

Dynamometer

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For the dynamometer used in railroading, see dynamometer car.

A **dynamometer** or "**dyno**" for short, is a device for measuring force or power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (rpm).

A dynamometer can also be used to determine the torque and power required to operate a driven machine such as a pump. In that case, a *motoring* or *driving* dynamometer is used. A dynamometer that is designed to be driven is called an *absorption* or *passive* dynamometer. A dynamometer that can either drive or absorb is called a *universal* or *active* dynamometer.

In addition to being used to determine the torque or power characteristics of a machine under test (MUT), dynamometers are employed in a number of other roles. In standard emissions testing cycles such as those defined by the US Environmental Protection Agency (US EPA), dynamometers are used to provide simulated road loading of either the engine (using an engine dynamometer) or full powertrain (using a chassis dynamometer). In fact, beyond simple power and torque measurements, dynamometers can be used as part of a testbed for a variety of engine development activities such as the calibration of engine management controllers, detailed investigations into combustion behavior and tribology.

In the medical realm, hand dynamometers are used for routine screening of grip strength and initial and ongoing evaluation of patients with hand trauma and dysfunction. They are also used to measure grip strength in patients where compromise of the cervical nerve roots or peripheral nerves is suspected. In the rehabilitation, kinesiology and ergonomics realms, dynamometers are used for measuring grip, arm and leg strength of athletes, patients and workers to evaluate performance, task demands and physical status.

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Principles of operation

An absorbing dynamometer acts as a load that is driven by the prime mover that is under test. The dynamometer must be able to operate at any speed, and load the prime mover to any level of torque that the test requires. A dynamometer is usually equipped with some means of measuring the operating torque and speed.

The dynamometer must absorb the power developed by the prime mover. The power absorbed by the dynamometer must generally be dissipated to the ambient air or transferred to cooling water. Regenerative dynamometers transfer the power to electrical power lines.

Dynamometers can be equipped with a variety of control systems. If the dynamometer has a torque regulator, it operates at a set torque while the prime mover operates at whatever speed it can attain while developing the torque that has been set. If the dynamometer has a speed regulator, it develops whatever torque is necessary to force the prime mover to operate at the set speed.

A motoring dynamometer acts as a motor that drives the equipment under test. It must be able to drive the equipment at any speed and develop any level of torque that the test requires.

In most dynamometers power (P) is not measured directly; it must be calculated from torque (τ) and angular velocity (ω) values or force (F) and linear velocity (v):

$$P = \tau \cdot \omega$$

or

$$P = F \cdot v$$

where

P is the power in watts

τ is the torque in newton metres

ω is the angular velocity in radians per second

F is the force in newtons

v is the linear velocity in metres per second

Division by a conversion constant may be required depending on the units of measure used.

For imperial units,

$$P_{\text{hp}} = \frac{\tau_{\text{lb-ft}} \cdot \omega_{\text{rpm}}}{5252}$$

where

P_{hp} is the power in horsepower

$\tau_{\text{lb-ft}}$ is the torque in pound-feet

ω_{rpm} is the rotational velocity in revolutions per minute

For metric units,

$$P_{\text{kW}} = \frac{\tau_{\text{N}\cdot\text{m}} \cdot \omega_{\text{rpm}}}{9549}$$

where

P_{kW} is the power in kilowatts

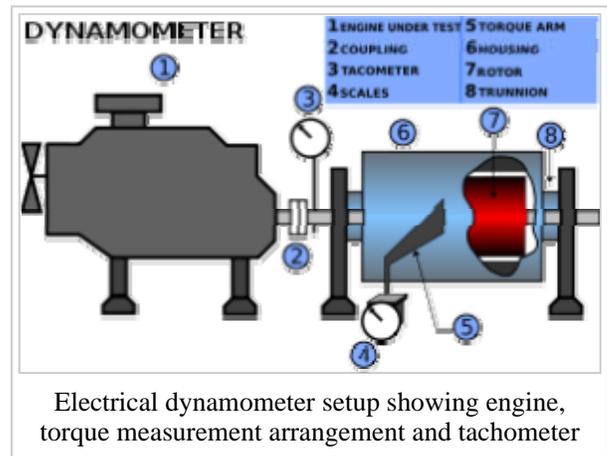
$\tau_{\text{N}\cdot\text{m}}$ is the torque in newton metres

ω_{rpm} is the rotational velocity in revolutions per minute

Detailed dynamometer description

A dynamometer consists of an absorption (or absorber/driver) unit, and usually includes a means for measuring torque and rotational speed. An absorption unit consists of some type of rotor in a housing. The rotor is coupled to the engine or other equipment under test and is free to rotate at whatever speed is required for the test. Some means is provided to develop a braking torque between dynamometer's rotor and housing. The means for developing torque can be frictional, hydraulic, electromagnetic etc. according to the type of absorption/driver unit.

