

TRANSPORT SYSTEMS

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O. V. Zuiev

GROUND RADIO NAVIGATION SYSTEMS MAINTENANCE PROCESSES IMPROVEMENT

Aviation Radio Electronic Complexes Department, National Aviation University, Kyiv, Ukraine
E-mail: zujew@mail.ru

Abstract—The modern ground Radio Navigation Systems for air traffic service are analyzed. Recommendations about possible variants of those systems maintenance processes improvement are proposed. Interconnection between control errors, control completeness, probabilities of failure-free operation and its indexes total influence on the Radio Navigation Systems technical state control veracity are investigated.

Index Terms—Radio Navigation Systems; operation system; maintenance processes; adaptive operation; technical state; control veracity.

I. INTRODUCTION

Radio Navigation Systems (RNS) are widely used for Air Traffic Service (ATS) systems. The modern RNS includes in its structure different electronic equipment. For all RNS types the next blocks are typical: power-generating set, antennas devices, power suppliers block, transceiver, navigation parameters sensors, technical state (TS) definition sensors, control system computer, measuring devices and calculating system for information processing and transmission on the control channel. The technical state of the difficult modern RNS is characterized by the set of the determinative parameters (DP) which have difficult physical nature.

The operation systems (OS) includes RNS (operation object), processes, performers, documentation, control-measuring equipment, technologies etc. [1]. The structure of OS may be based on the implementation of systematic approach. These processes must be implemented in controlled conditions, which provides the regulation realization of separate means parameters and components of their OS. Such operation strategy is being an adaptive approach to control of exploitation processes. It is necessary to implement the next steps, with purpose to realize the adaptive exploitation: to determine the main factors, which is preferably to take into account for the adaptive exploitation realization; to determine the main OS functions of RNS; to justify the basic actions and operations, which is necessary to implement during the exploitation (control, regulation etc.); to analyze schemes of informational interaction of separate elements of OS; to consider the probable variants of efficiency estimation in case of adaptive operation usage.

The maintenance (M) is one of the OS basic components. In general, the complex of control effects on the RNS is executed by the M systems. Maintenance systems contain such basic constituents as M objects (the RNS and devices), organizational elements and their construction, performers, technological processes or separate technologies, means of technological outfit, documentation, consumable and informative resources, etc. Optimization of M processes in total are solved by analytical methods, analytical-calculative methods or methods based on computerized simulation modeling.

II. PROBLEM STATEMENT

Operation system of RNS performs the functions, connected with a control influences about functioning efficiency increasing of this means in the part of providing the necessary levels of reliability indexes. So, as general, the modernization of RNS influences on the efficiency of these means usage, and on providing of flights' safety and regularity. Solving of tasks of creation the new and modernization of old OS can be realized using the theory of project decisions: sufficient efficiency, optimization and adaptability.

Availability of additional details reception about the functional conditions of the system due to the current information usage is being a distinguishing feature of adaptive OS. With the help of adaptive OS can be achieved the next advantages: to have a high flexibility, which allow to change the own parameters; to have a high mobility during the control and regulatory decisions acceptance; to be adequate forward to the current situation; to take into account the requirements of the personnel qualification level; to take into account risks, with

the probable retuning; to take into account factors, connected with the surrounding environment characteristics and so on.

It is necessary to solve the separate optimization problems of maintenance processes development during the adaptive exploitation systems projecting: control of RNS TS; regulation of RNS determinative parameters via control actions realization; prevention changing of RNS blocks, knots and elements.

III. REVIEW

Nowadays there is a gradual changing of old ground RNS on the new ones. In particular, an implementation of Instrumental Landing system, VOR/DME systems, Non Directional Beacons, Directional Finders. The providing of remote control, control of parameters and diagnostic of separate blocks are the main features of new RES. For the realization of those functions, new RES have software complexes. As general, they provide: continuous control of equipment's operation modes, control of basic parameters' state, parameter display in real time or in retrospective on the computer monitor, possibility of install and regulation of basic parameters, possibility of emergency threshold install for the tolerance control equipment, implementation of technical state control procedure; control of current time, date, time of operation; latching and registration of changes and its reasons, which are caused it.

