Agilent

Small Engine Dynamometer Testing

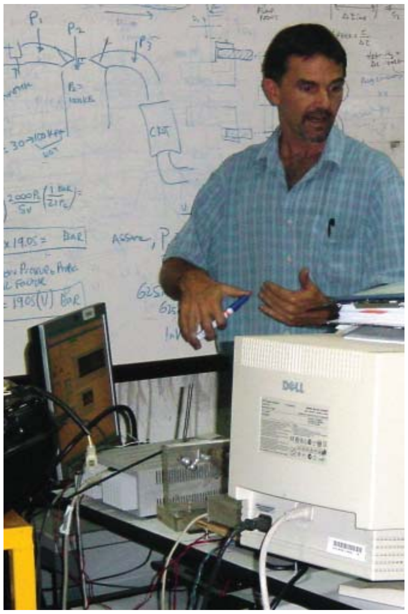
Performing Dynamometer Testing on Combustion Engines

Application Note

Dr. Gitano Horizon
University Science Malaysia

Agilent Technologies

About the Author



Dr. Horizon worked at Seagate R&D centers in the US and factories around the world including Mexico, Singapore, Malaysia, Thailand, and China (1992 – 2001). Since 2001 he has been working as a consultant focusing on controls and mechatronics systems. He was a lecturer at Colorado State University (2002 – 2004) and has been a professor at the University Science Malaysia since 2006. Dr. Horizon also founded a consulting company, called the Focus Applied Technologies Sdn. Bhd. in 2008 as a university technology spinoff company.

Areas of specialization: mechanics, dynamics, mechatronics, internal combustion engines, microcontroller applications

