RIGA TECHNICAL UNIVERSITY

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RAILWAY AUTOMATION AND TELEMATICS SYSTEMS' MONITORING AND DIAGNOSTIC METHODS' RESEARCH AND DEVELOPMENT

Summary of doctorate's dissertation

Rīga - 2013

RIGA TECHNICAL UNIVERSITY
Faculty of Power and Electrical Engineering
Institute of industrial electronics and electrical engineering

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DOCTORATE’S DISSERTATION
PROPOSED FOR ENGINEERING DOCTOR’S DEGREE IN RIGA TECHNICAL UNIVERSITY

Doctorate’s dissertation for engineering doctor’s degree is openly defended on 3 July 2013 at Faculty of Power and Electrical Engineering, Riga Technical University, Kronvalda bolivars 1, room 117.

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APPROVAL

I approve, that I have developed given doctorate’s dissertation that has been submitted for review to Riga Technical University for receiving engineering (or any other) doctor’s degree. Doctorate’s dissertation has not been submitted to any other university for receiving scientific degree.

Vladimirs Karevs ……………………………. (Signature)

Date: ………………………

Doctorate’s dissertation has been written in Latvian language, consists of introduction, 5 chapters, summary or conclusion, literature list, 7 annexes, 96 figures and illustrations, all together 172 pages. Literature list contains 129 titles.

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GENERAL DISSERTATION'S DESCRIPTION

Subject's topicality

During the lifetime of railway automation and telematics systems, it is necessary to guarantee high level of safety, which numerically is defined as fail-safe or continuous working time (Uptime). Overall, quality of system architecture is determined by the coefficient of readiness (Availability Factor) [27][28].

Railway automation and telematics systems' safety level maintenance is based on service methods. In Latvian Railway periodic or planned replacement of elements (TBM - Time Based Maintenance) with new or renovated elements independently of elements' condition (PM-Preventive Maintenance) is adopted [24]. The replacement plan as determined by the element's design, operation mode and is based on statistical observations of the element parameters. Thereafter, this maintenance method is not economically optimal, is in need of new elements' and repair kits' purchase [24].

Dissertation's aim and objectives

Dissertation's aim is the development and application of diagnostic methods, resulting in an increase of train traffic control system's reliability and safety indices.

Dissertation's objectives:

- to analyze the existing relay and microprocessor-based train control systems by the level of development of diagnostic algorithms, tools and methods taking into consideration the exposure of different elements to fast depreciation and the possibility to develop a built-in diagnostic methods;
- to develop mathematical tool for evaluation of railway elements' functionality in diagnostic exercise;
- to develop a real-time diagnostic method for controlling declared parameters in battery that will allow to assess the capacity without shutting off the battery from load;
- to develop a diagnostic method that will allow real-time continuous control of an electromechanical pulse relay's functionality, with particular emphasis on mechanical parts' wear and tear;

- to develop electromechanical code transmitter's prototype with built-in self-diagnostic functions and prove their level of safety in accordance with the SIL by CENELEC requirements.

Methodologies and tools used in the study

Programming environment:

- C++ Builder;
- Microchip MPLab ASM;
- HI-TECH C compiler.

Programming tools:

- Microchip MPLAB ICD2.

Measurement and signal recording tools:

- PicoScope® 6 - PC Oscilloscope software.

Simulation tools:

- Texas Instruments Tina 9.

Methodologies:

- FTA – fault tree analyze.

MIL HDBK – 217:

- Failure intensity's calculation methodology;
- Failure intensity's statistical data.

International and European institutions' recommendations:

- ANSI/ISA S84 (Functional safety of safety instrumented systems for the process industry sector);
- IEC 61508 (Functional safety of electrical/electronic/programmable electronic safety related systems);
- IEC 61511 (Safety instrumented systems for the process industry sector)
- IEC 62061 (Safety of machinery);
- EN 50128 (Railway applications - Software for railway control and protection);
- EN 50129 (Railway applications - Safety related electronic systems for signaling).

Industry standards:

- ОСТ 32. Безопасность железнодорожной автоматики и телемеханики.

Scientific novelty

- Degradation coefficient of the system as recovery repair's efficiency criterion;
- Universal diagnostic subsystem's concept:
  - subsystem's model;
  - numerical criteria for subsystem's diagnostic evaluation and optimization;
  - the use of system's adaptive readiness against failures to increase strength;
  - algorithm for determining the system's level of comfort;
- Railway automation and telematics systems' elements' state evaluation using the degrees of validity:
  - the use of relative conformity and non-conformity coefficients in diagnostic tasks;
  - assessment of elements' parameters' or function's nature of change using state functions;
  - assessment of element's degree of state using set of state functions;
  - optimization of the operation's starting using critical values of non-compliance coefficients.
- Battery's state diagnosis with high accuracy:
  - battery's equivalent diagram;
  - battery's duality characteristics;
  - load generator's use in diagnostic tasks.

- Pulse relay's real-time diagnosis:
  - pulse relay's equivalent diagram with anchor's presence;
  - pulse relay's anchor's and contact systems' state diagnostic method.
- Electronic code transmitter with self-diagnostic function:
  - safety and security concept;
  - electronic code transmitter's security proof.

The practical application of results achieved in dissertation

Results achieved in the dissertation can affect the quality of maintenance and system's safety and security indices. In dissertation is given:

- pulse relay's anchor's and contact systems' state diagnostic method;
- electronic code transmitter with self-diagnostic function (LR patent LV14466);
- battery condition's diagnosis after the internal resistance method for increased precision;
- load generator's use in battery's diagnostic tasks (LR patent LV14473).

Dissertation's approbation

1. 11th Conference of Young Scientists of Lithuania „Science – Lithuania's Future. TRANSPORT", VGTU, Vilnius, Lithuania, 2008. Referāts „Источник питания аппаратуры СЦБ.Функциональные схемы".
2. 11th Conference of Young Scientists of Lithuania „Science – Lithuania's Future. TRANSPORT", VGTU, Vilnius, Lithuania, 2008. Referāts „Электронный датчик для систем железнодорожной автоматики".
3. The 49th International Scientific Conference "Power and Electrical Engineering", Riga Technical University, Riga, Latvia, 2009. Referāts „Application of electronic gauges for automatic devices diagnostics".
4. The 50th International Scientific Conference "Power and Electrical Engineering", Riga Technical University, Riga, Latvia, 2009. Referāts „Modernization of the universal measuring device for mechanic".
5. The 51th International Scientific Conference "Power and Electrical Engineering", Riga Technical University, Riga, Latvia, 2010. Referāts „Using compatible with load power supply on Latvian railway".
6. The 51th International Scientific Conference "Power and Electrical Engineering", Riga Technical University, Riga, Latvia, 2010. Referāts „Numerical criteria for diagnostic subsystems, RTU zinātniskie raksti".
7. 7th International Scientific Conference "TRANSBALTICA 2011", VGTU, Vilnius, Lithuania, 2011. Referāts „Automatic device with fault tolerance".
8. The 52th International Scientific Conference "Power and Electrical Engineering", Riga Technical University, Riga, Latvia, 2011. Referāts „Condition monitoring for electromechanical relays in railway automation".
9. The 52th International Scientific Conference "Power and Electrical Engineering", Riga Technical University, Riga, Latvia, 2011. Referāts „Electronic code transmitter ECT".
10. Starptautiskā konference „Intelligent Technologies in Logistics and Mechatronics Systems (ITELMS'2012)"Lietuva, Paņeveži, 3-5 may 2012. Referāts „Power Consuption and Control of Storage Batteries".
11. Starptautiskā konference „Intelligent Technologies in Logistics and Mechatronics Systems (ITELMS'2012)"Lietuva, Paņeveži, 3-5 may 2012. Referāts „Model of Diagnostic and Monitoring Subsystem".
12. International symposium and doctoral school of electrical engineering, dedicated to the 150th anniversary of Michael Dolivo-Dobrovolsky, Ronishi, Latvia, 24-26 may, 2012. Referāts „Dzelzceļa automātikas un telemātikas sistēmas monitoringa un diagnosticēšanas metožu izpēte un izstrāde".

13. Riga Technical University 53rd International Scientific Conference dedicated to the 150th Anniversary and the 1st Congress of World Engineers and Riga Polytechnical institute / RTU Alumni, Rīga, Latvija, 11-12 october 2012. Referāts „Test Point for Battery under Load".

Author's list of publications

1. Mezitis M., Karevs V. Test point for the battery under load, Riga Technical University 53rd International Scientific Conference dedicated to the 150th Anniversary and the 1st Congress of World Engineers and Riga Polytechnic institute //RTU Alumni, Rīga, Latvija, 11-12 October 2012 – 616 lpp.
2. Mezitis M., Karevs V. Power consumption and control of storage battery // In proceedings of 7th International Conference Intelligent Technologies in Logistics and Mechatronics Systems (ITELMS'2012), Lithuania, Panevezys, 2012, 91-97 lpp.
3. Mezītis M., Karevs V. Model of diagnostic subsystem // In proceedings of 7th International Conference Intelligent Technologies in Logistics and Mechatronics Systems (ITELMS'2012), Lithuania, Panevezys, 2012, 98-104 lpp.
4. Mezitis M., Karevs V. Automatic device with fault tolerance, Vilnius, VGTU, Journal: Transport, 2011 – 103-108 p.
5. Mezītis M., Karevs V. Automatic Measurement for Internal Resistance of Battery in Uninterruptible Power Source // RTU zinātniskie raksti. 4. sēr., Enerģētika un elektrotehnika. - 25. sēj. (2009), 141.-144. lpp.
6. Mezītis M., Karevs V. Modernized Universal Measuring Device for Mechanic // RTU zinātniskie raksti. 6. sēr., Mašīnzinātne un transports. - 30. sēj. (2008), 180.-185. lpp.
7. Mezītis M., Karevs V. Application of Electronic Gauges for Automatic Devices Diagnostics // RTU zinātniskie raksti. 6. sēr., Mašīnzinātne un transports. - 30. sēj. (2008), 186.-190. lpp

The developed patents and inventions

1. Mezītis Mareks, Karevs Vladimirs, Ivanovs Maksims.
   Latvian patent and invention Nr. 14466 „Electronic code transmitter".
2. Mareks Mezītis, Vladimirs Karevs.
   Latvian patent and invention Nr. 14473 „Battery's testing secondary tool".

1. General work's description

Dissertation's aim is to develop diagnostic and monitoring methods for railway automation and telematics systems' relay part.

The first part focuses on general issues of monitoring and diagnostic subsystem's design and maintenance costs' optimization using diagnostic results and the use of diagnostic subsystem optimized by the criteria; considered measuring instruments that are used in the diagnosis, their advantages and disadvantages, as well as development of the measuring instruments. Analysis of the cluster system design's advantages has been made.

The second part focuses on the issues that are associated with the processing of information in monitoring and diagnostic subsystems for maintenance starting point optimization; damage cause and effect relation's analysis has been made; object's diagnostic description has been carried out using the degree of validity and description of the state function parameters. In the second part a mathematical apparatus for the transition from the physical values to the relative coefficients is given.

The third part presents and analyzes a new monitoring and diagnostic method for maintenance-free battery. The method is based on the assessment of the internal resistance of the battery with a higher accuracy. Conditions for clarifying the internal resistance evaluation methods have been set out, as well as the subsequent load generator's usage possibilities for the battery's diagnosis.

The fourth part analyses electromechanical relays' monitoring and diagnostic methods. Controllable elements are divided by the degree of security and suitability for diagnosis.

Transition processes in impulse relay's coil are discussed and the anchor's effect on external electromagnetic field. As a result a new real-time electromechanical system status' diagnostic method is offered and algorithm for additional equipment construction is developed.

The fifth part is devoted to the development of new methods of diagnosing and monitoring of electromechanical code transmitter. Analysis of electromechanical code transmitter's electronic analogue is given. An electronic code transmitter's prototype that has been tested in real conditions on Latvian Railway is designed and developed. Prototype's level of security is numerically demonstrated and safety indicators are calculated.

