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# SMART WIRELESS LOW POWER VALVE POSITIONER DEDICATED FOR USE IN AVIATION LABORATORIES

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**Abstract.** Testing aircraft components in laboratories is crucial phase of developing new technologies in aviation. Component testing helps to find design mistakes or check durability and efficiency, which increase safety. Despite such an important role of laboratory tests in Aviation, valve positioners with insufficient capabilities are often used during the research. In many cases range of tests are limited because too low flow or pressure control resolution. Moreover, valves with valve positioners are moved between test rigs and change placement in the test room which generate laborious work with wiring and configuration. This paper shows the way for increasing capabilities of laboratory control system with use of smart, wireless, battery powered valve positioners. Following sections show control algorithm, PCB design and test results. Research shows that designed valve positioner controller enables the system to reach control accuracy many times higher than typical valve positioners available on the market and could operate directly with external sensors. Moreover, low power design approach enables valve positioner to operate for months without battery replacement. In proposed approach, positioner could be controlled remotely through Bluetooth Low Energy and could work as a part of laboratory IoT (Internet of Things) network.

**Keywords:** valve positioner, IoT, smart transducer, aviation, laboratory, component testing.

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## 1. Introduction

Efficient and reliable testing of components is essential to ensure safety. Test results have a direct impact on the imposed temperature, load or fatigue limits, and in many cases are the basis for redesigning components. Tests performed in aviation laboratories are very diverse in nature due to different roles of the tested components. There are laboratories specializing in testing large aircraft components, e.g. engines (Fabry et al., 2019; Kotha, 2023), but in most cases smaller components or systems are tested, e.g. jet engine bearings, oil systems, starters, heat exchangers. In aviation research centers, there are many different laboratories focused on individual areas of research (SAE International, 2016; U.S. Department of Transportation, 2010; RTCA Inc., 2023; He et al., 2018; Łukasiewicz Research Network – Institute of Aviation, 2015). Despite the great diversity, many of them experience the same problems with insufficient flow control accuracy. For example, during heat exchanger tests, the maximum and minimum values of the set flow can differ from each other by more than 1000 times. A similar situation occurs in bearing tests where we check the minimum allowable flow for the bearing. Despite this, most positioners do not allow for accuracy greater than 0.25% of the full valve opening. The smallest flows in tests can start as low as 0.01 l/min (liters per minute), which exceeds the capabilities of positioners currently available on the market. This is largely due to the different requirements of typical industrial applications for which they were designed. The indicated limitations also apply to pressure and temperature control using positioners. Furthermore, valves with valve positioners are often moved between test rigs and change placement in the test room which generate laborious work with wiring and reconfiguration. The above problems can be solved by introducing smart wireless positioners dedicated to use in aviation laboratories, as will be presented. The main scientific purpose of the described research was to develop control methodology which will increase the control accuracy of valve positioners used during aircraft component testing, which is a real problem in many test campaigns. The goal of project is to design a valve positioner controller which could operate at low power mode for months with high control accuracy, working as a part of laboratory IoT wireless network. Smart IoT devices are currently revolutionizing many fields of technology (Schütze et al., 2018; Ullo & Sinha, 2021; Pech et al., 2021; Sharma et al., 2021), so their wider introduction in aviation laboratories could bring significant benefits. There has been much research on smart positioners over the years (Cheng et al., 2020; Kalaiselvi, 2015; Xu et al., 2019; Gu et al., 2012; Zhang et al., 2022), but there is a lack of research aimed at solving problems encountered during testing of aircraft components. This was a source of motivation to start research in this area. Literature research shows that two main test types could be distinguished in aviation laboratories, corresponding to long-term tests (even over 1 year) and shorter performance tests (usually a maximum of several weeks). In the case of long-term tests, it is required to maintain a constant valve opening level or change the opening at a specific moment of the test cycle. Typically, the goal of long endurance tests is to investigate wear of test object (Manikandan et al., 2018). In short performance tests, where the capabilities of the components are checked in extreme operating conditions, subsequent points of the planned test program are carried out. Each subsequent point consists of changing the temperature, pressure or flow and waiting for stabilization after changing the settings, which takes from several to several dozen minutes. Therefore, for both groups of tests, the positioner remains motionless for most of the time or performs short corrective movements. It is easy to find an analogy to the operation of low power measurement transducers which are woken up only for the time of measurement and data transmission (Nikolic et al., 2014; Dementyev et al., 2013; Djadour et al., 2019; Yang & Li, 2010). Noticing these features was the basis for assuming the possibility of constructing an actuator with low energy consumption and initiating the presented research. Research was focused on positioners with electric motors not positioners powered by air, because they are more convenient to redesign for wireless operation. Moreover, electric drives offer better stability in steady states which is important in components testing (Emerson, 2023).