The analysis of publications shows that due to widespread use of navigation systems and complexes attracted the attention of researchers and developers [3] – [5]. Main tasks in this case are: development and improvement of ground navigation equipment with functional capabilities optimization; maintenance processes efficiency increasing in terms of resource costs optimization for ground navigation equipment and its intended use.

IV. PROBLEM SOLUTION

The maintenance (M) is one of the basic OS components. Maintenance is a complex of operations or an operation to keep a device serviceable during its usage, storage and transporting [2]; [3]; [7]; [8]. The process of RNS maintenance belongs to the class of complex systems [2]. The analysis shows, that processes of M have all signs of a complex system. In fact, there is a lot of different elements in such system, which have a single functional aim – radio engineering support of aviation enterprise production activity. Tasks of necessary reliability level provision are solved by means of effective failure prevention and recovery

of failed RNS. Basic stages of solution of the M system structure and parameters optimization problems are :

- investigation of M system, determination of the system composition and features;
- determination of basic models of failures, damages, M operations, operation conditions;
- parameterization of models, the areas of admissible values of parameter models;
- choosing of optimization parameters and objects;
- determination of M systems operation efficiency indexes;
- defining one or a few efficiency criteria for M system operation or an optimization criterion for the system the element considered;
- determination of formulas or algorithms for estimating the M system efficiency indexes ;
- solution of equations for to the optimized parameters or determination of algorithms for finding parameters optimum parameters values.

One of basic directions of the M systems optimization is optimization of technological processes or separate RNS M technological operations. By basic M technological operations are the following:

- control of the RNS technical state;
- the RNS tuning;
- adjusting RNS determining parameters;
- preventive replacement of RNS blocks, units, aggregates;
- cleaning the construction and RNS structural elements.

Among prophylactic actions there is preventive control of RNS technical condition. So, as a result, one can find such elements of RNS which can fail. Then actions like adjustment, tuning or replacement are done. By means of this control one can timely prevent failures.

After failure occurrence recovery of availability is done. The process of availability recovery includes finding of failed elements and failure removal [8].

By the character of its occurrence all failures are divided into sudden and gradual failures. Taking into account the possibility of failure prevention during the preventive operations all RNS failures are divided into preventing and not preventing. So, in general, preventing failures refers to gradual failures and not preventing failures refers to sudden failures.

Ratio between quantity of preventing and not preventing failures is estimated by the coefficient of failure character:

$$A = \frac{n_{pr}(t)}{n_{pr}(t) + n_{npr}(t)},$$

where n_{pr} and n_{npr} the quantity of preventing and not preventing failures in given type of RNS.

Preventive operation quality is estimated by the probability of failure prevention. This probability is ratio between quantity of detected failures and general quantity of preventing failures:

$$P_{pr} = \frac{n_d}{n_{pr}},$$

where n_f is the quantity of detected failures; n_{pr} are general quantity of preventing failures.

Reliability increasing after preventive operations is estimated with the help of index which is called failure prevention efficiency. This index is a ratio between average time of preventive equipment no-failure operation and average time of not preventive equipment no-failure operation:

$$W = \frac{T_{0pr}}{T_0},$$

where T_{0pr} is the average time of preventive equipment no-failure operation; T_0 is the average time of not preventive equipment no-failure operation.

Let's, if RNS operates in the period of normal exploitation then exponential law is correct. Then [5]

$$Q(t) = \frac{n}{N}, \quad Q_{pr}(t) = \frac{n_{pr}}{N},$$

where n , n_{pr} is the failure quantity of preventive and not preventive equipment. Then

$$W = \frac{n}{n_{pr}} = \frac{n}{n - n_d},$$

where n_d is the quantity of detected failures.

Let's make transformation in the formula. So,

$$W = \frac{1}{1 - A(t)P_{pr}(t)}.$$

The efficiency of failure prevention depends on quality of prophylaxis $P_{pr}(t)$, and also depends on quantity of preventive failure in preventive equipment.

Control of TS as the M component is considered as process of receiving and data processing, which sets the correspondence of RNS state to the set requirements and provides the decisions making [1], [5]. Main types and aims of the control are:

- control of main functions realization (the control of functioning);
- control of determinative parameters (the control of availability);

– control which is done to determine the failure place (diagnostic control);

– control which is done to predict future REE condition (predictive control);

– control which is done to detect and change elements parameters of which run up to accepted value (preventive control).

