POSSIBILITIES CONCERNING DIAGNOSIS OF THE SSP-FK AIRCRAFT FIRE SUPPRESSION SYSTEM IN TERMS OF DETERMINATION OF REASONS FOR FALSE FIRE ALARMS

MOŻLIWOŚCI DIAGNOZOWANIA LOTNICZEGO SYSTEMU PRZECIWPÓŻAROWEGO SSP-FK W ASPEKCIE OKREŚLANIA PRZYCZYN FAŁSZYWEGO SYGNALIZOWANIA POŻARU

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Abstract: *The paper presents selected results of work at the Air Force Institute of Technology (AFIT) in the scope of testing of the SSP-FK fire suppression system used on many types of military aircraft operating in the Polish Armed Forces. For the purpose of determining conditions for false fire alarms, SSP-FK simulation models have been developed. The study was carried out on simulation models in Matlab-Simulink and Circuit-Maker packages. Results of this work have been used for diagnosis of the SSP-FK system during a test of real cases of false activation of these devices.*

Keywords: *aircraft fire suppression systems, research methods*

Streszczenie: *W artykule przedstawiono wybrane wyniki prac realizowanych w Instytucie Technicznym Wojsk Lotniczych (ITWL) w zakresie badań instalacji przeciwpożarowej SSP-FK stosowanej na wielu typach wojskowych statków powietrznych eksploatowanych w Siłach Zbrojnych RP. Dla określania warunków fałszywego sygnalizowania pożaru opracowano modele symulacyjne działania bloków wykonawczych SSP-FK. Badania modeli symulacyjnych wykonano w pakietach obliczeniowych Matlab-Simulink i Circuit-Maker. Wyniki tych prac zostały wykorzystane do diagnostyki instalacji SSP-FK w trakcie badania rzeczywistych przypadków fałszywego zadziałania tych urządzeń.*

Słowa kluczowe: *lotnicze systemy przeciwpożarowe, metody badań*

1. Introduction

Many cases of spontaneous activation of the SSP-FK aircraft fire suppression system, including launch of fire extinguishing cylinders (among others the event of 27.01.2014 - Mi-8 helicopter) testify to the fact that it is not yet fully understood in technical aspect, and because of its role on the aircraft, it is an essential element to ensure flight safety [3]. Solving problems with false fire alarms of the SSP-FK system is an issue important for safe operation of military aircraft [4, 6] since it is a preventive (that warns the crew about a possibility of fire) and rescue system (whose task is to put out the fire) in each phase of flight. In addition, the SSP-FK system is used on many types of military aircraft (including W-3/3W/3WA/3PL and Mi-8/14/17/24 helicopter family and An-28 / Tu-154M planes).

The SSP-FK aircraft fire suppression system on Mi-8 helicopter may be divided into two parts in terms of destination [1]: the fire detection installation and fire extinguishing system with a control panel. The fire detection system SSP-FK of Mi-8 helicopter consists of 12 groups of DPS sensors installed in 4 controlled compartments and 2 SSP-FK-BI electronic actuators. On Mi-8 helicopter the following compartments are controlled: left engine; right engine; main regulator and KO-50 oil heater. Due to the fact that Mi-8 helicopter fire extinguishing bottles are provided with one igniter cylinder, extinguishing agent distribution bus is divided into two parts: the part common to all controlled compartments and bottles (ended with 4 fire extinguisher shut-off valves), and 4 buses supplying firewater mix to a specific compartment.

The conditions for the start of the extinguishing process are in the following order: appearance of the signal at the input of the actuator, opening of the appropriate valve and feeding an igniter cylinder of a fire extinguishing bottle with the voltage amounting to + 27V. The main element generating the fire signal and controlling the operation of the fire protection system is the SSP-FK-BI actuator containing 6 electronic circuit boards called amplifiers' plates [1].

On the basis of the analysis of the operation of the SSP-FK fire suppression system and tests carried out on Mi-8 helicopter, the following hypotheses have been assumed as a possible cause of its self-activation:

- generation of the activating voltage in DPS sensors as a result of sudden changes in ambient temperature (impact of frost, and then a blast of cold or hot air);
- generation of the activating voltage in the control circuit of the output relay of the SSP-FK-BI amplifiers' block as a result of internal short circuits or damages in electronic components (e.g. impact of moisture or aging processes);
- generation of the activating voltage in the control circuit of the output relay of the SSP-FK-BI amplifiers' block as a result of the impact of electrical glitches in power or control circuits (e.g. influence of switching on/off of power sources and high power receivers).