For full biodata, visit http://www.skyshorz.com/personal/bio.php

Measuring Engine Performance with Agilent USB DAQ Modules

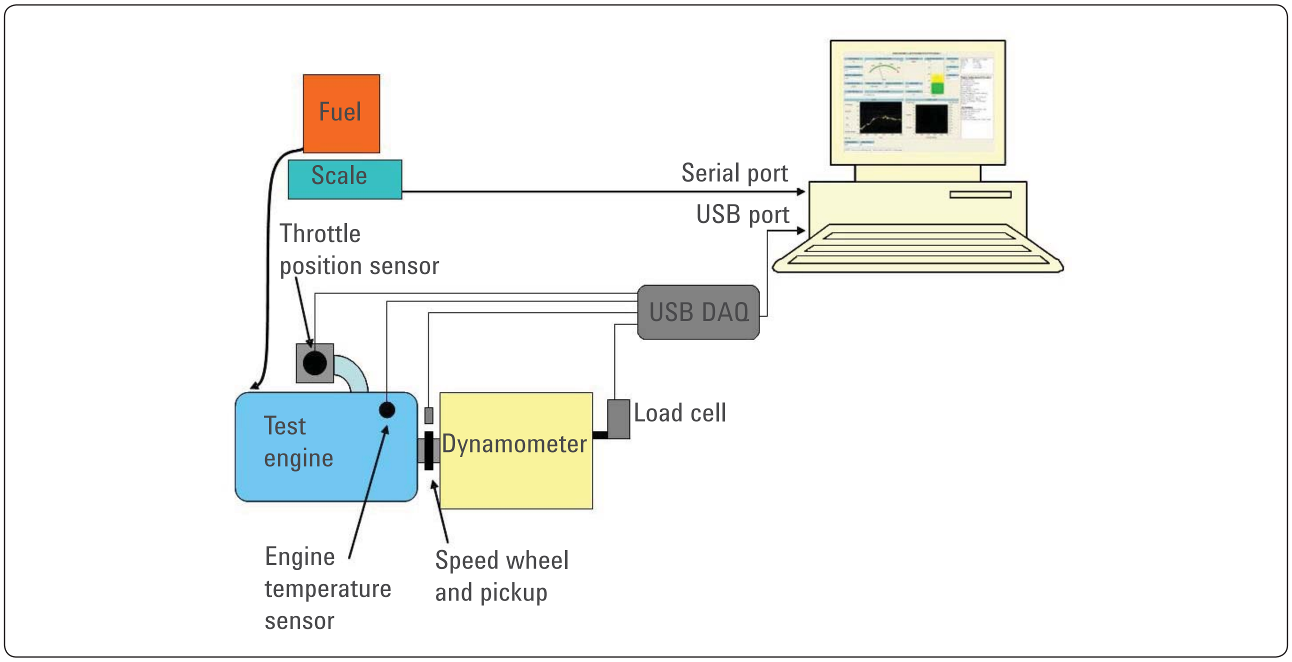


Figure 1. Schematic overview of test system

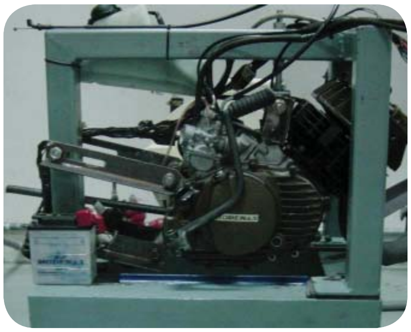


Figure 2. Motorcycle engine mounted for testing

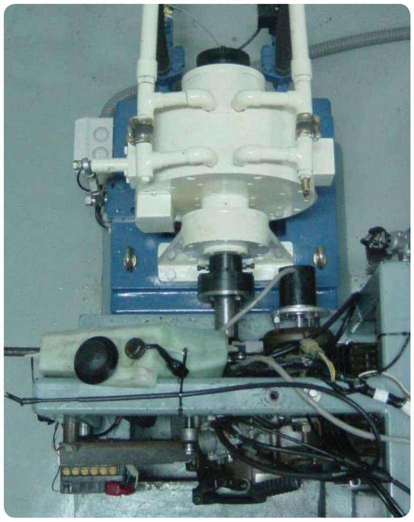


Figure 3. Top view of dynamometer (top) and engine (lower half)

Testing of engine performance is often important in the development of engine and fuel technologies. Many parameters affect an engine's performance: the basic engine design, compression ratio, valve timing, ignition timing, fuel, lubricant, and temperature.

The most critical factor governing an engine's power, fuel consumption and emissions is the amount of fuel consumed relative to the amount of air ingested. This is expressed as the air/fuel ratio; that is, the mass of air used divided by the mass of fuel burned. Larger engines typically have computer-controlled fuel injection governing the air/fuel ratio while smaller engines still use carburetors for controlling the air/fuel ratio. Proper tuning of an engine's carburetor requires careful measurements of torque, speed, temperature, and fuel consumption as a function of throttle position. Agilent USB data acquisition (DAQ) modules provide an inexpensive, flexible solution for engine testing.

To test engine performance in the laboratory, the engine is coupled to a dynamometer, which may be either an engine dynamometer (connected directly to the engine output shaft) or a chassis dynamometer (connected to the drive wheels). The dynamometer, which provides a load to the engine, can be easily controlled to allow testing under a wide range of speeds and torque.

Overview of Key Measurements

The most critical performance measurements are output torque and speed. The engine's brake power (output power) is determined from the engine speed and torque using the following equation:

$$P_b = T * \omega$$

P_b is brake power in watts
T is shaft torque in Nm
ω is shaft rotational speed in rad/sec

Figure 4. Speed wheel (top) and pickup (below)

Speed is measured with a pickup that monitors the spinning dynamometer. Typically, a toothed steel wheel is placed on the shaft and an inductive pickup is placed close enough to the wheel such that it generates pulses as the teeth pass by. This time-based pulse signal is analyzed in order to measure the period between pulses and converted to frequency. Shaft speed is directly proportional to the measured frequency. If the engine output is taken directly from the crankshaft, then the dynamometer shaft speed equals the engine speed. If the output shaft is geared (with respect to the engine speed), then the dynamometer speed must be multiplied by the gearing ratio to determine the engine speed.

