ADAPTTIVE GTE SURGE PROTECTION SYSTEM WITH SELECTIVE CONTROL OF ACTUATORS

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Abstract

Characteristics and experience in operation of present-day surge protection systems for III-IV generation gas turbine engines (GTE) are analyzed. The theoretical background and concepts used in designing highly efficient surge protection systems (SPS) for V-VI generation GTEs are discussed. The SPS contains a selective-type channel for GTE unstable operation registration, and uses adaptive control of actuators depending on the type gasdynamic stability (GDS) loss, engine operating modes, external disturbances, presence of pre-surge conditions. A prototype of a new unstable operation registration channel is developed, manufactured, and tested. It is shown that this-type surge protection system can decrease losses of total impulse by ~ 15...25% and reduce initial operation restoration time by ~ 20...30%.

1 Introduction

Development and implementation of new-type surge protection systems are associated with requirements for improvement the GTE performance when exposed to a wide range of external disturbances leading to loss of GTE’s gas dynamic stability (see Fig.1).

For civil aircraft engines, this system is required when flying in severe weather conditions (including thunderstorm activity), with an activated thrust reverser, in conditions of foreign objects or birds ingestion.

It is extremely important to install SPS in engines powering aircraft and helicopters used in fire extinguishing and rescue operations in fire zones.

Furthermore, the protection systems are useful if GDS losses are not associated with external disturbances but caused by erosion of the compressor (that is typical for helicopter GTEs), failure of automatic control devices, damage of components in the engine flowpath.

The completed research work shows that a promising focus area in SPS developments is the system designed on the basis of selective control of actuators depending on a specific operating mode of the engine, a type of GDS losses, presence of any input disturbance, etc., that, to a large extent, will compensate for revealed shortcomings and thereby improve the system efficiency.

This paper gives a theoretical background and concepts for designing highly efficient surge protection systems for V-VI generation GTEs.

Results and analysis of experimental data for a prototype of unstable engine operation registration channel are presented.

