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Design of a measuring system for the testing of pneumatic powertrains

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Abstract. This publication presents a new generation measuring system, designed and constructed for the testing of pneumatic powertrains, at the Faculty of Engineering of the University of Debrecen, as well as its design and assembly process. It also describes test measurements applying the measuring system together with their results. During the test measurements, the pressure in the cylinder and in other parts of the system were measured, as well as the kinematic functions of the piston, during the operation of the powertrain under loaded conditions. Finally, conclusions are drawn, and further development directions are set.

1. INTRODUCTION

The Faculty of Engineering at the University of Debrecen is a regular participant at the International Pneumobile Competition –organized by Emerson Automation FCP Ltd. every year in Eger – since 2008. The vehicles designed, constructed, and developed by the student teams of our Faculty, regularly perform in the forefront, so they have already received many awards. As a result of these activities, several TDK and thesis have been written [1], [2], [3].

Recently, we have embarked on the development of a compact, in-vehicle measurement system, that allows the team to collect and evaluate data in real time, during a race. This way, we can gain information to optimize the parameters of the vehicle for a given race task. The first step of the above-mentioned development is the design and realization of a measuring and diagnostic system for pneumatic powertrains. In this article, we compare our measurement results with the measurement results found in the literature [4], [5]. Pneumatic circuit diagrams and theoretical knowledge have been developed based on the literature [6], [7], [8]. In the following, we present the description and testing of this measuring and diagnostic system.

2. DESIGN OF THE MEASURING SYSTEM

As a first step, the parameters to be measured were selected, which are:

- system pressure in front of the filling valve
- cylinder pressure after the filling valve
- piston displacement
- piston velocity
- piston acceleration

The above parameters can be extensively tested by changing the operating conditions.

The second step was to design the layout of the pneumatic system (Figure 1), using the Festo Didactic - Festo FluidSIM program. The possibility for individual parameterization of the different pneumatic elements was a great help during the preliminary simulations.
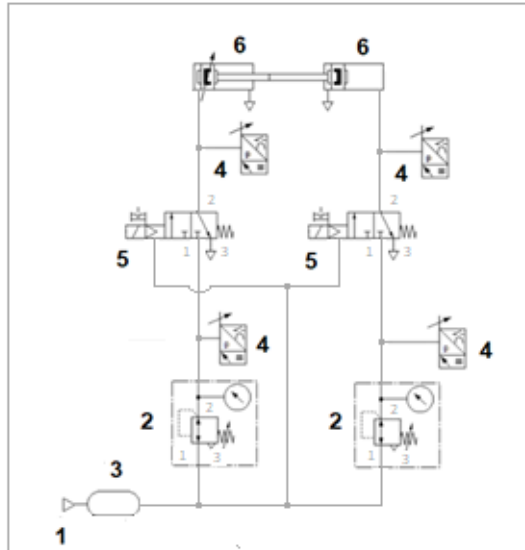

Figure 1. Layout of the designed pneumatic system (1. air source, 2. pressure regulator, 3. buffer tank, 4. digital pressure sensor, 5. diverter valve, 6. cylinder)

When designing the electrical circuit, our main aim was simplicity and to reduce and eliminate possible interfering signals. Thus, the circuit was divided into a measuring and a control circuit.

The measuring circuit consists of 4 pressure sensors, a distance measuring sensor, a 4-channel analog measuring card and a data recording program running on a laptop. The sensors were provided by Emerson Automation FCP Ltd. for the competition team. The measurement card is a NI 9239 high-speed measurement data acquisition card manufactured by National Instruments, for which we have developed a data recording program in NI LabVIEW software. The main parameters of data recording can be specified in the program.

The control circuit – which consists of 2 switches and an emergency stop button – is responsible for operating the valves.