## 2. Methodology

### 2.1. Basic system structure

The literature review and market analysis made it possible to made following design assumptions for the design of low power wireless smart controller of valve positioner:

- integration with selected positioner used in the Component Test Laboratory;
- cooperation with DC motors;
- battery power supply;
- low energy consumption ensuring long battery life;
- operation frequency in the range of 0.1–2 Hz (frequency of communication, measurements and maximal frequency of steps);
- wireless communication via BLE (Bluetooth Low Energy);
- high control accuracy, maximal deviation from the setpoint not higher than +/– 0.05 l/min (lpm, liters/minute);

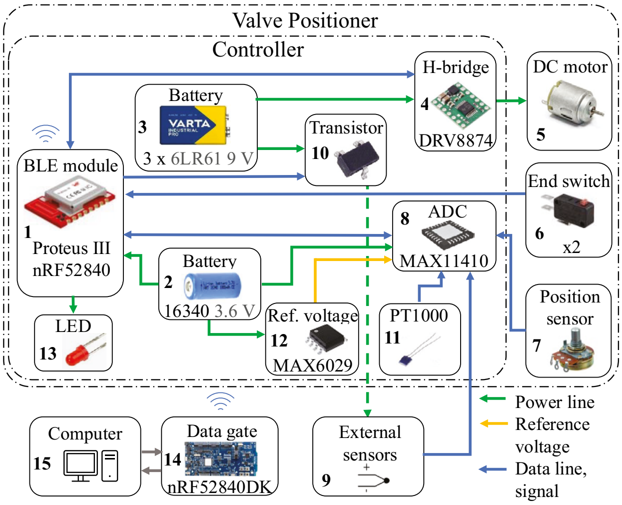


**Figure 1.** Basic diagram of control system

- operation with internal and external sensors: potentiometers, limit switches, RTD's (Resistance Temperature Detectors), thermocouples and voltage output sensors e.g. flow meters or pressure sensors.

The basic structure of the designed system is shown in Figure 1. One of the most important criteria when selecting components was to reduce energy consumption so most of components are low power. The BLE module based on popular SoC (System on Chip) nRF52840 (1) is responsible for handling BLE communication and controlling the operation of other components. That part of the device is powered by a single 3.6 VDC battery (2). Set of three 9V batteries (3) was connected in series to power motor controller (4) and motor (5). The DRV8874 motor controller chip is controlled by the EN, PH and SLEEP lines, which are responsible for turning on the drive, the direction of rotation and switching on the energy saving mode. The redesigned positioner has integrated end position switches (6) and a potentiometer (7) informing about the position of the valve head. The resistance is measured by the ADC MAX11410 (8) based on a reference to a precise reference resistor. Thanks to wide functions of MAX11410 transducer could also work with external sensors (9), e.g. thermocouples, pressure sensors, flow meters (Kabala & Weremczuk, 2024). The transistor (10) allows for switching on the power supply of external sensors (e.g., pressure sensor). The resistive temperature sensor (11) is used for temperature compensation in measurements with thermoelectric temperature external sensors. All voltage measurements are performed with reference to a reference voltage source (12). External sensors could be used to create a simple control system, e.g. flow, temperature or pressure. Moreover, the transducer has integrated LED (13) which could be used for basic communication with the user. Measurements are sent wirelessly to the data gateway (14) and then to the main computer (15). The same way but opposite direction is used to send control values.