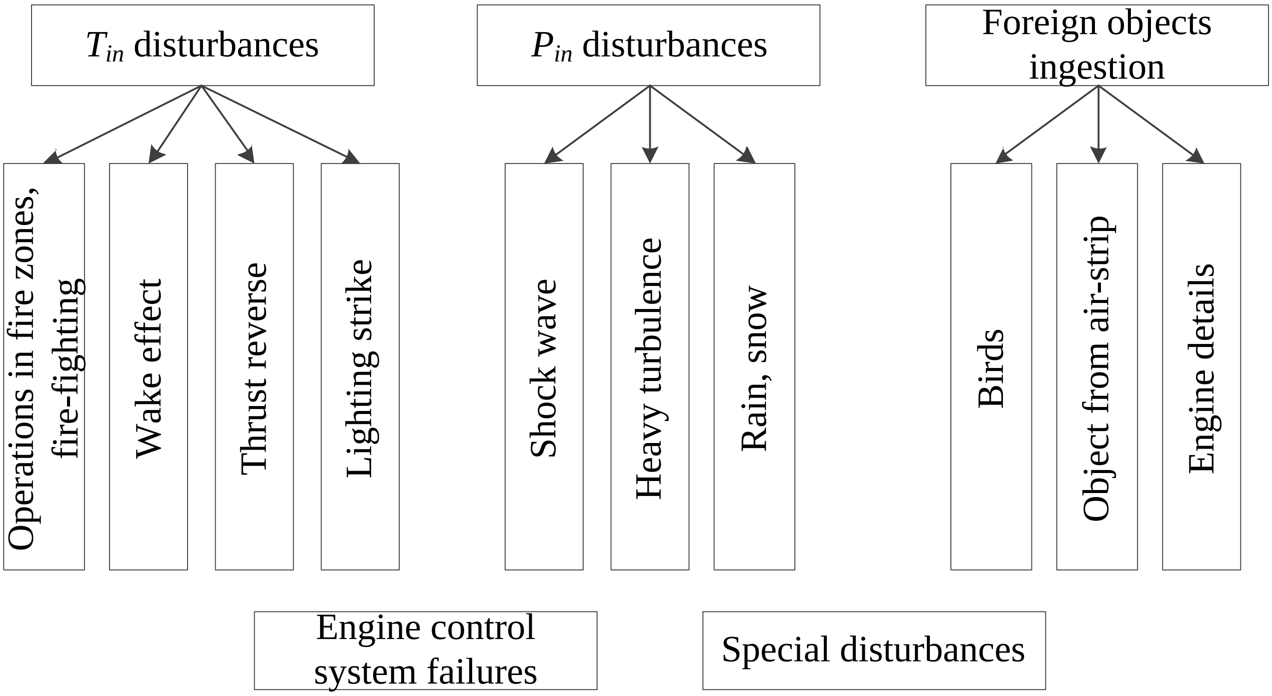
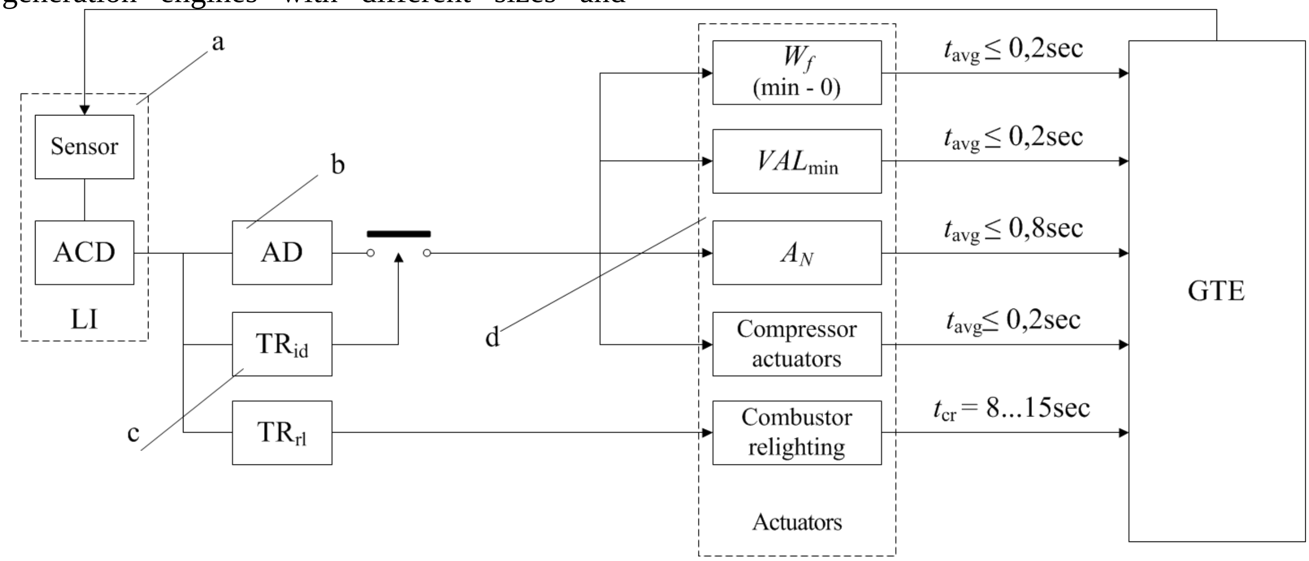


Fig. 1. Disturbing factors leading to GDS losses

2 Analysis of operating data of surge protection systems designed for III-IV generation GTEs

As of today, a considerable number of III-IV generation engines with different sizes and purposes equipped with surge protection systems are in operation [1].

A typical SPS block diagram is shown in Fig.2; a standard process aiming at surge elimination and initial operating mode restoration is shown in Fig.3.



a – GDS loss indicator (LI), b – amplifying device (AD), c - interlock device, d – actuators, ACD - amplifying and converting device, TR_{rl} – relighting time relay, VAL_{min} – position of automatic fuel controls corresponding to min fuel supply.

