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Accuracy Analysis on Dual Pressure (Positive and Negative) Calibrator Design to Investigate the Sensor Response

Abdi Wibowo¹, Triana Rahmawati¹, Priyambada Cahya Nugraha¹, I Dewa Gede Hari Wisana¹, Mansour Asghari², and Honey Honey³

¹ Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, INDONESIA

² Bonab Islamic Azad university, Bonab, Iran

³ Multani Mal Modi College, Patiala, India

#Corresponding author : Triana Rahmawati ([triana@poltekkesdepkes-sby.ac.id](mailto: triana@poltekkesdepkes-sby.ac.id))

ABSTRACT Calibration is an activity to determine the conventional correctness of the value of measuring instrument and material by comparing them against the national or international standards. A sphygmomanometer is a device used to measure blood pressure, while suction pump is a tool to suck various types of fluid formed from the body's secretion process that need to be cleaned when it is under certain conditions. Furthermore, DPM (Digital Pressure Meter) is a tool for calibrating both sphygmomanometers and suction pumps. Therefore, it takes a calibrator device to calibrate both tools. The purpose of this study was to determine the sensor response and analyze the accuracy of the dual pressure calibrator (+ and -) that can be used for two devices at once (sphygmomanometer and suction pump) using one sensor (pss-C01V-R18 autonics). The research was conducted at the Campus of the Department of Electrical Engineering of the Ministry of Health Surabaya. In this case, the first data were taken from three different brands of sphygmomanometer and suction pump, the second data were taken using module calibrators, and the third data were taken from modules and comparison tools (DPM). Furthermore, this study successfully measured positive and negative pressure using autonics sensors, where the results obtained were accurate and in accordance with the results of standard tools. Therefore, the result of this tool can be used for dual pressure calibrators using autonics sensors.

INDEX TERMS Autonics Sensor PSS-C01V-R18, Dual Pressure, Sphygmomanometer, Suction Pump.

I. INTRODUCTION

A sphygmomanometer or tensimeter is a device used to measure blood pressure that works manually or automatically in pumping or reducing pressure on cuffs with non-invasive systems [1][2][3]. Meanwhile, suction pump is a tool used to suck various types of fluids. A doctor will use this tool under certain conditions, such when there is fluid that can block the surgery process or cause emergency conditions that endanger the patient [4][5][6]. In order to maintain the accuracy of the measurement results on the Sphygmomanometer and Suction Pump, calibration is required to be done periodically. Calibration is the activity of determining the conventional truth of the value of measuring instruments and materials by comparing them against the national or international standards. In this case, DPM (Digital Pressure Meter) is a tool

used for calibrating both the Sphygmomanometer and Suction Pump [7][8] [9].

Previous research carried out by Tiar Prillian has created an Arduino-based DPM that can calculate the average and correct value of calibration results equipped with storage. However, the results were only displayed on the LCD (Liquid Crystal Display) so the calibration officer still had to manually input the data to the excel worksheet. In addition to that, the storage still used EEPROM with low battery capacity [10][11][12]. Furthermore, in Ida Ayu's research, DPM has been designed with automatic data processing, where the measurement results were stored in an SD Card and the software processed the data into a calibration worksheet and performed calculations automatically. However, the process of calculating and calibrating the data analysis must wait for the

SD Card [13][14][15]. Furthermore, another previous research was carried out by Adi Pramudono, in which a tool with the accuracy analysis of data acquisition system in sphygmomanometer design has been made, but has not been equipped with negative pressure measurements yet [16][17]. In addition, Junia Dyah Permata Wibisono conducted a study in 2017 where she made DPM using vacum mode [18]. In the following year, Yosef Kurniawan also made DPM with two modes but with a vacum limit of -400 mmhg with two different sensors [19][20]. Furthermore, Abdul Cholid Ridwan in 2019 made DPM with two modes equipped with temperature and humidity but with two different sensors as well [21][22]. In addition, in the following year, Ghassan Zafir Sasmita designed a digital pressure meter calibration tool equipped with a thermohygrometer in 2020 [23][24].

Based on the description above, the author analyzed the accuracy of the dual pressure calibrator (+ and -) design that can be used for two devices at once, namely the sphygmomanometer and suction pump using one sensor of the PSS-C01V-R18 autonics sensor. In this case, the positive pressure was used to calibrate the sphygmomanometer, while the negative pressure (vacuum) was used to calibrate the Suction Pump [25]. Then, the accuracy of the module was compared against the accuracy of the standard digital pressure

meter which was also carried out to know the sensor response under negative positive pressure.

The purpose of this study was to determine the sensor response and analyze the accuracy of the dual pressure calibrator (+ and -) design that can be used for two devices at once (sphygmomanometer and suction pump) using one sensor (PSS-C01V-R18 autonics).

