FUEL DISPENSERS

# New generation of system for the metrological control of fuel dispensers

Jaromír Markovič[1], Jozef Živčák[2], Milan Sága[3], Tomáš Kliment[1], Štefan Král[1]

[1] Slovak Legal Metrology, Hviezdoslavova, 31, 97401, Banská Bystrica, Slovakia

[2] Faculty of Mechanical Engineering, Technical University of Košice, Letná 9/B, 042 00 Košice, Slovakia

[3] Faculty of Mechanical Engineering, University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia

## Abstract

This article presents the new generation of the system for the metrological control of fuel dispensers. The new system is the result of research and development and subsequent practical implementation in the Slovak Legal Metrology Institute. The new generation of the system uses a high degree of automation, intelligent image processing, elements of artificial intelligence, and the application of innovative construction materials. The system enables metrological control of a wide range of measuring systems with a focus on the credibility and reliability of measurement results, measurement accuracy, and reducing the dispensers' shutdown time during their metrological control. The added value is the ease use of the system and the short training time needed for metrological staff to use it.

## 1 Introduction

Fuel dispensers that are used to measure the volume of liquids sold at fuel stations are included in the category of measuring systems for the continuous and dynamic measurement of quantities of liquids other than water. The metrological and technical requirements applicable to measuring systems for the continuous and dynamic measurement of quantities of liquids other than water, which are subject to legal metrological control, are set out in OIML R 117-1 [1], which is also used as a normative document in the conformity assessment of dispensers placed on the EU market in accordance with Directive 2014/32/EU for measuring instruments [3]. OIML R 117-1 includes metrological and technical requirements for dispensers for diesel, petrol (gasoline), LPG, AdBlue, washer fluids, etc.

Industrial practice is increasingly taking advantage of automation. Its benefits also extend to the field of metrology, in the form of streamlining frequently repetitive processes, and contribute to checking the reliability of the measurement results. Trends in the field of automation enter into all fields of industry, including metrology.

The idea of applying these trends to the area of metrological control services for measuring instruments used at fuel stations is based on the requirements of the practice and on the activities of the Research and Development Department of the Slovak Legal Metrology Institute, which as the main researcher of this project cooperated with leading Slovak technical universities.

The purpose of the article is to present a new generation of a compact system to perform metrological control, mainly the verification of dispensers used at fuel stations (a system for metrological control of fuel station dispensers hereinafter referred to as "MCoFD system"). The new MCoFD system has several previous versions, from which it differs by a significantly higher degree of automation and a wider range of provided services [4].

The aim of the research project was to create a measuring system that is capable of verifying all the dispensers available at fuel stations, using elements of artificial intelligence as a means of automation and acceleration of measurement processes, and whose size is compact enough and suitable to fit into commonly available commercial vehicles up to 3.5 T. The design process took into account the use of electrical systems in potentially explosive atmospheres with regard to the safety of use of the MCoFD system. Figure 1 shows the MCoFD system that can be built into a commercial vehicle to create a mobile technology. The individual subsystems are described in the following chapters.

## 2 Mechanical part of the MCoFD system

The design of the MCoFD system takes into consideration the weight of the total system, as well as whether it is sufficiently strong and rigid. The weight of the total system was designed to not exceed 3.5 T including the weight of the driver and the vehicle, as the maximum load capacity of a commercial vehicle. In addition, it