Parameters which determine equipment availability are called determinative parameters (DP). By results of DP control could be taken sound and error decisions about equipment condition. As the TS of RNS is characterized by the set of the DP which have difficult physical nature, so for decisions acceptance about RNS state by DP sets, it is necessary to realize the appropriate signals processing in accordance with definite algorithms [2].

During the TS control can be detected some elements of RNS, the state of which can result in failure of total means. Regulation operations, tuning and changing of element can help to prevent the failures. According to adaptive approach, regulation is based in controlling influences (CI) realization on the RNS DP on the base of received information about their technical state. Control actions are useful to use when determinative parameters achieve the boundaries of preventive tolerances. The aim of CI realization is a bringing together of DP regulated values, which are controlled up to the nominal values [6].

Control quality of RNS can be estimated via indexes of truth classification probability of technical state [5]: veracity of truth decision making about RNS serviceability D_s , about non-serviceable state D_{ns} , absolute veracity of truth classification D :

$$D_s = \frac{P - A}{P - A + B},$$

$$D_{ns} = \frac{1 - P - B}{1 - P - B + A}, \quad (1)$$

$$D = 1 - A - B,$$

where P is probability of RNS serviceable state; A is unconditional probability of error decision making about non-serviceable state of the actually serviceable RNS; B is unconditional probability of error decision making about serviceable state of the actually non-serviceable RNS.

The detailed classification of methods of veracity increasing is resulted in [2]. It is possible to take to the basic methods of veracity instrumental component increase:

- increase of RNS failure-free operation ;

- decrease of errors of control and measuring operations;
- decrease of noise level in the measuring channels of RNS technical state control, etc.

In particular, for the increase of veracity control tolerance in addition to guarantee admittance is entered, certain in technical terms.

If RNS technical state is defined to N independent parameters, so expressions for error decisions making probabilities calculation A_i and B_i are as follows:

$$A_i = \prod_{i=1}^N P_i - \prod_{i=1}^N (P_i - A_i), \tag{2}$$

$$B_i = \prod_{i=1}^N (P_i - A_i + B_i) - \prod_{i=1}^N (P_i - A_i).$$

So absolute veracity of classification D is as follows:

$$D = 1 - A - B. \tag{3}$$

Let's consider veracity instrumental component. If control is made by n from N independent RNS DP the control completeness V may be estimated by the expression [7]:

$$V = \prod_{i=n+1}^N P_i. \tag{4}$$

The probability of RNS serviceability by uncontrolled set of parameters is proposed to use as an estimation of control completeness. Taking into consideration probabilities W_i of RNS failure-free operation during time, which is left from the moment of some parameter estimation up to the moment of control ending, the expression (3) will be next [7]:

$$D = 1 - \prod_{i=1}^N P_i - \prod_{i=1}^N (P_i - A_i + B_i) + 2 \prod_{i=1}^N (P_i - A_i) W_i \frac{V + \prod_{i=1}^N P_i - 1}{V \prod_{i=1}^N P_i}. \tag{5}$$

In Figure 1 are shown graphs of dependences D from control completeness V for cases $W_i = 0.95$ and 0.99 .

Obtained dependences show that completeness of V parameters control is mostly influences on absolute veracity of classification D .

Necessary reliability level of RNS could be reached by the way of DP adjustment to the area of accepted values. Adjustment is done if parameters reach the limits of tolerances (Fig. 2).

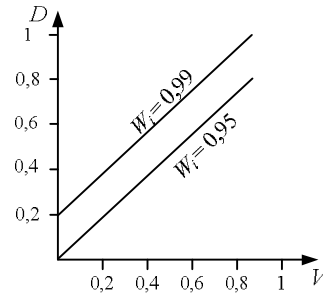


Fig. 1. Dependences graphs of absolute veracity of the classification on V parameters control completeness in the case of different probability values W_i