2. Railway automation and telematics systems' monitoring and diagnostic tasks' formulation

Monitoring and diagnostic subsystem is a tool to gather information about system's components and technical condition (Health) of the system from the safety's point of view.

Diagnostic function provides system's elements' technical condition's assessment by characteristics and their changes.

This kind of diagnostic subsystem's primary function is to control management system's elements' technical indicators. Thus, element's technical parameters' values degree of reading's accuracy and number of parameters to be monitored (Depth) significantly affect element's functionality assessments.

Choice of service technologies depends on the presence of diagnostic subsystem and its possibilities. Maintenance techniques can be divided into the statistical (TBM - Time Based Maintenance) and those that use element's parameters monitoring during operation (CBM - Condition Based Maintenance) (figure 1)

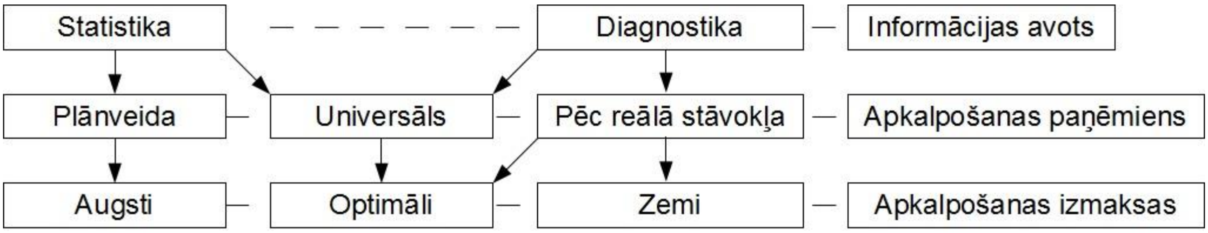


Figure 1. Maintenance techniques

Automation system's reliability's criteria release reliable elements from the argumentation for a partial capacity of work, which means that they are renovated during TBM procedure.

Coefficient of readiness - the possibility that the object will prove to be in functiona; condition at any selected time, except for scheduled periods during which the object is not intended for use and combines such concepts as reliability and repairability. Coefficient of readiness *AF* is borderline position of readiness function (figure 2) and is the probability of the system's running order within the time limit.

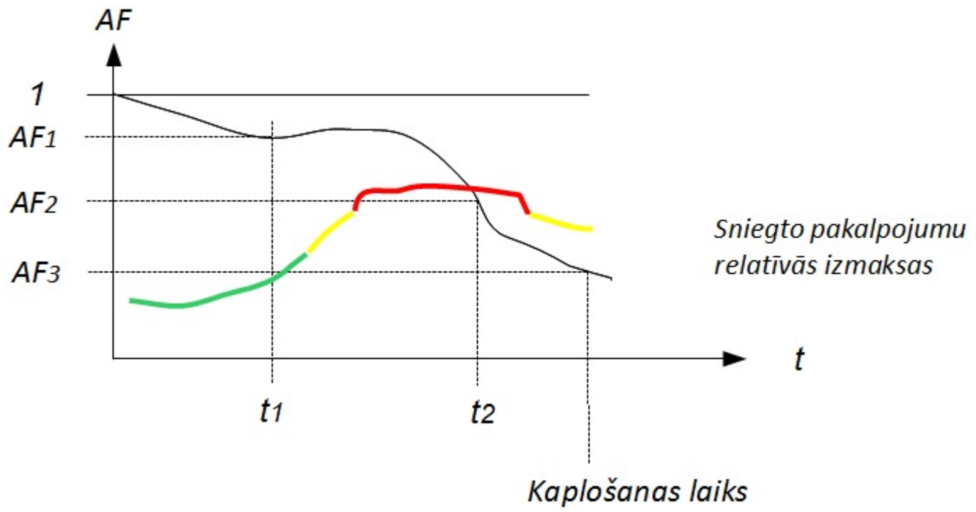


Figure 2. Readiness' function *AF(t, RCPS)* and running costs *RCPS*

During use of the control system the natural system's degradation occurs that is related to the wear and tear of the elements. Degradation of the system can be estimated by the degradation's coefficient size:

$$DgF = 1 - \frac{MTBF_{used}}{MTBF_{new}} = 1 - \frac{\lambda_{new}}{\lambda_{used}},$$

where $MTBF_{new}$ – average time of fail-safe operation of a new system;

$MTBF_{used}$ – average time of fail-safe operation for a renovated system;

λ_{new} - failure rate for a new system;

λ_{used} - failure rate for a renovated system.

In this way, system's safety function, or serviceable condition's probability using the coefficient of degradation (figure 3):

$$R_{used}(t) = e^{-\lambda_{used} \cdot t} = e^{-\lambda_{new} \cdot t \cdot (1-DgF)^{-1}}$$

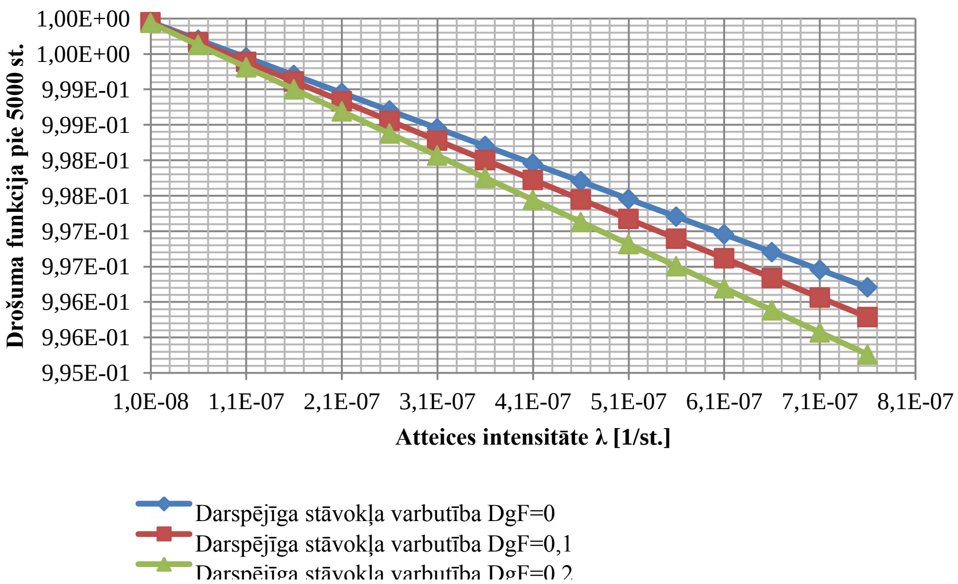


Figure 3. Safety function depending on coefficient of degradation

Service optimization strategy depends on the selected set of targets:

I. Coefficient of readiness $AF \rightarrow 1$;

II. Coefficient of degradation $DgF \rightarrow 0$;

III. Running costs per average service $RCPS \rightarrow min$.

Service according to the condition - CBM (Condition Based Maintenatce) is only possible when using a high-precision forecasting system based on deepened diagnostic functions, in which case the system will be optimal by the costs of RCPS (condition III).

However, for the coefficient of readiness' *AF* function to peak at CBM service, a elements' degradation coefficient *DGF* must be taken into account, which will not allow the decrease of value of the coefficient of readiness by introducing renovated elements instead of new ones into the system.

Usually, for starting diagnostic procedures the information about the symptoms that are associated with a particular type of event (Novelty) [22] is received, which may be malfunctioning, failure or damage:

$$\mathcal{F}(F_i) \rightarrow S(F_i) \ni \{s_i\},$$

where s_i – symptom;
F_i - event.

Correspondence "symptom - an event" increases rate of localization (Localization) of event's place, which in turn increases the system's coefficient of readiness. Event approval (Fault Detection) can be used for system's reconfiguration, which ensures system's failure sustainability (Fault Tolerance) or switching the system into a safe state (Fault Management).

Information processing algorithms' increase of "power" allows compensating for insufficient reliability of the information's source up to a certain degree.

Diagnostic subsystem in its composition includes hardware and software components. In order to analyze the different diagnostic subsystems' advantages and specific diagnostic optimization direction, as well as to compare the given options, it is necessary to introduce numerical criteria for assessing the quality of the execution of diagnostic functions.

Hypothetically, there are a number of possible subsystem's architecture sets that can ensure the requirements. Consequently, the requirements for diagnostic subsystem can have clearly defined criteria for assessing the subsystem:

$$Cr^{DSS} = (Cr^1, Cr^2, \dots, Cr^n, \dots, Cr^N)$$

where Cr^{DSS}- diagnostic subsystem's string of criteria;

Cr^n- n defined criterion. Reachable depth criterion's and used methods for estimating effectiveness and probability is given in dissertation. $PD(Prm) = \frac{Prm^D}{Prm^{\Sigma}} \cdot 100\%$.

Dissertation examines trends of criteria's usage possibilities for performance evaluation of the subsystem and service's starting point (Fig. 4). *Dir* (Direction) - Trend's criterion which characterizes diagnostic subsystem's quality and conformity of key objectives, according to the expression:

$$Dir = \begin{cases} 1, if\ P^{true} > r^{+} \cdot (Pr^{false} + Pr^{skip}) \\ 0, if\ P^{true} \cong r^{0} \cdot (Pr^{false} + Pr^{skip}) \\ -1, if\ P^{true} < r^{-} \cdot (Pr^{false} + Pr^{skip}) \end{cases} .$$

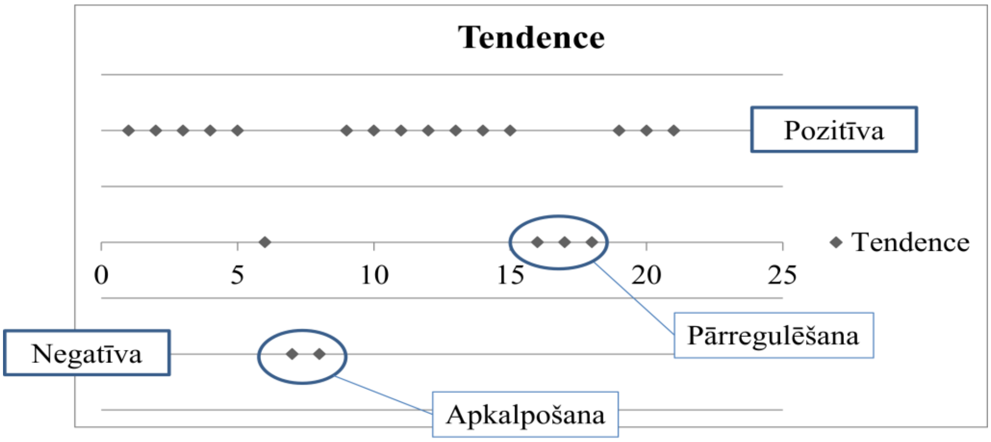


Figure 4. Use of trend criterion

Dissertation shows that a validation in its simple meaning is the validation of manufacturer's characteristics and properties. This means that testing is carried out by the manufacturer or developer, not all by the user’s appropriate methodology.

Diagnostic systems’ model provides the information flow about the current element’s functional state and uses instantaneous element’s withdrawal from the system for a period of time when element’s state does not affect functioning of the system and places only validated element back into the system.

If element’s withdrawal speed $SPEED_{replacement} \to \infty$, replacement frequency $F_{replacement} = const$, then validation interval is $T_{validation} = 2 \cdot (F_{replacement})^{-1}$.

Validation interval $T_{validation}$ defines information renewal’s flow’s speed.

Validation’s positive result is the element’s return into the system reason; otherwise element’s analogue remains in the system.

Results of validation procedure are placed in the level of validity’s degree:

$$DV(Idle) = \begin{cases} 1 \; if \; element \; is \; valid \\ 0 \; if \; element \; is \; not \; valid \end{cases}$$

Level of validity’s degree in a real diagnostic subsystem is expanded with a value according to the almost genuine condition and reflects system’s functioning deviation from the element’s status:

$$DV(Realization) = \begin{cases} +1 \; ja \; elements \; ir \; valids \\ \pm 0 \; ja \; elements \; ir \; kvazi \; valids \\ -1 \; ja \; \; element \; nav \; valid \end{cases} .$$

In the case of use of outstanding performance elements [21], then in the real system mean time between failures *MTBF* should be equal to or greater than the system's lifetime: MTBF ≥ LifeTime. However, not all elements of the subject can be executed brilliantly, or this execution raises non-foundedly system’s construction costs, therefore diagnostic methods for early detection of system-critical condition must be used.

