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10th IEEE EAST-WEST DESIGN & TEST SYMPOSIUM (EWDTS 2012)

Kharkov, Ukraine, September 14-17, 2012

The main target of the **IEEE East-West Design & Test Symposium** (EWDTS) is to exchange experiences between scientists and technologies of Eastern and Western Europe, as well as North America and other parts of the world, in the field of design, design automation and test of electronic circuits and systems. The symposium is typically held in countries around the Black Sea, the Baltic Sea and Central Asia region. We cordially invite you to participate and submit your contributions to EWDTS'12 which covers (but is not limited to) the following topics:

- Analog, Mixed-Signal and RF Test
- Analysis and Optimization
- ATPG and High-Level Test
- Built-In Self Test
- Debug and Diagnosis
- Defect/Fault Tolerance and Reliability
- Design for Testability
- Design Verification and Validation
- EDA Tools for Design and Test
- Embedded Software Performance
- Failure Analysis, Defect and Fault
- FPGA Test
- HDL in test and test languages
- High-level Synthesis
- High-Performance Networks and Systems on a Chip
- Low-power Design
- Memory and Processor Test
- Modeling & Fault Simulation
- Network-on-Chip Design & Test
- Modeling and Synthesis of Embedded Systems
- Object-Oriented System Specification and Design
- On-Line Testing
- Power Issues in Design & Test
- Real Time Embedded Systems
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- Scan-Based Techniques
- Self-Repair and Reconfigurable Architectures
- Signal and Information Processing in Radio and Communication Engineering
- System Level Modeling, Simulation & Test Generation
- System-in-Package and 3D Design & Test
- Using UML for Embedded System Specification
- CAD and EDA Tools, Methods and Algorithms
- Design and Process Engineering
- Logic, Schematic and System Synthesis
- Place and Route
- Thermal, Timing and Electrostatic Analysis of SoCs and Systems on Board
- Wireless and RFID Systems Synthesis
- Digital Satellite Television

The Symposium will take place in Kharkov, Ukraine, one of the biggest scientific and industrial center. Venue of EWDTS 2012 is Kharkov National University of Radioelectronics was founded 81 years ago. It was one of the best University of Soviet Union during 60th - 90th in the field of Radioelectronics. Today University is the leader among technical universities in Ukraine.

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CONTENTS

An Efficient Fault Diagnosis and Localization Algorithm for Successive-Approximation Analog to Digital Converters
Melkumyan T., Harutyunyan G., Shoukourian S., Vardanian V., Zorian Y. 15

Application of Defect Injection Flow for Fault Validation in Memories
Amirkhanyan K., Davtyan A., Harutyunyan G., Melkumyan T., Shoukourian S., Vardanian V., Zorian Y. 19

SSBDDs and Double Topology for Multiple Fault Reasoning
Raimund Ubar, Sergei Kostin, Jaan Raik 23

Self Compensating Low Noise Low Power PLL design
Vazgen Melikyan, Armen Durgaryan, Ararat Khachatryan, Manukyan Hayk, Eduard Musaelyan 29

Optimization Considerations in QCA Designs
Zahra NajafiHaghi, Marzieh Mohammadi, Behjat Forouzandeh, Zainalabedin Navabi 33

Implementation of Address-Based Data Sorting on Different FPGA Platforms
Dmitri Mihhailov, Alexander Sudnitson, Valery Sklyarov, Iouliia Skliarova 38

Comparison of Model-Based Error Localization Algorithms for C Designs
Urmas Repinski, Jaan Raik 42

Synthesis of Clock Trees for Sampled-Data Analog IC Blocks
Bilgiday Yuce, Seyrani Korkmaz, Vahap Baris Esen, Fatih Temizkan, Cihan Tunc, Gokhan Guner, I. Faik Baskaya, Iskender Agi, Gunhan Dundar, H. Fatih Ugurdag 46

Experiences on the road from EDA Developer to Designer to Educator
H. Fatih Ugurdag 50

Multi-Beam Constant Modulus Adaptive Arrays in Real-Valued Arithmetic
Victor I. Djigan 54

Simulation of Total Dose Influence on Analog-Digital SOI/SOS CMOS Circuits with EKV-RAD macromodel
Petrosyants K. O., Kharitonov I. A., Sambursky L. M., Bogatyrev V. N., Povarnitcyna Z. M., Drozdenko E. S. 60

Models for Embedded Repairing Logic Blocks
Hahanov V.I., Litvinova E.I., Frolov A., Tiecoura Yves 66

Real-time Interconnection Network for Single-Chip Many-Core Computers
Harald Richter 72

Invariant-Oriented Verification of HDL-Based Safety Critical Systems
Kharchenko V., Konorev B., Sklyar V., Reva L. 76

An Improved Scheme for Pre-computed Patterns in Core-based SoC Architecture
Elahe Sadredini, Qolamreza Rahimi, Paniz Foroutan, Mahmood Fathy, Zainalabedin Navabi 80

Synthesis of Moore FSM with transformation of system in CPLD
Aleksander Barkalov, Larysa Titarenko, and Sławomir Chmielewski 85