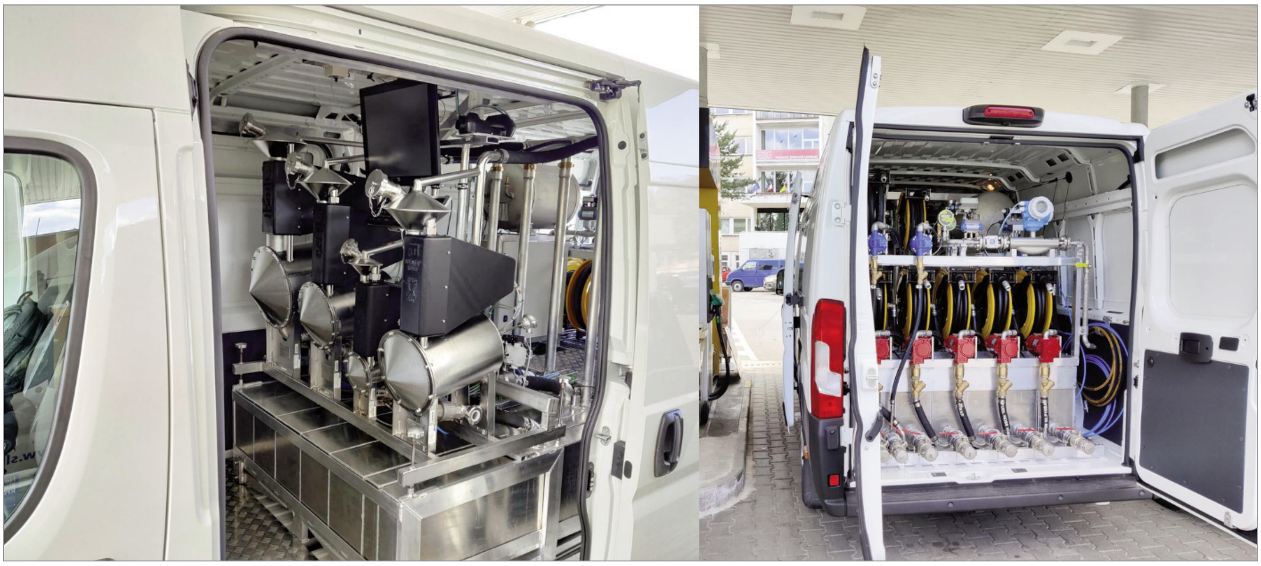


Fig. 1  MCoFD system as a part of the vehicle for verification

was required that the MCoFD system can be easily installed into the cargo space of commonly available commercial vehicles with only minimal modifications. Such a complex measuring system for the verification of all kinds of measuring systems includes a lot of sensors, tanks, standard vessels, pumps, hose systems, etc. According to the reasons mentioned above, it was not always possible to use ordinary materials (e.g. steel). Collecting tanks and the supporting structure frame were the most suitable parts to save weight. The supporting structure frame includes three parts: the main frame (Fig. 2), the frame for LPG technology and the frame for standard vessels.

The collecting tanks and the support frame system were made of aluminium alloy with a density equal to one third of the density and with a failure strength equal to half of the failure strength in comparison with commonly used steels. In this way, it was possible to reduce the weight of the entire construction by up to 350 kg. For safety reasons, simulation strength analyses of the supporting structure frame and collecting tanks were performed. The simulations were focused on:

- the static loading - for full collection tanks during the verification process;
- the quasi-dynamic load in the direction of the vehicle's motion (at the force equal to 0.8 g) - behavior of the system during vehicle braking;
- the quasi-dynamic load in the direction perpendicular to the vehicle motion (at a force equal to 0.4 g) - behavior of the system while moving round curves in the road.

The simulation results showed high safety factors (values of 4 and higher) [5] in all cases. The results of the main frame static loading simulation are shown in Fig. 2.

The 3D model of the MCoFD system as a compact measuring system is shown in Fig. 3.

