



Ecodesign of Electronic Devices

UNIT 12: Example of electronic device production process



Design of Oil aging device

- 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.

Design of Oil aging device

- 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.

Construction concept and development path

- Query and review of existing solutions.
- Required elements of the device (Sensors, actuators, steering, communication)?
- Modus operandi.
- Customer wishes
- Conclusion of the review of existing solutions and the proposed path of development.
 - Current industrial solutions do not offer low flow regulation as required by the standard. Also, the price per unit is very high.
 - The next problem was the choice of an affordable, reliable and accurate sensor. The 1l / h flows into the low-flow area, where the conventional aperture-based approaches are no longer as precise.
 - A suitable proportional valve was chosen for flow control through the measuring point.



Determining the functional properties of the device and the ecological requirements

Some functional characteristics of the device:

- Device precision $\pm 0.25\text{l/h}$.
- Flow management up to $0.5\text{-}2\text{l/h}$.
- 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.



Determining the functional properties of the device and the ecological requirements

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.



Choosing device elements – Flow sensor

- The main criteria in sensor determination were desired measuring range [0.5–2] l/h and adequate sensibility.
- 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.
- 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.



Choosing device elements – Proportionate valve

- The 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.
- 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.



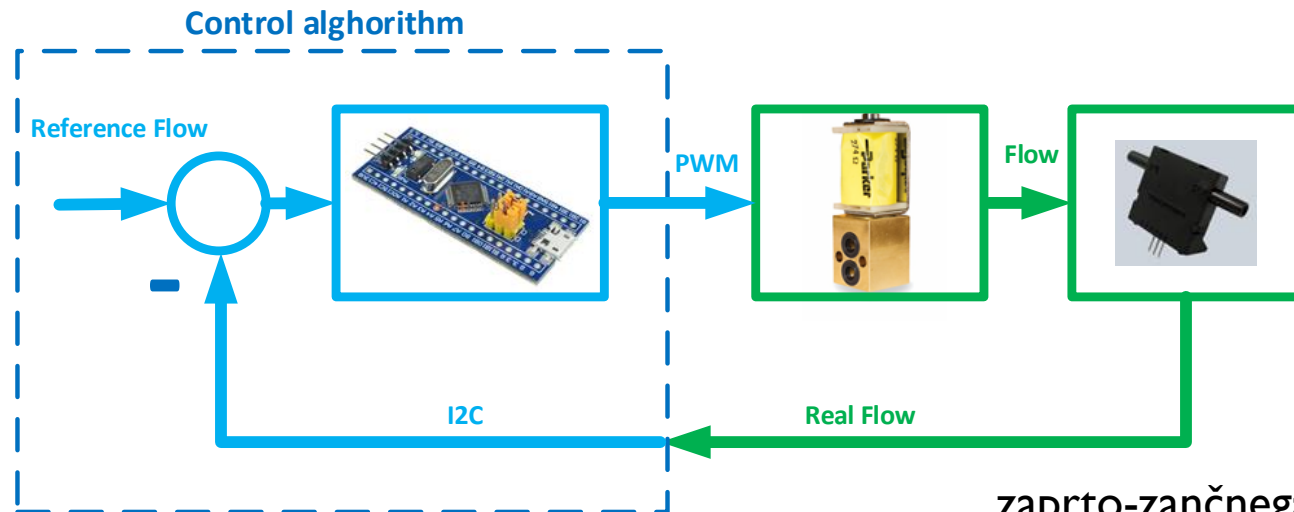
Choosing device elements – Controller

- 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.
- 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.