Every element can be defined by safety function $R(t) = \frac{n(t)}{N}$ (figure 5).

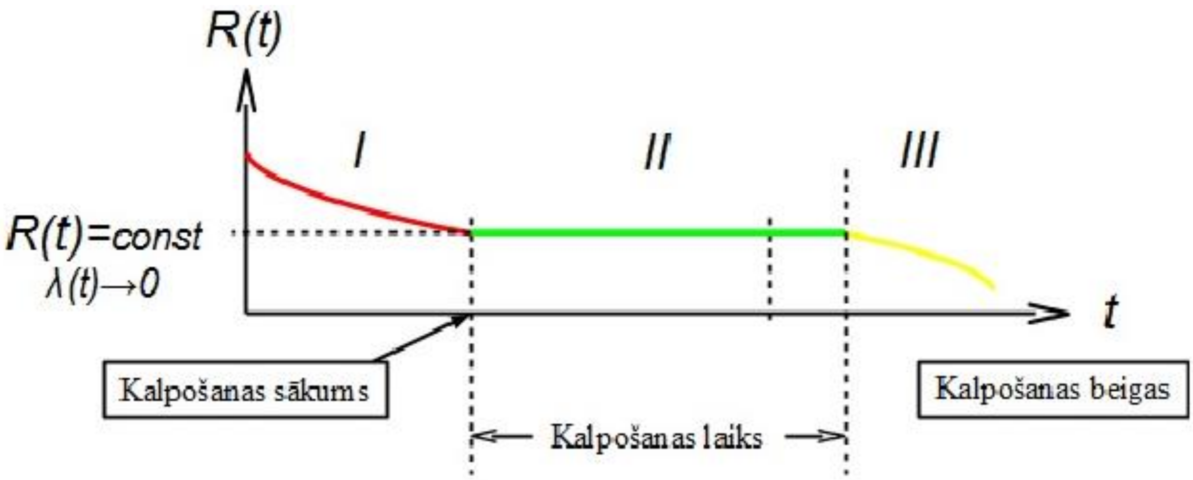


Figure 5. Safety function

Figure 6 shows an unexpected failure frequency's distribution during the year, where the parameter distribution is related to the operating conditions. Unexpected failure or damage probability for adopted system:

$$P_i^{ADAPT} = \sum_{Y=1}^{M} m_i(Y) \cdot AAF_i(Y) / \sum_{Y=1}^{N} \sum_{i=1}^{12} m_i(Y).$$

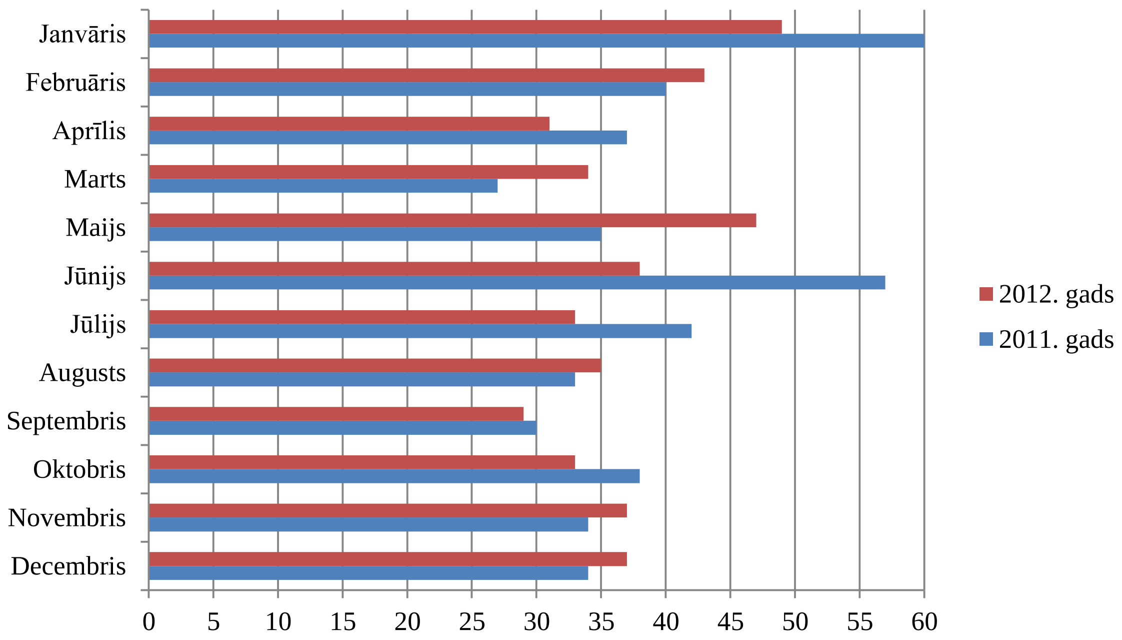


Figure 6. Unexpected failure's frequency during 2011 and 2012.

3. Parametric diagnosis

Implementation of service access by the real state requires determining the diagnostic results as well as validity of grade levels. (chart 1).

Table 1

Element's diagnostic results

Nr. of the element	0	1	2	…	…	n	…	…	N
0	$DV(0,0)$	$DV(0,1)$	$DV(0,2)$	…	…	$DV(0,n)$	…	…	$DV(0,N)$
1	$DV(1,0)$	$DV(1,1)$	$DV(1,2)$	…	…	$DV(1,n)$	…	…	$DV(1,N)$
…	…	…	…	…	…	…	…	…	…

m	$DV(m,0)$	$DV(m,1)$	$DV(m,2)$	…	…	$DV(m,n)$	…	…	$DV(m,N)$
…	…	…	…	…	…	…	…	…	…
M	$DV(M,0)$	$DV(M,1)$	$DV(M,2)$	…	…	$DV(M,n)$	…	…	$DV(M,N)$

The difference from [29], [34] examined approaches, where R_i^j Boolean algebra's value 1 for non-functional state and 0 for functional state is used for the result; in dissertation the three-digit system of degree of validity DV (m, n) is introduced, which is defined by +1 , ± 0, or -1 levels.

Element's parameter's state describes three-digit logical values:

$$SF(Prm,t,\tau) = \begin{cases} +1 \ \ if \ \ RDF(Prm,t) \leq RDF_{min.} \\ \pm 0 \ \ if \ \ RDF_{max.} > RDF(Prm,t) > RDF_{min.} \\ -1 \ \ if \ \ RDF(Prm,t) \geq RDF_{max.} \end{cases}$$

Planned service corresponds more with the ideal diagnostic subsystem's model's operation by validation frequency $T_{validation} \to 0$.

In relative non-compliance coefficients, element's parameter is described, as:

$$RDF(Prm) = \begin{cases} RDF_{(-)} = \left|\frac{Prm_{nom.} - Prm}{Prm_{nom.} - Prm_{min.}}\right| \\ RDF_{(+)} = \left|\frac{Prm_{nom.} - Prm}{Prm_{max.} - Prm_{nom.}}\right| \end{cases}.$$

Parameter's changes are described, using *RDF*:

$Prm = [Prm_{nom.}; Prm_{min.}; Prm_{max.}; RDF_{(-)}; RDF_{(+)}]$ vai $Prm = [Prm_{nom.};\ \Delta Prm_{(-)};\ \Delta Prm_{(+)};\ RDF_{(-)}; RDF_{(+)}]$.

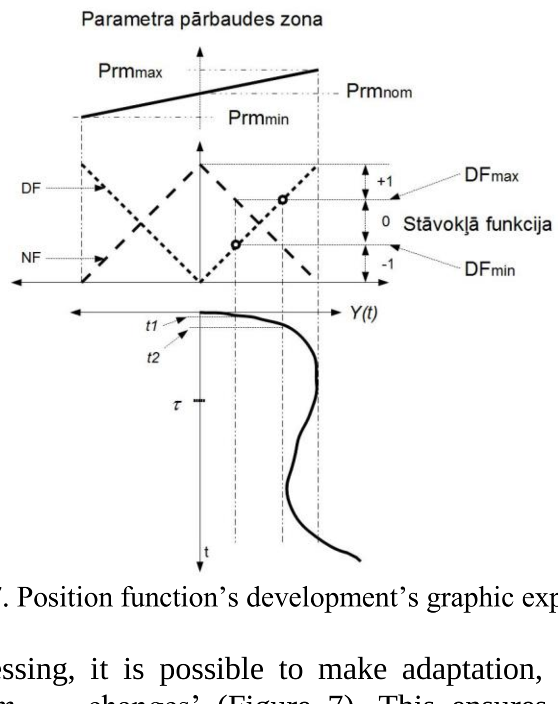


Figure 7. Position function's development's graphic explanation

During the processing, it is possible to make adaptation, using starting conditions $Prm_{nom.}$, $Prm_{min.}$, $Prm_{max.}$ changes' (Figure 7). This ensures flexibility of processing algorithm.

By this, element's degree of validity by observation of the set of parameters:

$$DV_{element} = \begin{cases} +1 \ if (RDF^1 \leq RDF_{min.} \wedge RDF^2 \leq RDF^2{}_{min.} \ldots \wedge RDF^k \leq RDF^k{}_{min.} \ldots \wedge RDF^K \leq RDF^K{}_{min.}) \\ \pm 0 \ if \begin{pmatrix} (RDF_{max.} > RDF^1 > RDF_{min.}) \wedge (RDF^2{}_{max.} > RDF^2 > RDF^2{}_{min.}) \ldots \\ \wedge (RDF^k{}_{max.} > RDF^k > RDF^k{}_{min.}) \ldots \wedge (RDF^K{}_{max.} > RDF^K > RDF^K{}_{min.}) \end{pmatrix} \\ -1 \ if (RDF^1 \geq RDF^1{}_{max.} \vee RDF^2 \geq RDF^2{}_{max.} \ldots \vee RDF^k \geq RDF^k{}_{max.} \ldots \vee RDF^K \geq RDF^K{}_{max.}) \end{cases}$$

Degree of validity in operators' form for set of parameters:

$$DV_{element} = \begin{cases} +1 \; if \;\; \sum_{k=1}^{K} SF^{k} = K \\ \pm 0 \;\; if \;\; \sum_{k=1}^{K} SF^{k} < K \;\; \prod_{k=1}^{K} SF^{k} \geq 0 \; \forall \; SF^{K} \geq 0 \\ -1 \;\; if \;\; \prod_{k=1}^{K} SF^{k} < 0 \end{cases}.$$

The number of monitored parameters K is conditioned with maximum consummation of diagnosis' depth in the subsystem. Thereby element's condition is described in relative values and information is widespread about the state of particular element in system, but not the information about the numerical values of the parameters (figure 8).

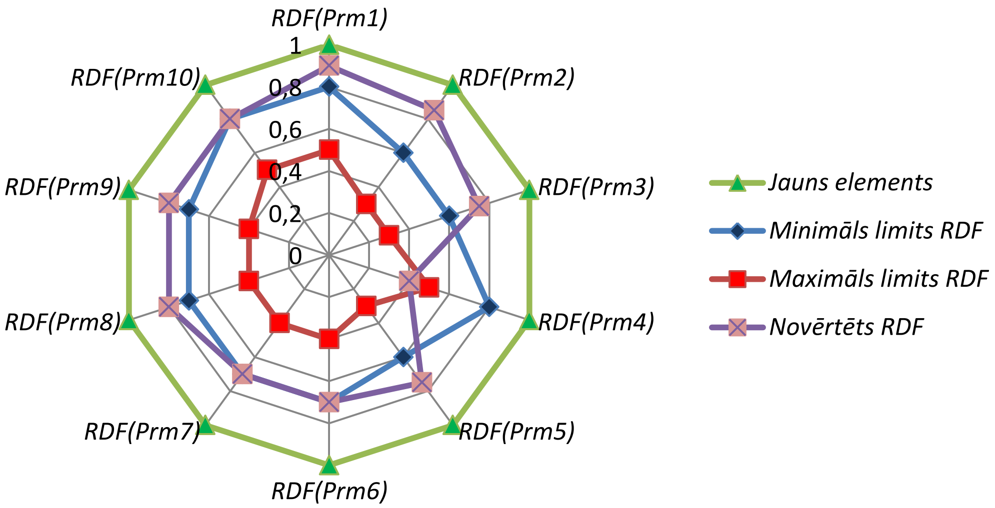


Figure 8. Condition function's example by set of parameters

In dissertation it is proven that such an approach, when for determining the state function information about the element is used that does not duplicate information on the system's functioning, allows ensuring the monitoring of system's elements by the operation of diagnostic subsystem.

