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TESTS OF THE ELECTROMAGNETIC COMPATIBILITY OF SELECTED ELEMENTS OF INDUSTRIAL AUTOMATION

Marek Płaczek[1], Michał Maćkowski[2], Igor Schab[1]

[1] Silesian University of Technology, Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Konarskiego 18A, 44-100 Gliwice, Poland
[2] Silesian University of Technology, Faculty of Automatic Control, Electronics and Computer Science, Institute of Informatics, Akademicka 16, 44-100 Gliwice, Poland

Corresponding author: Marek Płaczek, marek.placzek@polsl.pl

Abstract: The practical part presented in the work was devoted to the study of electromagnetic compatibility of two systems being elements of industrial automation. The first of these systems was built from SEW-Eurodrive components: frequency inverter and electric motor. Research was carried out twice using laboratory stands with two types of clamps: CDN (Charge Device Model) clamps and EM (Electromagnetic Model). The second system was the capacitive sensor. In this case, the tests took place only on the EM clamping bench. Thanks to this, during the tests, it was possible to check the function of the capacitive sensor when the direction of the generated interference was consistent or opposite to the direction of the sent object detection signal by the sensor. In both cases it was possible to determine the frequency values at which the sensor was malfunctioning. By performing further tests, the distance at which the sensor did not interrupt work was determined and compared with the manufacturer's data.

Key words: Electromagnetic compatibility, measurements, immunity, electromagnetic disturbances, sensors.

1. INTRODUCTION AND GENERAL INFORMATION

The increase in the weight of electromagnetic compatibility in the present times is related to the continuous increase in the number of electrical and electronic devices that are used in industry and home environments. Electromagnetic compatibility is the ability of electrical and electronic devices to function properly in an environment prone to electromagnetic disturbances and a lack or minimum level of emitted disturbances that could affect other devices in work environment.

This task is very important in modern devices that are usually mechatronic systems including mechanical and electronic elements connected by an advanced control system [1, 6, 8]. Such systems allow engineers designing very advanced technical means with application new materials including composite and smart materials [2, 5, 13, 16-19]. It allows obtaining for example a new functionality, high efficiency and low energy consumption, what is very important in modern market [7, 13].

Nowadays, manufacturers and distributors must face many regulations, directives and requirements that their products must meet or be compliant to. Some of them are state-regulated, other come from international entities like the European Union. The EMC directive (currently the directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014) is a legislative act, which is not binding on its own. However, most of the European Union members states have accommodated own laws, which are directly based on it. Guidelines to implementing the directive’s essential requirements are discussed in referenced sources [3, 9, 12, 14].

The practical part presented in the work was devoted to the study of electromagnetic compatibility of two systems being elements of industrial automation. The first of these systems was built from SEW-Eurodrive components: frequency inverter and electric motor. Research was carried out twice using laboratory stands with two types of clamps. The tests carried out on the test stands for resistance to disturbances conducted with CDN (Charge Device Model) clamps and EM (Electromagnetic Model) clamps resulted in obtaining identical results. The operation of the frequency converter and the electric motor has not been disturbed during the entire test cycles [12, 14].

The second system using elements of industrial automation was the capacitive sensor. In this case, the tests took place only on the EM clamping bench. This stand creates disturbances in two directions, depending on the position of the clamps. Thanks to this, during the tests, it was possible to check the function of the capacitive sensor when the direction of the generated interference was consistent or opposite to the direction of the sent object detection signal by the sensor. In both cases it was possible to determine the frequency values at which the sensor was malfunctioning. By performing further tests, the distance at which the sensor did not interrupt work was determined and compared with the manufacturer's data. The research described in the practical part was carried out in the Electromagnetic Compatibility Laboratory at the Faculty of Automatic Control, Information Technology of the Silesian University of Technology. The tests were carried out in accordance with the EMC Directive 2014/30/EU. Therefore, the research was performed in accordance with the requirements of the industrial environment standard IEC 61000-6-2:2005 "Generic standards – Immunity for industrial environments". Generic standards specify the environment conditions and set minimal EMI resistance that equipment in this environment must meet. Moreover, these standards also provide the general and fundamental rules for meeting the EMC requirements.