One means for measuring torque is to mount the dynamometer housing so that it is free to turn except that it is restrained by a torque arm. The housing can be made free to rotate by using trunnions connected to each end of the housing to support the dyno in pedestal mounted trunnion bearings. The torque arm is connected to the dyno housing and a weighing scales is positioned so that it measures the force exerted by the dyno housing in attempting to rotate. The torque is the force indicated by the scales multiplied by the length of the torque arm measured from the center of the dynamometer. A load cell transducer can be substituted for the scales in order to provide an electrical signal that is proportional to torque.



Another means for measuring torque is to connect the engine to the dynamometer through a torque sensing coupling or torque transducer. A torque transducer provides an electrical signal that is proportional to torque.

With electrical absorption units, it is possible to determine torque by measuring the current drawn (or generated) by the absorber/driver. This is generally a less accurate method and not much practiced in modern time, but it may be adequate for some purposes.

A wide variety of tachometers are available for measuring speed. Some types can provide an electrical signal that is proportional to speed.

When torque and speed signals are available, test data can be transmitted to a data acquisition system rather than being recorded manually. Speed and torque signals can also be recorded by a chart recorder or plotter.

Types of dynamometers

In addition to classification as *Absorption*, *Motoring* or *Universal* as described above, dynamometers can be classified in other ways.

A dyno that is coupled directly to an engine is known as an *engine dyno*.

A dyno that can measure torque and power delivered by the power train of a vehicle directly from the drive wheel or wheels (without removing the engine from the frame of the vehicle), is known as a *chassis dyno*.

Dynamometers can also be classified by the type of absorption unit or absorber/driver that they use. Some units that are capable of absorption only can be combined with a motor to construct an absorber/driver or universal dynamometer. The following types of absorption/driver units have been used:

Types of absorption/driver units

- Eddy current or electromagnetic brake (absorption only)
- Magnetic Powder brake (absorption only)
- Hysteresis Brake (absorption only)
- Electric motor/generator (absorb or drive)
- Fan brake (absorption only)
- Hydraulic brake (absorption only)
- Mechanical friction brake or Prony brake (absorption only)
- Water brake (absorption only)

Eddy Current type absorber

EC dynamometers are currently the most common absorbers used in modern chassis dynos. The EC absorbers provide the quick load change rate for rapid load settling. Most are air cooled, but some are designed to require external water cooling systems.

Eddy current dynamometers require an electrically conductive core, shaft or disc, moving across a magnetic field to produce resistance to movement. Iron is a common material, but copper, aluminum and other conductive materials are usable.

In current (2009) applications, most EC brakes use cast iron discs, similar to vehicle disc brake rotors, and use variable electromagnets to change the magnetic field strength to control the amount of braking.

The electromagnet voltage is usually controlled by a computer, using changes in the magnetic field to match the power output being applied.

Sophisticated EC systems allow steady state and controlled acceleration rate operation.

Powder Dynamometer

A powder dynamometer is similar to an eddy current dynamometer, but a fine magnetic powder is placed in the air gap between the rotor and the coil. The resulting flux lines create "chains" of metal particulate which are constantly built and broken apart during rotation creating great torque. Powder dynamometers are typically limited to lower RPM due to heat dissipation issues.

Hysteresis Dynamometers

Hysteresis dynamometers, use a steel rotor that is moved through flux lines generated between magnetic pole pieces. This design, as in the usual "disc type" eddy current absorbers, allows for full torque to be produced at zero speed, as well as at full speed. Heat dissipation is assisted by forced air. Hysteresis and "disc type" EC dynamometers are one of the most efficient technologies in small (200 hp (150 kW) and less) dynamometers. A hysteresis brake is an eddy current absorber which, unlike most "disc type" eddy

current absorbers, puts the electromagnet coils inside a vented and ribbed cylinder and rotates the cylinder, instead of rotating a disc between electromagnets. The potential benefit for the hysteresis absorber is that the diameter can be decreased and operating rpm of the absorber may be increased.