Fig. 2. Block diagram of SPS with automatic initial mode restoration

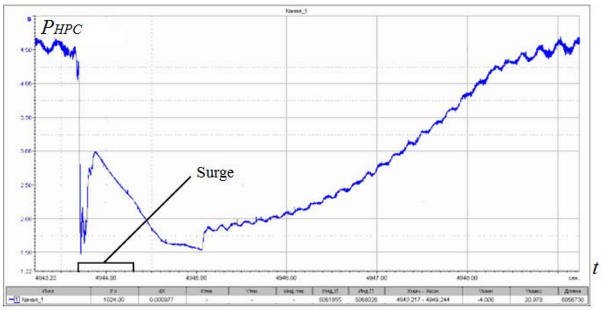


Fig. 3. Changes in P_{HPC} during surging, SPS operation and initial mode restoration for small-size turbofans (F ≈ 1500 kgf)

As shown by numerical and experimental investigations as well as experience in SPS operation for III-IV generation engines, efficiency of the systems depends, to a large extent, on the engine lay-out, availability of well-developed actuators in the flowpath, responsiveness of such actuators controlling compressor and cutting-off fuel supply.

In general, the SPS currently in operation ensure t_{el} = 0,5...2 s surge elimination time and t_{res} = 2...12 s initial mode restoration time.

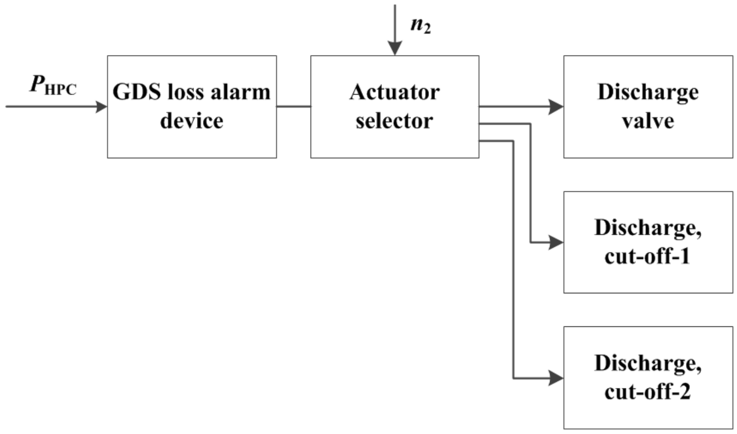
3 Approach to design a selective type channel for GTE unstable operation registration. Channel architecture

The above mentioned SPS for III-IV generation engines, providing one or another efficiency, have one common feature particular to any engine layout, presence or absence of control valves in the flowpath, a registration procedure of unstable operation. It consists in the fact that irrespective of the type of GDS losses, the mode of engine operation, and the type and intensity of input actions upon receiving an unstable operation signal, all SPS actuators shown in Fig.2 are energized simultaneously with max possible efficiency.

The systems designed on this basis are fairly simple and cheap. They need no hardware for recognizing the types of unstable processes, the nature and type of input disturbances, additional information on the gas-dynamic state of the engine flowpath.

However, max possible effect of these actuators used in SPS leads to noticeable losses in GTE’s total impulse, a considerable decrease in rotational speeds of engine rotors, and a sufficiently long restoration time of the initial operating mode as compared with unstable mode elimination time. Studies conducted in Central Institute of Aviation Motors (CIAM) showed that a possible promising trend in SPS developments is the systems designed on the basis of selective control of actuators depending on the specific engine operating mode, the type of gas dynamic stability loss, the presence of one or another input disturbance, etc., that will make possible to compensate for these shortcomings and thereby improve efficiency of the system.

The completed experimental studies of the SPS for a small-size turbofan with selective control components (see Fig.4), where a decrease in fuel flow depends on rotational speeds of the high-pressure spool, show that this type of control can reduce total impulse losses by ~ 15...25% and initial mode restoration time by 20...30%.

