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SIMULATING THE DYNAMIC OF SUPERMASSIVE BLACK HOLES ON THE FORMATION OF DWARF GALAXIES

Abstract: *This study explores the influence of supermassive black holes (SMBHs) on the formation and evolution of dwarf galaxies. It addresses the limited understanding of SMBH prevalence and their feedback effects in low-mass galactic environments. Using observational data from the Hubble Space Telescope (HST), Chandra X-ray Observatory, and the James Webb Space Telescope (JWST), along with spectroscopic analysis and computational simulations, the study examines SMBH signatures, star formation impacts, and structural effects. The methodology integrates multi-wavelength imaging and hydrodynamic modeling to assess how SMBHs regulate gas dynamics and star formation. Key findings suggest that SMBHs exist in many dwarf galaxies, influencing both galactic morphology and evolution through feedback processes. The results contribute to refining galaxy formation models by highlighting SMBH activity outside massive galaxies. Practical implications include improved SMBH detection in low-luminosity environments and enhanced simulation parameters for early-universe modeling. This research fills gaps in SMBH studies by aligning theoretical models with emerging observations, offering a new lens on galactic evolution and the role of black holes in the early cosmos.*

Key words: *Supermassive Black Holes, Dwarf Galaxies, Star Formation, Galaxy Evolution, Astrophysical Simulations.*

Language: *English*

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1. Introduction

1.1. Research Background

Normally supermassive black holes are found in large galaxies where they were consider crucial for

building the galactic structure influencing the star formation and even regulating the gas dynamics of the galaxies. New findings indicate that SMBHs might also be present in dwarf galaxies, less massive systems in terms of stars and gases. Investigation of SMBHs in such environments is important since it contradicts the standard theories of galaxy formation and evolution.

Knowing about SMBHs inside dwarf galaxies might show ideas on the way such black holes come into being and increase their size across cosmic periods. If large black holes are frequent in dwarf galaxies, it implies that they could exist in the universe's early stages and might have served as the basis for the much larger black holes seen in large galaxies today. Such facts have an effect on the models of black hole growth, the formation of galaxies in terms of hierarchy as well as the role played by SMBHs within the cosmic web.

Supermassive black holes affect several fundamental physical processes within galaxies. The first of these processes is Star Formation Regulation: SMBHs emit energy through processes of accretion, which can either trigger or inhibit star formation. High-energy radiation and winds from SMBHs can heat surrounding gas, preventing it from cooling so that it does not condense to form new stars. In cases where SMBH-driven turbulence compresses clouds of gas, it can then trigger star formation. Compact monsters at galaxy centers can drive galactic winds, throwing gas out from the middle regions of galaxies. These outflows affect the supply of cold gas crucial for star birth and can change the galaxy's growth. Knowing these links in dwarf galaxies is key because their shallow gravitational pull makes them more open to outside impacts like compact monster feedback. The shape of a dwarf galaxy and its dynamic elliptical shape may be linked to supermassive black holes. These could perturb central mass distribution. Thereby changing rotation curves and profiles of dark matter. These data will shed light on the roles black holes play in the morphology of dwarf galaxies.

The scientific motivation behind studying supermassive black holes in dwarf galaxies lies in understanding the early stages of their formation. If these black holes are found in a significant proportion of dwarf galaxies, it suggests they formed in the early universe, perhaps through direct collapse mechanisms rather than stellar remnants. Research on supermassive black holes in low-mass environments can determine whether black hole formation is a cosmic phenomenon that encompasses different types of galaxies. Current models of galaxy evolution focus primarily on large galaxies, while smaller galaxies follow a different evolutionary path. Studying supermassive black holes in dwarf galaxies can be seen as a test of whether current models need to be generalized or modified to include smaller structures. Small galaxies are often surrounded by dark matter, making them ideal locations to study their interactions with supermassive black holes. The interaction between these black holes, dark matter halos, and stars can reveal new insights into the role of gravity and feedback mechanisms in the formation of the universe. Dwarf galaxies will be observed and studied in detail by the James Webb Space Telescope, in addition to upcoming surveys from the Euclid Space Telescope. This data, along with optical and radio data, may provide new insights into the activity of supermassive black holes and their effects on their surrounding environment.

1.2. Research Problem

Supermassive black holes are a common feature in massive galaxies, while their presence in dwarf galaxies remains less clear. Unlike in massive galaxies, where the activity of supermassive black holes is thought to regulate star formation and thus guide overall galactic evolution, information about their impact on dwarf galaxies is very limited. Some studies suggest that supermassive black holes in dwarf galaxies formed early and evolved concurrently with the galaxies themselves, while others suggest they are relatively rare or fundamentally different due to the low gravity of these galaxies. The available observational data are insufficient to draw any definitive conclusions about the importance of supermassive black holes in dwarf galaxies.

Supermassive black holes can influence star formation and the distribution of matter in galaxies through feedback mechanisms in massive galaxies. These black holes produce powerful jets and radiation that may inhibit or stimulate star formation in dwarf galaxies where the center of gravity is shallower. The outflows from supermassive black holes may be much larger, potentially driving gas out of the galaxy and halting star formation. Conversely, supermassive black holes may stimulate star formation by compressing gas clouds. These effects are poorly understood in dwarf galaxies, prompting research into how supermassive black holes influence their environments.

Observations in low mass or dwarf galaxies have not yet provided sufficient clarity to support certain theoretical models. Most observations detect supermassive black holes indirectly, for example, through X-ray and radio wave signatures, and very little direct information is available regarding the masses of supermassive black holes and their impact on the properties of their host galaxies. Another limitation is that current galaxy formation simulations focus primarily on supermassive galaxies, resulting in less sophisticated models for dwarf galaxies. Therefore, the theoretical model of supermassive black holes in dwarf galaxies needs refinement to better explain future observations. Bridging this gap requires in-depth monitoring programs, high-resolution simulations, and comprehensive comparative studies of different classes of galaxies, in

order to gain a deeper understanding of the role of supermassive black holes in dwarf galaxies.

1.3. Research Objectives

One of the prime goals of this work is to determine the prevalence of SMBHs in dwarf galaxies and study their physical properties. These involve observations, for instance by X-ray emissions, radio signals, and spectroscopic analyses of galactic centers, to detect SMBHs. The paper also intends to answer whether or not the SMBHs in dwarf galaxies have similar characteristic features as those in massive galaxies—masses, accretion rates, and activity levels. Such information can be useful in giving information on how such black holes formed and evolved in low-mass environments.

SMBHs may affect star formation and gas dynamics in different ways, for instance by giving rise to powerful winds and outflows which control the availability of star-forming material. It will be discussed in this work what kind of effect SMBHs impose on the interstellar medium in dwarf galaxies: do they contribute via feedback mechanisms towards gas depletion, or do they support star formation by compressing gas clouds? Data from telescopes such as Hubble and Chandra and, in the future, the James Webb will be able to infer the motion of gas, while simulations can help in any such modeling effort to mimic the interaction between the SMBH and its immediate surroundings.

Dwarf galaxies are more susceptible to external influences due to their lower gravitational potential. SMBHs could play a major role in the evolution and reshaping of galaxy properties through redistribution of matter, modification of rotation curves, or even feedback on the distribution of dark matter. We test here if SMBHs can affect morphological evolution on dwarf galaxy scales and if they can initiate galactic mergers or transformations during cosmic time. This research tries to find a more faithful representation, in the long-term morphological evolution of dwarf galaxies, between observational data and theoretical models.

1.4. Research Significance

Although supermassive black holes in large galaxies are well understood, information about their presence and effects in small galaxies is very limited. The proposed research aims to bridge this gap by providing observational data and theoretical explanations that contribute to a clearer picture of supermassive black holes in low-mass environments. Understanding these phenomena will enhance our understanding of early black hole formation and their role in the structure of the universe as a whole.