Electric motor/generator dynamometer

Electric motor/generator dynamometers are a specialized type of adjustable-speed drives. The absorption/driver unit can be either an alternating current (AC) motor or a direct current (DC) motor. Either an AC motor or a DC motor can operate as a generator which is driven by the unit under test or a motor which drives the unit under test. When equipped with appropriate control units, electric motor/generator dynamometers can be configured as universal dynamometers. The control unit for an AC motor is a variable-frequency drive and the control unit for a DC motor is a DC drive. In both cases, regenerative control units can transfer power from the unit under test to the electric utility. Where permitted, the operator of the dynamometer can receive payment (or credit) from the utility for the returned power.

In engine testing, universal dynamometers can not only absorb the power of the engine but also, drive the engine for measuring friction, pumping losses and other factors.

Electric motor/generator dynamometers are generally more costly and complex than other types of dynamometers.

Fan Brake

A fan is used to blow air to provide engine load. Changing gearing or fan or simply measuring the max rpm attained.

Hydraulic brake

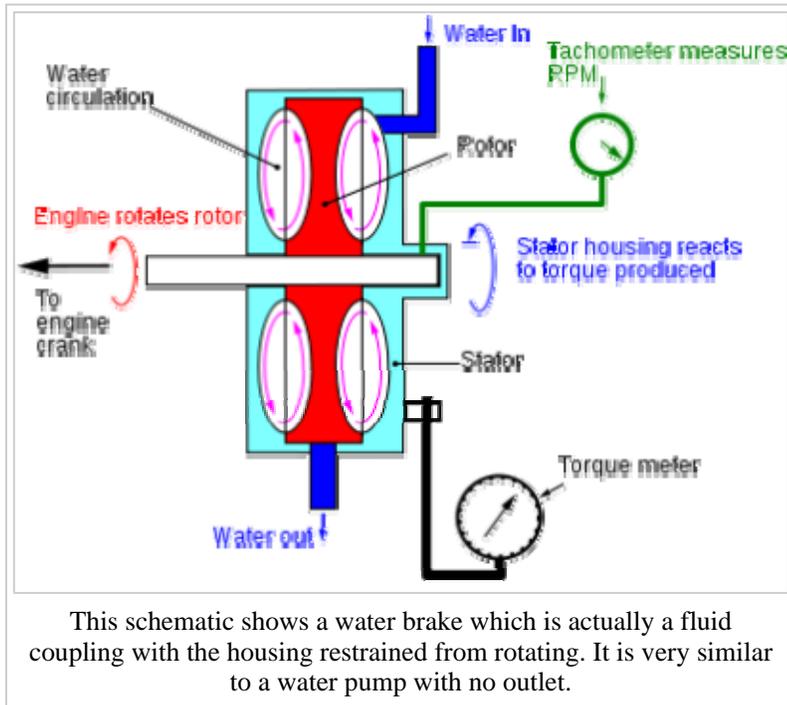
The hydraulic brake system consists of a hydraulic pump (usually a gear type pump), a fluid reservoir and piping between the two parts. Inserted in the piping is an adjustable valve and between the pump and the valve is a gauge or other means of measuring hydraulic pressure. Usually, the fluid used was hydraulic oil, but recent synthetic multi-grade oils may be a better choice. In simplest terms, the engine is brought up to the desired rpm and the valve is incrementally closed and as the pumps outlet is restricted, the load increases and the throttle is simply opened until at the desired throttle opening. Unlike most other systems, power is calculated by factoring flow volume (calculated from pump design specs), hydraulic pressure and rpm. Brake HP, whether figured with pressure, volume and rpm or with a different load cell type brake dyno, should produce essentially identical power figures. Hydraulic dynos are renowned for having the absolutely quickest load change ability, just slightly surpassing the eddy current absorbers. The downside is that they require large quantities of hot oil under high pressure and the requirement for an oil reservoir.