## 2.2. Printed Circuit Board design

One of main goals of PCB design was to prepare a controller which could replace PCB of valve positioner used in the laboratory, but it should be also easily adopted for another valve actuators. To fulfill the project requirements the project was divided into three modules: the base module (Figure 2) with batteries, the module responsible for control, measurements and communication (Figure 3) and the selected motor controller module (available on the market). The base module was prepared in such a way that the controller could replace the original electronic board of the selected positioner, which resulted in dimensional limitations. Measurements and communication module and motor controller module are installed on the top of base module. DC motor, and limit switches could be connected to screw terminal on the base module. Potentiometer integrated with the valve positioner and external sensors could be connected to screw terminal on the measurements and communication module. Installing the designed controller requires only removing the original PCB, installing the set of modules, reconnecting the motor wires, potentiometer, and end position switches. This design method will ensure easy adaptation to other positioners in the future by changing the shape of the basic module and changing the motor controller board, e.g. when the system will work with different types of motor.

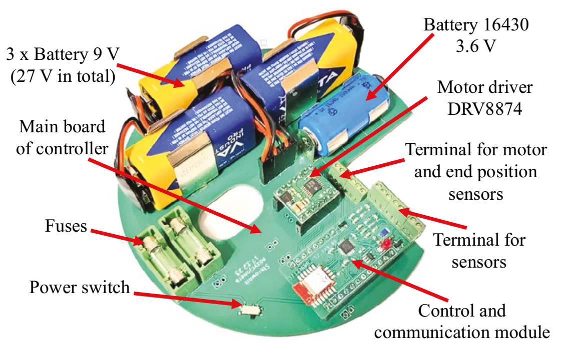


**Figure 2.** Main PCB

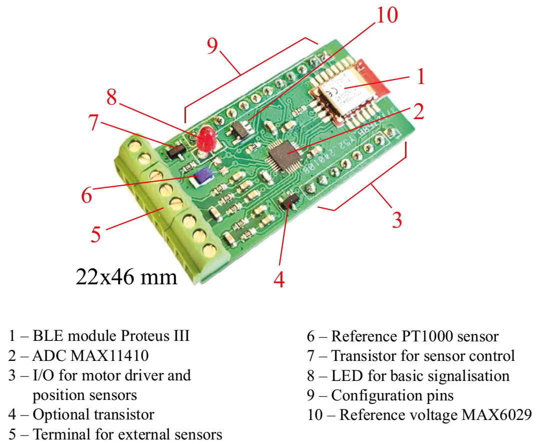


**Figure 3.** Measurements and communication module

## 2.3. Control algorithm

In accordance with the presented requirements control algorithm should be low power and very accurate, but it doesn't have to be very fast, because most of measurement are performed at steady states. The proposed DC motor control methodology is similar to the operation of a stepper motor and consists in performing steps at specific time intervals, between which the motor does not operate. However, the angular displacement of motor shaft during one step depends on the step duration set by the parameter T_time. The frequency of steps depends on the parameter T_step which is the period between beginning of subsequent steps (Figure 4). The step duration and frequency are changed according to range to which the current control error is assigned (Figure 5). The error is calculated as a difference between the setpoint for the controller and the measured value. Motor stops its movements when the error value reaches the deadband defined by parameter e0. The transducer is woken up from the energy saving mode in order to receive the setpoint from master device or perform movement. The direction of the step depends on the sign of the control error. The shortest possible time to set between drive activations is equal to the time between subsequent connections via BLE (basic operation frequency), configured in the connection settings. Slow movements close to the deadband has a positive effect on the control accuracy, because after change, the controlled process needs time to stabilize the physical parameters.

The motor controller board (available on the market) was built around DRV8874 (Figure 6) integrated circuit module from Texas Instruments. DRV8874 is responsible