II. MATERIALS AND METHODS

A. DATA COLLECTION

The research was conducted at the campus environment of Electrical Engineering. After the design was completed, the tool was tested through comparative tests to conduct measurements using both the modules and the standard tools. Then, the stability of the sensor was monitored in order to see the error of the sensor reading by recording the results for 4 minutes. Therefore, the results of the pressure sensor reading can be analyzed by displaying the reading graph for 4 minutes.

This study employed arduino uno microcontrollers to process the data transferred by ESP32 used to read the output of sensors, autonics pss-C01V-R18 sensor which was used to detect pressure exerted by the unit under the test, and Digital Pressure Meter used as a comparison tool when testing the modules. Furthermore, LCD TFT (Thin Film Transistor) and

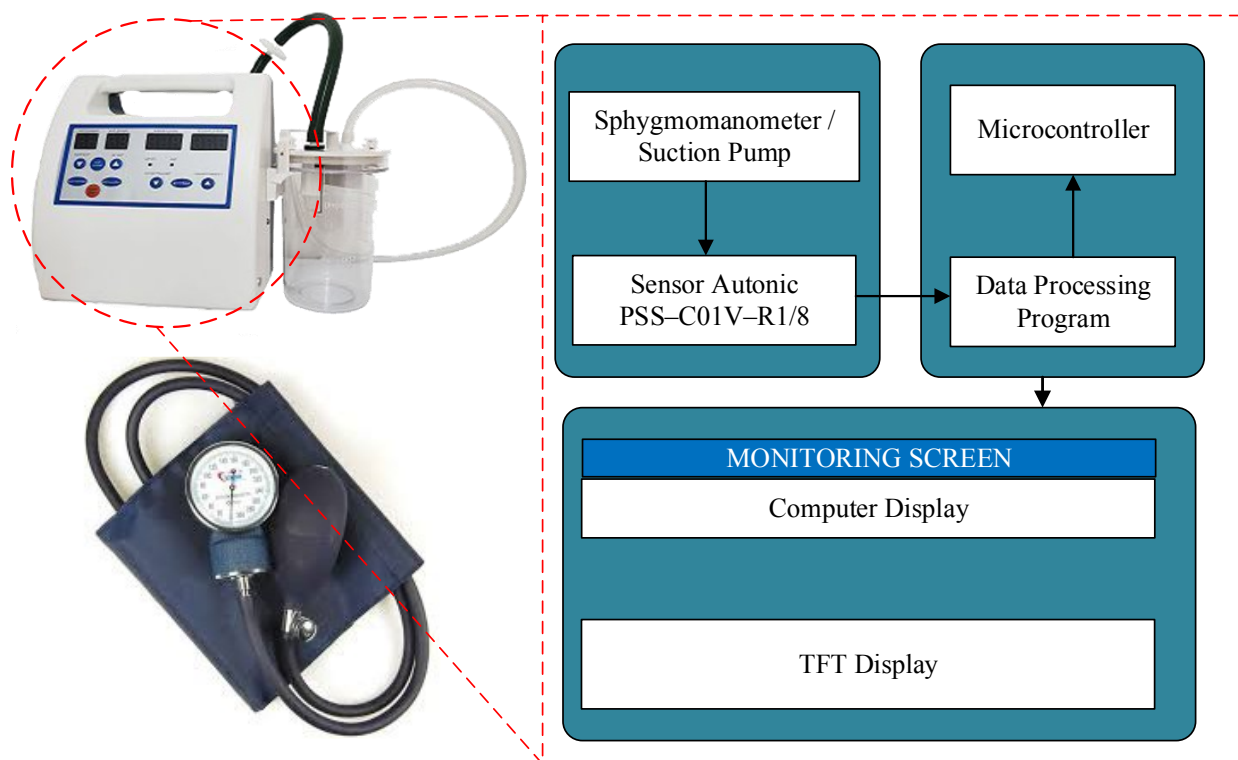


FIGURE 1. Block diagram of positive and negative pressure calibrators. The suction pump and sphygmomanometer were connected to the pressure sensor and the data were processed and displayed on the computer and tft screen.

PC (Personal Computer)/ Laptop were also used to display the module.

After the design was completed, the tool was tested through comparative tests to conduct measurements using both the modules and the standard tools. Then, the stability of the sensor was monitored in order to see the error of the sensor reading by recording the results for 4 minutes. Therefore, the results of the pressure sensor reading can be analyzed by displaying the reading graph for 4 minutes. Furthermore, 3 different brands of sphygmomanometer which work in accordance with the calibration method procedure were also employed to test the sensor at positive pressure. Therefore, it is necessary to analyze the accuracy of the dual pressure calibrator (+ and -) design that can be used for two devices at once, namely a sphygmomanometer and a suction pump, using one sensor. In this design, the positive pressure was used to calibrate the sphygmomanometer, while the negative pressure (vacuum) was used to calibrate the suction pump. Furthermore, the accuracy of the module was compared with the accuracy of the standard digital pressure meter, which at the same time, was conducted to know the sensor response when it gets negative positive pressure.

