ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1216482

RESEARCH METHOD OF DYNAMIC CAPABILITY OF AN ACTUATING BLOCK OF THE SSP-FK AIRCRAFT FIRE SUPPRESSION SYSTEM IN FALSE ALARM ASPECT

Andrzej Szelmanowski, Mariusz Zieja, Krzysztof Głyda, Tomasz Tokarski

Air Force Institute of Technology
Ksiecia Boleslawa Street 6, 01-494 Warsaw, Poland
tel.: +48 261851603, +48 261851132, +48 261851642
fax: +48 261851646, +48 261851612, +48 261851646
e-mail: andrzej.szelmanowski@itwl.pl, mariusz.zieja@itwl.pl
krzysztof.glyda@itwl.pl, tomasz.tokarski@itwl.pl

Abstract

Numerous cases of self-activation of the SSP-FK aircraft fire suppression system (including commissioning of valves and extinguishing tanks) testify about the fact that it is not yet fully understood in the technical aspect, and because of the performed role on the aircraft is the basic element to ensure flight safety. Solving problems with false fire signalling of the SSP-FK system is an important issue for the safe operation of aircraft and military helicopters, because it is preventive (to warn the crew of the possibility of fire) and rescue system (aiming at extinguish the fire) in each phase of a flight. In addition, the SSP-FK system is used on many types of military aircraft (including helicopters from W-3/3W/3WA/3PL and Mi/8/14/17/24 family as well as An-28 and Tu-154M aircraft.

The paper presents selected results of work in the Air Force Institute of Technology in the study of SSP-FK fire suppression system (as one of the main protection systems on-board) used on many types of military aircraft operated in the Polish Armed Forces. In determining the conditions of the false signalling of fire, simulation models of action blocks implementing of the SSP-FK fire suppression system were developed. The research on simulation models was performed in Matlab-Simulink and Circuit-Maker computing packages. The results of these works were used to diagnose selected modules and blocks of the SSP-FK system during the study of actual cases of their false activation.

Keywords: *transport, aircraft fire suppression systems, research and simulation methods, aircraft fire protection*

1. Introduction

The aircraft fire suppression system (fire protection system), due to the possibility and threat of fire, is switched on before starting the aircraft engines (turbo-prop and jet engines), and switched off just after they stopped [1, 2]. At the operating fire suppression system as well as the on-board power supply system and operating aircraft engines, other devices and on-board systems, among others, avionics, communication and weapons systems are switched off depending on the phase of flight and the performed task. One of the fire suppression systems, widely used in aircraft operated in the Polish Armed Forces, is the SSP-FK system (Fig. 1) installed, among others, in the Mi-8, Mi-17, Mi-17-1V, Mi-24D, Mi-24W, W-3, W-3WA, W-3PL helicopters and the An-28 aircraft. In order to detect the seat of fire, the system uses the DPS thermoelectric fire sensors (with a single system of thermoelectric joints) and the SSP-FK-BI execution blocks containing plate with operational electronic amplifiers [1]. The fire suppression system, which differs from the previous one in fire sensors with a double system of thermoelectric joints of the DTBG type and the BI-2A execution blocks, was installed in the An-28 aircraft. The DTBG sensors are more sensitive and generate higher electromotive force than the DPS sensors [5].

The research carried out by the Air Force Institute of Technology showed that, at the time of switching on and off the high power receivers on the aircraft board, there are instantaneous (millisecond) disturbances: voltage drops and over-voltages (Fig. 2), which can result in false (i.e. automatic, without the occurrence of the fire) activation of the fire suppression system [8].