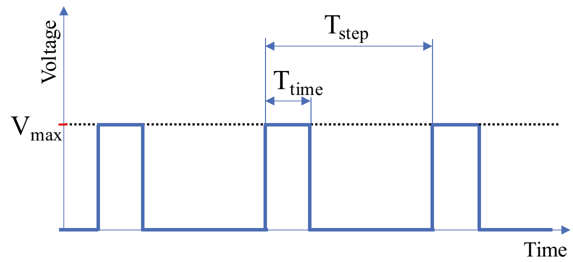


**Figure 4.** Control signal modulation

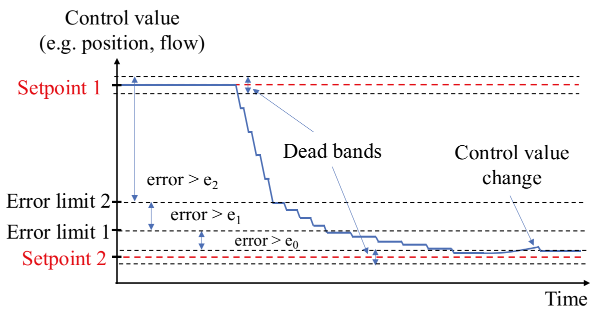


**Figure 5.** Example operation of control algorithm

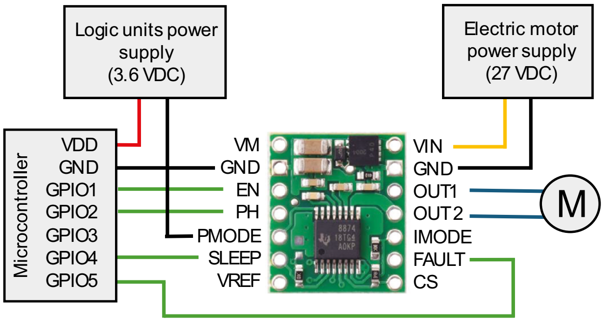


**Figure 6.** Connection diagram of module with DRV8874

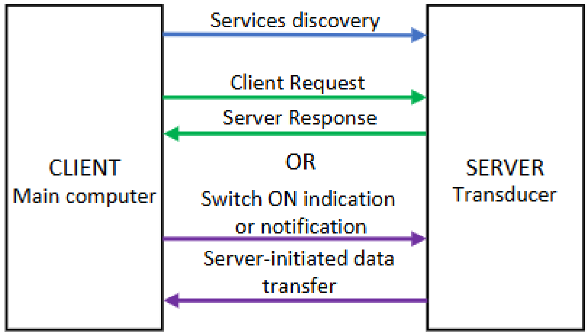


**Figure 7.** Two basic ways of data transfer in BLE

for changing the direction of the motor rotation. This is a chip with integrated H-bridge dedicated to drive operation, which can be supplied with a voltage from 4.5 V to 37 V, with a maximum continuous current of up to 2.1 A (Texas Instruments, 2019). It can also be used to amplify the PWM (pulse-width modulation) signal when it is necessary to control the speed of the motor rotation, but this option was not used in the project. The supply voltage during each step will therefore be constant, and only the average speed of movement will change, depending on the frequency and duration of the steps. The motor controller is equipped with protection against reverse polarity, too low voltage, too high temperature and too high current. To operate the motor controller board, only three microcontroller pins are required, connected to the EN, PH and SLEEP inputs. The EN input activates the drive. The PH connector allows you to control the direction of the motor rotation. It is responsible for switching the H-bridge built into the system. The DRV8874 can also operate in sleep mode, in which the current consumption drops below 1 μA.

### 2.4. Communication

When starting communication, the positioner controller acts as a peripheral device and sends advertising packets. The central device scans and establishes a connection when scanning and advertising occurs at the same time. BLE has 3 broadcast channels and 37 channels for data transmission (Kambourakis et al., 2020; Moreno-Cruz et al., 2020; Woolley, 2020; Li et al., 2019). The channels used are periodically changed to optimize transmission. After establishing the connection, the controller gets the role of a server that provides data to a client device, which in the tested case is a BLE module connected to a computer (Figure 7). The program simulates the operation of a serial port using data transmission via notifications. The BLE protocol is supported by the S140 system software provided by Nordic Semiconductors (Nordic Semiconductor, 2024). The communications frequency (showing how often it communicates) is set in the device parameters, which was also used to determine the moment of performing measurements and movement. The maximal frequency of measurements and movements couldn't be higher than communications frequency. Movements are performed a specific time before the data transmission operation which is controlled by the timer. It is possible to set measurements and movement to be performed in each or every few communication events, which was used to change the average speed of movement depending on the size of the control error. Higher communication frequencies cause higher power consumption which was investigated during power optimisation. According to the available documentation, it is possible to create a star network consisting of twenty devices (Nordic Semiconductor, 2019). Test rig presented in next chapter is equipped with inverter controlled electric motors which are potential sources of electromagnetic noise. Moreover, test rig is in range of Wi-Fi laboratory network. Test results show that BLE could be used in laboratory environment during operation of test rig equipment.