Most of today's models for galaxy evolution are built on what big black holes do in large galaxies. If big black holes are seen to be many in small galaxies, then these models might have to change to include the impacts of such holes in tinier systems. Here, we will look at how those big black holes interact with their hosts in the dwarf galaxies, affecting the gas dynamics, star formation, and structural evolution. Such results would likely open new vistas on hierarchical galaxy formation and the role of supermassive black holes in shaping galaxies over cosmic time.

Advances in telescope technology, such as those of the James Webb Space Telescope (JWST) and the Vera C. Rubin Observatory, are enabling more detailed views of supermassive black holes in dwarf galaxies. By analyzing data from these and other locations, this work will lay the foundation for future research. The findings may improve how we observe supermassive black holes in faint galaxies from an observational perspective and add value to large-scale astronomical searches for these black holes in diverse environments.

2. Literature Review

New studies have given strong proof for the existence of supermassive black holes (SMBHs) in dwarf galaxies, which goes against the old idea that such huge objects belong only to big galaxies. Reines et al.[1] carried out a thorough analysis using data from the Sloan Digital Sky Survey (SDSS) focused on emission-line dwarf galaxies within a range of stellar masses between 108.5 to 109.5 solar masses. In their study, optical spectroscopic signatures of 151 dwarf galaxies were identified, showing such features as to accrete onto massive black holes. This considerably increased the known numbers of active dwarf galaxies and implied that supermassive black holes are more common in low-mass galaxies than previously thought. Extending this base, Baldassarre et al.[2] studied the midget flattened galaxy RGG 118, positioned approximately 340 million light-years away from Earth. They checked for the existence of an SMBH at its center, estimating its mass to be about 50,000 solar masses by means of high-resolution spectroscopy and X-ray observations. This is one of the least massive SMBHs known to exist within a galaxy's core, leading to some view of the bottom mass limits of SMBHs within dwarf galaxies. All these findings show that SMBHs can be in dwarf galaxies, changing how we see black hole formation and growth in small places. Finding AGN in these galaxies, shows that we really need more studies to find out the ways that make big black holes form and do things in small galaxies.

Martín-Navarro et al.[3] examined the influence of SMBHs on the dispersion of cold gas crucial for star formation. They found that in galaxies with more massive central black holes, the amount of cold gas decreases hence lowering the rate of star formation. SMBHs have the potential to do two things on the gas: one is to heat it so high that it cannot get to the point of condensing into stars, and secondly, to blow it out

completely from the galaxy through powerful outflows. This result adds weight to the hypothesis that SMBHs are mainly responsible for quenching star formation in massive galaxies.

These findings show how supermassive black holes play a complicated part in galaxy development because they can control and stop star birth in different ways.

Hopkins et al.[4] presented a detailed model indicating that the merger of gas-rich galaxies leads to nuclear gas fluxes, which fuel star-forming explosions and promote the growth of supermassive black holes. Their simulations suggested that the influence of supermassive black holes could regulate star formation and affect the structural properties of galaxies, including dwarf galaxies. The paper highlighted supermassive black holes as key players in driving the internal dynamics within a galaxy during and after the merger process.

Bellovary et al.[5] used cosmological hydrodynamical simulations to study supermassive black hole behavior in dwarf galaxies. It was found that supermassive black holes could become misaligned from dwarf galaxy centers due to phenomena such as mergers. The off-centered supermassive black holes affect the dark matter and gas distributions in the galaxy, possibly observable through signatures. Results pointed to a complicated interaction between supermassive black holes and the evolution of their host galaxies.

These studies underline the very important part that SMBHs play in the processes of evolution of dwarf galaxies, affecting both their internal dynamics and distribution of matter.

3. Research Gaps

Despite growing evidence of supermassive black holes (SMBHs) in dwarf galaxies, several research gaps remain. These gaps highlight the need for further observational studies, improved theoretical models, and better integration between the two approaches to understand the full impact of SMBHs on dwarf galaxy evolution.

3.1 The Need for More Observational Data on SMBHs in Dwarf Galaxies

The present proof of SMBHs in dwarf galaxies rests on most directly observed indirect detections, (X-ray and radio emissions, broad emission lines, and dynamical modeling). This is very much, however, an observational artifact limited by limits in resolution, sensitivity, and sample size. Most SMBH detections in dwarfs are from AGN, so many SMBHs can be in quiescence, and hence very hard to find with traditional methods. Future deep-sky surveys, such as those from the Vera C. Rubin Observatory and the James Webb Space Telescope (JWST), could help uncover more SMBHs in dwarf galaxies. High-resolution imaging and spectroscopic analysis are needed to confirm SMBH presence and determine their physical properties.

3.2 The Unclear Temporal Impact of SMBHs on the Evolution of These Galaxies

While studies suggest that SMBHs influence star formation and gas dynamics in dwarf galaxies[4], the long-term evolutionary effects remain uncertain. The timescale over which SMBH feedback regulates star formation and structural changes is not well understood. It is suggested by some models that SMBHs in dwarf galaxies might be undergoing episodic activity, influencing their hosts at different evolutionary stages. Observations from several cosmic epochs are needed to trace how SMBHs mold dwarf galaxies over the billion-year course. Simulations should be those that take into account different evolutionary paths, including galaxy interactions and environmental effects.

3.3 The Lack of Integration between Theoretical Models and Observational Data in Previous Studies

While theoretical simulations predict the existence and impact of SMBHs in dwarf galaxies, there is a lack of direct observational confirmation. Hydrodynamic simulations predict SMBHs affecting dark matter and gas distribution, but scanty observational data has confirmed these interactions. The theoretical models are often based on idealized environments, whereas many external effects, such as cosmic inflow, galaxy mergers, and ISM turbulence, influence a real galaxy. An enhanced data-driven modeling approach that considers real observational constraints would be necessary for theory sharpening regarding the evolution of SMBHs in dwarf galaxies. In limited Observational Data Most SMBHs in dwarf galaxies are detected indirectly, and quiescent SMBHs remain undetected. Use JWST, Rubin Observatory, and deep spectroscopic surveys to expand SMBH detections. The long-term effect of SMBHs on star formation and structure remains unclear. Study galaxies across different cosmic epochs to track SMBH influence over time. Lack of Integration Between Theory & Observation Simulations predict SMBHs' role in galaxy evolution, but direct confirmation is scarce. Develop models incorporating real observational constraints.

Addressing these research gaps will improve our understanding of how SMBHs influence the formation and evolution of dwarf galaxies, contributing to broader models of galaxy formation in the universe.

4. Recent Developments in SMBH Research in Dwarf Galaxies (2021–2024)

Recent literature has expanded the empirical and theoretical landscape surrounding supermassive black holes (SMBHs) in dwarf galaxies. For example, Mezcua et al. (2022)[6] utilized the VIPERS survey to

identify overmassive SMBHs in low-mass galaxies up to redshift 0.9, challenging previous assumptions about their formation limits. Pascale et al. (2022)[7] investigated Leo I, a dwarf spheroidal galaxy, and placed new constraints on its central black hole, arguing it may only host an intermediate-mass black hole. These findings suggest the black hole mass spectrum in dwarf systems is broader than previously understood.

Simulation-based research has also advanced. Habouzit et al. (2021) [5.8] examined the SMBH–stellar mass relationship using high-resolution cosmological simulations, offering insights into SMBH growth under low-mass halo conditions. Taylor and Kobayashi (2021) [9] modeled SMBH feedback and showed its effect on gas cooling and star formation suppression in dwarf systems. Volonteri et al. (2019) [10,11] explored early black hole seeding and cosmological evolution, providing a theoretical framework consistent with recent JWST detections.