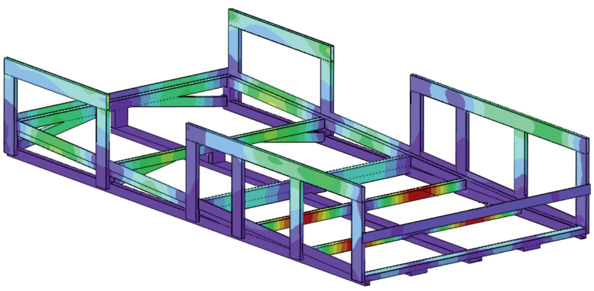


Fig. 2  Simulation of the static loading of the main frame

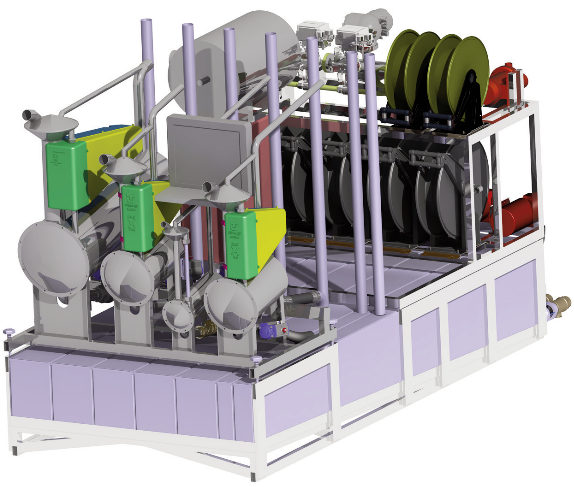
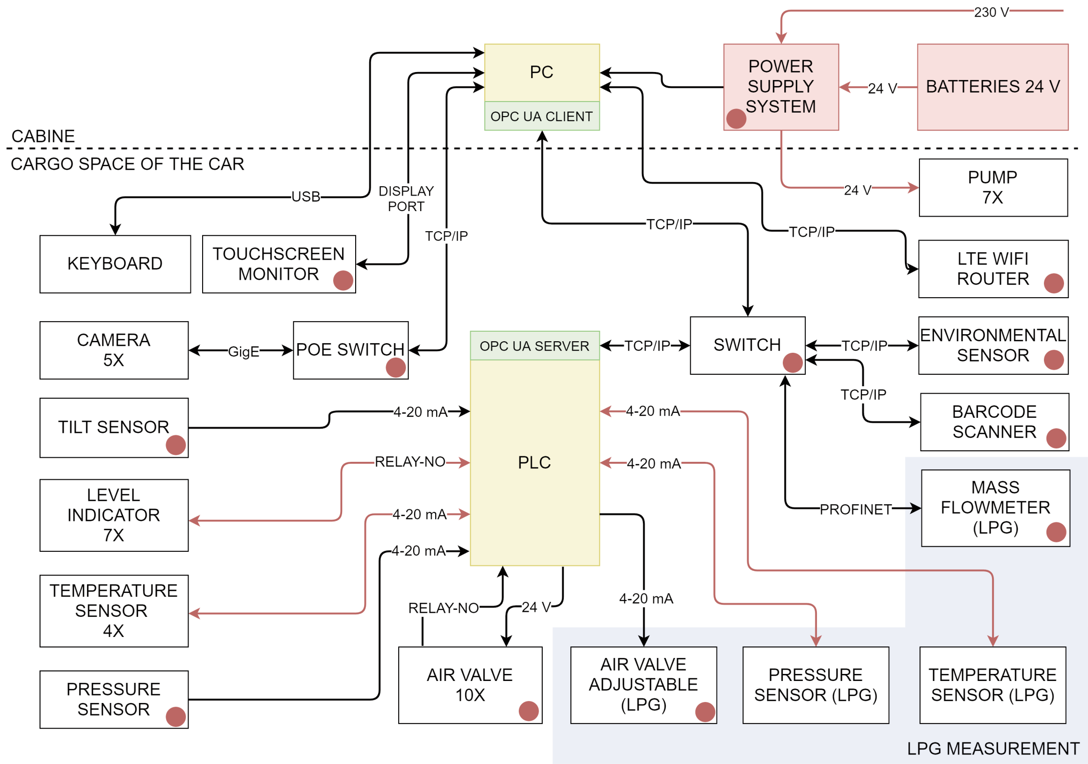


Fig. 3  Compact MCoFD system (3D model)




Note: Red circle is 24 V power supply from power supply system.
Red connection means that the power supply is via intrinsically safe barrier.

Fig. 4 The block diagram of the electrical system

## 3 Electrical system and software solution

The electrical system for the MCoFD system is designed to be energy independent. The power supply system uses four batteries with a total capacity of 200 Ah at 24 V. The power supply system includes converters, batteries, and a diode switch.

After connecting to the external 230 V power supply, the diode switch switches the power supply from the batteries to the converters and the batteries start the charging process. The entire electrical system with the batteries was designed to cover 15 hours of operation of the MCoFD system pumping 6 000 L of liquid (at a temperature of 20 °C inside the cabin) or 15 hours of operation pumping 4 500 L of liquid (at a temperature of 0 °C inside the cabin). The block diagram of the electrical system is shown in Fig. 4.

The MCoFD system is operated by the technician using software that runs on a PC and together with a PLC forms the control part at the highest level. The PC and the PLC communicate together via the OPC UA communication protocol [6], where the PLC is the server and the PC is the client. The OPC UA is a secure and an independent way of exchanging data between a PC and a PLC. Based on this data exchange, the control of air operated valves and the collection of data from all the sensors (except the cameras) can be performed and provides a high degree of automation. The PLC also checks the control parameters and includes regulatory algorithms.

The MCoFD system uses intelligent image processing to read the dispenser indicated data and the liquid volume in standard vessels.

The image processing is performed by cameras, which are connected to the PC via a POE switch. Sensors such as a barcode scanner (used to identify the measuring instrument from the verifier's instrument database), the environmental sensor (temperature, pressure and humidity) and the mass flow meter communicate with the PLC through the TCP/IP protocol via a switch. All the valves used are air operated with electrical control and use a compressed air tank. The pressure inside the compressed air tank is measured continuously. The control valve, used to adjust the flow when measuring LPG, is controlled by a 4 – 20 mA signal, while the start/stop valves are controlled by a 24 V signal. Each start/stop valve contains a pair of sensors with a relay output for monitoring its end position. These valves are used to empty the standard vessels into collecting tanks or for the verification of

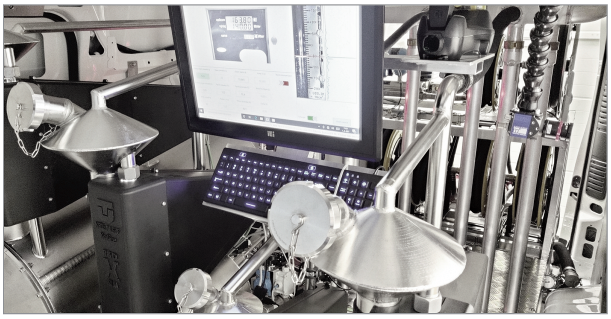


Fig. 5 The user interface of the MCoFD system with touch screen monitor

LPG dispensers. Approximately 90 % filling of the collecting tanks is indicated by level indicators. For the purpose of verification of dispensers with a temperature compensation function, the temperature of the liquid in standard vessels is measured. A two-axis tilt sensor is used to put the standard vessels into the equilibrium position. For the purpose of verification of LPG dispensers, the MCoFD system uses a thermometer and a pressure gauge with a current 4 – 20 mA output.

