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INVESTIGATING SPURIOUS ACTIVATIONS IN AIRCRAFT FIRE SAFETY SYSTEMS WITH CIRCUIT-MAKER NUMERICAL EQUIVALENTS

BADANIE FAŁSZYWYCH AKTYWACJI W SYSTEMACH PRZECIWPOŻAROWYCH STATKÓW POWIETRZNYCH ZA POMOCĄ NUMERYCZNYCH ODPOWIEDNIKÓW CIRCUIT-MAKER

Abstract

The aviation industry is responsible for ensuring the safety of aircraft and their occupants. Fire alarm systems operate reliably to ensure flight safety. However, false alarms can pose a serious challenge, leading to unnecessary disruption and potentially compromising the effectiveness of fire protection measures. This review of the literature aims to explore the causes and consequences of false activations of the aviation fire protection system caused by short circuits in control blocks. This paper focusses on the analysis of damage to the fire suppression system of the transport aircraft. The analysis of the construction and operation of the amplifier board allowed the determination of the electrical schematic (including the identification of the values of electronic components) and the development of its numerical equivalent in the Circuit-Maker computational package (which allows the design and testing of electrical circuits, including the imaging of the course of voltages and currents in dynamic states). The results of computer simulations and verification tests were used to diagnose the SSP-FK system during the investigation of selected cases of its spontaneous tripping.

Keywords: false tripping, Fire Safety Systems, aviation

Streszczenie

Branża lotnicza jest odpowiedzialna za zapewnienie bezpieczeństwa samolotów i ich pasażerów. Systemy sygnalizacji pożaru działają niezawodnie, zapewniając bezpieczeństwo lotów. Fałszywe alarmy mogą jednak stanowić poważne wyzwanie, prowadząc do niepotrzebnych zakłóceń i potencjalnie zagrażając skuteczności środków ochrony przeciwpożarowej. Niniejszy przegląd literatury ma na celu zbadanie przyczyn i konsekwencji fałszywych aktywacji lotniczych systemów przeciwpożarowych spowodowanych zwarciami w blokach sterowania. Niniejszy artykuł koncentruje się na analizie uszkodzeń systemu przeciwpożarowego samolotu transportowego. Analiza budowy i działania płytki wzmacniacza pozwoliła na wyznaczenie schematu elektrycznego (w tym identyfikację wartości elementów elektronicznych) oraz opracowanie jego numerycznego odpowiednika w pakiecie obliczeniowym Circuit-Maker (umożliwiającym projektowanie i testowanie obwodów elektrycznych, w tym obrazowanie przebiegu napięć i prądów w stanach dynamicznych). Wyniki symulacji komputerowych i badań weryfikacyjnych posłużyły do diagnostyki systemu SSP-FK podczas badania wybranych przypadków jego samoistnych zadziałań.

Słowa kluczowe: fałszywe zadziałanie, instalacja przeciwpożarowa, lotnictwo

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1. INTRODUCTION

Fire alarm systems must operate reliably to ensure the safety of buildings and their occupants. However, false alarms can pose a serious challenge, leading to unnecessary disruption and potentially compromising the effectiveness of fire protection measures. One potential cause of false alarms is the occurrence of short circuits due to moisture in the executive block of a fire alarm system. This analysis aims to investigate the possibility of a false triggering of the executive block due to humidity-induced short circuits and the associated consequences.

Humidity-induced short circuits can occur when excessive moisture or humidity penetrates the control circuits of a fire alarm system, leading to unintended electrical connections and false activation of the executive block. These false activations can trigger alarms and initiate fire suppression mechanisms when there is no actual fire, resulting in unnecessary evacuations, disruptions, and potential safety risks for building occupants.

To address this problem, researchers conducted model tests to investigate the possibility of false triggering of the executive block caused by humidity-induced short circuits. These tests include simulating different humidity levels and monitoring the response of the fire alarm system. By analysing the test results, the researchers aim to identify the conditions under which false triggering occurs and develop strategies to mitigate it.

An approach to mitigating false trigger is to improve the design and construction of the executive block to increase its resistance to moisture. This can include the use of moisture-resistant materials, improved sealing techniques, and enhanced insulation to prevent humidity from entering the control circuits. Additionally, the development of advanced moisture sensing technologies can enable the detection and monitoring of moisture levels in the vicinity of the actuator block, providing early warning of potential short-circuit risks.

Furthermore, it is essential to implement regular maintenance and inspection protocols to ensure that the fire alarm system is working properly and to detect any signs of moisture-related problems. Regular inspections can help identify and eliminate potential sources of moisture, such as leaks or condensation, which can contribute to short circuits and false triggers.

Novelity of the article: this article is the second one in the cycle of articles about false activation of fire alarm system.In the previous one authors concentrated on the false triping of the executive block. In this one authors focused mainly on short circiut as the reason of unintended triggering of the fire protection system on the aircraft.

In summary, the possibility of false tripping of the actuator block in fire alarm systems due to short circuits caused by moisture is a serious concern. Model tests and scientific research are needed to understand the conditions under which false

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triggering occurs and to develop effective mitigation strategies[1]. By improving the design, construction, and maintenance of fire alarm systems, the occurrence of false triggers can be minimised, increasing the reliability and effectiveness of fire protection measures.

2. REVIEW OF THE LITERATURE

The aviation industry is heavily relying on fire protection systems to ensure the safety of aircraft and passengers. However, false actions of these systems can lead to unnecessary disruptions and potential risks. This review of the literature aims to explore the causes and consequences of false actions of the aviation fire protection system caused by short circuits in control blocks. By examining relevant studies and research articles, we can gain insight into the factors that contribute to false actions and potential solutions to mitigate these issues.

One of the main causes of false actions in the aviation fire protection system is short circuits in control blocks[2]. Short circuits can disrupt the normal functioning of the system, leading to false alarms or failure to detect actual fires[3]. The presence of short circuits can trigger the system to activate fire suppression mechanisms when there is no real fire, causing unnecessary interruptions and potential risks. These short circuits can occur due to various factors, including electrical disturbances in the electrical network on board that supplies the fire protection system. Overvoltage, voltage drop, and voltage decay during the start of aircraft engines and during flight can contribute to short circuits and false actions.

False actions of the aviation fire protection system can have significant consequences for flight safety. When the system falsely detects a fire, it can force the crew to land in a risky area, potentially affecting the lives of passengers and crew members. In addition, false actions can cause interruptions and delays in tasks, affecting the overall efficiency and operation of the aircraft[4]. Therefore, it is crucial to identify the causes of false actions and develop strategies to minimise their occurrence.