B. DATA ANALYSIS

Based on the monitoring and recording of the sensor readings at positive pressure for four minutes at the measurement point of 50 mmHg on three different tensimeter brands, the graph of the results was obtained. In this case, the highest and lowest ranges that the sensor readings produced was 7 mmHg, where when converted to kPa units was about 0.9 kPa. Monitoring and recording for four minutes on the sphygmomanometer allowed a fairly high leak to occur, resulting in a high difference between the top graph point and the bottom graph point. When viewed in mmhg units, the difference was quite high, but when converted to kPa units, the reading difference was only 0.9 kPa because the sensor used had kPa units according to the sensor datasheet. For the reading of the output voltage from the sensor at the 50 mmHg measurement point, it was stable at 2.841 V DC.

FIGURE 1. shows that the system started working when the sphygmomanometer or suction pump put pressure on the PSS-C01V-R1/8 autonics sensor which was then processed by the microcontroller by entering the program used to give instructions to the microcontroller. After that, the results of data processing on the microcontroller were displayed on the TFT LCD. In ESP32, there was also wifi used to transmit data to the PC/ Laptop by first pairing them. In this case, the PC/ Laptop serves to receive and process data which was then displayed in the form of graphics.

C. THE FLOWCHART

FIGURE 2. shows the process starting from checking the connection between the sphygmomanometer or suction pump with the input module of the PSS-C01V-R1/8 autonics sensor. This checking was done through the installation of a sphygmomanometer hose or suction pump with pressure

sensor input. If it is connected, then the next process of the pressure sensor is to get pressure from the unit under test. Furthermore, the results of pressure readings by the PSS-C01V-R1/8 autonics sensor are displayed on the TFT LCD and the data on the module are sent to the PC/ laptop using the wifi. The process of reading the results of the pressure is complete.

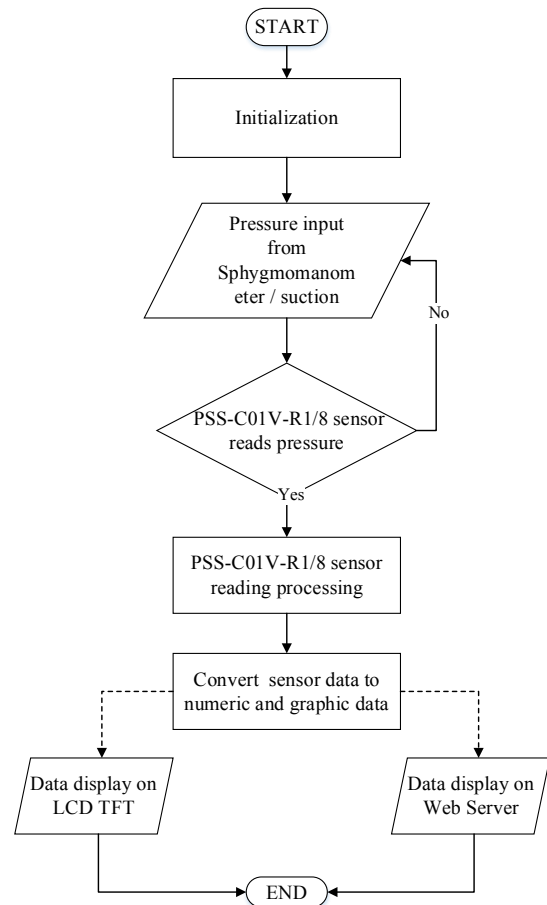


FIGURE 2. Flowchart measurement using Geiger Muller sensor for X-ray radiation measurement.

III. RESULTS

Three different brands of sphygmomanometer which work in accordance with the procedure of calibration were used to test the sensor at positive pressure. FIGURE 3. shows the entire module series. The schematic circuit consists of several components including PSS-C01V Sensor, ESP32, Arduino UNO, LCD TFT, Push button, and 12V adapter. The 12V adapter was connected to the VIN esp32 pin and +V PSS-C01V sensor that serve as a voltage supply. The Vo sensor output pin was connected to the D32 ESP32 pin. Push buttons were connected to D4, RX2 and TX2 pins respectively. Pin D14 and D27 on ESP32 were further connected to the RX and TX pins on the Arduino UNO, the pin serves to transfer the sensor reading data so that it can be processed by Arduino UNO.

FIGURE 3. shows how the module tests at positive pressure. In this figure, there are a sphygmomanometer, modules, comparison tools, and a PC/Laptop. Based on the results of the module testing carried out, the results showed that the sensor readings for positive pressure work was according to their characteristics, namely producing Ua on the suction pump.



FIGURE 3. Design of the module testing at positive pressure in the image, where there are a display on LCD TFT, PC/ Laptop as well as sphygmomanometer used for data retrieval on the tool.

