Design of a digital system for pressure control in a hydraulic pump

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Type of activity

This exercise is applicable in digital electronics, industrial automation, and control systems classes. It relates to SDGs 9 (Industry, innovation and infrastructure) and 12 (Responsible consumption and production), which promote the development of efficient infrastructure and the responsible use of resources in industry.

Recommended educational level

Aimed at students in the final years of secondary education (Baccalaureate) and Higher-Level Vocational Training, especially in areas of electronics, mechatronics, or automation. It is also suitable for university students of Electrical, Electronic, Mechanical, or Industrial Engineering.

Gathering information

Pressure control in hydraulic pumps is essential in many industrial applications to ensure safe and efficient operation. Keeping the pressure within appropriate ranges prevents equipment failures, energy losses, and safety risks. In industry, digital systems enable this control to be automated by using sensors and logic circuits that activate indicators or actuators according to the situation. This exercise proposes the design of a combinational circuit that monitors the pressure, represented in binary, and indicates the range it is in by means of LEDs:

- A yellow LED indicates that the pressure is within an acceptable medium range.
- A green LED indicates that the pressure is low.
- A red LED indicates that the pressure is too high.

This simple system prevents operational risks, improves safety, and promotes efficient use of energy and equipment, contributing to a more responsible and sustainable production process.

Problem statement

Four input signals A_3, A_2, A_1, and A_0 represent a 4-bit binary number coming from a hydraulic pump pressure control circuit.

You are asked to design a combinational circuit that activates:

- A yellow LED when the binary value is between 6 and 11, inclusive.
- A green LED when the binary value is less than 6.
- A red LED when the binary value is greater than 11.

The goal is to obtain the logic expressions that activate each LED and to design the corresponding circuit.
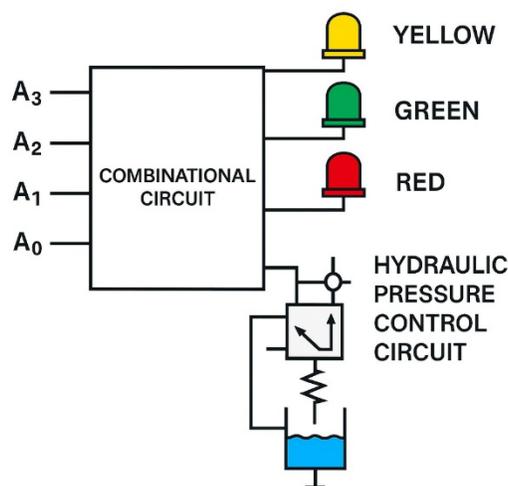

Figure 1. Block diagram of the hydraulic pressure monitoring system. The combinational circuit activates a yellow, green, or red LED based on the binary pressure level detected by the hydraulic pressure control circuit. Source of the image: AI generated image and subsequently edited by the authors.

How is the safe pressure level of the hydraulic pump monitored?

We first identify the inputs to our system, which are the binary signals A_3, A_2, A_1, and A_0. Together, they represent a 4-bit binary number indicating the current pressure measured in the hydraulic pump control system. This number increases as the pressure in the pump increases. On the other hand, the outputs of the system are three LEDs —green, yellow, and red— which indicate whether the pressure is within a safe range, too low, or dangerously high.

- When the binary value is less than 6, the green LED is activated to signal that the pressure is low.
- When the binary value is between 6 and 11, the yellow LED is activated to indicate that the pressure is within an acceptable range.
- When the binary value is greater than 11, the red LED is activated to warn that the pressure is too high and could be hazardous.

The objective of this problem is, therefore, to design a combinational circuit that generates the signals to control the LEDs according to the binary value of the pressure measurement.

Monitoring and controlling the pressure of a hydraulic pump is critical in industrial environments, as insufficient pressure may prevent the system from operating properly, while excessive pressure can lead to equipment damage, safety hazards, and wasted energy. The circuit designed in this exercise helps to ensure that the system remains within optimal operating conditions, contributing to both safety and efficiency.

In this way, the proposed solution contributes to the Sustainable Development Goals 9 and 12, promoting efficient and safe industrial infrastructure and the responsible use of resources.

Let's analyse how to implement this circuit fulfilling the established criteria.