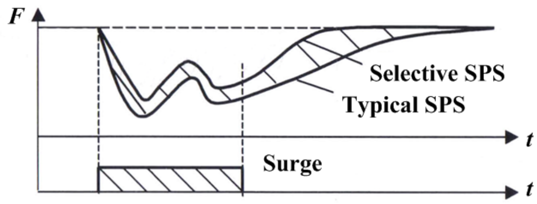


Control commands

n_2, %	< 75	75…90	> 90
Actuators	discharge valve	cut-off-1 valve	cut-off-1, cut-off-2

Effieciency

Systems



Actuators

Actuators	discharge valve	cut-off-1 valve	cut-off-2 valve	cut-off-1, cut-off-2
W_f decrease	~ $W_{f\ idle}$	~ $W_{f\ idle}$ / 2	~ $W_{f\ idle}$ / 4	$W_f \approx 0$
Response time, s	0.6… 1	~ 0.1	~ 0.1	~ 0.1

- t_{res} decrease ≈ 20…30%
- total impulse losses reduction ≈ 15…20%

Fig. 4. Block diagram and algorithms of operation of the experimental selective-type SPS for a small-size turbofan ($F \approx 1500$ kgf)

The present work discusses the conceptual design of highly efficient channels for registration of unstable operation, the development of functional block and schematic diagrams of a selective-type registration channel for advanced V-VI-generation engines.

Findings of many-year CIAM’s works in cooperation with engine manufacturers on tests and operational development of protection systems for various engine layouts show that frequency ranges of surge vibrations and rotating stall vibrations are different. Table 1 shows frequencies of surge and rotating stall vibrations for various engine layouts and sizes.

The values of relative pulsations, $C = \Delta P/P$, used as the parameter characterizing GDS loss are within $C_{surge} \sim 0.6…0.9$ for surge and $C_{RS} \sim 0.2…0.5$ for rotating stall.

Based on the above-discussed data, it is possible to formulate the general principles used in designing the selective-type registration channels:

- availability of 2 channels with different amplitude-frequency characteristics for separate registration of surge and rotating stall modes;
- use of different triggering thresholds based on $\Delta P/P$ value in each channel, keeping in mind that the triggering threshold in the surge channel is 1.5...2.5 times lower than in the rotating stall channel;
- providing automatic switching-over of actuators when implementing one or another type of GDS loss or transition of one type of unstable operation to another.

Table 1

Engine	f_{surge}, Hz	f_{RS}, Hz	W_{air}, kg/s
Turboshaft	18…23	90…120	7
Turbojet	12…15	50…80	150
Turbofan	20…23	40…80	78
Turbofan	8…10	30…60	491

Fig.5 and Fig.6 show a block diagram and a cyclogram of a selective SPS with mixed registration of surge and rotating stall for the case, where frequencies of stalling processes are the same. The above diagram provides three types of control (see the SPS cyclogram and the block diagram).

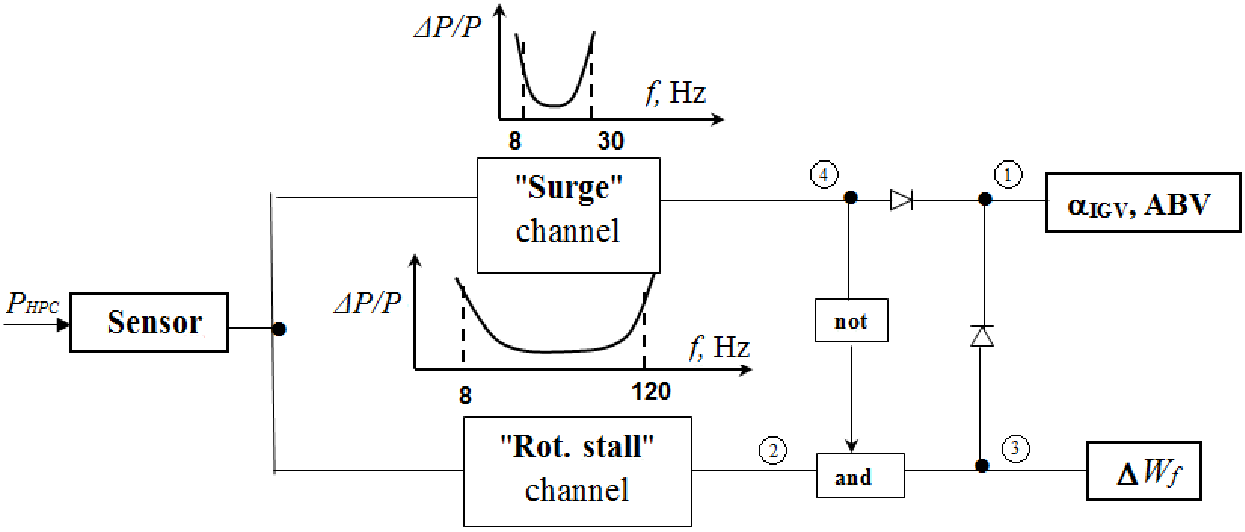


Fig. 5. Block diagram of the selective registration channel for GDS losses (surge and rotating stall); "NOT", "AND" – logical elements, ABV – air bleed valves, IGV – inlet guide vanes