A WSN Approach to Unmanned Aerial Surveillance of Traffic Anomalies:
Some Challenges and Potential Solutions
**David Afolabi, Ka Lok Man, Hai-Ning Liang, Eng Gee Lim, Zhun Shen, Chi-Un Lei,
Tomas Krilavičius, Yue Yang, Lixin Cheng, Vladimir Hahanov, and Igor Yemelyanov** 91

Synthesis of Qubit Models for Logic Circuits
**Wajeb Gharibi, Zaychenko S.A., Dahiri Farid, Hahanova Yu.V., Guz O.A.,
Ngene Christopher Umerah, Adiele Stanley** 95

Theory of Optimal Nonlinear Filtering in Infocommunication's Problems
Victor V. Panteleev 102

Verification of Specifications in the Language L with respect to Temporal
Properties Expressible by GR(1) Formulas
Anatoly Chebotarev 110

Properties of code with summation for logical circuit test organization
Anton Blyudov, Dmitry Efanov, Valery Sapozhnikov, Vladimir Sapozhnikov 114

Loop Nests Parallelization for Digital System Synthesis
Alexander Chemeris, Julia Gorunova, Dmiry Lazorenko 118

Decreasing the Power Consumption of Content-Addressable Memory
in the Dataflow Parallel Computing System
Levchenko N.N., Okunev A.S., Yakhontov D.E., Zmejev D.N. 122

WebALLTED: Interdisciplinary Simulator Based on Grid Services
Zgurovsky M., Petrenko A., Ladogubets V., Finogenov O., Bulakh B. 126

Malfunctions Modeling of Converters and Homogeneous-chain Distributed Structure Devices
Artur Gulin, Zhanna Sukhinets 130

On structure of quasi optimal algorithm of analogue circuit designing
Zemliak A., Michua A., Markina T. 134

A Neuro-Fuzzy Edge Based Spectrum Sensing Processor for Cognitive Radios
**Mohammadreza Baharani, Mohammad Aliasgari, Mohammadreza {Najafi, Jamali},
Hamid Noori** 138

Qubit Model for Solving the Coverage Problem
**Hahanov V.I., Litvinova E.I., Chumachenko S.V., Baghdadi Ammar Awni Abbas,
Eshetie Abebech Mandefro** 142

PDF testability of the circuits derived by special covering ROBDDs with gates
Matrosova A., Nikolaeva E., Kudin D., Singh V. 146

Compositional Microprogram Control Unit with Operational Automaton of Transitions
Alexander Barkalov, Roman Babakov, Larisa Titarenko 151

Observability Calculation of State Variable Oriented to Robust PDFs and LOC or LOS Techniques
Matrosova A., Ostanin S., Melnikov A., Singh V. 155

Low-Voltage Low-Power 2.5 GHz Linear Voltage Controlled Ring Oscillator
Hayk H Dingchyan 161

High Speed IC Output Buffer with Reduced Power Consumption
Karine Movsisyan 165

Engineering-Maintenance Methods of the Calculation Service Area Fixed BWA-paths
Sergey I. Myshlyakov, Victor V. Panteleev 170

Analyses of two run march tests with address decimation for BIST procedure
Ireneusz Mrozek, Svetlana V. Yarmolik 176

Design of Area Efficient Second Order Low Pass Analog Filter
Andranik Hovhannisyan 180

Power Consumption Analysis of Content-Addressable Memories
Levchenko N.N., Okunev A.S., Yakhontov D.E. 183

IC Physical Design Optimization Due to Effects of Device Physical Geometries
Avag Sargsyan 187

System-on-Chip FPGA-Based GNSS Receiver
Alexander Fridman, Serguey Semenov 190

Testware and Automatic Test Pattern Generation for Logic Circuits
Victor Zviagin 196

Artificial Neural Network for Software Quality Evaluation Based on the Metric Analysis
Oksana Pomorova, Tetyana Hovorushchenko 200

Self-Compensation of Influence of Parasitic Gate-Drain Capacitances of
CMOS Transistors in Analog Microcircuitry
Sergey G. Krutchinsky, Grigory A. Svizev, Alexey E. Titov 204

Hash-based Detection of OFDM Watermarking Symbol for Radiotelephone Identification
Aleksandr V. Shishkin, Aleksandr A. Lyashko 208

A Novel Wideband Circular Ring DGS Antenna Design for Wireless Communications
Rakesh Sharma, Abhishek Kandwal, Sunil Kumar Khah 211

Universal technique of the analysis of round-off noise in digital filters with
arbitrary structure described by topological matrixes
Vladislav A. Lesnikov, Alexander V. Chastikov, Tatiana V. Naumovich, Sergey V. Armishev 215

Hardware Reduction for Compositional Microprogram Control Unit Dedicated for CPLD Systems
Barkalov A., Titarenko L., Smolinski L. 219

Conservative Finite-difference Scheme for the Problem of Laser Pulse Propagation
in a Medium with Third-order Dispersion
Vyacheslav A. Trofimov, Anton D. Denisov 225

A Four Bit Low Power 165MSPS Flash-SAR ADC for Sigma-Delta ADC Applications
Hasan Molaei, Khosrow Hajsadeghi 229

Matrix Implementation of Moore FSM with Nonstandard Presentation of State Codes
Titarenko L., Hebda O. 233

Alowpower1.2GS/s4-bitflashADCin0.18mCMOS
Mohammad Chahardori, Mohammad Sharifkhani, Sirous Sadughi 237