DV elements' indicators' conveyor type calculating result is shown in figure 9.

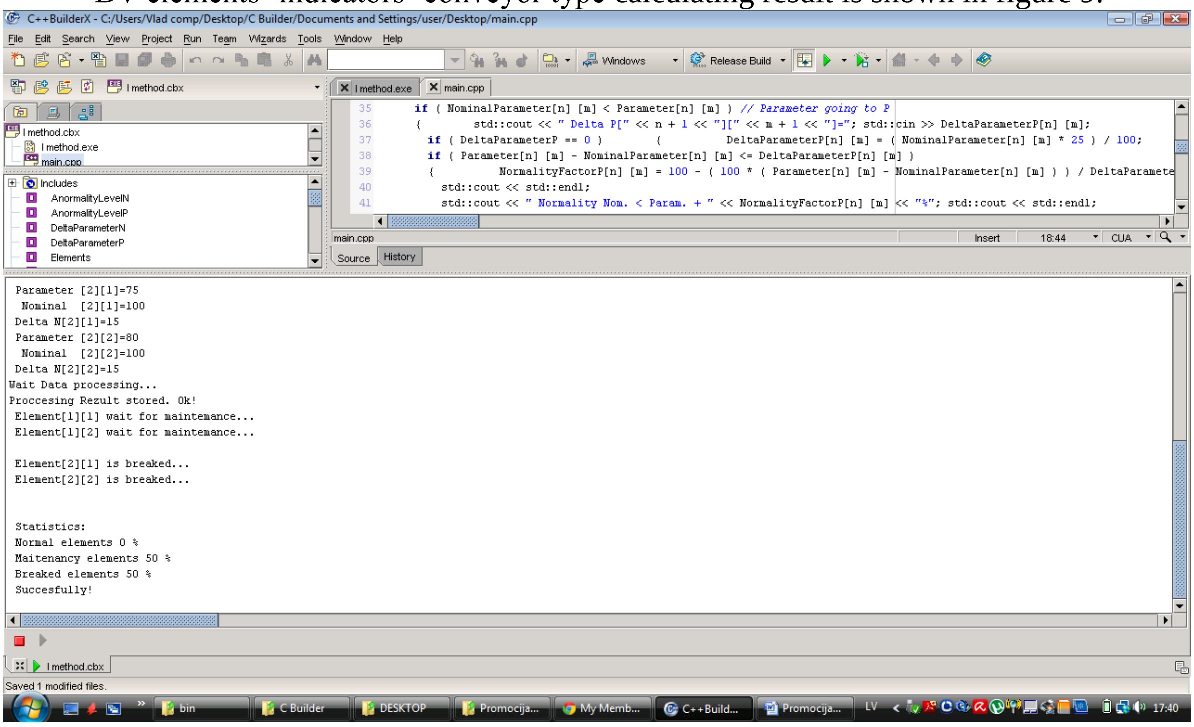


Figure 9. *DV* software for multiplying and decision making in automatic mode

After the rate of change of cell parameters two groups can be distinguished: elements of rapid and gradual changes [1][2] (figure 10).

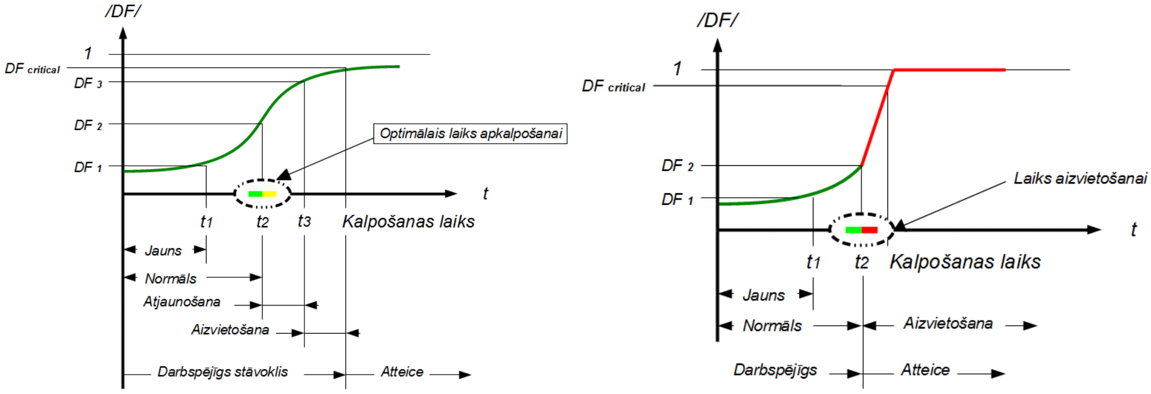


Figure 10. Determination of the moment by failure classification

Staff response rate is determined by the rate of change of the RDF in classification group and is the criterion for the appropriate repair service's selection (figure 11).

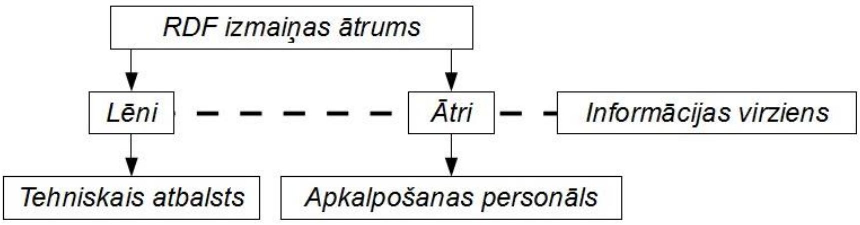


Figure 11. Information dissemination direction

4. Batteries' diagnosis

Battery in one moment of the time is the load with a specific function, which is related to electrical energy's storage, but at any other time moment it is a DC voltage source that provides additional or all required power for base load, depending on the power supply conditions (figure 12).

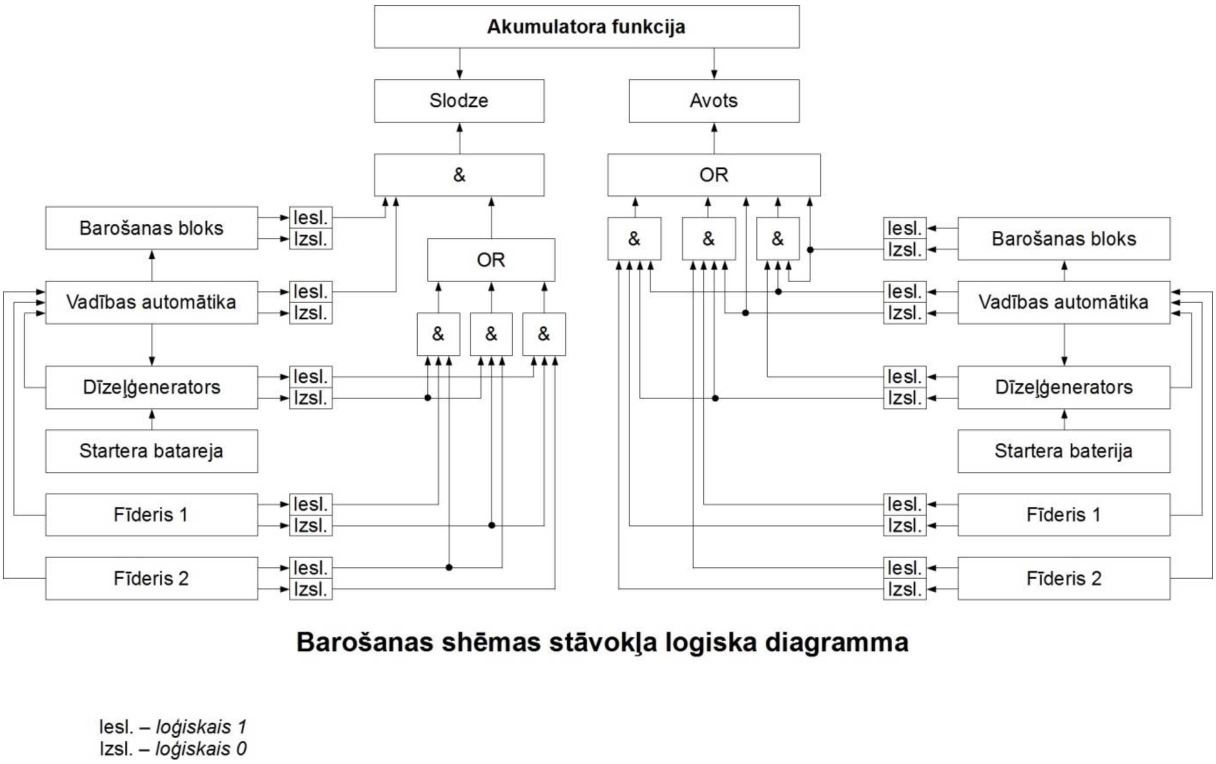


Figure 12. Logical explanation to the change of battery's function

By the manufacturer data it is possible to provide maintenance voltage adjustment depending on the ambient temperature, which allows saving battery's capacity in the whole temperature range:

$$if \quad T < T_{(-)}\,, then\ U_{Storage}^{Battery}(T) = N_{cells} \cdot \left(U_{Cell}^{Battery}(T_0) + k_{T_{(+\Delta U)}}^{Type_{Battery}} \cdot \left(T_{(+\Delta U)} - T\right) \right)$$

$$if \quad T = T_0\,, then\ U_{Storage}^{Battery}(T_0) = N_{cells} \cdot \left(U_{Cell}^{Battery}\left(Type_{Battery}\,, T_0\right) \right)$$

$$if \quad T > T_{(+)}\,, then\ U_{Storage}^{Battery}(T) = N_{cells} \cdot \left(U_{Cell}^{Battery}(T_0) - k_{T_{(-\Delta U)}}^{Type_{Battery}} \cdot \left(T_{(-\Delta U)} - T\right) \right).$$

Battery status' determination by the value of internal resistance is adopted $R_{int\ min.} \leq R_{int}^{measured} \leq R_{int\ max.}$ or by load's holding test:

$$\begin{cases} I_{load} = (0.1 \div 0.15) * C * st.^{-1} \\ U_{battery} \geq U_{battery\ nom.} \\ t_{load} \geq T_{load\ min.} \end{cases} .$$

In figure 13 battery's equivalent scheme with its self-discharge current's effect is given (self-discharge): $U_{battery}(t) = U_{battery}^{nom} - (I_{discharge}^{load}(t) + I_{discharge}^{self}(t, T)) \cdot R_{int}(t)$.

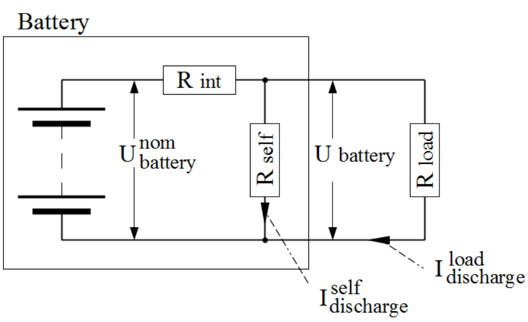


Figure 13. Battery's equivalent scheme

Summarizing internal resistace measurements carried out on A400 "Sonnenschein" 12V batteries, by the adopted at "Latvian Railway" rules of technical operation's instructions internal resistance's average value, measurement deviation is calculated and chart is offered: $R_{int}, U_{battery}^{storage}, n$ (figure 14).

