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STOCHASTIC CONTROL INFORMATION SYSTEMS THE AVIATION GAS TURBINE ENGINE

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Abstract

Development of a robust system for the detection of self-tuning parameter regulator in automatic control system gas turbine engines (ACS GTE) will benefit both military and civil aviation through improved aircraft reliability and maintainability. Presented is a gas turbine engine stochastic information system that integrates information from various advanced control analysis techniques to achieve robust self-tuning loop awareness. This paper presents the computational techniques for identifying the accurate sequence parameter regulator by using: firstly, the Lyapunov function application with the performance analyzer for ensuring the stability of optimization processes; secondly, the Wiener-Hoph function application with the white noise generator (random processes) for defining the intensity and impulse transition function of the signal, as a result, accurate set up of the aviation engine control unit. The main control loop is represented by a transfer function of the object and the regulator, their self-tuning models, criteria for setting regulator parameters and sensitive function. An important feature of the information system GTE is the presence of heterogenous hardware and software, which is often associated with a long period of taking system into operation, it is necessary to use the portable serving device and request host for satisfying the requirements of the correct engine operation.

Keywords: self-tuning; gas turbine engine; stochastic processes, sequence net request

1. Introduction

The intensive expansion the areas of informatization and the implementation of digital technologies in the functioning processes of the aircraft engine building industry is one of the actual and intensively embodied directions of scientific and technological progress in many leading countries of the world [1,2]. The complexity of the industry-specific tasks of the automatic control system for gas turbine engines (ACS GTE) leads to the widespread introduction of highly efficient control information systems that ensure the collection and processing of the entire spectrum of information and the development of optimal solutions. Given a wide range of native and foreign developments in the field of creating distributed information systems [2, 3], this scientific and technical problem is far from exhausted and today it reaches a new level in the content and complexity of interdisciplinary production tasks. A further increase in the effectiveness of information systems is associated with a qualitative increase in their high technology in terms of using the most modern methods of system analysis and optimization of distributed control systems (DIS) the GTE, as well as innovative technologies for converting, transmitting and storing information in the concepts of their synthesis. The tasks are set to flexibly link developments to standards in the field of aircraft engine building and computerization, to a compromise in terms of technological and economic requirements for the coverage of functions, work processes of computerized ACS GTE, and to a balanced approach to the formation of a set of applied methods of computer-mathematical modelling and IT technologies. The key tasks in the further analysis of the problem under consideration are related to the methodologies of processing and intellectual analysis of large arrays of heterogeneous fuzzy information, insufficient systematization and structure of data, issues of standardization of electronic representations and interaction of information resources. The methodology of organizing the information space of the designed systems in the form of an integrated set of local databases that accumulate and provide storage of information, which predetermines the configuration of the entire control system in the form of a set of interacting local information subsystems with client request, requires further development.

On the other hand, automatic control systems of

GTE with self-tuning regulators are nonlinear systems in which the issues of stability are not fully resolved due to the complexity of the analytical description of systems. By the way, there are researches of eminent scientists in the area of development the self-tuning information systems Roger Dixon, Scott Herber, Pete Bradly, Hong Yue, Georgi Dimirovsky, O.S. Gurevich, Laine Campbell, Kenneth P. Birman, Andrew S.Tanenbaum and international enterprises Aerospace testing international, Inside HPC, AVIC Shenyang Engine Design, SKY brary, Flight Control System, according to the standards of EUROCAE [1-3], ICAO, EASA and many others.

The goal of this research is define the techniques for the self-tuning parameter regulator in automatic control system gas turbine engine and for making a right choice to build a communication system that reduce the load of net, speed up the delivery of transmitted messages and increase the reliability of connections.

2. Stochastic Distributed Control System the Aviation Engine

Solving the problem of control a gas turbine engine (GTE) requires the collection, processing and storage of large amounts of data, the exchange of information between the operating units, between the systems and subsystems of the GTE, solving complex computational problems. To solve the problems of GTE control, it is necessary to create a specialized information system that allows to apply the tools of computer engineering and modern computational and mathematical methods.