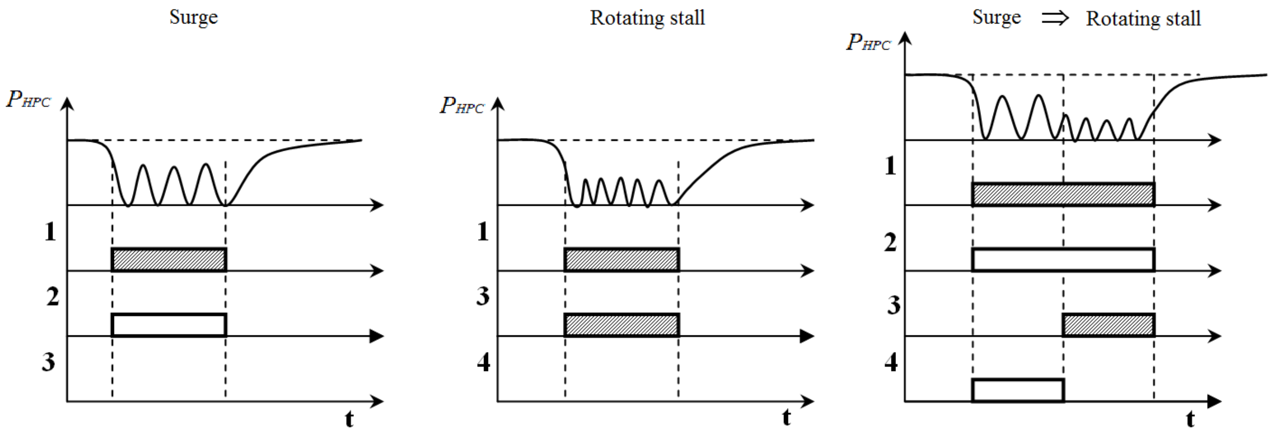


Fig. 6. Cyclogram of the selective SPS with mixed registration of surge and rotating stall (pos.1 ...pos.4 in Fig.5 correspond to p.1 ...p.4 in Fig.6)

In the first case, only compressor actuators are activated with occurrence of surge vibrations. In the second case, when rotating stall starts immediately, the compressor actuators and fuel flow cut-off valves are activated simultaneously. In the third case, when after surge cycles a transition to a rotating stall occurs, the fuel flow cut-off valve is activated (see Fig.6) in addition to activation of the compressor actuators.

As shown by experience in experimental developments and operation of SPS for III-IV-generation GTEs, the optimum value of triggering threshold in the "Surge" channel within $f = 8\ldots30$ Hz frequency range can be taken equal to $C_{surge} \cong 0.2$ and in the "Rotating Stall" channel within $f = 8\ldots120$ Hz frequency range $- C_{RS} \cong 0.1$.

4 Development of a digital alarm device circuit for unstable operation of a selective SPS

To implement the SPS with selective control of actuators with the block diagram shown in Fig.5, a digital alarm device for SPS unstable operation is developed (see Fig.7). The device is based on the STM32F103RE microcontroller with the Cortex-M3 core (72 MHz timing frequency, 512 KB flash memory, 64 KB RAM). Registration algorithms for compressor surge and rotating stall and generation of control signals transmitted to one or another actuator depending on the type of compressor unstable operation are implemented in the microcontroller within the required frequency range. These actuators can be air bleed valves, fuel cut-off valves, inlet guide vanes.