The electromagnetic phenomenon is the cause of the possibility of electromagnetic disturbance. It may result in interference that leads to equipment failure or malfunction. The electromagnetic compatibility of a given device consists of two issues:

- emissivity - an action during which the device or system during the work does not generate electromagnetic interference that would exceed the tolerance level of devices present in its environment,
- immunity - the ability of a device or system to work properly in an environment where electromagnetic disturbance occurs [3, 9, 10, 15].

In electromagnetic compatibility, there are three ways that devices interact with each other in an electromagnetic environment:

• low frequency interference - occurs in the range up to 9 kHz. They constitute deformations of the supply current, which are characterized by the content of so-called harmonics and occur as a result of fluctuating the effective value of the supply voltage,

• conducted interference - affecting devices performing work through the power supply network with a frequency range from 9 kHz to 30 MHz,

• induced interference - acting through the electromagnetic field in the 30 MHz to 1 GHz frequency range [3, 9, 10, 15].

Disturbances are conditions that hinder or prevent the correct operation of electronic or electrical systems, while disturbances are a direct impediment to the operation of the systems or components from which they are made. Devices or systems exposed to interference may be permanently damaged. Undesirable signals can usually not be eliminated, but it is possible to bring them to an appropriate level so that their occurrence does not lead to disruptions in the work of a group of devices. A useful signal in one system may be an interfering signal in another system.

There are four basic types of interference couplings:

• impedance coupling - this is galvanic coupling. Occurs when the currents of at least two electrical circuits have a common impedance, i.e. they have a common ground or common neutral wire.

• capacitive coupling - this is a coupling that occurs when electrical circuits are connected to each other through electrical capacity. This coupling is also called parasitic coupling, has a small range of action and occurs at low frequencies. The receiver for such coupling is low and high voltage wires.

• induction coupling - the magnetic flux generated by the current flowing in a conductor affects neighbouring electrical circuits, generating electromotive force in them. This is a short-range coupling occurring at low frequencies. The receiver for such coupling is low and high voltage wires.

• radiation coupling - the source of radiation coupling is electromagnetic fields. They could be produced by radio and television transmitters, cell phones and all devices with wireless communication. Interference with radiation coupling affects adjacent electrical systems, and they occur during a series of fast signal transients or their high-frequency components. This is a long-range coupling that operates in the high frequency range. Receivers for such coupling are high and low voltage wires [3, 9, 10, 15].

Couplings usually do not occur individually, but there is the possibility of simultaneous couplings and their joining in series or parallel.

As part of the research, an attempt was made to determine the immunity to electromagnetic disturbances of selected elements and systems of industrial automation, considering the significant importance of meeting the requirements for electromagnetic compatibility, which directly translates into their safety of use and reliability.

2. TESTS OF FREQUENCY CONVERTER AND ELECTRIC MOTOR

The first part of the research was to analyse how the system built of the SEW-EURODRIVE R27 DRS71M2BE1HR / TH / LN electric motor, the SEW-EURODRIVE Movitrac B frequency converter and the power supply behaves when it is exposed to disturbances. The speed of the electric motor during tests in this system was controlled in two ways: the first way was control using a Movitrac B frequency converter. The second way was control via a computer and the MOVITOOLS MotionStudio software and communication with the frequency converter via an RJ-45 network wire.

The system described above was initially installed in a stand for conducting tests of resistance to conducted disturbances using CDN clamps (See Figure 1). In the CDN clamps, a cable was installed that sends the signal from the frequency converter to the electric motor. The station using CDN clamps emits an impulse disturbing signal at specified intervals, the value of which was 5 seconds.

Using the first way of controlling with a frequency converter, the system was exposed to disturbances in the range from 200 V to 2 kV during operation. These tests were aimed at checking the impact of conducted disturbances on the rotational speed of the electric motor. A tachometer was used to measure the differences in rotational speeds. The obtained rotational speed results during the broadcast disturbances coincided with the set rotational speed of the electric motor. This means that the disturbances created did not affect the operation of the electric motor.

