Wojciech WALENDZIUK, Adam IDŹKOWSKI

Department of Electrical Engineering, Bialystok University of Technology, Wiejska 45D str., 15-351 Bialystok, Poland

Comparative research on the uroflowmetry system based on a weight transducer

Streszczenie. *Celem niniejszej pracy jest ocena właściwości metrologicznych opracowanego przyrządu do pomiaru przepływu moczu. Badaniu poddano przepływy wzorcowych próbek, które dozowano przy pomocy stworzonego stanowiska laboratoryjnego. Dzięki przeprowadzonym próbom możliwe było porównanie kształtu charakterystyk przepływów, zarejestrowanych przy pomocy opracowanego przyrządu oraz przepływomierza elektromagnetycznego SM6000. W niniejszej publikacji przeprowadzono analizę zbieżności serii danych pomiarowych przy wykorzystaniu szacunku współczynników korelacji oraz odchylenia standardowego.* ***Ocena właściwości metrologicznych opracowanego przyrządu do pomiaru przepływu moczu***

Abstract. *The aim of the present work is to evaluate metrological properties of a specially constructed device used to measure the flow of urine. Model samples, which were dosed with the use of a specially prepared laboratory unit, were put under analysis. Due to the test, it was possible to compare the shapes of the flow characteristics which were recorded with the use of the specially constructed device and a magnetic inductive flow meter SM6000. For the purpose of this article, convergence analysis of a series of measurement data was conducted with the use of estimation of coefficient correlation and standard deviation.*

Słowa kluczowe: akwizycja danych, pomiar przepływu cieczy, techniki pomiarowe, metrologia.
Keywords: Data acquisition, fluid flow measurement, measurement techniques, metrology.

doi:10.12915/pe.2014.07.06

Introduction

One of the most frequent diseases of the urinary tract is benign prostatic hyperplasia (BPH). It is diagnosed when the volume of the gland exceeds 30 cm3 and the maximum flow of urine is less than 15 ml/s. It is estimated that the benign prostatic hyperplasia occurs at about 50% of men aged about 50 [1]. The disease, then, affects a large part of male population. This causes the necessity of building devices which can support medical diagnostics in this field. One of them, used for non-invasive examination of urine flow, is a uroflowmeter [2-5]. The machine measures the speed of the flow of urine released to a measurement container. Due to the analysis of the urine flow curves, the physician receives information which indicates the possibility of BPH occurrence. The advantages of this method are worth stressing. First of all, it is non-invasive. Moreover, the procedure of examining patients is not very complicated [6]. This makes it possible to conduct cheap and effective screening tests and selecting patients with possibility of pathogenic lesion within the urinary tract. Next, in order to confirm the initial diagnosis, the patient is interviewed on the basis of the IPSS questionnaire (International Prostate Symptom Score). Then a series of more expensive clinical and laboratory tests are done (e.g. indicating the level of prostate specific antigen – PSA). After that ultrasonography of the urinary tract is conducted.

As there are many advantages of examining patients with the use of a uroflowmeter, it was decided to construct such a device. Therefore, it was necessary to perform appropriate laboratory tests which would confirm that the flow recording is correct. For this reason it was decided that the results of a specially constructed uroflowmeter should be compared with the results recorded by a magnetic inductive flow meter SM6000 [7].

Measurement system

The newly built device measuring the urine flow is a cheap alternative of commercial ones. This was achieved through implementing a cheap strain gauge transducer, whose construction is based on a strain gauge placed on a cantilever beam. Basic technical parameters of the beam and the measurement system are presented in Tables 1 and 2.