## 3. Results

### 3.1. Test rig configuration

Positioner (1) with the designed controller (2) was installed on the test stand in the Component Testing Laboratory, as shown in Figure 8 and Figure 9. The positioner works with a 1/2" valve with linear characteristics (3) and a stroke of 16 mm, at an oil input pressure of 35 bar. A precise dial gauge (4) was used to measure valve head movement with an accuracy of 0.001 mm. A thermocouple (5), a turbine flow meter (6) and a pressure sensor (7) were located next to the valve. The oil from the test installation was pumped back to the main oil tank through a pressurized tank (8). The role of the central point of the network was played by the nRF52840DK development module (9). A MAX11410 development module (10) was installed on the top of it to measure the voltage at the flowmeter transducer output. Information about the flow could be sent wirelessly, which was used in the flow control tests. In each test case, the measurement data were available on the computer (11) in the terminal application, which was also used to send set point values for controller. The nRF Power Profiler Kit II (12) was used to measure the current of the communication module, and the oscilloscope (13) was used to measure the current of the motor. Program of the designed controller could

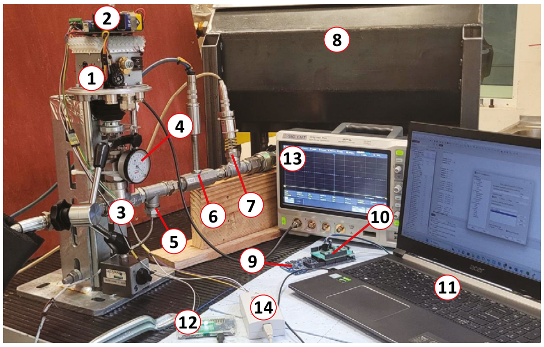


**Figure 8.** Test stand

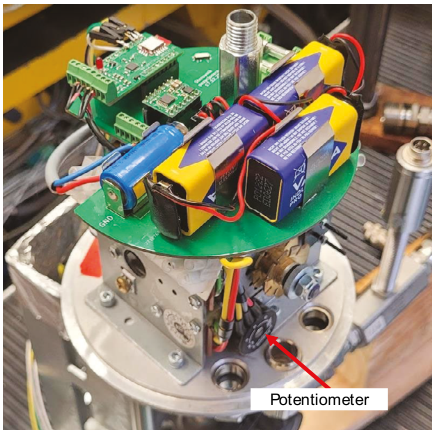


**Figure 9.** Valve positioner with designed controller board

be uploaded with use of programmer (14). To check the system in real conditions of component test all systems in the test cell were operating during one of the experiments. Test show that there were no visible consequences on valve positioner operation.

## 3.2. Single step control

There are some tests in which using automatic opening, flow or pressure control may not be the optimal solution. Especially in tests where changing these parameters is only a means to investigate changes in another area of the test stand or test object, and introducing a minimal change allows for estimating the response of the tested system or approaching the limit value. Insufficient measurement accuracy or stability of feedback signal could decrease the quality of automatic control. Moreover, automatic control is sometimes unacceptable, because it could disturb the tested process e.g., when we want to set a precise input pressure or flow value and observe changes of these parameters due to wear of sealing or another component. For these reasons, a manual control mode has been implemented. In this mode, the operator could perform a set number of steps towards closing or opening which give high accuracy of position control. The highest possible valve head positioning resolution that could be achieved in a given hardware configuration is 0.00375% of full range movement, which gives

