Redundancy in the control of a gas turbine for naval applications

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Abstract. The gas turbine used in marine propulsion for increased efficiency and safety and with a very good power / weight ratio, have a control system that provides alarm, monitoring and control functions, including over-speed protection. The paper presents the inclusion of redundancy in the control of the gas turbine so that it works under optimum operating conditions under any regime. The authors' contribution consisted in the elaboration of control schemes so as to ensure a redundancy of the gas turbine control in case the main control module fails. The analysis of the gas turbine construction led to the elaboration of the hardware structure of the system, based on the doubling of the fuel and speed controls as well as of the related transducers by the gas turbine manufacturer. This redundancy is ensured by the introduction of an additional control module that ensures minimal functionality until the status of the main module is restored. The operation of the two modules, the basic one and the redundant one, are ensured on the basis of software, designed by the authors of the paper. The implemented program also limits the size of the variation, keeping the turbines in a correct operating mode.

1. Introduction

At present, gas turbines are technical equipment of high complexity intensely used in different fields of activity from the energy industry - natural gas pumping and the production of electric power to car, naval and aviation propulsion [1].

Since the invention of the reactive propulsion in 1910 by the Romanian scientist Henry Coandă, this type of engine has evolved through the classic engine solutions provided with the turbo-compressor group proposed by Frank Whittle and Hans von Ohain during World War II to the solutions modern today.

In the field of ship propulsion, the direction of development is oriented towards the use of gas turbine with high compression ratios and very high cycle temperatures that run on diesel [4]. In this way, small specific consumption and large operating ranges are ensured. Another orientation is that the motor automatic is exclusively electronic and the power shaft is positioned in front of the motor. By using the electronic automatic, an accurate control of the engine speeds and its exploitation at optimal parameters is ensured [7].

The modernization and reconditioning of the ships involves the replacement of other installations on board and the replacement of the propeller groups. With the consumption of the resource, the problem of replacing the gas turbines present in naval applications with new turbines, more efficient of
the same power with the old ones, is posed. In our case Tyne turbines manufactured by Rolls Royce was replaced with marine ST40M turbines manufactured by Pratt and Whitney.

The implemented automated electronic control system has proved reliable, accomplishing the optimum control of the gas turbine, with the functions of monitoring, displaying and acquiring of the values of operation parameters. The operation was performed in good conditions and a safe and smooth has been achieved by setting the temperature lower limiting protection [6].

If extremely high system maintainability is required, the command and control system is no longer sufficient. Therefore, considering the capabilities provided by the turbine manufacturer, a secondary module has been considered in emergency cases when the command and control system is blocked for various reasons [5]. To ensure turbine start-up and operation in the event of failure of the main control system, the redundant module must provide the strictly necessary turbine commands and read the essential parameters [8].

2. Gas turbine presentation and redundant signals from the engine

The ST40M is an aero derivative gas turbine, manufactured by Pratt & Whitney Canada, whose performance is correlated with the performance of the PW150A gas turbine. The power turbine (free turbine) consisting of two axial stages remained virtually unchanged except that the power shaft of the last two stages was lengthened to exceed the width of the new intake device.

The compressors remained unchanged being the same as in the PW150A. The low-pressure axial compressor has 3 axial stages being driven by a low pressure axial turbine with 1 stage. The high-pressure axial compressor has a single centrifugal stage being driven by a high pressure axial turbine with 1 stage. The ST40M gas turbine has been modified to meet the marine standard, is treated for resistance to salt mist corrosion.

From the data provided by the engine manufacturer, we observe that the following signals are doubled.

In addition to the signals from table 1 provided by the engine manufacturer, the following parameters will be acquired through additional transducers:

- T1- engine inlet air temperature, value that intervenes in the engine control process;
- PRM - control pressure of the engine speed, size imposed from the ship automatically proportional to the position of the engine power lever;
- PDUM - differential pressure of engine oil, important parameter in engine control.

Redundant controls for oil pump, ignition and pneumatic starter are required to start the engine.
### Table 1. Double signals on the engine ST40M

| Signal Description                  | Symbol |
|------------------------------------|--------|
| High pressure compressor speed     | NH     |
| Low pressure compressor speed      | NL     |
| Power turbine speed                | NP     |
| Fuel flow control                  | FMU    |
| Fuel valve position                | FMUF   |
| Control overflow valve             | OSS    |
| P22 bleed valve control            | P22    |
| Bleed valve position               | P22F   |
| P27 bleed valve control            | P27    |
| Temperature of exhaust gases       | ITT    |

![Diagram of fuel metering unit of ST40M](image)

**Figure 2.** Section through fuel metering unit of ST40M [2]

### 3. Redundant turbine control system implementation

Redundancy is ensured by the addition of an electronic panel that ensures turbine control when the main control system fails.

