National Instruments Student Design Competition

Contact Information
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Project Information

Title: Design and Construction of a Hydraulic Dynamometer

Description:
This project aimed to design a state of the art dynamometer to measure engine torque and horsepower for the Kawasaki four-cylinder engine in use by Edinburgh University’s Formula Student (EUFS). The test system offers seamless power transmission and boasts integrated sensors for monitoring and control purposes. Using a hydraulic axial piston pump to load the engine, a Datum Electronics rotary torque transducer outputs shaft speed, torque and power readings. These mV signals are sent to National Instrument’s LabVIEW interface to log and display real-time data. Use of NI’s CompactDAQ enabled the NI 9201 module to acquire the data, and a connection to the engine control unit (ECU) is established using the NI 9263 analogue output module which is capable of initiating shutdown when the system operating limits are approached, hence protecting both equipment and users of this test system.

Products:

- NI 9201 Screw Term, +/-10 V, 12-Bit, 500 kS/s, 8-Ch AI Module
- NI 9263 Screw Term, +/-10 V, 16-Bit, 100 kS/s/ch, 4-Ch AO Module
- cDAQ-9174, CompactDAQ chassis (4 slot USB)
- NI PS-15 Power Supply, 24 VDC, 5 A, 100-120/200-240 VAC Input
- NI LabVIEW® Software Package
The Challenge:

This task demanded the design of a hydraulic dynamometer that can safely handle the performance criterion of the four-cylinder Kawasaki motorcycle engine under test. Construction of a customised powertrain coupling the engine and pump that perfectly supports the inline rotary torque transducer to its high installation specifications was necessary. System monitoring was needed to protect the pump whose speed is limited to 3,000 RPM, and the pressure applied to its working fluid (hydraulic mineral oil) cannot exceed 265 bar. Integration of pressure and temperature sensors as well as a connection to the ECU is therefore vital. This way, if the LabVIEW code detects excessive system parameters, it sends an analogue voltage signal to cut power to the engine by preventing spark ignition.

The Solution:

The engine final drive sprocket is connected via a chain link to the shaft along which the rotary inline torque transducer is connected. This shaft turns the pump and imparts a torque detected by bonded strain gauges within the transducer, outputting amplified voltage signals representing shaft speed, power and torque. These signals are acquired by LabVIEW using the NI 9201 module and Compact DAQ chassis. They are sampled, scaled and filtered using LabVIEW’s DAQ Assistant, a low-pass Butterworth filter with cut-off frequency 5Hz, and a 10ms counter which ensures optimal data resolution. They are then represented as clean torque-speed and power-speed curves, fundamental for describing engine performance.

National Instruments products for data acquisition and logging were crucial to obtaining speed, torque and power readings with high data resolution. Moreover, they were essential in guaranteeing safe operation of the dynamometer by pre-programming system limits within LabVIEW to continuously monitor operation and communicate to the ECU to safely prevent overload and protect both users and components.

Figure 1: Dynamometer Test Stand
The LabVIEW Code:

The code begins with a User Prompt to obtain a gear number that accesses the corresponding case structure. Here, sub-VI’s define the corresponding gear ratio which is sent as a scale factor to the end of the execution chain for plotting actual engine camshaft speed against measured torque and power. This case structure prior to the while loop asks the user if engine speed according to the ECU is within a pre-defined range that will not exceed speed or pressure ratings for the pump, where LabVIEW carefully monitors the shaft speed immediately feeding into the pump accounting for meshing and gearing losses in the powertrain. Only when the speed is within this range, will the while loop initiate and the DAQ Assistant begin data acquisition. Signal conditioning, data logging, and display of torque-speed curves is achieved with this code.

Figure 2: LabVIEW® Block Diagram - 4th Gear Case

The WARNING sub-VI’s detect pump speed and torque (relating these quantities to maximum allowable pressure) and contain Boolean operators and another case structure and DAQ Assistant which outputs a 5.0 V signal slightly above the 4.4 V threshold for the ECU, that will hence automatically alert and activate the vehicle-down sensor, simultaneously informing the user, and

Figure 3: LabVIEW® Sub-VI with DAQ Assistant for Analogue Output
 exiting the While loop to prevent further data acquisition.

Future improvements are using a solenoid valve in the hydraulic portion of the system actuated by the same NI 9263 AO module to restrict mineral oil flow and force the engine to work harder, controlling its speed. Closed-loop feedback control can be established using LabVIEW to compare current and desired speed of the pump shaft for a fixed gear when the engine is being tested for steady-state performance to observe how torque levels vary. The next step in design sophistication is to control the motion of the gear pedal again with a solenoid valve or relay switch configuration that could introduce gear number as a dynamic variable. This would be optimal for transient and steady-state testing of the team’s gear-changing and throttle handling strategies.

This project was an innovative and exciting addition to the selection of Masters of Engineering (MEng) projects at the University of Edinburgh and started from scratch in September 2016, aiming to produce a working test system by the July 2017 SAE race at Silverstone. This goal is on the brink of being realised. Final steps remaining are:

1. Fill the 200L storage reservoir tank with the hydraulic mineral oil and connect tubing, valves, and gauges.
2. Move this entire test rig to a designated outside test area to perform testing.

**Link to Video**
https://www.youtube.com/watch?v=OK_bKD3jvEY&feature=youtu.be

**LabVIEW Code**

Front Panel displays the waveform charts within the while loop and therefore highly dynamic signals which auto-scale on the y-axes and give the user a real-time impression of how the system is handling the speed and torque. In preliminary tests the final XY graph plots engine speed against power or torque and the filtered signals waveform chart shows all three signals with a common Y-axis scale.

![Figure 4: LabVIEW® Front Panel Example](image-url)
DAQ Assistant Menu

LP Butterworth Filter

SPEED_WARNING Sub-VI and DAQ Assistant
(TORQUE_WARNING is equivalent)