Water brake type absorber

The water brake absorber is sometimes mistakenly called a "hydraulic dynamometer". Water brake absorbers are relatively common, having been manufactured for many years and noted for their high power capability, small package, light weight, and relatively low manufacturing cost as compared to other, quicker reacting "power absorber" types. Their drawbacks are that they can take a relatively long period of time to "stabilize" their load amount and the fact that they require a constant supply of water to the "water brake housing" for cooling. In many parts of the country, environmental regulations now prohibit "flow through" water and large water tanks must be installed to prevent contaminated water from entering the environment.

The schematic shows the most common type of water brake, the variable level type. Water is added until the engine is held at a steady rpm against the load. Water is then kept at that level and replaced by constant

draining and refilling, which is needed to carry away the heat created by absorbing the horsepower. The housing attempts to rotate in response to the torque produced but is restrained by the scale or torque metering cell which measures the torque.



How dynamometers are used for engine testing

Dynamometers are useful in the development and refinement of modern day engine technology. The concept is to use a dynamometer to measure and compare power transfer at different points on a vehicle, thus allowing the engine or drivetrain to be modified to get more efficient power transfer. For example, if an engine dynamometer shows that a particular engine achieves 400 N·m (300 lbf·ft) of torque, and a chassis dynamometer shows only 350 N·m (260 lbf·ft), one would know to look to the drivetrain for the major improvements. Dynamometers are typically very expensive pieces of equipment, reserved for certain fields that rely on them for a particular purpose.

General testing methods with types of dynamometer systems

A **Brake** dynamometer applies variable load on the engine and measures the engine's ability to move or hold the rpm as related to the "braking force" applied. It is usually connected to a computer which records the applied braking torque and calculates the power output of the engine based on information from a "load cell" or "strain gauge" and rpm (speed sensor).

An **Inertia** dynamometer provides a fixed inertial mass load and calculates the power required to accelerate that fixed, known mass and uses a computer to record rpm and acc. rate to calculate torque.

The engine is generally tested from somewhat above idle to its maximum rpm and the output is measured and plotted on a graph.

There are essentially only 2 types of dynamometer test procedures:

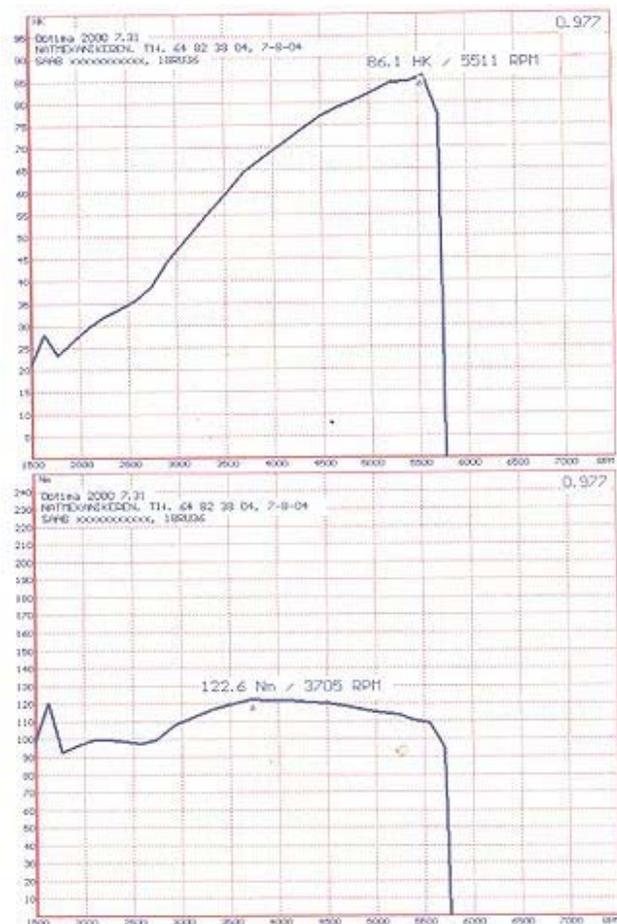
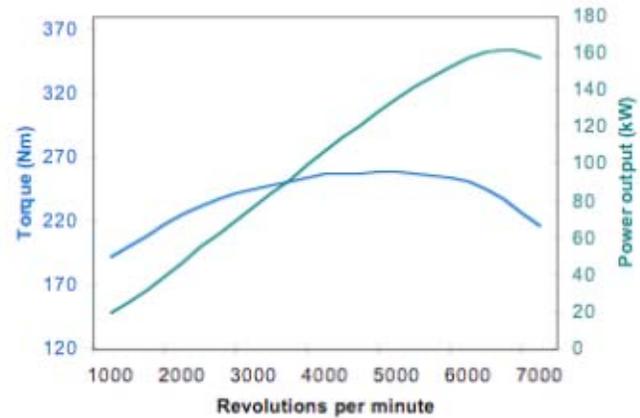
1. Steady State (only on brake dynamometers), where the engine is held at a specified rpm (or series of

