DEVELOPING STARTING PROGRAMMES OF GAS TURBINE ENGINES INTO A TEST BENCH

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The paper achieves a general starting sequence of a classical gas turbine engine, which is not equipped with an electronic control unit, and which will be running into a test bench. To perform the starting sequence is created an instrumentation scheme with all the parameters and commands that are involved into the starting phase. To start a gas turbine engine, into a test bench, it involves using an operating and acquisition system, with a programmable logic controller, in which the starting sequence is inserted in a code programming form. The structure of the starting sequence is presented into a general logic sequence diagram based on the general engine instrumentation scheme. The starting sequence is applied for different types of startings as dry motoring, wet motoring and engine run.

Keywords: starting, sequence, algorithm, acquisition, instrumentation, test bench

1. Introduction

Generally, the starting of gas turbine engines represents a complex process and require an operating system to control, to monitor and to execute the startup proccess. In present, the aircraft engines are equiped with programmable electronic modules, which operate the engine for starting, based on a series of sequences, written as a software into the electronic modules.

To start an engine into a test bench it requires to assure the engine the equivalent facilities as on aircraft. The test bench has an operating sytem which contains electrical installations and electronical devices, which programmed, are capable to execute the starting sequence and to control the engine for running.

The purpose of this work is to educate and teach how to start a gas turbine engine, and there are some reference paper works [1,2] about gas turbine engine education starting but there is not presented the logical structure of starting phase which can be applied on any type of engine.

In this paper it is presented the creation of a general starting procedure and a general logical scheme, for running the engine which are not equiped with electronic modules. The general logical scheme is the base of writing the software,

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into a cod programming form, to execute a starting phase, to run the engine into a test bench.

The gas turbine engines contain a starting system which serves to obtain the mixture of air-fuel, and then to be ignited [3] into the combustion chamber. To supply air and fuel, the engine is rotated by the starter which transfers mechanical energy through the accessory gearbox to the engine starting shaft, for driving the compressor, to intake the air flow, and for driving the main fuel pump, to deliver the fuel into the combustion chamber, to form optimum mixture between air and fuel. To ensure the ignition, the starting system contains an ignition system which ignites the air-fuel mixture. The starter supplies power to the starting shaft, to accelerate the engine until a maximum speed is achieved at which is obtained the optimum mixture air and fuel which will be ignited. Starting the engine means to set in motion the starting shaft speed until is gets on the idle speed.

2. Engine instrumentation scheme

To start the engine it is required to control the components of the starting system that are implicated into the starting sequence [4]. To have the control over the engine, the parameters and the commands, which participate to run the start sequence, will be established. To run different types of starting, the test bench must hold an operating system, consisting of an acquisition system and a programmable controller, which serves to execute the sequence of the selected start type. A classical engine is not equipped with an electronic engine control and to perform an automatic or manual starting for a certain start type, it is required to create a soft into a programmable controller which is connected with the engine by instrumentation of parameters and actual commands of engine starting system, as presented in fig.1.

So the logic sequence of controlling the engine depends on what engine parameters were established and what engine actual commands will be switched on or off. To operate the engine there are monitored the engine parameters by the acquisition system and displayed on control panel and to control the engine there are actuated the commands from the controller by the programmable unit to operate the starting system components.

To start the engine it is necessary to have control over the main engine parameters, using display equipment, and on the actual starting system commands, using a control unit in connection with the control panel from the control room. The main parameters, presented in fig.1, of a gas turbine engine which are started into a test bench are: shaft speeds, N1, N2, inlet turbine temperature ITT, fuel flow FF, oil pressure EOP, oil temperature EOT, vibration VB, air flow AF, inlet fuel pressure IFP, and to operate the engine the actual commands of starting operation

are represented by the fuel pump FPU, starter, engine start lever SLEV, ignition exciters IGNS, starting fuel valves SFV.