Symmetrical Differential Stages on CMOS Transistors with Circuits ofSelf-Compensation and Cancellation
Sergey G. Krutchinsky, Grigory A. Svizev, Alexey E. Titov 241

Lower Bound of Error in AOA Based Passive Source Localization Using Single Moving Platform
Hejazi F., Norouzi Y., Nayebi M.M. 245

A Design for Testability Technique for Quantum Reversible Circuits
Joyati Mondal, Debesh K. Das, Dipak K. Kole, Hafizur Rahaman 249

A Flexible Design for Optimization of Hardware Architecture in Distributed Arithmetic based FIR Filters
Fazel Sharifi, Saba Amanollahi, Mohammad Amin Taherkhani, Omid Hashemipour 253

Models for Quality Analysis of Computer Structures
Murad Ali Abbas, Chumachenko S.V., Hahanova A.V., Gorobets A.A., Priymak A. 258

Expanding Wireless Bandwidth in a Power-Efficient Way: Developing a Viable mm-Wave Radio Technology
Daniel Foty, Bruce Smith, Saurabh Sinha, Michael Schröter 264

Sampling Theorem for Finite Duration Signal in Limited Frequency Band
Gamlet S. Khanyan 270

SiGe HBT Performance Modeling after Proton Radiation Exposure
Konstantin Petrosyants, Maxim Kozhukhov 274

Classical Models of Test used in Advanced Electronics Quality Assurance
Surendra Batukdeo 278

The Use of Natural Resources for Increasing a Checkability of the Digital Components in Safety-Critical Systems
Drozd A., Kharchenko V., Antoshchuk S., Drozd J., Lobachev M., Sulima J. 283

New version of Automated Electro-Thermal Analysis in Mentor Graphics PCB Design System
Petrosyants K.O., Kozynko P.A., Kharitonov I.A., Sidorov A.V., Chichkanov Y. N. 289

An Approach to Testing of Planar Integrated Antennas in Frequency Range of 5–7 GHz
Aleksandr Timoshenko, Ksenia Lomovskaya, Victor Barinov, Andrey Tikhomirov 293

Optimal project solution decision making in telecommunication systems using multicriteria optimization methods
Valery Bezruk, Alexander Bukhanko 298

Software implementation and debugging of forward error correction codes
Alexey Smirnov, Danila Migalin, Ilya Muravyev, Leonid Pertsev 303

Architecture of Built-In Self-Test and Recovery Memory Chips
Andrienko V.A., Moamar Diaa, Ryabtsev V.G., Utkina T.Yu. 307

The methods of exclusion of variables in symbolic time models of linear periodically time-variable circuit
Yuriy Shapovalov, Dariya Smal 311

Two-Component Encoding of Approximating Picture Pixels in Telecommunication Facilities
Barannik V., Dodukh A., Safronov R. 315

Development of parameterized cell using Cadence Virtuoso
Vadim Borisov 319

Simulation Methods of Diffusion Alloying Process by Means of Taurus TSUPREM-4 Programme
Lagunovich N.L., Borzdov V.M. 321

Control and Diagnosis by Complexity Indicators of System Functioning Process
Tverdokhlebov V.A. 323

Features of the Transfer of Information with Different Reliability in a Single Channel
Alexander Bakhtin, Leonid Pertsev, Olga Timofeeva 327

Construction of Signals with Controlled Peak-Factor
Koshevyy V. M., Dolzhenko D.O. 330

The Effective Method of Space Filtering of Noise in Rayleigh Communication Channel with the Adaptive Antenna
Maistrenko G. V., Rybalko A. M., Shokalo V. M., Strelnitskiy A. A. 333

A New Structure for Interconnect Offline Testing
Somayeh Sadeghi-Kohan, Shahrzad Keshavarz, Farzaneh Zokaee, Farimah Farahmandi, Zainalabedin Navabi 336

Researching of Mathematical Models Based on Optimal Control Approaches for Congestion Control in Telecommunication Network
Lemeshko A.V., Semenyaka M.V. 341

Higher Order Propagation Modes Error and Its Compensation
Zaichenko O. B., Klyuchnyk I. I., Martynenko L. G. 345

Strategy of analyzing most common algorithms for path finding in discrete labyrinth using software statistic data collector
Krasnov Evgeniy, Dmitry Bagaev 349

Method of Implementation of Technology of Orders Based Transparent Parallelizing for Solving Computationally Complex Problems on Cluster
Vitaliy D. Pavlenko, Viktor V. Burdejnyj, Sergey V. Pavlenko 353

Scheduling Tests for 3D SoCs with Temperature Constraints
Indira Rawat, Gupta M.K., Virendra Singh 356

Automated application mapping into Network-on-Chip topologies
Bykov S. O. 360

MIMO Radar with Phase-coded waveforms
Amirsadegh Roshanzamir, Bastani M. H. 363

BBN-based Approach For Assessment of Smart Grid And Nuclear Power Plant Interaction
Eugene Brezhnev, Vyacheslav Kharchenko 367

Design, Test and Fault Detection in QCA 4-to-1 Multiplexer
Zahra NajafiHaghi, Behjat Forouzandeh 374