The LTE WiFi router connects the MCoFD system to the measuring instruments database of the verification authority via the GSM. This connection can be used to upload the measurement data to the cloud that is under the control of the verification authority. The user interface of the MCoFD system is shown in Fig. 5.

## 4 Measurements

The MCoFD system is a complex measuring device suitable for the verification of all available dispensers located at a fuel station. The MCoFD system uses the following measuring principles:

- the volume measurement of a liquid using standard vessels at atmospheric pressure (diesel, petrol, AdBlue and washer fluid),
- the volume measurement of a liquid using a standard mass flow meter in a closed loop (LPG).

All measurements are highly automated. The volume of liquid in the standard vessels, as well as the reading of the volume indicated by the indicating device of the fuel dispenser, is done by means of intelligent image processing.

Measurements that are not based on image processing but that directly affect the measurement of the volume of liquid are controlled by the PLC (see Fig. 4). These measurements include the following:

- the measurement of the titling of the standard vessels in two axes;
- the measurement of the temperature of the liquid (temperature compensated volume);
- the measurement of the temperature, pressure and humidity of the environment;
- the measurement of the volume of liquid by means of a mass flow meter in the closed-loop (LPG);
- the measurement of the temperature in the closed-loop (LPG);
- the measurement of the pressure in the closed-loop (LPG).

The measurements that are important in the automation process but that do not directly affect the measurement of the volume of liquid are following:

- the indication of the liquid level in the collecting tanks;
- the measurement of the pressure in the compressed air tank - for correct operation of the air-operated valves;
- the measurement of the voltage of batteries;
- the monitoring of the position (opened/closed) of the air-operated valves;
- the reading of the barcode from the measuring instruments - for unambiguous identification of the measuring instruments in the database of the verification authority.

### 4.1 Measurement of liquid volume using standard vessels at atmospheric pressure

The measurement is performed by the volumetric method with a fixed start. The system allows to choose from four standard vessels in order to ensure the verification of the dispenser in its full measuring range.

The configuration of the standard vessels for the MCoFD system is shown in Fig. 6. The standard vessels

Fig. 6 Configuration of standard vessels for the MCoFD system

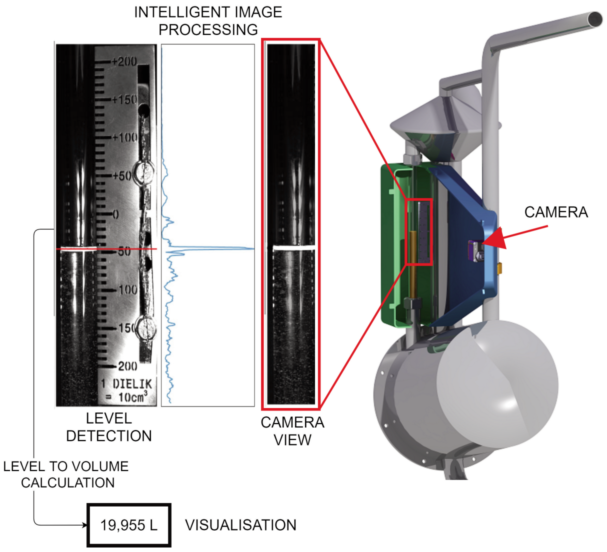



Fig. 7 Reading of the volume of liquid in standard vessels by means of intelligent image processing

and their shape were designed to reduce the formation of foam on the surface of the liquid during the measurement process. This allows the time for reading the received volume of liquid to be reduced.

Reading of the volume of liquid from standard vessels is performed by means of intelligent image processing (Fig. 7).

The camera scans the image of the level indicator (Fig. 7 - camera view), which is used as the input to the correlation-derivation algorithm (Fig. 7 - intelligent image processing). The algorithm determines the location of the line of the level indicator and based on the specified sensitivity performs the conversion to volume (Fig. 7 - level to volume calculation). The issue of edge detection and machine vision is discussed in general in [7]. In this way, the volume is measured continuously within the scale range. The metrology personnel only check the value recognized by the algorithm.

Several measurement principles have been considered in the design process of volume measuring. The advantage of the chosen principle is significantly better measurement dynamics in comparison with other principles. For example, a radar level transmitter needs some time to stabilize the indicated value and its electronics are sensitive to the temperature influence. Measuring the volume of liquid by means of the optical principle (camera) has another significant advantage, namely the possibility of visual control of the measurement results.