#### 3.1. Redundant control system diagram

To ensure the redundancy of the command and control system it was started from the block diagram used in the command and control of the ST40M engine to the tests performed successfully on the stand and on the ship.
Furthermore, the red-drawn panel that takes over the command signals from the main panel and switches them if it has failed with those provided by the redundant panel. The redundant panel has a minimal construction ensuring a basic control and control for the engine until the main panel operation is restored.

The comparison between figures 5 and 6 shows the electronic modules that have been used.

Mainly the same type of modules was used to ensure interchangeability with the modules used in the main panel.
The redundant module is connected to the local control panel through communications lines that allow it to determine its operating status. It checks the status of the main panel through both a watchdog hardware connection and an Ethernet connection. The hardware connection consists of a connection between the output of the digital output mode connected to the input of the digital input module of the redundant local panel. Once at 0.5 seconds the digital output is switched from 0 to 1 and vice versa. This switch resets a value acquired by the digital input. When this value does not change, the local panel malfunction is detected. This hardware connection is also doubled by the Ethernet connection between the two panels. Through this connection the local panel is queried at each program cycle of the redundant panel. The lack of an answer leads to the redundant panel taking over control.

The panel in the control room will be powered both from the main local panel and from the redundant local panel through a trio diode module, to prevent the failure of at least one of the power sources. Possible fault cases for the local control panel are shown in table 2.

| Failure type                  | Analogue / Digital outputs state | Remarks                                           |
|-------------------------------|----------------------------------|---------------------------------------------------|
| 1 Power supply failure       | 0mA, 0V                          | It can be fixed “Hold last state” in the Hardware Manager |
| 2 Central processing unit failure | At the appearance of the defect | It can be fixed “Hold last state” in the Hardware Manager |
| 3 Blocked software           | At the appearance of the defect |                                                   |

Figure 6. PLC configuration layout for Redundant Local Control Panel

Figure 7. Communication between the redundant local panel and the local control panel
In cases 2 and 3 the redundant panel can easily take over the engine control, but in case 1 the lack of the fuel dosing output will lead to the closing of the fuel valve and the speed decrease. If the speed drops too fast during the detective interval, this may cause the engine to stop before the redundant panel takes over the engine control.

Analyzing a stop of the engine from the idle speed we will see (figure 8) that the speed decreases by 10,000 rpm in about 4.5 seconds. So the system could detect the main local panel locking and decrease of speed from about 29000 rpm (cruising speed) in time for the redundant local panel to accelerate the engine.

Figure 8. Decrease engine speed when stopped

The redundant panel may break first. To avoid failure of the controls in this case, the lines coming from the main panel pass through the redundant panel and go to the motor through the switching relays will be provided by their normally closed contacts. When the redundant panel fails, these contacts remain in the same position ensuring the connection of the main local panel to the motor.

3.3. Description of redundant local panel software

The program running on the redundant panel is a small program of the application on the main panel, as it has several additional functions. Some of the screens of the main application will disappear, no longer necessary in the case of a reduced application to the strictly necessary.

Figure 8. The screens that will be deleted in the redundant local control panel application
The remaining screens will be modified to display only the essential parameters processed by the local redundant panel. The screen corresponding to the hot running of the engine will show as in figure 9.

![Figure 9](image.png)

**Figure 9.** Hot start screen in the redundant local control panel application

On this screen, the parameters meanings are: *Pornire Calda* – Hot start-up; *PRM* – Throttle pressure signal; *Maneta* – lever; *Turatie elice* – propeller speed; *NHM* – Speed of high pressure compressor; *NLM* – Speed of low pressure compressor; *NTPM* – speed of the power turbine; *ITT* – Calculated Inter Turbine Temperature; *T6_M* – measured gas temperature after turbine; *XDC* – Position of fuel metering valve; *XV2.2* – Position of bleed valve; *PDUM* – engine oil differential pressure; *Tcap* – Engine cell temperature; *PV27* – Command signal open/close of bleed valve 2; *T1* – air temperature at engine inlet; *NHref* – Reference imposed speed; *3 minute pornire* – 3 minutes start-up; *5 minute oprire* – 5 minutes stop. The program will no longer have the screens corresponding to the parameters and tests and the others will be reduced to a minimum.

4. **Conclusions**

Redundancy by adding a local control panel is based on the ability of the ST40M engine to accommodate an additional row of commands and to provide information on turbine speed. The addition of the redundant panel allows the control and start of the turbine in the critical case when the troubleshooting team cannot reach the ship. Also doubling the control allows the engine to be operated if a local main control panel is damaged. The tests with the redundant system will show the viability of the chosen.

5. **References**

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