Several studies have proposed mitigation strategies to reduce false activations of the aviation fire protection system caused by short circuits in control blocks. An approach is to develop simulation models of electronic actuators to determine the conditions under which false alarms occur[5]. By understanding the specific conditions that trigger false actions, engineers can design more robust control blocks and implement preventive measures to minimise the occurrence of short circuits. Another strategy is to improve the reliability and accuracy of fire detection systems. Traditional

[1] A. Żyluk et al., Electrical Disturbances in Terms of Methods to Reduce False Activation of Aerial Fire Protection Systems. Sensors, no. 20 (2022). 8059. https://doi.org/10.3390/s22208059.

[2] K. Głyda et al., Actions of the Aviation On-Board Fire Protection System Caused by Short Circuits in Control Blocks. Journal of KONBiN 52, no. 4 (2022). https://journalofkonbin.com/resources/html/article/details?id=236288&language=pl.

[3] A. Żyluk et al., Electrical Disturbances in Terms..., op. cit.

[4] K. Głyda et al., Actions of the Aviation..., op. cit.

[5] A. Żyluk et al., Electrical Disturbances in Terms..., op. cit.

photoelectric smoke detectors used in cargo fire detection systems have a high false alarm rate[6]. To address this issue, researchers have proposed the use of infrared imaging and deep learning methods for fire detection. These advanced technologies can accurately distinguish between combustion particles and interference particles, reducing the occurrence of false alarms. Furthermore, the development of more reliable battery systems for electric-propulsion aircrafts can also contribute to reducing false actions. Battery degradation during operation can lead to internal short circuits and power fade, affecting the performance of the fire protection system. Research on battery materials, such as lithium metal anodes, shows promise in achieving higher specific energy and reducing the risk of internal short circuits[7].

An approach is to develop simulation models of electronic actuators to determine the conditions under which false alarms occur[8]. In addition to these strategies, it is important to consider the socioecological aspects of mitigating false activations of the aviation fire protection system. Community-specific, place-based strategies to reduce wildfire vulnerability have been effective in addressing exposure, sensitivity, and adaptive capacity. Collaborative partnerships between agencies and citizens are critical for identifying and implementing place-based solutions to reduce vulnerability[9]. Furthermore, ensuring the cyber-security of smart microgrids is essential for the reliable operation of fire protection systems. Cyber-attacks on the communication network can affect the performance of the protection system and lead to disastrous consequences[10]. Implementing protection and detection/mitigation strategies can help protect smart microgrids from cyberattacks. In conclusion, mitigating false activations of the aviation fire protection system caused by short circuits in control blocks requires a multifaceted approach. Developing simulation models, improving fire detection technologies, improving battery systems, implementing community-specific strategies, and ensuring cyber security are all important aspects to consider. By addressing these factors, the aviation industry can improve the reliability and effectiveness of fire protection systems, thus improving flight safety.

False actions of the aviation fire protection system caused by short circuits in control blocks can have significant implications for flight safety and operational efficiency. Understanding the causes of false actions and implementing mitigation strategies is crucial to minimise the occurrence of these incidents. Simulation models, advanced fire detection technologies, and improvements in battery systems are among the proposed solutions to address this problem. By continuously researching and

6 L. Deng et al., Fire Detection with Infrared Images Using Cascaded Neural Network. Journal of Algorithms & Computational Technology 13 (2019). https://doi.org/10.1177/1748302619895433.

7 S. Sripad, A. Bills, and V. Viswanathan, A Review of Safety Considerations for Batteries in Aircraft with Electric Propulsion. MRS Bulletin 46, no. 5 (2021): 435–42. https://doi.org/10.1557/s43577-021-00097-1.

8 A. Żyluk et al., Electrical Disturbances in Terms..., op. cit.

9 C. Kolden and C. Henson, A Socio-Ecological Approach to Mitigating Wildfire Vulnerability in the Wildland Urban Interface. Fire 2019, 2(1), 9; https://doi.org/10.3390/fire2010009.

10 F. Nejabatkhah et al., Cyber-Security of Smart Microgrids. Energies 14, no. 1 (2021): 27. https://doi.org/10.3390/en14010027.

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developing more reliable and efficient fire protection systems, the aviation industry can improve the safety and reliability of aircraft operations.

3. ANALYSIS OF THE FAILURE OF THE FIRE PROTECTION SYSTEM OF THE AN-28 AIRCRAFT

The An-28 aircraft fire protection system is designed to detect and suppress fires in the engine nacelles and crew cabin. Unfortunately, like any system, it shows signs of malfunctioning of individual system components depending on operating conditions. Certain factors such as changes in ambient temperature, humidity, or voltage drops in the onboard network can affect the negative functioning of selected components of this system.

In the case of the An-28 aircraft fire protection system, whose operation is based on the first and second order of fire extinguishing, the proper functioning of the system components responsible for detecting and signaling a fire is particularly important, as the first order is activated automatically. Therefore, in the event of a false fire warning, the crew is unable to decide on manual control of the extinguishing process.

Incorrect fire signaling or lack of signaling during flight operations are significant problems that can lead to serious incidents.

In this paper, the analysis of damage to the fire suppression system of the An-28 aircraft was based on data obtained from the operation operation process of eight aircraft used in Poland in 2015–2019. The damage found to elements of the An-28 aircraft fire protection system is presented in Table 1.

Table 1. Number of failure cases

Number of An-28 aircraft in service	8
Number of aircraft in which fire protection system damage occurred.	3
Number of fire system component failures.	5

Source: own study.

The operating data in Table 1 show that the most frequent failures are the DPS transmitters, located in the engine nacelles, and the BI-2A executive block. Failures of these components are regarded important defects, as correct signaling of the occurrence of a fire depends on their failure.

Due to the limited number of examples of failures of the fire protection system components of the An-28 aircraft included in the article, in the following section, only the operation of the DPS transmitters and the executive block BI-2A is analysed in terms of the causes of their false activation.

4. ANALYSIS OF THE CONSTRUCTION AND OPERATION OF THE SSP-FK SYSTEM UNDER NORMAL ELECTRICAL SUPPLY CONDITIONS

To prepare data for modelling the operation of the SSP-FK system, an analysis of the construction and operation of its various components was performed. It was determined that the most sensitive element of the SSP-FK system in terms of its false tripping is the SSP-FK-BI executive block, which contains amplifier boards[11].