Intelligent image processing is also used for reading the indicated value from the dispenser indicating device. Digitizing of results using optical character recognition (OCR) as part of the automation process is useful for their subsequent processing. Intelligent image processing is a powerful tool and a future trend in the field of legal metrology. Image recognition can be used in difficult conditions and the following three factors have the most influence on image recognition:

- fuel stations use dispensers from different manufacturers and with different indication devices;
- ambient lighting conditions - if the dispensers are placed outdoors, a wide range of lighting conditions may occur;
- indicating devices of dispensers have a plastic or glass protective cover that is a source of light reflections.

The illustration of OCR digitization of the indicated value displayed by the indicating device is shown in Fig. 8.

In most cases, light reflections on the covers of the indication device prevent reliable image processing. The camera with a Polarsens chip can capture a four-directional polarization image (0°, 45°, 90° and 135°) in one shot by the four-directional polarizer, which can remove the reflections.

If some indication devices display the indication in a certain polarization, it is possible to select another polarization that does not suppress the displayed indication.

The image without reflections is then the input into the OCR algorithm, which uses elements of artificial intelligence, namely convolutional neural networks with deep learning [8]. The output is not only the recognized value, but also the probability with which this value was recognized. In this automated process, the technician only checks the recognized value.

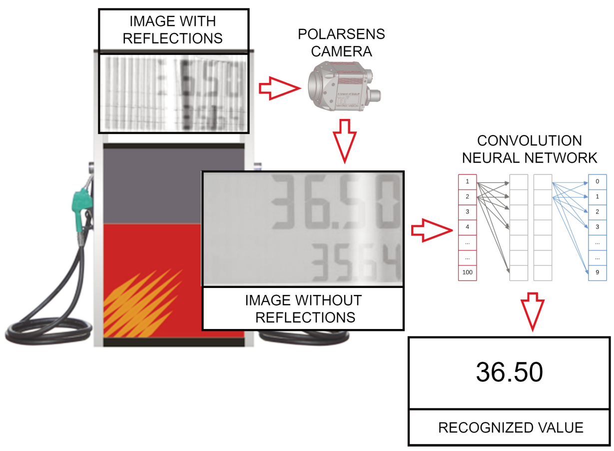



Fig. 8 Illustration of OCR digitization of the indicated value displayed by the indicating device

### 4.2 Measurement of liquid volume using standard mass flow meter in a closed loop (LPG dispensers)

The measurement is performed by the volumetric method with the fixed start and is carried out using a mass flow meter (Fig. 9).

After connecting the LPG dispenser to the MCoFD system, the measurement process is fully automated. The technician enters the required flow rates and volumes at which the measurements shall be performed. The software user interface on the basis of which the LPG verification is performed is shown in Fig. 10.

The PC and PLC automatically control the verification process based on the steps as shown in Fig. 12.

Figure 13 shows an example of the regulation process of the required flow rate, which is achieved by means of an electro-pneumatic positioner and operated by the control algorithm implemented in the PLC.

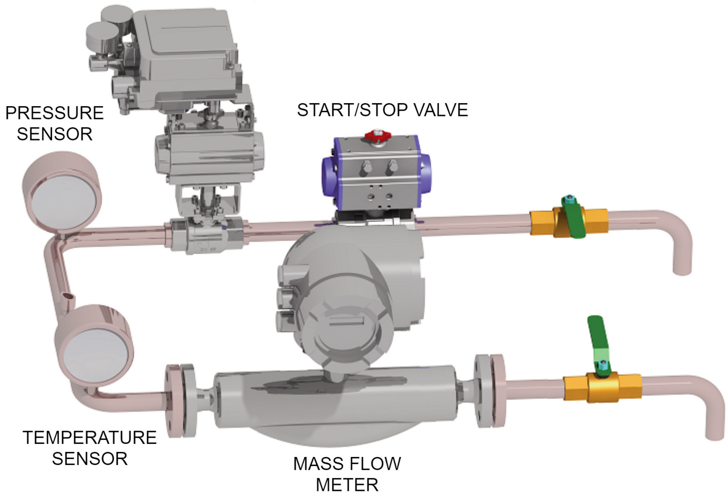



Fig. 9 Standard measuring system for the continuous and dynamic measurement of quantities of LPG as a part of the MCoFD system

## 5 Credibility of measurement results

An important aspect of verification is the credibility of the measurement results. The MCoFD system uses three control levels of measurements results credibility:

- the use of intelligent data processing - the technician is not the only one who reads the values from the measuring instruments;
- in case the technician changes the recognized value indicated by the measuring instrument, the change is recorded;
- the recording of witness photography with all key measurement information: values displayed by the indicating device of the dispenser, values indicated by the level indicator of the standard vessels, temperature compensation values, time and place of the measurement, etc.

A witness photography from the measurement is shown in Fig. 11.