The considered system (Fig. 1) is intended for complex solution of control problems the ACS GTE, which includes: planning, organization, availability, coordination, control, analysis, estimation of efficiency, decision making, selection of system elements, optimization of individual operation, presentation and interaction (integration) with other subsystems. Obviously, these tasks are inextricably linked and must be addressed in light of their specificities and capabilities of the engine.

In general, the information system should provide the following basic tasks:

- **motion control of sensors**: provides registration of all movements of sensors between GTE subsystems and on the basis of these data allows to generate daily reporting and statistical information.

- **creation and storage of statistics**: automation of statistical services, as well as storage of archival information (history of defects of replaced nodes) and prompt access to this information for the purpose of its use in statistical scientific researches.

- **diagnostic unit control**: automation of the working registration nodes, which are defined in the database of the system and provide the output of the technical characteristics of the GTE.

- **active workplace control (control unit)**: provides quick search of tasks in the system database and displays the automated workstation, full or selective, depending on the information security settings, the amount of data related to the defect of a particular node.

- **operating unit control**: automation of planning and preparation of scheduled maintenance and repair, as well as storage of information for analysis of the functioning the ACS GTE and operational access to this information from different subsystems.

- **instrumental research control**: provides automated reporting of instrumental research results, including the effectiveness of these results directly with instrumental equipment.

- **verification unit control**: provides automated documentation of the results of verification investigations, including the reading of these results directly with the equipment.

- **GTE subsystems control**: automation of the whole technological cycle of subsystem work, from the moment of registration of input information to determination of information on the results of subsystems functioning.

- **GTE subsystem reality control**: automation of ACS GTE subsystem traffic accounting.

- **reality control**: automation of the process of receiving information (traffic) from external sources, forming requirements for sending messages.

- **control of state maps**: automation of formation and registration of state maps.

- **control of the GTE nodes**: determination of fast searching of the GDD node request in the database and displaying the volume of information of a specific node.

- **control of telecommunication systems**: automation ZigBee instrumental research registration, video monitoring.

For ensuring the solutions of the listed information system (IS) tasks, the ACS GTE should be able to collect and process information from remote subsystem nodes, each of which performs its specific functions.