usually sequential rpms) for 3–5 seconds by the variable brake loading as provided by the PAU (power absorber unit).

2. Sweep Test (inertia or brake dynamometers), where the engine is tested under a load (inertia or brake loading), but allowed to "sweep" up in rpm in a continuous fashion, from a specified lower "starting" rpm to a specified "end" rpm.

Types of Sweep Tests:

1. Inertia Sweep: An inertia dyno system that provides a fixed inertial mass flywheel and computes the power required to accelerate the flywheel (load) from the starting to the ending rpm. The actual rotational mass of the engine or engine and vehicle in the case of a chassis dyno is not known and the variability of even tire mass will skew power results. The inertia value of the flywheel is "fixed", so low power engines are under load for a much longer time and internal engine temperatures are usually too high by the end of the test, skewing optimal "dyno" tuning settings away from the outside world's optimal tuning settings. Conversely, high powered engines, commonly complete a common "4th gear sweep" test in less than 10 seconds, which is not a reliable load condition as compared to operation in the outside world. By not providing enough time under load, internal combustion chamber temps are unrealistically low and power readings, especially past the power peak, are skewed low.
2. Loaded Sweep Tests (brake dyno type) consist of 2 types:
 1. Simple fixed Load Sweep Test: A fixed load, of somewhat less than the engine's output, is applied during the test. The engine is allowed to accelerate from its starting rpm to its ending rpm, varying in its acceleration rate, depending on power output at any particular rpm point Power is calculated using $\text{torque} \times \text{rpm} / 5252$ + the power required to accelerate the dyno and engine's / vehicle's rotating mass.
 2. Controlled Acceleration Sweep Test: Similar in basic usage as the above Simple fixed Load Sweep Test, but with the addition of active load control that targets a specific rate of acceleration. Commonly, 20fps/ps is used.



The advantage of controlled acc. rate is that the acc. rate used is relatively common from low power to high power engines and unnatural overextension and contraction of "test duration duration" is avoided, providing more accurate and repeatable test and tuning results.

There is still the remaining issue of potential power reading error due to the variable engine / dyno / vehicle's total rotating mass. Most modern computer controlled brake dyno systems are capable of deriving that "inertial mass" value to eliminate the error.

Interestingly, A "sweep test" will always be suspect, as many "sweep" users ignore the inertial mass factor and prefer to use a blanket "factor" on every test, on every engine or vehicle. Inertia dyne systems aren't capable of deriving "inertial mass" and are forced to use the same inertial mass.

Using Steady State testing eliminates the inertial mass error, as there is no acceleration during a test.

Engine dynamometer

An engine dynamometer measures power and torque directly from the engine's crankshaft (or flywheel), when the engine is removed from the vehicle. These dynos do not account for power losses in the drivetrain, such as the gearbox, transmission or differential etc.



HORIBA engine dynamometer TITAN

Chassis dynamometer

A chassis dynamometer measures power delivered to the surface of the "drive roller" by the drive wheels. The vehicle is often parked on the roller or rollers, which the car then turns and the output is measured.

Modern roller type chassis dyne systems use the Salvisberg roller,^[1] which improved traction and repeatability over smooth or knurled drive rollers.

On a motorcycle, typical power loss at higher power levels, mostly through tire flex, is about 10% and gearbox chain and other power transferring parts are another 2% to 5%.



Saab 96 on chassis dynamometer

Other types of chassis dynamometers are available that eliminate the potential wheel slippage on old style drive rollers and attach directly to the vehicle's hubs for direct torque measurement from the axle. Hub mounted dynos include units made by Dynapack and Rototest.

Chassis dynos can be fixed or portable.

