Ecodesign of electronic devices

UNIT 12: Example of electronic device production process

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Chapter summary:

- Electronic device production process
- Product development and upgrading
- Prototyping and testing

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12.1. Electronic device production

Let us take a look at the electronic device production process. The customer has ordered a study and making of laboratory equipment for measuring low airflow in the aging process of transformer oil. Transformer oil is used for cooling of the transformer system. The oil is generally produced from highly refined material and has to be stable at high temperatures. It also needs to have great insulating properties because it has to prevent corona (low energy smoldering) and sparking. Oil characteristics are important for reliability of energy devices and due to this, there is a standard and process for testing the oil.

Before we start with the production principles, let us briefly present device functions. The process of aging the transformer oil is a test of oil quality. With constant airflow through the oil at temperature 120˚C we induce the process of rapid aging. If we use 0.5 dl of oil and constantly put air with airflow 1l/h at temperature 120 ˚C for 10 days through it, then we reach oil age that is equivalent to 25-year use. Forcibly aged oil can then be tested in the chemical laboratory to research its chemical composition and quality. Production of the device for forced aging process consists of documentation that includes functional and panoramic analysis. The panoramic analysis determines audit of devices and elements existing on the market. Functional documentation determines the type of selected elements and describes device functioning. After reviewing the existing solutions, we came to the conclusion that we will make all elements of the device. By this, we mean use of industrial flow regulators that are stand-alone devices. The industrial device can be connected to own system or platform through communication interfaces. Current industrial solutions do not offer regulation of low flows as required by the standard. The price per unit is also very high. The next issue is choosing an affordable, reliable and precise sensor. The flow of 1l/h falls within the low flow area where classic approaches to measurement with an aperture are not very precise and reliable. For measuring flow through measurement point, we have chosen suitable proportionate valve. We have connected both devices to a microcontroller that was responsible for closed-loop flow management and communication with other external devices.

Some functional characteristics of the device:

- Device precision ±0.25l/h.
- Flow management up to 0.5-2l/h.
- The device has to be as small as possible.
- High reliability.
- Communication with a personal computer: USB, Bluetooth.
- Industrial communication RS485.
- Windows application for capturing and saving data during the test.

Main ecological aspect in device design process.

- Use of elements that do not contain hazardous substances (lead, mercury, etc.).
- Reliability.
- Lowest possible energy consumption.
- Device minimization and lowest possible number of used materials at same reliability.
- Weight.

12.2. Choosing device elements

When choosing elements, we have focused on reliability, precision, and price.

12.2.1. Airflow sensor

The main criteria in sensor determination were desired measuring range [0.5–2] l/h and adequate sensibility. On the market, we can find a limited number of airflow measurement sensors that are dimensionally and price related affordable. For the production of the regulator, we will need a sensor that can communicate with the controller through one of the classic communication interfaces: analog input, protocol I2C or SPI. We have chosen a sensor with I2C protocol, temperature compensation, and linear measurement scale. This way, we have avoided the additional need for program linearization and additional compensation of measurement error. Chosen sensor WBI is presented in image 1. It meets the following criteria: measurement range [0.1–2.5] l/h, resolution 0.1l/h, communication I2C, measurement time 5ms, dimensions w/h/d- 3.5x1x2.5cm.

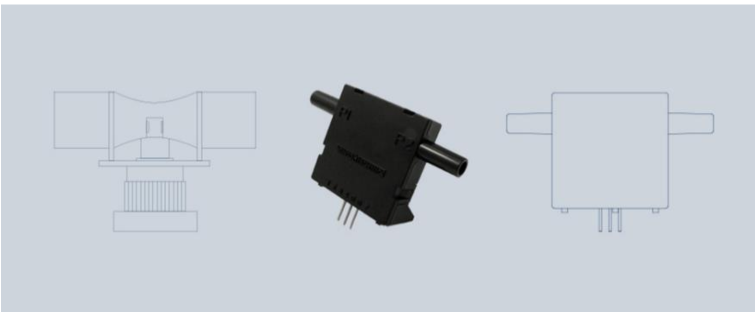

IMAGE 1: WBI AIRFLOW SENSOR.

