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(54) A GAS TURBINE ENGINE CONTROL SYSTEM

(71) We, GENERAL ELECTRIC COMPANY, a corporation organised and existing under the laws of the State of New York, United States of America, residing at 1, River Road, Schenectady, 12305 State of New York, United States of America,

do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a control system for a gas turbine engine.

Gas turbine engine control systems particularly for use in aircraft generally include electrical sensors which measure various engine performance parameters. Such sensors have typically measured gas generator and fan rotational velocities and engine operating and engine operating pressures and temperatures. These, in turn, are used to control the position of the actuators which vary engine controlled parameters, typically fuel flow and geometry. In conventional engine control systems the engine performance parameter sensors and sensors indicating the value of controlled parameters are connected by electrical cables to the electronic computation sections of the engine control system. The electronic computation section may be analog in which dedicated circuits perform continuous computations or it may be digital in which computations are performed sequentially on a time-sharing basis. In either case, the computational unit of the control using the sensed values for performance and controlled parameters and known engine behavior characteristics computes values of control signals to modify the controlled parameters in order to maintain a desired level of engine performance. The electrical outputs from the computation section are amplified, conditioned and then input to the various electrohydraulic and electromechanical actuators which position the electrically controlled fuel and hydraulic valves which alter the controlled parameters. These in turn modify engine operation which change the measured performance parameters, i.e. engine rotational velocity, pressures, and temperatures, thereby completing closed loop control of the engine.

A major problem associated with such prior art control systems is that loss of the proper input from one or more sensors may cause loss of control of the corresponding engine parameter resulting in major degradation of engine performance. Such signal loss may be due to any number of factors including failure of the sensor, failure of the interconnection between the sensor and control or failure of any of the processing circuitry for such signals.

Accordingly, it is an object of this invention to provide a control system for gas turbine engines which prevents major degradation of engine performance in the event of loss of the proper signal from the engine performance parameter sensors.

Accordingly the invention provides a gas turbine engine control system including sensor means for sensing actual engine performance parameters and actual engine controlled parameter, control computational means for generating control signals, actuator means for receiving said control signals and for modifying the controlled parameters in order to maintain a selected level of engine performance, and computer means disposed between said sensor means and said control computational means for receiving signals from said sensor means and for generating signals representing estimates of said actual engine performance parameters, while said engine is in operation, said estimate signals being transmitted to said engine control computational means.

In a preferred embodiment of the invention, a small digital computer is provided between the input sensors which measure engine performance parameters and the computational unit which computes values of output signals to the actuators which control engine controlled parameters such as fuel flow, and geometry. The digital computer includes a stored program which models the engine being controlled and which is continually updated by the signals received from the performance parameter sensors and signals received from sensors for the controlled parameters. The computer in turn uses these inputs, the model and stored data items representing estimates of the internal status of the engine to generate engine performance signals for transmittal to the control computational unit. These signals represent the models estimate of the actual value of the control parameter sensor signals input to the computer and are continuously updated by received performance and controlled parameter sensor signals. The computer continuously compares each engine performance parameter sensor input with the corresponding output to the control computational unit and in the event a difference exceeding stored or calculated tolerances is detected that engine performance parameter sensor is inhibited from updating the engine model. However, the loss of an engine performance parameter sensor input does not significantly degrade engine performance, since the computer continues to provide output signals corresponding to the inhibited input sensor signal. This output represents the computers best estimate of the value of the inhibited input signal which is calculated using the stored engine model updated by the remaining uninhibited performance parameter input signals and by the controlled parameter input signals. An indication that a particular performance parameter sensor input signal has been interrupted may be provided to the engine operator through an engine operator interface circuit. The control system of this invention thus permits continued operation of the engine control without major performance degradation, even though one or more performance parameter sensor signals is not properly received.

Further, because the model uses the interaction between the various performance parameters to compute the value of a signal parameter, spurious error or small inaccuracies in measured parameters is minimized such that when no sensors are inhibited the value of the performance parameters input from the computer are more accurate than those input directly from the individual performance sensors.

When used with a control system incorporating a digital computer, the system may be integrated into the control without the need of separate computer components. The system may also be added to an existing analog or other electrical control as an interconnection between engine performance sensors and the control computational unit.

The invention may be better understood by reading the following description of the preferred embodiment in conjunction with the accompanying drawings wherein:

Figure 1 is a schematic diagram in block format of the control system of this invention.

Figure 2 is a computer flow diagram of a control program for the control system of this invention.

Referring to Figure 1 there is shown a control system for a gas turbine engine 10.