Modern chassis dynamometers can do much more than display RPM, horsepower, and torque. With modern electronics and quick reacting, low inertia dyne systems, it is now possible to tune to best power and the smoothest runs, in realtime.

In retail settings it is also common to "tune the air fuel ratio" , using a wideband oxygen sensor which is graphed along with RPM.

Some, like Dynojet and others, can also add vehicle diagnostic information to the dyno graph as well. This is done by gathering data directly from the vehicle using on-board diagnostics communication.^[2]

Because of frictional and mechanical losses in the various drivetrain components, the measured rear wheel brake horsepower is generally 15-20 percent less than the brake horsepower measured at the crankshaft or flywheel on an engine dynamometer.^[3] Other sources, after researching several different "engine" dyno software packages, found that the engine dyno user can integrally add "frictional loss" channel factors of +10% to +15% to the flywheel power, raising the claim that 20% to 25% or even more power is actually lost between the crankshaft at high power outputs.

Common misconceptions about dynos

Drag racing: Horsepower and torque figures are a strong predictor but do not guarantee a specific 0-60 mph or 1/4 mile elapsed time (ET). An engine accelerating in a vehicle experiences different conditions than on a dyno. G forces and different temperatures as well as different modes of vibration in a vehicle can cause significant differences in power output.

When attempting to crosscheck dynamometer power figures to drag strip performance, it is relatively consistent to compare improved brake hp figures to terminal MPH.

Engine damage: Can dyno testing damage engines? A brake dyno, in steady state mode only provides a load that is equal the amount of power that the engine is making at any specifically selected rpm point. If the engine makes 200 brake HP at 5000 rpm, the dynamometer's brake or power absorber will provide exactly 200 hp (150 kW) of load against it, keeping the RPM at 5000 rpm. That's a realistic load, it's as if the engine was in a vehicle pulling a large trailer up a hill. Should be no problem on the dyno - if there's no problem on the road. However, the apprehension over dyno testing and engine damage does have solid roots in fact. Old style dynamometers commonly used an inexpensive water brake type of power absorber. Load was increased or decreased by filling and draining water in the housing to change the amount of internal water volume to change the load, all the while draining and refilling the water to keep the water from boiling - It would sometimes take quite some time for the operator or computer to get inflow and outflow rates stabilized and that is the problem. It's not the "amount" of load, it's the amount of "time" spent trying to stabilize the load at the desired rpm.

Water brakes are still commonly used in applications where their small size and light weight are important and engine torque curves are relatively straight, as in large automotive and boats.

History

Gaspard de Prony invented the de Prony brake in 1821. The de Prony brake (or Prony brake) is considered to be one of the earliest dynamometers.

Froude Hofmann of Worcester, UK, manufactures engine and vehicle dynamometers. They credit William

Froude with the invention of the hydraulic dynamometer in 1877 and say that the first commercial dynamometers were produced in 1881 by their predecessor company, Heenan & Froude.

In 1928, the German company "*Carl Schenck Eisengießerei & Waagenfabrik*" built the first vehicle dynamometers for brake tests with the basic design of the today's vehicle test stands.

The eddy current dynamometer was invented by Martin and Anthony Winther in about 1931. At that time, DC Motor/generator dynamometers had been in use for many years. A company founded by the Winthers, Dynamatic Corporation, manufactured dynamometers in Kenosha, Wisconsin until 2002. Dynamatic was part of Eaton Corporation from 1946 to 1995. In 2002, Dyne Systems of Jackson, Wisconsin acquired the Dynamatic dynamometer product line. Starting in 1938, Heenan and Froude manufactured eddy current dynamometers for many years under license from Dynamatic and Eaton.^[4]

See also

- Dynamometer car for railroad usage
- Engine test stand dynamometer for engines, e.g. combustion engines
- Hand strength dynamometer

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External links

- Automobile Road Dyno Measuring horsepower and torque while driving.
- Froude Hofmann - Re: history of hydraulic the dynamometer
- Concept2 for a manufacturer of dynameters designed for measuring leg press, arm pull, and chest press of athletes.
- Dynos Explained Sport Rider Magazine: How chassis dynamometers work with Marc Salvisberg of Factory Pro Dynamometer
- Power Dynamometers Resource for main power dynamometers types explained

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