The Evaluation of Statistical Characteristics of the Retransmission Meter Signal Frequency and Initial Phase on the Basis of VHDL-model
Dmitry A. Velychko, Iegor I. Vdovychenko 378

A Research of Heuristic Optimization Approaches to the Test Set Compaction Procedure Based On a Decomposition Tree for Combinational Circuits
Valentina Andreeva, Kirill A. Sorudeykin 382

Power Reduction of 7T Dual-Vt SRAM Cell Using Forward Body Biasing
Sahba Sabetghadam Jahromi, Raziyeh Bounik 388

VLSI: An Investigation into Electromagnetic Signatures (EMS) for Non-Invasive Testing and Signal-integrity Verification
Kadim HJ, Coulibaly L. M. 392

Secure Data over GSM based on Algebraic Codebooks
Kazemi R., Nashtaali D., Boloursaz M., Behnia F. 397

Simulation of Telecommunication Channel Using Volterra Model
Vitaliy D. Pavlenko, Viktor O. Speranskyy 401

Extracting Complete Set of Equations to Analyze VHDL-AMS Descriptions
Arezoo Kamran, Vahid Janfaza, and Zainalabedin Navabi 405

A Data Modem for GSM Adaptive Multi Rate Voice Channel
Boloursaz M., Hadavi A. H., Kazemi R., Behnia F. 409

Trends and prospects of development of techniques for extracting acoustic sounding information of the atmospheric boundary layer
Klyuchnik I., Panchenko A., Umyarov R. 413

Decision-Making in Robotics and Adaptive Tasks
Tsymbal A.M., Bronnikov A.I. 417

Design of Nonvolatile Memory Based on Magnetic Tunnel Junction for Special Electronic Systems
Aleksandr Kostrov, Vladislav Nelayev, Viktor Stempitsky, Anatoly Belous, Arkady Turtsevich 421

Improving the Dependability of a Water Supply System via a Multi-Agent based CPS
Teodora Sanislav, Liviu Miclea, Paolo Prinetto 425

Cyber Security Lifecycle and Assessment Technique for FPGA-based I&C Systems
Illiashenko Oleg, Kharchenko Vyacheslav, Kovalenko Andriy 432

FPGA Technologies in Medical Equipment: Electrical Impedance Tomography
Perepelitsyn Artem, Shulga Dmitry 437

A Trend-based Design Space Exploration of Multi-core Systems Using Regression Modeling
Fazeleh Hajari Taheri, Omid Fatemi 441

Synchronous Rectifiers Enable High Efficiency for Buck-Boost Converter
Yurii Shynkarenko and Igor Klyuchnyk 445

Test Data Compression Strategy While Using Hybrid-BIST methodology
Elmira Karimi, Mohammad Hashem Haghbayan and Mahmood Tabandeh 449

Self-Adaptive Mobile Wireless Hotspot Zones
Yanovsky M., Kharchenko V., Gorbenko A. 454

The Systolic Compositions of Two-dimensional and Multidimensional Lattice Filters for Space-Time Signal Processing
David I. Lekhovytskiy, Andrii V. Semeniaka, and Dmytro S. Rachkov 458

Power Efficient Implementation of Homogenous Multi-Core Processors
Aram Poghosyan 462

Assertion Based Method of Functional Defects for Diagnosing and Testing Multimedia Devices
Vladimir Hahanov, Karyna Mostova, Oleksandr Paschenko 465

Improved Scaling-Free CORDIC algorithm
Leonid Moroz, Taras Mykytiv, Martyn Herasym 470

Coding Tangible Component of Transforms to Provide Accessibility and Integrity of Video Data
Barannik V.V., Hahanova A.V., Krivonos V.N. 475

Review of the botnet detection techniques
Oleg Savenko, Sergiy Lysenko, Kryshchuk Andrii 479

MEMS Intellect Multiprobes Contacting Devices for Electrical Checking-up of Multilayers Commutative Boards and BGA/CSP Electronic Components
Nevliudov I.Sh., Palagin V.A., Razumov-Frizjuk E.A., Zharikova I.V. 483

Internet of Things: A Practical Implementation based on a Wireless Sensor Network Approach
Michele Mercaldi, Andrea D'Oria, Davide Murru, Hai-Ning Liang, Ka Lok Man, Eng Gee Lim, Vladimir Hahanov, Mischenko Alexander 486

Investigation of EM Wave Propagation of the Wireless Capsule in Human Body
Eng Gee Lim, Zhao Wang, Jin Hui Chen, Tammam Tillo, Ka Lok Man 490

Using pyroelectric detectors in the design of temperature measuring devices
Bondarenko A.Yu, Klyuchnik I.I. 494

Transaction Level Model of Embedded Processor for Vector-Logical Analysis
Irina V. Hahanova, Volodymyr Obrizan, Alexander Adamov, Dmitry Shcherbin 497

Embedded Intelligent Control Systems on the Basis of Elementary Fuzzy-Logic Cells
Dontsova A., Vassiliev A.E. 502

Interconnection Analysis of the Integral Reliability Characteristics of the Monoergative Computer System and User's Competency
Krivoulya G., Shkil A., Kucherenko D. 505

