Stand for testing the electrical race car engine

M Baier\textsuperscript{1}, J Franiasz\textsuperscript{1}, P Mierzwa\textsuperscript{2} and D Wylenzek\textsuperscript{2}

\textsuperscript{1} Silesian University of Technology, Faculty of Mechanical Engineering, 18A Konarskiego Street, 44-100, Gliwice, Poland
\textsuperscript{2} Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, 16 Akademicka Street, 44-100, Gliwice, Poland

E-mail: maja.baier@gmail.com

Abstract. An engine test stand created especially for research of electrical race car is described in the paper. The car is an aim of Silesian Greenpower project whose participants build and test electrical vehicles to take part in international races in Great Britain. The engine test stand is used to test and measure the characteristics of vehicles and their engines. It has been designed particularly to test the electric cars engineered by students of Silesian Greenpower project. The article contains a description how the test stand works and shows its versatility in many areas. The paper presents both construction of the test stand, control system and sample results of conducted research. The engine test stand was designed and modified using PLM Siemens NX 8.5. The construction of the test stand is highly modular, which means it can be used both for testing the vehicle itself or for tests without the vehicle. The test stand has its own wheel, motor, powertrain and braking system with second engine. Such solution enables verifying various concepts without changing the construction of the vehicle. The control system and measurement system are realized by enabling National Instruments product myRIO (RIO – Reconfigurable Input/Output). This controller in combination with powerful LabVIEW environment performs as an advanced tool to control torque and speed simultaneously. It is crucial as far as the test stand is equipped in two motors – the one being tested and the braking one. The feedback loop is realized by an optical encoder cooperating with the rotor mounted on the wheel. The results of tests are shown live on the screen both as a chart and as single values. After performing several tests there is a report generated. The engine test stand is widely used during process of the Silesian Greenpower vehicle design. Its versatility enables powertrain testing, wheels and tires tests, thermal analysis and more.

1. Introduction
One of the crucial elements of the vehicle being studies is a DC motor. All participants of the race are equipped in identical 240W motors and 12V batteries. In order to choose the motor with optimal parameters, several of them are being thoroughly tested on the engine test stand designed and built by participants. The research lead to excluding the worse motors from further use [1].

The paper covers both description of the control system of the engine test stand and results of the research. The study was conducted on the engine test stand designed for the measurement of the whole drive system. It was designed to keep conditions as close as possible to those on the racetrack. Versatility of the test stand allows to verify only motor with powertrain or the whole car, depending on needs. The principle of operation of the measurement is based on the behavior of kinetic energy. Test stand shaft’s moment of inertia $I$ rotating at a predetermined angular velocity $\omega$, corresponds to the
vehicle of mass $m$ and moving with velocity $v$. In addition, the test stand is equipped with loads and measurement system.

2. The test stand control system
The aim of the test stand is to provide racing conditions in laboratory. Actual components tested on the stand are particularly: motor, batteries, high beam current, motor controller, measurement system and many transducers. The elements participating in the motion simulation of the vehicle include mechanical and electronic components cooperating with the control and measurement software. These components allow to simulate racing conditions properly, which is mainly to provide calculated load. The load may be put manually or it may be calculated basing on advanced mathematical models describing vehicle motion in particular conditions [2].

Application used on the test stand was written in the LabVIEW programming environment. Measurement environment enable creating measurement-control software for complex and fast-changing processes, which includes controlling of test stand elements.

Software works closely with controllers manufactured by National Instruments. The test stand performance is controlled by myRIO-1900 controller. A multitude of analog and digital inputs and outputs allows to provide highly advanced test stand (figure 1.). In the figure 1. MyRIO is closing the feedback loop by allowing for interpretation and determination of measurement signals for main engine control and brake engine control. Brake engine is of the same kind as the tested engine but they are rotating in opposite directions. Brake engine operates in regenerative mode and thanks to a special device we can regulate the amount of energy dissipated and thus the braking torque.