In order to verify these hypotheses, appropriate computer simulations were performed and their results have been verified under laboratory conditions.

2. Computer simulations in the scope of the SSP-FK system's response

The SSP-FK aircraft fire suppression system on Mi-8 helicopter runs in such a way [1, 2] that DPS sensors generate thermoelectric power (electromotive force), whose value is proportional to the difference between the temperature of the outer weld thermocouple (heated or chilled by flowing stream of air) and the internal temperature of the weld placed in the sensor connector. In the SSP-FK-BI actuators, thermoelectric power, supplied from DPS sensors is compared with the acceptable level of voltage and, if this value is exceeded, the signal activating the fire alarm and fire extinguishing installation appears at the output of the actuator. This signal is transferred to the winding of the TKE-54PODG relay which, by closing its contacts, enters into a state of "self-maintaining" of the coil power circuit. At the same time, it provides the fire signal to the signal and fire extinguishing circuit (among others to the 781100 valves block, which opens the appropriate fire extinguishing bus). On the basis of the analysis and initial tests of the SSP-FK aircraft fire suppression system simulation models of the operation of its chosen elements have been developed. The table below presents selected possibilities of using computer support based on Matlab-Simulink and Circuit-Maker computational packages at the stage of theoretical studies of this system.

Simulations of the response of DPS and DTBG fire detectors

The hypothesis about the possibility of generation of the voltage activating the SSP-FK system as a result of sudden changes in ambient temperature (impact of frost, blast of cold or hot air) has been chosen as the first to be assessed. For the purpose of the studies, the models for two types of those sensors developed at AFIT has been adopted (fig. 1): DPS (single weld system) and more sensitive DTBG (with dual weld system).

Fig. 1 DPS (on the left) and DTBG (on the right) thermoelectric fire sensors

In the course of simulation studies (developed in Matlab-Simulink package) it was found that when the KO-50 heating furnace on helicopter in winter conditions is turned on and the assumed course of changes in air temperature surrounding external weldings of the sensor is as follows: -20°C , $+60^{\circ}\text{C}$, -20°C , the thermoelectric power value amounts to: 0 mV, +7,2 mV, 0 mV (for DPS sensor) and 0 mV, +18,2 mV / +14 mV, -4,5 mV / 0 mV (for DTBG sensor), respectively. The minimum value of the thermoelectric power generated from a single sensor required to run the fire alarm is about 10 mV, and it follows that DTBG sensors may cause false tripping of the SSP-FK system due to sudden application of warm air from the KO-50 furnace (while the furnace fan is on).

In addition, the studies have shown that a rapid cooling of the air surrounding the sensor subjected to heating from the KO-50 furnace, when the assumed changes in temperature are: -20°C , $+60^{\circ}\text{C}$ / -50°C / $+60^{\circ}\text{C}$, -20°C , generates the thermoelectric power mounting to: 0 mV, +7,2 mV / -2,6 mV / +7,2 mV, 0 mV (for DPS sensor) and 0 mV, +18,2 mV / +14 mV, -12 mV / -5,1 mV, +21 mV / +14 mV, -4,5 mV / 0 mV (for DTBG sensor), respectively. The rapid cooling of DPS sensor does not cause any significant increase in thermoelectric power generated in the sensor, and it cannot be the cause of self-actuation of the SSP-FK system for adopted thermal conditions (e.g. switching on the KO-50 heater).

Simulations of tripping of SSP-FK-BI actuators

The aim of the research carried out on simulation models of selected electric circuits of SSP-FK-BI actuators (developed in Circuit-Maker package) was to verify the hypothesis regarding the possibility of their false tripping as a result of the occurrence of short circuits between the circuits or the effect of glitches occurring in the power or control circuits amplifiers' plates. Each of the six amplifiers' plates (fig. 2) of SSP-FK-BI actuators with a group of DPS sensors is a separate (independent of each other) fire detection channel. Power from a storage battery flows through the Sz4 connector clips of the SSP-FK-BI actuator and is supplied to the power supply terminal of each amplifiers' plate. For each plate "plus" power is supplied to the power supply terminals 1, 4 and 12 of the plate connector, while "minus" power is supplied to the power supply terminal 7 of the plate connector [1].