System approach to determination of ADC parameters
Knyshev Ivan 511

Methodological Aspects of Complex Ecological Estimation of Man-Caused Territory State and Mathematical Modelling of Processes in a Environment System
Kozulia T. V., Sharonova N. V. , Emelianova D. I., Kozulia M.M. 514

Method for “Failure on Demand” Latent Faults Diagnosis of NPP Safety Control Systems
Gerasymenko K.E. 519

Informational Saturation of Noise Signals
Kolodiy Z. A., Kolodiy A.Z. 523

The Positional Structural-Weight Coding of the Binary View of Transformants
Barannik V., Krasnoruckiy A., Hahanova A. 525

Synchronization of a Fuzzy Automata
Speranskiy Dmitriy 529

Models for SoC Infrastructure of Radio Frequency Identification with Code-Division Multiple
Filippenko I.V., Hahanova I.V., Filippenko I.O, Maksimov M., Chugurov I. 535

Factorization of Rhythmograms Parametric Spectra on the Base
of Multiplicative Linear Prediction Models
Nataliia V. Kudriavtseva, Iryna O. Fil 538

Logi-Thermal Analysis of Digital Circuits Using Mixed-Signal Simulator Questa ADMS
Petrosyants K.O., Rjabov N.I. 541

Method of Hybrid Regression Analysis in the Calibration Experiments
Ordinartseva N. P. 545

Keynotes speeches and Invited Reports 548

AUTHORS INDEX 554

Interconnection Analysis of the Integral Reliability Characteristics of the Monoergative Computer System and User's Competency

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Abstract

Integral reliability characteristics of the monoergative computer system, one of the basic components of which is a human-operator, are examined. Mathematical models and analytical dependences of the restorable system dependability on the numeral values of the user's competency are received. These dependences allow to define necessary expense on the improvement of the operator's learning level, depending on the state of his current competence as an user of the technical system.

1. Introduction

The appearance of the complex organic ergative systems (ES) is associated with the rapid development of the computer information technology and the necessity for operators' work with a control interface of the modern technical complexes, such as objects in the space and aviation engineering, power plants, process control systems, networks, internet, etc. ES found application in those objects where the intervention of an operator in the object operation is currently the requirement for error-free performance of these objects.

In most cases, ES is a complex computer-aided control system (CCS), a major component of which is a human-operator or group of operators, and depending on the number of operating staff the monoergative (one operator) and poliergative (several people) system are distinguished. By the operators hierarchy ES can be the first, second and higher order. For example, the second-order system has two levels of control, on the first of which an operator works with a technical device and on the second – the operator in addition to the work with a technical device to provide guidance of the first operator [1].

The research related to the development and improvement of the ES can be described by three stages. At the first stage, the goal of the ES improvement was a human adaptation to the technical device, at the second stage – the technical device to a human: his psychological, physiological, anthropometric and other characteristics. The third stage is characterized by a human factors analysis together with the characteristics of the technical object as a total integral character of the ES. But it is not a man is considered as an average link included to the technical system, but a technical device – as a tool included to the activity of a human-operator. That human generates and implements the goals of the ES operation by technical devices [2].

The mandatory components of the ES besides operating staff involved in control are computer hardware and software tools. The effectiveness of the ES operation considerably depends on the reliability (availability) of all three components. Subject to this the important task is to ensure their trouble-free operation during the operation. This task has three main components – the ES reliability, the availability to the system application and the qualitative characteristics of the service, in particular, the level of the diagnosability provision. These three components assume the diagnosis and elimination of the possible system problems, generated by faults and failures.

2. Problem definition

The reliability of the technical computer environment has been researched quite extensively and deeply. The reliability of the complex software systems is studied less and the reliability properties of the ES operators, the evaluation of their performance is currently research not well.

A human-operator is the basic link of the modern ES, statistics show that 20-30% of the accidents and disasters, directly or indirectly, related to the human error. Consequently, the overall assessment of the technical systems reliability and their integral characteristics must necessarily include the analysis of the human factor. In this connection, the development of the ES integral characteristics evaluation procedure, taking into account the properties of all three components – the operating staff, hardware and software – is actual task. In the capacity of the basic integral ES characteristics the reliability factor of the restorable technical system taking into account the readiness of the operator based on his competence is proposed to use.

3. ES reliability subject to the human-operator activity

Systematic approach of the ES reliability assessment provides the assessment of a human as one of the main components of the system. In the general case, this reliability is defined as the need of the successfully accomplish of the task on given stage of the system operation within a specified period of time under certain requirements to the activity time.

The ES reliability assessment is based on the following assumptions:

- both hardware failures and operator errors are rare, random and independent events;
- an appearance of more than one single-type event during the time of the system operation is almost impossible;

the ability of the operator to errors compensation and to the error-free operation – are independent properties of the operator.

Error (failure) of the human-operator is defined as the non-execution of the task (or perform forbidden acts) which can lead to violation of the scheduled operations.

The operator error can be divided into three groups:

- the goal of the problem solving can't be achieved due to the erroneous actions of an operator;
- the operator seeks to achieve the erroneous goal;
- the operator is inactive at the moment when his participation is necessary.

The criteria of the performance and reliability are used for evaluation of an operator activity [3].