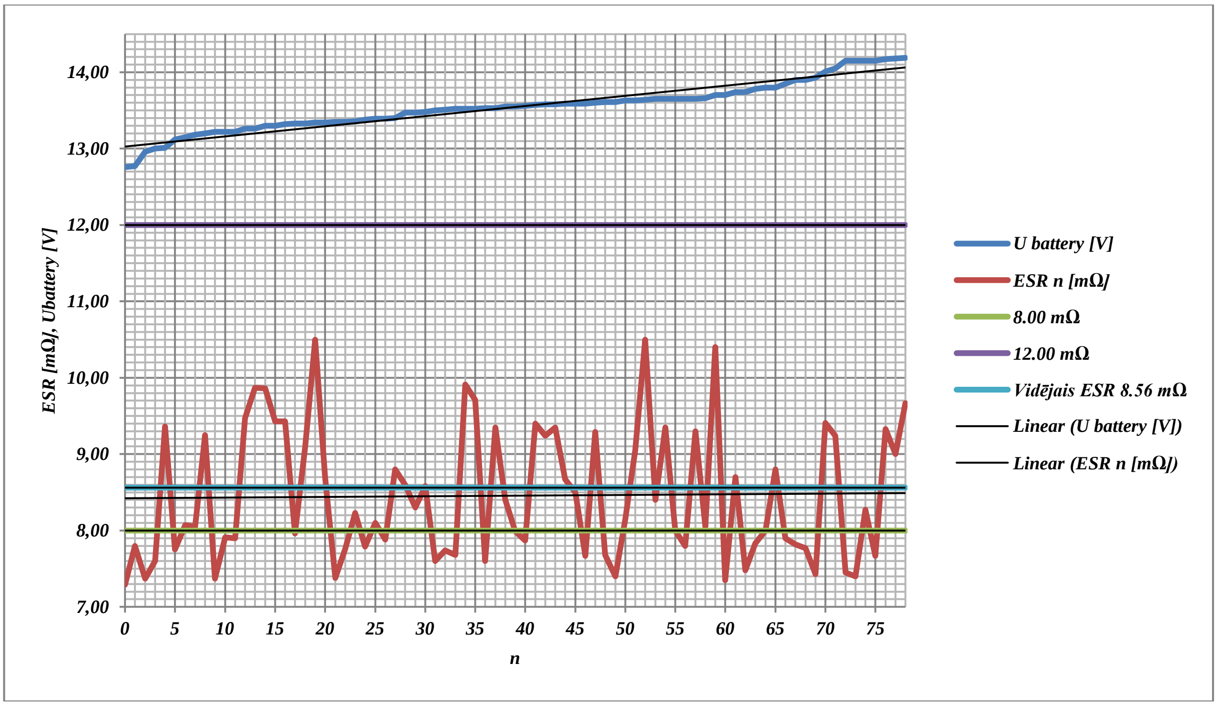


Figure 14. Chart $ESR = f(U_{battery}^{storage})$

Average value of internal resistance $R_{int}^{mean} = \frac{\sum_{n=1}^{N} R_{int}^{n}}{N} = 8{,}25\ m\Omega$ with measuring set's deviation after Cornfield's method $\Delta R_{int}^{measured} = 1.6\ m\Omega$. As a result: $R_{int}^{estimated} = 8.25\ m\Omega \pm 19.4\%$.

Battery's electrochemical properties allow expressing the following dependence. Positive current's change ΔI^{+} gives an increase of battery's remaining capacity $\Delta C_{battery}^{+}$ $\Delta C_{battery}^{+} = \Delta I^{+} \Delta t$ and negative current's change ΔI^{-} gives a decrease of battery's remaining capacity $\Delta C_{battery}^{-}$ $\Delta C_{battery}^{-} = \Delta I^{-} \Delta t$ (figure 15).

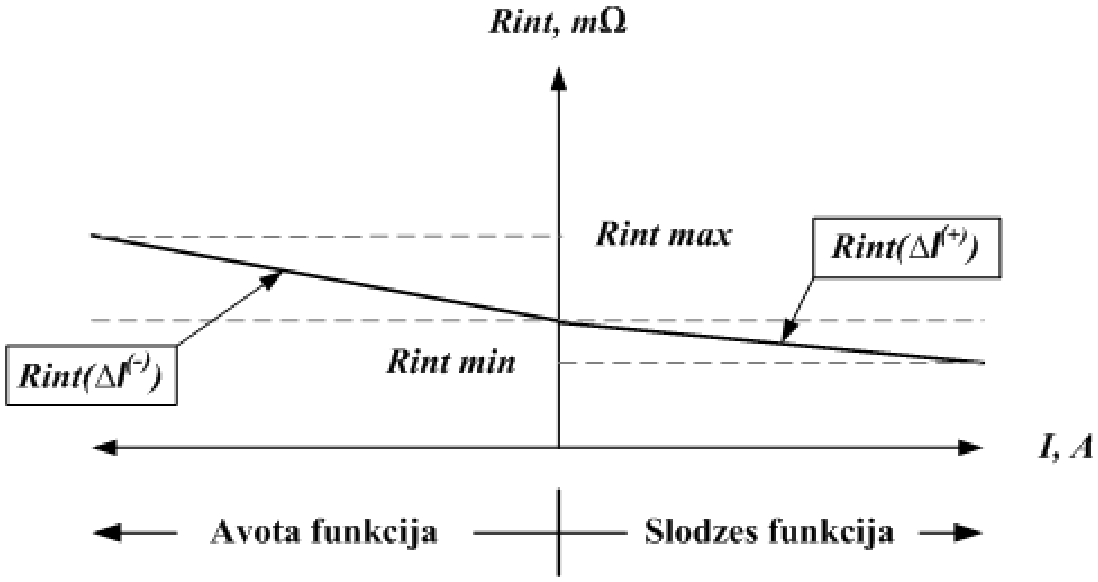


Figure 15. Battery's duality

In dissertation's presented battery's diagnosis' method it is allowed that during battery's load function and source's function, the parameters are different: $\left|\Delta C_{battery}^{-}\right| \neq \left|\Delta C_{battery}^{+}\right|$ and as a result $R_{int}^{+} \neq R_{int}^{-}$. In order to increase testing method's precision following state's conditions were introduced:

- During testing, battery performs source's function;
- A specific testing point was chosen for the battery (0.1÷0.15) · C [A] (Figure 16);
- Assessment of internal resistance occurs by load holding test's (5.5), (5.6), (5.7) positive results;
- Battery's condition is assessed by $\mathrm{R_{int}}(\Delta \mathrm{I}^{-})$, it excludes mistake, which is related with battery's function's duality (5.22);
- Additional equipment's connection is ensured at certain points.
  -

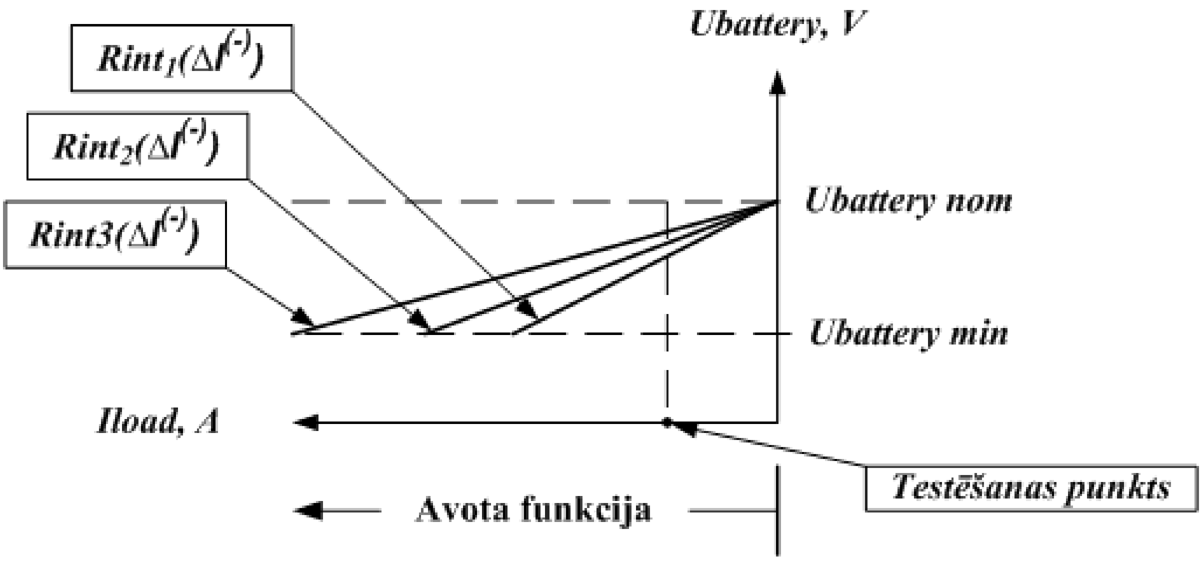


Figure 16. Battery's testing point

During dissertation an experiment was carried out to examine the impact of battery's duality on internal resistance evaluation. During the experiment measurements of five LC-X1224APG "Panasonic" 12V 24 A · hr. batteries were made. Measurements were ensured with the help of measuring tool "HiTESTER HIOKI3551". Measurement results are summarized in the table 2.

Table 2

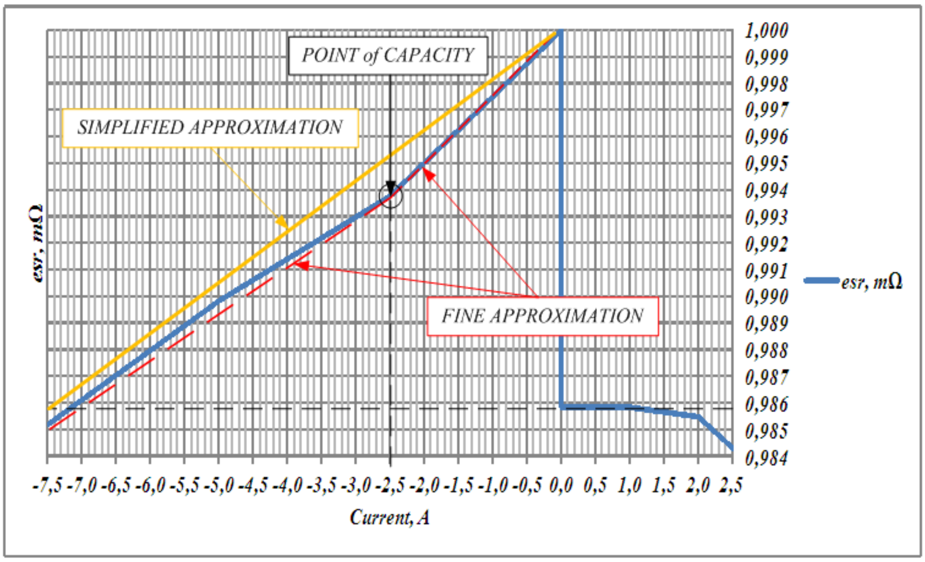
ESR measuring results of LC-X1224APG batteries

Function	***Source***				***Load***				
Current, A	***-7,5***	***-5,0***	***-2,5***	***0,0***	***0,0***	***0,5***	***1,0***	***2,0***	***2,5***
ESR[mΩ], bat. #1	12,73	12,78	12,84	12,91	12,73	12,73	12,74	12,73	12,71
ESR[mΩ], bat. #2	12,07	12,13	12,19	12,30	12,11	12,11	12,11	12,11	12,09
ESR[mΩ], bat. #3	12,75	12,81	12,87	12,95	12,74	12,74	12,74	12,74	12,73
ESR[mΩ], bat. #4	11,22	11,27	11,31	11,38	11,24	11,24	11,23	11,22	11,21
ESR[mΩ], bat. #5	10,72	10,78	10,80	10,85	10,71	10,71	10,71	10,71	10,70

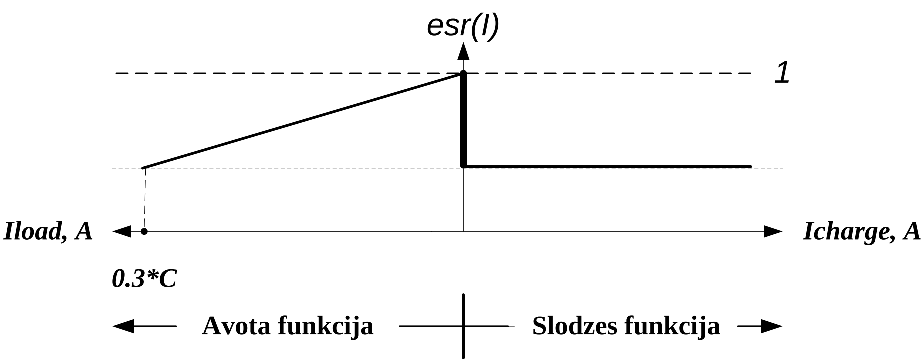
Graphically, the results are shown in Figure 16. The analysis of the results proves battery's duality.

