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RETROFIT OF A ROLLER BRAKE TESTER AT FAMENA

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Summary

The vehicle brake tester described in this paper is placed in the Laboratory for IC Engines and Motor Vehicles at the Faculty of Mechanical Engineering and Naval Architecture (FAMENA) in Zagreb. As the device, built in 1983, was inoperative, a decision was made for retrofit rather than repair. The retrofit included a reconstruction of some parts and modification of the braking force measurement. Adaptation of monitoring and control was made on electronic components that control the roller set during the manual and the automatic operation.

Using the LabVIEW programming software [1], our team created a computer program for monitoring the positioning of a vehicle on the device, the measuring of vehicle mass needed for the calculation of braking coefficient, the control of operating mode (automatic or manual) and the start/stop mode of electro motors inside the device.

Key words: *Vehicle, Brake test, Wheel Force, LabVIEW*

1. Introduction

The roller brake tester is a widely used device for testing the automotive brake system performance under stationary and controlled conditions. During the testing, the braking force of a wheel is measured and the difference in braking force between the left brake force and the right brake force of a single axle as well as the brake efficiency are calculated.

In the Laboratory for IC Engines and Motor Vehicles, a 30-year-old *Brekon 2/3* roller brake tester [2] was used for the testing of road vehicle brakes. The device was out of order for a long period of time due to the problems with the pneumatic measuring system. To make it useable and competitive with new devices, a retrofit was performed. The outdated pneumatic measuring system was replaced with a new electronic one, as well as control cabinet components.

The National Instruments LabVIEW programming software is used to create a program that can control, acquire signals or measurement data, display, store, and print reports.

Calculation of values, such as coefficient of adhesion and the difference in braking force between the left and the right wheel, which are usually determined during technical inspection of a vehicle (as required by the local law on vehicle road worthiness [3]) is done during the measurement test.

The reason for doing this retrofit was re-putting the device in running order so that it can be used for educational purposes (students, technical inspection supervisors, etc.), or other purposes. Mechanical parts in the device represent a large share of its value. By keeping these elements and replacing only the elements for measurement that represent a smaller value in the overall device value, it was possible to make the system operational again. The costs of replacing measurement parts of the device with new ones were lower than those of buying a new device.

Another reason was that it was an opportunity for the whole team to carry out an experiment, to gain training experience, and to verify its own ability to do this kind of professional work and to use most advanced measuring and control equipment in the process.

2. Working principle of the vehicle brake tester

Main elements, rotating directions, forces and dimensions of the roller brake tester are shown in Fig. 1. The scheme in this fig. is essential for understanding the brake tester working principle and for the determination of braking force.

1 – Torque lever
2 – Rear roller
3 – Front roller
4 – Force transducer
5 – Middle roller
6 – Wheel of a vehicle

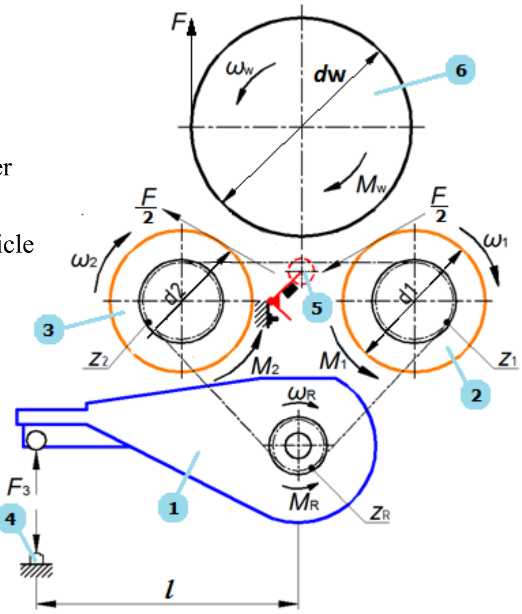

Fig. 1 Schematic diagram of a roller brake tester

Calculation of braking forces and the coefficient of adhesion is done by the following equations:

$$z_1 = z_2 = z_V \tag{1.1}$$

$$d_1 = d_2 = d \tag{1.2}$$

$$M_R = \frac{z_R}{z_V} \cdot \frac{d_W}{2} \cdot F \tag{1.3}$$

$$F_3 = \frac{M_R}{l} \tag{1.4}$$

$$F_3 = \frac{1}{l} \cdot \frac{z_R}{z_V} \cdot \frac{d_W}{2} F \tag{1.5}$$

$$F = 2 \cdot l \cdot \frac{z_V}{z_R d_W} F_3 \tag{1.6}$$

$$K = \frac{F_{L,1} + F_{R,1} + F_{L,2} + F_{R,2}}{m \cdot g} \cdot 100 \tag{1.7}$$

$$R = \frac{F_2 - F_1}{F_2} \cdot 100 \tag{1.8}$$

Where:

d	–	Roller diameter, m
d_1	–	Front roller diameter, m
d_2	–	Rear roller diameter, m
d_W	–	Vehicle wheel diameter, m
z_V	–	Number of roller gear teeth, -
z_1	–	Number of front roller gear teeth, -
z_2	–	Number of rear roller gear teeth, -
l	–	Length of torque lever, m
z_R	–	Number of torque lever gear teeth, -
F	–	Vehicle braking force (braking force of the wheel on the roller), N
M_R	–	Torque on the motor stator, Nm
F_3	–	Force on the force transducer, N
K	–	Coefficient of adhesion of the vehicle, %
R	–	Difference in braking force between the left and the right wheel, %
$F_{L,1}$	–	Braking force on the front left wheel, N
$F_{R,1}$	–	Braking force on the front right wheel, N
$F_{L,2}$	–	Braking force on the rear left wheel, N
$F_{R,2}$	–	Braking force on the rear right wheel, N
F_1	–	Weaker braking force, on the left or the right wheel, N
F_2	–	Stronger braking force, on the left or the right wheel, N
m	–	Mass of the vehicle, kg
g	–	Gravity, m/s^2.

Both rollers rotate at a constant speed ($\omega_{W1} = \omega_{W2}$) driven by a constant torque from the electromotor. When braking force is applied, the wheel decelerates and a torque M_W is created. The torque lever connected to the electromotor stator rotates in the opposite direction from the rollers, the electromotor rotor (ω_R), and the vehicle wheel (ω_W). The torque from the vehicle wheel (M_W) is transmitted over roller sprockets and chain through the electromotor rotor to the electromotor stator (lever).

The lever that transmits the force (F_3) to the force transducer is connected to the electromotor stator housing. The force on the sensor is proportional to the braking force on the wheel. The connection between the braking force on the wheel of the vehicle (F) and the force acting on the sensor (F_3) is shown in Fig. 1.

Technical specifications [3] that the tested vehicle needs to comply with are the coefficient of adhesion (K) and the difference in braking force (R) between the left and the right wheel. The coefficient of adhesion shows the ability of the vehicle to brake in dependence on the vehicle mass and the braking force achieved on the wheels. For the main brake, the coefficient of adhesion has to be at least 50% for passenger cars, 40% for motorcycles, and 45% for trailers to be sure that the vehicle brakes are functioning correctly [3].

2.1 Replacement of pneumatic components

All mechanical parts of the roller brake tester set (Fig. 2) were left unchanged. The roller brake tester consists of two sets, the left and the right roller set (placed inside the floor).

One roller set is an assembly of an electric motor, a reduction gearbox, sprockets, a chain, a torque leaver, a force transducer, main rollers, a positioning middle roller, and housing. All of the old pneumatic components, such as force sensors, measuring components, filters and connecting pipes were replaced. Electric motor drive transmits rotation through rollers onto the vehicle wheels. When brakes are applied, the torque lever pushes the force transducer with a force proportional to the braking force between the wheel and the rollers.