The performance criterion is problem time, i.e. the time from the moment of an operator reaction on the signal to the moment of the stimulus end: $T_{on} = a + bH = a + H / V_{on}$, where a – a hidden reaction time, i.e. period of the time from the signal appearance to the operator's response on it (0,2 ... 0,5 sec); b – the time of the one information unit processing (0,15–0,35 min); H – the amount of processed information; V_{on} (2 … 4 units/sec), or bandwidth, which characterizes the time during which the operator grasps the meaning of the information.

The reliability of the operator is characterized by his faultlessness, availability, accuracy, recoverability and timeliness. For each of these indicators the analytical dependences can be developed.

Let's consider the case when the compensation of the operator error and hardware failure is impossible [2]. If hardware failure and human error – are independent events, the probability of the failure-free operation is: $P(t_0, t) = Pt(t_0, t)P_0(t)$, where $Pt(t_0, t)$ – the probability of the no-failure operation of the hardware over a period t_0 , $t_0 + t$; $P_0(t)$ – the probability of the error-free operator operation over a period t, subject to the hardware trouble-free operation, t_0 – the total time of the system operation, t – the current period of the system operation.

The ES with noncompensible operator errors and hardware failures is occurring in practice relatively rare. The reliability of such systems can be enhanced by the operators' redundancy with periodic diagnosis of their activities results.

The technical systems with failures recovery and operator errors compensation are widespread. The operators can fix (compensate) the part of the admitted errors in proper time. The errors compensation is an important alternate way of the ES reliability improving. Bringing into the technical system the attachments facilitated the error correction, increases the ES reliability significantly.

The system with errors and failures compensation will work without failures during the time t_0 , $t_0 + t$ under the following conditions:

1. the technical system didn't fail and the operator didn't make a mistake;
2. the technical system didn't fail and the operator made a mistake, but fixed (compensated) it;
3. the operator didn't make a mistake, the technical system failed, but through the operator intervention a system performed its functions;
4. the operator made a mistake, but fixed (compensated) it, the technical system failed but, trough the operator intervention, system and operator performed their functions.

4. The reliability factor of the repairable system

For an approximate reliability indexed calculation of the repairable ES let's accept the following assumptions. We consider the set of flows occurring in the system in case of the separate elements failure. The analysis of all the situations that lead to the system failure as a whole is conducted. As a result, the intensity of the events' flow of this type and the length of the failed state by each of the reasons is computed. Then the procedure of the flows superposition of those situations, each of which leads to the system failure or flows' depression for those situations that lead to the system failure during simultaneous implementation is consistently applied. As a result, we obtain the resulting flow with two summary characteristics: average uptime and average recovery time. Subject to the reliability of the systems uptime, as a rule, will be exponentially distributed, so these two parameters are sufficient for the evaluation of any other reliability indexes [2].

The process of the repairable object operation can be represented as a sequence of alternating periods of availability and recovery (standing idle).

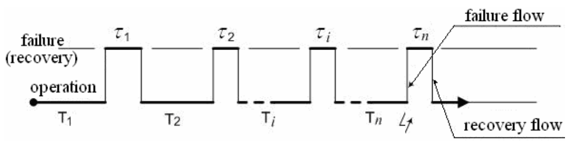

Figure 1. The repairable object operation, $T_1 \ldots T_n$ – the periods of the availability; $\tau_1 \ldots \tau_n$ – the periods of the recovery

The reliability factor – is the probability that an object will be in working order at any time, except for the scheduled periods during which intended application of the object is not provided. This index assesses at the same time the properties of the availability and maintainability of the object.

For restorable object on conditions that there is a simple flow of failures and recoveries the reliability factor equal

$$K = \frac{T}{T+\tau} = \frac{\mu}{\lambda+\mu} = \frac{1}{1+\frac{\lambda}{\mu}} = \frac{1}{1+\frac{\tau}{T}} = \frac{1}{1+\gamma}, \qquad (1)$$

where $\mu = \frac{1}{\tau}$, $\lambda = \frac{1}{T}$ and $\gamma = \frac{\lambda}{\mu} = \frac{\tau}{T}$ – recoverability index.

From the expression (1) it follows that the reliability factor of the object can be increased by increasing of the mean time between failures and reducing of the average time of recovery. On the other hand the reliability factor depends not on the absolute values of the variables T and τ, but of their relations, i.e. on value γ. Note that for the high-reliability systems $T >> \tau$ or $\gamma =<< 1$.

For high-reliability CCS $0,9 < K_R < 0,999$, i.e. $0,9 < \frac{1}{1+\gamma} < 0,999$.

In other words

$$0,9(1+\gamma) < 1 < 0,999(1+\gamma),$$

$$0,9 + 0,9\gamma < 1 < 0,999 + 0,999\gamma.$$

Solving the inequality, we obtain: $0,001 < \gamma < 0,111$.

For the practical calculations an approximate K calculations is used. For this let's perform the following transformation:

$$K = \frac{1+\gamma-\gamma}{1+\gamma} = 1 - \frac{\gamma}{1+\gamma}.$$

We assume that $\frac{\gamma}{1+\gamma} \approx \gamma$, so the conversion error will be:

$$\Delta = \left|\frac{\gamma}{1+\gamma} - \gamma\right| = \left|\frac{\gamma-\gamma-\gamma^2}{1+\gamma}\right| = \frac{\gamma^2}{1+\gamma},$$

as $\gamma << 1$, $\Delta \approx \gamma^2$.

