# Measuring Internal Combustion Engine In-Cylinder Pressure with LabVIEW

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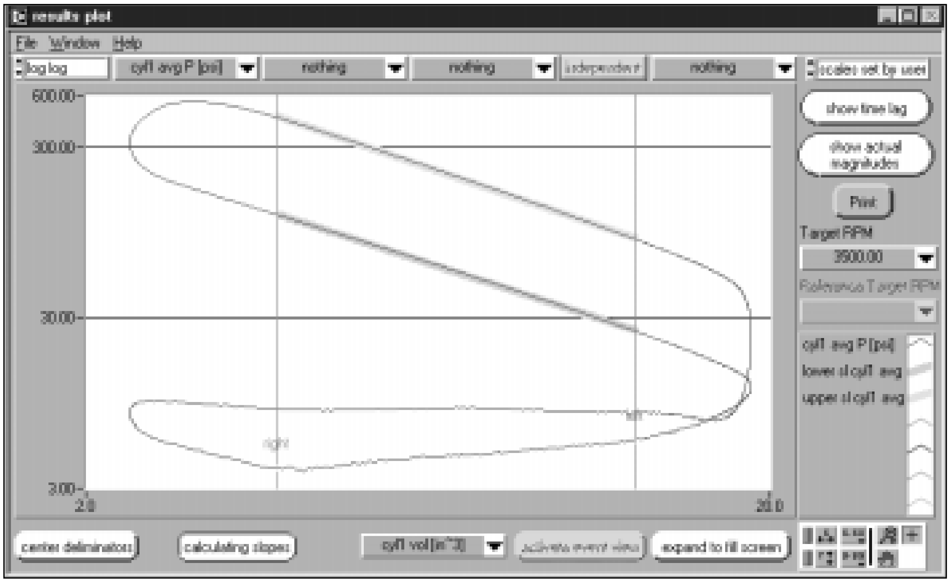


*Log-Log Plot of Pressure versus Volume*

## The Challenge:
Creating an affordable in-cylinder pressure measurement and analysis system to optimize internal combustion engine design and performance.

## The Solution:
Developing the OPTIMIZER, a flexible, low-cost PC-based in-cylinder pressure measurement and analysis system based on a DAQ board controlled by LabVIEW software.

## Introduction
Anyone who has worked on the design of an internal combustion (IC) engine will understand the tremendous advantage that an inexpensive, accurate device for measuring and analyzing in-cylinder pressure would offer a designer. Creative Technical Solutions, Inc. has used a National Instruments DAQ board and LabVIEW to build the OPTIMIZER, a PC-based system for use by engine builders, research laboratories, small racing shops, and hobbyists.

## Background
The performance of an IC engine, depends on a number of variables. For a given compression ratio, optimum horsepower and engine torque are generated when:

- Each cylinder receives the maximum amount of air from the inlet and intake valve assembly
- The fuel/air ratio is adjusted properly for the operation conditions
- The fuel and air are well mixed
- The spark advance is adjusted for incipient knock

Because the pressure resulting from combustion of the fuel/air mixture generates torque and power, the most fundamental parameter to examine during engine development is the magnitude and timing of the in-cylinder pressure during the compression and power strokes. Bench testing of an inlet manifold will document the flow for a given pressure drop under steady-flow conditions. But when installed on an engine, the inlet manifold flow is a nonsteady-flow process driven by the piston motion, inlet valves area, valve timing, and overlap and runner geometry. The coupling of these parameters often results in unequal charging of different cylinders in a multicylinder engine.