Gas turbine engine 10 may be of any type known in the art including a turbojet, turboprop, turboshaft, or high or low bypass turbofan. All such engines generally include a plurality of sensors 12 used to measure values of engine performance parameters, for example gas generator and fan rotational velocity. A plurality of sensors 13 is also provided to measure the value of the controlled parameters, for example fuel flow and geometry.

The signals output from the sensors 12 and 13 are input to signal processing amplifiers and digital to analog converters 16 which amplify the signals to a standard DC analog voltage range and thereafter converts these analog signals to a digital format. The digital control signals are then input to a failure indication and corrective action means consisting of digital computer 18 through the input/output unit 20 thereof. Digital computer 20 is of the type well-known in the art which includes an input/output unit 20 for external interface, an arithmetic unit 22 for performing arithmetic calculations and a programmable memory 24 for storing programs, information and data. In accordance with this invention, the program memory 24 includes an engine model which simulates the performance of the gas turbine engine 10. Such models are well-known in the gas turbine engine art and generally comprise a set of mathematical equations defining the interrelationship between the engine performance parameters typically the pressures and temperatures of the various engine components as a function of the value of controlled parameters typically engine fuel flow and geometry (e.g. inlet and exhaust area) and the internal status of the engine. Thus, for any given set of controlled parameter conditions, the model will provide values for engine performance parameters and vice versa.

The program memory 24 also includes an operational program to control data processing. Referring to Figure 2, therein is shown a flow chart for the operational program. After an initialization in which initial values for both performance and controlled parameters are preset into the computer, the operational program continually receives the values of input signals from the sensors 13 which are input to the engine model. The engine model uses the controlled parameter values plus the stored data representing estimates of the internal status of the engine to compute corresponding values for the performance parameters. These calculated (or estimated) performance parameter values are then input to the control computational unit which uses them and the controlled parameter values from the sensor 13 to calculate control signals for positioning the actuators 14. The calculated (or estimated) performance parameter values are also compared with the actual performance parameter values received from the engine sensors 12 and their difference calculated. If this difference exceeds a tolerance, which may either be stored or calculated as a function of other sensed engine performance or controlled parameters, the control program takes action (as will be described below) to prevent the out of tolerance inputs from further updating the model. The control program may also output a signal to the engine operator indicating that an out of tolerance sensor signal has been received and that sensor has been inhibited from updating the engine model.

The engine model is updated by changing the stored data representing estimates of the internal status of the engine as a function of the difference between the calculated input performance parameter values and those corresponding actual performance values input from the engine sensors 13. Thus, for each performance parameter difference computed, a corresponding change is made to each stored data item representing an estimate of the internal status of the engine which is affected by that parameter. If the performance parameter has been inhibited then no corresponding changes are made to the data items affected by that parameter. Further, for greater accuracy of response, the magnitude of the change to each stored data item representing an estimate of the internal status of the engine may be weighted so as to be proportional to the degree of control the sensed performance parameter has over that data item as compared with the degree of control the remaining performance parameters have over that data item.

The calulated values for the performance parameter sensors are output by the computer to the control computational unit 26. The control computational unit 26 is of the type well-known in the art which may be digital or analog. If analog, a digital to analog converter (not shown) must be provided between the computer 18 and computational unit 26. The computational unit in the manner well-known in the gas turbine control art uses signals representing the engine performance parameters and controlled parameters and known engine behavior characteristics, which are generally stored as analog algorithms or digital data, to compute values of control signals to position the engine electromechanical and electrohydraulic actuators 14 in order to maintain a desired engine performance level. Suitable amplifiers and digital to analog converters 28 are provided intermediate the control computational unit and actuators 14, in order to condition and/or convert the signals input from the control computational unit to the standard voltage range required to operate actuators 14.

The signal processing amplifiers and analog to digital converters 16, digital computer 18, control computational unit 26, signal processing amplifiers and digital to analog converters 28 are all commercially available devices well-known in the art, the details of which do not form a part of this invention.

In this manner, the control system of this invention permits continued operation of the engine control without major performance degradation even though one or more performance parameters sensors inputs are lost.

Various changes could be made to the digital control system as shown in Figures 1 and 2 without departing from the scope of this invention. Thus, if this system is used with a digital control the logic described herein may be programmed and integrated therein without the need of separate computer components. Alternatively, this system may be applied following a sensor failure in a control system in which direct sensor input to the control computational unit is used. In this case, the failed sensor signal will be supplied by the engine model.