The next stage was testing using the second control method. During this part of the research, disturbances were transmitted in the amount of 200V, 500V and 1kV. In this case, the disturbances produced had a direct impact on the system's operation. Disorders of 200V and 500V led to a situation in which, when the impulse was given, the system stopped working and the connection between the computer and the frequency converter was interrupted for a short period of time. The length of the time gap was slightly dependent on the amount of interference voltage. After this time, the computer and the frequency converter regained the connection and further operation of the system was possible. However, when the system was subjected to 1kV interference, the connection between the computer and the frequency converter was broken. In this case, the interruption was permanent and was not resumed. In order to obtain further operation of the system, computer and frequency converter connection had to be reconfigured using the MOVITOOLS MotionStudio program.

The reason for the incorrect operation of the system under the influence of generated disturbances could be the use of a standard PC. This computer was not adapted to work in industrial conditions and did not have adequate suppression of generated interference.

Fig. 1. Stand for testing the resistance for conducted disturbances with the use of CDN (Charge Device Model) clamps together with the frequency converter and the electric motor

The next stage of the research was to test the frequency converter and the electric motor on a station designed for conducting tests of resistance to conducted disturbances using EM clamps (Figure 2).

Fig. 2. Stand for testing the resistance for conducted disturbances with the use of EM (Electromagnetic Model) clamps together with the frequency converter and the electric motor

The disturbances to which the tested system was subjected had a constant value of 10V, but a variable frequency, which increased over time in the range from 0Hz to 80MHz. A characteristic feature of this station is the possibility of directional interference setting, depending on the EM clamp setting. These interferences may be directed in the same direction or in the opposite direction of the data flow. The tests carried out, however, showed no impact of the generated disorders on the correct operation of the tested system.

3. CAPACITY SENSOR TESTS

The next part of the work was to carry out tests of the resistance of the capacitive sensor using EM clamps. A Balluff BCS M18 sensor was tested.

The basic operation, in order to be able to check the capacitive sensor in terms of resistance to interference, was to make a system that received the sensor signal when it detected an object located at a certain distance from the sensor. Figure 3 presents the completed capacitive sensor testing system. The principle of the system is that the capacitive sensor is located at a constant distance from the object and constantly transmits the signal of its detection. The wire connecting the sensor and the system was placed in EM clamps and then disturbances were generated. In the situation when the transmitted disturbances cause the capacitive sensor not to detect the object,

the diode in the system stops lighting, whose task is to indicate whether the element is detected by the sensor. The constructed system was supplemented with a solenoid valve, controlled by the tested sensor.
The wire connecting the capacitive sensor and the sensor control system were placed in EM clamps. These clamps can be positioned in two directions, which allow changing the direction of generated disturbances. The capacitive sensor was set at the maximum distance from the object. This distance was measured using a calliper with a reading accuracy of 0.1mm.

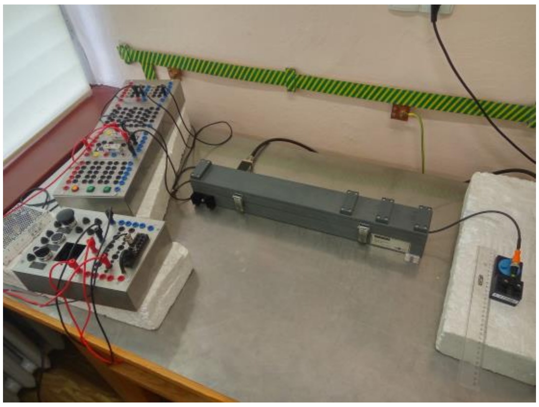

Fig. 3. Stand for testing the capacitive sensor with EM (Electromagnetic Model) clamps