In this paper it is presented the engine instrumentation scheme and the logical sequence which describes the starting of the engine for three types of startings as are dry motoring, wet motoring and engine run.
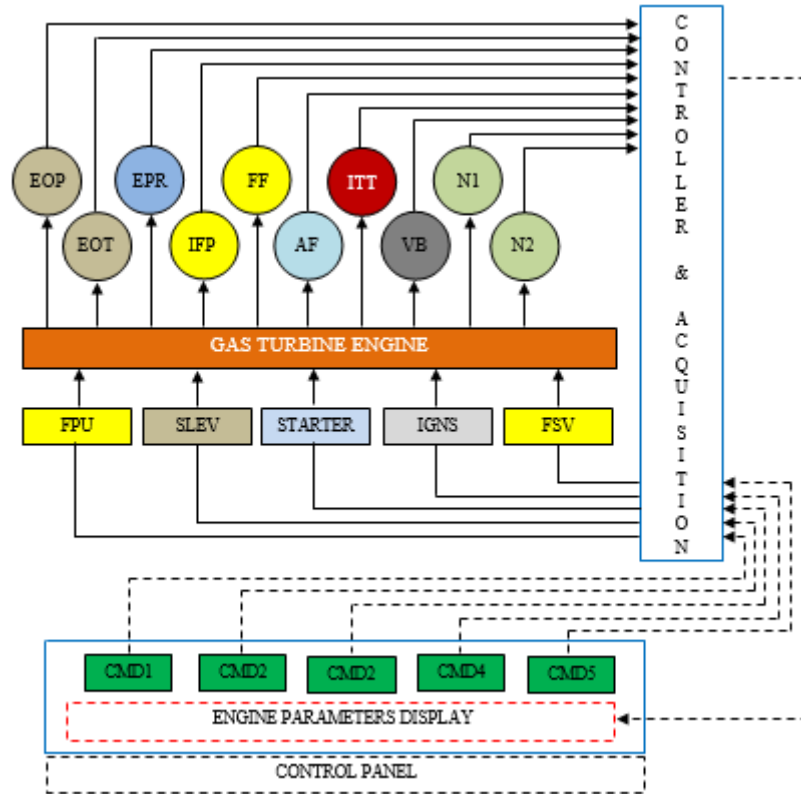

Fig. 1. Engine Instrumentation and Acquisition System

3. General engine starting sequence

The general start sequence presents the starting stages of different types of startings, expressed by a logic diagram, presented in fig.2 and fig.3, based on the general instrumentation scheme and the configuration of the operating system. The sequence of engine starting [5] can be performed in three types of startings, selected by three selectors, one for each type of starting, so selector one SL1 is for dry motoring, selector two SL2 is for wet motoring and selector three SL3 is for engine run. The starting sequence begins with the initialization of the selectors, commands and warning lights. After the initialization, it is imposed a working condition for a series of parameters, and if the condition is satisfied, the warning light will be closed which confirms that the engine is ready to start, if the condition is not satisfied, then the programme waits until it is accomplished.

To perform a dry motoring, fig.2, select SL1 button and then the dry motoring sequence will start automatically or manually in function of time and starting shaft speed parameter. To execute a dry motoring there are followed the next steps: select dry motoring type by acting SL1 button in ON position and a time start to be counted. At t1d time, the starter is turned on by setting CMD3 command in ON position, the starter increases the starting shaft speed and gets the maximum value N1d. At this speed the oil pressure EOP must exceed a minimum admissible value. If the condition is satisfied, the warning light will close, the programme continues to run the engine for a tfd time and then turns off the starter by setting CMD3 command in OFF position to stop the dry motoring sequence. If the condition in not satisfied the warning light will go on and the programme automatically turns off the starter by setting CMD3 command in OFF position, and the dry motoring sequence will stop.