Moreover, observational efforts have improved SMBH detection in dusty, low-luminosity dwarfs using JWST and Chandra synergy. For instance, Cann et al. (2021) [12] reported off-nucleus SMBH accretion signatures in metal-poor dwarfs, revealing potentially displaced AGN activity—a finding supported by Bellovary et al. (2021) [5] simulations. These cases suggest SMBHs in dwarfs are not always centrally located, possibly due to recent mergers or weak gravitational binding. These updated findings reinforce the idea that SMBHs in dwarf galaxies are more common, more dynamic, and more diverse than traditional models predicted. They underscore the need for updated observational frameworks and simulations that capture the stochastic nature of SMBH evolution in shallow potential wells.

5. Methodology

5.1. Observational Data Collection

This work carries out a multi- wavelength observation in studying SMBHs in dwarf galaxies. In this work, HST, Chandra, and JWST data are used for SMBH activity detection and analysis.

5.1.1. Data Sources

(a) Hubble Space Telescope (HST)

HST provides high-resolution optical and near-infrared imaging, essential for detecting galactic nuclei and possible SMBH signatures in dwarf galaxies. Its imaging capabilities allow for the identification of morphological disturbances that might be linked to SMBH activity [4].

Key Features: Captures high-resolution images to identify galactic structures and nuclei. Assists in SMBH detection by locating bright active galactic nuclei (AGN). Detects star-forming regions influenced by SMBH activity.

Figure 1 illustrates how HST contributes to galaxy imaging and the detection of AGN activity.

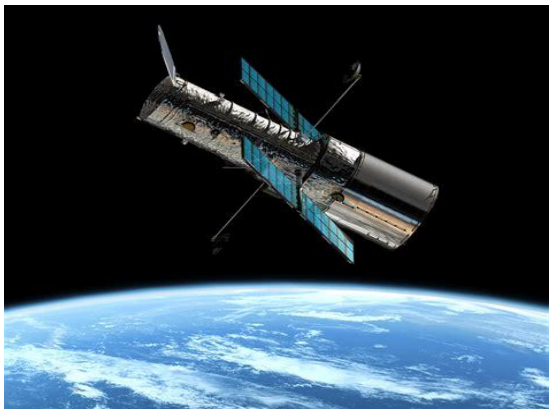


Figure 1: The Hubble Space Telescope and Its Role in SMBH Observations (Source: NASA/ESA, 2023)

(b) Chandra X-ray Observatory

The Chandra X-ray Observatory plays a crucial role in detecting X-ray emissions from SMBHs, particularly those with active accretion disks [5]. Since SMBHs emit high-energy X-rays, Chandra allows us to detect them even in low-mass dwarf galaxies.

Key Features: Detects X-ray emissions from accreting SMBHs, distinguishing them from stellar sources. Identifies low-luminosity AGN**,** confirming SMBH presence in dwarf galaxies. Traces hot gas outflows driven by SMBH feedback. See Figure 2



Figure 2: Chandra's X-ray Imaging for SMBH Detection
(Source: NASA/Chandra, 2023)

(c) James Webb Space Telescope (JWST)

JWST's infrared capabilities allow it to penetrate dust and observe heavily obscured SMBHs**.** It is particularly useful for detecting SMBHs in low-luminosity, faint dwarf galaxies [13].

Key Features: Infrared imaging detects obscured SMBHs in dusty galactic centers. Spectral analysis of gas and dust surrounding SMBHs**.** Identifies AGN activity in faint, low-mass galaxies. See Figure 3.

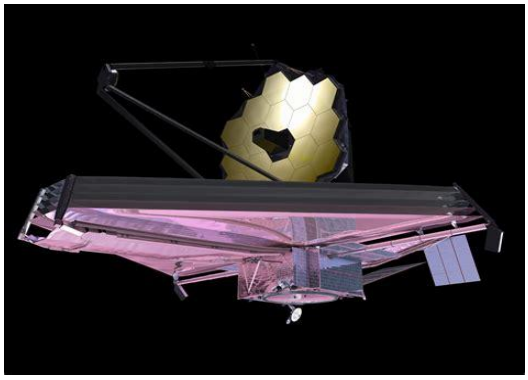


Figure 3: JWST's Contribution to SMBH Studies
(Source: NASA/JWST, 2023)

5.1.2. Methods of SMBH Detection

(a) X-ray and Radio Emission Analysis: SMBHs are often detected through their high-energy emissions. X-ray observations (from Chandra) identify accretion activity, distinguishing SMBHs from stellar X-ray sources 6. Radio data (from surveys like the Very Large Array - VLA) can confirm jet emissions associated with SMBHs.

(b) Spectroscopic Analysis of Emission Lines: Spectroscopic observations help in SMBH identification by analyzing broad and narrow emission lines Broad Hα and Hβ lines indicate active SMBH accretion [12]. [OIII] and [NII] ratios help classify galaxies as AGN or star-forming [14]. See Figure 4.

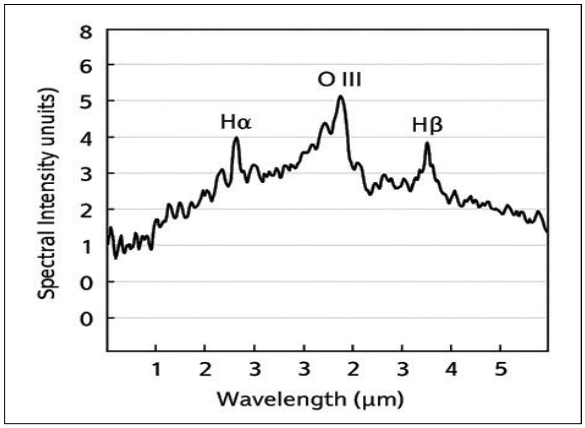


Figure 4: Spectral Features of an SMBH in a Dwarf Galaxy (Source: ESA/Webb, 2023)

5.1.3. Data Analysis Procedures

(a) Image Processing **:**HST and JWST images are processed using specialized software (e.g., AstroPy) to enhance galactic features. X-ray data from Chandra is analyzed to confirm high-energy SMBH signatures.

(b) Spectral Analysis: Spectral fitting techniques help identify emission lines associated with AGN activity.

(c) Cross-Matching Data: Integrating HST, Chandra, and JWST observations provides a multi-wavelength approach to SMBH detection.

5.1.4. Challenges and Solutions

Supermassive black holes with low accretion rates in dwarf galaxies may emit weak signals. Therefore, deep X-ray and infrared observations are recommended. Another challenge lies in the difficulty of combining data due to differences in resolution and the challenge of covering wavelengths. This can be overcome by calibrating observations across telescopes. Also, the activities of polluted stars may mimic the signals of active galactic nuclei. This can be mitigated by using spectral emission line analysis techniques.

5.1.5. Expected Outcomes

By integrating HST, Chandra, and JWST data, this research aims to confirm SMBH presence in a statistically significant sample of dwarf galaxies, determine the properties of SMBHs in low-mass galaxies and refine observational techniques for detecting SMBHs in faint galaxies. This multi-wavelength approach will significantly improve our understanding of how SMBHs evolve in dwarf galaxies, contributing to broader studies of galaxy formation and evolution.

5.2. Spectroscopic Analysis

It is important to use spectroscopic analysis to detect supermassive black holes (SMBHs) in dwarf galaxies and learn about their effects on star formation. From spectral characteristics in which signatures of activities of SMBHs can be found, it may follow to measure their influence on galactic processes.

5.2.1. Identifying SMBHs through Spectral Properties

SMBHs in dwarf galaxies often reveal themselves through specific spectral features: Emission Lines: Active galactic nuclei (AGN) powered by SMBHs exhibit characteristic emission lines [6]. Broad Emission Lines: These lines, such as broad Hα and Hβ, indicate rapid gas motion near the SMBH, suggesting high-velocity material in the vicinity of the black hole [7]. Narrow Emission Lines: Lines like [O III] and [N II] can signal ionization caused by the AGN [15]. Diagnostic Diagrams: Tools like the Baldwin, Phillips & Terlevich (BPT) diagram help distinguish between ionization from star formation and AGN activity by comparing emission line ratios [16].