Internal resistance's value is normalized by the value when battery's function is determined only by self-discharge current (Self Discharge) (Figure 17): $\overline{esr}(I) = \frac{1}{N} \cdot \sum_{n=1}^{N} \frac{ESR_n(I)}{ESR_n^{max}}$.

a)



b)



17. att. Normalized *ESR* dependence from battery's experimental a) and idealized b) function

Battery's condition's function at testing point $0.3 \cdot C$:

$$SF_{battery} = \begin{cases} +1 \ \ if \ \ esr(0.3 \cdot C) > esr_{max} \\ \pm 0 \ \ if \ \ esr_{max} \leq esr(0.3 \cdot C) < esr_{min} \\ -1 \ \ if \ esr(0.3 \cdot C) \leq esr_{min} \end{cases}$$

If testing point is not defined, but source function's current is defined $I_{discharge}$ and $0 > I_{discharge} \geq -(0.3 \cdot C)$, using expression it is possible to describe that $esr(I) \to esr(0.3 \cdot C)$ and to use the expression for determining battery status' function:

$$esr(I) \cong \frac{(ESR_{min} + \frac{|I_{discharge}|}{0.3 \cdot C} \cdot (ESR_{min} - ESR_{max}))}{ESR_{max}}.$$

Corrected *ESR* assessment:

$$ESR^{\text{corrected}}(I) = \frac{ESR(I) \cdot U_{battery}(t)/I^{load}_{discharge}(t)}{U_{battery}(t)/I^{load}_{discharge}(t) - ESR(I)} = \frac{ESR(I) \cdot R_{load}(t)}{R_{load}(t) - ESR(I)}.$$

To achieve testing point and to remove influence from main load's changing nature $R_{load} \neq const$ ($I^{load}_{discharge}(t) \neq const$) un self-discharge $I^{self}_{discharge}$, as well as to ensure load current's ΔI^{-} production, testing equipment needs to be merged with additional equipment, which scheme is shown in figure 18.

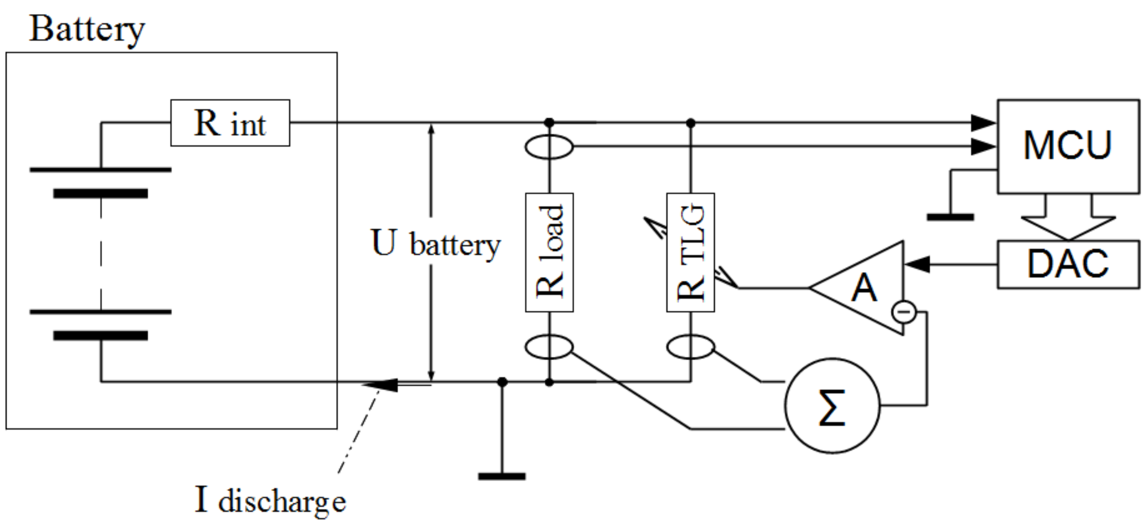


Figure 18. Additional equipment's realization's functional scheme

In dissertation additional equipment's work simulation is made. Simulation environment is made in Texas Instruments TINA-TI V9 for 12V battery with 10mΩ internal resistance (figure 19).

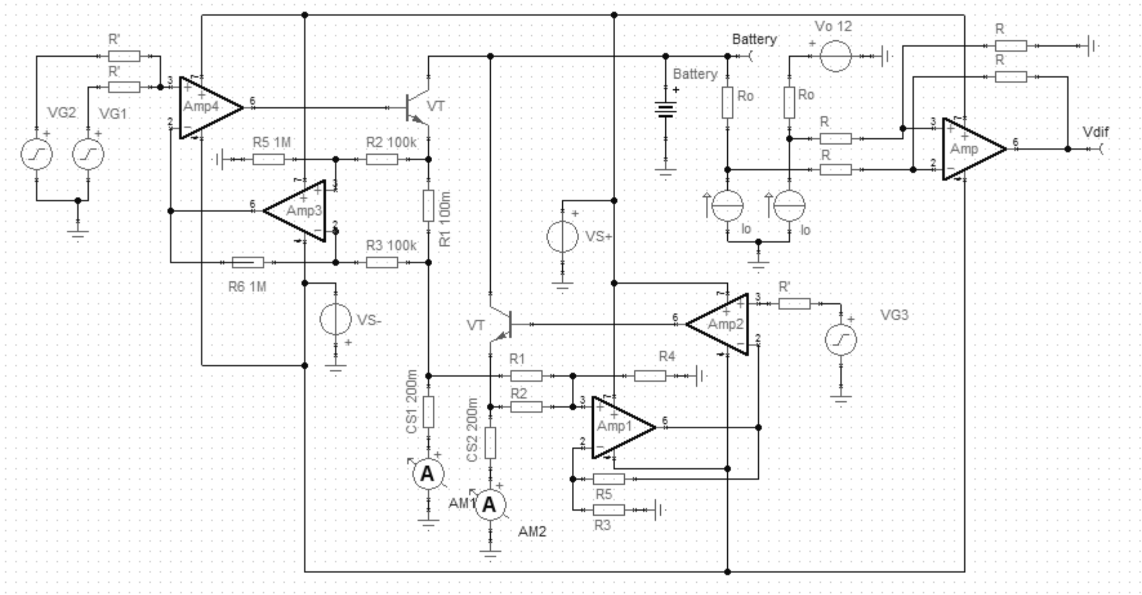


Figure 19. Simulation scheme

Simulation analysis shows that uneven manipulation of the load during the test forms uncontrollable load current peaks at the test point conversion moments. Practical use of trapeze (figure 20) or harmonic law for load manipulation. In both cases, uncontrolled peaks are not observed, but using the harmonic law requires additional equipment for signal detection.

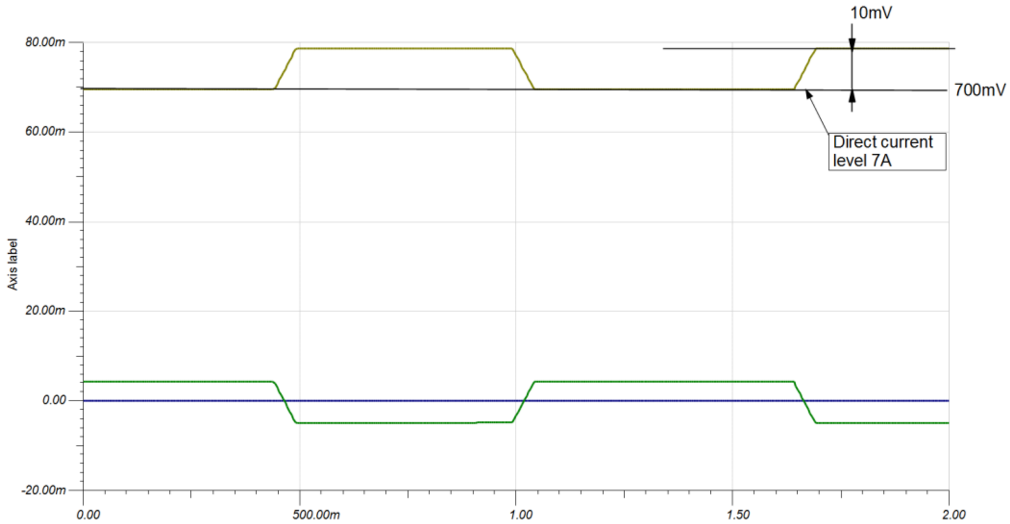


Figure 20. Law for manipulating with the load

5. Relay diagnosis

Railway automation and telematics system's relay equipment is divided into two groups according to compliance to safety rules; it is the first-class safety relays and others.

First-class safety relays are used as the basic elements in making of electrical interlocking circuits. Safety requirements are guaranteed with a contact state's change by the initiation's removal in all operating conditions. Degree of safety is achieved through the special design and is set for periodical replacement after 10 years. The relay structure and specificity of the use reduces the need for the establishment of additional equipment for diagnosis.

Other safety-class relays are a completely opposite picture. For example, pulse-repeater relay ТШ-65В with the intensity of contact engagement 2 times per second with switching power 300 V*A reaches an extreme state or 42 million engagements after 243 days.

Relation with scopes of use, pulse relay contacts and electromechanical part are subject to fast wear and tear. In Latvian Railway ТШ-65B relay is changed to renovated relay once a year. Counted with a partial restoration repairs, relay resource is reduced from time to time.

Loaded amount of energy in the relay coil in an electromechanical system with anchor. $E\left(L_{coil} + L_{anchor\ on}\ (\varDelta)\right) > E(L_{coil})$. In table 3 summarized inductance measurement results show that difference between values $L^1(\varDelta){-}L^2$, which is determined by anchor's anti-magnetic pin $\varDelta$[mm], is commensurable with measuring tool's inaccuracy ±1% and cannot be used for defining anchor's state as a credible assessment.

Table 3

ТШ-65 relay's inductance measurements' processing results

N	$\varDelta, mm$	$\bar{L}^1$, mH	ΔL^1, mH	$\bar{L}^2$, mH	ΔL^2, mH	$\bar{L}^3$, mH	ΔL^3, mH	$L_{anchor\ on}\ (\varDelta)$, mH
1	0,5	348.5	0.5	347.3	0.5	346.6	0.4	1.2
2	0,6	347.8	0.6	347.7	0.4	345.9	0.4	1.3
3	0,7	349.1	0.5	347.7	0.5	346.1	0.4	3.0

After the end of initiation, magnetic energy stored during coil's inductance creates a voltage pulse in interval T3. During the moment t5 is observed anchor's defection impact on the transition process (figure 21).

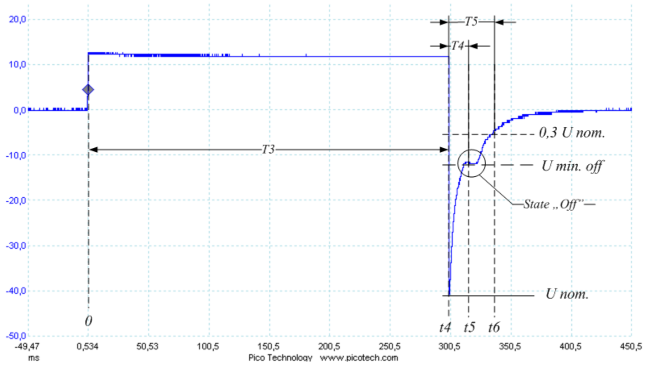


Figure 21. Transition process in relay's coil after removal of initiation

The effect from the anchor's dynamics impact observed in figure 21 is considered in the equivalent scheme shown in figure 22.

