line is that an engine is not the best object to use for testing of repeatability. The uncertainty is even worse if the tests are done at different occasions and/or locations. The only way to be sure of the measurements is to calibrate with a known source, i.e. dead weights.

Real Life Repeatability

Variation of cylinder pressure at 2000 rpm WOT (10 cycles)



Another important area, which can have a big influence on the results, is ´Test Conditions´. This makes it important to include information about how the test was performed so it can be repeated later or compared to other results. The best is to have as close to normal conditions as possible.

Test Conditions

Ambient

- Inlet air temperature
  - Measurement point
- Atmospheric pressure
  - Weather / altitude
- Relative humidity
  - Geographic location / Season

Other

Fuel
- Fuel type and quality
- Octane number / energy contents
- Fuel temperature

Drive-train temperature
- Engine cooling fluids
- Gearbox oil
- Rear axle oil

Performance measurements on chassis dynamometers

No matter how hard you try you cannot achieve exactly the same conditions from time to time or even during a test series. A way of adjusting the numbers to normal conditions is to use ´Power corrections´. There are numerous corrections depending of engine type, fuel etc. This formula describes the correction for petrol engines. It is important to understand that general corrections are exactly that, general! All engines are individuals and respond slightly different from others. For this reason the total amount of correction should be small. The standard even sets a limit on the amount; it has to be less than 7%.
The power corrections have always to be described in detail.

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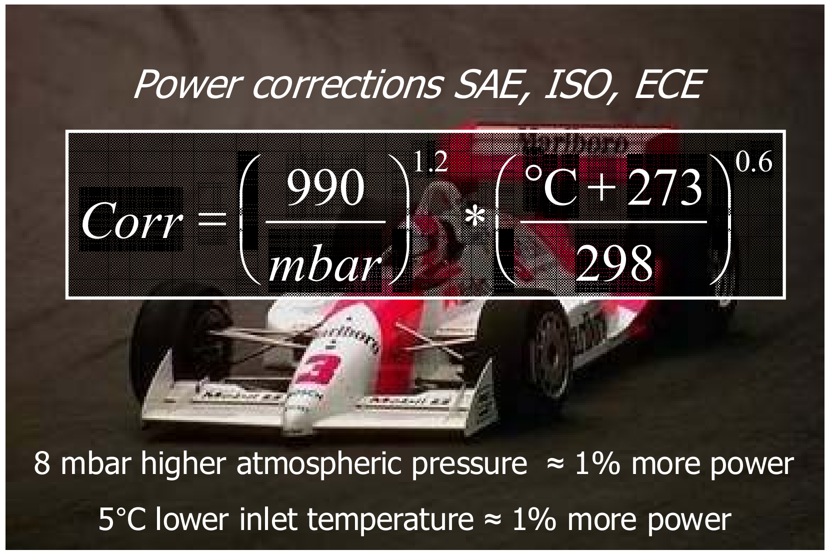
Test Conditions



Power corrections SAE, ISO, ECE

$$Corr = \left(\frac{990}{mbar}\right)^{1.2} * \left(\frac{°C + 273}{298}\right)^{0.6}$$

8 mbar higher atmospheric pressure ≈ 1% more power

5°C lower inlet temperature ≈ 1% more power

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Power output can be measured in two ways, at steady state or during acceleration. Both have benefits as well as drawbacks.

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Test & Measurements

Steady State — INFLUENCES — *Acceleration*

Steady State

- Cooling capacity
- Engine knocking problems
- General overheating problems (exhaust system, etc)

Acceleration

- Drive-train inertia (engine flywheel etc)
- Dynamic engine ECU control
- Turbo response
- Dynamic cam phasing & induction system

