Development of a monitoring device for metal fragments in food products – hardware

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Abstract. This report presents a development of a device for monitoring metal fragments in food products. The work is focused on the design and hardware implementation of the device. The offered similar developments with industrial application by companies are at a relatively high price. This gives reason to look for a solution at a lower price with components offered in the commercial network, using the Arduino platform. From the known methods for detecting metal fragments, the Induction Pulse method was chosen. The present development could be applied, for example, in small companies with activities in the food industry, in the retail network, in catering establishments, as well as in activities from other industries.

1 Introduction

Foreign bodies in food and beverages are a major problem for all manufacturers and retailers, as well as for end consumers. The accidental landing of unwanted objects can happen even in the best organized productions. The possible range of foreign bodies is practically limitless. Various parts and fragments of machines have the potential to become external bodies for the final product. Factors such as the minimum size of the captured particle, the size of the detector, the material, shape and location of the contaminant, the physical and chemical characteristics of the product being inspected, the material of the packaging and other factors.

Very often foreign bodies are metal particles. The main problems are that the sizes of the fragments are small, and the location, orientation, shape, metal, product characteristics are different. This leads to the need for devices (systems) with high sensitivity to various metals and sufficiently high operating speed and reliability for their application in production lines.

The detector for metal fragments (metal detector) is a device (system) with extremely high detection sensitivity and anti-fading ability of signals from the surrounding environment and depth in the product under investigation, and have a detection performance that is high enough for food application and other industries. It can be used to detect, for example, broken needles, wire, copper, lead, aluminium, tin, stainless steel and other metals that are lost or found in raw materials or finished products.

The control and prevention of contamination with metal parts of the final product and machines is an important part of any production. This makes metal detectors widely used in various industries - the food, pharmaceutical, chemical, textile and sewing industries, in the production of toys, food, beverages, textiles, clothing, plastics, chemicals, woodworking, packaging, etc.

In the food and packaging sectors, metal detectors are now standard. These devices serve to detect all metal particles in the production environment, allowing their removal from the final products.

According to the specifics of the application in various industries, special requirements are imposed on metal detectors regarding their sensitivity to detection, protection against interference, high levels of dust and water resistance, etc.

There are metal detectors for industrial applications from different manufacturers that are suitable for different industries and production lines, for example:

- Techic - an industrial metal detector mainly for food, but also for other areas of the company Ren Technology (Fig. 1) [1];

Fig. 1. Industrial metal detector Techic

- DYX-6030 - the industrial detector is mainly used to detect needles, broken needles, wire and other metal particles in toys, clothing, textiles, shoes, food and other industries (Fig. 2);
- Safeline Series 80 - a metal detector suitable for bulk and packaged products, located on a belt conveyor of the METTLER TOLEDO company (Fig. 3) [2].

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Fig. 2. Industrial metal detector DYX-6030

Fig. 3. Industrial metal detector Safeline Series 80

The presented sample industrial detectors for metal fragments offer excellent characteristics and can be applied not only in the food industry. They have great functionality, a high degree of reliability, high sensitivity, high noise resistance, etc., but their significant drawback is their high price. For a relatively small company engaged in food production, the purchase of such a machine represents a serious financial problem.

The present development could be applied, for example, in small companies with activities in the food industry, as well as in companies with other activities, solving the problem of detecting metal fragments in products, which is imposed by mandatory standards.

This report examines one of the possible ways to register metal fragments by means of an electromagnetic field, and the main goals for the implementation of the device are to have relatively cheap components and, at the same time, to provide relatively good sensitivity to fragments of different metals. In the development, a simple and cheap solution based on the Arduino platform [3] was sought.

2 Exposition

2.1 Method for detection of metal fragments

There are various methods for detecting metal fragments in products, the main ones being [4]:

- Metal detectors with IP system (Induction Pulse);
- Metal detectors with BOF system (Bias-Of-Frequency);
- Eddy current principle metal detectors;
- Metal detectors with IB system (Induction Balance);
- Metal detectors with "transmitter - receiver";
- Metal detectors with other working principles:
  - o Electrical resistances;
  - o Geo radar (scanner);
  - o Magnetometric method;
  - o Gravity method;
  - o Seismic method;
  - o Nuclear Magnetic Resonance;
  - o Ultrasound examination;
  - o X-ray examination.

On the basis of the research done, for the present development, it was chosen to use the method of detecting metal fragments with a pulsed electro-magnetic field (IP-system, Induction Pulse, pulsinductive), due to their ability to work at a great depth, due to the use of only one circular or elliptical coil in the seeker head without shielding (relatively cheap and uncomplicated to manufacture) and due to the possibility of achieving high sensitivity to different metals.