A straightforward method was used to identify the circuit board structure of the executive block amplifiers SSP-FK-BI (Figure 1) and the parameters of its components by disassembling the component and reading the values of its electrical parameters. These values served as input data for modelling the operation of the SSP-FK-BI executive block and testing its properties during electrical disturbances in the form of momentary surges and power outages, as well as short circuits of selected electrical circuits on the amplifier board.

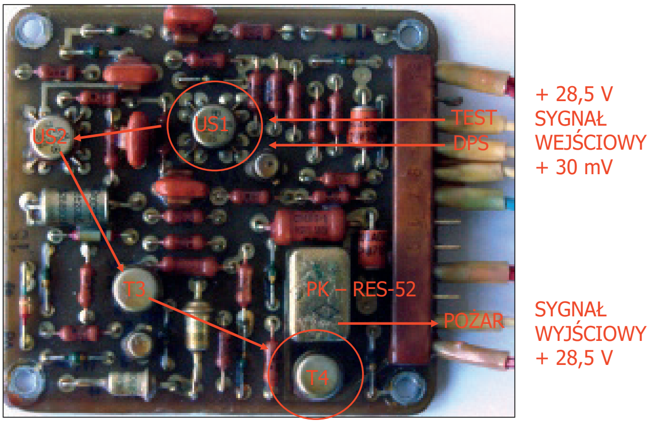

Fig. 1. View of the electronic components built into the amplifier board
Source: K. Głyda, „Badanie właściwości lotniczego..., op. cit.

For this purpose, it was necessary to analyse the assembly connections and reconstruct the electrical schematic of the amplifier board, determining the interrelationships of electronic components and allowing one to define the functions performed by the various electrical circuits on the amplifier board in the executive block SSP-FK-BI.

The results of the analysis of the construction and operation of the amplifier board allowed the determination of the electrical schematic (including the identification of the values of electronic components) and the development of its numerical equivalent in the Circuit-Maker computational package (which allows the design and testing of electrical circuits, including the imaging of the course of voltages and currents in

[11] K. Głyda, Badanie właściwości lotniczego systemu przeciwpożarowego. ITWL, Warszawa 2022.

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dynamic states). To verify the model, the results of tests performed at ITWL, obtained in the framework of ongoing expert reports for the Aircraft Accident Investigation Commission and the Support Inspectorate of the Polish Armed Forces were used.

Based on the identification of the components and the structure of their connections, four functional modules were distinguished, occurring on the amplifier board: the power module (based on power transistors T1 and T2), the input signal module (processing the signal from DPS sensors or the control signal), the signal comparison module and amplification of signals (using comparator US1 and amplifier US2), and the output signal generation module (transistors T3 and T4 and executive relay RES-52 built on the executive block amplifier board).

The selected functional modules were modeled in the Circuit-Maker package (Figure 3) using elements from standard libraries (numerical models: integrated circuits, diodes, transistors, resistors and capacitors, and output relay), for which the values of electrical parameters determined by the process of identifying the components and connection structure on the amplifier board in the SSP-FK-BI executive block were defined.

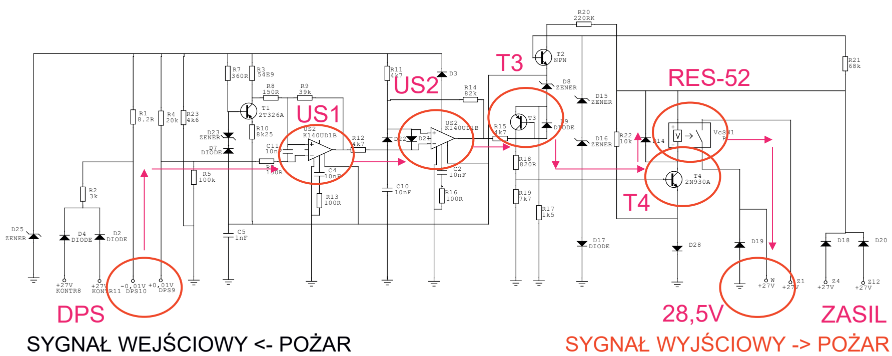

Fig. 2. Circuit board diagram of the SSP-FK-BI executive block amplifiers
Source: K. Głyda, Badanie właściwości lotniczego..., op. cit.

For simulation studies, two areas of interference signal effects on the electrical circuits of the amplifier board were selected: the comparator input signal comparison channel US1 and the base control channel of transistor T4[12].

The functional analysis performed on the amplifier board showed that under normal conditions (without disturbances in the electrical supply), the tripping of the system is triggered by the heating of the DPS sensor or the application of the CONTROL signal. The fire signal given to the input of comparator US1 causes a positive voltage to appear at the base of transistor T4, which in turn activates the RES-52 output relay on the amplifiers board.

12 Ibidem.

5. MODELLING POSSIBILITIES FOR FALSE TRIPPING STATES OF THE SSP-FK SYSTEM UNDER ELECTRICAL SHORT-CIRCUIT CONDITIONS

A special case in modelling the operation of the SSP-FK system, in which false tripping of the system occurs, is the occurrence of moisture-induced local short circuits between selected electrical circuits on the SSP-FK-BI executive block amplifier board, without causing permanent damage to its electronic components. False tripping of the system in the state of local short-circuit is limited to the rated voltage of 28.5 V or its overvoltage according to the Defence Standards: Polish Ministry of Defence and USA[13].

In the state of occurrence of a local short-circuit (Figure 4), the operation of the supply voltage path from the board of amplifiers of the executive block SSP-FK-BI to the control circuit of the transistor T4 working in the gate system (which activates the relay RES-52 closing the final fire signaling circuit) is that the signal at its base is the result of the transmission of power through the reduced insulation resistance due to moisture and electronic elements (resistive and capacitive) occurring in the short-circuit circuit.

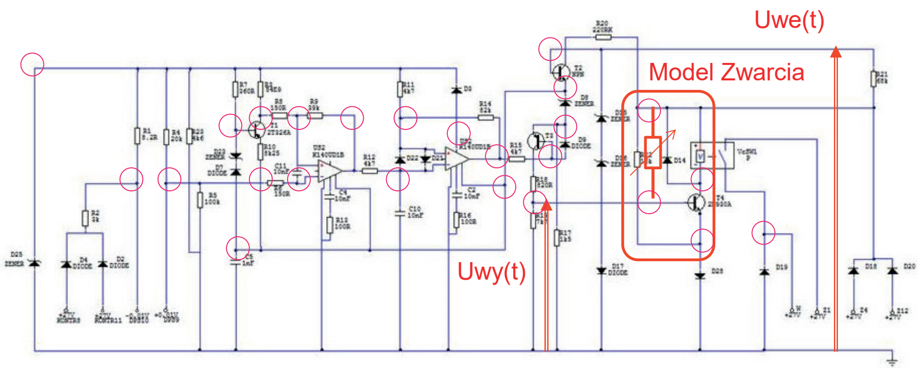

Fig. 3. Schematic diagram of the short-circuit model of selected electrical circuits in the SSP-FK-BI executive block

Source: K. Głyda, Badanie właściwości lotniczego..., op. cit.