Torque is measured by attaching a load cell (force transducer) to the dynamometer housing. The load cell strains slightly with applied load, and the strain is measured using strain gages connected to a preamplifier that outputs a voltage proportional to the load. In accordance with Newton's first law, the measured torque on the dynamometer housing equals to the torque on the dynamometer shaft.

Figure 5. TPS pot (right) and throttle linkage (left)

Another useful parameter to measure is the throttle position. Many fuel-injected vehicles include a throttle position sensor (TPS) that relays the throttle position to the electronic control unit (ECU) of the fuel-injection system. The TPS is basically a potentiometer configured as a voltage divider that rotates with the throttle. For carburetted engines, a TPS can easily be added to the throttle linkage, allowing direct measurement of throttle position.

Generally, a controller provides servo control of the load in order to maintain constant speed or torque. A typical test might first set the dynamometer controller to a specific speed and then measure torque variation as a function of throttle setting. Alternatively, the throttle may remain fixed (for example, wide open) and the speed control set point varied. The resulting speed and torque values are measured, and power is calculated i.e., speed times torque.

Figure 6. Controller in the foreground, engine and dynamometer behind

During testing, important parameters such as fuel consumption, exhaust emissions, and air flow may also be measured. These provide quantitative measures of how efficiently an engine is running. Several temperatures, such as exhaust gas temperature, lubricant temperature, and cylinder head temperature, may also be worth measuring. The temperature measurements are useful in determining if the engine is being operated safely or is overheated. Often, engine parameters such as air/fuel ratio vary from test to test and the resulting effects on fuel consumption, overall efficiency, or power are measured.

This type of testing requires fairly low data-rate measurements because all variables are averaged over several engine cycles. Data acquired in this manner are referred to as "cycle-average data." Relatively slowly changing values, such as engine speed, fuel flow, engine temperature, and manifold pressure, are measured directly. Torque fluctuates over the cycle of an engine, being highest during the power stroke and lowest during the compression stroke. Fluctuating signals may be filtered electronically to remove this higher-frequency variation, and various digital techniques (such as exponential averaging) may also be applied once the data has been acquired.