In the chosen method, powerful short electromagnetic pulses are used, which are created by a search coil (coil). They penetrate into the studied product and in the presence of metal, depending on whether it is ferromagnetic or not and its size and the depth at which it is located, changes the form of the voltage that is self-induced when the field drops, after the end of the current pulse in the coil of the metal detector. The presence of metal, its amount, depth and type is judged by the change in the shape of this voltage after appropriate processing. Metal detectors built on the basis of pulse induction are very suitable for searching great depths - they are the only ones that can achieve this - the depth at which they work depends on the power of the emitted pulse. They have only one coil, which, unlike all other detectors, does not need shielding. The main disadvantage of metal detectors working on this principle is that they are relatively more complex schematically than the other types.

The variation of the shape of the input signal (Uin) in time (T) according to the type of metal detected is presented in Fig. 4.

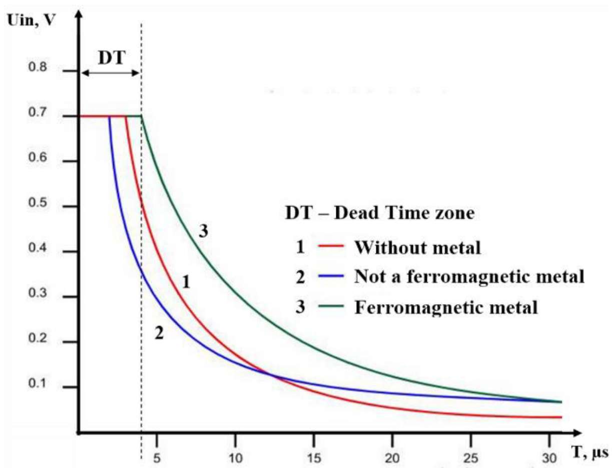

Fig. 4. Change of the input signal depending on the type of detected metal

The input voltage Uin in Fig. 4 is the result of the self-induction of the coil when the supply voltage to it is interrupted. Depending on the parameters of the winding, it is possible to obtain a short pulse with a voltage of the order of hundreds of volts. Of interest is the accurate measurement of the voltage at precisely selected moments as it decreases with time. Due to the high values of the pulse voltage at the initial moment and its rapid change, it is difficult to measure - this is the so-called "dead time zone" (DT). Measurements can be made after DT when the voltage changes relatively slowly and its level is low enough. Often this is implemented schematically by measuring the voltage drop across a forward-connected diode in parallel with the coil when the voltage drops to values of 0.7 V and less. The variation of the input voltage in the absence and presence of a metal object in the field of the coil can reach several tens of millivolts.

2.2 Functional block diagram and principle of operation

In Fig. 5 shows the functional block diagram of the developed device, where the thick arrows show the path of the analog signals, the thin arrows represent the digital signals, and the two-way white arrow between the Control and Synchronization Block and the User Interface block represents the I2C interface for communication with the LCD module (via an I2C adapter).

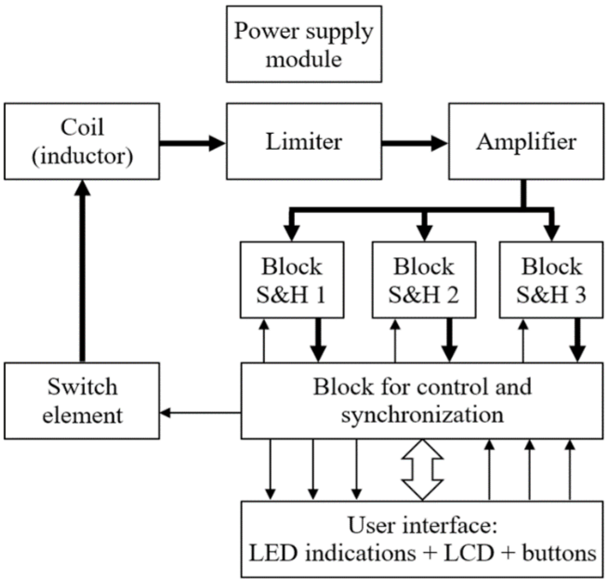

Fig. 5. Functional block diagram of the metal fragment detector

Using a powerful key element with a suitable driver for it, the coil in the metal detector is powered. After a certain set time, when enough energy has accumulated in the coil, the control unit signals to cut off the power supply to the coil. At this point, a timer starts. As a result of the self-induction of the coil, a powerful electromagnetic pulse is generated around it. The limiter in the circuit does not pass to the Amplifier a higher voltage than the circuit set (about 0.7 V). The amplifier must be fast, high gain, and low noise so that its output is sufficiently high for the operation of the monitor-memorization circuits connected to its output.