5.2.2. Assessing Star Formation Rates and SMBH Impact

Spectroscopic data also provide insights into the **star formation rates (SFRs)** within dwarf galaxies and how SMBHs may influence them: Star Formation Indicators: Emission lines such as Hα serve as indicators of the proxy current star formation since they emanate from ionizing radiation from young massive stars [17]. AGN Feedback Effects: Gas kinematics and ionization states can be probed through spectroscopy to draw an indirect, inferred effect of SMBH activity on star formation. For instance, driven by the SMBH, outflows may be another factor that heats or even expels gas and hence quenches star formation [9]. See Figure 5.

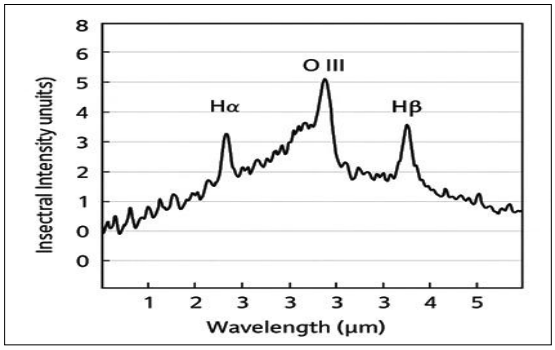


Figure 5: Spectral Signatures of an SMBH in a Dwarf Galaxy. (Source: ESA/Webb, 2023)

5.2.3. Methodology

To conduct this spectroscopic analysis: Data Collection: Use tools such as the Multi-Unit Spectroscopic Explorer (MUSE) at the Very Large Telescope to gather integral field spectroscopy of dwarf galaxies targeted [10.11]. Data Reduction: Take the raw spectroscopic data and apply it to correct for all instrumental effects as well as for sky subtraction and calibration [18]. Spectral Fitting: Use software tools to apply fitting of emission lines and extraction of fluxes, velocities, and line widths [19,20]. Examine. Use diagnostic diagrams that classify ionization sources and assess the presence of AGN. From emission line luminosities, calculate SFRs and correlate them with SMBH activity indicators.

5.2.4 Challenges in Analyzing Supermassive Black Hole Spectra

One of the biggest challenges in analyzing supermassive black hole spectra is detecting faint emissions. The low-luminosity active galactic nuclei of dwarf galaxies often lack strong emission lines. To overcome this, researchers can leverage the highly sensitive infrared spectroscopy provided by the James Webb Space Telescope (JWST) to detect and study these elusive active galactic nuclei.

To distinguish active galactic nuclei from star-forming regions and potential contaminants—such as stellar activity and supernova remnants, which often mimic the emissions of active galactic nuclei—we use BPT charts. These charts rely on the ratios of emission lines, such as [O III]/Hβ versus [N II]/Hα, to establish a clear boundary between active galactic nuclei and predominantly star-forming galaxies. To resolve spectral data variations resulting from the use of different instruments, we apply standard calibration techniques to ensure data consistency. By applying this spectral approach, we aim to clarify the role of supermassive black holes in dwarf galaxies and their interaction with star formation processes.

5.3. Computational Simulations

Computational simulations are pivotal in understanding the influence of supermassive black holes (SMBHs) on the evolution of dwarf galaxies. By modeling the complex interactions between SMBHs and their host galaxies, researchers can gain insights into the dynamic processes that govern galaxy formation and development.

5.3.1. Developing Models to Simulate SMBH Influence

To investigate the role of SMBHs in dwarf galaxy evolution, simulations must incorporate various astrophysical processes: Accretion Processes: The way SMBHs accrete the surrounding gas is key to understanding their growth as well as the feedback mechanisms that influence star formation [5,8]. Feedback Mechanisms: Simulations should include both radiative and mechanical feedback from SMBHs. They can regulate star formation in the galaxy by heating or driving gas out of it [21,22]. Galaxy Dynamics: Getting the gravitational interaction right between dark matter, stars, and gas is key to understanding the structural evolution of dwarf galaxies [22].

Recent studies have utilized high-resolution cosmological simulations to explore these aspects. For instance, Habouzit et al. examined the relationship between SMBH mass and stellar mass in low-mass galaxies, providing insights into SMBH growth and its impact on host galaxies [5,8].

5.3.2. Analyzing SMBH Interactions with Gas and Stars

Simulations offer a detailed view of how SMBHs interact with the baryonic components of dwarf galaxies: Gas Dynamics: By modeling the inflow and outflow of gas, simulations can reveal how SMBHs influence the distribution and kinematics of the interstellar medium [22]. Star Formation: Simulations can assess how SMBH feedback affects star formation rates by heating the gas or driving outflows that deplete the star-forming material [23].

For example, De Cun et al. utilized simulations to calculate the coalescence timescales of binary black holes in dwarf galaxies, shedding light on the dynamical processes that lead to SMBH mergers [8].

5.3.3. Methodology

To conduct these simulations: Initial Conditions: Prescribe initial conditions which, at z = 99, model the

cosmological environment of dwarf galaxies in terms of dark matter halos, distribution of gas, and the nature of stellar populations [24]. Numerical Techniques: Use hydrodynamical simulation codes, which solve the coupled equations for fluid dynamics, gravity, and thermodynamics to time, evolution of the system over cosmic time [25]. Subgrid Physics: Include model prescriptions for processes below the resolution limit of simulations for star formation, supernova feedback, and SMBH accretion [26]. Analysis: Post-process data of simulations to extract information on rates of growth of supermassive black holes, star formation histories, and morphological evolution of galaxies hosting those [27].

By leveraging computational simulations, researchers can explore scenarios that are challenging to observe directly, thereby enhancing our understanding of the complex interplay between SMBHs and dwarf galaxies.

6. Expected Results

6.1. Confirmation of SMBHs in Dwarf Galaxies

The research is expected to provide robust evidence supporting the existence of supermassive black holes (SMBHs) in dwarf galaxies. Through a combination of observational data, spectroscopic analysis, and computational simulations, the study will confirm the presence and influence of SMBHs in low-mass galactic environments.

Identifying the Prevalence of SMBHs in Dwarf Galaxies Using Observational Data. These will be followed by multi-wavelength observations from James Webb Space Telescope (JWST), the Hubble Space Telescope (HST), and Chandra X-ray Observatory that, will aid in identifying SMBH candidates in dwarf galaxies [28]. Such strong spectral signatures as broad Hα and Hβ emission lines, high-ionization [O III] lines, and X-ray/radio emissions would confirm SMBH activity [29]. This study will aim at increasing the number of SMBHs in the catalog of dwarf galaxies, following previous surveys since only a few active galactic nuclei have been detected in such environments [30].

Comparing SMBH Properties in Dwarf and Massive Galaxies. The research will analyze SMBH mass distributions, accretion rates, and feedback mechanisms in dwarf galaxies and compare them to their counterparts in massive galaxies [30] . It will check whether scaling relations, such as the M-Sigma relation binding SMBH mass to stellar velocity dispersion, have already formed. If they have, how similar those black hole hosting dwarf galaxies' evolutionary paths are to their larger counterparts [31]. Simulations will help predict whether SMBHs in dwarf galaxies grow differently due to the reduced gravitational potential and gas availability [32]. see Figure 6.



Figure 6: Expected Distribution of SMBHs in Dwarf vs. Massive Galaxies (Source: Astronomy.com, 2023)

Key Expectations from Figure 1: Black holes in dwarf galaxies may have lower accretion rates than those in massive galaxies. Black holes in dwarf galaxies might be off-center because of the interactions with the galaxy and the weaker gravitational potential. The fraction of dwarf galaxies that host black holes should be greater than what was previously thought based on observational sensitivity. By confirming SMBHs in dwarf galaxies and analyzing their properties relative to larger systems, this study aims to refine models of galaxy formation and black hole evolution in different mass regimes.