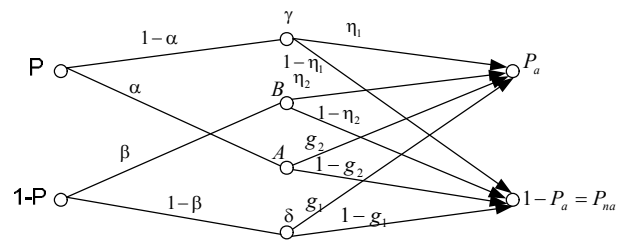


Fig. 2. Probabilistic graph of control and adjusting operations: P_a is the probability that parameter is at the area of availability as a result of adjustment; $1 - P_a$ is the probability that parameter is at the area of non-availability as a result of adjustment; $1 - \eta_1$ is the conditional probability of parametric failure (objectively small); η_2 is the probability of parameter self-restorability (small); g_1, g_2 is the probability of qualitative adjustment; $1 - g_1, 1 - g_2$ is the probability of non-qualitative adjustment

Formula for control and adjusting operations efficiency is [7]:

$$W = \frac{1}{1 - P_{pr} + Q_{in}}$$

where P_{pr} is the probability of failure prevention, Q_{in} is the probability of failure insertion.

Failure which was prevented as a result of control and adjusting operations is event which will be determined by two combined realization of independent events. They are:

- correct determination when parameter will run up to the limits of tolerances with conditional probability $1 - \beta$;
- qualitative parameter adjustment in the area of availability with conditional probability g

$$P_{pr} = (1 - \beta) g_1.$$

Failure insertion is determined by combined realization of next independent events:

- false parameter determination out of availability area with conditional probability α ;
- non-qualitative adjustment with conditional probability $1 - g_2$.

$$Q_{in} = \alpha(1 - g_2),$$

So,

$$W = \frac{1}{1 - (1 - \beta)g_1 + \alpha(1 - g_2)},$$

Further analysis shows that maximum values W can be reached by optimal choosing of tolerances on determinative parameters of equipment.

V. RESULTS

The technical state of many modern RNS is determined three-alternatively: Up State (US), State of Deterioration (SD), Down State (DS). If the DP of the RNS has got out of bounds of exploitation tolerances, so according to the results of TS control, forms a decision about deterioration and implements some CI with the purpose to timely failures prevention. If control shows, that DP of RNS is absent or out of the bounds, so the RNS is in down state and it's necessary to replace the failed element. Let's adaptive model of decision making and CI realization in the process of RNS M like a graph, shown below on the Fig. 3. In the process of model construction the following designations are used: P_1, P_2, P_3 – probabilities of RNS in conditions of US, SD, DS; G, F_1, F_2 – unconditional probabilities of correct decision-making about true TS of RES by the results of DP control; $A_1, A_2, A_3, B_1, B_2, B_3$ – unconditional probabilities of error decision-making about the true TS of RNS; $W_{ij} (i = j)$ – conditional probabilities of correct decision-making; $W_{ij} (i \neq j)$ – conditional probabilities of error decision-making; H_1 – unconditional probability of RNS US as a result of decisions-making about TS and CI realization; H_2 – unconditional probability of RNS DS as a result of decisions-making about TS and CI realization; $\eta_i, 1 - \eta_i, g_i, 1 - g_i$ – conditional (transitional) probabilities in the process of CI realization.

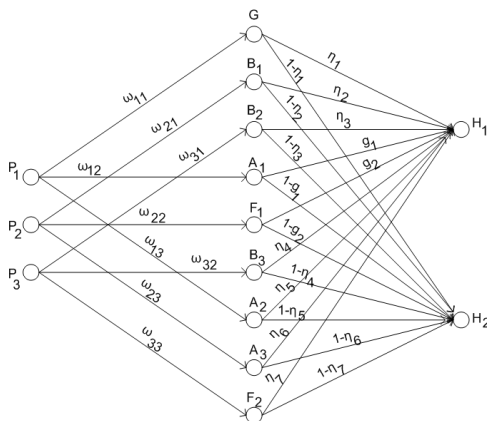


Fig. 3. Adaptive model of the decision-making and controlling influences realization

Situations which can arise in the decision-making process and the CI realization is thoroughly considered in [6]. The TS efficiency with the adaptive exploitation consumption can be defined by the quantitative criterion [5], [6].

$$Q = \frac{1}{1 - P_{ep} + P_{ei}},$$

where P_{ep} is the probability of the errors prevention considering the decision making about RES TS and the CI realization; P_{ei} is the probability of errors insertion.