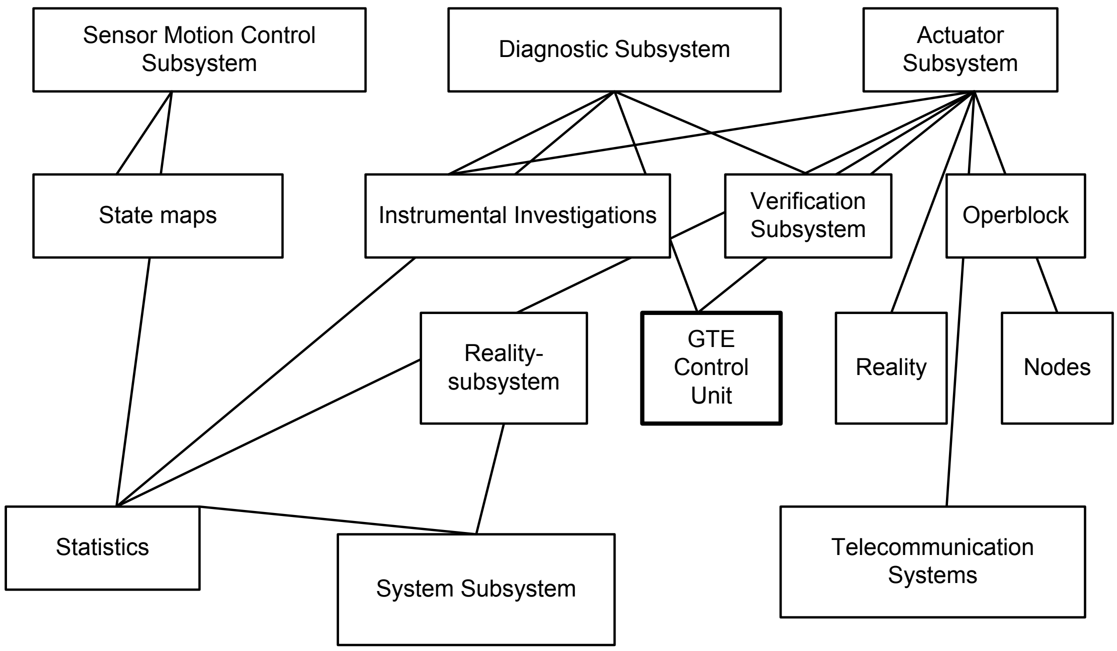

Fig. 1. Structure diagram of the GTE system

2.1. GTE Control Unit Set Up

In stochastic optimization method for the regulator parameter set up solves the system of equations [4]:

$$\dot{\beta}_i(t) = k(t)\left[J_{st}(\dot{\beta}_i, t) - J_{st}(\beta_i, t) + n(t)\right] \quad i = 1, r, \quad (1)$$

where $n(t)$ is the measurement error caused by hindrance; r is a set up parameters number; $k(t)$ is some variable coefficient.

During the usage of the gradient equation method, that determine the settings of the regulator are recorded relatively private derivative of a quality indicator:

$$\dot{\beta}_i \approx \pm k(t)\frac{\partial J_{st}(\beta_i, t)}{\partial \beta_i} + n(t), \quad (2)$$

where the sign "+" is accepted if J_{st} has max, "-" if J_{st} has min.

The coefficient $k(t)$ must satisfy conditions similar to (1). If the self-tuning criterion is given as an integral of the error square $\varepsilon(\overline{\beta}, t)$ discrepancies between the desired signal $y_{in}(t)$ and the real $y(t)$, then the equation that determines the parameter set up is:

$$\dot{\beta}_i \approx \pm k\left[-2\int_{t_i}^{t_i+T_i} \varepsilon(\overline{\beta}, t)\frac{\partial y(\overline{\beta}, t)}{\partial \beta_i}dt\right], \quad (3)$$

where T_i is the interval of quasi-stationary parameters of the regulator.

Application the Lyapunov functions allows to solve the problem of ensuring stability of self-tuning or optimization processes self-tuning processes according to a given quality criterion. Usually, Lyapunov function is constructed in the form of a quadratic positive a certain form [4, 5]:

$$V = \overline{X}^T P \overline{X} + C^T(t) \wedge C(t), \quad (4)$$

where $\overline{X}$ is the state vector of the control object; P is symmetric positive definite matrix; $C^T(t)$ is the vector of variables in time coefficients associated with custom parameters; $\wedge = diag\lambda_i$ is diagonal matrix of constant coefficients $\lambda_i > 0$.

In the case when the law of change of the self-tuning parameters $\beta_i(t)$ is determined only from the conditions of stability of self-tuning processes, the derivative of the Lyapunov function is calculated, which should be negative definite $(\dot{V} < 0)$ and on this condition system of differential equations is form, whose solution allows determine the setting of the regulator parameters.

It should be noted that the considered tasks demonstrate the complexity of the self-tuning procedure (Fig. 3), related to computational operations requiring a certain time.

An example of an adaptive control system, where for self-tuning a performance analyzer [5] was used, shown in Fig. 2.