The voltage at the base of transistor T4 under conditions of instantaneous supply voltage perturbation of the amplifier board for selected points of the short-circuit circuit can be represented by the formula[14]:

$$U_{BT4}(s) = K_{zas}\left[\frac{1}{\tau_{ZAST}\cdot s+1}\cdot\frac{R_{ZAST}}{R_{ZAST}+R_{ZWARCIA}}\cdot U_{ZASIL}(s)\right] \quad (1)$$

13 Norma Obronna USA: MIL-STD-704F (W/CHANGE-1), Department of Defense Interface Standard: Aircraft Electric Power Characteristics; Norma Obronna MON: Wojskowe statki powietrzne. Pokładowe układy zasilania elektrycznego. Podstawowe parametry, wymagania i badania.

14 K. Głyda et al., Actions of the aviation..., op. cit.

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where:

U_{BT4} – Laplace transform of the voltage generated at the base of transistor T4, causing false tripping of the system;

K_{ZAST} – equivalent gain of the fault transmission path for selected short-circuit points;

τ_{ZAST} – time constant of the inertial component characterising the properties in a circuit containing resistances and capacitances;

R_{ZAST} – equivalent resistance in a circuit containing resistances;

$R_{ZWARCIA}$ – insulation resistance representing the path of the short-circuit current for the selected points;

U_{ZASIL} – Laplace transform of the supply voltage that includes instantaneous disturbances in the power supply circuit of the amplifier board.

At steady state, the above relationship can be presented in a simplified form, given in[15], convenient for making actual measurements to verify the simulation results:

$$U_{BT4} \ = K_{ZAST}\left[\frac{R_{ZAST}}{R_{ZAST} \rightleftarrows +R_{ZWARCIA}} \cdot U_{ZASIL}\right] \tag{2}$$

A prerequisite for false tripping of the fire alarm system is that the signal at the base of transistor T4 has a suitable instantaneous value. This condition for a rectangular pulse is fulfilled similarly to the case of overvoltage disturbances, while for disturbances of a different shape, the determination of their parameters triggering the fire alarm system requires the performance of appropriate theoretical and experimental tests. The aim of the simulation studies was to determine what kinds of short circuits (i.e. with which insulation resistance and between which points of the amplifier board's electrical circuits) cause false tripping of the system, and what kind of design solutions (in terms of the layout of the printed paths or the use of coatings) should be used to protect the board against the occurrence of these short circuits.

When performing simulation studies in terms of the effects of short-circuited electrical circuits using the developed model, it must be taken into account that when local short circuits occur, not all measurement points on the amplifier board are characterised by the occurrence of false system tripping. Some of these short-circuits may cause only a change in the values of electric currents and potentials (without the occurrence of false tripping), and some may cause permanent damage to electronic components. Therefore, when evaluating the effects of a short circuit, it is necessary to additionally determine the power dissipated on the electronic component under test and compare it with its normative value (which provides protection against permanent damage to the component due to overheating).

[15] Ibidem.

6. SHORT-CIRCUIT SIMULATING

In the presented research, the case in the modelling of the SSP-FK system's operation, where false tripping occurs, is the occurrence of local short-circuits of the supply voltage between selected electrical circuits on the amplifier board, which do not cause permanent damage to the electronic components. False tripping of the system in a local short-circuit condition was limited to a nominal voltage of 28.5 V (the effect of overvoltage was neglected).

The simulation studies carried out showed that when local short circuits occur, not all measuring points on the amplifier board characterise the occurrence of false system tripping. Some of these short-circuits may only result in a change in current values and electrical potentials (without the occurrence of false tripping), and some may cause permanent (costly) damage to electronic components.

Investigations into the effect of short circuits on false tripping of the executive block began by modelling short circuits between selected points on the amplifier board and the stabilised supply voltage circuits built on transistors T1 and T2 (Figure 4). The test results showed a number of possibilities for false tripping.

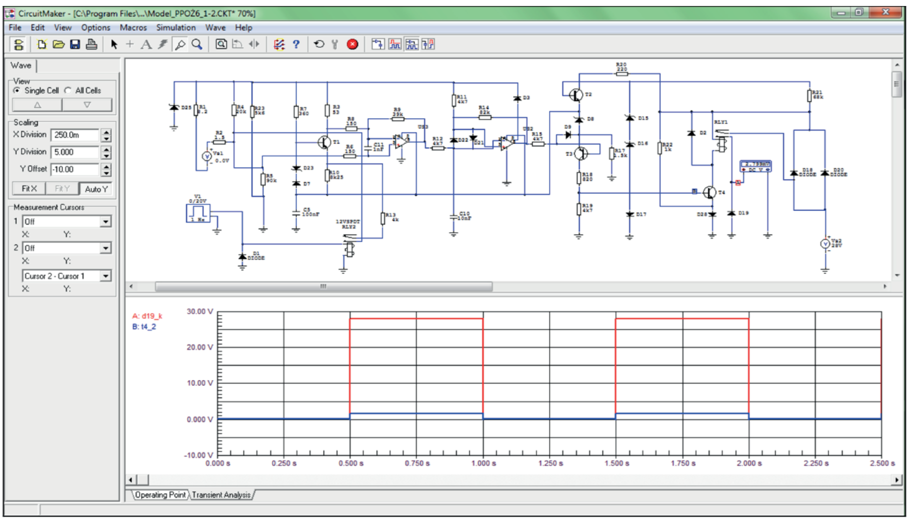

Fig. 4. Simulation model of the influence of the insulation resistance of selected electronic circuits built on transistors T1 and T2 on the false activation of the executive block

Source: own elaboration.

Checking the distribution of short-circuit points on the amplifier board confirmed the possibility of false tripping in three cases: a short circuit in the power supply circuits involving the WE9 input circuit and the ET1 emitter of transistor T1, a connection between the WE9 input and the base of T1, and a connection between the board ground and the CT1 collector of T1. These short circuits, with maximum resistances of 4.5 kΩ, 390 Ω, and 12 kΩ respectively, caused significant voltage changes that triggered the amplifier board.