Table 1. Strain gauge based, load sensor parameters

Measuring range	1000 g
Accuracy class	0.05
Supply voltage	10 V
Sensitivity	1 mV/V
Operating temperature	253 ÷ 353 K
Cantilever beam material	aluminum

Table 2. Uroflowmeter parameters

Resolution of the ADC	24 bits
Maximal measurement error in the temperature of 20ºC	< 0.0015% + load sensor error
Sampling rate	0.125 s
Number of maximal registered measurement series	10
Maximal registration time of measurement series	180 s
Internal memory	32 KB
Communication interfaces	RS232, USB
Transmission frame	9600 bps, 8 data bit, 1 stop bit, no parity

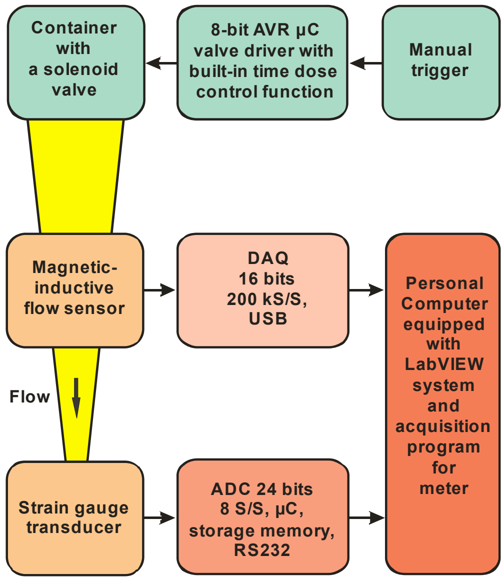

Fig. 1. Flow chart presenting the way of connecting the sub-assemblies elements of the laboratory unit

To conduct the research on comparing the flow curves achieved from the uroflowmeter and the magnetic conductive flow meter demanded building an appropriate laboratory unit (Fig. 1). Therefore, a measurement system consisted of functional modules was worked out. One of them is a liquid dozing module (water being this liquid). It consists of a container and an electromagnetic valve which initiates the flow of liquid. A microprocessor system, which activates the valve, measures time intervals between its opening and closing. The time interval for the present research equals 10 s.

The system of a magnetic inductive flow meter IFM Electronic SM6000 is another module. It is connected with a PC by a 16-bit measurement card. Basic technical parameters of the SM6000 sensor are presented in Table 3.

Table 3. SM6000 magnetic-inductive flow meter parameters

Measuring range	0.10÷25.00 l/min
Resolution	0.05 l/min
Analog output	4÷20 mA, 0÷10 V
Accuracy	± (2% MW + 0.5% MEW)
Repeatability	± 0.2% MEW

where: MW - measured value, MEW - final value of the measuring range

The aim of this part of the system is to activate measurement data from the device and, later, to process it with the use of LabVIEW. The last element of the laboratory unit is a uroflowmeter whose working procedure enables independent data recording. The worked out device makes it possible to store data of maximum 10 measurement series in its internal memory. Then, the data can be read and analyzed through the program created with the use of C++. General view of the laboratory stand is presented in figure 2.

Research procedure and achieved results

The research on comparing the liquid flow measured with the use of a uroflowmeter and a magnetic inductive flow meter was carried out on the laboratory unit presented in Fig.1. Using such a unit enabled obtaining repetitiveness of measurement through recording data in two devices at the same time moment and for equal amount of liquid dozed by a microprocessor sensor. All in all, 10 measurement trials were carried out, recorded and analyzed.

The first phase of the research was to check work correctness of the laboratory unit, including fluid dozing during the experiment. This was completed through analysis of the measurement results which proved repetitiveness of experiments. For this purpose, a correlation coefficient was calculated for particular series of measurement related to the average value of all series of measurement.

Particular correlation coefficients $corr\_uro(X_i, X_{mean})$ and $corr\_SM6000(X_i, X_{mean})$ were computed for the results recorded by the uroflowmeter and the magnetic inductive flow meter SM6000 with the use of the following formula (1):

(1) $$corr(X_i, X_{mean}) = \frac{\sum_{t=1}^{m}\left(\bar{x}_{mean(i,t)} - x_{mean(i,t)}\right)\left(x_{(i,t)} - \bar{x}_{(i,t)}\right)}{\sqrt{\sum_{t=1}^{m}\left(\bar{x}_{mean(i,t)} - x_{mean(i,t)}\right)^2\left(x_{(i,t)} - \bar{x}_{(i,t)}\right)^2}}$$

where: X_i – subsequent series of measurement $i=1...10$ obtained by the uroflowmeter or the SM6000 device, X_{mean} – averaged flow, $x(i,t)$ - value of the X_i – series sample, $x_{mean(i,t)}$ – value of X series sample.