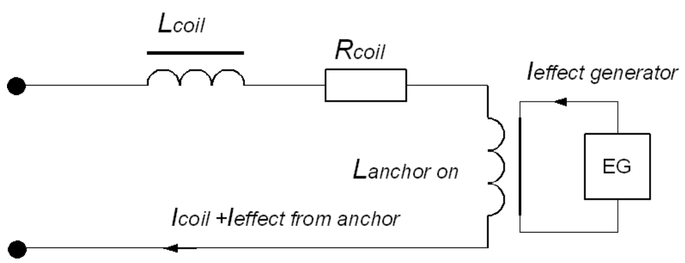


Figure 22. Relay's equivalent scheme with anchor's presence effect

$\varDelta$ un Pr state assessment using properties of the transition process which are associated with the anchor's dynamics effect.

In that way, transition process after removal of power pulse:

$$U_{coil}(t) = f(U, R_{coil}, L(t, \Delta, Pr)).$$

After the transition process analysis it is concluded that the pulse position in time axis depends on the contact pressure Pr and Δ hardening and there is an interconnection:

$t_5(\Delta_1, Pr_1) < t_5(\Delta_2, Pr_2)$ $when$ $\Delta_1 > \Delta_2$ & $Pr_1 \approx Pr_2$ and
$t_5(\Delta_1, Pr_1) < t_5(\Delta_2, Pr_2)$ $when$ $\Delta_1 \approx \Delta_2$ & $Pr_1 < Pr_2$ and
$t_5(\Delta_1, Pr_1) < t_5(\Delta_2, Pr_2)$ $when$ $\Delta_1 > \Delta_2$ & $Pr_1 < Pr_2$,

that gives a chance to assess the hardening Δ, or anchor's degree of wear and tear and pressure's Pr decrease, in real-time, using t_5^{min} value.

Analyzing in figure 23 difference signal between relays and anchors «a4» and «a6» with different hardening values $\Delta_{a4} = 0.62\ mm$ and $\Delta_{a6} = 0.26\ mm$ was established that $\Delta_{aN1} \cong \Delta_{aN2}$, or $(\Delta_{aN1} - \Delta_{aN2}) \to 0$ then difference signal $\to 0$. Δ_{aN1} is valid anchor's minimum acceptable hardening, then difference signal sign (+) after time moment $t_5(\Delta_{aN2})$ describes the anchor with an invalid hardening.

Conclusions allow creating a set of diagnostic methods based on differential pulse time moment's dependency on hardening state.

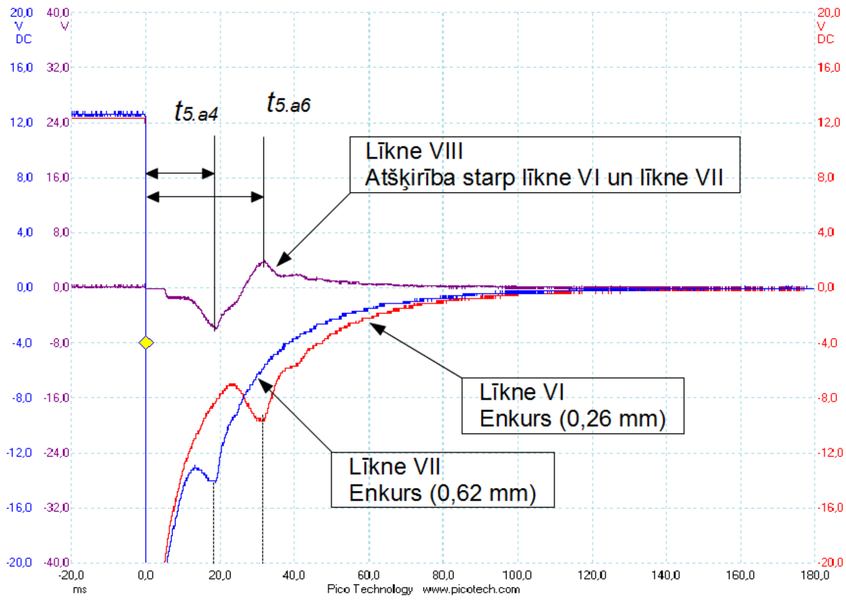


Figure 23. Difference signal

According to conclusions functional circuits of the diagnostic device are designed (figure 24, a)), that allow determining faulty hardening, or $SF_{anchor}(\Delta) = -1$ and (figure 24, b)) that allows determining:

$$SF_{anchor}(\Delta) = \begin{cases} +1\ if\ Signal < 0 \\ \pm 0\ if\ Signal = 0 \\ -1\ if\ Signal > 0 \end{cases}.$$

a)

b)

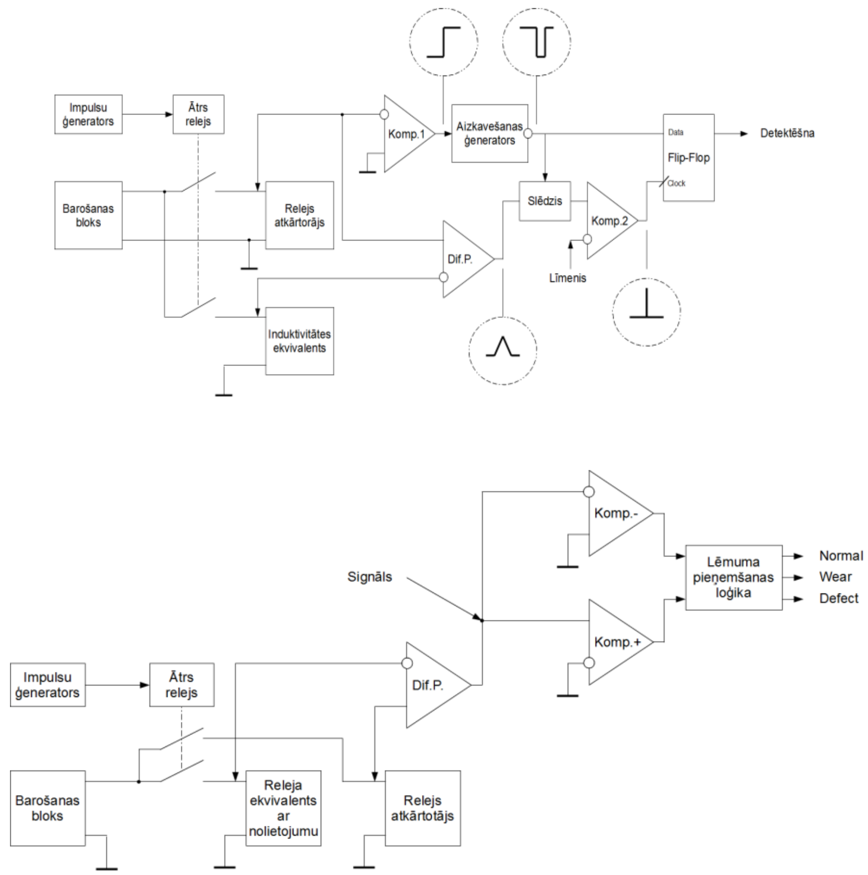


Figure 24. Anchor’s hardening suitability defining methods’ functional schemes

Test equipment’s TST-2 structure provides information shifting depending on the diagnostic results. TST-2 controller board contains a connector that allows connecting to a computer via an RS-232 interface or CAN via an RS-485 interface (figure 25). TST-2 can be used as additional equipment and control relay characteristics in real time or after the renovation’s output control

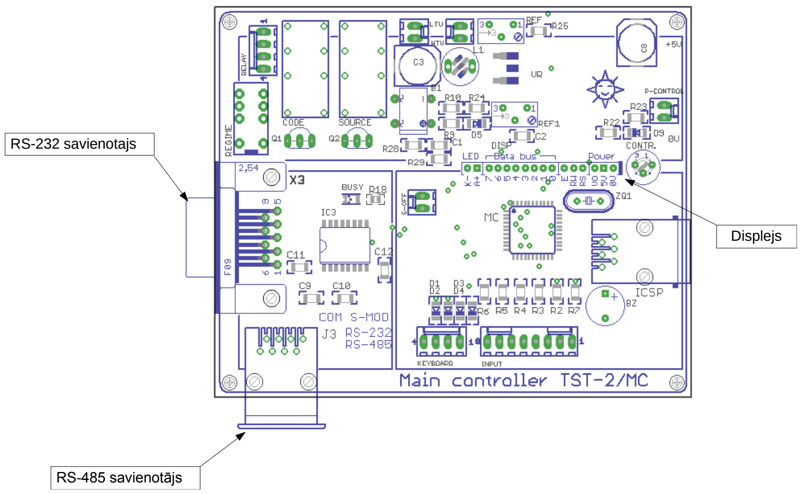


Figure 25. TST-2 main controller’s printed board

Time parameter $t5(\Delta, Pr)$ can be taken as a unique for relay-repeater. Anti-magnetic pins and contact pressure diagnosis ensures increase of reaching the depth from 23% to 41%

$$PD(Prm) = \frac{Prm^D}{Prm^\Sigma} \cdot 100\% = \frac{7}{17} \cdot 100\% \cong 41\%.$$

6. Code transmitter's diagnosis

For electromechanical code transmitter (EMCT) diagnosis problem's solution with a complex electromechanical device parameters' monitoring, but in general it does not remove costs related to the EMCT replacement for the restoration, preventive repair and during recovery service. EMCT diagnostic methods' development tasks are converted to an electronic code transmitter ECT creation with built-in self-diagnosis.

At first it is important to look at the electronic devices used in critical application areas for security and safety issues [54-74]. Railway automation and telematics systems' safety assurance is subject to strict [55-61] [68] standards, recommendations and legislative documents. The analysis of these documents and recommendations allows determining the strategy to achieve the maximum level of safety (figure 26).

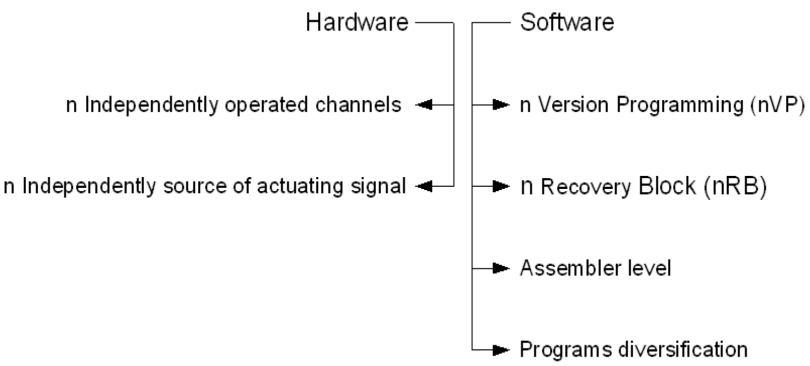


Figure 26. Safety strategy

PFD^* and λ^{**} are mutually compatible with expression $PFD = 1 - e^{-(\lambda \cdot LifeTime)}$ and $\lambda = \frac{-ln(1-PFD)}{LifeTime}$. Required life time is 20 years, and then it is possible to establish requirements for dangerous failure intensity (table 3).

Table 3

Dangerous failure rate for 20-year service life in accordance with SIL

SIL-safety integrity level	Functioning with interruptions		Functioning without interruptions	
	PFD^*	$\lambda(20\,year)^{**}$[st.$^{-1}$]	PFD^*	$\lambda(20\,year)^{**}$[st.$^{-1}$]
1	10^{-2}	$5{,}7{\cdot}10^{-8}$	10^{-6}	$5{,}7{\cdot}10^{-12}$
2	10^{-3}	$5{,}7{\cdot}10^{-9}$	10^{-7}	$5{,}7{\cdot}10^{-13}$
3	10^{-4}	$5{,}7{\cdot}10^{-10}$	10^{-8}	$5{,}7{\cdot}10^{-14}$
4	10^{-5}	$5{,}7{\cdot}10^{-11}$	10^{-9}	$5{,}7{\cdot}10^{-15}$

* - probability of failure on demand
** - demanded failure rate

Split of functions (figure 27) allows minimizing the amount and simplifies microcontroller software in channels; it even allows for controlling device to implement the necessary decoding algorithm. In this way, the basic function's execution is independent of the control algorithm (Control Algorithm) and, in turn, control algorithm's execution does not affect the basic functions' secure execution.