According to the results of the tests described in [4], in the event of a fire in a compartment controlled by the SSP-FK system, the thermoelectric power in DPS sensors group of a given channel (i.a. of the KO-50 heater compartment) increases as a result of a sudden increase in temperature and causes an increase of the voltage supplied to the non-inverting input of the US1 comparator of the amplifiers' plate of this channel. At the moment when the voltages fed to the signal inputs of the

US1 comparator come level with each other, a jump of the output voltage from the US1 comparator to a high level occurs.

Fig. 2 Amplifiers' plate from the perspective of electronic elements (on the left) and their connections (on the right)

The voltage is supplied to the US 2 inverting input of the US2 amplifier, and is higher than the reference voltage supplied to the non-inverting input, which is why it causes a drop in voltage to a low level. This signal is given on the base of the T3 transistor, opens the T3 collector system and the current flows in the T3 collector unit. This causes a voltage drop in the R19 resistor, which, when given to the base of T4 transistor, opens it and, at the same time, closes the minus circuit of the RES-52 output relay through the D28 diode. Tripping of the relay causes a voltage supply to the end of the second amplifier's plate, from which the fire signal is received. This signal is further transmitted to actuating circuits, which trigger the fire alarm and fire extinguishing for a controlled compartment (TKE-54PODG actuating transmitter and 781100 valves block are triggered, among others). For the amplifiers' plate operation described in this way, an electrical schematic diagram has been determined (together with electronic components) and its numerical equivalent has been developed in Circuit-Maker package (which allows designing and testing of electrical circuits). Simulation studies of the developed circuit diagram showed that possible short circuits between selected electronic elements in amplifiers' plates circuits (i.a. short in the circuit of the US1 comparator output to the circuit ground through the C10 capacitor, short in the US2 amplifier output circuit to the ground circuit through the C2 capacitor, short in the collector's and base's circuits or in the collector and T4 emitter's transistor circuits) triggers the RES-52 relay on the amplifiers' plate and automatic activation of the fire alarm system. In addition, it was stated that actuation of the RES-52 relay and appearance of the fire alarm signal can also be caused by momentary glitches occurring in the power or control circuit of the amplifiers' plate by switching on or off of high

power receivers [2]. However, this occurs when filtering systems on amplifiers' plate are not working in humid conditions (such as C2, C5, C10 capacitors and T3 transistor internal capacities).

The conducted simulations showed that the circuit "emitter transistor T3 - the base of transistor T4" is an internal filter system with properties of derivative term (causing the characteristic "pins" for rectangular pulse). In order to obtain the control voltage in form of a rectangular pulse on the T4 transistor's base that lasts longer, one has to use a triangular (or sawtooth) waveform interference. It has been estimated that to produce a voltage controlling the T4 transistor having the parameters of 500 mV / 10 ms (triggering the SSP-FK-BI actuator), a glitch in the power supply of the amplifiers' plate would have to be shaped similarly to a triangular pulse with an amplitude of 1.5 kV / 10 ms, which is unlikely to occur on a helicopter under normal conditions (and can cause a permanent damage of some electronic components).

The simulations have shown however that electrical impulses can trigger the fire alarm system in the case of a temporary failure to maintain the operating parameters by filtering systems (i.a. T3 transistor internal capacities). In this case the interference in the power supply circuits with impulses of triangular shape and amplitude of 30 V / 10 ms can enter the amplifiers' plate control circuits (i.a. the T4 transistor base). In such a situation, it is possible that a voltage opening the T4 transistor occurs and actuates the RES-52 relay (which causes false generation of the fire signal).

3. Use of computer simulations in the SSP-FK system diagnosis

The results of the computer simulations were used for diagnosis of the SSP-FK actuators during the study of real cases of spontaneous response of these devices (i.a. expert analyses conducted at AFIT in 2010 and 2014/2015). Results for thermal interferences (interacting directly with sensors) and electrical noise (appearing in the power and control circuits) have been chosen as examples.