FIGURE 4. shows how the module tests at positive pressure. In this case, there are a sphygmomanometer, modules, comparison tools, and a PC/Laptop. Based on the results of the module testing carried out, the results showed that the sensor readings for negative pressure work is according to their characteristics, namely producing Ua on the suction pump.

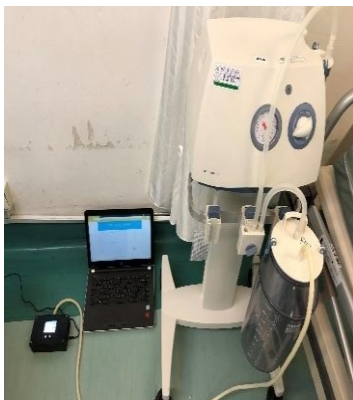


FIGURE 4. Design of the module testing at negative pressure in the image, where there are a display on LCD TFT and PC/ Laptop and a sphygmomanometer used for data retrieval on the tool

TABLE 1

Positive pressure measurement results with modules for parameters 1

Brand Positive Pressure Parameters 1			
Setting (mmHg)	Standard Deviation	Error	Ua
50	0.164317	0.70	0.027386
100	0.561249	0.95	0.093541
150	0.602218	0.04	0.10037
200	0.508593	-0.07	0.084765
250	0.763544	0.30	0.127257

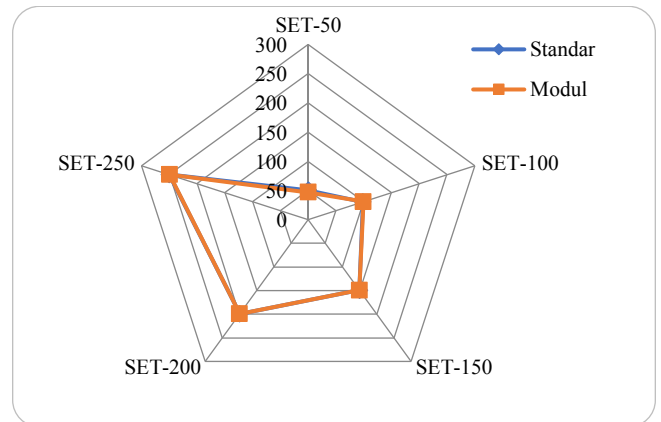


FIGURE 5. A comparison radar graph between sphygmomanometer measurements with standards and research modules results positives pressure

TABLE 1 shows the results of module tests conducted. Based on the table, it was found that the sensor readings against pressure has worked according to its characteristics, namely producing the largest Ua on the measurement of 250 mmHg and the lowest Ua on the measurement of 50 mmHg. Based on the results of the module testing carried out, it was found that the sensor readings for pressure work was according to their characteristics, namely producing the largest Ua at 250 mmHg and the lowest Ua at 50 mmHg.

TABLE 2

Positive pressure measurement results with modules for parameters 2

Brand Positive Pressure Parameters 2			
Setting (mmHg)	Standard Deviation	Error	Ua
50	0.613188	0.60	0.102198
100	0.492612	1.07	0.082102
150	0.477493	0.07	0.079582
200	0.685322	-0.01	0.11422
250	0.730525	0.13	0.121754

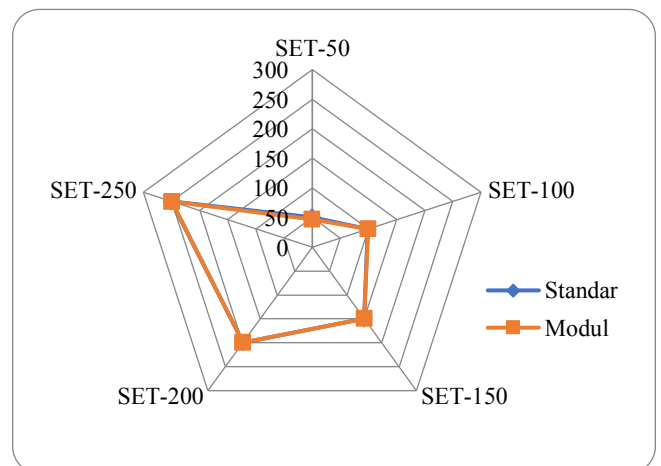


FIGURE 6. The figure shows a comparison radar graph between sphygmomanometer measurements with standards and research modules results positives pressure

TABLE 2 shows the results of module tests conducted, and it was found that the sensor readings against pressure work was according to its characteristics, namely producing the largest Ua on the measurement of 250 mmHg and the lowest Ua on the measurement of 50 mmHg. Based on the results of the module testing carried out, it was found that the sensor readings for negative pressure worked according to their characteristics, namely producing the largest Ua at the 10 kPa measurement at the first suction pump and the lowest Ua at 80 kPa at the second suction pump.

TABLE 3

Positive pressure measurement results with modules for parameters 3.