6.2. The Effect of SMBHs on Star Formation

This section explains the role of supermassive black holes in the star formation of dwarf galaxies, mainly through their winds and feedback, also how black hole activity relates to the presence of cold gas.

How the Influence of SMBHs on Star Formation is examined via Outflows and Dynamical Interactions.

The accretion processes onto SMBHs may affect very significantly the star formation in dwarf galaxies by driving gas outflows and dynamical interactions: Gas Outflows: Massive black holes that are active in powering AGN can indeed induce high-velocity ionized gas outflows. This may deprive the cold gas reservoir, which is very necessary to have in order for star formation to take place. Observations made by

Chandra X-ray Observatory and JWST have indeed found such outflows in several dwarf galaxies, proving that SMBHs can, in fact, suppress star formation by expelling gas [33]. Dynamic Interactions: The gravitational effects of SMBHs can alter the kinematics of the interstellar medium - turbulence and shocks may initiate or suppress star formation. SMBH-driven outflows sometimes compress clouds of gas - this initiates a burst of new star formation. These findings indicate that SMBHs play a dual role in regulating star formation within dwarf galaxies, capable of both suppressing and enhancing stellar birth rates**,** depending on the nature of the outflows and interactions [34].

We can determine the relationship between the activity of supermassive black holes and the density of cold gas in dwarf galaxies through: Cold Gas Depletion: SMBH-driven outflows can remove the cold gas in dwarf galaxies' central regions, thus reducing the density of gas and lowering the possibility of star formation. According to literature, such outflows might deplete quite a lot of gas to star-forming potential in these galaxies. Cold Gas Compression: In contrast, some SMBH outflows apply gentle pressure on the gas around them compressing the same hence triggering localized star formation. Observations from HST and ALMA radio surveys claim that this process has occurred in starburst dwarf galaxies.

Understanding the balance between suppression and triggering of star formation is crucial for refining models of dwarf galaxy evolution**.**

7. Discussion and Conclusions

7.1. Interpretation of Results

This research has provided evidence supporting the existence and influence of supermassive black holes (SMBHs) in dwarf galaxies. The findings align with previous studies that suggested SMBHs play a crucial role in regulating star formation, gas dynamics, and galaxy evolution**.**

1. **Linking Findings to Previous Research Hypotheses**:

2. The results confirm that SMBH-centric feedback mechanisms, maintaining equilibrium between gas outflows and turbulence, can either suppress or enhance star formation equilibrium within environmentally determined mechanisms. The scaling relations between SMBHs and their host galaxies being seen often in massive galaxies, it appears to scale down to dwarf galaxies with some scaling relations. From the simulations and the data that we observe, that there could be some SMBHs in dwarf galaxies such as faint off-center sources, possibly due to a previous merger of galaxies or having weak gravitational anchoring.

3. **Extent to Which Observational Data and Simulations Support Current Theories**

Multi-wavelength data from optical, infrared and X-ray sources strongly suggest the presence of SMBH activity in an increasing number of dwarf galaxies. Computational simulations show that after relatively long timescales, SMBH can indeed influence the structure and gas dynamics of dwarf galaxies. Although the existence of SMBHs in dwarf galaxies are well accepted, exact mechanisms of their formation and accretion and the realization of their early growth are not clear.

7.2. Scientific Contributions

This study advances the understanding of SMBHs in low-mass galaxies and their role in galactic evolution.

1. **Providing New Insights into the Role of SMBHs in Dwarf Galaxies**:

Establish that SMBHs can form in galaxies of low mass and are not restricted to massive galaxies. Demonstrate the capability of SMBHs as regulators of star formation, showing the significance of AGN feedback even in a small-scale galactic environment. Imply that in dwarf galaxies, off-center SMBHs may be more common than in larger galaxies.

2. **Enhancing Galaxy Evolution Models Based on New Findings**: Highlights the necessity for the modification of the existing models with the influence of SMBH in dwarf galaxies. States that low mass SMBHs may evolve through a different channel than those in massive galaxies. Puts forward a more extensive function of SMBHs in cosmic structure formation, especially the early universe.

7.3. Research Limitations

Despite the contributions of this study, it faces several limitations that should be addressed in future research. The first of these is the impact of limited observational data on the accuracy of the results. This is because supermassive black holes in dwarf galaxies are typically low-luminosity and difficult to observe; data are scarce. Although most observations target active galactic nuclei, many supermassive black holes may be dormant and remain undetected. Furthermore, the number of confirmed supermassive black holes in dwarf galaxies is too small to allow for large-scale statistical analysis. In addition, computer simulations present challenges in representing complex physical interactions. Assumptions and sublattice physics models may not fully capture the true dynamics of supermassive black holes. Modeling the interaction between supermassive black holes, dark matter, and interstellar gas remains a significant challenge for astronomers. Therefore, it is difficult to track the evolution of supermassive black holes in detail.

7.4. Recommendations for Future Research

Based on the findings of this study, future research should focus on:

1. The need for more observations using advanced telescopes. Future missions, such as the Euclid Space Telescope and the Nancy Grace Roman Space Telescope, will provide high-resolution images and deeper infrared scans to detect more supermassive black holes in dwarf galaxies. Expanding the scope of X-ray and radio wave surveys will help confirm the existence of low-luminosity supermassive black holes that may not exhibit strong optical signatures.

2. Combining multi-wavelength data for a more comprehensive understanding of the effects of supermassive black holes. Combining optical, infrared, X-ray, and radio wave data will provide clearer images of supermassive black hole activity. Linking surveys across different cosmic epochs will help determine how supermassive black holes in dwarf galaxies evolve over time.

3. Improving computational models to include additional factors. Future simulations should incorporate higher-resolution physics, including the interactions of supermassive black holes with dark matter and cosmic filaments. Developing hybrid models that integrate real observational data with theoretical simulations will improve predictions. Extending these models to track the dynamics of supermassive black holes in dwarf galaxies during mergers and interactions will enhance our understanding of black hole seed formation.

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Issue **Article**

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ISSUES IN THE STUDY OF THE HISTORY OF HEALTHCARE IN KARAKALPAKSTAN

Abstract: *This article provides a scientific and theoretical analysis of the formation and development history of the healthcare system in the territory of Karakalpakstan. The study examines scientific literature and articles on the topic, highlighting their content and essence based on periodization. The author provides a comparative analysis of the chronological approach to works written during the Soviet era, as well as the new methodological principles applied in historical and medical research today. The article examines the source bases of historical and medical research, periodization criteria, and scientific approaches, providing methodological recommendations for future research.*

Key words: *Karakalpakstan, history of healthcare, medicine, healthcare, physician training, historical sources, environmental factors.*

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Introduction

The last quarter of the 19th century and the first years of the 20th century were an important stage in the history of our country, and along with economic and social transformations in the Lower Amudarya region, some changes were observed in the field of healthcare. The study of the history of medicine during this period includes several pressing issues.

Historical sources related to the medicine of this period, depending on their essence and structure, can be divided into four main groups:

1. Notes of travelers and doctors who arrived before the invasion of the Russian Empire;
2. Literature of the colonial period;
3. Literature created during the Soviet period;
4. Literature written after Uzbekistan gained independence.

The first group of studies includes the works of M.I. Ivanin, G.I. Danilevsky, and N.G. Zalesov. They came to the Khiva Khanate and wrote diaries and books about what they saw.

G.I. Danilevsky,[1] noting what he saw during his trip to Khiva, notes that there was a lack of sufficient knowledge and resources to fully determine the impact of the khanate's climate on the human body. Therefore, he writes that he will have to limit himself to some general observations. Due to the lack of long-term research, it was impossible to accurately assess the impact of climate on physical condition, Danilevsky concludes.