Flow Controller

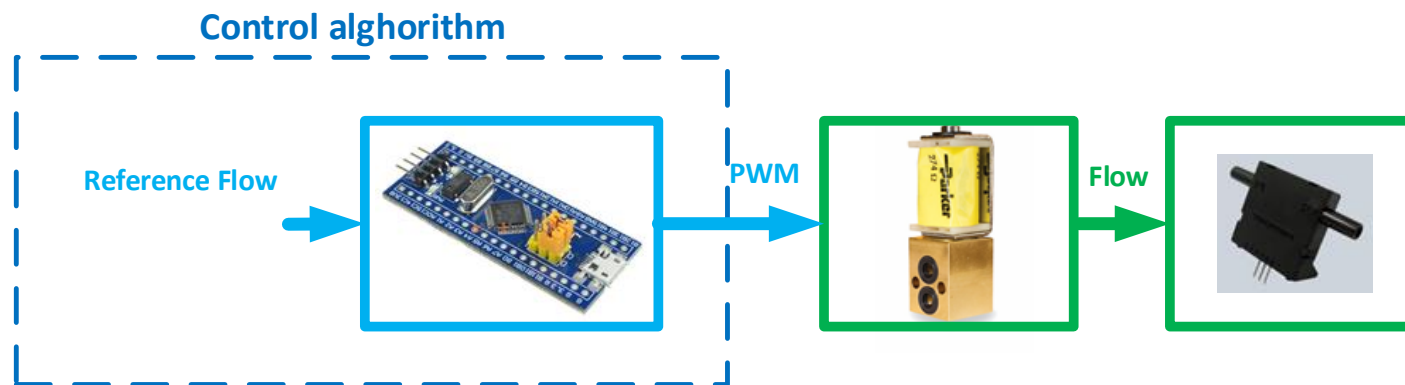
- In flow control mode we have decided for to use closed-loop control structure.
- Closed-loop control enables higher reliability, better disturbance elimination, and precision.
- Closed-loop control uses the principle of measuring output values and reverse transfer of information to the system where control error is calculated. Control error is calculated depending on the desired value and current sensor measurement.
- For the given system, we have used classic PID regulator structure. PID regulator is highly established regulator structure in an industrial environment.



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Flow Controller

- 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 feedback information from the output.
- 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.

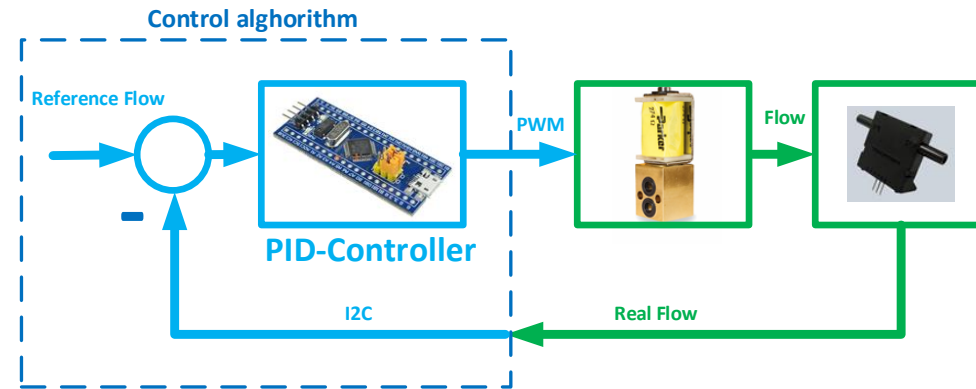


Open-loop control

PID Controller

- PID controller structure.

$$u(t) = \underbrace{K_p}_{P} e(t) + \underbrace{K_i \int_0^t e(\tau) d\tau}_{I} + \underbrace{K_d \frac{de(t)}{dt}}_{D}$$



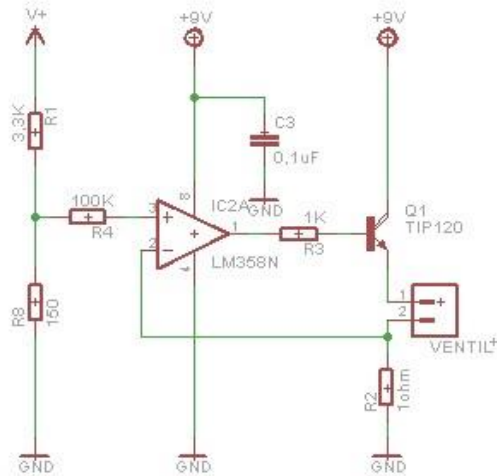
- From the equation, we can see that PID algorithm consists of three parts (P, I and D). P part is proportionate, meaning regulator error can be multiplied by constant. P part improves dynamic characteristics of closed-loop. I part eliminated control errors, which is important for precision, but on the 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.