12.2.2. Proportionate valve

When choosing valve, we had similar requirements as for the sensor. Valve has to provide sequential control, be suitable for small airflow, affordable, have smaller dimensions and have linear functioning. Due to this, we have chosen linear valve family VSO Low Flow by manufacturer Parker, seen in image 2. The valve can sequentially regulate airflow up to [0.01–10] l/h, has dimensions w/h/d-2x3x2cm and its working range is 0-2Bar.

IMAGE 2: PROPORTIONATE VALVE.

For controlling valve with a microcontroller, we need to construct the adaptive-control circuit. The valve will be controlled by PWM signal from microcontroller. For ecological design, we will present multiple iterations of control circuit development. The main criteria are small dimensions, low weight, simplicity, and energy consumption.

12.2.3. Microcontroller

For control purposes, we have chosen microcontroller that is capable of executing all regulator algorithm functions, data gathering and communication with external devices. When choosing a controller, we need to consider several factors, such as operating frequency of the processing unit and a number of input-output connectors. We have searched for a controller with approximately the same number of connectors as we needed, low energy consumption and affordable price. To the set of criteria for determining microcontroller adequacy, we have added requirement for adequate data processing capability (AD conversions, timers, etc.). For the production of low airflow regulator prototype, we have chosen 32-bit ARM microcontroller by manufacturer STMicroelectronics from family F1xx, and the model is STM32F103C8T6. The product family ARM STM32F1xx is the balance between efficiency and energy saving. Development module with STM32F103C8T6 is shown in image 3.

IMAGE 3: MICROCONTROLLER.

Microcontroller STM32F103C8T6 has 48 pins and fulfills communication modules: 4xUSART, 2xI2C, 3xSPI. One USART communication module will be used for industrial communication through RS485 and the second one will be used for connection between personal computer via USB or Bluetooth interface. Flow sensor WBI will be connected to the I2C interface. For valve control, we will use a digital output with PWM modulation. Some digital outputs will be used for status and display lights. We will also add some keys to the device, such as for physical device launch, choosing of operating mode and device turn-off. The device can also be launched through the data gathering application.

12.2.4. Flow control mode

In flow control mode we have decided for closed-loop control, image 4. Closed-loop control enables higher reliability, better disturbance elimination, and precision. Closed-loop control uses the principle of measuring output values and reverse transfer of information to the system where control error is calculated. Control error is calculated depending on the desired value and current sensor measurement. This value can then be managed by the regulator. Regulator calculates needed output value with which it influences the system. For the given system, we have used classic PID regulator structure. PID regulator is highly established regulator structure in an industrial environment. It is distinguished by simple and relatively high functioning reliability. PID algorithm is executed in the microcontroller.

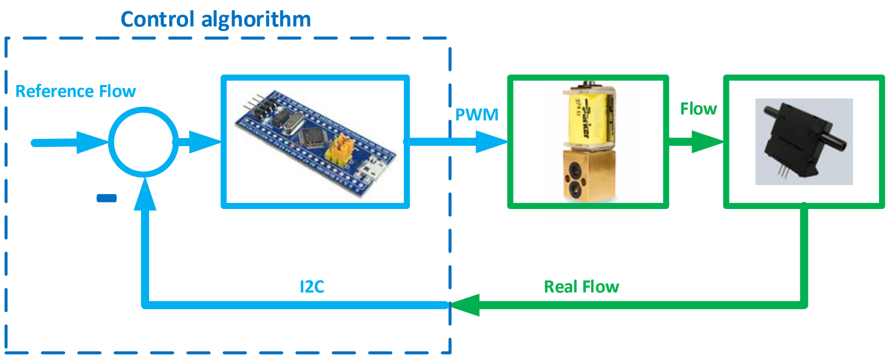

IMAGE 4: CLOSE-LOOP CONTROL.