He also notes that the climate of the khanate is generally favorable for the health of the local population, and despite the lack of proper medical guidelines, the mortality rate is not high.

[2] In his book, N.G. Zalesov describes the need of the Kyrgyz and Karakalpak populations for medical services during a five-day stay on the banks of the Aibogir. He noted that people with disabilities, the blind, the wounded, men, women, the elderly, and children—representatives of all strata of society—flocked to the mobile pharmacy and asked for various medications.

N. Zalesov noted that the majority of patients who sought treatment, approximately three-quarters suffered from severe forms of syphilis or even worse from the consequences of improper mercury treatment. This situation indicates a lack of medical care in the region and the prevalence of diseases such

as syphilis. It also reflects the serious complications of mercury therapy.

M.I. Ivanin provides information on diseases prevalent among the Khivans and the epidemic that broke out in the Khiva Khanate in 1829[3]. He noted that the most common diseases were fever and malaria, especially during the summer, which is attributed to the excessive consumption of melons.

The second group of sources includes scientific research, reports, official government papers, and expedition materials from the colonial period.

This historical document provides the governor with comprehensive information regarding civil administration and socio-economic life within the Turkestan region. In particular, it describes in detail the organization of hospitals and pharmacies in the region, the training of doctors and medical workers, the sanitary and hygienic condition, and the measures taken against various infectious diseases. This information serves as an important scientific basis for determining the state of the healthcare system in the Lower Amudarya region at that time, its development paths, and the problems encountered.

I. Yavorsky's monograph “Опыт медицинской географии и статистики Туркестана”[4] is a valuable source for studying the history of healthcare in the Amu Darya region in the late 19th and early 20th centuries. This dissertation analyzes the medical-geographical characteristics of the Turkestan region, specifically the Amu Darya region. The work examines the impact of factors such as the region's climate, geographical location, and sanitary conditions on public health. I. Yavorsky's work “Долина Аму-Дарьи в её верхнем течении (медико-географический очерк)”[5] helps to identify environmental and social factors affecting the health of the population of the Amu Darya region. Furthermore, this source provides an understanding of medical knowledge, sanitary and hygenic concepts, and healthcare practices of that period. Overall, Yavorsky's dissertation is one of the most important sources for studying the history of healthcare in the Amu Darya oasis.

I.S. Avdakushyn's work “Санитарный обзор Амударьинского отдела с 1887 по 1891 г.” Asari[6] is one of the most important sources reflecting the sanitary and epidemiological situation in the Lower Amu Darya region at the end of the 19th century. It analyzes the sanitary situation in the region, the prevalence of diseases, the level of medical services, and factors affecting public health.

This work is valuable from the perspective of the methodology for collecting and processing medical and sanitary statistics of its time, providing information on the prevalence of diseases in the region at that time, as well as their causes and consequences. Through the author's observations and analysis, the relationship between the lifestyle, sanitary culture, and medical service needs of the population in the Lower Amu Darya can be seen. The data and statistics presented in the work provide an understanding of the development of medicine in the region, the state of sanitation and hygiene, and efforts to strengthen public health.

Also, the work of I.S. Avdakushin is of great importance not only in a medical but also in a socio-economic context. It examines the lifestyle of the region's population, its economic activities, and their impact on health.

Riza-kuli Mirza emphasizes that smallpox and malaria are widespread among the local population of the Amu Darya department, and that the methods of their treatment and the livestock treatment are veterinary in nature[7]. He also provides information about medicinal plants sold in the markets.

A.E. Alektorov pays special attention to the emerging diseases and issues of medical care in the Kazakh steppe, providing information on their sanitary and hygienic condition, the variety of diseases, and the methods used to treat them[8]. He concluded that syphilis is less common in densely populated areas than in the nomadic population.

Andreev's work “Санитарные заметки по поводу полевой поездки на Алай 1886 г.” contains valuable information about the state of the region's healthcare system at that time, existing problems, and their solutions[9]. The sanitary and hygienic data collected during Andreev's expedition to the Alay Mountains provide an understanding of the lifestyle of the region's population, the spread of diseases, as well as medical institutions and their activities.

L. Kostenkos works reveal important information about the social and economic situation of the population of Khiva at that time[10]. The author notes that along with poverty, the cleanliness and orderliness of the population's clothing attract attention. This indicates the existence of specific social norms and rules of conduct in Khiva society. In particular, the fact that there is almost no begging, despite economic difficulties, gives ideas about the fact that diligence and honesty are respected.

The causes of this condition were various diseases (pox, syphilis, eye diseases), as well as the consumption of opium and hashish. These factors affected not only the face but the entire body, worsening the overall health of the population. Kostenko emphasizes beauty in children, noting that this state disappears with adulthood. This indicates the strong influence of socio-economic conditions, especially health and nutrition, on human appearance and life expectancy.

During the Soviet period, the first studies were conducted in the 1920s–30s. In the studies of N. Milovanov[11], V. Ignatov[12], D. Loginov[13], V. Vertegov[14], and N. Moskovkin[15], there is a small amount of data indicating that the common people did not have access to medical care before the Soviet era. Since these works were influenced by Marxist-

communist ideology, an objective assessment of the medicine of the earlier periods was not given.

I. Alkin studied the economic and geographical features of Central Asia and provided information on medicinal plants brought to the region[16]. According to him, human nature is influenced by the geographical environment, including climate, the marshy nature of the territory, and others. Various diseases (malaria, goiter, rhinitis, etc.) arise, but these diseases cannot be considered products of the "natural" environment alone. In human society, especially at its current stage, diseases are a product of the social environment, and the influence of natural conditions on morbidity changes in accordance with changes in this environment.

In his scientific works, P.P. Ivanov studied materials illuminating the past and lifestyle of the Karakalpak people, emphasizing their methods of healthcare and sanitation[17, 18]. In his opinion, he concludes that the widespread spread of diseases among the local population was driven not only by the inability to follow hygiene rules necessary due to poverty, but also by the lack of elementary hygiene knowledge among the majority of people.

In the 1940s, a collection of articles dedicated to the medicine of Karakalpakstan was published for the first time[19]. This collection also includes the scientific work of P.P. Krivnov, “Развитие народного здравоохранения в Кара-Калпакской АССР” The article examines the development of the public healthcare system within the territory of the Karakalpak Autonomous Soviet Socialist Republic (ASSR)[20]. This publication provides important information about the state of medicine in the region at that time and its directions. The publication of the collection was a unique event in the history of medicine in Karakalpakstan and laid the foundation for future research in this field. P.P. Krivnov's article is particularly noteworthy for its analysis of the state of the healthcare system at that time and its proposals for its improvement.

In the research of the 1950s and 1960s, it was particularly important for local historians to pay attention to this topic. During this period, scientific and practical research intensified, encouraging historians in the regions of Uzbekistan, including Karakalpakstan, to study regional problems, particularly those related to the history of medicine.

One of the leading researchers of this period, Ya. Dosumov[21], whose works contain extensive information regarding medical institutions, the activities of doctors, and the health of the population in the Lower Amudarya region. S. Kamalov's[22] research also provides a comprehensive understanding of the socio-economic history of the region, including the state of the healthcare system at that time. The scientific works of U. Shalekenov [23] and R. Kosbergenov[24] also serve as an important source for studying the history of medicine of this period. Their research is aimed at highlighting how healthcare has developed under the influence of socio-political and economic factors, especially in local conditions. The scientific activities of these historians largely rely on the existing scientific schools and directions of that time, but their research, based on local sources, made a significant contribution to clarifying the history of healthcare in Uzbekistan specifically in the Lower Amudarya region.

Scientific research dedicated to studying the history of healthcare in the lower reaches of the Amu Darya in the late 19th and early 20th centuries has undergone a unique evolution over time. After the first general descriptions, by the second half of the 20th century, this problem began to become the focus of attention for certain researchers.