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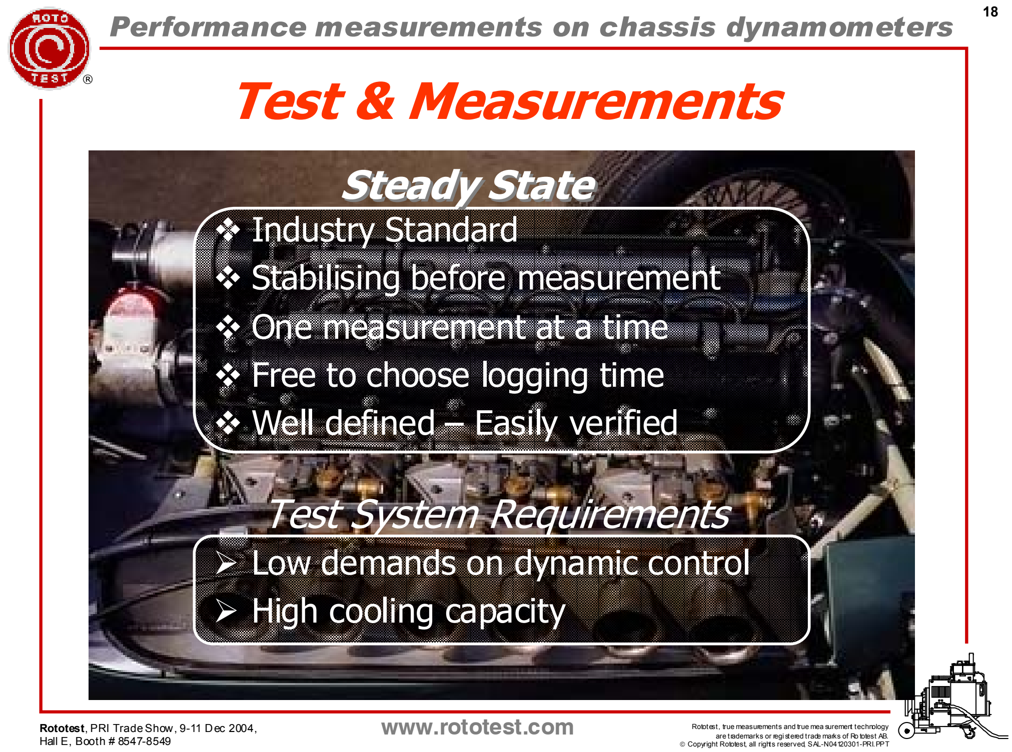
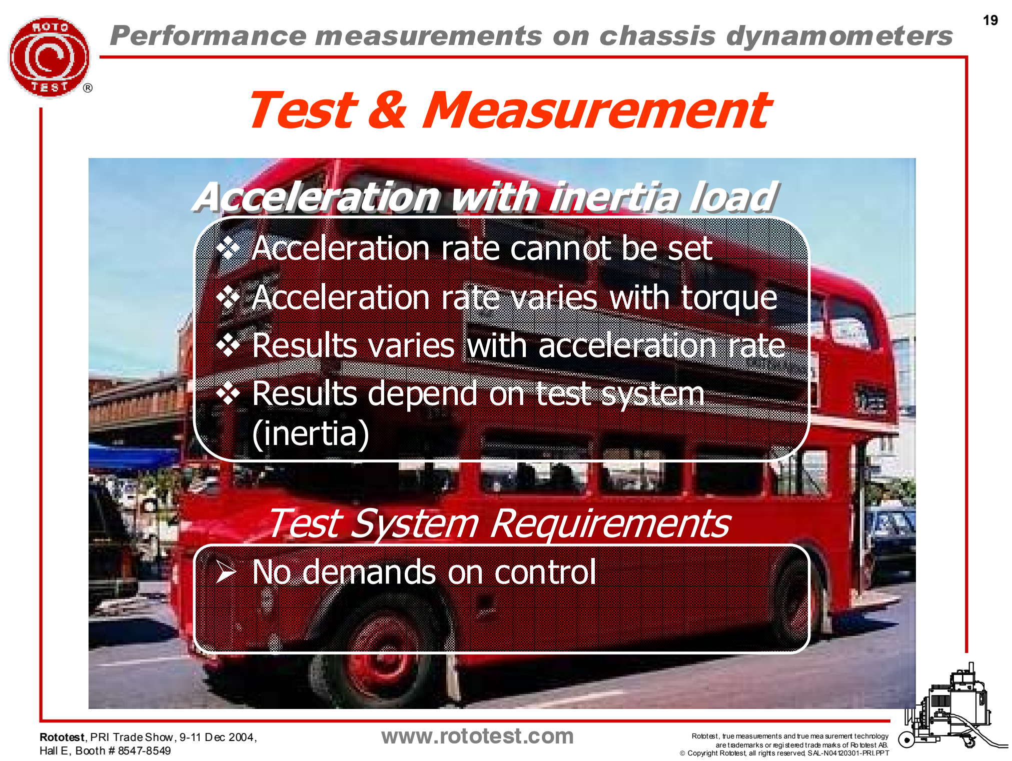
Car manufacturers are required to use steady state tests for certification of power output. It has an advantage as it is a well-defined test that is easy to repeat and verify. However, it demands a high cooling capacity for the engine / car.