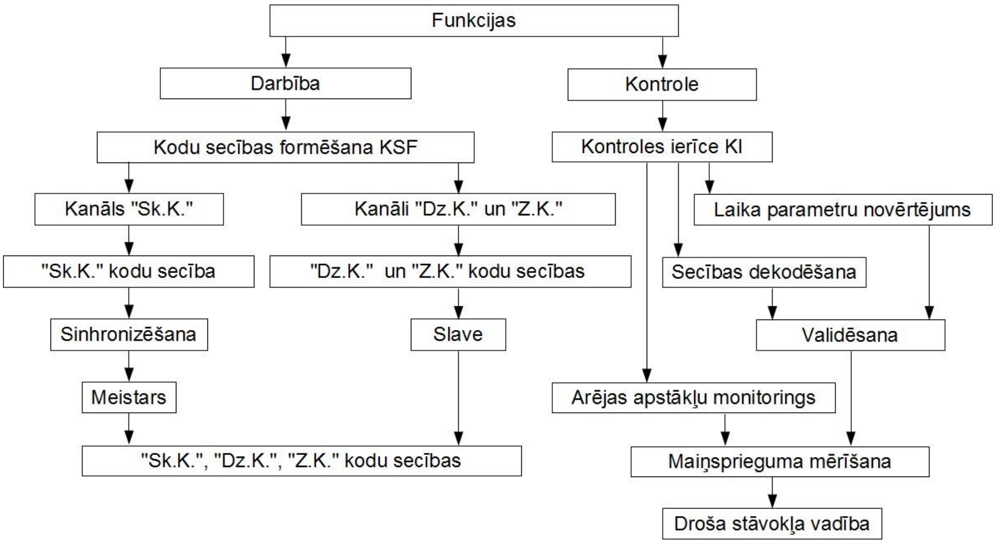


Figure 27. Distribution of functions in ECT

Electronic code transmitter's prototype "KPT-E" is designed and developed in dissertation which has been experimentally operated for 2 years in real-life conditions in Latvian Railway.

The goal of safety approval is to determine prototype's SIL level. Safety calculation was made in accordance with ГОСТ Р 27.301-95 Н and MIL-HNDB-217 [36] methodologies.

ECT prototype's failure intensity's calculation is simplified by identical structure of the channels:

$$\lambda^{\text{KPT-E}}_{\text{estimated}} \cong \lambda^{\text{CU}}_{\text{estimated}} + 3 \cdot \lambda^{\text{RED channel}}_{\text{estimated}}.$$

The failure intensity of control device:

$$\lambda^{\text{CU}}_{\text{estimated}} \cong 3{,}953635746 \cdot 10^{-6} [st.^{-1}].$$

The failure intensity of channels „Sk.K.", „Dz.K." and „Z.K.":

$$\lambda^{\text{GREEN channel}}_{\text{estimated}} \cong \lambda^{\text{YELLOW channel}}_{\text{estimated}} \cong \lambda^{\text{RED channel}}_{\text{estimated}} = 3{,}167567387 \cdot 10^{-6} [st.^{-1}].$$

ECT prototype's failure intensity:

$$\lambda^{\text{KPT-E}}_{\text{estimated}} \cong 13{,}456337907 \cdot 10^{-6} [\text{st.}^{-1}].$$

Mean time before failure:

$$\text{MTBF}^{\text{KPT-E}}_{\text{estimated}} = \left(\lambda^{\text{KPT-E}}_{\text{estimated}}\right)^{-1} \cong 74314 \text{ [st.]}$$

MTBF requirement is 43824 hours. This means that required MTBF is achieved with coefficient 1.7.

Using *FTA* (Fault Tree Analysis), safety failure's circumstances and time before achieving have been defined:

- ✓ occurs after KI control device's power circuit's failure during ECT's starting time, when power is not supplied to the KSF moulder:
  $$t^{KI\ bar.\ sh\bar{e}ma}_{Dro\check{s}s\ st\bar{a}voklis} \rightarrow 0;$$
- ✓ occurs after KI control device's power circuit's failure ECT with normal startup, when power is switched off from the KSF moulder and filter's capacitors Cf1, Cf2, Cf3 discharge:
  $$t^{\text{KI bar. shēma}}_{\text{Drošs stāvoklis}} \cong T^{715}_{\text{kods}} \leq 1.7 \text{ [s]};$$
- ✓ in the KSF moulder in case of at least one link's failure detection time is determined by the KI control device's operation and operates by two non-validated sequences:
  $$t^{KSF\ kan\bar{a}ls}_{Atteices\ detekt\bar{e}\check{s}ana} \leq 2 \cdot T^{515\,/\,715}_{kods};$$

- ✓ time interval after at least one link failure up to a safe condition with the filter capacitors' discharge:

$$t^{KPT-E}_{Drošs\ stāvoklis} \leq t^{KSF\ kanāls}_{Atteices\ detektēšana} + t^{KI\ bar.\ shēma}_{Drošs\ stāvoklis};$$

- ✓ ECT with code numerical sequence according to EMCT 515 type:

$$t^{KPT-E\ 515}_{Drošs\ stāvoklis} \leq 2 \cdot 1.6 + 1.7 = 4.9\ [s];$$

- ✓ ECT with code numerical sequence according to EMCT 715 type:

$$t^{KPT-E\ 715}_{Drošs\ stāvoklis} \leq 2 \cdot 1.86 + 1.7 = 5.42\ [s];$$

- ✓ The maximum time after which the switching into a safe state occurs:

$$t^{KPT-E\ max.}_{Drošs\ stāvoklis} = 5.42\ [s].$$

Dangerous failure intensity for KPT-E prototype:

$$\lambda^{KPT-E}_{Bīstams\ stāvoklis} \approx t^{KPT-E\ max.}_{Drošs\ stāvoklis} \cdot \left(\lambda^{KSF\ "Sk.K"}_{apr.}\right)^2. \quad (5.5)$$

Calculated dangerous failure's indicator after formula (5.5) is

$$\lambda^{KPT-E}_{Bīstams\ stāvoklis} = 1.51059663 \cdot 10^{-14}\ [h^{-1}].$$

Dangerous failure intensity for 20-year lifetime complies with the third level security requirements (SIL 3) for functioning without interruption

General conclusions

Railway automation and telematics system's operation analysis is given in dissertation. A number of critical moments are revealed that affect systems' and equipment safety, which in turn affects repair and maintenance technology and as a result may reflect on train movement safety. Stressed that important automation systems' safe and secure work's component is advanced real-time parametric diagnostic system that allows moving to the CBM - Condition Based Maintenance technology instead of TBM - Time Based Maintenance.

The dissertation shows that approach, when one element of the system is changed to renovated or repaired element without a specific element's component aging inventory and usage safety, availability coefficient or maintenance period calculation as a result can lead to an accumulation of errors and to an incorrect result in system's functioning safety assessment.

For accounting work of elements' natural wear and tear and aging the concept of DGF rate of degradation is introduced. This coefficient represents the fail-safe time with renovated elements' relation to the system's fail-safe time with new elements. As a result, system performance reliability can be specified as a function of:

$$R_{used}(t) = e^{-\lambda_{used} \cdot t} = e^{-\lambda_{new} \cdot t \cdot (1-DgF)^{-1}}.$$

Main parametric diagnostic system's development's new concept rules for railway automation systems are described in the dissertation that operate in real time mode with an elements' failure prediction by coefficients of conformity *DV* that are set in many parameter's $\{SF^K\}$ state functions:

$$DV_{element} = \begin{cases} +1\ if\ \sum_{k=1}^{K} SF^k = K \\ \pm 0\ if\ \sum_{k=1}^{K} SF^k < K\ \ \prod_{k=1}^{K} SF^k \geq 0\ \forall\ SF^K \geq 0 \\ -1\ if\ \prod_{k=1}^{K} SF^k < 0 \end{cases}$$

Criteria $\mathrm{Cr}^{\mathrm{DSS}} = (\mathrm{Cr}^1, \mathrm{Cr}^2, \ldots, \mathrm{Cr}^n, \ldots, \mathrm{Cr}^N)$ are established and their usage in optimization, usage, job evaluation, diagnostic system as a whole. Formula is developed for establishing diagnostic system's quality and compliance's assigned conditions of functioning

:

$$Dir = \begin{cases} 1, if\ P^{true} > r^{+} \cdot (Pr^{false} + Pr^{skip}) \\ 0, if\ P^{true} \cong r^{0} \cdot (Pr^{false} + Pr^{skip}) \\ -1, if\ P^{true} < r^{-} \cdot (Pr^{false} + Pr^{skip}) \end{cases}$$

Based on the signaling systems' allowed and used analysis of measuring instruments, a necessity for use of special measurement algorithm is concluded that excludes operator's errors and that could be realized in advanced measuring tool.

Based on the statistical data analysis about damage or failure of automation systems, it is detected that the failure intensity's dependence on the moments of usage failure and the reduction of failure possibility while system's downtime during standby realization. On this basis, the adapted coefficient of readiness is introduced, which is calculated as:

$$AAF \approx \frac{MTIO}{MTIO+MTIW}.$$

The battery diagnostics analysis, which used in railway automation systems, there is detected such a characteristic as the battery's duality, which directly affects the battery's technical parameters' evaluation accuracy. Dissertation offers a new approach to the assessment of the battery status without switching it off the circuit, which takes into account mentioned property. The new method makes it possible to evaluate the *ESR* (Effective Serial Resistance) parameter under load and bring it to the value in the selected test point:

$$SF_{battery} = \begin{cases} +1\ \ if\ \ esr(0.3 \cdot C) > esr_{max} \\ \pm 0\ \ if\ \ esr_{max} \le esr(0.3 \cdot C) < esr_{min} \\ -1\ \ if\ esr(0.3 \cdot C) \le esr_{min} \end{cases}$$

Accuracy of the method was verified by software simulation, laboratory and natural (field) experiments. Mentioned generator was developed, tested by simulation and patented for load for the method's realization.

Based on the pulse relay's ТШ-65 functionality assessments, it was found that the use of current diagnostic methods do not allow switching to the Condition Based Maintenance (CBM). During measurement experiments a strong relation between EMF initiation's nature and anti-magnetic anchor's hardening depreciation was revealed. Within the dissertation's given anti-magnetic hardening depreciation evaluation methods allow for increasing the reach of diagnostic systems depth by assessing the parameters up to 40%, thus making it possible to withdraw from the elements' time based maintenance technology. In the course of the dissertation a diagnostic measurement device for ТШ-65 pulse relays is designed, developed and tested.

As a result, the evolution of railway automation hardware security and safety requirements' analysis and developed concepts, when main functions are separated from the diagnostic functions has led to the development of self-diagnostic electronic code transmitter, which is an analogue to used mechanical code transmitter and is the main train movement safety assurance system's element. It was found that the use of developed approach increases the hardware's reliability and security, while lowering costs, performs BITE technology that does not increase the proportion of equipment. The dissertation cites safety indicators' calculation, such as:

- dangerous failure intensity indicator:

$$\lambda^{KPT-E}_{Bīstams\ stāvoklis} = 1.51059663 \cdot 10^{-14} [h^{-1}];$$

- probability of dangerous failure during the 20-year lifetime:

$$PFD = 2.63823995983 \cdot 10^{-9}.$$

- mean time before repair:

MTBF = 74314 [h].

Calculation's indicators confirm device's level of security - SIL3 which complies with the requirements of railway automation systems. Self-diagnosis depth achieving indicator is 80%.

The device has obtained an invention patent, and a problem of device certification at an independent accredited certification center was being solved during dissertation's submission.

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129. *RU* ***2411151*** *Трансмиттер бесконтактный кодовый путевой резервируемый (БКПТ-Р)*