After the expiration of the first set time interval t1, an enable signal of a certain duration is applied to the first monitoring-memory block (S&H Block 1), whereby the current value of the output voltage from the amplifier is stored in it. The expiration of the second set time interval t2 is the time when the current output voltage from the amplifier is stored in the second tracking-memory block (S&H Block 2), and the third sensed time interval t3, respectively, records the current value of the voltage in the third tracking block -memorization (Block S&H 3). The measured and stored three analog voltage values can then be converted to digital form by the Control and Timing Unit and processed appropriately to extract useful information about the presence or absence of a metal fragment. The resulting output can then be appropriately output to the User Interface (as well as to other implements not shown in the diagram). With the buttons, the user has the opportunity to control the operating mode of the device and the displayed information. The described measurement cycle is repeated with a selected low frequency (e.g. 10 Hz). The power supply module provides the necessary supply voltages to all blocks in the circuit.

2.3 Selection of components for implementation and a schematic circuit diagram

The blocks of the diagram in Fig. 5 is chosen to be implemented through:

1. Coil (inductor) - an induction search head (Fig. 6), which has an annular shape and a method of making the detector coil, having multiple windings arranged spirally in one plane, according to the patents of Klaus Ebinger Fig. 6a and Fig. 6b;

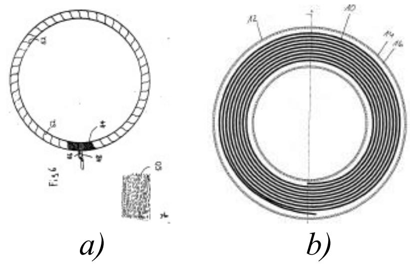

Fig. 6. Coil of the metal detector

2. Control and synchronization block - Arduino Uno R3, based on ATmega328P microcontroller, with 14 digital and 6 analog I/O, 16MHz clock frequency, 32 kB program memory, USB connector, built-in stabilizer and possibility of external power supply [5];
3. Limiter - based on high-voltage rectifier diodes, parallel to the coil;
4. Amplifier - a two-stage amplifier based on the high-speed operational amplifier LM 318 with a gain rate of up to 70V/µs and a 15MHz bandwidth [6];
5. Blocks S&H 1, 2 and 3 - based on a fast sample-hold (Sample&Hold) LF 398 circuit with a hold time of less than 10 µs, operating from ± 5 V to ± 18 V, with low output noise in hold mode [7];

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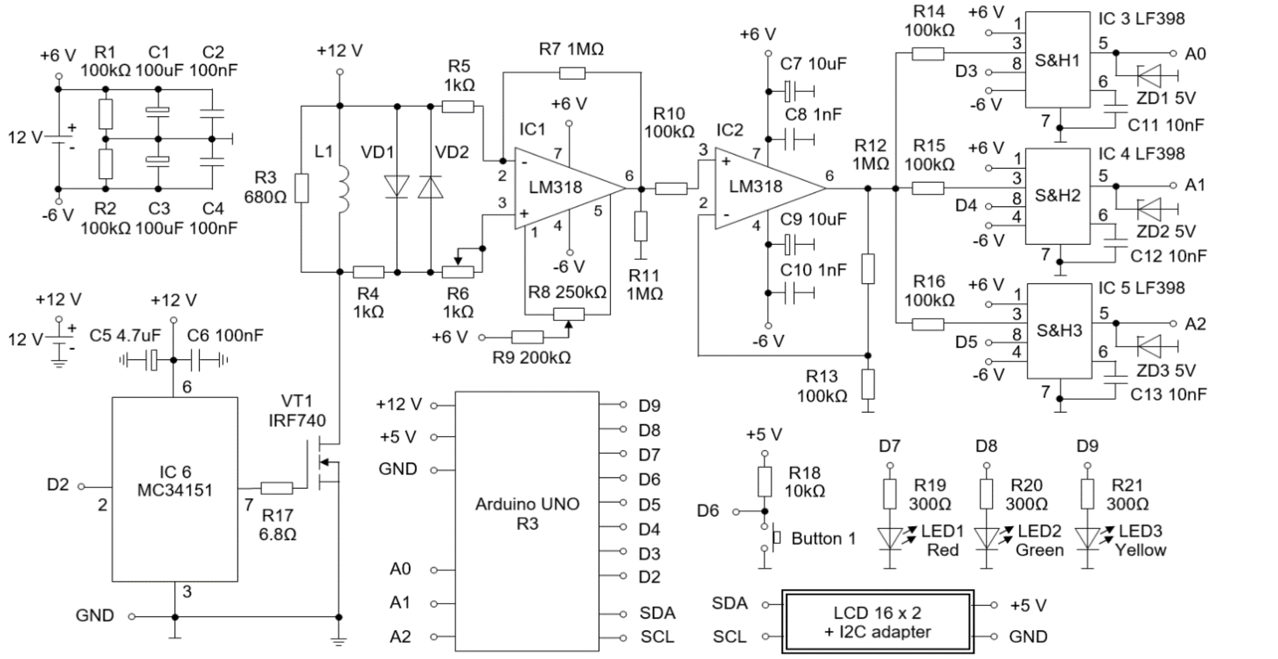