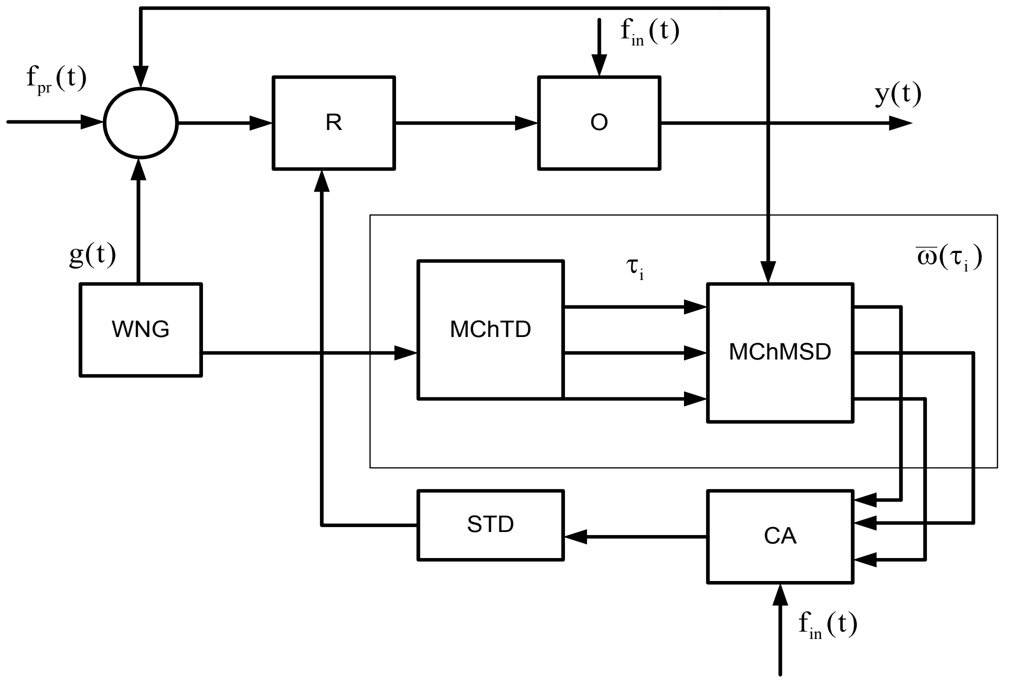

Fig. 2. Adaptive system with characteristic analyzer

The analyzed characteristic is a impulse transition function $\overline{\omega}(t)$, on the basis of which the self-tuning criterion is calculated $J_{ST}(\overline{\omega}(t))$ and then the correction signals for regulator tuning are determined. For determine $\overline{\omega}(t)$, an identification method is used based on the analysis of random processes such as "white noise". If random processes are stationary, then to determine $\overline{\omega}(t)$ can be used the Wiener-Hopf equation. At input random signal $g(t)$ of the type of "white noise" the correlation function $R_g(\tau)=\Phi_0\delta(\tau)$ has the form of a δ-function and the Wiener-Hopf equation go into equality:

$$R_{yg}(\tau)=\Phi_0\overline{\omega}(\tau), \quad (5)$$

where Φ_0 is the intensity of white noise. In accordance with (5) $\overline{\omega}(t)$ is determined by the mutual correlation function $R_{yg}(t)$. Therefore self-tuning contour has a generator of "white noise" (WNG), multi-channel time delay (MChTD), multi-channel multiplier and summing device (MChMSD), the analyzer of characteristics (CA) and self-tuning device (STD).

Building a self-tuning loop based on (5) provides for the introduction of a source of white noise WNG. CA structure determined by type of criterion J_{ST} and shape $\overline{\omega}(t)$.

Application of the model in adaptive control systems is very common, and the purpose of their use is very diverse. So, on fig. 3 is an example of an adaptive system in which there are two system models. One reference with W_{em} transfer function used to determine the desired quality of the system, and another with parameters self-tuning for the current system for determining the sensitivity functions of varying parameters, necessary for the implementation of the self-tuning procedure.

The main control loop is represented by a transfer function of the object $W_{ob}(s)$ and the regulator $W_R(s)$, self-tuning model contains transfer functions of the object model $W^M{}_{ob}(s)$ and regulator $W^M{}_R(s)$. J_0 is criterion for setting regulator parameters β_i. $\frac{\partial W_R(s)}{\partial \beta_1}$ is sensitivity functions according to the parameters of the regulator. Adaptive system operate on the basis of the gradient method using working signals. According to the gradient method, the regulator parameters are determined based on the expression:

$$\beta_i=\beta_i(0)-k\int_0^t \frac{\partial}{\partial \beta_i} J(\varepsilon,\overline{\beta},t)dt \quad . \quad (6)$$

Obviously:

$$\frac{\partial J}{\partial \beta_i}=\frac{dJ}{d\varepsilon}\frac{\partial \varepsilon(\overline{\beta},t)}{\partial \beta_i}=-\frac{dJ}{d\varepsilon}\frac{\partial y(t,\overline{\beta})}{\partial \beta_i}. \quad (7)$$