Values of correlation coefficients are presented in Table 4.

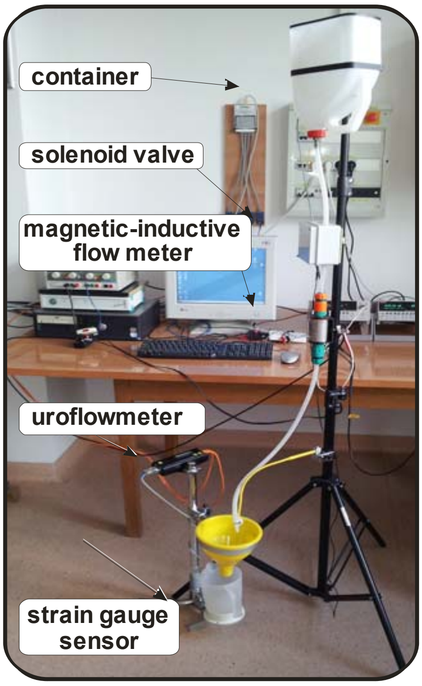

Fig. 2. General view of the laboratory stand

Table 4. Values of correlation coefficients for particular flows

Flow No	Uroflowmeter	SM6000
1	0.9982	0.9996
2	0.9986	0.9998
3	0.9979	0.9990
4	0.9974	0.9985
5	0.9966	0.9999
6	0.9977	0.9998
7	0.9986	0.9996
8	0.9986	0.9994
9	0.9937	0.9997
10	0.9893	0.9989

It is easily observable that maximum difference between correlation coefficient and the value of 1 - $corr\_uro(X_i, X_{mean})$ exceeded slightly 0.01, and $corr\_SM6000(X_i, X_{mean})$ almost equals 0.0015. On the basis of those results, it can be concluded that the flows in subsequent series of measurement are repetitive for both tested devices.

Another method which can prove repetitiveness of the achieved measurement results is the analysis of sample standard deviation. To analyze data series recorded by both devices, the following formula (2) was used:

(2) $$s_{(i,t)} = \sqrt{\frac{\sum_{i=1}^{n}\left(x_{(i,t)} - \bar{x}_{(i,t)}\right)^2}{n-1}}$$

where: n – number of analyzed measurement series, i – subsequent number of a measurement series, t – number of a sample of the recorded flow value in a particular measurement series.

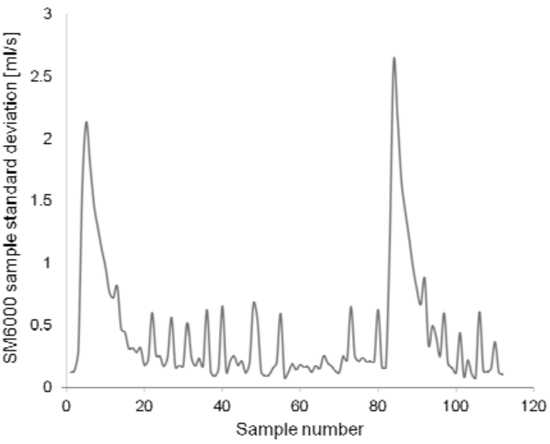

Fig. 3. Sample standard deviations computed from a series of measurement for SM6000 meter.