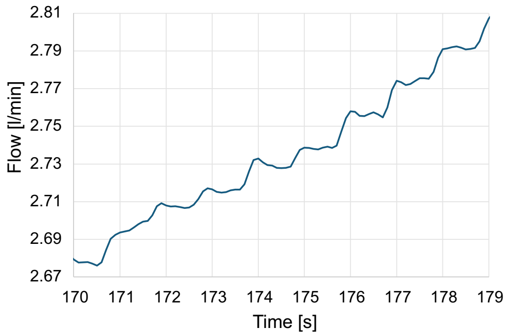


**Figure 10.** Flow changes for T_time equal to 25 ms

0.0006 mm. That measurement was confirmed by a test with dial gauge, where measurement from 1000 steps was averaged. The indicated maximum position control resolution corresponds to an actuator turn on time T_time equal to 5 ms. The minimum tested T_time value which generates movement is equal to 2 ms but the range of movement is very small and highly non-repeatable. In order to obtain a margin and higher repeatability of movement, a value 2.5 times greater was used as the limit in the control program. Figure 10 shows the change in flow resulting from a series of steps with a frequency of 1 Hz and time T_time equal to 25 ms. For 5 ms the changes were comparable to the noise level on the flowmeter signal and therefore difficult to demonstrate.

## 3.3. Position control

The basic function of all valve positioners is automatic control of valve opening, typically with feedback from valve head position sensor. In the first test of automatic control that basic function was tested. The feedback for the controller was the change in the resistance of the potentiometer connected to the controller. During the automatic control test, sample settings were selected to ensure stable operation, presented in the Table 1. Five ranges were proposed, switched in relation to the error value in accordance with the implemented control algorithm. Each range is described by the error value defining the range switching point (e0...en), movement duration (T_time) and frequency of steps (T_step). As it was shown in the Figure 11, the positioning accuracy was reduced by

**Table 1.** Controller settings selected during valve head position regulation test

| Error range number | Switch point en (%) | Time of operation T_time (ms) | Time between steps T_step (s) |
|---|---|---|---|
| 1 | e0 = 0.1 | 15 | 2 |
| 2 | e1 = 0.3 | 50 | 2 |
| 3 | e2 = 1 | 75 | 1 |
| 4 | e3 = 2 | 100 | 1 |
| 5 | e4 = 5 | 200 | 1 |

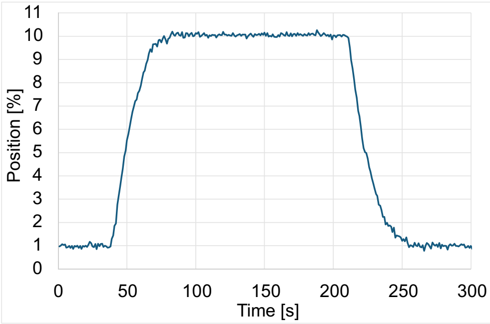


**Figure 11.** Automatic position control in range 1–10%

the potentiometer accuracy, but it was possible to reach accuracy of +/−0.1% of full range which corresponding to +/−0.016 mm. The minimal T_time value equal to 5 ms was not used in automatic control because it generates movements which are many times shorter than movements which could be measured by the potentiometer. Research also shows that positioning accuracy could be at least few times higher if the position sensor would have higher accuracy.

## 3.4. Flow control

In many cases main control system of the laboratory uses valve positioner with feedback from the valve head position as an internal control loop in cascade regulator. A second external control loop is feedback from flow, pressure or temperature which enable the system to control these parameters. It means that overall accuracy of that system is limited by the accuracy of position control even if we want to control different parameter. In the designed smart control system that problem was solved because flow, pressure of temperature feedback signal could be connected to the PCB of valve controller (by wire or wirelessly). There is only one feedback loop, and the minimal step is many times smaller in comparison to the valve positioners available on the market. In the second automatic control test, the source of feedback for the positioner was the flow measurement provided wirelessly via a BLE connection, in the same way as the setpoint for the controller. In this case, the setpoint could be given directly as the expected flow value. As for the position control, five movement speed zones were assumed, as shown in Table 2. The test showed the possibility of flow control with an accuracy of +/−0.01 l/min, as it was shown in the Figure 12. Narrower dead zones caused more frequent movements due to oscillations of the measured value and increase power consumption. One of the greatest achievements is that such accuracy is offered over the entire operating range of the valve, which corresponds to operation in the range of 0–25 l/min at a given pressure. Step operation of the valve positioner had a positive effect on the regulation process because the controlled system has time to stabilize. Performed research has shown that finding controller settings is not a difficult task if we know the controlled process.