To perform a wet motoring, fig.2, select SL2 button and then the wet motoring sequence will start automatically or manually, according to time and starting shaft speed parameter. To execute a wet motoring the next steps need to be followed: select wet motoring type by acting SL2 button in ON position and turn on the fuel pump by setting CMD1command ON. The programme checks if the fuel pressure increases and waits the fuel pressure to exceed the minimum value. If the condition is satisfied, the warning light will go off and the programme will continue the sequence, if the condition in not satisfied, the warning light is still on, the sequence is blocked and the programme waits until the fuel pressure exceeds the minimum value. The time starts to be counted, at t1w time, the programme opens the start lever by setting CMD2 command ON to allow the fuel to enter into the engine. At t2w time the programme turns on the starter by setting CMD3 command in ON position. After the starter is turned on, the speed N1 begins to increase, the programme opens the starting fuel valve by setting CMD5 command in ON position to allow the fuel to enter into the engine fuel system and then to be delivered in the combustion chamber.

The starter runs the starting shaft until it gets a maximum dry speed N1w and at this speed the oil pressure EOP must exceed a minimum value. If the condition in satisfied, the warning light will close, and the software continues to run the engine with starting fuel valves opened for tfw time. When the tfw time is over, the software turns off the starting fuel valves by setting CMD5 command in OFF position, turns off the starter, by setting CMD3 command in OFF position, the shaft speed decreases slowly, and at 10 [%] the shaft speed turns off the fuel pump and the fuel pressure begins to decrease, and the wet motoring sequence is ended. If the condition in not satisfied, the warning light will still be on and the programme automatically turns off the starter by setting CMD3 command in OFF position, and the wet motoring sequence will stop.
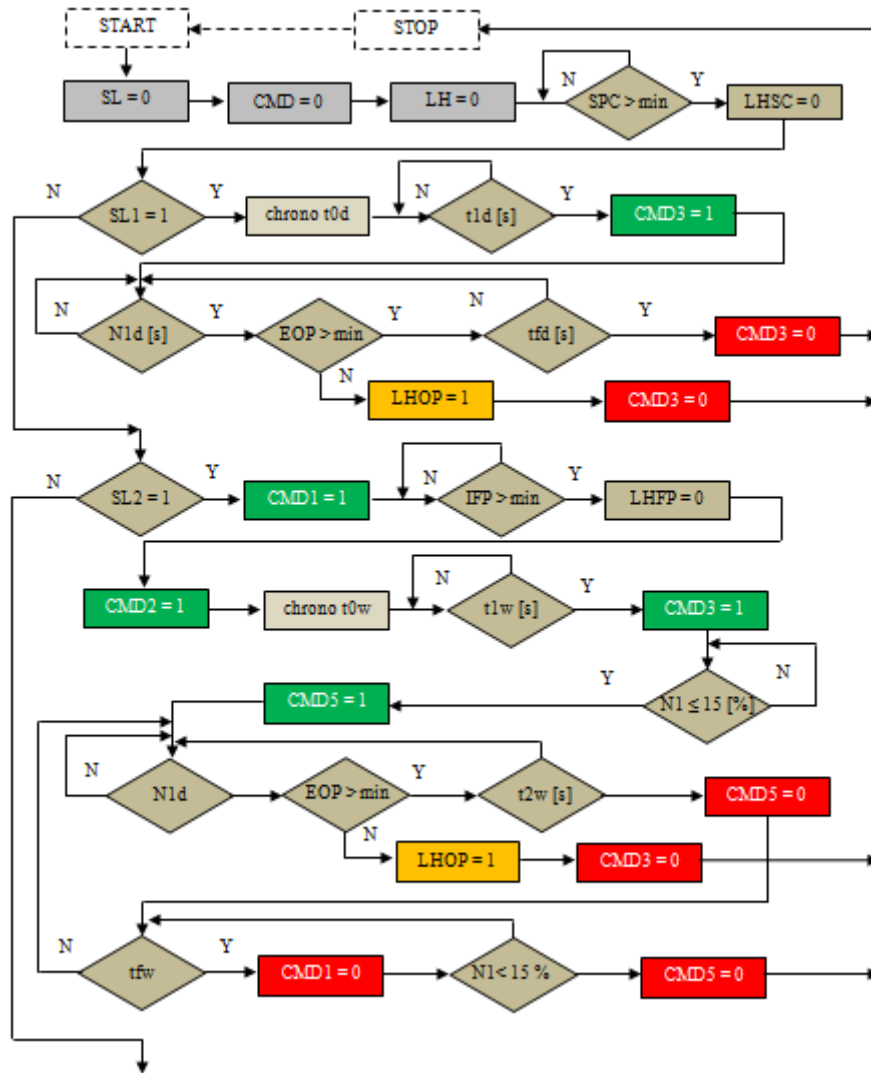
Fig. 2. Logical starting scheme (dry and wet motoring)