Thereby, for computing $K \approx 1 - \gamma$.

Together with the rise of the period under review an average reliability factor seeks to the reliability factor as to the limiting value, which with the increase of the interval time, i.e. $K(t) = \lim_{t\to\infty} K(t)$, where $K(t)$ – the probability that at time t the product is up (in certain initial conditions at $t = 0$), i.e. $K(t) = \frac{1}{T+\tau}\int_0^\infty P(t)dt$, $K(t)$ – the probability of the failure-free operation.

For an exponential distribution T and τ the dependency diagrams of the basic values

$K_R(t) = K_R + ke^{-(\lambda+\mu)t}$ and the time for the corresponding values γ are showed on figure 2.

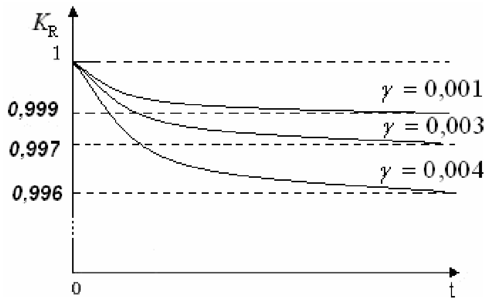

Figure 2. Dependency diagrams K_R

5. The relationship of the reliability factor and user competency

The high-reliability CCS is a set of the technical tools, dataware and software (SW), as well as operating staff that combined to perform control functions. It is assumed that failing of any three components leads to the system failing, which have to operate continuously over a preset time [3].

To simplify further discussion let's introduce the following restrictions, which, in toto, don't affect the calculation nature of the reliability factor:

– mean-time-between-failures T and recovery time τ are random variables that obey an exponential distribution;

– CSS technical parameters which determine the value T and τ, don't change over time;

– T and τ correlation doesn't change over time (stationary process);

– staff qualification (training) affects the changes of the T and τ as well.

The evaluation model of the human-operator activity in the capacity of the CCS component was proposed in [4]. The availability conservation property of the operator under appropriate functional activities on the assumption of training is represented by double exponential model:

$$P_3(t,\tau) = e^{-\lambda t_3 e^{-\nu\tau}}, \qquad (2)$$

where t_3 – the operator's time which required to perform task in the information system; λ – the error intensity during work performance, τ – learning time, ν – the error intensity during learning time.

A consequence of (2) is a formula of the conditional intensity of the operator failure (error) on the assumption of pretraining:

$$\Lambda(t) = P(t)\lambda(t), \qquad (3)$$

where $P(t)$ – the conditional probability of the successful CCS operator activity under availability resource consumption which accumulated during training period, $\lambda(t)$ – unconditional failure (errors) intensity of the operator.

From the equation (3) follows that the conditional failure intensity $\Lambda(t)$ comes to the minimization of the unconditional failure (errors) intensity $\lambda(t)$ in P time. As applied to systems with recovery, where $\lambda = \frac{1}{T}$, it can be assumed that the mean time to failure T_y increases in P_1 time, i.e. $T_y = T \cdot P_1$ (actually, conditional mean time to failure decreases as $0 \le P_1 \le 1$). Applying the similar reasoning to the restorations intensity $\mu = \frac{1}{\tau}$, we can assume that the recovery time τ will decrease in P_2 time, i.e. $\tau_y = \frac{\tau}{P_2}$ (actually, the recovery time will increase, as by-turn $0 \le P_2 \le 1$). On the assumption that the operator learning affect the T and τ as well, let's assume that the conditional probability for them will be identical, i.e. $P_1 = P_2 = P$.

For the operating CCS staff let's define the conditional reliability factor: $K_y = \frac{T_y}{T_y + \tau_y}$, that can also be referred as K_P (operating personnel).

Taking into account $T_y = T \cdot P$ and $\tau_y = \frac{\tau}{P}$, we obtain:

$$K_p = \frac{T \cdot P}{T \cdot P + \frac{\tau}{P}} = \frac{T \cdot P}{\frac{T \cdot P^2 + \tau}{P}} =$$

$$= \frac{T \cdot P^2}{T \cdot P^2 + \tau} = \frac{P^2}{P^2 + \frac{\tau}{P}} = \qquad (4)$$

$$= \frac{P^2}{P^2 + \gamma} = \frac{1}{1 + \frac{\gamma}{P^2}}.$$

If we accept that $\gamma = 0{,}01$, we will get $K_p = \frac{P^2}{P^2 + 0{,}01} = \frac{1}{1 + \frac{0{,}01}{P^2}}$.

The dependency diagram of the conditional reliability factor K_P on the conditional probability in the range from 0 to 1 when $\gamma = 0{,}01$ is showed on figure 3.