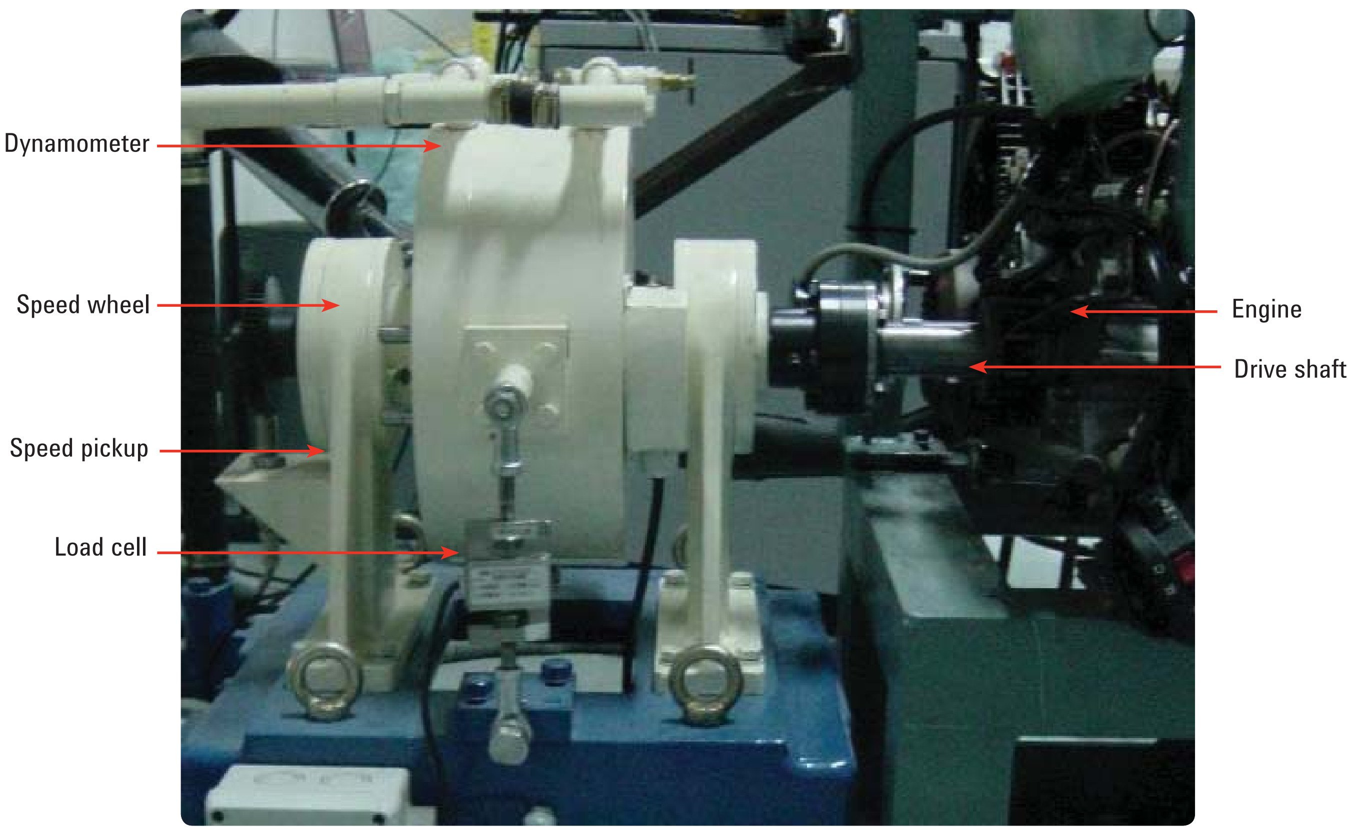


Figure 7. Side view of dynamometer and engine

The Measurement System

Given the volume of data and the number of real-time calculations required, a computer-controlled data acquisition (DAQ) system is generally used to calculate, display, and archive test data from tests. Agilent DAQ modules devices such as the U2355A multifunction DAQ module and U2802A 31-channel thermocouple input module are good examples. When used together, these devices are especially helpful in engine testing that requires measurements of speed, torque, throttle position, and temperature of cylinder and exhaust.

The speed, torque, and throttle position signals are measured using the analog input ports of the U2355A. Shaft speed is calculated from the period of the sinusoidal speed using the formula:

Speed = 60 / (n * T)

Speed is shaft speed in RPM
T is the period of the sine wave
n is the number of teeth on the speed wheel

Depending on the engine characteristics, this speed value may fluctuate based on the timing of each sample acquisition. For example, a single-cylinder engine will slow down significantly during compression and speed up during the expansion or power stroke. To reduce this fluctuation, it is common to perform an exponential average of the calculated speed value. A simple way to implement exponential averaging is to declare the averaged value equal to a weighting factor times the current value, then add one minus the weighing factor times the previous averaged value. In a scripted language this might be represented by the following statement.

AverageSpeed = Speed * 0.1 + PreviousAverage * 0.9
PreviousAverage = AverageSpeed

The torque value — minus an offset or zero level — can be multiplied by a calibration factor, as follows:

Torq = (TorqVoltage – VoltageOffset) * NmperVolt

Torq is the value of the shaft torque in Nm
TorqVoltage is the voltage read from the load cell
VoltageOffset is the “no load” torque reading
NmperVolt is the calibration factor in Nm per volt

Using Agilent’s VEE programming language, we can perform both a linear calibration of the TPS and an exponential average (Figure 8). In this case, the current TPS voltage is multiplied by 60 percent and added to the previous value (from the shift register), which is multiplied by 40 percent. This effectively yields an exponential average of the TPS voltage, thereby reducing the influence of electronic noise and high-frequency variations in the signal. The results are then sent to the TPC calibration formula, where they are linearly interpolated between the high and low TPS calibration levels. The result is given as a percentage of full throttle: zero percent when the throttle is closed and 100 percent when it is wide open.