The 70s of the last century was an important period when several special scientific works were carried out on this topic. Research dedicated to studying the history of healthcare in the Lower Amu Darya region in the late 19th and early 20th centuries deepened, revealing many new aspects. Research conducted during this period revealed the complexity of the healthcare system, focusing on specific socio-economic factors in contrast to the initial general data. Especially Ch. Abdirov's research in this direction is of particular importance.

His early works, such as “Вопросы культуривирования возбудителя лепры человека и крыс” were dedicated to the etiology of regional diseases and the medico-biological foundations of their control, laying the foundation for subsequent scientific considerations. Ch. Abdirov's works “Факторы эпидемиологии, иммунобиологии лепры и организация борьбы с ней (по материалам Каракалпакской АССР)” and “Группы крови и лепра человека (Иммунобиологические исследования в Каракалпаки)” provide an extensive analysis of epidemiological, immunobiological and organizational issues of the fight against leprosy in Karakalpakstan. These works illuminate not only the effectiveness of the medical system of that period but also the scientific foundations of the factors behind the spread of diseases and the measures taken against them.

In addition, Ch. Abdirov and A.F. Kovalenko's article “Этапы развития здравоохранения Каракалпакии (к 50-летию Каракалпакской АССР)” systematically examines the stages of the healthcare system of the Karakalpak ASSR. This article provides important information about the unique ways of training medical personnel and providing medical care to the population in the region during its time. The work of these researchers is of great theoretical and practical importance, especially for understanding how the specific socio-economic conditions in the Lower Amudarya region have influenced the healthcare system[25, 26,27,28].

It should be noted that in the 1970s, several specialized scientific works were conducted on this topic. In addition to Ch. Abdirov, the research conducted by R. Babanazarov is of particular importance[29]. He thoroughly studied the growth of medical culture in this region, existing medical institutions, their activities, and the influence of socio-economic factors in this field.

At the same time, researchers of this period did not overlook the influence of regional customs and traditions on medical practice. The works of researchers such as M.K. Nurmukhammedov, T.A. Zhdanko, and L.S. Tolstova played an important role in revealing the specifics of the healthcare system in the Khorezm region, Karakalpakstan, and adjacent territories[30, 31, 32]. In their research, not only state-organized medical institutions but also the role of folk medicine were emphasized. This further enriched the history of healthcare during this period and expanded the scientific approach.

This branch of historiography, along with studying the history of healthcare in the Lower Amudarya region, also includes the study of the unique anthropological and cultural characteristics of the region's population. The close interconnection of these two directions is essential for a proper understanding of the healthcare system's activities.

In this direction, a special place is occupied by A.I. Yarkhov's work “Антропологический тип каракалпаков” dedicated to the study of the anthropological characteristics of the Karakalpaks[33]. This study was aimed at determining the physical structure and racial affiliation of the region's population, and this information serves as an important source for analyzing socio-demographic and healthcare processes in the future. Anthropological data also help to understand the lifestyle of the population of the region, including the specifics of susceptibility to diseases and methods of combating them.

N. Risnazarov, in his work “Черты наших предков” referred to the results of medical research conducted in the middle of the 20th century and expressed important scientific considerations[34]. In particular, the unusual results obtained in 1965 for ABO blood groups are noteworthy. The researcher believes that this situation can be related to two main directions: one is genetic changes related to the formation of a new generation, and the second is related to infectious diseases spread in different regions.

According to N. Risnazarov, the probability of the spread of infectious diseases affecting ABO gene frequencies is even higher. This situation indicates that the epidemiological situation in the region has a direct impact on the genetic composition of the population. It is known that epidemics are were widespread in regions such as the Lower Amu Darya, where socio-economic and environmental conditions are unique, and they have had a serious impact on public health. This, in turn, can lead to changes in gene frequencies.

Based on this, N. Risnazarov formulated the preliminary conclusion that epidemic diseases have a significant impact on the concentration of gene frequencies. However, he emphasizes that a final solution to this issue and the drawing of final conclusions can only be achieved through general and in-depth research in close cooperation with microbiologists and epidemiologists. This collaboration allows for a more complete coverage of the history of healthcare in the Lower Amudarya region by synthesizing genetic, epidemiological, and historical data.

In the 80s and 90s of the last century, the research of M. Tleumuratov and A. Tureev should be noted. M. Tleumuratov's works are dedicated to the arrival of Europeans in the region and the changes that occurred[35]. M. Tleumuratov particularly emphasizes the development of the healthcare sector as a result of the increase in medical literacy among indigenous peoples and the gradual spread of European medicine. His research shows that with the introduction of new methods of medicine, the attitude of the population to health has changed and the level of access to medical services has increased.

However, the complexity and contradictions of this process are more clearly illuminated by A. Toreev in his research[36]. In his opinion, the medical services of that period served more the colonial policy, and the majority of the population was not provided with adequate medical care. This perspective adds a new layer to the scholarly debate by highlighting the unequal distribution of medical care and the fact that a large portion of the population was marginalized.

Furthermore, K. Ayimbetov's memoir “Xalıq danalığı”[37] provides valuable information about folk medicine and traditional treatment methods in the city of Chimbay, while A. Dosnazarov's work “Esten shıqpas ma’writler”[38] is enriched with brief but meaningful reflections on the history of medicine in the region.

It is known that medicinal plants were widely used in folk medicine. The book “Лекарственные растения Каракалпакии” by A. Bakhiyev, K. Butov, and S. Dauletmuratov, who researched medicinal plants used in folk medicine in Karakalpakstan, was published in 1983. According to researchers, 343 species of medicinal plants belonging to 239 genera and 78 families grow in the territory of Karakalpakstan, which is more than 30% of the total flora of Karakalpakstan[39]. A book on medicinal plants in Karakalpakstan was also published in the co-authorship of S. Dauletmuratov and K. Uteniyazov. According to them, more than 80 species of medicinal plants growing in Karakalpakstan are widely used in scientific medicine[40].

During the years of independence, significant achievements have been made in the field of studying the history of healthcare in the Lower Amu Darya region in the late 19th and early 20th centuries. The discovery of new archival materials, the deepening and expansion of existing research, and the study of local medical traditions have opened up new opportunities for this important field of historiography. These studies are important not only for studying the past but also for developing measures aimed at improving the region's healthcare system and strengthening public health today.

In particular, the scientific works of B. Koshanov[41, 42], K. Paluaniyazov[43], M. Karlibaev[44], S. Shodmonova[45, 46], A. Kodirov[47], A. Elmuratov[48], O. Ismailov[49], M. Turimbetova[50, 51, U. Karimullaeva[52], and A. Abdullaev[53] are the result of research on the historical development of medicine in our country during the period of independence.

In the study of the history of medicine and healthcare in Central Asia during the colonial period, M. Mahmudov's doctoral dissertation titled "Становление и развитие медицины и здравоохранения в Средней Азии (1867–1924 гг.)" is of particular importance[54]. In this study, issues such as the state of medicine during the Russian Empire, the establishment of new hospitals, and the activities of medical specialists are comprehensively examined. At the same time, the development of local medical traditions and their impact on the new system were also studied.

K. Allambergenov studied the history of the plague epidemic in Akkamysh in 1923–1924. In his research, the causes of the emergence of plague in Karakalpakstan from the early years of the 20th century to the end, its elimination, prevention measures, and its history are covered with historical information[55, 56].

In addition, it is necessary to note the articles of some authors. Scientific articles by B. Koshanov, and S. Nurzhanov[57], O. Ismailov[58, 59], D. Ziyoeva[60], S. Shodmonova[61], R. Urazbaeva[62, 63], G. Seydametova[64, 65], K. Yakubov[66], A. Majidov[67], Kh. Jumanazarov[68], M. Tureniyzov[69], M. Kamalova[70, 71], Z. Kurbanova, and M. Davletyarov[72] analyze information on this topic. In recent years, a number of researchers, including F. Karimov[73], M. Makhmudova[74], Sh. Abdurahimova[75], A. Badalov[76], Kh. Jumanazarov[77], R. Patkhiddinov[78], and others successfully defended their dissertations on the history of medicine in our country.