Acording to the starting theory [6] the equation which describes the phase of cranking process, until the engine is not ignited, is the momentum equilibrium equation, presented in the next form:

$$M_{de} = M_{rez} + J_a \cdot \frac{\pi}{30} \cdot \frac{dn_{de}}{dt} \tag{1}$$

where M_{de} is shaft starter torque, M_{rez} is rezistive torque of engine starting shaft, J_a momentum of inertia of gears reported to the starter shaft, n_{de} starter speed and t is the running time.

After the engine is ignited and the turbine starts to produce power and the momentum equilibrium equation is modified in the next form:

$$M_{de} + M_{tb} = M_{rez} + J_{de} \cdot \frac{d\Omega}{dt} \qquad (2)$$

where M_{tb} is turbine torque corresponding to turbine power P_{tb} and Ω is the angular speed of engine starting shaft

Also, according to the starting theory on the acceleration phase to the idle on starting procces, the momentum equilibrium is transformed into next form:

$$M_{tb} = M_{rez} + J_{de} \cdot \frac{d\Omega}{dt} \qquad (3)$$

$$M_{rez} = M_c + M_f + M_{agr} \qquad (4)$$

where M_C is dynamic rezistive compressor torque, M_{agr} is accessory gear box consumed torque, and M_f is friction consumed torque on bearings and train gears

$$M_c \approx k_1 \cdot n^2 \qquad (5)$$

$$M_f + M_{agr} \approx 3\% \cdot M_{rez} \qquad (6)$$

To perform an engine run, fig.3, select SL3 button and then the engine run sequence will start automatically or manually depending on time and starting shaft speed parameter. To execute an engine run phase, the next steps are followed: select engine run type by acting SL3 in ON position, and turn on the x fuel pump by setting CMD1 command in ON position. Check if the fuel pressure increases and wait the fuel pressure to exceed the minimum value. If the condition is satisfied, the warning light will close and the programme continues the sequence, if the condition in not satisfied, the warning light is still on, the sequence is blocked and the programme waits until the fuel pressure exceeds the minimum value. The time starts to be counted, and at t1r time the software opens the start lever by setting CMD2 command ON to allow the fuel enter into the engine. At t1r time it turns on the starter by setting CMD3 command in ON position. The starter increases the starting shaft speeds and when it exceeds 10[%] the ignition is energized by acting CMD4 command in on position. While starting shaft speed increases and when it exceeds 20[%], it opens the main fuel supply valve by acting CMD5 command in ON position to allow the fuel to enter into the engine fuel system and to be ignited into the combustion chamber. When starting shaft speed N1 exceeds 45[%] the starter is turned off by acting CMD3 in OFF position and the engine must accelerate until it is obtained 55[%] of the starting shaft speed. At the same time, oil pressure EOT must exceed a minim pressure of 2 [bar] and the inlet turbine temperature must not exceed the maximum starting temperature of 600[°C]. If N1 speed, oil pressure EOP and ITT temperature respect the condition, then the programme continues to run the engine, meaning the engine is on the stable idle speed, then the programme stops the ignition and main fuel supply valve by acting virtual CMD4 and CMD in OFF position. If one of the protections do not respect the condition, the engine will be shut down by acting CMD2 command in OFF position and the engine run