By usage the simple transformations, can be shown that

$$\frac{\partial y(s)}{\partial \beta_i} = G(s)\frac{\partial}{\partial \beta_i}\left[W(s)\right] = G(s)\frac{1}{1+W_R W_{ob}} \times \times \frac{W^M{}_{ob}}{1+W^M{}_R W^M{}_{ob}}\frac{\partial}{\partial \beta_i} W_R\left(\overline{\beta}, s\right). \quad (8)$$

The last expression explains the construction of the structural diagram of the whole systems and the principle of its operation.

In a number of articles, much attention is paid to the problem of synthesis adaptive tuning algorithms: determining the form of analytical expressions of the adaptation law and analytical proof of AACS stability properties. In this thesis, a number of basic schemes were considered adaptive control: adaptive control with a reference model for state [6,7], adaptive control with a reference model in output using the extended error signal [8], adaptive systems with an implicit reference model [6,8] and adaptive observers [9].

Some papers [4, 6, 8] propose an approach to solving the problem building adaptive systems for object control where not all object parameters are known. Dynamic objects class is considered, whose mathematical description is:

$$\dot{x} = f(x) + W(x,t)^T \theta + g(x)u + \delta(t)$$
$$y = h(x), \quad (9)$$

where $W(x,t)$ is the known matrix function; $\delta(t)$ - uncontrolled external disturbance; θ - unknown parameters.

Such a model is shown in fig. 3.

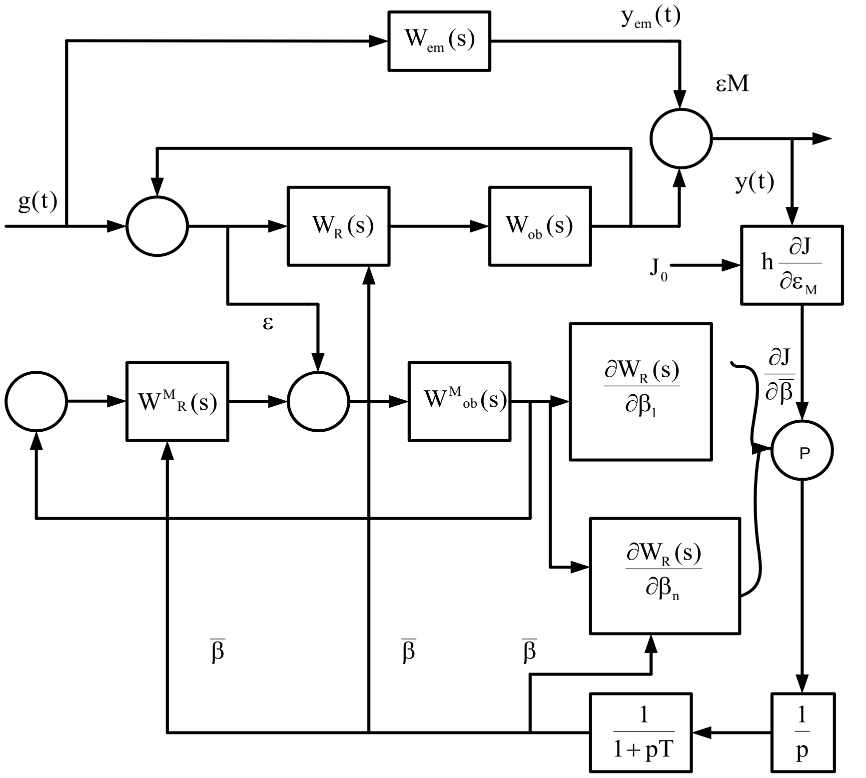

Fig. 3. Adaptive system with self-tuning model

The purpose of the synthesis is to provide the conditions:

$$\lim_{t\to\infty} Q(x,t) = 0, \quad (10)$$

where $Q \geq 0$ is the minimized aim function. Control law defined as: $u = U\left(y, \hat{\theta}, t\right)$ and unknown parameters are determined from the definition:

$$\dot{\hat{\theta}} = \Theta(y,t),$$

where $\hat{\theta}$ is an estimate of the vector θ obtained during the functioning of a closed system; Θ is set up function.