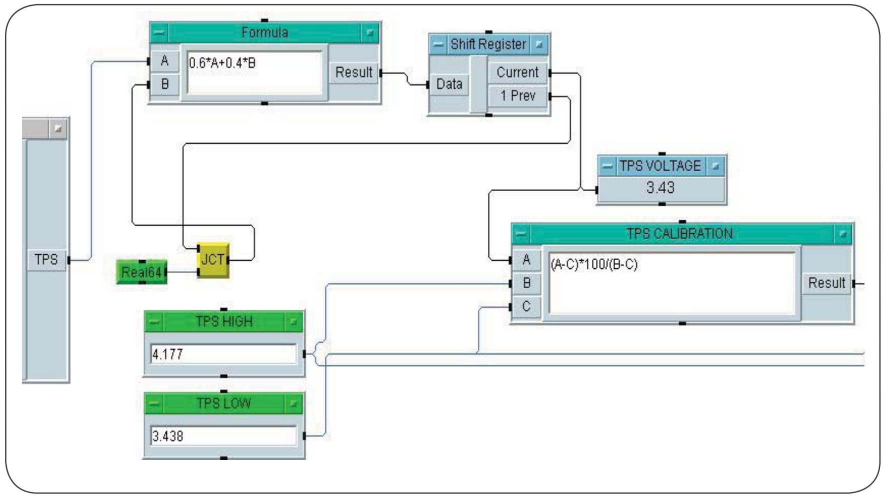


Figure 8. Exponential averaging and linear calibration of TPS value

The torque value can also be exponentially averaged, as with the speed value. Power may then be calculated from the measured speed and torque values:

Power = Torq * AverageSpeed * 6.28 / 60

Power is the shaft power in watts
6.28 / 60 converts the speed from RPM to radians/sec

Fuel consumption is generally calculated based on changes in the weight of the fuel tank over a given period of time (for example, one minute). Precision scales can be used to report the weight of a fuel tank through a serial port. The scale weight can be polled for the initial fuel tank weight and then polled again later after the running engine has consumed part of the fuel. The fuel consumption is then computed as follows:

FuelConsumption = (Weight1 – Weight2) / FuelPeriod

FuelConsumption is the fuel consumption rate in gm/sec
Weight1 is the initial reported fuel scale weight in grams
Weight2 is the reported fuel scale weight after time FuelPeriod
FuelPeriod is the time between the two weight readings in seconds

Once the data has been properly calculated, the results are presented in numerical and graphical forms on a computer display. The data is also saved to a data file for later analysis.

Several temperatures are generally monitored during testing. For example, lubricant temperature is monitored to ensure that the engine has achieved normal operating temperature. If the lubricant is too cold, engine friction will be unusually high, adversely affecting power and fuel-efficiency measurements. Another example is cylinder-head temperature, which is especially crucial during high-power operation. Running with a high air/fuel ratio (for example, too little fuel for complete combustion of the oxygen present in the air) is referred to as lean operation. While lean operation is desirable at low loads, as it is cleaner and more efficient, it can rapidly overheat and destroy an engine at high loads. Therefore, it is important to monitor the cylinder-head temperature at high power conditions to ensure that the temperature is low enough to avoid engine destruction.

Previously, either a dedicated thermocouple reader was required, or a special amplifier was needed. With the Agilent U2802A, however, we can now read thermocouples directly, greatly simplifying the system.