sequence is ended. The engine is maintained at idle mode for a tfr time and when the time is exceeded, it turns off the start lever by acting CMD2 command in OFF position, after that the starting shaft speed decreases slowly and when it is lower than 20[%], it stops the fuel pump, the engine does not receive fuel and the engine run sequence is ended.
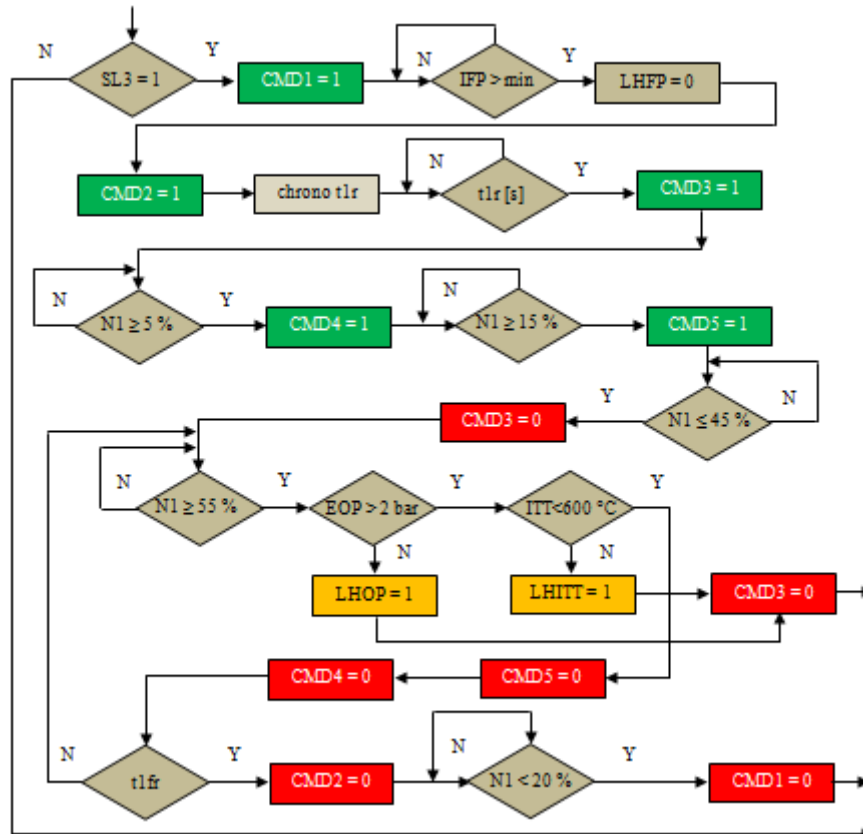
Fig. 3. Logical starting scheme (hot run)

4. Experiments and Results

The structure of the general starting scheme can be applied on any type of engine to execute the starting sequence. Every engine has specific values of the main parameters and a specific starting sequence, as the time when the starter is acting, the time when the ignition is excited, the time when starting fuel valves are acting and different values of gas generator speed, oil pressure and inlet turbine temperature to respect the operational conditions.

The logical starting scheme was particularly applied to create the starting sequence for two engines with free power turbines as are TV2-117A and TV3-117A turboshaft engines.

To start the engine it is created a graphic interface to allow the operator to control the starting of the engine. For every engine it was created a proper graphic interface, as is presented in fig.4, with particular parameters and commands that are involved into the starting sequence.

Fig. 4. TV2-117A operator graphic interface

The engine is fixed into the test cell [7] on a mounting support, as is presented in fig.5, and is instrumented with a series of parameters and commands to assure the monitoring in time of functioning. The engine is geared with a dynamometer to assure for the free power turbine a brake for the starting.

Fig. 5. TV2-117A (left) and TV3-117MT (right) engines into the test bench

By starting the engine on the test bench, according to the starting sofware and logical diagrams, it is obtained a series of experimental variation curves between the engine parameters.

In the next graphics there is presented the variation of the parametres of TV2-117A and TV3-117MT engines for different types of startings.

In the first two graphics, from fig.6 and fig.7, it is presented the variation of the engines main parameters for a dry motoring.