Fig. 7. Schematic diagram of the metal detector being developed

6. Key element – fast and powerful MOSFET transistor IRF740 with Uds=400V Id=10A and Rds(on)=0.55Ω [8]. A high speed MOSFET driver MC34151 [9] with a maximum output current of up to 1.5 A is used to control the transistor;
7. User interface: 3 color LEDs, LCD 1602 (2 lines x 16 characters) with I2C adapter, 1 button;
8. Power supply module - to reduce the interference transferred on the power lines between the power part (the key element and the coil), the control part (the Arduino UNO board) and the measurement part of the device (the operational amplifiers and the follow-memorization circuits), will two separate power supplies are used: a 12 V rechargeable battery - to power the power and control parts (unipolar power supply), and for the measuring part - with another 12 V rechargeable battery with a symmetrical divider and capacitors to realize a bipolar power supply with artificial middle point (mass).

In Fig. 7 presents the developed basic circuit diagram of the metal detector for metal fragments in food products. With potentiometers R6 and R9, the amplitude of the input voltage to the amplifier and the offset of its level relative to the midpoint of the bipolar supply can be changed, respectively. The gain of the two-stage amplifier is about 10000, but can be changed as needed by the values of resistors R5 to R13. Enable signals lasting 10μs or longer are applied to the watch-to-memory circuits. In order to protect the analog inputs of the Arduino UNO, there are 5V zener diodes connected to them.

2.4 Prototype of the system

In Fig. 8 is a view of the developed prototype of the detector for metal fragments. In Fig. 9 is a view of the LED indicators when are tested.

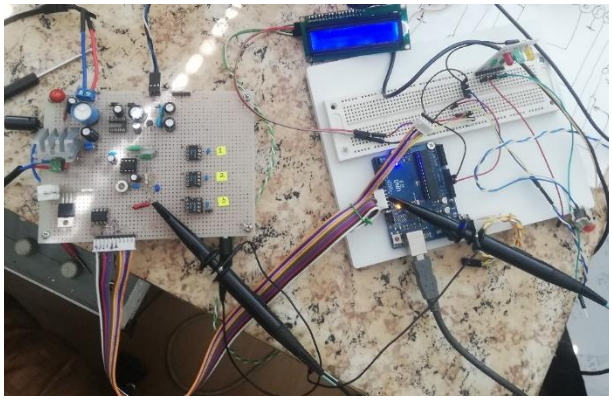

Fig. 8. A view of the developed prototype of the detector for metal fragments

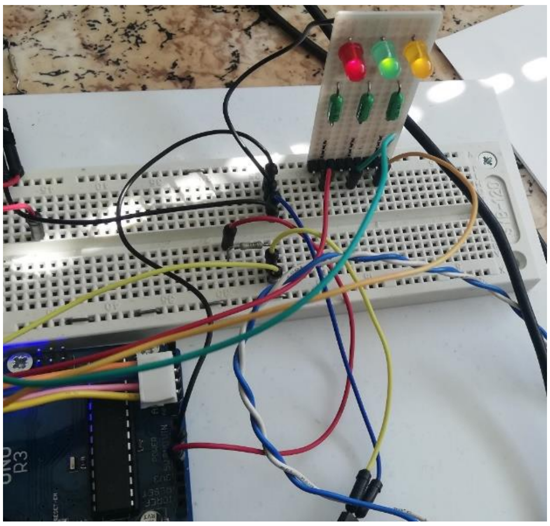

Fig. 9. Testing of LED indicators of the prototype

The all hardware components and modules are tested for correct connection and work with created test sourse code with Arduino IDE.

3 Conclusion

The developed device is operational and has been realized as a prototype, and the values of the electronic components have been further specified experimentally. Software development is pending for the Arduino UNO controller to generate synchronized control signals to the power switch and sample-hold circuits, process the measured signals, and output the results appropriately to the user interface and external signalling and processes control systems.

The development was made with relatively cheap components and compared with the studied industrial metal detectors the prototype device is with less than 5% from their prices.

In future development can be implemented more protection measures from the environmental parameters, such as temperature, humidity, dust particles, etc. with appropriate housing of the device. Also to implement more control outputs with galvanic protection by relays or optical insulation to external systems for signalization and process control. For realization of more complicated user interface can be implemented also more buttons and LED indicators.

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