Sample data and screen shots

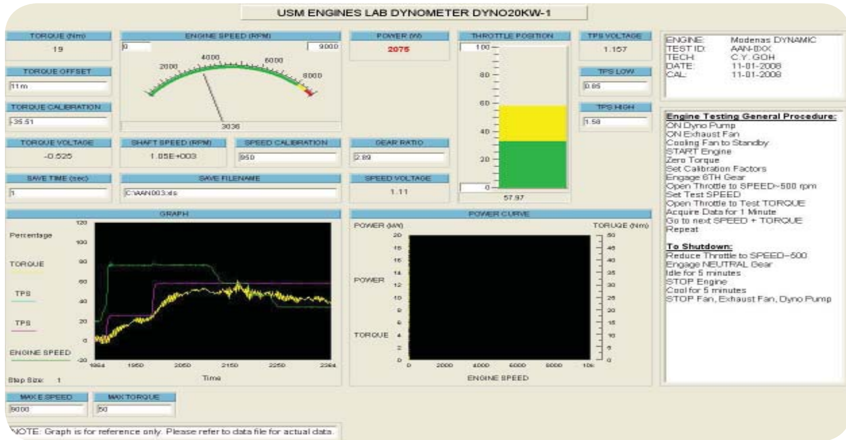


Figure 9. Computer screen with Agilent VEE front panel during engine testing

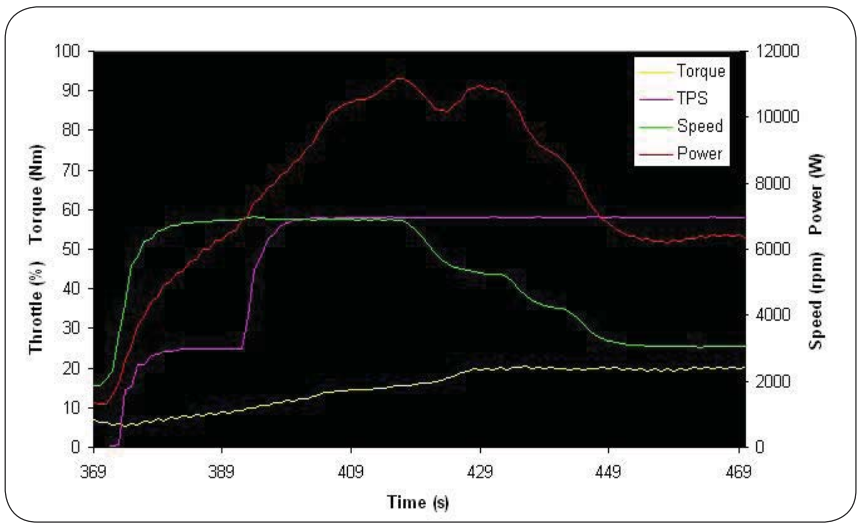


Figure 10. Post-processed data (from run shown above) with power calculated

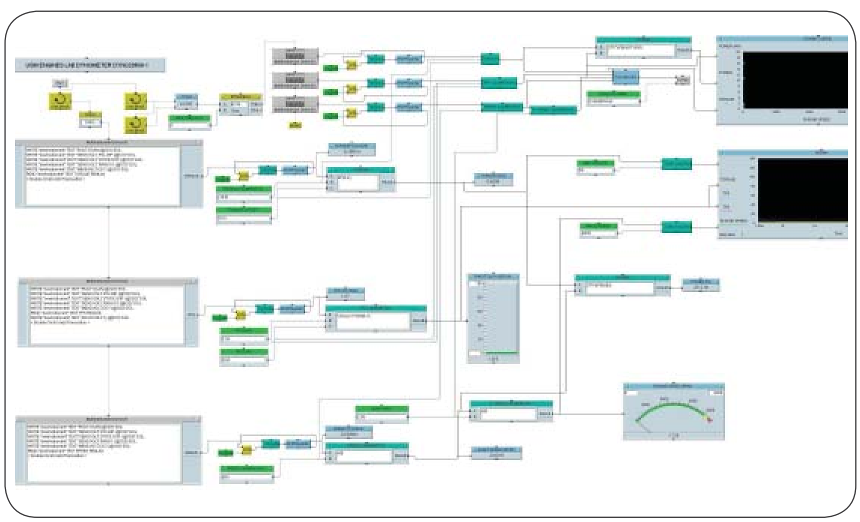


Figure 11. Agilent VEE 8.5 program used during engine testing

The Testing Sequence

A typical test will consist of running the engine at a number of speeds and loads under varied engine conditions. For example, when investigating the effect of carburetor tuning, it is important to test at both high and low speeds and high and low throttle settings. Table 1 shows an example set of test points.

Table 1. Example test conditions

Speed (rpm)	Torque (Nm)	Power (W)
1500	1	157
1500	8	1257
2500	4	1047
2500	8	2094
4000	5	2094
4000	12	5027
6000	10	6283

At each test point, the system software sets the dynamometer speed and then opens the throttle until the desired torque is achieved. The engine is then operated at the desired condition long enough to consume a significant amount of fuel. This generally takes one or two minutes, which is enough time to obtain results from exhaust-gas emissions analysis. Once the test point is finished, the system proceeds to the next test point. Once all of the test points have been run, carburetor tuning may be adjusted and a new test performed using the entire set of test points.