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Functional analysis revealed that these short circuits increased the voltage at the non-inverting input of the signal comparator US1. For instance, the connection between the WE9 input and ET1 emitter of T1 caused a voltage increase from 6.71 V to 8.68 V, leading the output signal from US1 to change from a low of 1.34 V to a high of 6.53 V, triggering the amplifier board. Similar voltage changes occurred in the other cases, leading to false tripping.

These scenarios were selected for verification in experimental studies.

7. MODELLING THE EFFECT OF SHORT CIRCUITS TO CONTROL CIRCUITS (US1 AND US2 AMPLIFIERS)

Following this, tests were performed on the effect of modelled short circuits on the false tripping of the actuator block for short circuits between selected points on the amplifier board and the control circuits containing operational amplifiers US1 and US2 (Figure 5). The test results showed multiple possibilities for false tripping.

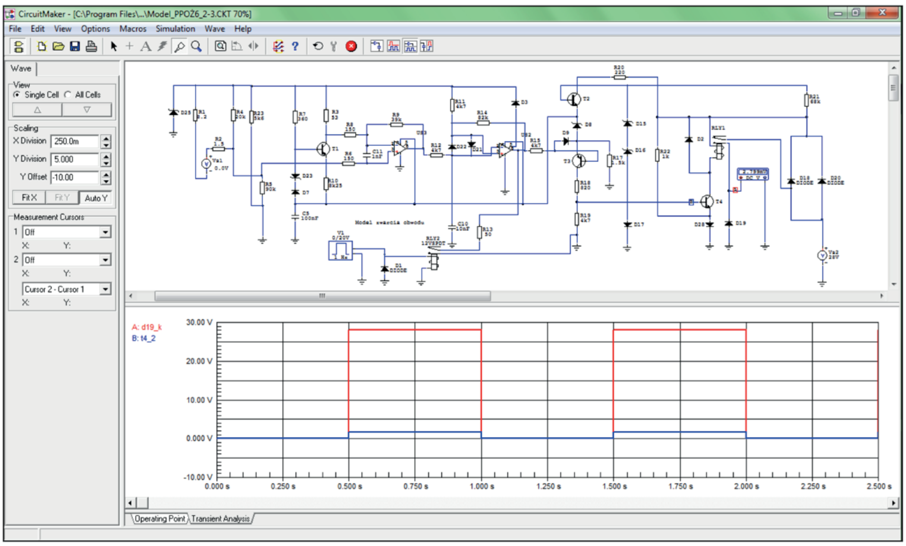

Fig. 5. Simulation model of the influence of the resistance and insulation of selected electrical circuits built on the US1 and US2 amplifiers on the false activation of the actuator block

Source: own elaboration.

Checking the distribution of short-circuit points on the amplifier board confirmed the possibility of false tripping in three cases: short circuits in the control circuits involving the supply circuit 7US1 to the output 5US1 of the signal comparator US1, the ground circuit 1US2 to the output 5US2 of the signal amplifier US2, and the ground circuit 1US2 to the input 10US2 of the signal amplifier US2. These cases were selected for verification in experimental studies.

Functional analysis showed that these short circuits caused significant voltage changes. Specifically, the short circuit between 7US1 and 5US1 caused the output voltage of the signal amplifier US2 to drop from 7.33 V to 0.83 V, the short circuit between 1US2 and 5US2 caused the voltage to drop from 7.33 V to 0.76 V, and the short circuit between 1US2 and 10US2 caused the voltage to drop from 7.33 V to 0.93 V, all of which triggered the amplifier board.

8. MODELLING THE EFFECT OF SHORT CIRCUITS TO OUTPUT CIRCUITS (TRANSISTORS T3 AND T4)

Investigations into the effect of modelled short circuits on the false tripping of the executive block were completed for short circuits between selected points on the amplifier board and output circuits built on transistors T3 and T4 (Figure 6). The results showed multiple possibilities for false tripping.

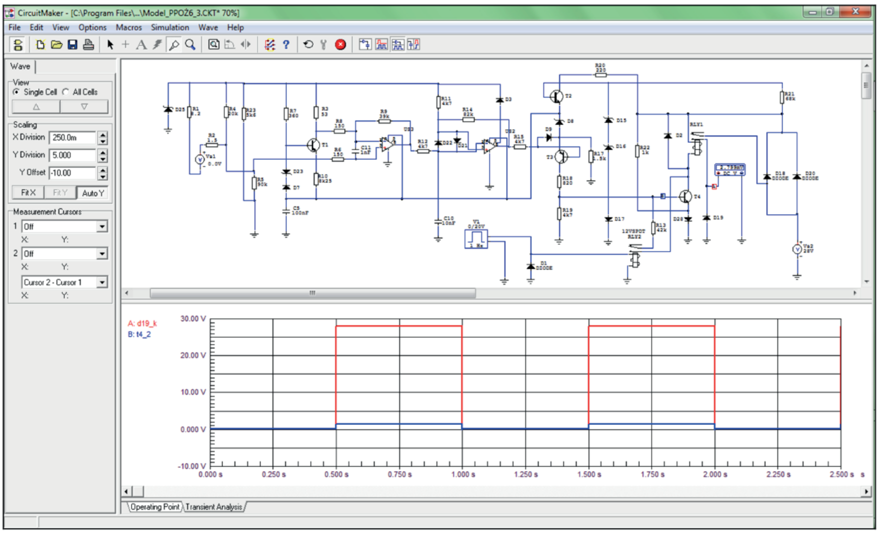

Fig. 6. Simulation model of the influence of the insulation resistance of selected electrical circuits built on transistors T3 and T4 on the false operation of the executive block
Source: own elaboration.

Checking the distribution of short-circuit points on the amplifier board confirmed the possibility of false tripping in several cases. Specifically, short circuits involving the CT3 collector and the BT3 base or ET3 emitter of transistor T3, as well as the CT4 collector and BT4 base or ET4 emitter of transistor T4, demonstrated maximum short circuit resistances ranging from 2.8 kΩ to 49 kΩ. These short circuits caused significant voltage changes that consequently triggered the amplifier board.