The simplest way of testing is to let the engine / car accelerate against a fixed inertia load. Simple in one way most often means drawbacks in other ways. In this case it has numerous drawbacks, which affects the results. Also you are limited to just one type of test.



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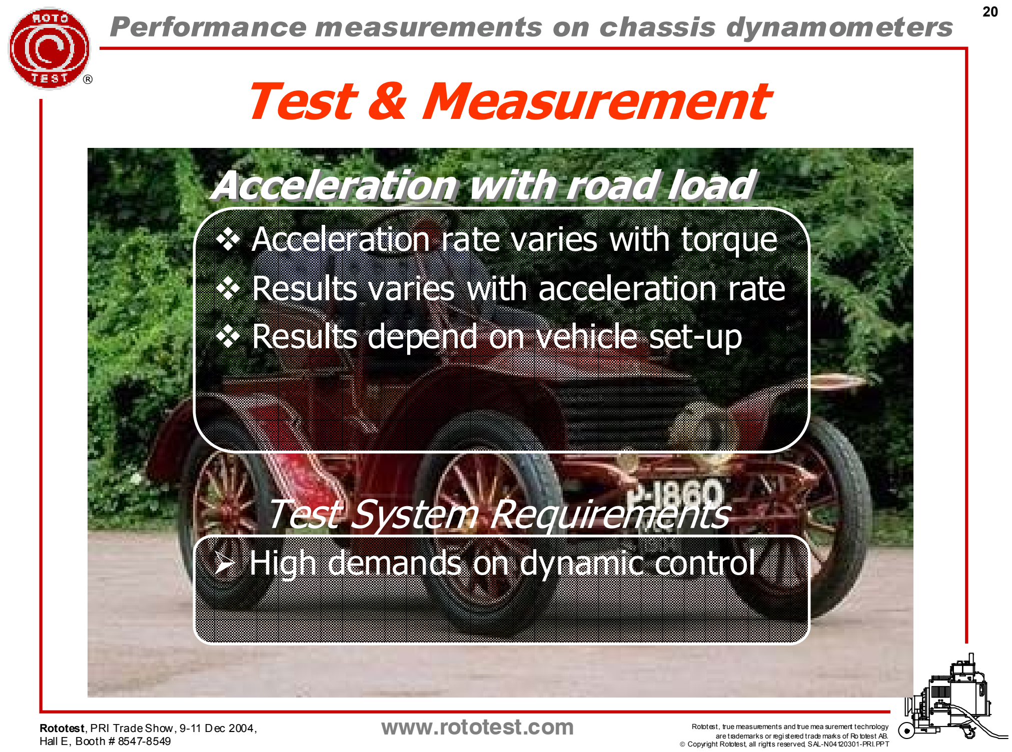
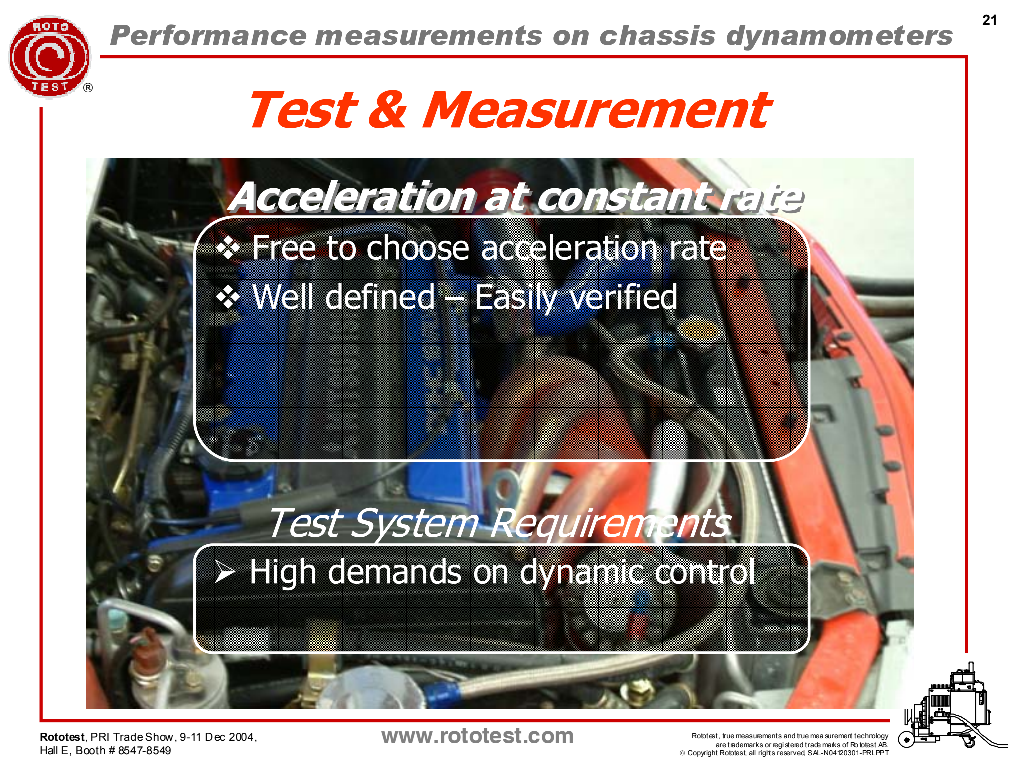
A more demanding test for the dyno is to accelerate against the road load. Then the dyno has to simulate running on the road. This can be good when tuning a specific car. However the result will be affected by the vehicle set-up. Changing the weight of the car will produce different power readings even if it is the same engine.