Fig. 1. Aircraft equipped with the SSP-FK fire suppression system

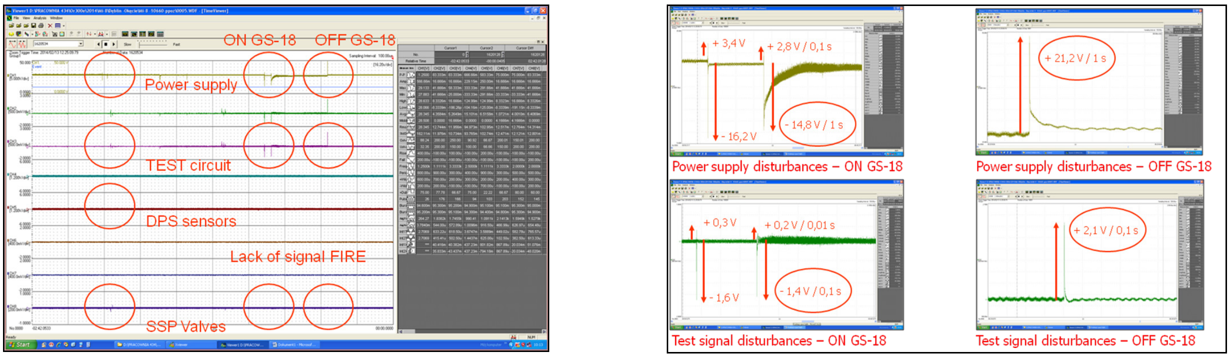

Fig. 2. Electrical interference occurring in the SSP-FK fire suppression system circuits

The statistical analysis of the cases related to false activation of the SSP-FK fire suppression system for a selected period of operation (Fig. 3) demonstrated that the most common causes of this false activation include automatic wear of fire extinguishers, false signalling of fire, and malfunction of execution blocks. The analysis of consequences of these events in military helicopters showed that they most often cause the performed task interruption and off-field landing [4] putting the aviation personnel at risk.

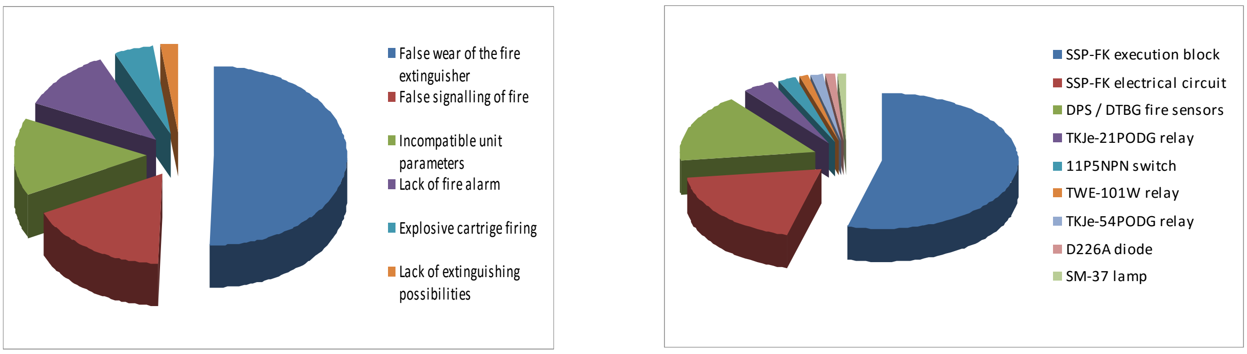

Fig. 3. Results of the statistical analysis in terms of symptoms and causes of the SSP-FK system failure

Among the causes of false activation of the SSP-FK fire suppression system, the failures of the execution block, electrical circuits and fire sensors are primarily mentioned. The detailed research carried out by the Air Force Institute of Technology showed that among possible causes of the SSP-FK system false activation there is also its “sensitivity” to instantaneous supply voltage drops, occurring in the aircraft on-board network while switching on and off the high power receivers, e.g. the GS-18P starter generator and the anti-icing system in the Mi-8 helicopter [8].

In addition, during the research, it was found that instantaneous changes of the isolation resistance between two electronic circuits of the execution blocks’ amplifiers occurring under the influence of dampness can cause the system false activation. The research demonstrated the need for performing the simulation of transition processes and experimental studies, which confirm such an action of the execution block of the SSP-FK fire suppression system, thus improving flight safety [2, 3, 6].

2. Computer aided simulation of false activation of the aircraft fire suppression system

The detailed analysis of functioning of the SSP-FK fire suppression system, based on technical descriptions and own research of the Air Force Institute of Technology [1, 7, 8], allowed to develop numerical models of functioning of the SSP-FK-BI execution block with the use of the construction packages of electrical circuits and simulation research of the Matlab-Simulink and Circuit-Maker types.