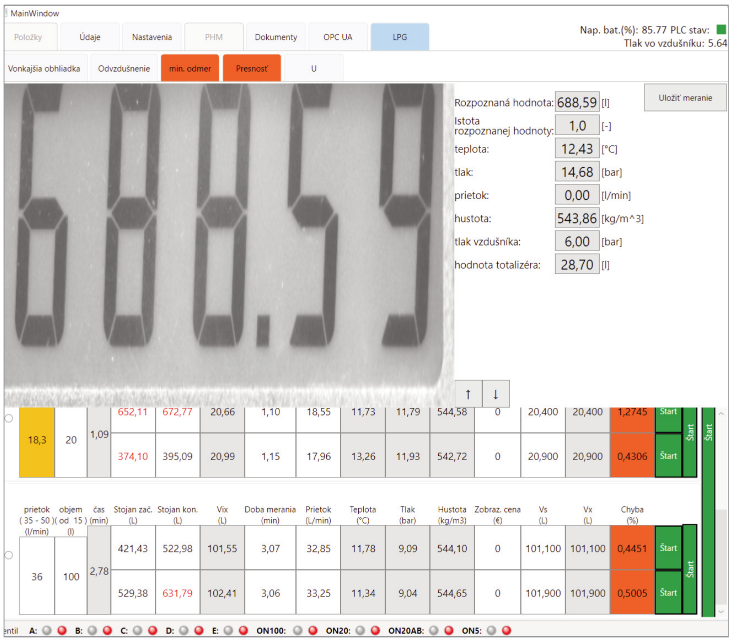



Fig. 10 Software user interface for verification of the LPG dispenser

## 6 Technical data of the MCoFD system

The MCoFD system is suitable for the verification of dispensers used on fuel stations with a flow rate of up to 200 L/min. It includes dispensers for the following liquids:

- standard hydrocarbon fuels (without temperature compensation);
- standard hydrocarbon fuels (with temperature compensation);
- liquefied petroleum gas (LPG);
- washer fluids;
- AdBlue – uric acid.

The following documents can be issued as result of the metrological control of dispensers:

- verification certificate;
- calibration certificate;

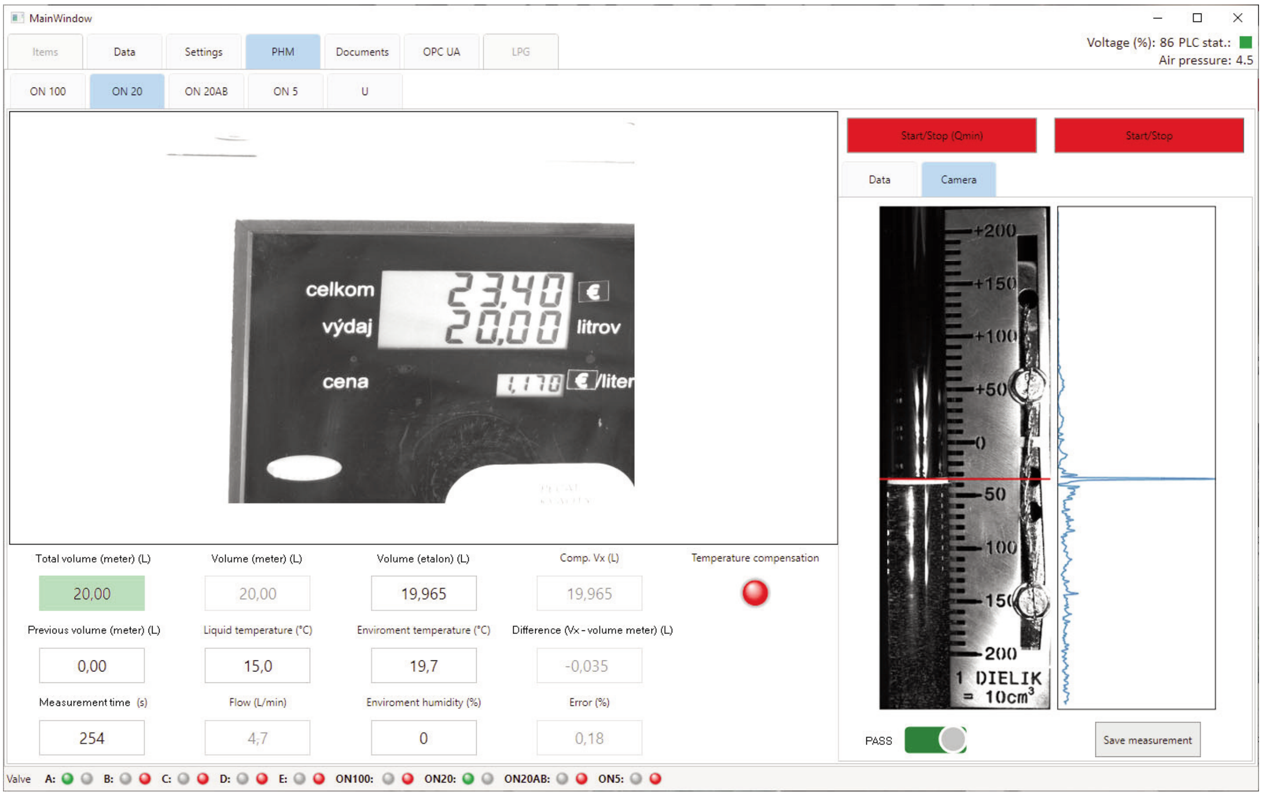



Fig. 11 Witness photography as the control of the credibility of measurement results