In the next two graphics, from fig.8 and fig.9, there are presented the variations of the TV2-117A engine main parameters, depending on the starting time and gasogenerator speed N2 for a hot starting or an engine run. The hot starting of engine is performed and presented until the idle mode is on.
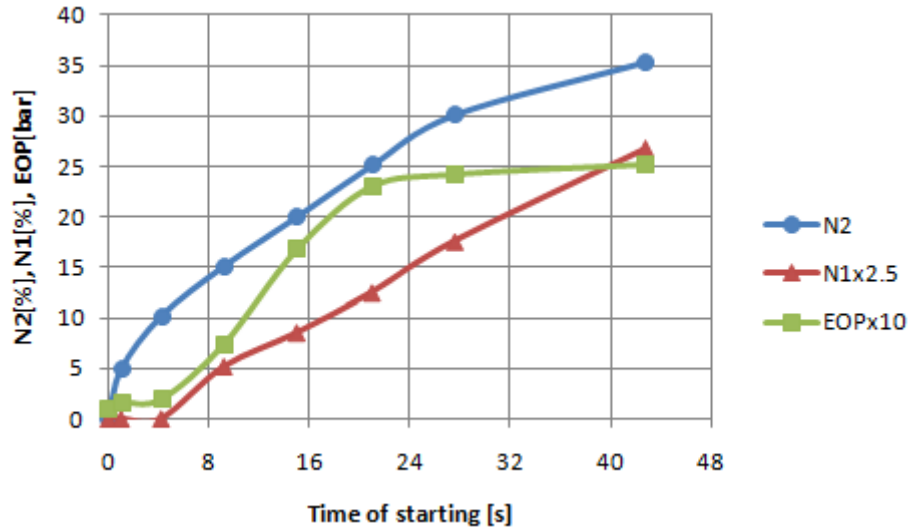

Fig. 6. Variation of TV2-117A engine main parameters for a dry motoring
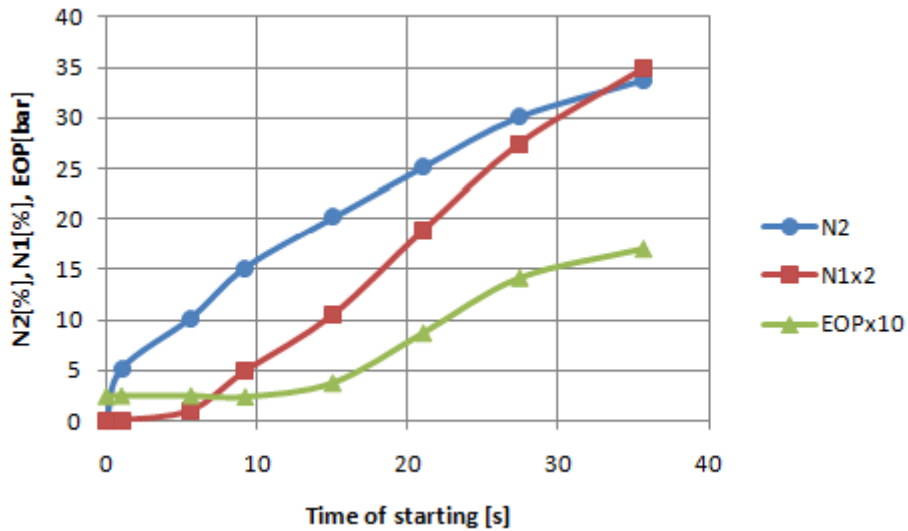