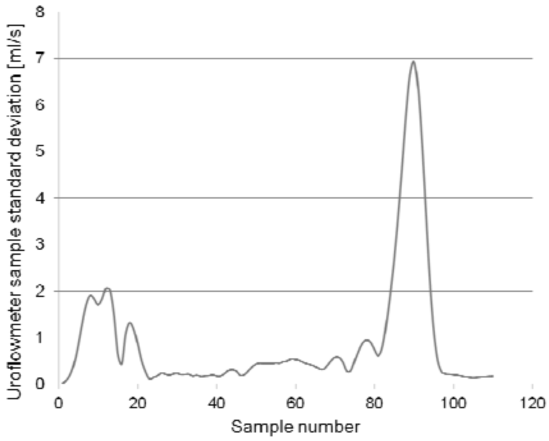

Fig. 4. Sample standard deviations computed for uroflowmeter

As it can be observed in Fig. 3 and Fig. 4, the biggest deviations from the average value occurred in the initial and final phases of the liquid flow. This derives from the fact that, in both cases, flow values change dynamically. Another reason of this situation can be the inaccuracy of timing of a data series. In the case of constant flow (middle part of the chart), the values of standard deviations were not very significant, which can prove fair repetitiveness of the experiment. Next phase of the research was analysis of the measurement results in order to compare them. As the true value of the measured flow is unknown, it was approximated with the help of an estimator (3), in this case it was the average value.

(3) $$\bar{x}_{(i,t)} = \frac{\sum_{i=1}^{n} x_{(i,t)}}{n}$$

Averaging of particular sample values for measurement series in a particular time moment (t) was achieved in this way. Mean flow charts are presented below, in Fig. 5.

Absolute error of flows recorded by two devices was calculated on the basis of the averaged data x_{uro} and x_{SM6000} due to the following formula (4):

(4) $$Err_{abs}\left(\bar{x}_{SM\,6000}\right) = \left|\bar{x}_{uro} - \bar{x}_{SM\,6000}\right|$$

and the relative error according to formula (5):

(5) $$Err_{rel}\left(\bar{x}_{SM\,6000}\right) = \frac{\left|\bar{x}_{uro} - \bar{x}_{SM\,6000}\right|}{\bar{x}_{SM\,6000}} \cdot 100\%$$

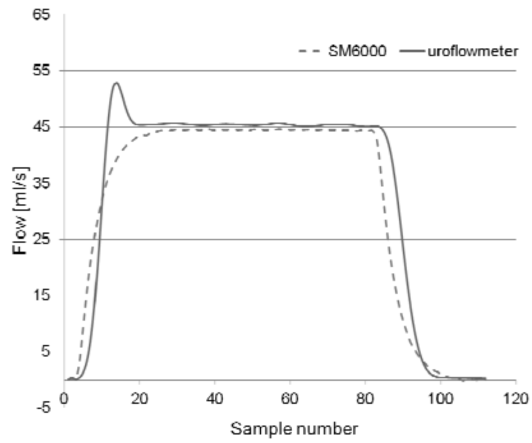

Fig. 5. Mean flow calculated from 10 series of measurement with the use of uroflowmeter and SM600 meter

As it can be observed in Fig. 5, maximum difference of the absolute error reached almost 20 ml/s. Its relatively high value is caused by the fact that the magnetic inductive flow meter was placed in the distance of about 1 m from the uroflowmeter. For this reason, the flow of fluid through the magnetic inductive flow meter finished earlier than through the uroflowmeter. Additional reasons of differences is the principle of working of both devices. The SM6000 machine measures the flow of liquid inside the tube conducting the liquid. The uroflowmeter uses the strain gauge transducer to collect the fluid in a container, and then calculates the increase of mass in time. For this reason, the uroflowmeter is very sensitive to measurement of fluid which is strongly distorted, especially in the initial phase of the flow recording (Fig. 6).

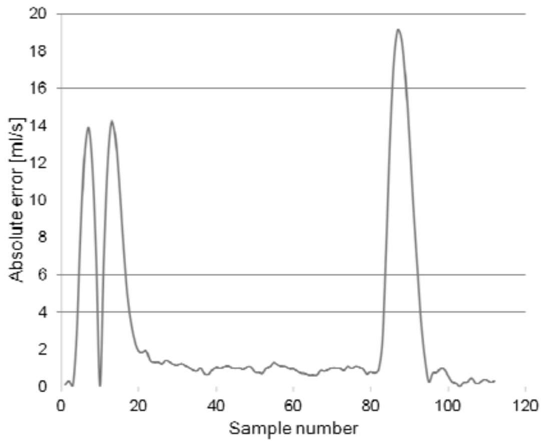

Fig. 6. Absolute errors of the flow registered with uroflowmeter and SM6000 meter

Figure 7 presents also relative error which, apart from previously described differences, perfectly shows a constant difference between both flows. The difference related to a slight offset towards zero point. It was observed at measurements done by the SM6000 device.