Closed-loop control is more complex and requires more calculating power in comparison to open-loop control. Open-loop control is simpler but also less reliable because it does not use reverse information from the output, image 5. In our case, open-loop control would be significantly cheaper because we would not need flow sensor that is the most expensive component in the control system.

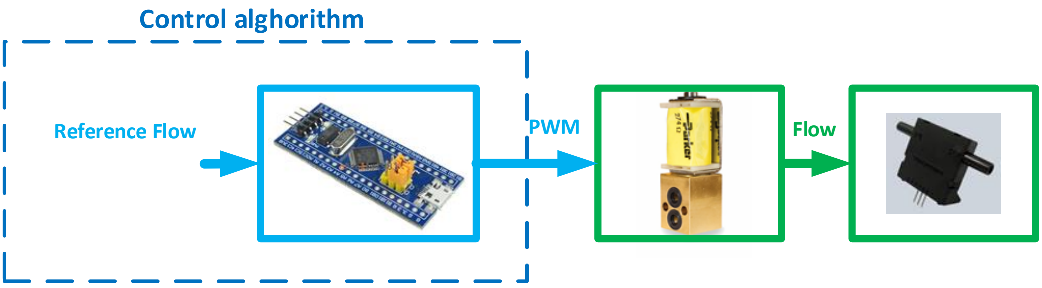

IMAGE 5: OPEN-LOOP CONTROL.

PID regulator structure is presented in the following expression:

$$u(t) = \underbrace{K_p e(t)}_{P} + \underbrace{K_i \int^{t} e(\tau)d\tau}_{I} + \underbrace{K_d \frac{de(t)}{dt}}_{D}.$$

From the equation, we can see that PID algorithm consists of three parts (P, I and D). P part is proportionate, meaning regulator error can be multiplied by constant. P part improves dynamic characteristics of closed-loop. I part eliminated control errors, which is important for precision, but on the other hand, decreases system dynamics. System dynamics means that regulator needs more time to reach reference value. D part increases system dynamics and amplifies sensor noise. Correct setting of PID is a compromise between precision and speed.

12.3. Production of printed matter prototype

Production and design of flow regulator consist of several steps. The first prototypes did not give satisfying and sufficient results. There were problems with device size, the high working temperature of control electronics and too many used components. Due to this, we have made several prototypes where we have mainly worked on valve control electronics.

12.3.1. First prototype

For the first prototype, we have used valve control scheme by manufacturer Parker. For microcontroller functioning, we have added voltage stabilizer and connection clamps for external power supply of valve. Prescribed supply voltage was 9V.

Image 6 presents the first version of valve control electronics. As previously mentioned, the valve will be controlled by PWM signal with frequency 10kHz. Control electronics use operational amplifier LM358 that provides stable current through the coil. For the switching element, we used transistor TIP120 that is Darlington connection of two BJT transistors.

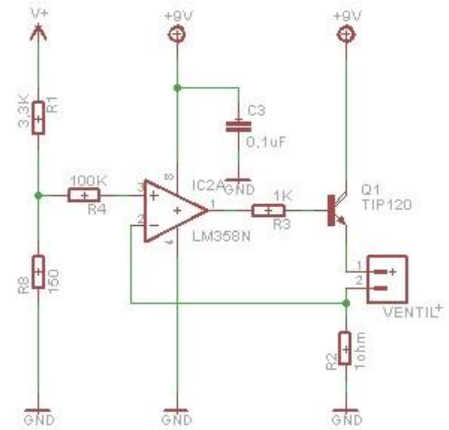

IMAGE 6: VALVE CONTROL CIRCUIT.

A printed matter design in program Altium with power supply connectors and substrate for the microcontroller is presented in images 7 and 8.