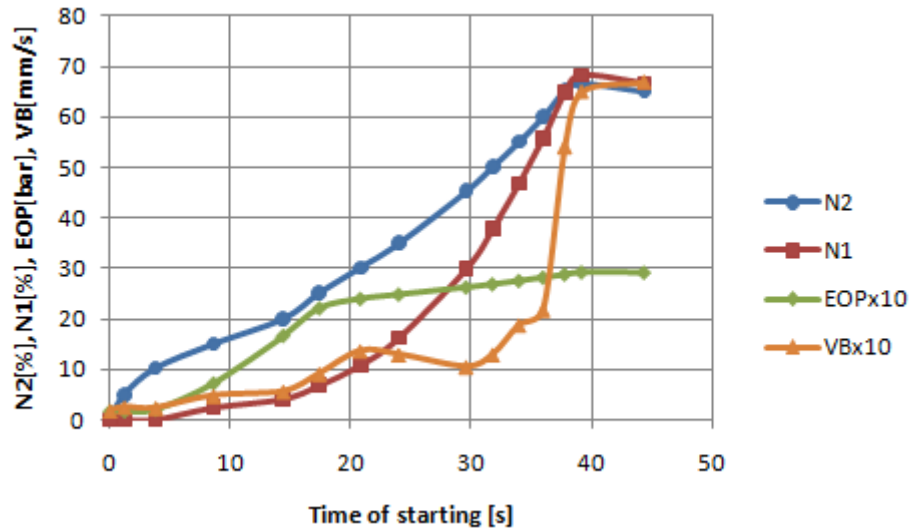Fig. 7. Variation of TV3-117MT engine main parameters for a dry motoring

Fig. 8. Variation of TV2-117A engine main parameters for a hot run
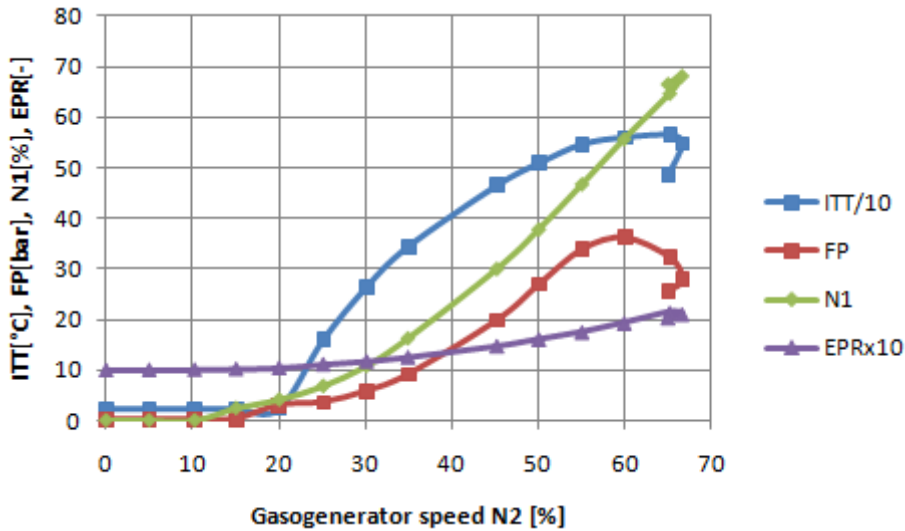

Fig. 9. Variation of TV2-117A engine parameters for a hot run

The graphics are obtained by using the recorded values of parameters during the starting time. To show the variation of different engines parameters, on the same graphic it was modified the limits of parameters domain by multiplying or by dividing with the correct values to obtain close domains of variation.