Brand Positive Pressure Parameters 3			
Setting (mmHg)	Standard Deviation	Error	Ua
50	0.219089	3.00	0.036515
100	0.438178	0.40	0.07303
150	0.34641	0.60	0.057735
200	0.383406	0.57	0.063901
250	0.652431	0.43	0.108739

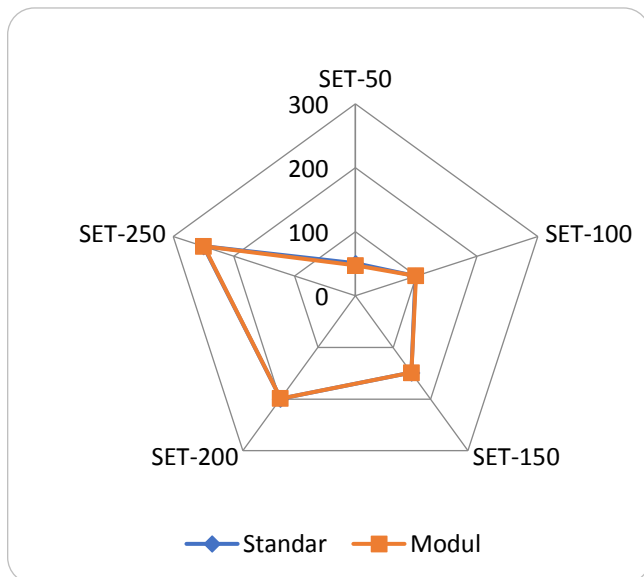


FIGURE 7. The figure shows a comparison radar graph between sphygmomanometer measurements with standards and research modules results positives pressure

TABLE 3 shows the results of module tests conducted, and it was found that the sensor readings against pressure has worked according to its characteristics, namely producing the largest Ua on the measurement of 250 mmHg and the lowest Ua on the measurement of 50 mmHg. Based on the results of the module testing carried out, it was found that the sensor readings for pressure has worked according to their characteristics, namely producing the largest Ua at 250 mmHg and the lowest Ua at 50 mmHg.

TABLE 4

Negative pressure measurement results with modules for parameters 1

Brand Negative Pressure Parameters 1			
Setting (kPa)	Standard Deviation	Error	Ua
-10	0.225093	5.33	0.037515
-20	0.116905	3.08	0.019484
-30	0.121106	0.44	0.020184
-40	0.075277	1.29	0.012546
-50	0.08165	1.67	0.013608
-60	0.147196	0.47	0.024533
-70	0.075277	0.31	0.012546
-80	0.150555	-0.21	0.025092
-85	0.08165	0.43	0.013608

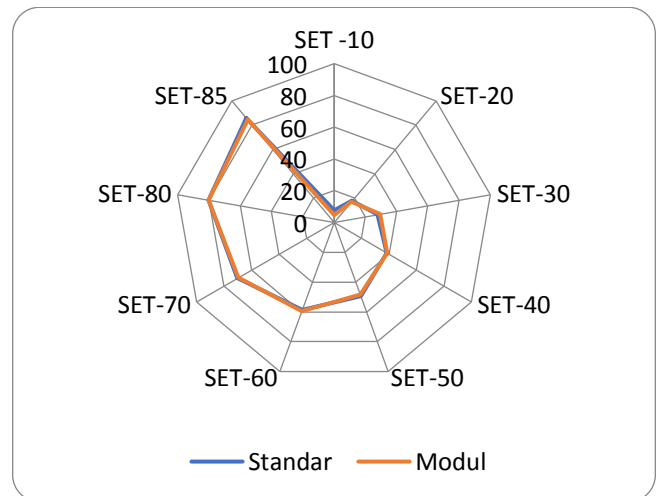


FIGURE 8. The figure shows a comparison radar graph between sphygmomanometer measurements with standards and research modules results at negative pressure

TABLE 5

Negative pressure measurement results with modules for parameters 2 and 3

Setting (kPa)	Standard Deviation	Error
-10	0.141421	6.00
-20	0.141421	3.50
-30	0.075277	2.72
-40	0.104881	2.88
-50	0.063246	5.40
-60	0.10328	2.72
-70	0.08165	3.52
-80	0.054772	2.19

TABLE 5 shows the results of the module tests conducted, and the results showed that the sensor readings against negative pressures have worked according to its characteristics, resulting in the largest Ua measurement at the first Suction Pump Under Test (UUT) and the lowest at the measurement of 80 kPa on the second UUT suction pump. Based on the results of the module testing carried out, it was found that the sensor readings for negative pressure have worked according to their characteristics, namely producing the largest Ua at the

10 kPa measurement at the first suction pump and the lowest Ua at 80 kPa at the second suction pump.

TABLE 6

Positive pressure measurement results against the standards

Setting (mmHg)	Standard Deviation	Error	Standard Deviation
50	0.17224	-0.43	0.13784
100	0.294392	1.37	0.34448
150	0.56006	0.72	0.361939
200	0.240139	0.49	0.685322
250	0.285774	-0.25	0.196638

TABLE 6 shows the results of positive pressure measurements by standard. It was known that the largest Ua was on measurements of 250 mmHg and the lowest Ua was on measurements of 50 mmHg.