To load the drive system, we designed a braking system that was applied directly on the output shaft of the gear unit using a bicycle disc brake. Its braking force can be adjusted by biasing a cable using a screw. The whole unit was built on a hollow section, base frame (Figure 2).
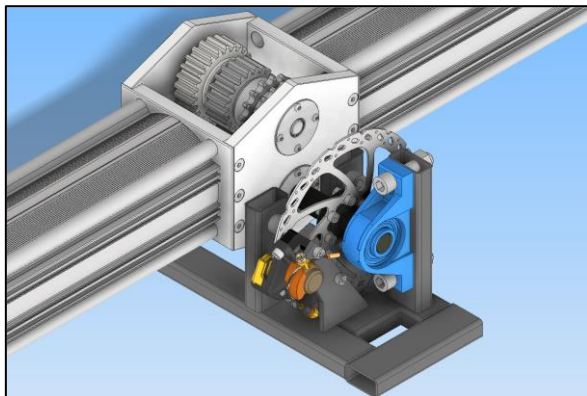

Figure 2. Gear unit load system

3. APPLIED PNEUMATIC ELEMENTS AND INSTRUMENTS

The PRA-type cylinder that drives the gear unit, has a stroke length of 500 [mm] and a diameter of 100 [mm]. It is equipped with end-of-stroke damping and a magnetic ring piston. The cylinders are operated by a 3/2 electro-pneumatic diverter valve.

The air reserve of the system is provided by two buffer tanks of 60 [l] each. The first one maintains a constant overpressure of 8 [bar], and the second, the system pressure required for the measurement. The second tank is continuously replenished by the first one. The entire system is supplied with air by a compressor.

A pressure sensor type PE 5 with a digital display was used to measure the pressure, and a high-precision distance measuring sensor type SM6-AL-503 was used to detect the piston position.

The above sensors have an analog output signal in the 0-10 [V] voltage range, so an NI 9239 analog measuring card could be used to process the signals. The above card is connected to the recording laptop via an NI USB-9162 USB adapter.

4. INSTALLATION OF THE MEASURING SYSTEM

The measuring system was installed in the Cutting Laboratory of the Faculty of Engineering of the University of Debrecen. The needed custom parts, such as the output shaft, brake disc adapter and hollow section base frame, were also manufactured there.

First, the gear unit and load unit were assembled, and then attached to the workbench. Subsequently, the pneumatic system was built, using the largest available ø16mm pneumatic tubes. The gear unit was connected to the system, applying the same tube length on both sides, to avoid defects and losses due to internal friction. Finally, the measuring system was installed, the sensors were placed onto their designated location and then were calibrated. The sensors were connected to the DAQ card with original shielded cables.
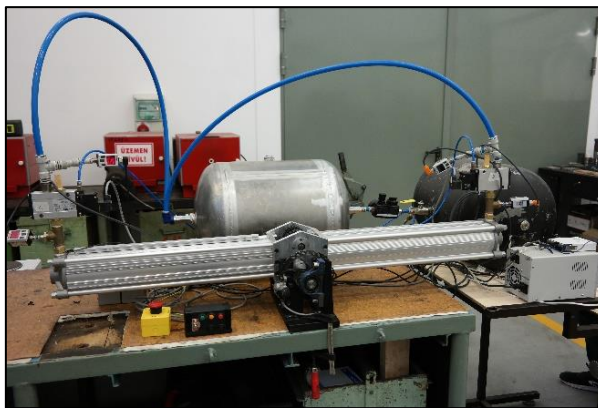

Figure 3. Assembled measuring system

5. TEST MEASUREMENTS AND RESULTS

Measurements were performed at pressures from 3 [bar] (black line) to 6 [bar] (blue line) in 0.5 [bar] steps (Figure 4-8). There were 3-3 measurements at a given pressure value, so a total number of 42 measurements were taken, on both sides of the gear unit. The gear load was pre-set but its exact value was unknown.