The tests carried out using a capacitive sensor were divided into two parts depending on the position of the EM clamps. In the first part of the study, the disturbances generated by the clamp were directed in the opposite direction as to the signal received from the sensor. In the second part of the study, the interference generated by the clamps was oriented in the direction of the signal received from the sensor.
The tested capacitive sensor was set to the maximum distance from which the object detection signal was generated. The distance set was 12.5mm. The wire connecting the capacitive sensor with the signal detection system has been exposed to the interference with a constant value of 10V, but with increasing frequency in the range from 0Hz to 80MHz. Constantly received information about object detection was interrupted at a frequency of 5.66MHz. Until the end of the test cycle, i.e. reaching a frequency of 80 MHz, the tested sensor did not detect the presence of the object. Despite the end of the test cycle and the lack of disturbance generation, the sensor signal was not generated again. It was necessary to move and reposition the capacitive sensor to the initial distance to get the signal of the presence of the object.
The next stage of this study was to determine the distance of the capacitive sensor from the object in which the disturbances generated by the clamps did not affect the reading continuity. While reducing the distance of the sensor from the object by 0.5mm, changes could be observed in the frequency of the sensor operation interrupting and returning. The frequency range between these parameters decreased with each change in the distance between the sensor and the detected element. When the distance between the capacitive sensor and the element was 10mm, the entire test cycle did not interrupt the sensor's detection of the object. The obtained results were confirmed by repeated testing. The tests were also repeated with randomly selected sensor distances from the object in the range from 0mm to 10mm to check the effect of disturbances produced by clamps at smaller object distances from the sensor. Based on the tests carried out, it could be determined that the maximum distance that allows the sensor to work when the interference is in the opposite direction to the signal from the sensor is 10 mm. According to the manufacturer's data, the Balluff BCS M18 capacitive sensor has a range of 1mm to 8mm.
During subsequent tests, the direction of disturbances generated using clamps was consistent with the direction of the sensor signal. In this case, the capacitive sensor under test was also set to the maximum distance at which the object detection signal was received. This distance was identical to the previous case and was 12.5mm. After determining the distance to the wire connecting the sensor with the system, disturbances were given with a constant value of 10 V and an increasing frequency from 0Hz to 80MHz. The object detection information was interrupted at 6.01MHz.
As in the previous case, after reaching the 80MHz interference frequency and completing the test cycle at the maximum distance, the sensor did not re-detect the object. Only after re-positioning the sensor, but without changing the maximum reading distance, the signal was transmitted again. Each of the research trials gave reproducible results.
During subsequent tests, the distance from the sensor to the object was reduced by 1 mm. The change in distance had a direct impact on the frequencies at which the system with the capacitive sensor lost the ability to detect the object. At 11.5mm, detection was interrupted at a frequency of about 5.8MHz. Re-detection signal was generated when the disturbance frequency reached 24.1MHz and was generated until the end of the test cycle. There were no further gaps in the sensor reading.
Further reduction of the object distance from the sensor by 0.5mm had a significant impact on the frequency of interruptions and read back. The first interruption of the object reading by the sensor occurred at a frequency of 6.01MHz, and the return to element detection appeared at a frequency of 9.8MHz. The second loss of detection signal occurred at a frequency of 20.05MHz, and the reading was resumed at 20.5MHz.
The last part of the test during which interferences were

directed in accordance with the sensor signal was to determine the distance of the capacitive sensor at which the disturbances generated by the clamps did not interrupt its signal throughout the entire test cycle. The distance from the sensor to the object was reduced by 0.5mm every three test cycles. Reaching 9mm from the capacitive sensor from the object, passing the entire test cycle did not cause loss of signal from this sensor. After determining this distance, tests were carried out with random values in the distance range from 0mm to 9mm. As a result of the tests, it can be determined that the maximum distance of the capacitive sensor from the object being tested with the interference directed towards the sensor signal is 9mm. According to the manufacturer's data, the tested capacitive sensor has a range of 1mm to 8mm.

Obtained results of carried out tests of the sensor are summarized in Table 1.