2.2. Self-Tuning Net Technology for Engine Information System

An important feature of the IS ACS GTE is the presence of heterogeneous hardware and software (heterogeneity), which is often associated with a long period of putting the system into operation (in parts), periodic (spontaneous) financing, and many other factors. This necessitates the use of such technologies for organizing work in the system that would provide users with access to local information resources regardless of the hardware and software platforms on which they are installed, and application software developers can be portable and run on various platforms.

At present, there is an effective and well-practiced approach to building such systems, which allows satisfying user requests and the needs of applied programmers, this is the use of -server technology, network technologies, and database technology [8, 9].

Massive service systems (MSS) were selected as mathematical models for the analysis of the system's operating modes in operation, which is due, firstly, to a wide experience of their application for the analysis of various information processing systems, and, secondly, to a sufficient variety of different types of MSS, which makes it possible to select models the most adequate in each specific case and, thirdly, by a deep study of the analysis methods of the selected MSSs to obtain practically useful results [9].

The considered system consists of one serving device (SD) and N hosts, request sources. Hosts form requests for service at the SD. In this case, the application server corresponds to the serving device.

All messages received from host create a common queue and are served in the order received.

A host spends a certain time to form and send a request, the duration of which is a random variable $\gamma > 0$ with a distribution function $G(t) = 1 - e^{-\gamma t}$, the same for all clients.

All requests await service on the DS in the general queue and are served in the order they are received in the queue.

The duration of the request service, in the case when n requests are in service at the DS, can be considered a random variable $\beta(n)$ with a distribution function $B(t,n)$, where n is the number of requests already served on the server (DS). Here, the need to take into account the number of serviced requests n is due to the fact that in practice multitask servers are used and server performance depends on the value of n. The maximum number of requests that can be simultaneously served by the server (multitasking coefficient) is K, i.e. on a SD model there can be at most K requests at a time.

All random variables have finite first and second moments:

$$0 < b_1(n) = \int_0^\infty t dB(t,n),$$
$$0 < b_2(n) = \int_0^\infty t^2 dB(t,n) < \infty. \quad (11)$$

All hosts work independently of each other, requests are not lost and can wait for service for as long as necessary, the service device does not stop if there are requests ready for service in the queue (Fig. 4).

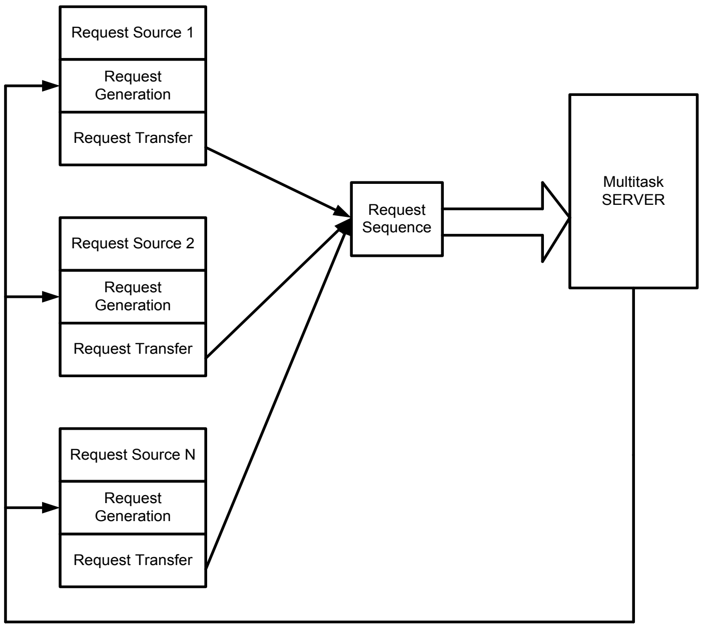

Fig. 4. Request processing diagram

Served requests instantly leave the DS and return to the hosts that created them, where they are delayed for a time determined by a random value γ, after which they again enter the service queue. Fig. 4 shows the request processing diagram.