The problem with results measured during acceleration is that the acceleration itself has a considerable effect on the result. It is therefore important that the rate of acceleration is defined and controlled within tight tolerances. Only then can the test be repeated and verified.



Performance measurements on chassis dynamometers

As a professional you have to not only use quality tools but also use them in a professional way.

Test & Measurements

Minimum demands for professional performance measurement suppliers

- ✓ Power and torque must be presented with measured and corrected values.
- ✓ Correction method must be defined and used with caution.
- ✓ Testing must be performed with acceptable cooling of the test car.
- ✓ Calibration routines for measurement equipment must be present and documented.
- ✓ Performed measurements must be within an acceptable quality level, so that they can be controlled and repeated by others.

Vital information must be included with the measured data to assure a high level of quality.

Test & Measurements

Quality assurance information

- Inlet air temperature, measurement point
- Engine oil temperature
- Atmospheric pressure
- Relative air humidity
- (Turbo pressure)
- Fuel quality, octane no.

- Test system Make and Model
- Test type
  - Steady State (At every 200 [rpm], average during 10 [sec]).
  - Acceleration at constant rate (Acceleration rate 500 [rpm/sec], start and finish engine speed [rpm]).
  - Acceleration with road load (Mass of the car, rolling and air resistance).
  - Acceleration with inertia load (Used testing inertia).