**Table 2.** Controller settings selected during oil flow regulation test

| Error range number | Switch point en (l/min) | Time of operation T_time (ms) | Time between steps T_step (s) |
|---|---|---|---|
| 1 | e0 = 0.01 | 30 | 2 |
| 2 | e1 = 0.1 | 100 | 2 |
| 3 | e2 = 0.4 | 200 | 1 |
| 4 | e3 = 1 | 300 | 1 |
| 5 | e4 = 2 | 400 | 1 |

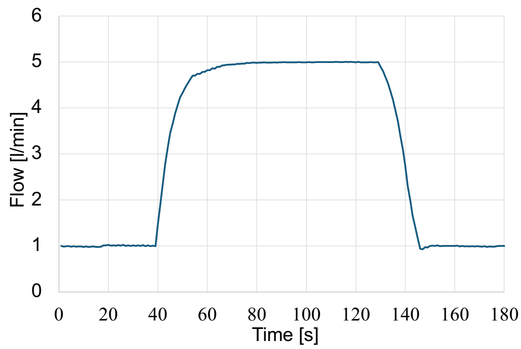


**Figure 12.** Automatic flow control in range 1–5 l/min

The accuracy from the datasheet attached to the original valve positioner shows that the deadzone (terminology from the datasheet) around the setpoint could be set in range 0.25–1.5% of full position range. It could be switched by rotary switch on the PCB. There are five positions: 0.25%; 0.5%; 0.75%; 1% and 1.5%. There is a note in the datasheet that this parameter should be increased till the valve stop moving forward and backward continuously. The tests showed that the stability starts to be acceptable from the deadzone 1%, which corresponds to the flow control accuracy +/–0.35 l/min. The narrower deadzones cause too many position corrections, which don't stop even if we wait longer on a specific setpoint. Therefore, the accuracy of the proposed system (0.01 l/min) is many times higher in comparison to the original version.

## 3.5. Power consumption

The energy consumption of the drive part of the system is strongly dependent on the number of the setpoint changes. Therefore, it was necessary to select a test case that well represents the tests performed in laboratories testing aircraft components. It was assumed that the representative test case will consist of 1 l/min changes at 10 minutes intervals. Such successive flow changes are similar to the test points of jet engine bearings or heat exchangers, where controlled system needs time for stabilisation after each change. Figure 13 shows example with these six set point changes but in shortened time to look closer at regulation process. Final power consumption test was performed in one hour. Controller settings were optimised

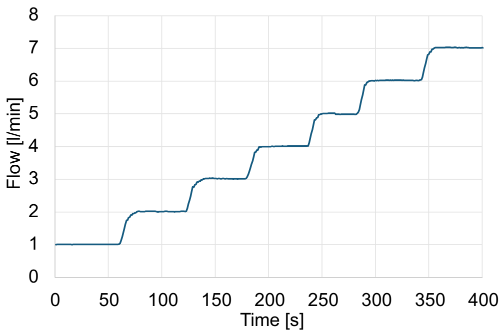


**Figure 13.** Series of 1 l/min changes

**Table 3.** Flow controller settings optimised in terms of energy consumption

| Error range number | Switch point en (l/min) | Time of operation T_time (ms) | Time between steps T_step (s) |
|---|---|---|---|
| 1 | e0 = 0.01 | 15 | 2 |
| 2 | e1 = 0.1 | 30 | 2 |
| 3 | e2 = 0.4 | 50 | 1 |
| 4 | e3 = 1 | 100 | 1 |
| 5 | e4 = 2 | 200 | 1 |

in terms of power efficiency and become less dynamic, as shown in the Table 3.