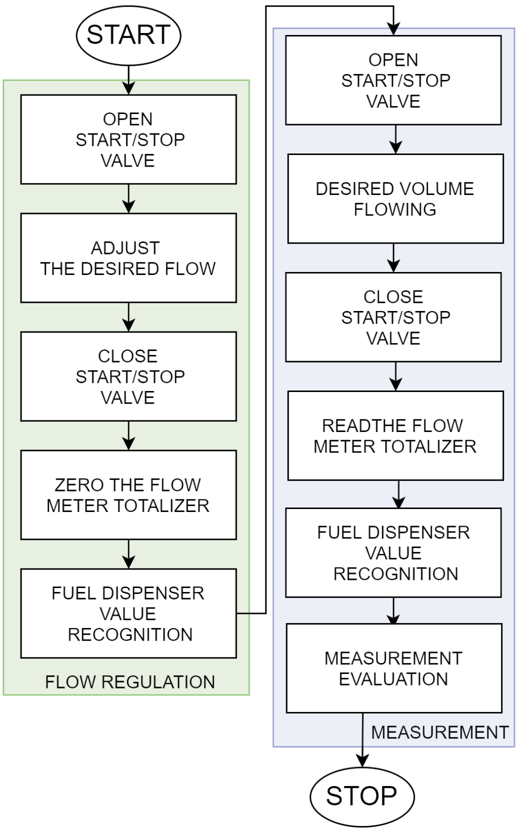



Fig. 12 Fully automated verification process for LPG dispensers

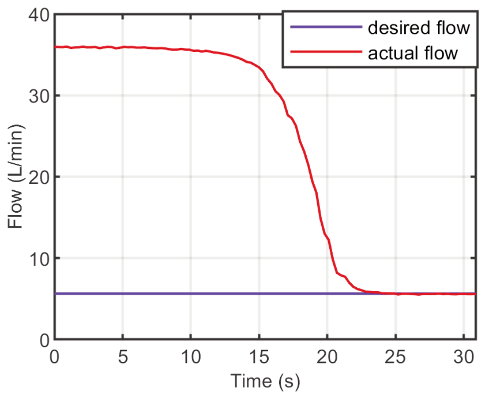



Fig. 13 Example of the regulation process of the required flow rate (the flow rate is regulated from 36 L/min to 5.25 L/min)

- receipt concerning the volume of liquid used during the metrological control;
- confirmation regarding the metrological control realization.

The MCoFD system has four standard vessels and the characteristics of the standard vessels and of the collection tanks are given in Table 1.

The expanded uncertainty of the determination of the error on indication of the volume conforms to the requirements of OIML R 117-2 [2].

Table 1 Characteristics of standard vessels and collection tanks

| Standard measure | Specification | Nominal capacity (L) | Measuring range (L) | Collection tanks capacity (L) and their number |
|---|---|---|---|---|
| ON5 | Washer fluids | 5 | 4.95 – 5.05 | 90 (1 ×) |
| ON20AB | AdBlue | 20 | 19.8 – 20.2 | 110 (1 ×) |
| ON20 | Hydrocarbon fuels | 20 | 19.8 – 20.2 | 240 (5 ×) |
| ON100 | Hydrocarbon fuels | 100 | 99 – 101 | |

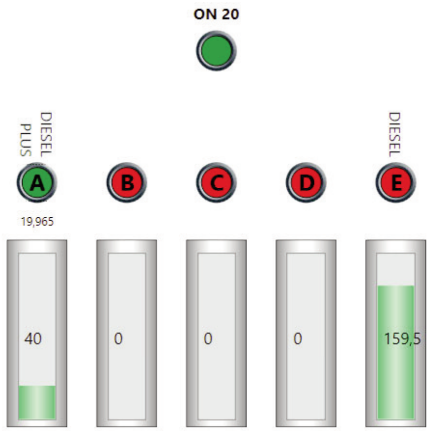



Fig. 14 Sorting of the liquids into separate collection tanks according to the kind of liquid (screenshot taken from the user interface)