Solution

1. **Truth table:**

No.	A_3	A_2	A_1	A_0	G	Y	R	
0	0	0	0	0	1	0	0	→ Low pressure since it is lower than 6.
1	0	0	0	1	1	0	0	→ Low pressure since it is lower than 6.
2	0	0	1	0	1	0	0	→ Low pressure since it is lower than 6.
3	0	0	1	1	1	0	0	→ Low pressure since it is lower than 6.
4	0	1	0	0	1	0	0	→ Low pressure since it is lower than 6.
5	0	1	0	1	1	0	0	→ Low pressure since it is lower than 6.
6	0	1	1	0	0	1	0	→Acceptable pressure (between 6 and 11).
7	0	1	1	1	0	1	0	→Acceptable pressure (between 6 and 11).
8	1	0	0	0	0	1	0	→Acceptable pressure (between 6 and 11).
9	1	0	0	1	0	1	0	→Acceptable pressure (between 6 and 11).
10	1	0	1	0	0	1	0	→Acceptable pressure (between 6 and 11).
11	1	0	1	1	0	1	0	→Acceptable pressure (between 6 and 11).
12	1	1	0	0	0	0	1	→High pressure since it is higher than 11.
13	1	1	0	1	0	0	1	→High pressure since it is higher than 11.
14	1	1	1	0	0	0	1	→High pressure since it is higher than 11.
15	1	1	1	1	0	0	1	→High pressure since it is higher than 11.

2. **Karnaugh maps to simplify the logic function:**

G Output: Y Output: R Output:

A_1A_0 \ A_3A_2	00	01	11	10
00	1	1	0	0
01	1	1	0	0
11	1	0	0	0
10	1	0	0	0

A_1A_0 \ A_3A_2	00	01	11	10
00	0	0	0	1
01	0	0	0	1
11	0	1	0	1
10	0	1	0	1

A_1A_0 \ A_3A_2	00	01	11	10
00	0	0	1	0
01	0	0	1	0
11	0	0	1	0
10	0	0	1	0

$$\text{Green} = \overline{A_3} \cdot \overline{A_2} + \overline{A_3} \cdot \overline{A_1}$$

$$\text{Yellow} = A_1 \cdot A_2 \cdot \overline{A_3} + \overline{A_2} \cdot A_3$$

$$\text{Red} = A_2 \cdot A_3$$

3. **Circuit:**

The circuit shows logic gates producing outputs G, Y, and R:

- $\overline{A_2}$, $\overline{A_3}$ → AND gate
- $\overline{A_1}$, $\overline{A_3}$ → AND gate
- Both AND outputs → OR gate → **G**

- A_1, A_2, $\overline{A_3}$ → AND gate
- $\overline{A_2}$, A_3 → AND gate
- Both AND outputs → OR gate → **Y**

- A_2, A_3 → AND gate → **R**
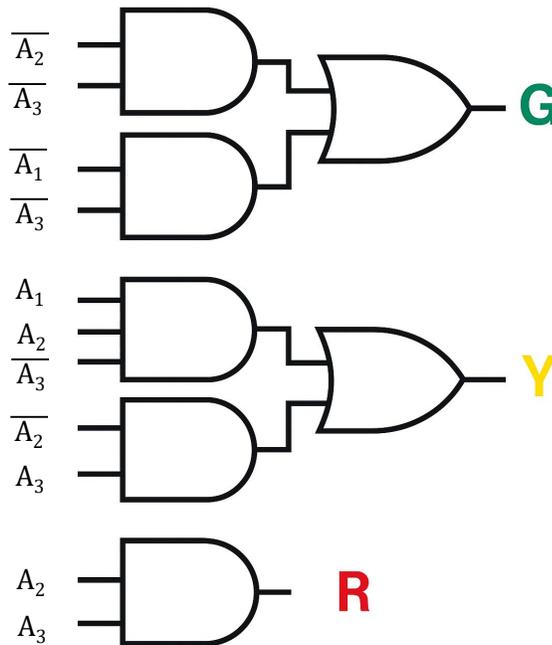
Conclusion

The designed system enables monitoring of a hydraulic pump's pressure in a simple and efficient way, clearly indicating whether the pressure is low, appropriate, or dangerously high using LEDs of different colours. This contributes to safety, energy efficiency, and sustainability in industrial settings. Moreover, by ensuring that the equipment operates within optimal conditions and avoiding unnecessary energy consumption or mechanical failures, this system supports the objectives of the Sustainable Development Goals 9 and 12, which promote resilient and efficient industrial infrastructure and responsible production practices.

This type of exercise also encourages critical thinking and the ability to apply digital electronics to real-world industrial problems, highlighting how technology can directly contribute to achieving global sustainability goals.

To extend this problem, additional options could be considered, such as:
- Adding audible alarms in addition to the LEDs.

- Implementing a delay to avoid rapid oscillations in the indicators.
- Using a microcontroller for greater flexibility and programmability.