From the carried-out situational analysis follows:

$$P_{ep} = \omega_{22}g_2 = \frac{F_1}{P_2}g_2 = \frac{P_2 - B_1 - A_3}{P_2}g_2;$$

$$\begin{aligned} P_{ei} &= P_{ei1} + P_{ei2} + P_{ei3} \\ &= \omega_{21}(1 - \eta_2) + \omega_{12}(1 - g_1) + \omega_{22}(1 - g_2) \\ &= \frac{B_1}{P_2}(1 - \eta_2) + \frac{A_1}{P_1}(1 - g_1) + \frac{P_2 - B_1 - A_3}{P_2}(1 - g_2). \end{aligned}$$

The probabilities $P_1, P_2, P_3, A_1, A_2, A_3, B_1, B_2, B_3$ can be defined using the probability theory and mathematical statistics' methods, previously being established: the determinative parameters (DP) of RNS; mathematical expectation of DP; DP control errors; DP control results; mean root square deviation and density probability distribution of DP; installed exploitation tolerances on DP; preventive tolerances on DP.

The received results of the decision making and CI realization analysis in the processes of RNS control, allow to solve the following problems of adaptive operation: if the RES and its control devices DP characteristics are known, so the received mathematical expressions can be used for determination of the TS correct and error decision making probabilities about the TS, the corresponding probabilities of decision making and efficiency of the control processes may estimated; if the RNS characteristics are known, then setting the requirements to processes of control quality, possible reasonable determining the control devices accuracy and the limits of preventive tolerances which application allows most effectively to carry out control of the definite the TS RNS type.

V. CONCLUSION

The characteristics of modern RNS are given, and their exploitation features, which can be used during the exploitation systems' developing and modernization of the radio engineering different functional equipment, are analyzed. The adaptive OS usage allows: to carry out optimization of the RNS

object operating modes; to provide the system serviceability in the conditions of extended updating of the object dynamic properties; to increase reliability of the system, unify separate regulators or their blocks and adapt them for the operation with different types of the same objects; to reduce operational costs. The obtained results of the decision making and controlling influences realization analysis in the processes of RNS control, allow to solve the set of adaptive operation problems.

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Zuiev Oleksii. Candidate of Science (Engineering). Associate Professor.
Aviation Radio Electronic Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Civil Aviation Engineers Institute, Kyiv, Ukraine (1989).
Research area: radio navigation equipment, operation systems, maintenance processes.
Publications: 98.
E-mail: zujew@mail.ru

О. В. Зуєв. Вдосконалення процесів технічного обслуговування наземних радіонавігаційних систем

Проаналізовано сучасні наземні радіонавігаційні системи обслуговування повітряного руху. Запропоновано рекомендації щодо можливих варіантів вдосконалення процесів технічного обслуговування зазначених систем. Досліджено взаємозв'язок між похибками контролю, повнотою контролю, ймовірностями безвідмовної роботи та сукупний вплив цих показників на вірогідність контролю технічного стану радіонавігаційних систем.
Ключові слова: радіонавігаційні системи; система експлуатації; процеси технічного обслуговування; адаптивна експлуатація; технічний стан; вірогідність контролю.

Зуєв Олексій Володимирович. Кандидат технічних наук. Доцент.

Кафедра авіаційних радіоелектронних комплексів, Національний авіаційний університет, Київ, Україна.

Освіта: Київський інститут інженерів цивільної авіації, Київ, Україна (1989).

Напрями наукової діяльності: радіонавігаційне обладнання, системи експлуатації, процеси технічного обслуговування.

Кількість публікацій: 98.

E-mail: zujew@mail.ru

A. V. Zuiev. Совершенствование процессов технического обслуживания наземных радионавигационных систем

Проанализированы современные наземные радионавигационные системы обслуживания воздушного движения. Предложены рекомендации для возможных вариантов совершенствования процессов технического обслуживания названных систем. Исследована взаимосвязь между ошибками контроля, полнотой контроля, вероятностями безотказной работы и совокупное влияние этих показателей на достоверность контроля технического состояния радионавигационных систем.

Ключевые слова: радионавигационные системы; система эксплуатации; процессы технического обслуживания; адаптивная эксплуатация; техническое состояние; достоверность контроля.

Зуев Алексей Владимирович. Кандидат технических наук. Доцент.

Кафедра авиационных радиоэлектронных комплексов, Национальный авиационный университет, Киев, Украина.

Образование: Киевский институт инженеров гражданской авиации, Киев, Украина (1989).

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E-mail: zujew@mail.ru