First prototype

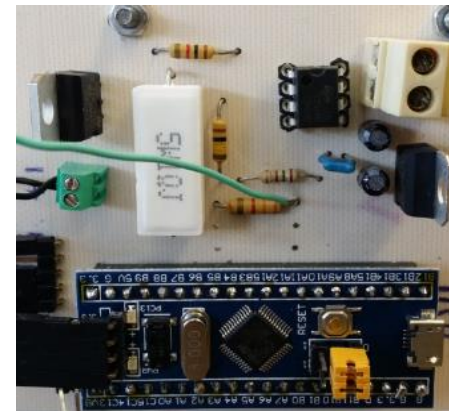
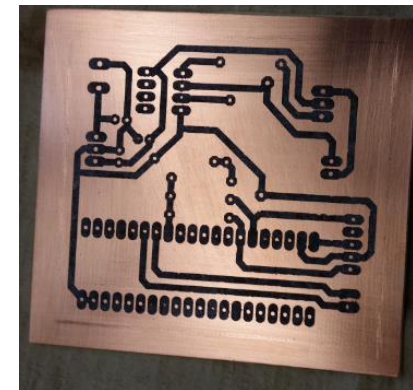
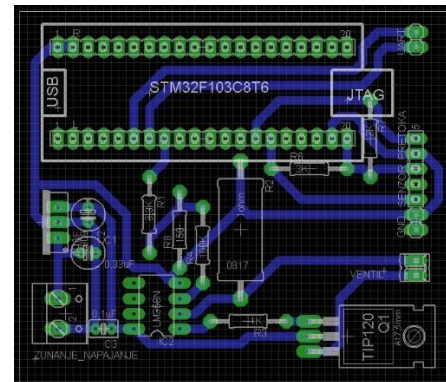
- For the first prototype, we have used valve control scheme by manufacturer Parker.
- For microcontroller functioning, we have added voltage stabilizer and connection clamps for external power supply of valve.
- Prescribed supply voltage was 9V. As previously mentioned, the valve will be controlled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

First prototype

- Valve control drive:

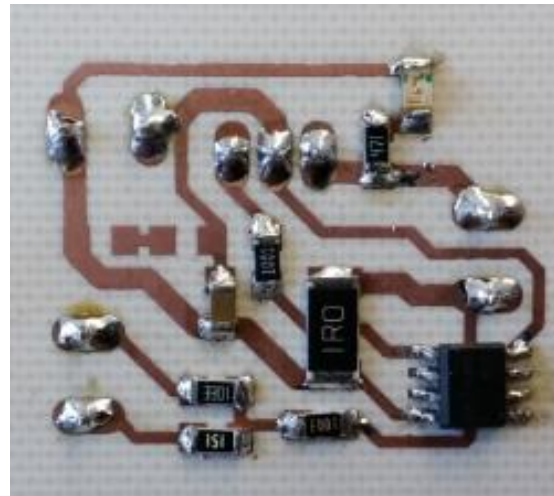
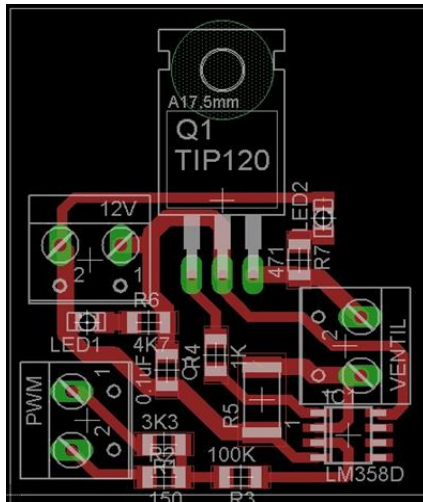


- PCB board.



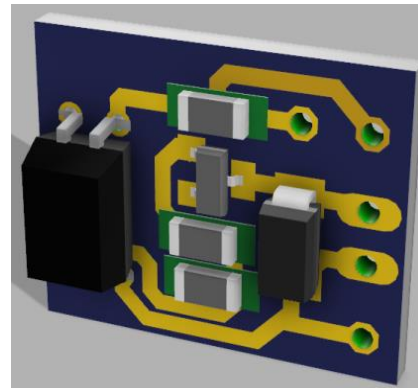
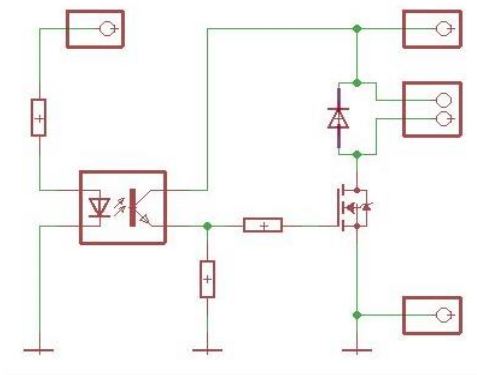
Second prototype

- 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.