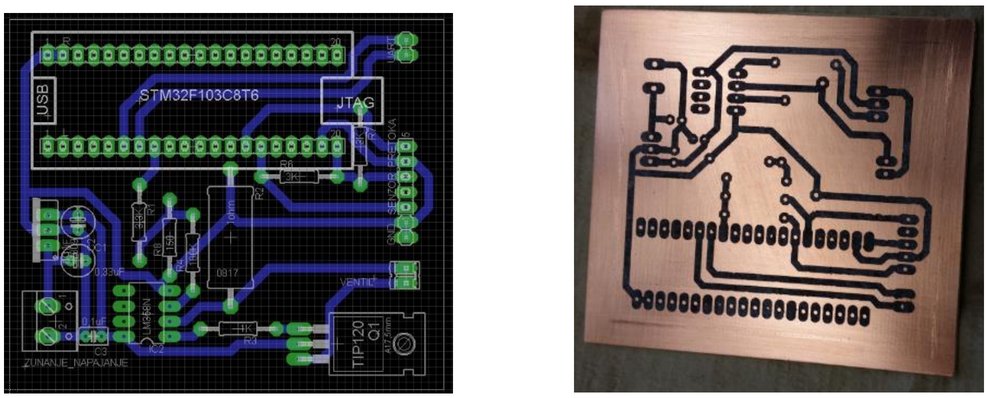

IMAGE 7: PRINTED MATTER APPEARANCE.

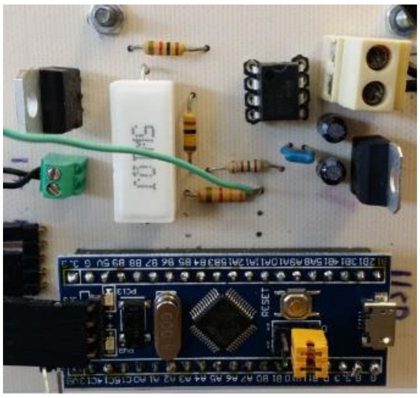

IMAGE 8: FINAL PROTOTYPE.

The first prototype version was fully working device. The biggest problem was overheating of switching element TIP120. The measured temperature was close to 70˚C. For long-term functioning and for installation into housing we needed to add cooling element. The circuit dimensions were 5x5cm.

12.3.2. Second prototype

The second prototype was based on the same circuit, but the control circuit was redimensioned and reduced. All elements except switching element TIP120 were replaced with elements based on SMD technology. This technology enables the production of smaller elements with the same characteristics. From the ecological design aspect, this means we have replaced the elements with elements that are lighter and made of fewer materials. The second circuit prototypes are presented in image 9.

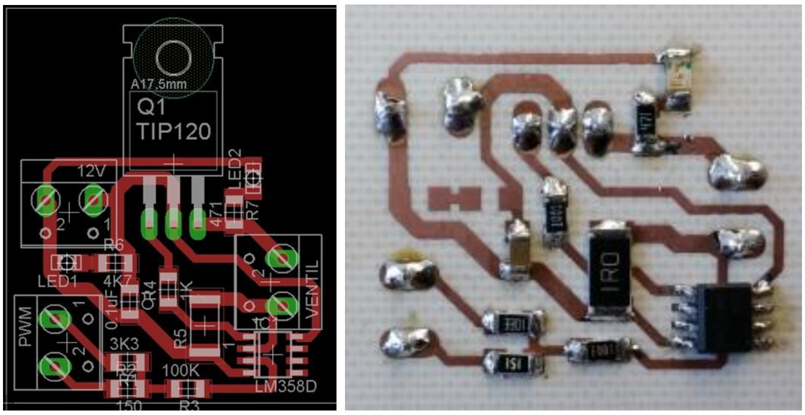

IMAGE 9: SECOND CIRCUIT PROTOTYPE.

In the second prototype, we have reduced the circuit to half. Circuit dimension was now 2.3x2.2cm. But the main problem-overheating of switching transistor remained the same.