The example functional diagram (Fig. 4) makes it possible to determine the voltage conduct at the output of the comparator of signals from the DPS fire sensors, based on the US1 operational amplifier at the time of instantaneous voltage drops of the execution block power supply.

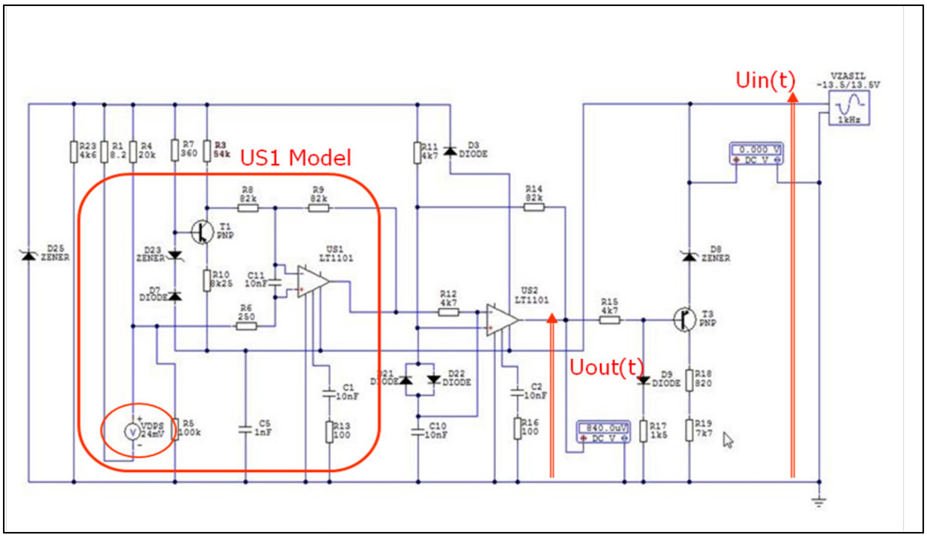

Fig. 4. Block diagram of a numerical model of the SSP-FK-BI block testing

A simplified analysis of the phenomenon of the SSP-FK-BI execution block false activation can be conducted with the use of a mathematical description (1), which allows to determine the instantaneous voltage value at the output of the US1 comparator, depending on the instantaneous voltage value obtained from the DPS sensors and the instantaneous voltage value of the power supply of the plate of amplifiers during the voltage drop resulted from switching on the high power receiver:

$$U_{US1}(s) = K_{US1}\left[G_{DPS}(s)\cdot U_{DPS}(s) - G_{ZASIL}(s)\cdot U_{ZASIL}(s)\right], \tag{1}$$

where:

$U_{US1}(s)$ – Laplace's transform at the US1 comparator voltage output,
K_{US1} – coefficient of amplification of input signals of the US1 comparator,
$G_{DPS}(s)$ – Laplace's transform of the signal path for signals from the DPS sensors,
$U_{DPS}(s)$ – Laplace's transform of voltage obtained from the DPS sensors,
$G_{ZASIL}(s)$ – supply path transform of the plate of amplifiers of the SSP-FK-BI execution block,
$U_{ZASIL}(s)$ – Laplace's transform of the power supply voltage of the SSP-FK-BI execution block.

The obtained results of the performed simulation made it possible to develop a graph (Fig. 5) defining the areas of the execution block activation (and its maintenance) depending on the signal value of the group of DPS sensors and parameters of the instantaneous supply voltage drops.