TABLE 7

Negative pressure measurement results against the standards

Setting (kPa)	Standard Deviation	Error	Setting (kPa)	Standard Deviation	Error
-10	0.054772	2.50	-10	0.163299	6.33
-20	0.104881	2.25	-20	0.13784	11.25
-30	0.136626	2.11	-30	0.151658	4.17
-40	0.08165	1.67	-40	0.104881	3.13
-50	0.075277	0.57	-50	0.075277	3.37
-60	0.075277	1.36	-60	0.22286	3.31
-70	0.104881	-0.36	-70	0.13784	3.50
-80	0.075277	-0.27	-80	0.075277	1.52
-85	0.136626	-0.78			

TABLE 7 shows the results of negative pressure measurements against the standard. It was known that the largest Ua was on the measurement of 600 mmHg on the third suction pump and the lowest Ua was on the measurement of 10 kPa in the first suction. Furthermore, **FIGURE 8.** shows the results of monitoring and recording the sensor readings at positive pressure for 4 minutes at the measurement point of 50 mmHg on three different brands of tensimeters. Based on the graph, it was seen that the highest and lowest range produced by the sensor readings were 7 mmHg, where when converted to kPa units then the result is approximately 0.9 kPa.

Based on the results of monitoring and recording the sensor readings at positive pressure for four minutes at the measurement point of 50 mmHg on three different brands of tensimeters, it can be seen in the graph that the highest and lowest ranges produced by sensor readings are 7 mmHg, where when converted to kPa units, the results are approximately 0.9 kPa. Monitoring and recording on the sphygmomanometer for four minutes allows a fairly high leak to occur, resulting in a high difference between the top graph point and the bottom graph point. When viewed in mmhg units, the difference was quite high, but when converted to kPa units, the reading difference was only 0.9 kPa because the sensor used has kPa units according to the sensor datasheet. Furthermore, regarding the reading of the output voltage from

the sensor at the 50 mmHg measurement point, it was stable at 2.841 V DC.

IV. DISCUSSION

In this study, researchers have made a tool and analyzed the accuracy of the design of a dual pressure calibrator (+ and -) that can be used for two devices at once, namely the sphygmomanometer and suction pump using one sensor, which is the PSS-C01V-R18 autonics sensor. The PSS series analog pressure sensor features a compact rectangular design (L 11.8 mm x T 29.3 x P 24.8 mm, including pressure port). The results of the tool testing can be seen in the TFT LCD on the tool and can also be seen on the PC/ Laptop. On the positive pressure measurement on the sensor reading module, the pressure works according to its characteristics, resulting in the largest Ua on the measurement of 250 mmhg and the lowest Ua on the measurement of 50 mmHg. Meanwhile, concerning the negatf pressure measurement in the module, it produced the largest Ua on the first 10 kpa suction pump on the first Suction Pump Under Test (UUT) and the lowest Ua on the measurement of 80 kpa on the second UUT suction pump. On standard positive pressure measurements, it was known that Ua was the greatest on measurements of 250 mmHg and was the lowest on the measurements of 50 mmHg. Furthermore, on standard negative pressure measurements, it was known that Ua was the greatest on the measurement of 600 mmHg on the third suction pump and lowest on the measurement of 10 kPa on the first suction.

The results of monitoring and recording sensor readings at positive pressure for 4 minutes at the measurement point of 50 mmHg on three different brands of tensimeters are seen on the graph of the highest and lowest range produced sensor readings. The results obtained were 7 mmHg where if it was converted to kpa units, it obtained approximately only 0.9 kPa with the output voltage of the sensor stable at 2.841 V DC. At the point of measurement of 100 mmHg, the highest and lowest range produced sensor reading was 14 mmhg, where if converted to kpa units then the result was approximately 1.8 kPa with the output voltage of the sensor stable at 2.968 V DC. Furthermore, at the point of measurement of 150 mmHg, the highest and lowest range produced sensor readings were 9 mmhg, where if converted to kpa units, then the result was approximately 1.18 kPa with a stable output voltage at 3.083 V DC. At the measurement point of 200 mmHg, the highest and lowest range produced sensor reading was 20 mmHg where if converted to kPa units then the result was approximately 2.6 kPa with the output voltage of the sensor stable at 3.213 V DC. At the measurement point of 250 mmHg, the highest and lowest range produced sensor reading was 70 mmHg where if converted to kPa units then the result is approximately 9.2 kPa with the output voltage of the sensor stable at 3.326 V DC. At the measurement point of -10 kPa, the graph range was 2 Kpa with the output voltage of the sensor stable at 2.528 V DC. At the measurement point of -20 kPa, the graph range was -20 kPa with the output voltage of