WHAT WE CLAIM IS:—

1. A gas turbine engine control system including sensor means for sensing actual engine performance parameters and actual engine controlled parameters, control computational means for generating control signals, actuator means for receiving said control signals and for modifying the controlled parameters in order to maintain a selected level of engine performance, and computer means disposed between said sensor means and said control computational means for receiving signals from said sensor means and for generating signals representing estimates of said actual engine performance parameters while said engine is in operation, said estimate signals being transmitted to said engine control computational means.

2. The control system of Claim 1 wherein said computer means includes an engine model for simulating the performance of the engine including the interrelationships between the engine performance parameters and the engine controlled parameters and for generating said estimate signals, and means for comparing said actual sensor signals with said estimate signals and for generating difference signals corresponding to the differences between said compared signals; changing said model in response to said signals, and comparing each of said difference signals with tolerance limits and for preventing a change being made to said model in response to difference signals which exceed said tolerance limits.

3. The control system of Claim 2 wherein the magnitude of the change to said engine model produced by each difference signal is proportional to the degree of control that the engine parameter corresponding to the difference signal has over said engine model as compared with the degree of control that remaining engine parameters have over said engine model.

4. The control system of Claim 3 wherein said tolerance limits are predetermined fixed values.

5. The control system of Claim 2 wherein said computer means also provides an indication to an engine operator when any of said difference signals exceeds said tolerance limits.

6. The control system of Claim 5 wherein said computer means is comprised of a programmed digital computer.

7. A gas turbine engine control system in accordance with claim 1 including sensor means for sensing actual engine performance parameters and actual engine controlled parameters, control computational means for generating control signals, actuator means for receiving said control signals and for modifying the controlled parameters in order to maintain a selected level of engine performance, and computer means disposed between said sensor means and said control computational means for receiving signals from said sensor means, for receiving said control signals, and for generating signals representing real time estimates of said actual engine performance parameters and of said actual engine controlled parameters while said engine is in operation, said estimate signals being transmitted to said engine control computational means.

8. The control system of Claim 7 wherein said means disposed between said sensor means and said control computational means includes; an engine model for simulating the performance of the gas turbine engine including the interrelationships between the engine performance parameters and the engine controlled parameters and for generating said estimate signals; first comparison means for comparing said actual sensor signals with said estimate signals and for generating difference signals corresponding to the differences between said compared signals, model updating means for changing said model in response to said difference signals, and second comparison means for comparing each of said difference signals with tolerance limits and for inhibiting said model updating means from modifying said model in response to difference signals which exceed said tolerance limits.

9. The control system of Claim 8 wherein said second comparison means also provides an indication to an engine operator when any of said difference signals exceeds said tolerance limits.

10. The control system of Claim 9 wherein said computer means is comprised of a programmed digital computor.

11. The control system of Claim 7 in which at least one of said estimate signals is representative of fuel flow to said engine.

12. The control system of Claim 7 in which at least one of said estimate signals is representative of the rotational velocity of the gas generator or fan.

13. The control system of Claim 7 in which at least one of said estimate signals is representative of engine geometry.

14. A control system substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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1597129 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

Fig 1

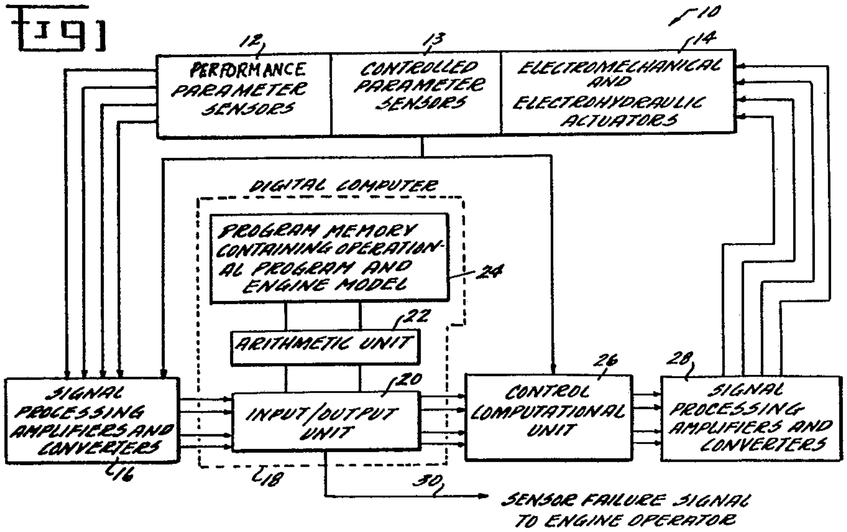

Fig 2