Table 2 Technical data of the MCoFD system

<table>
<tr><th>Feature</th><th colspan="6">MCoFD</th></tr>
<tr><td rowspan="2">Power supply</td><td colspan="2">Batteries</td><td colspan="2">Externally</td><td colspan="2">Charging</td></tr>
<tr><td colspan="2">24 V</td><td colspan="2">~230 V</td><td colspan="2">yes</td></tr>
<tr><td rowspan="2">Temperatures</td><td colspan="3">Operating</td><td colspan="3">Charging</td></tr>
<tr><td colspan="3">–20 °C ~ +60 °C<br>(external temperature)</td><td colspan="3">–10 °C ~ +40 °C<br>(cabin temperature)</td></tr>
<tr><td rowspan="8">Collection tanks</td><td colspan="6">Volume</td></tr>
<tr><td colspan="2">240 L</td><td colspan="2">110 L</td><td colspan="2">90 L</td></tr>
<tr><td colspan="6">Pcs</td></tr>
<tr><td colspan="2">5</td><td colspan="2">1</td><td colspan="2">1</td></tr>
<tr><td colspan="6">Pump</td></tr>
<tr><td colspan="2">50 L/min</td><td colspan="2">30 L/min</td><td colspan="2">30 L/min</td></tr>
<tr><td colspan="6">Approximate time to empty the entire tank</td></tr>
<tr><td colspan="2">5 min</td><td colspan="2">4 min</td><td colspan="2">3 min</td></tr>
<tr><td>Connectivity</td><td colspan="6">GSM, WiFi</td></tr>
</table>

After the measurement of the volume by means of standard vessels, the liquid can be transferred to the specified collection tank and the standard vessels can be used again. In the case of hydrocarbon fuels, two standard vessels (ON20 and ON100) are connected to five collection tanks. This allows the individual liquids (petrol, diesel, etc.) to be sorted as shown in Fig. 14.

The collection tanks for hydrocarbon liquids can be emptied using pumps with a flow rate of 50 L/min. The collection tanks for the washer fluids and AdBlue can be emptied using pumps with a flow rate of 30 L/min. All collection tanks also have the possibility to be emptied by gravity (Fig. 15).

Other technical data are given in Table 2.

Fig. 15 Ways of emptying the measured liquids (by gravity or pump)

## 7 Conclusion

Fuel dispensers are one of the most frequently used measuring instruments in business relations worldwide. Therefore, they require special attention. This was the main motivation for the development of a new generation of systems for the metrological control of dispensers used at fuel stations. The aim of the project was to develop and produce the MCoFD system for the verification of a wide range of dispensers in order to increase the credibility and efficiency of verification. The new MCoFD system enables the shutdown duration of dispensers during their metrological control to be shortened, thereby reducing financial losses for the seller.

The MCoFD system uses automation by means of intelligent image processing, complex data collection, and monitoring of accompanying quantities and their evaluation.

The new system has passed the phase of complete testing and is already in use in the Slovak Republic. The MCoFD system was presented to owners of fuel stations and received a positive response. Based on this positive response, the distribution of the design or even of the final product itself to countries expressing potential interest is being considered.

The development and production of the MCoFD system is the result of a research team that also included experts in the field of legal metrology – Miloš Ujlaky, Peter Cintula, Tomáš Kováč, Rastislav Bánik, Branislav Florek (Slovak Legal Metrology Institute) and experts in the field of science and research – Teodor Tóth (Faculty of Mechanical Engineering, Technical University of Košice) and Ľuboš Kučera (Faculty of Mechanical Engineering, University of Žilina).

The composition of the research team was balanced and allowed the theoretical knowledge of science and research from the university environment to be connected with the practical and technical knowledge from the field of legal metrology. This created a synergy of science and practice, which was a key factor in the design and realization of new MCoFD system. ■

## References

[1] OIML R 117-1, *Dynamic measuring systems for liquids other than water, Part 1: Metrological and technical requirements*, Edition 2019 (E)

[2] OIML R 117-2, *Dynamic measuring systems for liquids other than water, Part 2: Metrological controls and performance tests*, Edition 2019 (E)

[3] Directive 2014/32/EU of the European Parliament and of the Council, 2014/32/EU, The European Parliament and the Council of the European Union, 2014.

[4] Slovak Legal Metrology, *Method for automated verification of a fuel dispenser and equipment for carrying out the method*, Slovak utility model no. 7735, 2014, Jul. 3. 2021.

[5] F. M. Burdekin, *General principles of the use of safety factors in design and assessment*, Engineering Failure Analysis, vol. 14, no. 3, pp. 420-433, 2007.

[6] OPC Foundation, *OPC Unified Architecture Specification – Part 1: Overview and Concepts*, Version 1.04, 2017.

[7] E. R. Davies, *Computer and Machine Vision*, 4th. ed, Cambridge, MA, USA: Academic Press, 2012.

[8] I. Goodfellow, Y. Bengio and A. Courville, Deep Learning, Cambridge, MA, USA: MIT Press, 2016.