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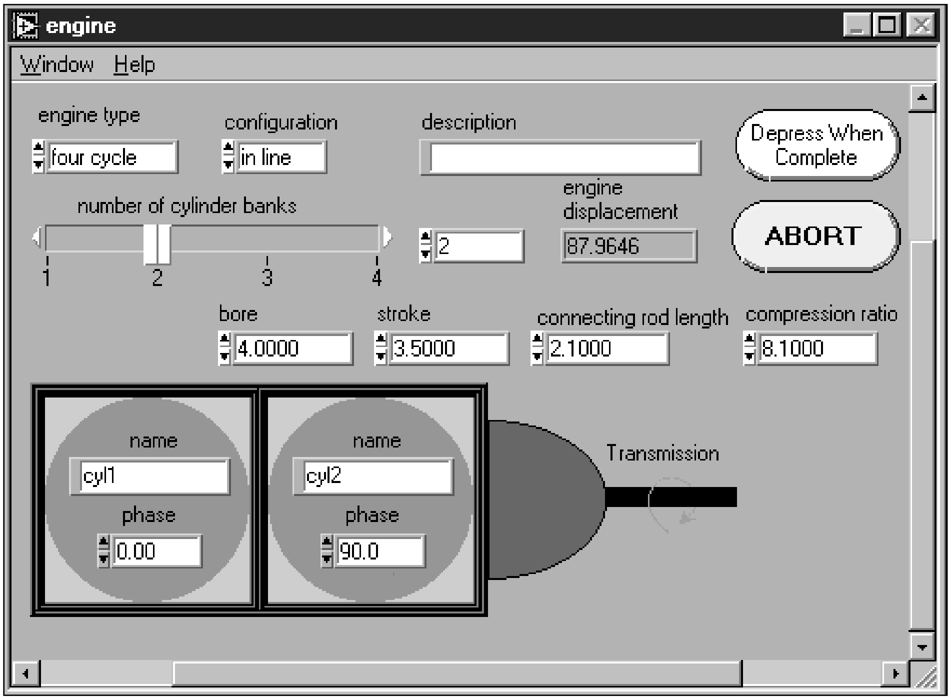
The first step in optimizing engine performance is to design the inlet manifold and valve train to deliver maximum and equal masses of air to the cylinders. For a given compression ratio and air inlet temperature, the operator can derive this charging information from the level of the cylinder pressure during the compression stroke prior to ignition. Because combustion of the fuel/air mixture is a complex function of a number of combustion chamber geometric variables, as well as many other variables – such as local fuel/air mixing, octane number, local equivalence ratio, engine temperature, air temperature and humidity, and spark timing – adjusting these parameters to obtain optimum performance is a considerable challenge.

By observing the measured in-cylinder pressure and the location of the peak pressure with respect to the top-dead-center piston position (TDC), the engine operator can quickly tune the engine for optimum performance. Most conventional engines exhibit optimum performance when the peak pressure occurs 12 to 15 deg after TDC and the combustion event occurs during the nearly constant volume condition near TDC, as indicated by the mass fraction burned. For a given compression ratio and fuel octane number, the spark advance needed for peak performance may lead to overheating of the pistons because of severe spark knock. Thus, during the performance optimization process, the operator needs to monitor the cylinder pressure for spark knock between 10 and 40 deg after TDC. If knock is detected, the spark advance must be reduced to avoid piston damage.

## System Description
We chose LabVIEW for the OPTIMIZER because of its flexibility in integrating data acquisition and analysis functions without the need for additional software. We designed the system to measure and




*OPTIMIZER Engine Setup Screen*

present in-cylinder pressure measurements in a number of graphical formats so the engine operator can assess the effects of design changes and operating conditions on performance as a function of engine operating speed and load. The pressure distributions for each cylinder can be averaged for any desired number of engine cycles and at several engine speeds. The figure on the previous page shows a log-log plot of pressure volume for 100 cycles. The derived parameters that result from analysis of the pressure recorded as a function of crank angle are tabulated along with their standard deviations. The operator can record the dynamometer torque on one of the low-speed channels and use it to compare the brake horsepower with the indicated power derived from the pressure data. The differences in these values are a measure of the friction and pumping losses.

To develop a low-cost PC-based data acquisition (DAQ) system for in-cylinder pressure measurements, we selected Optrand fiber-optic-based pressure transducers. These relatively low cost gauges have been used successfully in a number of development and monitoring programs. Single gauges have accumulated more that 800 million cycles to date in engine operation and control applications. In addition to providing 5 V full scale, the gauges have a sense signal that you can monitor to ensure that the pressure signal is valid. We measured the pressure transducer signals with the National Instruments PCI-MIO-16-E-1 DAQ board, triggered from an optical encoder with 0.36 deg resolution. To ensure that the encoder index pulse is properly aligned with engine TDC, we used a Philtec fiber-optic displacement sensor to accurately determine TDC during motoring tests. This technique eliminates the need to use indexed wheels and markers to estimate TDC.

## System Architecture

Within the LabVIEW-based measurement system, the engine operator uses a number of subroutines to set up the engine parameters, enter gauge parameters, determine TDC, capture data as a function of engine speed, and present the measured and derived results in a number of useful formats. The engine setup screen is shown in the adjacent figure.

## Conclusion

We developed a low-cost PC-based data acquisition and analysis system using a DAQ board and LabVIEW to acquire and analyze in-cylinder pressure for IC engines, for the purpose of optimizing engine performance. We used low-cost fiber-optic-based pressure transducers and a fiber-optic displacement sensor to determine TDC. An optical encoder triggers and clocks the DAQ board. Both gasoline and diesel engine versions of the system are available. Future development plans include upgrading to simultaneous sampling for very high rpm operation and accurate pumping mean effective pressure (MEP) measurements.

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