Tests of the SSP-FK system for interfering temperature extortions

In order to verify the results obtained in the simulations, the verification of thermoelectric power generated for DTBG and DPS sensors placed in the flame of a lighter was conducted. The maximum value of the voltage generated at the output of the fire sensor reaches 270 mV (DTBG sensor) and +30 mV (DPS sensor). Sudden cooling of the sensor external joints reduces the thermoelectric power, and even causes that it can have negative value (which blocks jump of the output voltage on the US1 comparator). The results confirmed the hypothesis that DTBG sensors may cause false tripping of the SSP-FK system as a result of a rapid heating of welds by hot air due to their high sensitivity. However, they excluded the assumption that a sudden cooling of a DPS sensor can cause an automatic

activation of the SSP-FK system for the assumed thermal conditions (i.e. turning on or off the KO-50 heater).

Tests of the SSP-FK system for interfering electrical extortions

Two "paths" of the impact of glitches have been selected for the studies: US1 comparator signaling channel and T4 transistor control channel. The analysis of the operation of the amplifiers' plate showed that the actuation of the system under normal conditions is triggered by heating of a DPS sensor or transmitting the CONTROL signal. The start signal at the input of the US1 comparator causes the appearance of positive voltage on the T4 transistor base, which in turn activates the RES-52 relay on the amplifiers' plate [4]. During the tests of the noise level occurring in the power system circuit of the SSP-FK system on Mi-8 helicopter it was found that during switching on and off of power sources (e.g. GS-18TP starter / generator) and high power receivers (e.g. KO-50 heating furnace), glitches occur. The parameters of these impulses may amount to: $+2,8\text{V} / 0,1\text{s}$ i $-14,8\text{V} / 1\text{s}$ (during switching on receivers) and $+21\text{V} / 1\text{s}$ (during switching off receivers). In the SSP-FK control circuits the occurrence of interferences of approximately 10 times lower level was stated, i.e. $+0,2\text{V} / 0,01\text{s}$ and $-1,4\text{V} / 0,1\text{s}$ (when switching on receivers) and $+2,1\text{V} / 0,1\text{s}$ (when switching off receivers).

On the basis of these data, a high current generator of disturbing impulses has been developed and built at AFIT and tests of the SSP-FK fire suppression system were performed in laboratory conditions [5].

Interfering impulses with amplitude up to 50 V and frequency of 1 Hz to 1 MHz were applied on the voltage change in the range of 24 to 32 VDC. As shown by laboratory tests, pulses which last ca. 10 ms (fig. 3) are too short to have enough time to activate the RES-52 relay, even though the amplitude value on the T4 transistor base is sufficient to open it (it closes the supply circuit relay coil).

Fig. 3 Waveforms of the voltage on BT4 for disturbing rectangular (on the left) and triangular (on the right) pulse

However, for a longer glitch (which lasts ca. 10 ms), the voltage on the T4 transistor base that could be able to activate the RES-52 relay, was not stated. According to the results of computer simulations, the circuit "power supply of the plate - T4 transistor base" contains filtering systems and shows characteristics of derivative term (fig. 3). The situation in which electrical impulses occurring in the power circuits of amplifiers' plates can actuate the fire alarm system, is a temporary loss of filtering properties of selected electronic components (such as capacitors and transistors) as a result of their dampness or short in their circuits caused by dampness of the amplifiers' plate. Laboratory studies showed that for the amplitude of the glitch amounting to 30 V and lasting 10 ms, the opening voltage is present on the T4 transistor base and the RES-52 relay is actuated. This confirmed the hypothesis about the possibility of false tripping of the SSP-FK system due to temporary disturbances in the onboard electrical grid.

4. Summary

The simulation studies concerning numerical diagnostic models of the SSP-FK fire suppression system conducted at AFIT allows to determine conditions that can cause its spontaneous activation and to specify parameter values for selected disturbing factors (i.a. impulse shape, amplitude value and duration). Computer aided research can also be used to design specialized measurement and control systems designed for the production of electrical noise that may be a cause of self-actuation of the SSP-FK fire suppression system [4, 6].

The measuring system developed at AFIT enables generation of glitches simulating dynamic phenomena occurring in the power supply network during engine start or turning on / off sources of energy and high power electrical devices (e.g. GS-18TP generator / starter or KO-50 heating furnace fan). The proposed simulation test methods used at AFIT support the process of diagnosing the SSP-FK fire suppression system in the scope of determining causes of their spontaneous activation. They may be a basis for development of so called SSP-FK fire suppression system simulator for operational needs in the scope of processing of signals from onboard sensors for specific types of aircraft using the system.

4. References

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