The secondary power supply unit for the device consists of two converters. The first converter decreases voltage of the aircraft electrical system from 27 V to 5 V, and the second converter decreases voltage from 5 V to 3.3 V to power the microcontroller. To receive an analog signal from the pressure sensor, we can use an A/D converter (ADC) built into the microcontroller. To receive the signal from the pressure sensor, it is also possible to use SPI serial interface to receive data from an external ADC. For data exchange with a personal computer, a USB interface is provided to make changes in registration settings and corrections in algorithms of microcontroller operation. The microcontroller sends digital signals to signal conditioners to control the air bleed valves, inlet guide vanes and cut-off valves for fuel supply to the combustion chamber. It is possible to control the electric drive of inlet guide vanes by means of an analog signal generated by a digital-to-analog converter (DAC) built into the microcontroller.

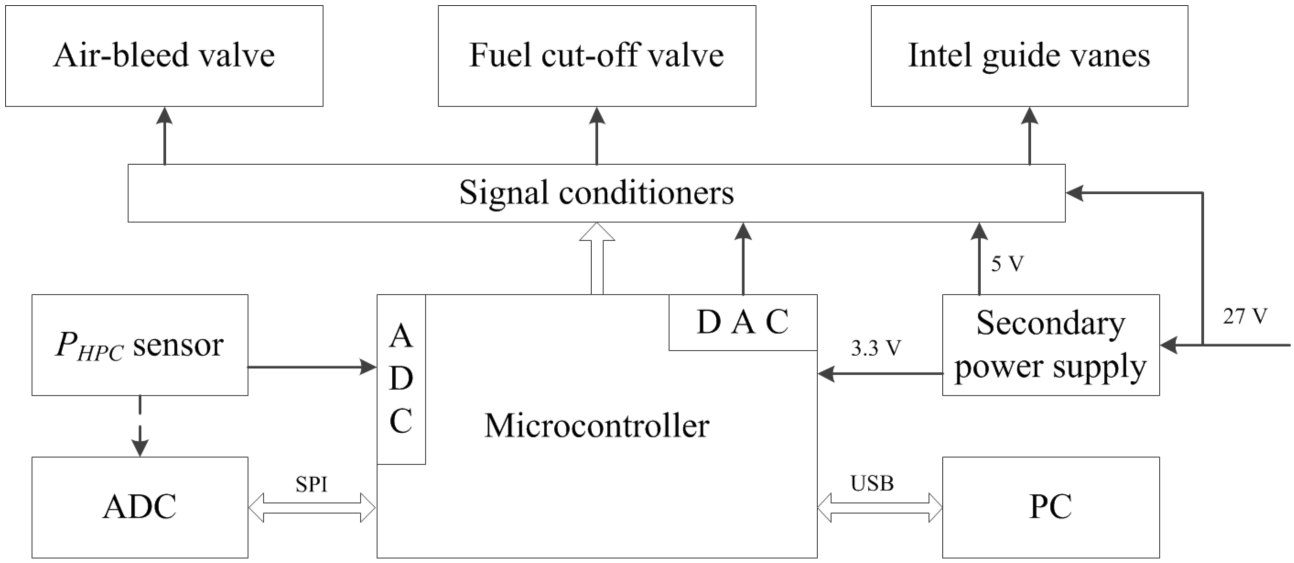


Fig. 7. Diagram of a digital alarm device for the selective SPS unstable operation

5 Conclusion

1. The design principles for registration channels of GTE compressor gas-dynamical stability loss are defined using a selective approach to the choice of control commands. Their application provides an automatic choice of control methods for elimination of instability by commands sent to controllable components in the engine flowpath (inlet guide vanes, bleed valves) and fuel flow separately or simultaneously, depending on the type of GDS loss process (surge, rotating stall).

2. Input data processing algorithms are developed. They use a system of band-pass filters in surge and rotating stall channels, as well as estimation of disturbance levels in each channel, that determine the method having an effect on the operating process. To send an output command to actuators, the value of relative air pressure pulsations in the "Surge" channel should be $C_{surge} > 0.2$ within $f = 8...30$ Hz frequency range, and in the "Rotating Stall" channel – $C_{RS} > 0.1$ within $f = 8...120$ Hz frequency range. If the type of the GDS loss process changes, control commands automatically switch over at $f = 30 \pm 5$ Hz.

3. The digital alarm device circuit for unstable operation is developed for a selective surge protection system that provides registration of surging processes with parameters listed in it.2 above.

References

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