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Functional analysis revealed that short circuits in the power supply and control circuits, such as those involving the WE9 input and ET1 emitter of transistor T1, the WE9 input and BT1 base of T1, and the ground and CT1 collector of T1, showed maximum resistances from 390 Ω to 12 kΩ. Short circuits in control circuits involving connections like 7US1 to 5US1 of comparator US1 and ground to 5US2 or 10US2 of amplifier US2 also led to false tripping.

Simulated short circuits under 28.5V supply conditions identified specific points capable of causing false tripping. These included circuits such as the WE9 input to ET1 emitter of T1, WE9 input to BT1 base of T1, ground to CT1 collector of T1, 7US1 power supply to 5US1 output of comparator US1, ground to 5US2 output of comparator US2, and ground to 10US2 input of amplifier US2. Additionally, circuits involving CT3 collector to BT3 base or ET3 emitter of T3, CT4 collector to BT4 base or ET4 emitter of T4, and power supply behind diodes D18 and D20 to BT4 base of T4 were identified.

These findings, highlighted through simulation studies, indicate the potential for false tripping due to short circuits on the amplifier board, as illustrated in Figure 7.

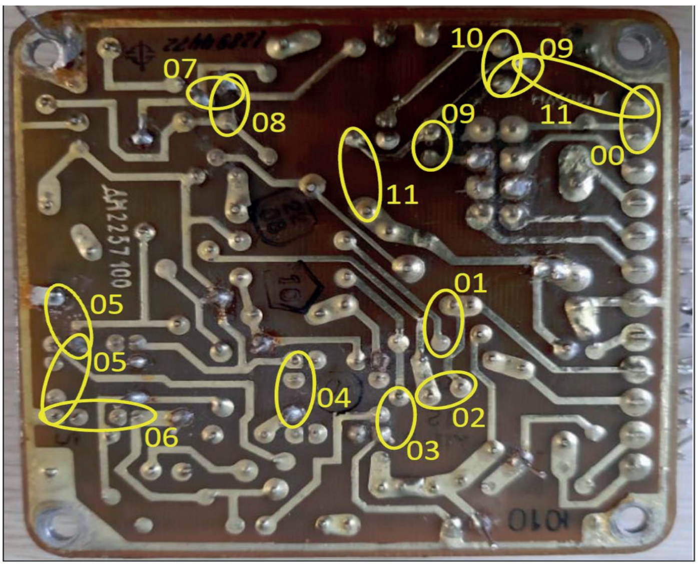

Fig. 7. Location of short-circuit points for selected electrical circuits of the amplifier board causing false operation of the actuator block (yellow)
Source: own elaboration.

An additional case, not subjected to simulation testing due to its obviousness, is the direct shorting (00) of the power supply circuit (pin 1) to the fire signal output circuit (pin 2) on the amplifier board. The results of the simulation studies performed on the effect of reducing the insulation resistance of selected electrical circuits of the amplifier board on the possibility of creating conditions for false tripping of the fire protection system provide the starting material for verification within the framework of experimental studies. The short-circuit model used in the simulation model of the amplifier board, which is connected between selected points of the electrical circuits (Figure 4–6), can be used for their implementation. The short-circuit model includes a step-switchable insulation resistance (R13) between selected circuit points. By varying the value of the resistance of the short-circuit circuit, tests should be carried out to see whether a reduction in resistance will cause a false tripping of the actuating block. Particularly those electrical circuits on the amplifier board that are directly adjacent to each other and exposed to short circuits should be selected to evaluate the test results.

The effect of a local short circuit should be tested at selected measurement points on the amplifier board. The example waveform (Figure 8) illustrates the generation of a false fire system trip pulse and the voltage change at the base of transistor T4 when the insulation resistance limit in the short-circuit circuit is exceeded.

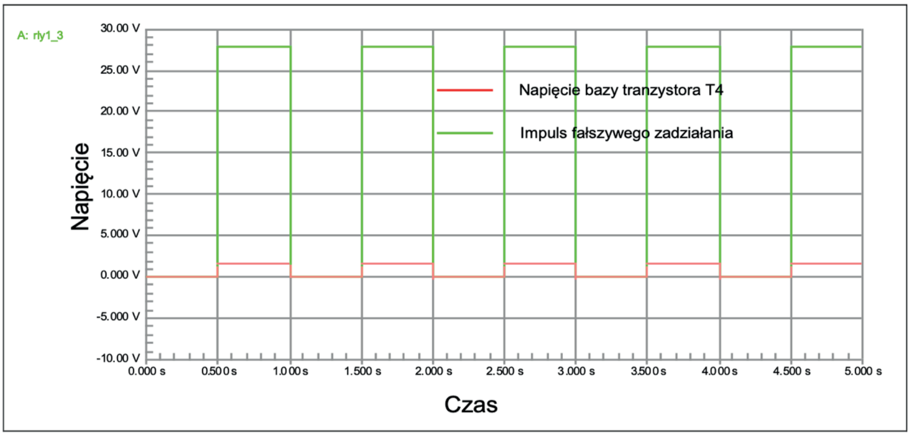

Fig. 8. Voltage change course based on the T4 transistor and the false activation pulse when the insulation resistance limit of the short-circuit circuit is exceeded

Source: own elaboration.

In contrast to the disturbances occurring in the power supply circuits of the executive block, when the deterioration of the insulation resistance is simulated, the phenomenon of disturbance propagation and false tripping pulse towards the fire sensor does not always occur, as demonstrated for the output circuit of the US2 amplifier (Figure 9), the output circuit of the US1 comparator (Figure 10) and the output circuit of the fire sensor (Figure 11).

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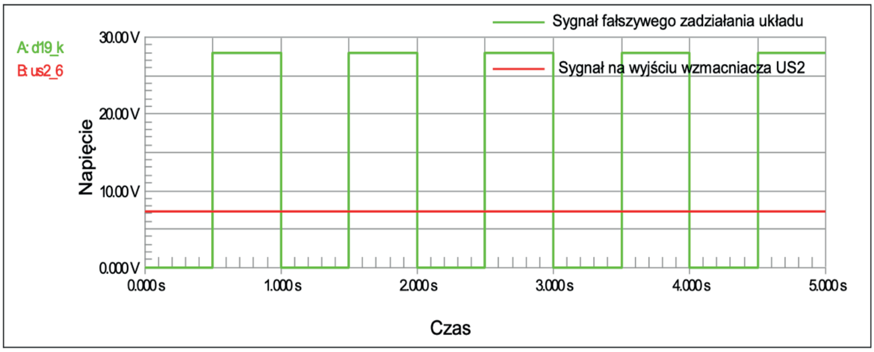

Fig. 9. No pulse propagation to the US2 fire sensor output when the insulation resistance limit of the short-circuit circuit is exceeded, causing false activation

Source: own elaboration.