A wireless network model based on the star topology in NetCracker software was created to investigate the organization (adaptive request processing) of the aviation engine automatic control system (Fig. 5).

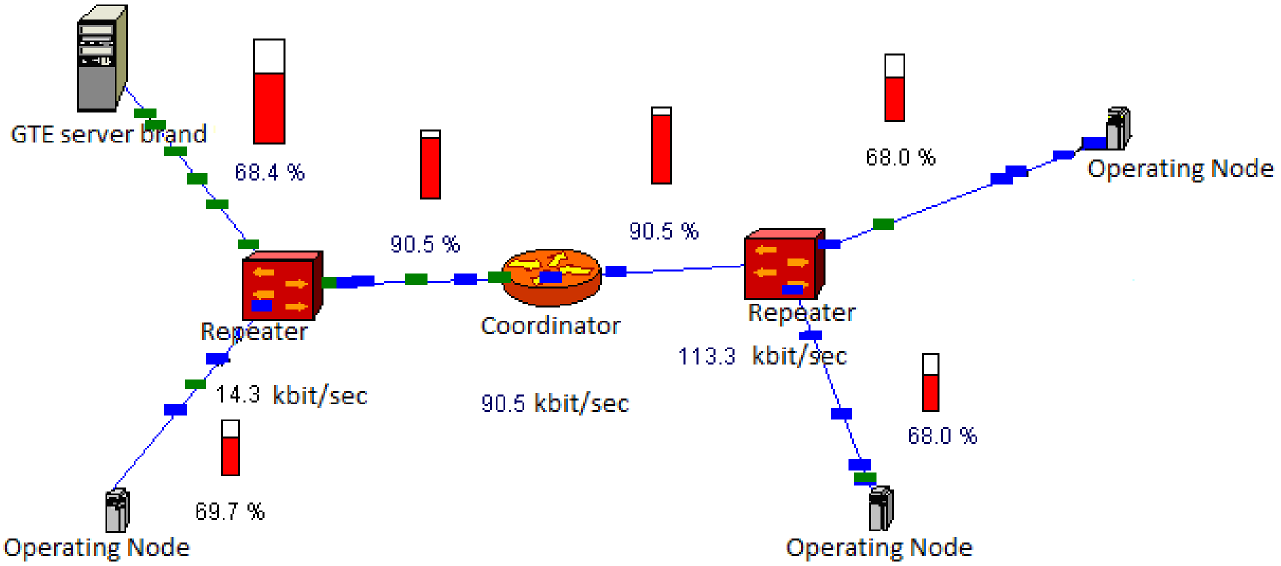

Fig. 5. Modeling of receiving and transmitting GTE net path

As network hosts, 3 IEEE 802.15.4 ACS GTE nodes were used [10]. For the server special software is selected to support SQL server's host traffic. Repeater and PAN-Coordinator are used to connect operating nodes and servers. The maximum network load is about 88%.

3. Conclusions

As part of this work, conventional and new information processing techniques were combined in different ways to design stochastic control information system the aviation gas turbine engine. These methods were applied to data collected from request source node to GTE control unit and seeded self-tuning tests to verify the efficacy of the integrated techniques.

The proposed GTE information system sequence tasks are able to collect and process information from remote subsystem nodes in a power signal with a very high accuracy. The accuracy of the proposed GTE control unit set up has been verified by tests conducted to a computer-simulated signal and a field signal. Two techniques are adopted to achieve accurate self-tuning regulators.

Firstly, characteristic analyzer is used for the determine the setting of the regulator parameters by the Lyapunov function application that allows to solve the problem of ensuring stability the optimization processes and constructed in the form of the state vector of the control object, symmetric positive definite matrix, the vector of variables in time coefficients, diagonal matrix of constant coefficients.

Secondly, the self-tuning model is used an identification method based on the analysis of random processes with the Wiener-Hopf equation that allows to determine the intensity of white noise and impulse transition function. Therefore, the control loop regulator is represented by white noise generator, multi-channel time delay, multi-channel multiplier and summing device, performance analyzer and self-tuning device. According to the definition of transfer function and sensitive functions, the simple expression transformation of regulator explains the construction and structural diagram of the whole GTE stochastic information system.