The measurement results were recorded and then exported to an Excel spreadsheet. After processing the data, the results were presented in the form of diagrams. Figure 4 shows the distance-time function of the piston.
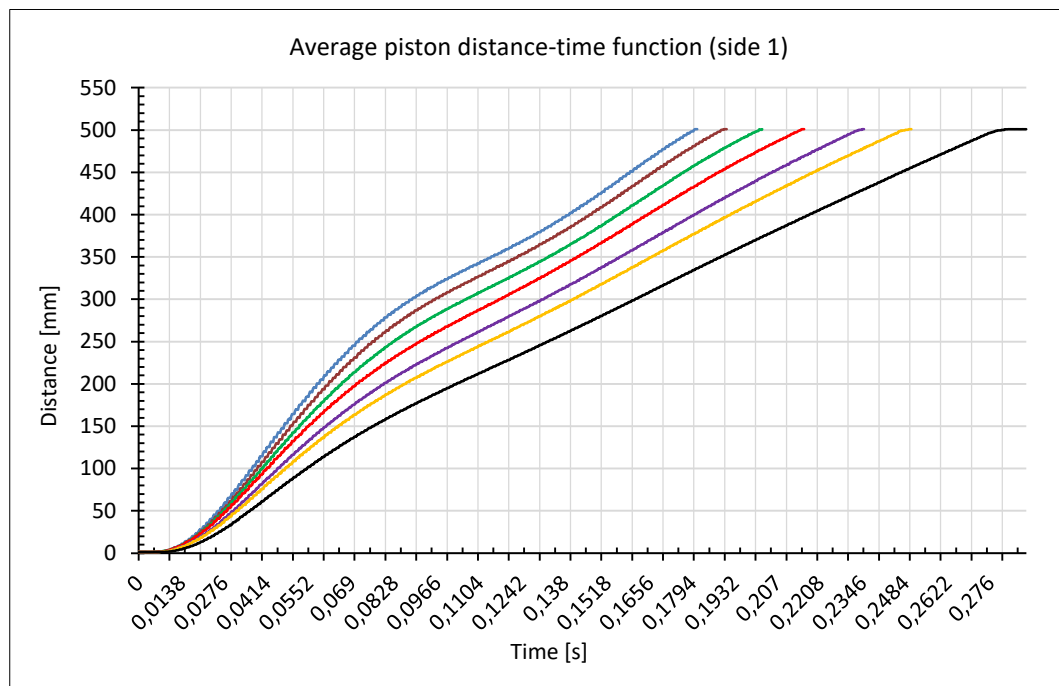
Figure 4. Distance-time functions of the piston

The first and second time derivatives of the polynomial functions, fitted to the distance-time functions give the velocity-time and acceleration-time functions of the piston (Figure 5 and 6).
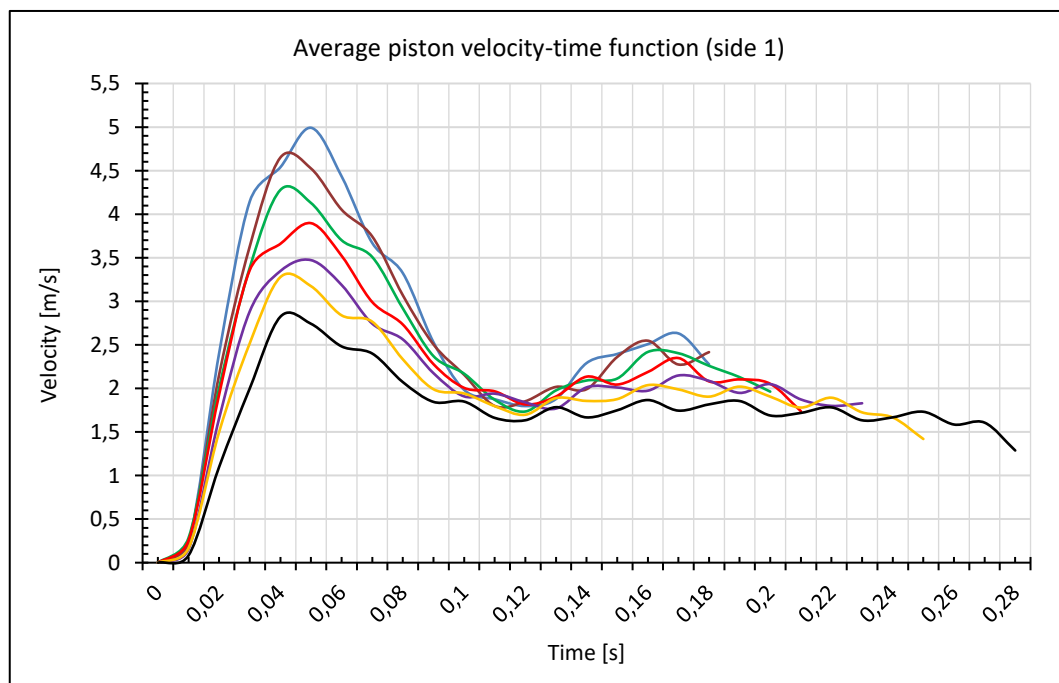