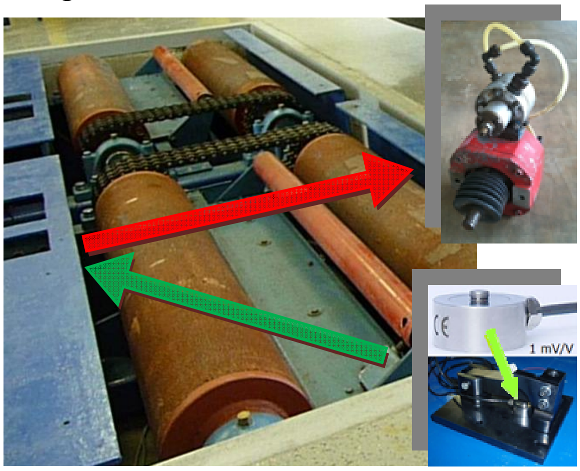

Fig. 2 Roller brake tester propelled by electric motors and a new force transducer

2.2 Implementation of electronic measurement components

In order to modernize the device, a new data acquisition system was installed. The new data acquisition system consists of electric force transducers, amplifiers, an analogue/digital converter, a computer, power supply, and wiring. Both the left and the right roller have their independent transducers for the braking force measurement. The new force transducer with some additional positioning parts is placed inside the rollers in the same place where the old pneumatic was situated. In that way, the rest of mechanical parts of rollers were left unchanged.

After the installation of the new force transducers in the roller assembly, the wiring of components was carried out. Fig. 3 shows a scheme with the definition of channels and components used to obtain measurement data.

A NI-LP68 connector block is used to enable the wiring of electronic components with the analogue/digital NI-6220 PCI card [4]. *DC power supply* (24 V) is used to supply the *ADVANTECH ADAM-3016* strain gauge signal conditioning module [5] connected to the force transducer. The signal conditioning module supplies excitation voltage to the force transducer and amplifies the measured signal. The installed force transducer, based on the Wheatstone bridge circuit principle, is made by HBM, C9B series [6] with the characteristic of 1 mV/V and a range of +10 kN. This means that with the power of 10 V supplied the force transducer and a force of 10 kN applied, the measurement signal would be 10 mV. The signal is amplified to 10 V and sent to analogue input channels of the analogue/digital NI-6220 PCI card.

Besides the measurements, the A/D card is also used for the control of the vehicle brake tester operation. Control switches (power, start/stop of rollers, automatic/manual mode, and manual start of the left or the right roller) from the old cabinet were replaced with relays that are controlled by the PFI (Programmable Function Interface) digital output channels.
Electronic components used for the new measurement and control system are:

1. *HBM 9CB* Force Transducer,
2. *ADAM-3016* Voltage Amplifier,
3. 24 V DC Power Supply,
4. *SCHRACK - RT314005*Relay Switch,
5. *NI-6220* PCI Express DAQ Card,
6. *NI-LP68* Connector Block

A special feature of the new measuring system is its ability to measure braking force of up to 20 kN on each wheel. Mechanical parts of brake rollers are unchanged so the maximum authorized axle force is the same as it was declared by the manufacturer (130 kN) [2].