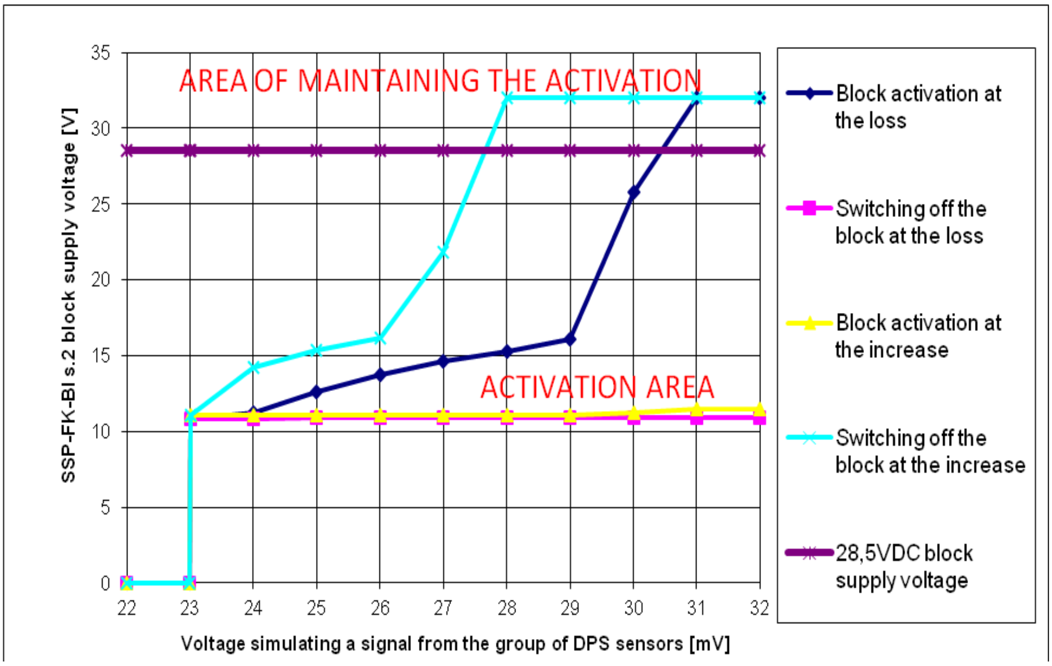

Fig. 5. Designated areas of the SSP-FK-BI block activation in the function of a signal from the group of DPS sensors

The analysis of the area of the SSP-FK-BI execution block activation shows that its activation may take place at the occurrence of signals from the group of fire sensors lower than the values provided by the manufacturer for the nominal supply voltage (28÷32 mV) in the aircraft on-board network. This graph explains why not every voltage drop in the on-board power supply network results in the execution block activation, but only the one, which is included in the area of activation and lasts long enough (until the switch of uninterruptible power supply systems).

The band of maintaining the activation allows starting up the execution block for times of the supply voltage drops shorter than the ones required in the area of activation, but sufficiently long for the uninterruptible power supply system.

3. Verification of theoretical reasons of false activation of the aircraft suppression fire system

In order to verify the results obtained in simulation research, the measurements of the voltage values of activation and activation maintenance of the execution block for selected values of the signal obtained from the group of the DPS fire sensors (Fig. 6) were made.

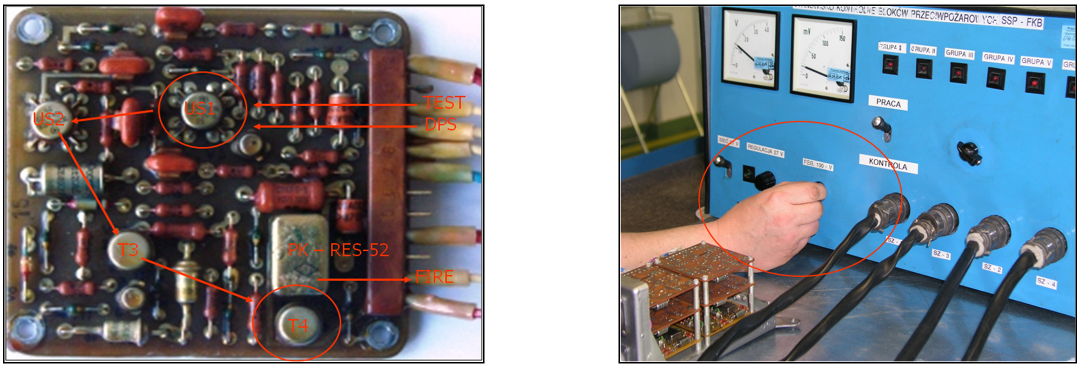

Fig. 6. Test bench for activation areas of the SSP-FK-BI block

The example voltage values of starting up the SSP-FK-BI execution block activation in the dry (without the effect of dampness) and damp states (after long-term keeping in damp conditions) were given in relevant tables (Tab. 1-2).