It is concluded that for designing the engine information system, it is important to make a right choice of the solutions used to build a telecommunication system (network technologies) that provides information interaction between system elements and users. Here it is necessary to define the network structure, the network software used, the protocols of different levels, the network hardware.

Solving these problems will reduce the load of communication channels, reduce network traffic, speed up the delivery of transmitted messages and increase the reliability of connections.

Also can be identified the main problems that need to be solved for design the define systems:

1) organization the interaction using host-server technology;

2) organization the communication service of the system with the use of network technologies - creation of a calculated network the information system;

3) formation and organization the operation of the integrated database system of the information system.

Solving these problems allows you to formulate requirements for application and system software that has been considered in this paper as a interaction between serving device and request host sources by implementation of the network model GTE control unit receiving and transmitting GTE path with the load of 88%.

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С.С. Товкач

Стохастичні інформаційні системи керування авіаційним газотурбінним двигуном

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Розробка надійної системи визначення самоналаштовуваних параметрів регулятора в автоматичних системах керування газотурбінними двигунами (САК ГТД) принесе користь як військовій, так і цивільній авіації за рахунок підвищення надійності та ремонтопридатності повітряного судна. Представлена стохастична інформаційна система газотурбінного двигуна, яка об’єднує інформацію з різних сучасних методів аналізу керування для досягнення надійної поінформованості контуру самоналаштовування. У статті представлені обчислювальні методи ідентифікації точної послідовності параметрів регулятора за допомогою: по-перше, застосування функції Ляпунова з аналізатором характеристик для забезпечення стабільності процесів оптимізації; по-друге, застосування функції Вінера-Хопфа з генератором білого шуму (випадкові процеси) для визначення інтенсивності та імпульсної перехідної функції сигналу, як результат, точного налаштування блоку управління авіаційним двигуном. Основний контур керування представлений передавальною функцією об'єкта та регулятора, їх моделями самоналаштовування, критеріями встановлення параметрів регулятора та чутливою функцією. Важливою особливістю інформаційної системи газотурбінного двигуна є наявність неоднорідного апаратного та програмного забезпечення, яке часто пов'язане з тривалим періодом підтримування експлуатації системи, необхідно використовувати мобільний обслуговуючий пристрій і хост запиту для задоволення вимог правильної експлуатації двигуна.

Ключові слова: самоналаштовування; газотурбінний двигун; стохастичні процеси; послідовність мережевого запиту

С.С. Товкач

Стохастические информационные системы управления авиационным газотурбинным двигателем

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Разработка надежной системы обнаружения самонастраивающихся параметров регулятора в системе автоматического управления газотурбинными двигателями (САУ ГТД) принесет пользу как военной, так и гражданской авиации за счет повышения надежности и ремонтопригодности воздушного судна. Представлена стохастическая информационная система газотурбинного двигателя, которая объединяет информацию из различных современных методов анализа управления для достижения надежного самонастраивающегося контура. В данной статье представлены вычислительные методы для идентификации точной регулятора последовательности параметров с использованием: во-первых, применением функции Ляпунова с анализатором характеристик для обеспечения стабильности процессов оптимизации; во-вторых, применением функции Винера-Хопфа с генератором белого шума (случайные процессы) для определения интенсивности и импульсной переходной функции сигнала, в результате чего выполняется точная настройка блока управления авиационным двигателем. Основной контур управления представлен передаточной функцией объекта и регулятора, их самонастраивающимися моделями, критериями настройки параметров регулятора и чувствительной функцией. Важной особенностью информационной системы газотурбинного двигтеля является наличие разнородного аппаратного и программного обеспечения, что часто связано с длительным периодом ввода системы в эксплуатацию, необходимо использовать мобильное обслуживающее устройство и хост запроса для удовлетворения требований правильной работы двигателя.

Ключевые слова: самонастройка; газотурбинный двигатель; случайные процессы; последовательность сетевого запроса

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