the sensor stable at 2.352 V DC. At the measurement point of -30 kPa, the graph range was -30 kPa with the output voltage of the sensor stable at 2.165 V DC. At the measurement point of -40 kPa, the chart range was 0.7 kPa with the output voltage of the sensor stable at 2.008 V DC. At the measurement point of -50 kPa, the graph range was -50 kPa on the first suction and 1.4 kPa for the second suction with the output voltage of the sensor stable at 1.814 V DC. At the measurement point of -60 kPa, the chart range was 1.2 kPa on the first suction and 0.7 kPa for the second suction with the output voltage of the sensor stable at 1.644 V DC. At the measurement point of -70 kPa, the chart range was 1 kPa on the first suction and 1.1 kPa for the second suction with the output voltage of the sensor stable at 1.470 V DC. At the measurement point of -80 kPa, the graph range was 0.8 kPa with the output voltage of the sensor stable at 1.286 V DC. At the measurement point of -85 kPa, the chart range was 0.7 kPa with the output voltage of the sensor stable at 1.203 V DC. At the measurement point of 500 mmHg, the chart range was 13 kPa with the output voltage of the sensor stable at 1.528 V DC.

Previous research conducted by Yosef Kurniawan has made DPM with two modes but with a vacuum limit of up to -400 mmhg with two different sensors [28]. In 2019, another research project was also done by Abdul Cholid Ridwan making a DPM with two modes equipped with temperature and humidity but with two different sensors as well [23]. Meanwhile, the current study successfully measured the sphygmomanometer and suction pump using the PSS-C01V-R18 autonics sensor as a medium of positive and negative pressure readings using one sensor. This module produced a reading output that is close to the standard tool so it is considered to be accurate as a calibrator to calibrate the sphygmomanometer and suction pump according to the calibration working method.

V. CONCLUSION

The purpose of this study is to determine the sensor response and analyze the accuracy of the dual pressure calibrator design (+ and -) that can be used for two devices at once (sphygmomanometer and suction pump) using one sensor (pss-C01V-R18 autonics). This study successfully measures the sphygmomanometer and suction pump using the PSS-C01V-R18 autonics sensor as a medium of positive and negative pressure readings using one sensor. This module produces a reading output that is close to the standard tool so it is considered accurate as a calibrator to calibrate the sphygmomanometer and suction pump in accordance with the calibration working method. Thoroughly, it can be concluded that the sensor response used is very responsive to positive and negative pressure readings. It is further suggested that the future research use a battery system so it does not always rely on adapter cables that are used continuously and look for other sensor references that can be used to read both positive and negative pressures with just one sensor and that have thoroughness in mmhg units. The results of positive pressure

measurements by standard showed that the sensor readings for pressure worked according to their characteristics, which produced the largest error value of 0.87%, while the results of positive pressure measurements by standard obtained 11.25% results.