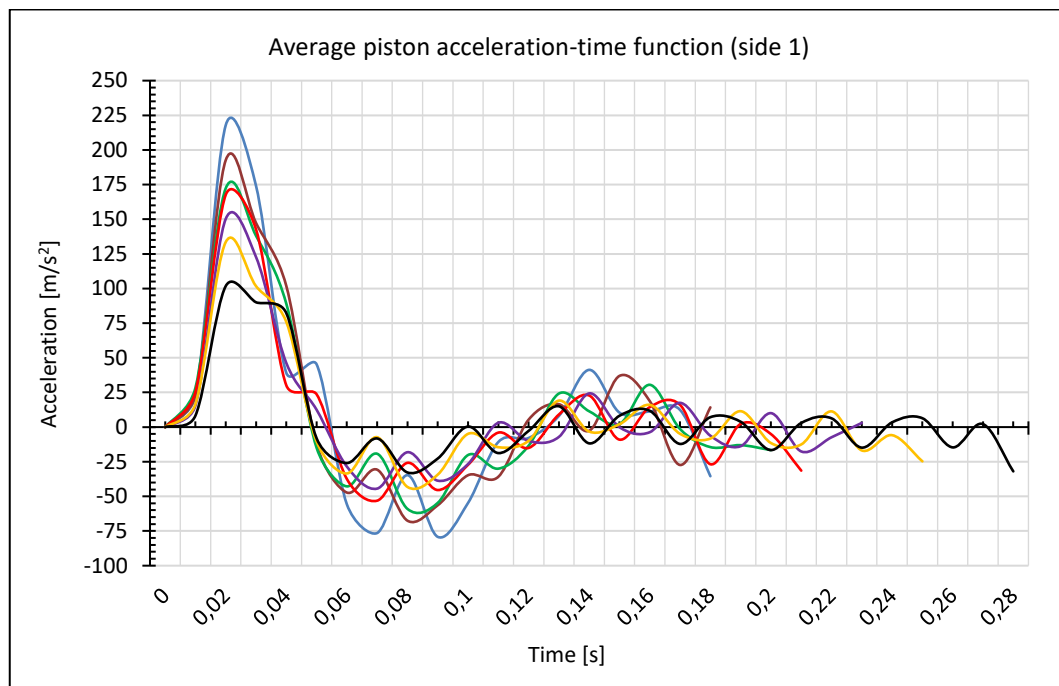**Figure 5.** Velocity-time functions of the piston

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Figure 6. Acceleration-time functions of the piston.