12.3.3. Third prototype

In the third prototype, we have decided to design a stand-alone circuit where we will use switching element that will be capable of loss-less switching. We have decided to design a circuit with MOSFET switching element. Because flow control is done in a closed-loop, valve control electronics do not need flow stabilization through the valve as in the previous prototype. We have removed operational amplifier from the circuit. Valve controls scheme is shown in image 10.

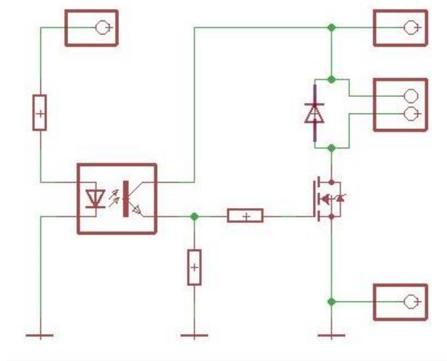

IMAGE 10: THIRD CONTROL CIRCUIT PROTOTYPE WITH MOSFET TRANSISTOR.

Switching element MOSFET in SMD technology is five times smaller than a transistor TIP120. The latest prototype was working without excess heating. The temperature of MOSFET at room temperature was not higher than 35˚C, meaning we had lower losses than in previous versions. Circuit dimension was 1.2x1.5cm, so we used less and cheaper materials. For comparison transistor, TIP120 was three times more expensive than SMD version of MOSFET. In the latest version, we have added optical contactor that is used for Galvanic isolation and microcontroller protection. The final control circuit appearance is shown in image 11.

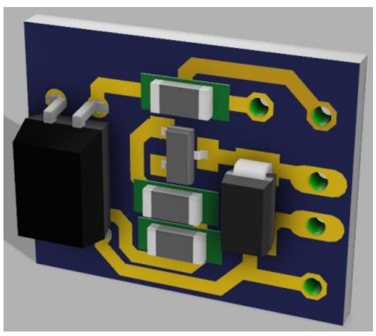

IMAGE 11: FINAL CIRCUIT APPEARANCE.

The last prototype was also the last version with the intention of producing the complete device. A short comparison of all three prototypes is presented in table 1.

Characteristics	Ver. 1 (TIP120)	Ver. 2 (TIP120)	Ver. 3 (MOSFET)
Dimension	5x5cm	2.3x2.2cm	1.2x1.5cm
Number of elements	8	8 (SMD)	5 (SMD)
Temperature of the switch	70℃	70℃	35℃
Weight	16g	11g	3g
Average Price	17€	13€	8€

TABLE 1: COMPARISON OF THREE CIRCUIT PROTOTYPES.

12.4. Modeling the system and performance test

The final appearance of the complete device was designed using 3D modeling. This way, we have presented full device appearance and its internal composition. Images 12 and 13 present final device and its components.

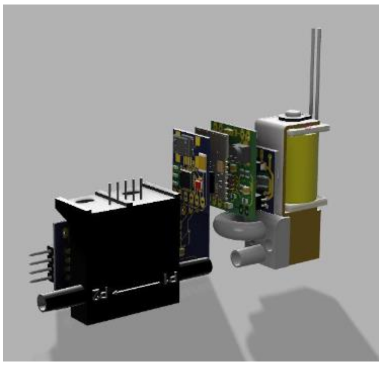

IMAGE 12: ELEMENT ARRANGEMENT WITHOUT HOUSING.

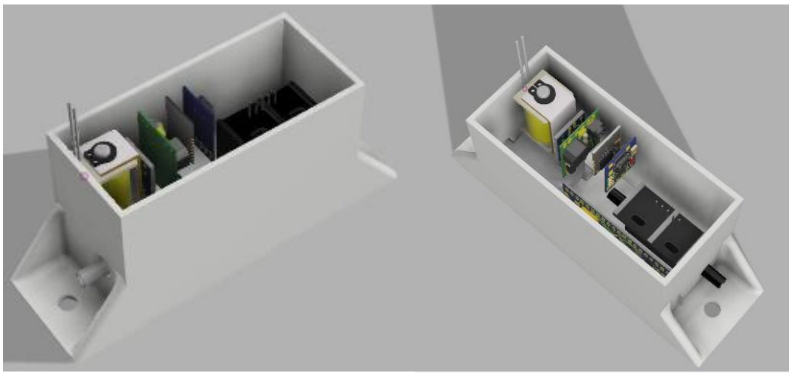

IMAGE 13: ELEMENT ARRANGEMENT WITH DEVICE HOUSING.