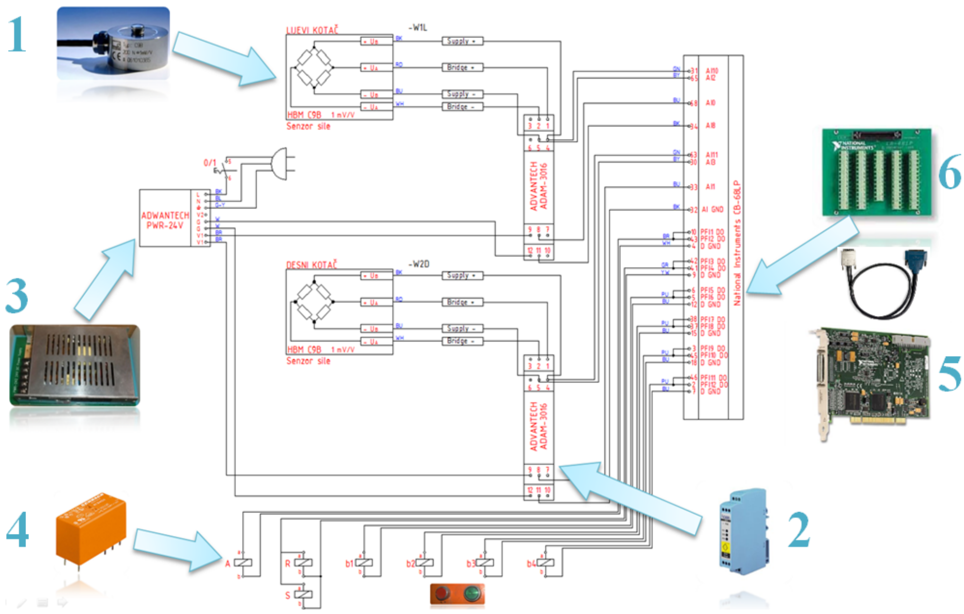

Fig. 3 Scheme electronic measurement components

3. New Graphical User Interface (GUI)

In the old measuring system (Fig. 4, left), measured forces were presented by analogue gauges with the needles operated by pneumatic cylinders placed inside the cabinet. In the modernized version, the display of braking force is done through the PC monitor and a classroom projector. Besides by displaying the measured results, the monitoring and control of the roller brake tester is done through the control software created within the NI LabVIEW programming environment.

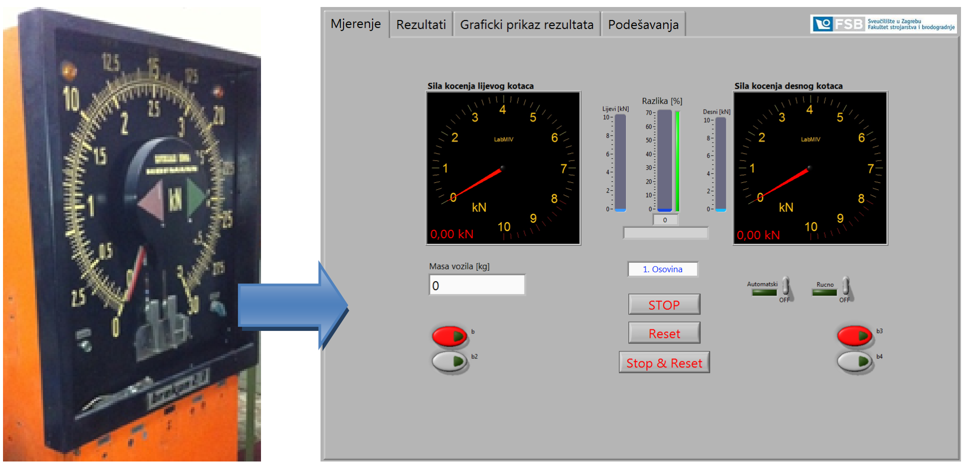

Fig. 4 Roller brake tester propelled by electric motors and a new force transducer

3.1 Front Panel

The Graphical User Interface (GUI) of the developed application is divided into four tabs: Measurement, Results, Graphic display of results, and Settings. The Measurement tab includes the monitoring and the control panel with numeric indicators (Gauges, Numeric, and Fill Slide) and controls used during the test procedure (Fig. 5).

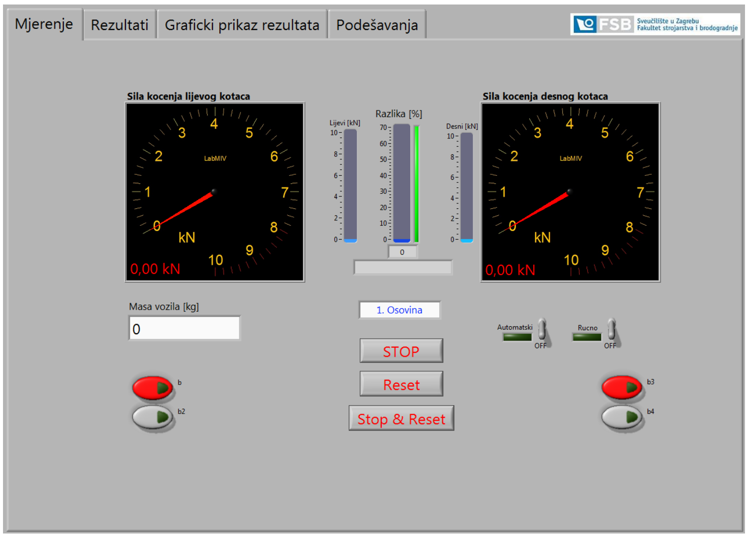

Fig. 5 Front Panel GUI in LabVIEW – Tab: Measurement

The measuring process requires one operator. At the beginning (start) of the measurement, the operator starts the program (.vi or .exe). In the initialization phase of the measurement, the operator has to enter the data on the vehicle mass and to choose between the manual and the automatic operation mode. In the manual mode, the left and the right roller set are operated independently.