The measured pressure values before and after the 3/2 diverter valve are shown in Figure 7 and 8 as a function of time.
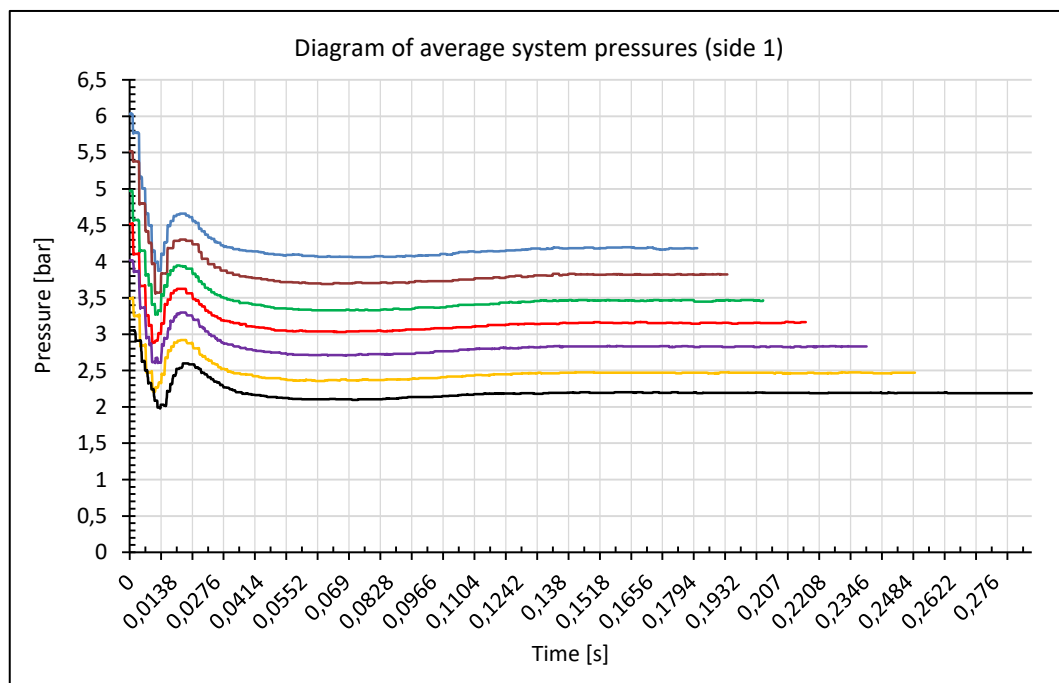

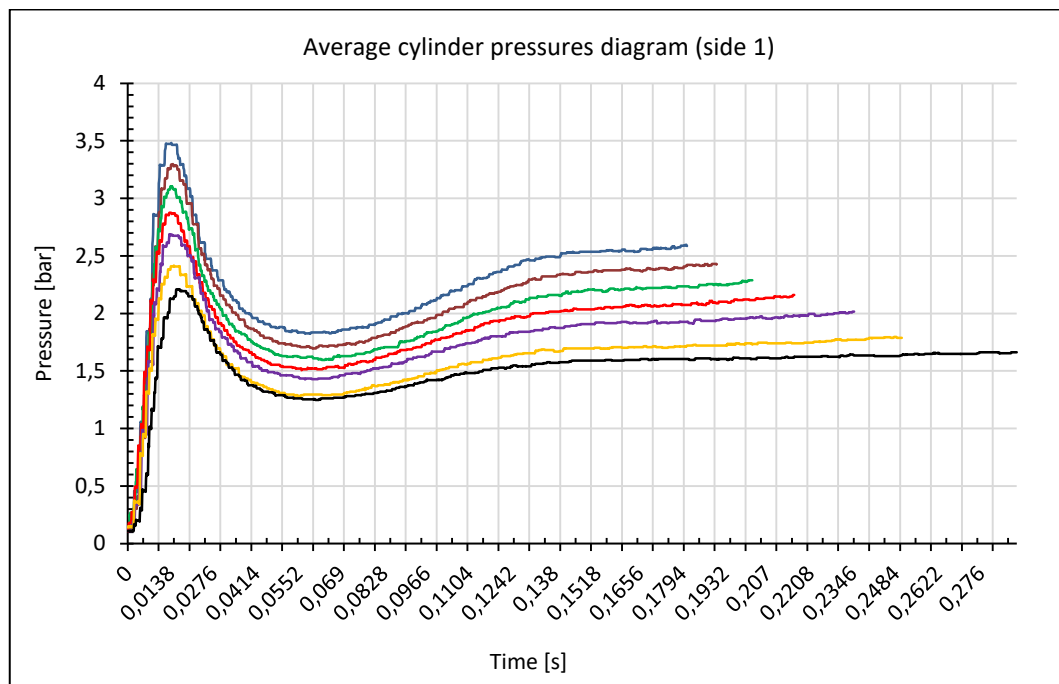**Figure 7.** System pressure as a function of time