![Figure 1. Schematic diagram of the test stand.](image)

The test stand control system (figure 2) provides the regulation of any of the given values. Controlling process works in three modes: constant current, constant speed, constant braking torque. The control system is based on PID controller implemented on the FPGA of myRIO controller. Depending on chosen mode controller settings and control signals are selected. The control system in myRIO controller has known parameters but includes a closed autonomous control system - Kelly controller [3]. Knowing the mathematical model of myRIO and input and output signals, there is a possibility to estimate the parameters of the Kelly controller.
An additional advantage of the test stand is the ability to carry out automated tests which consist of a sequence controlling test stand elements, often performed repeatedly. The test procedure and its parameters are set in the sequence file. This approach allows to perform the exact same test for various motors [4].

LabVIEW implementation makes it easy to create a user control panel. The user is able to control the test stand and also observe measured values diagrams during a test. Three applications are working on the test stand. FPGA of myRIO controller is programmed and its real-time system. The application that combines everything as a whole is shown in figure 3.
3. Research of the motors
The stand is the real object consisting of the same motor and powertrain that are present in the vehicle. Research conducted on the test stand focused mainly on the parameters which are crucial in terms of the race, i.e. speed, torque and energy consumption. In order to maintain comparable conditions during all tests, several parameters were always equal: current, initial battery voltage supply, ambient temperature, level of air pressure in the wheel, downforce of the wheel to the shaft, gear ratio and measurement time [5].

During the study the following phases of motor performance can be defined: starting and accelerating to full speed, maintaining the maximum speed, free run and stop. To determine the value of the energy consumed by individual motors, battery voltage and current consumption were measured for each of the above phases. The graphs of relative voltage and current are presented in figure 4. And figure 5. Motors have been numbered in order to ensure unambiguous identification.

![Figure 4. Voltage-time graph for 5 motors.](image1)

![Figure 5. Current-time graph for 5 motors.](image2)
The obtained data and the transformations of the simple mathematical relations allowed to obtain value of the energy (table 1). The maximum speed of individual motors were significantly different to each other. In order to analyse them further they were converted to rotational speed as shown in the following table. Basing on the speed gained in time and known motor parameters, average torque was calculated during the first phase of work - acceleration.

**Table 1.** Selected parameters of the motors.

| Parameter          | Unit | Motor 1 | Motor 2 | Motor 3 | Motor 4 | Motor 5 |
|--------------------|------|---------|---------|---------|---------|---------|
| Energy consumption | Wh   | 144.55  | 147.64  | 138.48  | 141.34  | 264.81  |
| Max. rotational speed | RPM | 1900.6  | 2018.2  | 1934.1  | 1833.3  | 2102.4  |
| Average torque     | Nm   | 1.930   | 1.556   | 1.945   | 1.737   | 1.585   |

Usefulness of the motors was determined by comparing them to each other and by confronting them with nominal values specified by the manufacturer (figure 6.).

**Figure 6.** Nominal parameters of the motor provided by FRACMO.

The graph above shows that the motor maximum speed is slightly over 2000 RPM. The motor 5 exceeds this value going faster even being under load. However, this motor uses the greatest amount of energy and additionally, generated comparably low torque. In terms of these facts motor 5 was labelled as not suitable to be used during the race. Motor 3 optimally meets the established criteria - it has the lowest energy consumption, high torque and the speed is satisfactory.

**4. Conclusions**

The synergy between automation and mechanics enabled creating the test stand (figure 7.) which occurred to be a powerful tool in determining parameters of DC motors. The test stand control system allows to set values of tests adjusted to current needs of the user thanks to user-friendly application. Everything is gathered in complex device – myRIO controller – which makes the control and measurement systems highly effective. The combination of tested motor and braking motor is the
optimal solution to depict race conditions in laboratory comparably accurately. The motors research presents how crucial it is to choose the motor which is characterized by the most optimal parameters. Such operations lead to improved performance of the vehicle on the race track and have priceless meaning during the contest.

![Figure 7. Stand for testing the electrical race car engine – front view.](image)

References
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