When the brake testing procedure is completed, results are shown on the second tab (Fig. 6). The maximum braking force of each wheel, the difference in braking forces and the comment on whether the brake system meets safety regulations [3] are presented. Also, based on the entered vehicle mass and the measured braking forces, the braking coefficient for the whole vehicle (K) is calculated.

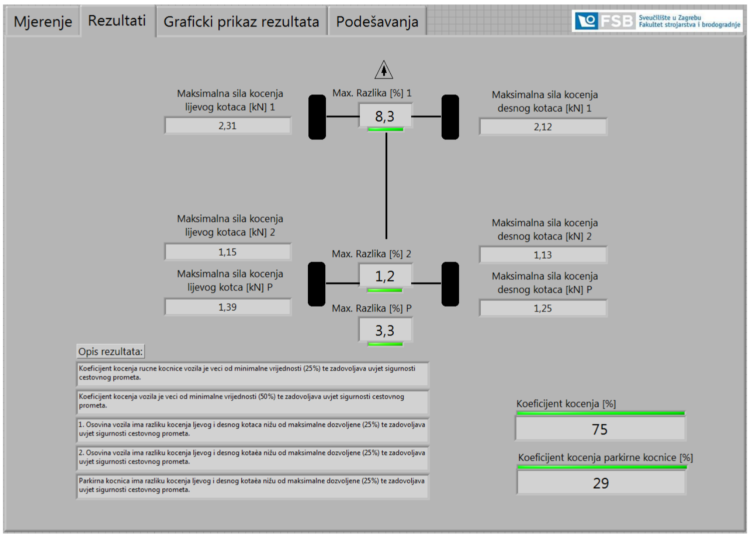

Fig. 6 Display of information important for the vehicle safety

The next tab “Graphic display of results” (Fig. 6) displays information about the braking force recorded during the braking process. This means that it is possible to see the difference between the left and the right braking force through measurement. The Tab "Graphic display of results" is divided into two sub-tabs. The first of them shows diagrams with the braking force on the left and the right wheel (N), and the second compares the values of braking forces and shows the difference in braking force between the left and the right wheel (as a percentage).

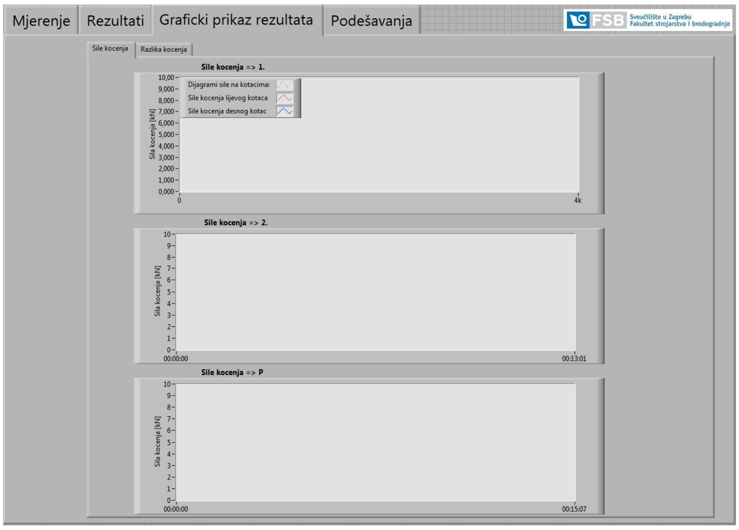

Fig. 7 Diagram with the left and the right wheel braking force

3.2 Block Diagram

The block diagram contains a graphic source code (data acquisition tools, signal analysis, output devices, programming tools, arithmetic operators, and other processing tools) [7].