Trends in fuel consumption, emissions, or engine temperature can then be seen as a function of the carburetor settings, making it possible to determine the optimum settings. Sample results from an example study are shown in Figure 12.

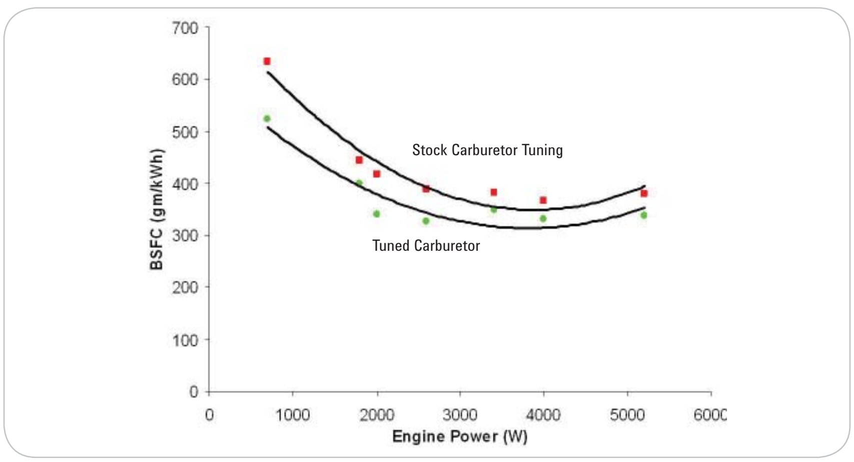


Figure 12. Brake-specific fuel consumption vs. engine power for stock and tuned carburetor

Offline Analysis

Often, it may be useful or necessary to calculate other factors at a later time. Examples include overall thermal efficiency of the engine, the brake specific fuel consumption, and the brake mean effective pressure.

The overall fuel conversion efficiency, ηt, (sometimes called brake thermal efficiency), is the power output divided by the chemical energy of the fuel consumed. Chemical energy of the fuel can be calculated by multiplying the mass consumed per unit time (for example, **FuelConsumption** mentioned previously) times the heating value (the chemical energy, typically approximately 42 kJ/gram for hydrocarbon fuels) of the fuel Q_{lhv}:

$$\eta t = P_b \,/\, (\,\text{FuelConsumption} * Q_{lhv})$$

A convenient way to compare engines of different sizes is through brake-specific fuel consumption (BSFC), which is the fuel consumption rate divided by the power output:

$$BSFC = \text{FuelConsumption} \,/\, P_b$$

Finally, a common measure of an engine's power density is the brake mean effective pressure (BMEP), which is calculated from the brake power divided by the engine's displacement volume times the engine speed. One additional factor is the number of revolutions per power stroke. This factor, denoted n, is 2 for four-stroke engines and 1 for two-stroke engines:

$$BMEP = P_b * n \,/\, (\,Vd * Speed \,/\, 60\,)$$

BMEP is the brake mean effective pressure in Pascals
n is the number of revolutions per power stroke
Vd is the displacement of the engine in m^3
Speed is the engine speed in RPM

Conclusion

Given the world's limited petroleum resources and the growing concern over environmental issues, it is important and beneficial to tune engines to ensure the proper balance of power, fuel consumption, and emissions. Agilent USB DAQ modules such as the U2802A and the U2355A allow rapid development of flexible systems capable of measuring the various parameters required for proper engine tuning. These systems also have the added advantage of simultaneously receiving data from other sources such as serial devices. Finally, the U2802A has the ability to directly read thermocouples, simplifying system design and helping ensure safe operation of the engine under test. This provides an excellent solution for seamless integration into existing engine dynamometer test beds.

Agilent Email Updates

www.agilent.com/find/emailupdates
Get the latest information on the products and applications you select.

Agilent Direct

www.agilent.com/find/agilentdirect
Quickly choose and use your test equipment solutions with confidence.

Agilent Open

www.agilent.com/find/open
Agilent Open simplifies the process of connecting and programming test systems to help engineers design, validate and manufacture electronic products. Agilent offers open connectivity for a broad range of system-ready instruments, open industry software, PC-standard I/O and global support, which are combined to more easily integrate test system development.

Remove all doubt

Our repair and calibration services will get your equipment back to you, performing like new, when promised. You will get full value out of your Agilent equipment throughout its lifetime. Your equipment will be serviced by Agilent-trained technicians using the latest factory calibration procedures, automated repair diagnostics and genuine parts. You will always have the utmost confidence in your measurements.

Agilent offers a wide range of additional expert test and measurement services for your equipment, including initial start-up assistance, onsite education and training, as well as design, system integration, and project management.

For more information on repair and calibration services, go to:

www.agilent.com/find/removealldoubt

www.agilent.com

For more information on Agilent Technologies' products, applications or services, please contact your local Agilent office. The complete list is available at:

www.agilent.com/find/contactus

Americas

Canada	(877) 894-4414
Latin America	305 269 7500
United States	(800) 829-4444

Asia Pacific

Australia	1 800 629 485
China	800 810 0189
Hong Kong	800 938 693
India	1 800 112 929
Japan	0120 (421) 345
Korea	080 769 0800
Malaysia	1 800 888 848
Singapore	1 800 375 8100
Taiwan	0800 047 866
Thailand	1 800 226 008

Europe & Middle East

Austria	0820 87 44 11
Belgium	32 (0) 2 404 93 40
Denmark	45 70 13 15 15
Finland	358 (0) 10 855 2100
France	0825 010 700*
	*0.125 € fixed network rates
Germany	01805 24 6333**
	**0.14€/minute
Ireland	1890 924 204
Israel	972-3-9288-504/544
Italy	39 02 92 60 8484
Netherlands	31 (0) 20 547 2111
Spain	34 (91) 631 3300
Sweden	0200-88 22 55
Switzerland (French)	41 (21) 8113811(Opt 2)
Switzerland (German)	0800 80 53 53 (Opt 1)
United Kingdom	44 (0) 118 9276201

Other European Countries:
www.agilent.com/find/contactus

Revised: October 24, 2007

Product specifications and descriptions in this document subject to change without notice.

© Agilent Technologies, Inc. 2008

Printed in USA, June 6, 2008
5989-8070EN

Agilent Technologies