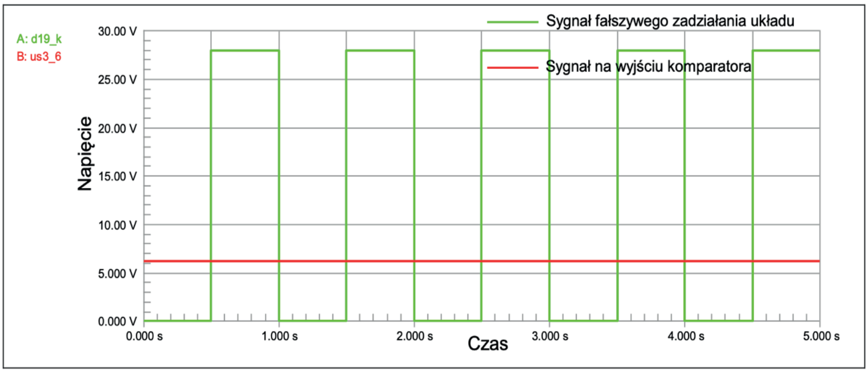

Fig. 10. No pulse propagation to the US1 fire sensor output when the insulation resistance limit of the short-circuit circuit is exceeded, causing false activation

Source: own elaboration.

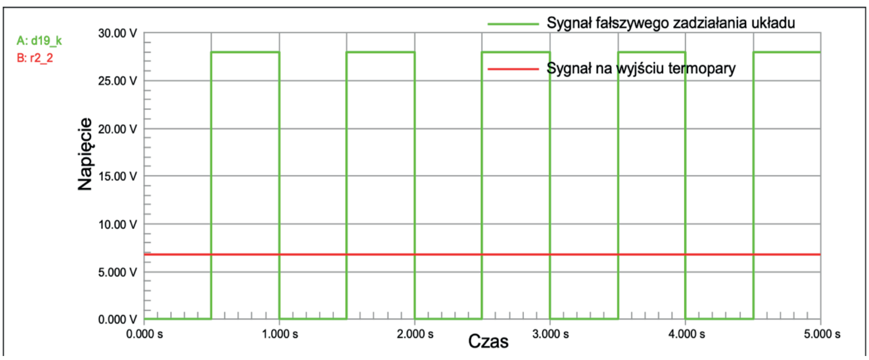

Fig. 11. No pulse propagation to the DPS fire sensor output when the insulation resistance limit of the short-circuit circuit is exceeded, causing false activation

Source: own elaboration.

9. TESTS OF THE EXECUTIVE BLOCK FOR POSSIBLE FALSE TRIPPING FROM SHORT CIRCUITS BETWEEN CIRCUITS CAUSED BY THE INFLUENCE OF HUMIDITY

Experimental tests on the possibility of false tripping of the SSP-FK-BI executive block from short circuits caused by the influence of moisture (water), when supplied with a nominal voltage of 28.5 V, were aimed at determining the maximum resistance between circuits on the amplifier board at which the RES- 52 relay contacts will close and the TKE-54PODG executive relay will go into a self-powered state.

Only the cases selected in the numerical tests were verified, taking into account the limitation of the energy parameters of the individual electronic components (permissible current in the electrical circuits and voltage on the electronic components) and the assumption that the shorted circuit points cannot be more than 1 cm apart (maximum diameter of the conductive water droplet).

9.1. VERIFICATION OF THE EFFECT OF SHORT CIRCUITS TO THE SUPPLY CIRCUITS

Under the specified conditions, it was confirmed that short-circuits to the power supply circuits with transistors T1 and T2 on the amplifier board, simulated by applying a drop of water, could cause false tripping of the executive block. Specifically, a short circuit involving the connection of the WE9 input circuit to the ET1 emitter of transistor T1, which is the stabilised reference voltage source for the US1 signal comparator, had a maximum short circuit resistance of 6.8 kΩ. Another short circuit in the power supply circuits, connecting the WE9 input circuit to the BT1 base of transistor T1, which serves as a stabilised reference voltage source for the comparator of US1 signals, had a maximum short-circuit resistance of 470 Ω. Lastly, a short circuit involving the ground circuit to the CT1 collector of transistor T1, the stabilised reference voltage source for the US1 signal comparator, had a maximum short circuit resistance of 9.1 kΩ.

The phenomenon of false tripping of the SSP-FK-BI executive block (under conditions of changes in the insulation resistance of circuits or parameters of electronic components caused by humidity) occurs not only for momentary overvoltages caused by a change of load in the power network, but also at the rated supply voltage of the SSP-FK fire protection system, which is consistent with the results of ITWL's expert opinions[16,17].

9.2. VERIFICATION OF THE EFFECT OF SHORT CIRCUITS TO CONTROL CIRCUITS

For the given conditions, it was confirmed that short circuits in the control circuits with US1 and US2 on the amplifier board, simulated by applying a water drop, could

16 S. Michalak et al., Badanie przyczyn fałszywego zadziaływania instalacji przeciwpożarowych.Sprawozdanie z pracy, BT ITWL nr 10514 (Warszawa 1993).

17 A. Szelmanowski et al., Sprawozdanie z pracy pt.: Badania możliwości samoczynnego zadziałania instalacji przeciwpożarowej SSP-FK śmigłowca Mi-8 nr 660 przy zaniku/spadku napięcia zasilania. Warszawa 2015.

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cause false tripping of the executive block. Specifically, a short circuit between the supply circuit 7US1 and the output 5US1 of the signal comparator US1 (max resistance 4.6 kΩ), and false tripping between 9US1 and the ground circuit (max resistance 31.7 kΩ) and between 12US2 and the ground circuit (max resistance 13.3 kΩ) were observed. However, short circuits between the ground circuit 1US2 and output 5US2 of signal amplifier US2 (max resistance 50 Ω), and between ground circuit 1US2 and input 10US2 of signal amplifier US2 (max resistance 10 Ω) did not confirm false tripping.

False tripping of the SSP-FK-BI executive block, caused by changes in insulation resistance or parameters of electronic components due to moisture, can occur not only from momentary overvoltages but also at the rated supply voltage, as consistent with ITWL's expert opinions.