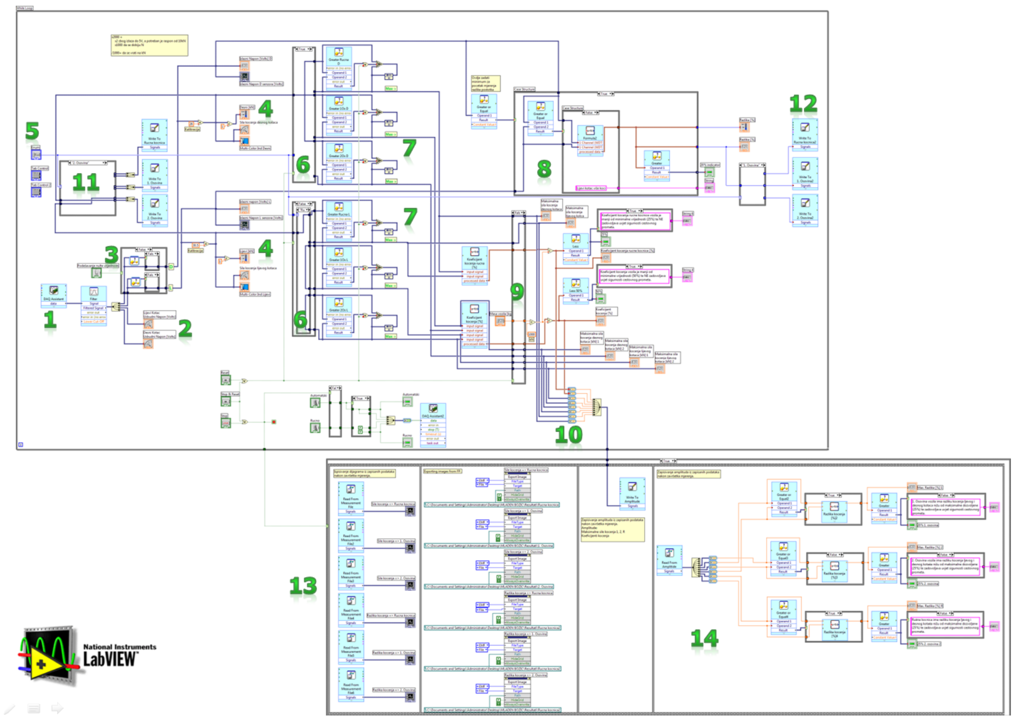

Fig. 8 LabVIEW Block Diagram overview

The code is divided into 14 sections shown in Fig. 8 and listed below:

1. Signal acquisition and filtering.
   Signal from data acquisition device is acquired and filtered. In this section, analogue input channels are defined and data is integrated inside a while loop to be processed and displayed.
2. Excitation voltage display.
   Excitation voltage is displayed for the calibration of the force transducer amplifier.
3. Determination of the measurement start to avoid initial disturbance in the signal.
   In this section the lowest force on the sensor is defined, after which the measurement is displayed and saved to a data file.

4. Signal conversion from voltage to force, and its display.
5. Selection of brake type (main or parking brake).
6. Redirecting the signal depending on the brake type selection.
7. Determination of maximum braking force.
   Maximum force is defined for all loops inside one measurement.
8. Determination of difference in braking force between the left and the right wheel.
9. Display of the maximum braking force.
10. Saving data of braking forces and their maximum differences to the measurement file.
11. Saving wheel force values of the complete measurement process.
12. Saving the values of differences in braking forces for the whole measurement process to the file.
13. Reading the values from measurement files and displaying them.
14. Determination and display of maximum difference in braking force between the left and the right wheel.
    In order to consider all the differences in one measurement, the maximum difference is calculated last.

4. Conclusions

Mechanical component relations are described with a system of equations to define the relationship between a force applied to the sensor and a force on the wheel of a vehicle so that the measurement can be displayed as the braking force of the wheel.

The measurement chain for the force measurement and the control of brake rollers with a new digital data acquisition program was created.

Digital data acquisition opens a possibility for a later analysis of the vehicle ability to brake with an insight into the whole brake test measurement.

The deviation in results obtained with the new measurement system is significantly decreased.

The new parts are quicker and give a faster response, so it is possible to save the vehicle tires.

This paper shows that it is possible to upgrade an outdated brake tester to the technology level of modern brake testers.

Through the retrofit, an obsolete and malfunctioning device was put into operation again. In the process of retrofit, a number of genuine parts were replaced with new components.

This project has also enabled students to see an example of control and monitoring of electric motors in the Laboratory for IC Engines and Motor Vehicles.

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