REFERENCES

- [1] J. E. Yoo *et al.*, "Blood pressure variability and the risk of dementia a nationwide cohort study," *Hypertension*, pp. 982–990, 2020, doi: 10.1161/HYPERTENSIONAHA.119.14033.
- [2] K. Soueidan, S. Chen, H. R. Dajani, M. Bolic, and V. Groza, "The effect of blood pressure variability on the estimation of the systolic and diastolic pressures," *2010 IEEE Int. Workshop Med. Meas. Appl. MeMeA 2010 - Proc.*, pp. 14–18, 2010, doi: 10.1109/MEMEA.2010.5480215.
- [3] S. I. Ando, "What does a perfect blood pressure meter look like from a clinician point of view?," *IEEE Instrum. Meas. Mag.*, vol. 17, no. 3, pp. 15–20, 2014, doi: 10.1109/MIM.2014.6825383.
- [4] A. E. Cattaert, "High pressure pump efficiency determination from temperature and pressure measurements," *IEEE PES PowerAfrica 2007 Conf. Expo. PowerAfrica*, no. July, pp. 16–20, 2007, doi: 10.1109/PESAFR.2007.4498076.
- [5] A. Ferreira, J. R. Boston, and J. F. Antaki, "A control system for rotary blood pumps based on suction detection," *IEEE Trans. Biomed. Eng.*, vol. 56, no. 3, pp. 656–665, 2009, doi: 10.1109/TBME.2008.2005960.
- [6] A. Ferreira, M. A. Simaan, J. R. Boston, and J. F. Antaki, "Frequency and time-frequency based indices for suction detection in rotary blood pumps," *ICASSP IEEE Int. Conf. Acoust. Speech Signal Process. - Proc.*, vol. 2, pp. 1064–1067, 2006, doi: 10.1109/icassp.2006.1660530.
- [7] S. Qiu *et al.*, "Body Sensor Network-Based Gait Quality Assessment for Clinical Decision-Support via Multi-Sensor Fusion," *IEEE Access*, vol. 7, pp. 59884–59894, 2019, doi: 10.1109/ACCESS.2019.2913897.
- [8] K. Barbe, W. Van Moer, and D. Schoors, "Analyzing the Windkessel Model as a Potential Candidate for Correcting Oscillometric Blood-Pressure Measurements," *IEEE Trans. Instrum. Meas.*, vol. 61, no. 2, pp. 411–418, Feb. 2012, doi: 10.1109/TIM.2011.2161933.
- [9] A. Turk, A. Hamarat, and B. Karaboce, "Comparison of Manual and Automated Pressure Calibration Methods of Medical Pressure Calibrator," in *2020 IEEE International Symposium on Medical Measurements and Applications (MeMeA)*, Bari, Italy, Jun. 2020, pp. 1–6. doi: 10.1109/MeMeA49120.2020.9137288.
- [10] Medicine & Healthcare Products Regulatory Agency, "Blood Pressure Measurement Devices," *Med. Heal. Prod. Regul. Agency*, vol. 2, no. 1, pp. 1–16, 2021.
- [11] J. Kijonka and M. Penhaker, "Electronic invasive blood pressure simulator device for patient monitor testing," *Elektron. Ir Elektrotechnika*, vol. 122, no. 6, pp. 49–54, 2012, doi: 10.5755/j01.eee.122.6.1820.
- [12] A. Turk and A. Hamarat, "Automated Pressure Calibration of Blood Pressure Measuring Device Calibrator To Realize Its Traceability," in *2019 IEEE International Symposium on Medical Measurements and Applications (MeMeA)*, Istanbul, Turkey, Jun. 2019, pp. 1–5. doi: 10.1109/MeMeA.2019.8802215.
- [13] S. I. Ando, H. R. Dajani, and J. S. Floras, "Frequency domain characteristics of muscle sympathetic nerve activity in heart failure and healthy humans," *Am. J. Physiol. - Regul. Integr. Comp. Physiol.*, vol. 273, no. 1, pp. 42–1, 1997, doi: 10.1152/ajpregu.1997.273.1.r205.
- [14] W. W. Nichols, C. R. Conti, W. E. Walker, and W. R. Milnor, "Input impedance of the systemic circulation in man," *Circ. Res.*, vol. 40, no. 5, pp. 451–458, 1977, doi: 10.1161/01.RES.40.5.451.
- [15] V. Vijay, B. Akila, and Sabitharamakrishnan, "Development of calibration procedure and calculation of uncertainty for critical care medical parameters," in *2014 International Conference on Green Computing Communication and Electrical Engineering*

- (ICGCCEE), Coimbatore, India, Mar. 2014, pp. 1–6. doi: 10.1109/ICGCCEE.2014.6922407.
- [16] Y. C. Yu and J. Porter, “Mathematical modeling of ventricular suction induced by a rotary ventricular assist device,” *Proc. Am. Control Conf.*, vol. 2006, pp. 707–712, 2006, doi: 10.1109/acc.2006.1655439.
- [17] E. Lim *et al.*, “Parameter-Optimized Model of Cardiovascular-Rotary Blood Pump Interactions,” *IEEE Trans. Biomed. Eng.*, vol. 57, no. 2, pp. 254–266, 2010, doi: 10.1109/TBME.2009.2031629.
- [18] Jin Wanyu, Zuo Siran, Sun Dehui, and Wang Zhongyu, “Multi-channel automatic calibration system of pressure sensor,” in *2016 IEEE Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC)*, Xi’an, China, Oct. 2016, pp. 506–510. doi: 10.1109/IMCEC.2016.7867263.
- [19] D. W. Jones and J. E. Hall, “Hypertension: Pathways to success,” *Hypertension*, vol. 51, no. 5, pp. 1249–1251, 2008, doi: 10.1161/HYPERTENSIONAHA.108.113746.
- [20] A. C. Ridwan and H. G. Ariswati, “DPM Two Modes Are Equipped With Temperature And Humidity,” vol. 1, no. 1, pp. 1–5, 2019.
- [21] L. Xu and M. Fu, “Computer modeling of interactions of an electric motor, circulatory system, and rotary blood pump,” *ASAIO J.*, vol. 46, no. 5, pp. 604–611, 2000, doi: 10.1097/00002480-2000090000-00020.
- [22] Z. S. Ghassan, “Rancang Bangun Alat Kalibrasi Digital Pressure Meter,” pp. 1–7, 2020.
- [23] Z. Machacek and V. Srovnal, “Automated System for Data Measuring and Analyses From Embedded Systems,” *Meas. Control*.
- [24] N. Thongpance, Y. Pititeeraphab, and M. Ophasphanichayakul, “The design and construction of infusion pump calibrator,” in *The 5th 2012 Biomedical Engineering International Conference*, Muang, Ubon Ratchathani, Thailand, Dec. 2012, pp. 1–3. doi: 10.1109/BMEiCon.2012.6465429.
- [25] D, “Dpm Dua Mode,” *עלון דנטש*, vol. 66, pp. 37–39, 2012.

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