In the output circuits, short circuits with transistors T3 and T4 on the amplifier board, simulated by water drops, were confirmed to cause false tripping of the actuator block. These included short circuits between CT3 collector and BT3 base of T3 (max resistance 10.3 kΩ), CT3 collector and ET3 emitter of T3 (max resistance 9.9 kΩ), CT4 collector and BT4 base of T4 (max resistance 36.1 kΩ), CT4 collector and ET4 emitter of T4 (max resistance 1.6 kΩ), and the power circuit behind diodes D18 and D20 to the BT4 base of T4 (max resistance 60.4 kΩ). In addition, a false tripping of the block was found for a short circuit (14) between the BT3 base of transistor T3 and the ground circuit (maximum short circuit resistance is 3.8). The phenomenon of false tripping of the SSP-FK-BI executive block (under conditions of a change in the insulation resistance of circuits or parameters of electronic components caused by moisture) occurs not only for momentary overvoltages caused by a change of load in the power network, but also at the rated supply voltage of the SSP-FK fire protection system, which is in accordance with the results of ITWL expert opinions[18, 19].

In the performed experimental tests, it was confirmed that false tripping of the SSP-FK fire protection system can occur in all considered circuits: power supply, control and amplifier board output circuits. The results obtained supported the hypothesis adopted during the work of the Aircraft Accident Investigation Committee on the possibility of false tripping of the SSP-FK system as a result of short circuits caused by wetting the amplifier boards of the SSP-FK-BI executive block and momentary overvoltages occurring in the on-board power network[20, 21].

Additional experimental tests of the wet SSP-FK-BI executive block performed on a test stand (Figure 12) at the Military Aviation Works WZL- 1 Łódź showed that possible electrical short circuits between selected electronic components in the amplifier board circuits (e.g. short-circuit of the collector and base circuits or collector

18 Sprawozdanie z pracy, Badanie przyczyn fałszywego zadziaływania instalacji przeciwpożarowych, BT ITWL nr 10514/I.

19 A. Szelmanowski et al., Sprawozdanie z pracy pt.: Badania..., op. cit.

20 Ibidem.

21 Program badań pt.: Badania możliwości samoczynnego zadziałania instalacji przeciwpożarowej SSP-FK przy spadku / zaniku napięcia zasilania, Archiwum Z-43 nr 67/43/15, BT ITWL nr 10952/I, Warszawa 2015.

and emitter circuits of the T4 transistor) cause activation of the RES-52 relay on the amplifier board and false activation of the fire signalling system[22].

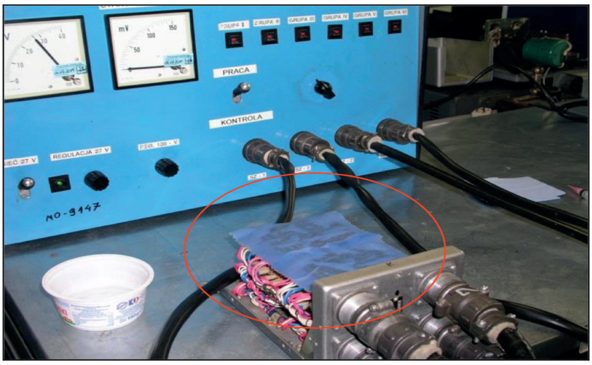

Fig. 12. Station for testing the SSP-FK-BI block in conditions of moisture (water) exposure
Source: own elaboration.

Based on the verification carried out, short-circuit connections (Figure 13) that cause false tripping of the SSP-FK fire protection system on board helicopter Mi-8, caused by the influence of humidity and overvoltages in the power supply of the executive block, were determined[23].

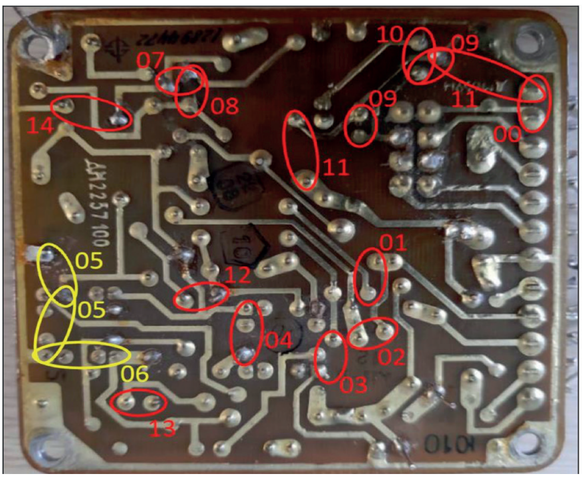

Fig. 13. Short-circuit connection causing false activation of the SSP-FK system (red)
Source: own elaboration.

22 A. Szelmanowski et al., Sprawozdanie z pracy pt.: Badania..., op. cit.
23 Ibidem.

 DOI: 10.55676/asi.v4i2.84

The results of computer simulations and verification tests were used to diagnose the SSP-FK system during the investigation of selected cases of its spontaneous tripping.

10. SUMMARY

The goal of the numerical studies using the developed simulation model of the SSP-FK-BI executive block was to test the hypothesis that the SSP-FK fire protection system could falsely activate due to electrical short circuits. The research focused on identifying instances of false activation caused by electrical surges, changes in electronic component parameters, and moisture-induced insulation resistance reduction, which lead to short circuits on the amplifier board or power supply circuits.

The findings indicated that local short circuits on the amplifier board can cause false activations without permanently damaging electronic components, which resolve once the board is dried. Numerical analysis provided details on specific conditions under which the SSP-FK system falsely activates. It was found that some short circuits merely alter current and voltage levels without triggering false alarms, while others could cause permanent damage.

Experimental studies mostly confirmed the numerical results, showing minor differences due to modeling limitations. The experiments supported that local short circuits on the amplifier board, due to moisture reducing insulation resistance, can trigger false alarms. The critical threshold resistance for false activation at 28.5 V might be sufficient during a power surge.

Further tests showed that moisture-induced short circuits in circuits, such as the "board power supply – T4 transistor base," can result in the loss of filtering properties and subsequent fire alarm activation due to surges. Laboratory tests also demonstrated that reduced insulation resistance in the T4 transistor circuits, with a disturbance pulse of +30 V lasting 10 ms, could trigger the RES-52 relay, confirming the hypothesis of potential false activations from short circuits and transient overvoltages.

The research facilities at the Air Force Institute of Technology and WZL-1 S.A. enable thorough diagnostics of the SSP-FK system to understand the impact of environmental factors, like moisture, on insulation resistance and false activations. Diagnostic tests should be customized based on analyzing false activation cases and forming preliminary hypotheses about their causes to optimize the investigation process.

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