Tab. 1. Values of the start-up (activation) thresholds of the SSP-FK-BI block (dry block)

Voltage of the group of DPS fire sensors	Voltage band of starting up the execution block activation the most sensitive plate		Voltage band of starting up the execution block activation the least sensitive plate	
	Lower threshold	Upper threshold	Lower threshold	Upper threshold
[mV]	[V]	[V]	[V]	[V]
22	11.04	11.04	11.36	11.36
24	11.08	11.23	11.36	12.84
26	11.08	13.74	11.40	14.68
28	11.08	15.29	11.41	16.08
30	11.10	17.32	11.45	27.54
32	11.14	32.00	11.48	32.00

Tab. 2. Values of the start-up (activation) thresholds of the SSP-FK-BI block (damp block)

Voltage of the group of DPS fire sensors	Voltage band of starting up the execution block activation the most sensitive plate		Voltage band of starting up the execution block activation the least sensitive plate	
	Lower threshold	Upper threshold	Lower threshold	Upper threshold
[mV]	[V]	[V]	[V]	[V]
22	11.08	11.08	11.41	11.41
24	11.08	11.42	11.41	13.84
26	11.10	13.96	11.42	14.78
28	11.12	15.58	11.43	16.15
30	11.13	17.62	11.46	28.06
32	11.14	32.00	11.48	32.00

The obtained results showed that the existence of the band of activation voltage values (thresholds) is already present for a group of fire sensors of the 22 mV value. The required supply voltage drops of the execution block, which can cause false activation, should reach the values exceeding 17 V (instantaneous voltage of the block power supply would amount to about 11 V).

The occurrence of voltage with a value activating the execution block is connected with the properties of the measuring lines described by the dependency and results in the situation that during the supply voltage drop, a signal from the group of fire sensors is higher than the reference voltage on the comparator [8].

The example voltage values of maintaining the SSP-FK-BI execution block activation in the dry (without the effect of dampness) and damp states (after long-term keeping in damp conditions) were given in relevant tables (Tab. 3-4).

Tab. 3. Values of the start-up (activation) thresholds of the SSP-FK-BI block (dry block)

Voltage of the group of DPS fire sensors	Voltage band of maintaining the execution block activation the most sensitive plate		Voltage band of maintaining the execution block activation the least sensitive plate	
	Lower threshold	Upper threshold	Lower threshold	Upper threshold
[mV]	[V]	[V]	[V]	[V]
22	10.84	11.26	11.20	12.96
24	10.84	14.20	11.20	15.16
26	10.89	16.18	11.21	17.23
28	10.89	32.00	11.24	32.00
30	10.89	32.00	11.27	32.00
32	10.89	32.00	11.32	32.00

Tab. 4. Values of the maintenance thresholds of start-up (activation) of the SSP-FK-BI block (damp block)

Voltage of the group of DPS fire sensors	Voltage band of maintaining the execution block activation the most sensitive plate		Voltage band of maintaining the execution block activation the least sensitive plate	
	Lower threshold	Upper threshold	Lower threshold	Upper threshold
[mV]	[V]	[V]	[V]	[V]
22	10.88	12.75	11.20	13.90
24	10.90	14.54	11.24	14.96
26	10.94	16.38	11.25	16.73
28	10.95	32.00	11.26	32.00
30	10.96	32.00	11.27	32.00
32	10.97	32.00	11.30	32.00

The obtained results showed that the existence of the voltage values of maintaining the execution block activation occurs as extension of the voltage value of starting up the activation and begins for signals of the group of fire sensors also of the value of 22 mV (there is no block activation below).

The parameter determining the occurrence of the execution block false activation is the duration of the supply voltage drop. The research demonstrated that the lower the supply voltage during a drop, the longer time of the supply voltage drop is required.

The example values of duration of supply voltage of the square wave causing the execution block false activation were presented in relevant tables: for the dry (Tab. 5) and damp blocks (Tab. 6).