The current consumption at the beginning of the movement is close to the rated current of the motor and is up to 300 mA, as it was shown in the Figure 14. Therefore, the longer the movement step takes, the lower the average current consumption in a given step. However longer movements and higher frequencies increase total power consumption. That test was performed by the

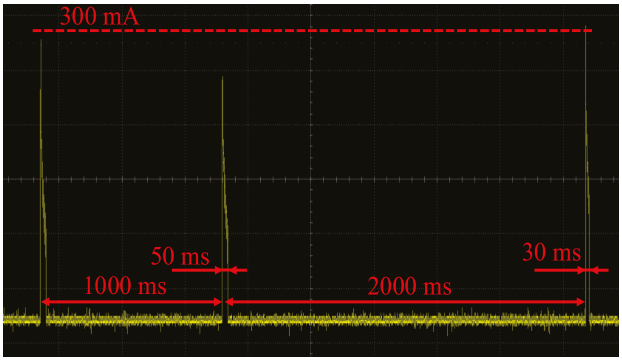


**Figure 14.** Current peaks during flow control

measurement of voltage drop on the low value resistor connected in series with the electric motor controller. The average current consumption of the measurement and communication part was also measured during the research. In this case, the measurements are more universal because the current consumption does not depend on the number and frequency steps due to the constant communication frequency.

The current consumption, however, changes with the type of supported sensor providing feedback. Measured currents and estimated battery operation time for motor controller with electric motor and the rest of components are presented in the Table 4. Current consumption of measurement and communication module could be easily optimised by deactivation of position measurement during the flow control, but it was not included in the research.

## 4. Discussion and conclusions

The analysis of aviation laboratories needs led to the proposal of a battery-powered, wirelessly communicating valve positioner controller with low energy consumption. Work include PCB design of controller, proposal of control algorithm and BLE communication implementation, all with low power approach. The review shows that most of valve positioners do not offer high control accuracy necessary in aircraft components tests. Therefore, improving the control accuracy was main goal of the design work. As a result, an algorithm was proposed that involves performing short steps between which the controller switches to the energy saving mode. The positioner operation was tested for automatic position and flow control. In position control mode test the accuracy was sufficient (+/−0.1% of full range), but it was significantly reduced by the accuracy of potentiometer which measure the position. Also in the automatic flow control test, it was possible to meet the design requirements and achieve an accuracy of +/−0.01 l/min. In addition to the automatic control modes, a manual control mode was introduced, which offers a positioning resolution of 0.0006 mm. In that operation mode operator could define the number of steps and direction of movement. The designed controller could directly operate with external sensors (e.g., temperature sensors, pressure sensors, flowmeters with voltage output) allowing for the implementation of local control systems, which was also confirmed during the test. For all tested cases, energy consumption was very low. Research finishes with power consumption test which reproduce typical valve operation during tests of aircraft components.

**Table 4.** Current consumption and estimated operation time

| All units, without DC motor and controller, powered by 16340 type battery (3.6V, 900 mAh) | | DC motor with controller powered by 6LR61 type batteries (3 x 9V, 540 mAh) | |
|---|---|---|---|
| Average current | Operation time | Average current | Operation time |
| 121.4 μA | 7413 hours | 109.1 μA | 4949 hours |

Results show that proposed control method allows the valve positioner to operate for months with BLE communication maintained and offer great accuracy. BLE communication was tested during operation of other systems in the test cell. Drive system, lubrication system, load system and pneumatic system are all equipped with inverter controlled electric motors which are potential sources of electromagnetic noise. Moreover, the positioner was tested in a range of laboratory Wi-Fi network. Test results show that even though the system operated in an environment with potential sources of electromagnetic noise, it functioned properly. The proposed solution can be successfully used in both short-term and long-term tests in aviation laboratories. The introduction of wireless positioners with high control accuracy significantly simplifies the method of preparing tests in laboratories. Wireless communication speed up test preparation by reducing the need of wiring connection. Long battery operation enables laboratory teams to follow proposed approach instead of using typical valve positioners controlled by wire, without introduction additional significant limitations. Wirelessly controlled valve positioner could work in laboratory IoT network which was one of main aims of presented research. Presented research open new frontier for the design methods of actuators used in aviation laboratories. The control algorithm was tested with DC motor, but it could be easily reconfigured for operation with different types of electric motors, by changing motor controller. The presented methodology was developed and introduced in the Component Test Laboratory in the Łukasiewicz Research Network – Institute of Aviation. Presented control approach could be not sufficient when the valves are influenced by high vibrations. The results are presented for valves and positioners isolated from potential sources of high vibration. If such conditions occur, additional improvements may be necessary to prevent a reduction in control accuracy.

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