Device efficiency was tested after 240 operating hours. Image 14 presents flow control and monitoring of reference flow.

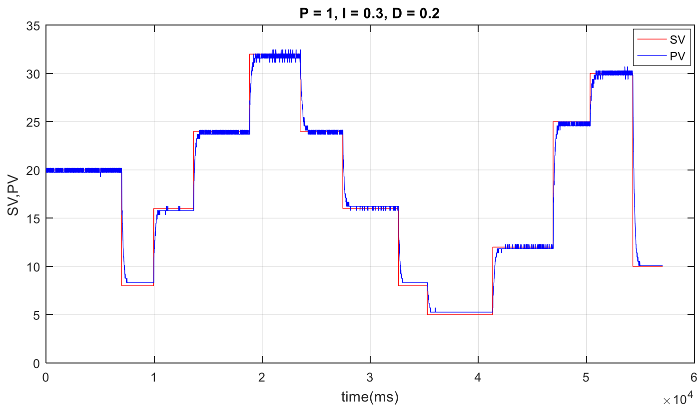

IMAGE 14: FLOW CONTROL. RED COLOR - REFERENCE VALUE, BLUE COLOR - REAL FLOW VALUE.

12.4. Application for gathering and monitoring of data from the device

For the purpose of continuous display and monitoring of current data was created the Windows application, shown in image 15. The application is designed to display the measured results and save them in a file. In case of computer failure, a new file for saving data is created every hour.

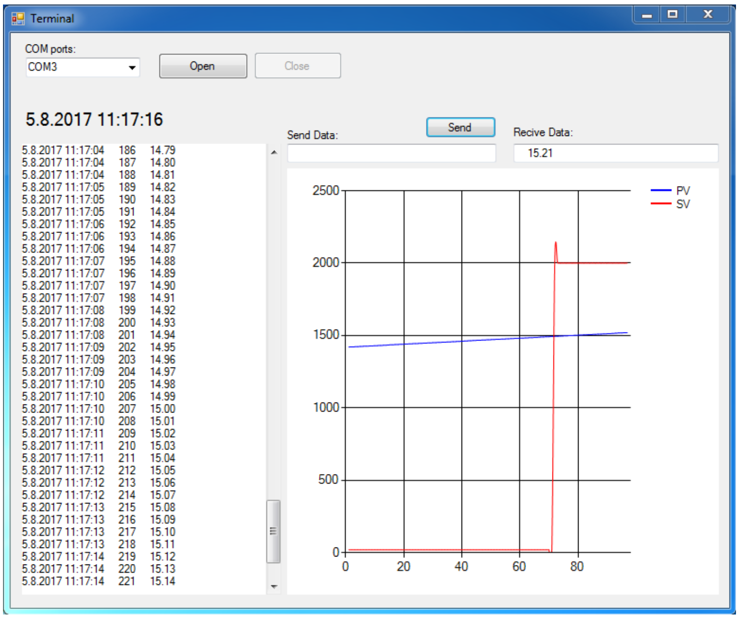

IMAGE 15: APPLICATION FOR DISPLAY AND SAVING OF DATA.

After a finalized pilot version of the device was done, we have also made a comparison with an industrial version of the flow regulator. The current version is reliable, has the precision of 0.1l/h and uses a minimal amount of elements. The price of the complete regulator is approximately 150€, which is in comparison to the cheapest industrial version that has precision 0.8l/h five times less.