Tab. 5. Values of the minimum duration of the supply voltage drop causing the SSP-FK BI block activation (dry block)

Voltage of the group of DPS thermoelectric fire sensors	Minimum duration of the supply voltage required for the execution block activation the most sensitive plate		Minimum duration of the supply voltage drop required for the execution block activation the least sensitive plate	
	Lower threshold	Upper threshold	Lower threshold	Upper threshold
[mV]	[ms]	[ms]	[ms]	[ms]
22	78	78	184	184
24	26	25	46	40
26	18	16	20	16
28	1.4	1.2	1.6	1.2
30	0.03	0.02	0.04	0.02
32	0.01	0.01	0.01	0.01

Tab. 6. Values of the minimum duration of the supply drop causing the SSP-FK BI block activation (damp block)

Voltage of the group of DPS thermoelectric fire sensors	Minimum duration of the supply voltage required for the execution block activation the most sensitive plate		Minimum duration of the supply voltage drop required for the execution block activation the least sensitive plate	
	Lower threshold	Upper threshold	Lower threshold	Upper threshold
[mV]	[ms]	[ms]	[ms]	[ms]
22	74	74	168	168
24	24	20	38	32
26	16	12	18	12
28	1.2	1.1	1.4	1.1
30	0.02	0.01	0.03	0.01
32	0.01	0.01	0.01	0.01

A characteristic feature of the SSP-FK fire suppression system is that in case of the signal values from fire sensors at the level of 30-32 mV, the SSP-FK-BI execution block converts to the state of activation for the voltage drops shorter than the time required to switch the executive relay installed on the plate of amplifiers of this block [8].

4. Summary

Due to the used execution blocks including operational amplifiers, the SSP-FK aircraft fire suppression system constitutes a complex dynamic object, which is characterised by specific properties of its operation depending on the type of interference in its power supply. One of such interference includes instantaneous voltage drops resulted in connecting the high power receivers (e.g. starter generator, heating elements of the anti-icing system, heating furnace fans) to the electricity grid.

The carried out simulation research, confirmed by verification tests, showed the existence of thresholds for the SSP-FK-BI execution block activation depending on the signal value from fire sensors. These thresholds form the voltage areas of the execution block start-up and voltage values of maintaining its start-up, which are responsible for false activation of the fire suppression system during the occurrence of supply voltage drops of individual blocks.

The obtained research results demonstrated that one of the fundamental protections against the occurrence of the SSP-FK fire suppression system false activation as a result of the power supply instantaneous interference is the introduction of the supply voltage regulation circuit of the SSP-FK-BI execution block.

References

[1] Air Force Command, *Mi-8 helicopter Equipment operation and technical service*, Wydawnictwo Ministerstwa Obrony Narodowej, Poznań 1970.

[2] Lewitowicz, J., *Aircraft operation fundamentals, Aircraft operation research*, Wydawnictwo Instytutu Technicznego Wojsk Lotniczych, Vol. 4, Warsaw 2007.

[3] Lindstedt, P., *Practical diagnostics of machines and its theoretical fundamentals*, Scientific Publishers AKSON, Warsaw 2002.

[4] Analytical materials of the Air Force Institute of Technology, *List of causes of the SSP-FK fire suppression system false activation in 2010-2014*, SI SAMANTA Information Technology System, Warsaw 2015.

[5] Michalak, S., Szelmanowski, A., Skoczylas, D., Gierat, J., *Research of causes of false activation of fire suppression systems, Research protocol and report*, Technical Library of the Air Force Institute of Technology, Warsaw 1993.

[6] Defence Standard Document, *Military aircraft, On-board power supply systems, Basic parameters, requirements and research*, NO-15-A200:2007.

[7] Szelmanowski, A., Borowski, J., Sajda, K., Gajewski, T., Sekuła, A., *Research of malfunction causes of the blocks of amplifiers of the SSP-FK-BI fir suppression system, Research protocol and report*, Technical Library of the Air Force Institute of Technology, Warsaw 2010.

[8] Szelmanowski, A., Głyda, K., Tokarski, T., Gajewski, T., Kalisiak, M., Sekuła, A., *Research of possibilities of the SSP-FK fire suppression system self-activation of the Mi-8 helicopter No. 660 at the supply voltage loss / drop, Research protocol and report*, Technical Library of the Air Force Institute of Technology, Warsaw 2015.