Table 1. Obtained results of carried out tests of the Baluff BCS M18 sensor

Type of disturbances	**Distance between the sensor and the object**	**Results**
Disturbances generated by EM clamps with a constant value of 10V with a variable frequency that increased over time in the range from 0Hz to 80MHz. Disturbances directed in the direction of the data flow.	Less than 9 mm (8 mm given by the producer)	No effect on the operation
	10mm	No item detection with interference in the range from 20.05MHz up to 20.25MHz
	11mm	No item detection with interference in the range from 6 up to 9.8MHz and 20.05 up to 20.5MHz
	11.5mm	No item detection with interference in the range from 5.8 up to 24.1MHz
	12.5mm	No item detection with interference in the range from 6MHz up to the end of the test (80MHz)
Disturbances generated by EM clamps with a constant value of 10V with a variable frequency that increased over time in the range from 0Hz to 80MHz. Disturbances directed in the opposite direction to the data flow.	Less than 10mm (8mm given by the producer)	No effect on the operation
	11. mm	No item detection with interference in the range from 6.57 up to 8.9MHz and 20.05 up to 20.5MHz
	12.5mm	No item detection with interference in the range from 5.66MHz up to the end of the test (80MHz)

4. CONCLUSIONS

Conducted studies of the capacitive sensor have shown that the direction of disturbances in accordance with the direction of the signal generated by the sensor or opposite to it has a direct impact on its operation.

When the sensor was positioned at a maximum possible distance (12.5mm), the effect of the direction of interference was limited only to differences in frequency, which causes the interruption of signal generation on detection. The difference between the values of these frequencies was less than 0.5MHz. In the rest, the test results overlap. There was a possibility of interference the sensor regardless of the direction of disturbances, and only setting it back to the appropriate position allowed readings to be taken again.

Analysing the case in which the maximum distance was reduced by mm, it can be observed that the direction of interference has a direct impact on the results obtained. In the situation when the clamps were transmitting in the opposite direction to the signal from the sensor, the frequency range in which there was a break in detecting the object was from 6.57MHz to 9.3MHz. However, when the disturbances transmitted by the clamp were directed in the direction consistent with the signal from the capacitive sensor, the frequency range in which the object was not detected began from 5.8MHz and ended at 24.4MHz.

Analysing the obtained results, it can also be seen that when the disturbances cease to affect the detection signal generated by the sensor, the influence of the disturbance direction also results in a difference in the results obtained. While reducing the distance between the capacitive sensor and the object, several effects could be observed. In the case where the disturbances were directed in the opposite direction to the sensor signal, the frequency range of disturbances causing the lack of object detection, was reduced by increasing the minimum frequency needed to interrupt the reading and reducing the maximum frequency at which the reading was still absent. The distance at which the gap in frequency ceased to occur was 10mm. In the case where the interference transmitted by the clamps was in accordance with the direction of the signal from the sensor, the frequency range of disturbances interfering with the operation of the sensor was divided into two parts. The first of the breaks appeared in the range from 6MHz to 9.9MHz, while the second occurred from 19.9MHz to 20.4MHz. By reducing the distance from the sensor to the object, the first break occurred decreased by increasing its lower frequency value. However, the second break did not show any major changes. The distance at which the sensor worked properly despite the disturbances occurred at 9mm from the capacitive sensor from the object.

According to the manufacturer's data, the tested sensor has a range of 1mm to 8mm. The results obtained as well as the manufacturer's data overlap in terms of the range of correct sensor operation.

By examining the system built of a frequency converter and an electric motor, as well as a capacitive sensor, it can be determined that when using these elements on production lines, one should consider the possibility of undesirable situations caused by electromagnetic disturbances. Such situations can be fatal. Starting from production line downtime, through damage to components up to the damage to health or even death of persons in the vicinity of disturbed devices. To reduce unwanted events, various types of tools can be used to reduce the impact of interference. This impact can be reduced using knowledge and available means constituting a collection of so-called good engineering practices in the field of electromagnetic compatibility [4, 15]. Elements of these activities may be the use of additional elements, such as shielded wires, chokes, suppressors and filters or appropriate wiring and proper grounding of devices. Each of these tools allows to improve the operation and ensure the proper operation of systems exposed to electromagnetic disturbances [11,12].

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