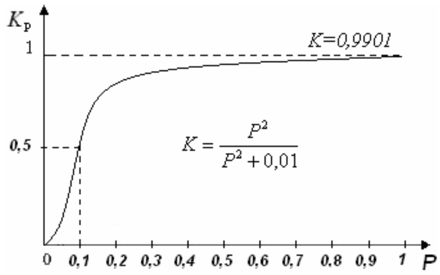

Figure 3. The dependency diagram K_P

For approximate determination of the K_P let's define tolerance range for P :

$$K = 1 - \gamma = 1 - \frac{\tau}{T} = 1 - \frac{\frac{\tau}{P}}{T \cdot P} = \qquad (5)$$

$$= 1 - \frac{\tau}{T \cdot P^2} = 1 - \frac{\gamma}{P^2}.$$

On the basis of $K = 1 - \frac{\gamma}{P^2} > 0$, we obtain $\frac{\gamma}{P^2} < 1$ or $P^2 > \gamma$, i.e.

$$P > \sqrt{\gamma}. \qquad (6)$$

The dependence P on K_P will be:

$$\gamma = (1 - K) \cdot P^2; \quad P^2 = \frac{\gamma}{1 - K}; \quad P = \sqrt{\frac{\gamma}{1 - K}},$$

which makes it possible to calculate the increment ΔP depending on ΔK:

$$P + \Delta P = \sqrt{\frac{\gamma}{1 - (K + \Delta K)}}$$

$$\Delta P = \sqrt{\frac{\gamma}{1 - (K + \Delta K)}} - P. \qquad (7)$$

6. The model of the operator learning

Operator learning C let's define as the frequency of the correct task performance of the operating activities (learning outcome). At the same time $(C - 1)$ – the frequency of the incorrect task performance.

Then $C = \frac{R}{N}$, where R – the number of correct actions of the operator in unit time, N – the total number of operations per unit time.

In terms of (2) and (3) the probability of failure-free operation is $P(t) = e^{-\nu t}$, where ν – the operator error intensity during learning time t. If we abstract from the random nature of the human error during the training period and from the learning time t, and consider only the training outcome C, then the operator error intensity during learning time can be replaced by the number of errors during learning time $(C - 1)$:

$$P = e^{-(1-C)} = e^{(C-1)}. \qquad (8)$$

For the transition from the conditional probability P to learning C let's find the logarithm:

$$\ln P = C - 1; \quad C = \ln P + 1.$$

Let's define the tolerance range for P on the basis of $0 \le C \le 1$:

$$0 \le \ln P + 1 \le 1, -1 \le \ln P \le 0,$$

$$e^{-1} \le P \le e^0, 0.368 \le P \le 1. \qquad (9)$$

Thus, then $\gamma = 0.01$ the turndown K_P will be $0{,}932 \le K_p \le 0{,}9901$.

Based on a comparison of (6) and (9), we can conclude that to compute the conditional reliability factor of the personnel K_P it's more than enough to use only approximate formula (5).

Let's consider the extreme case. With the highest level of learning $C=1$, $P=e^0=1$ as well as K_P is equal to the maximum value of the unconditional reliability factor, which corresponds to the objective nature of the learning process.

With minimal learning level $C=0$, $P=e^{0-1}=e^{-1}=0.37$, as well $K_P=0.932$. This value of the minimum K_P due to the fact that the two-level exponential model takes into account other factors except the personnel learning, for example, learning time, ways of the personnel restorative function and others.

The dependency diagram of the conditional reliability factor K_P on the personnel learning level C with $\gamma=0.01$ is showed on figure 4.

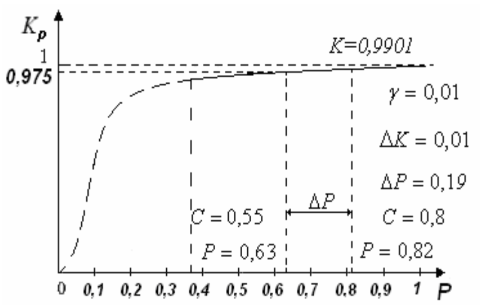

Figure 4. The dependency diagram K_P on P

Let's show an example of the personnel learning level calculating in assumption of the reliability factor changes. Let's suppose that there is a CCS with recoverability indices $\gamma=0{,}01$. The analysis results of the staff's skill level showed that the learning level (competency) is equal to $C=0{,}55$. We have to determine how much personnel learning have to increase for the conditional reliability factor K_P rose to 0.01 ($\Delta K_P=0{,}01$).

Using equation (7) $P=e^{(C-1)}$, let's calculate the conditional probability $P=e^{0{,}55-1}=e^{-0{,}45}=0{,}63$, and base on it – the conditional reliability factor.

On the basis of (6) let's calculate $\Delta P=\sqrt{\dfrac{0{,}01}{1-(0{,}975+0{,}01)}}-0{,}63=0{,}19$ .With reverse transition to the learning index (competency) C on the basis $C=\ln P+1$ we will get: $C=\ln 0{,}82+1=0{,}801$.

Thus, the conditional reliability factor or staff reliability factor can be increased by increasing of the personnel learning level (competency) C, on $\Delta K=0{,}01$ in assumption of $\Delta P=0{,}19$, but the competency level has to be raised to $C=0{,}8$ (i.e. $\Delta C=0{,}25$). For the competency assessment of the ES user we can use the method given in [5].

7. Conclusion

The analysis of the integral reliability characteristics of the monoergative computer system showed that the availability of the repairable system appreciably depends on the functional availability level of the technical system user, which is determined by his learning (competency) as an operator. The received mathematical models and analytic dependences between system reliability factor and numerical values of user competency make possible to determine improvement costs of the operator learning level according to the state of his current competency.

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