The last element of comparing measurement data was calculating the correlation coefficient of averaged data x_{uro} and x_{SM6000}. The coefficient shows the coherence of both graphs, and in the analyzed case it equaled 0.9633. This proves a good correlation of both mean flows.

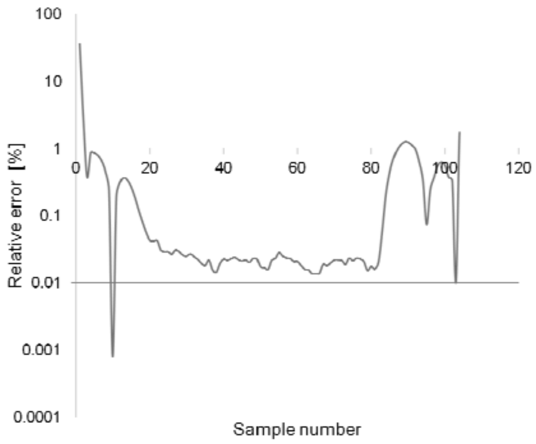

Fig. 7. Relative and absolute errors of the flow registered with uroflowmeter and SM6000 meter

Conclusions

The aim of this work was to compare liquid flows recorded by a specially built device for measuring the flow of urine and a commercial flow meter. Considering the results of experiments, it can be concluded that there is a strong correlation of the absolute values and the shape of the flow charts. The biggest differences between recorded data occurred in the initial and in the final phases of flow recording. This was caused by the capabilities of the measuring devices which were placed from each other in the distance of 1 m. Thus, they recorded the flow at different points of the laboratory unit. This fact caused slight differences of flow measurement at a given time moment.

The method of flow measurement was another source of differences. The uroflowmeter recorded the flow on the basis of the amount of collected liquid in a container, whereas the SM6000 machine measured the flow in a tube transmitting the liquid to the container. In spite of this imperfectness, only minor differences in the central parts of the graphs (Fig. 4) of the absolute and relative errors were observed. A slight difference of the absolute error of about 2 ml/s, which is directly connected with offset generated by the SM6000 device, proves that the achieved results are well correlated.

This work was supported by Bialystok Technical University research grant No S/WE/1/2013.

REFERENCRES

[1] I. Ostrowski, "Benign Prostatic Hyperplasia – selected issues", Urological Review, 2006/7/5 (39) (in Polish).
[2] Ch. R. Chapple, A. Mangera, "Overview of the Evaluation of Lower Urinary Tract Dysfunction", Practical Urology: Essential Principles and Practice, Springer Specialist Surgery Series 2011, pp. 261-282.
[3] A. Bray, C. Griffiths, M. Drinnan, R. Pickard, "Methods and Value of Home Uroflowmetry in the Assessment of Men With Lower Urinary Tract Symptoms: A Literature Review", Neurourology and Urodynamics, Vol 31, Issue 1, 2012, pp. 7-12.
[4] J. Makal, A. Idzkowski, W. Walendziuk, "Computer assisted uroflowmetry diagnostic system", Proceedings of SPIE, Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments, vol. 6347, Warsaw 2006.
[5] W. Walendziuk, A. Idzkowski, "Portable acquisition system for domiciliary uroflowmetry", Journal of Vibroengineering, Volume 11, Issue 3, 2009, pp. 592-596.
[6] P. Abrams, Urodynamics, Springer, 1997.
[7] Magnetic-inductive flow meter SM6000, Datasheet, http://www.ifm.com/

***Authors**: dr inż. Wojciech Walendziuk, Politechnika Białostocka, Wydział Elektryczny, ul. Wiejska 45D, 15-351 Białystok, E-mail: w.walendziuk@pb.edu.pl; dr inż. Adam Idźkowski, Politechnika Białostocka, Wydział Elektryczny, ul. Wiejska 45D, 15-351 Białystok, E-mail: a.idzkowski@pb.edu.pl*