The next graphics, from the fig 10 and fig.11, present the variation of TV3-117MT engine main parameters, depending on the starting time and gasogenerator speed N2, for a hot starting.
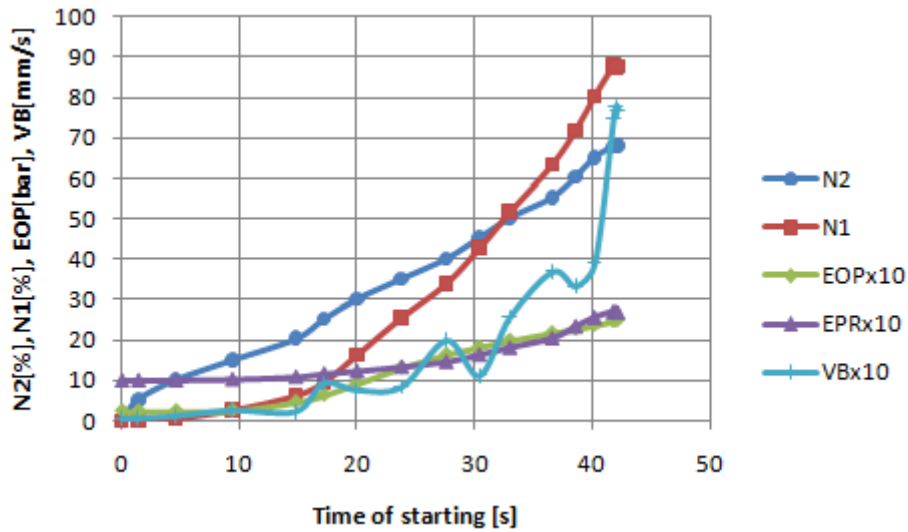
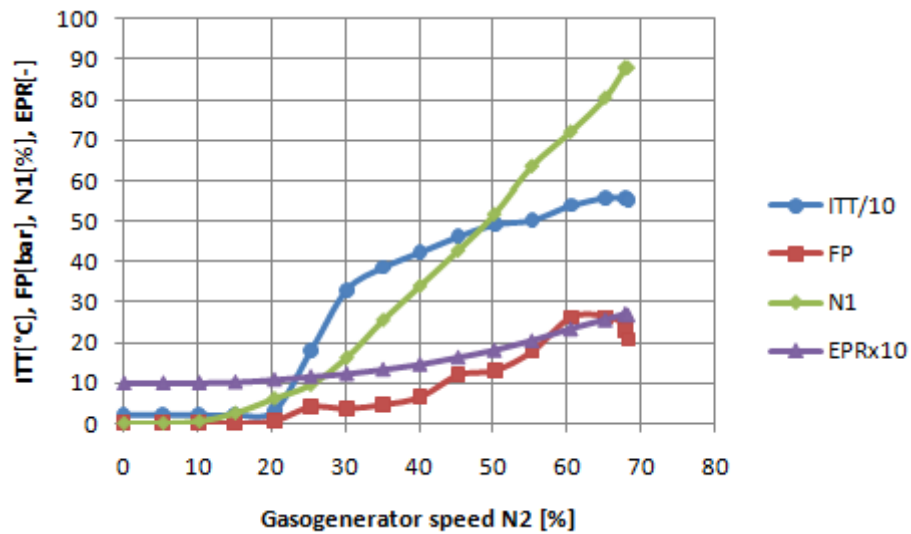Fig. 10. TV3-117MT hot run, variation of engine main parameters

Fig. 11. TV3-117MT hot run, variation of engine main parameters

Because the studied engines are both turboshafts, with different powers, made by the same manufacturer, using the same sequence for starting type, with approximative values of counted time and shaft speed, from the graphics presented it is observed that the engines parameters have the same variation and approximately the same values of working, available for hot starting, presented until the idle mode, but also for dry motoring.

5. Conclusions

The paper achieved a general starting sequence, of a classical gas turbine engine, which is not equipped with an electronic control unit, and which is run into a test bench. To start the engine and to have an automatic control it is used an operating system with an acquisition unit and a programmable logic controller in which it is performed a logical algorithm to execute the starting phase. The structure of the starting phase is presented into a general logic sequence diagram based on the engine starting procedure and engine instrumentation scheme. The structure of starting sequence is available and adaptable for any type of engine and for different types of starting mode as dry motoring, wet motoring and hot start. The starting sequence contains the steps of the starting phase, detailing the time of acting commands, confirmations and protections to evaluate the engine into a safe mode starting proccess. Generally the logic sequence is made according to time and/or starting engine shaft speed. At different time values and speed, depending on which starting mode was selected, the programmable controller sends signals to the different engine commands to perform the selected starting type. The logical starting sequence is converted into a programmable logical algorithm written as a software programme into the programmable controller to launch the sequence of the starting type that the operator has selected.

In conclusion the starting sequences presented above can be applied and adapted for different types of engine. Every engine sets up proper parameters and actual commands that are used in starting mode, necessary to create the software which execute the new starting sequence.

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