Figure 8. Pressure inside the cylinder as a function of time

6. CONCLUSION AND DEVELOPMENT DIRECTIONS

The results obtained, show a good agreement with the diagrams, found in the written works of Dr. Imre Csernyánszky - Pneumatic Control Engineering [4]; which confirms that our measuring system works properly.
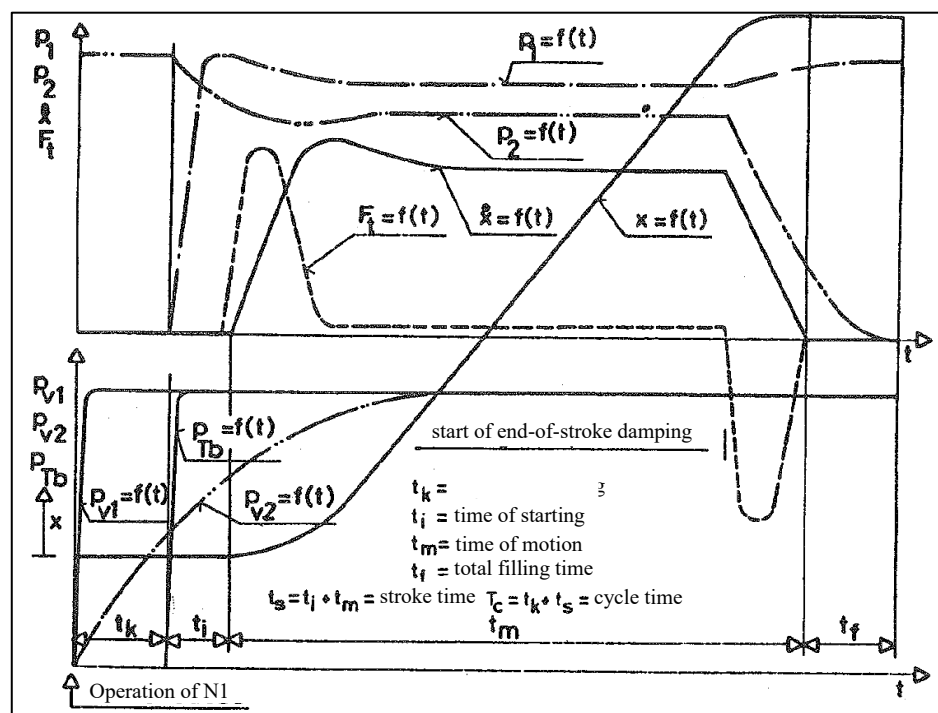

Figure 9. Typical sections of pneumatic control systems [4]

The aim of the present research was to realise a basic but upgradable measuring system. In the future, we intend to do further developments and achieve the following measurement goals:

- flow and air consumption measurement
- torque measurement
- examination of end-of-stroke damping
- application of variable gear unit load
- speed measurement
- load force measurement

In addition, we would like to examine how the operation of the gear unit depends on the following factors:

- tube cross section
- tube length
- permeability of pneumatic elements
- internal friction of pneumatic elements
- shape of pneumatic tubes and fittings

Through the development of the control system, the measurements can be made significantly more accurate. This can be achieved by installing a PLC control unit, with which the measurement can be performed automatically, according to a predetermined plan; thus, eliminating the human factor.

It is also necessary to develop a more advanced gear unit load system; with which the gear unit can be safely tested even at the maximum operating pressure of 10 [bar].

Improvements on the measuring system, presumably allows the simultaneous examination of more parameters than at present. An NI Compact RIO measurement data logger, which can handle multiple DAQ cards at the same time, can provide a suitable solution.

7. Summary

A measuring system for the testing of pneumatic drives has been realized, including the design of the pneumatic and electrical connections, and a load system for the drive. The necessary, but missing elements have been manufactured and assembled. Finally, we performed a series of test measurements, evaluated the obtained results, drew conclusions, and set the directions for further development; which are the following:

- further development of our measuring system and examination of new parameters
- development of a compact measuring system that can be installed on the pneumatically driven race car, thus it can be used under race conditions

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