Third prototype

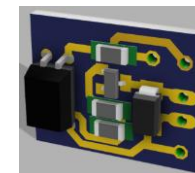
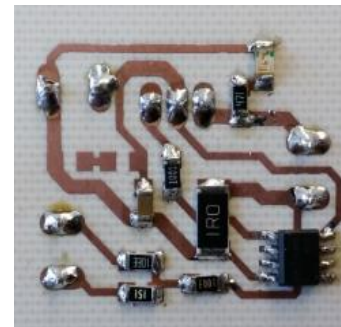
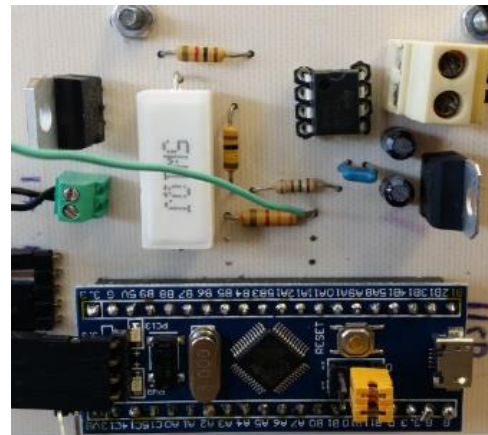
- In the third prototype, we have decided to design a stand-alone circuit where we will use switching element that will be capable of loss-less switching. We have decided to design a circuit with MOSFET switching element. Because flow control is done in a closed-loop, valve control electronics do not need flow stabilization through the valve as in the previous prototype.
- Improved valve controller:



Third prototype

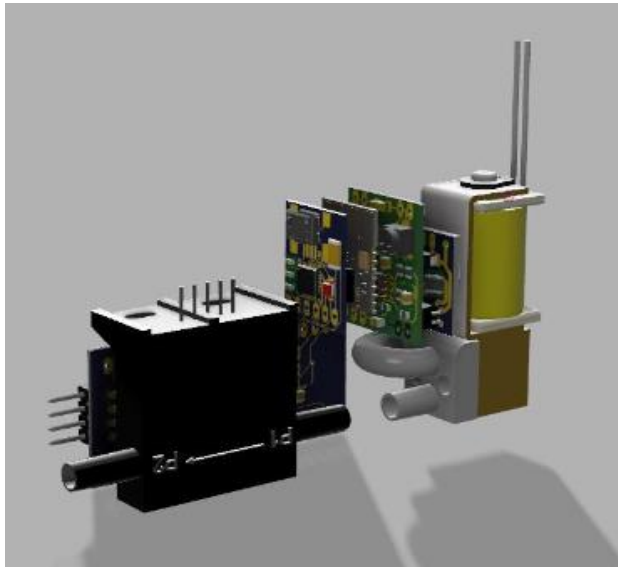
- Comparison of prototypes:

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



Device 3D Modeling

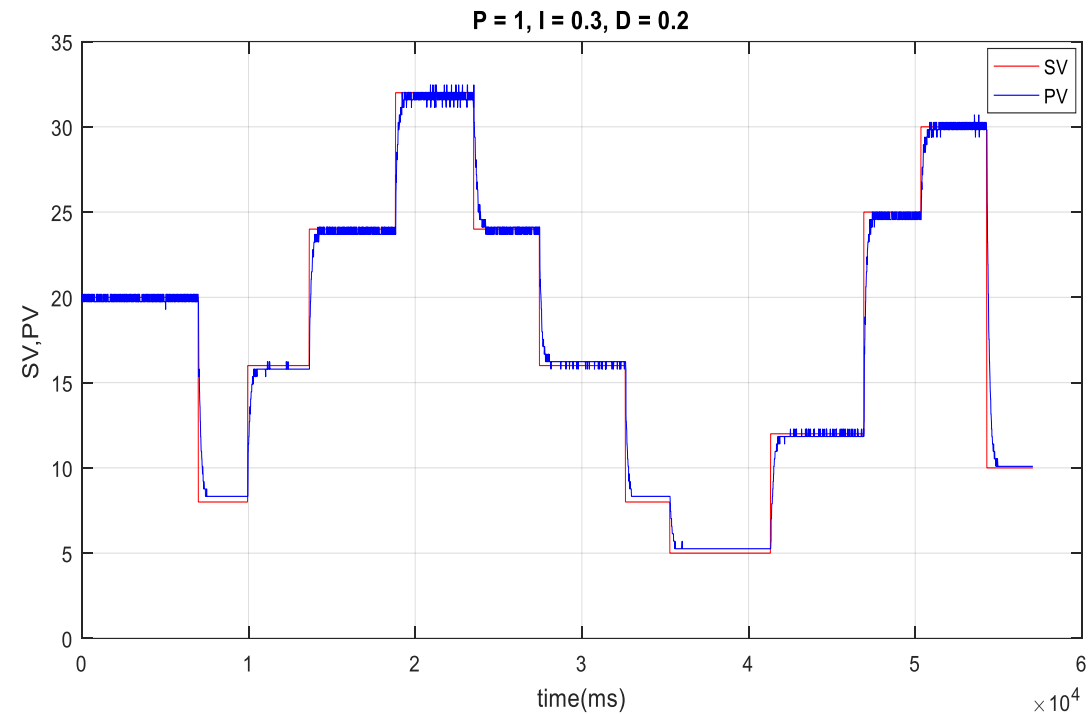
- Modeling results:



Performance test

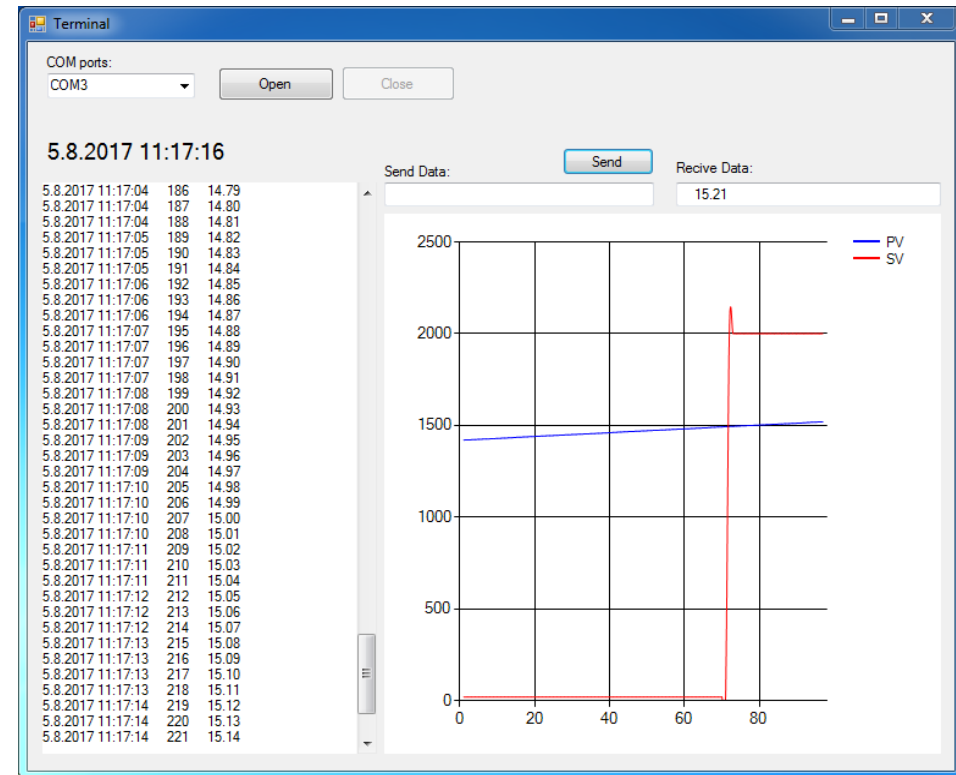
Example of flow control in a closed loop:

- The system has met the set criteria.
- The system was tested 400 hours.
- No errors occurred during the test.
- The system abstained from tests such as sensor failure, power failure.



Monitoring Application with User Interface

- For the needs of continuous display and recording of current data, a Windows application was created.
- The app is designed to show the measured results and save them to a file. In case of a computer failure, the data storage file is created every hour.





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