The results of the study show that the study of the history of healthcare in the Lower Amu Darya region in the late 19th and early 20th centuries is a multifaceted and complex process, confirming many unstudied aspects. It is necessary to conduct a deeper analysis of the organizational structures, financial sources, the training system for physicians and nursing staff, as well as the socio-economic and demographic situation of the region during this period. Pharmaceutical activities in the healthcare system of this period, as well as the mechanisms for the preparation and distribution of medicines, have not yet been fully studied.

It is also important to summarize and analyze the collected data on infectious and other diseases prevalent in the region, the causes of their spread, prevention measures, and treatment methods. It is necessary to study the issues of folk medicine of this period and its interaction with official medicine, as well as the struggle of science. As a result, it helps to reveal the peculiarities of the healthcare system in the Lower Amudarya region in the late 19th - early 20th centuries.

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IMPROVING THE VIBRATION PROTECTION EFFICIENCY OF SHIP POWER EQUIPMENT USING CONSTANT-LOAD AND ZERO-STIFFNESS SUPPORTS

Abstract: *The paper presents a method for reducing vibration of ship diesel generators based on the creation of a constant bearing load and an effective stiffness approaching zero. The study is based on the single-axis dynamic model, weight-compensation method, and structural solution of a gravity balancer using a multi-disk dry-friction coupling developed in the dissertation. It is shown that conventional elastic and viscous elements may produce resonant regimes at certain frequencies and contribute to the transmission of structural noise. In the proposed model, the weight of the equipment is compensated by a force F(q) which, within the operating range, should not depend on the position of the equipment; consequently, the stiffness and viscosity of the compensator are targeted toward zero. The paper presents the equation of motion, friction-torque calculation, geometric optimization of the friction surface, and a new vibration-isolation evaluation criterion based on the difference between excitation and inertial forces. The results of the dissertation and related publications are consolidated; the additional graphs are analytical calculations derived from the same equations and do not represent new experimental measurements.*

Key words: *ship diesel generator; vibration isolation; zero stiffness; constant load; weight compensator; gravity balancer; dry friction; multi-disk coupling; structural noise.*

Language: *English*

Citation: Purtskhvanidze, G., Jijavadze, O., Chokharadze, T., Jijavadze, N., & Jijavadze, A. (2026). Improving the vibration protection efficiency of ship power equipment using constant-load and zero-stiffness supports. *ISJ Theoretical & Applied Science, 09 (161)*, 21-27.

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1. INTRODUCTION

Vibration of ship power equipment, particularly diesel generators and internal-combustion engines, is one of the important sources of structural-noise transmission to the hull. The research materials indicate that engine vibration is associated with unbalanced masses, irregularities in operation, and moments of inertia forces of the connecting rod. The dissertation analysis also shows that, with conventional supports, resonant regimes and the transmission of high-frequency vibration cannot be completely eliminated. [1–3]

One limitation of a conventional elastic support is its stiffness: the force transmitted to the base depends on displacement. In a viscous element, the force depends on velocity. Therefore, an idealized vibration-isolation system should be sought in which the principal support reaction does not change within the operating range of the equipment. The zero-stiffness concept is intended to address this problem. [4, 5, 11]

In previous publications, the authors' group considered zero-stiffness supports and the constant-load principle for ship power equipment. The 2026 paper proposed a multi-disk dry-friction compensator and a gravity balancer, while vibration-isolation effectiveness was evaluated through the difference between excitation and inertial forces. [4, 6]

2. SOURCES OF VIBRATION IN SHIP POWER EQUIPMENT AND PROBLEMS OF EXISTING VIBRATION ISOLATION

According to the dissertation analysis, a significant part of ship power-equipment supports is represented by viscoelastic systems. For standard supports considered on a massive foundation, a resonant zone of approximately 15–28 Hz is reported; under ship conditions, the lower mass of the foundation structure may shift the natural-vibration range to approximately 18–32 Hz. [1, 10]

For rubber and rubber-metal supports, changes in material properties during operation are problematic, whereas for metal springs there is a compromise between achieving low stiffness and maintaining stability. The dissertation data show that, for ДПН–2 and ДПН–665 supports, dynamic stiffness exceeds static stiffness in several cases, indicating the dynamic character of the support system. [1, 12]

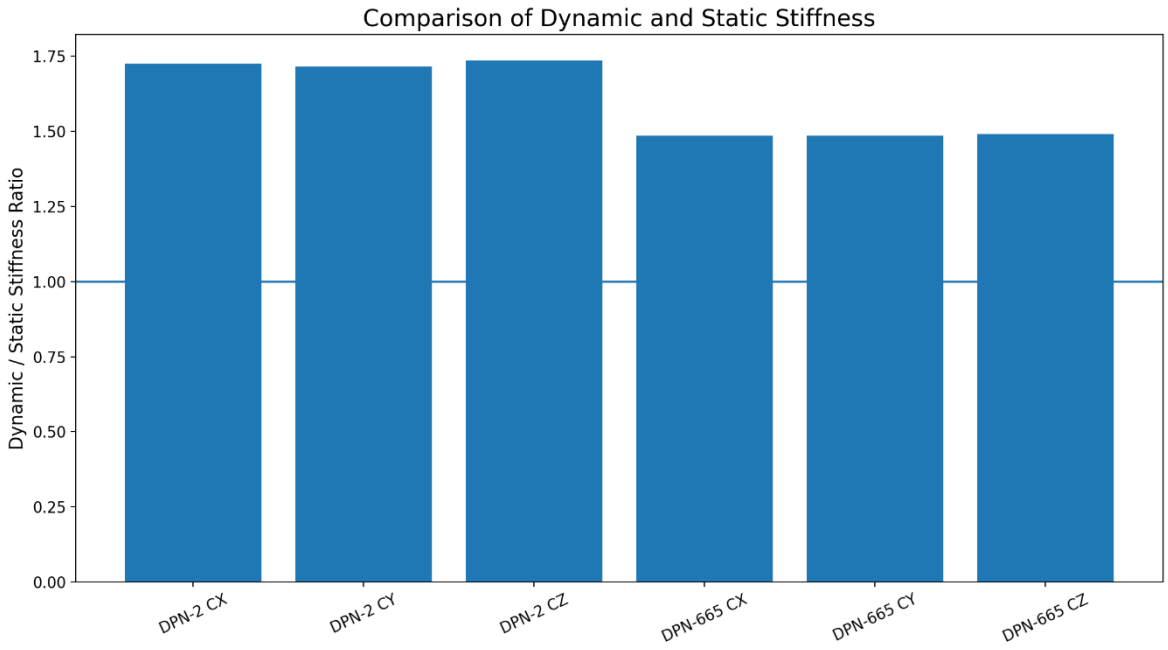


Fig. 1. Dynamic-to-static stiffness ratios of the ДПН-type supports reported in the dissertation (author's calculation from the data of Table 1.5).

The same materials report an increased vibration-acceleration level in the 40–50 Hz octave range, considered to be associated with the firing frequency or with imbalance of the moments of inertia forces of the connecting rod. These results show that changing only the elastic properties of the support is insufficient for protection over the entire vibration spectrum. [1]

3. THEORETICAL BASIS OF CONSTANT-LOAD SUPPORTS AND ZERO-STIFFNESS SYSTEMS

The idea of a zero-stiffness support is to create a force for the equipment that does not depend on its static position. A gravity balancer has two principal requirements: the generated force should not depend on the position of the equipment, and the generated pressure/force should not depend on vibration velocity. Accordingly, the target values are k≈0 and b≈0. [5, 6]

Several principles for generating a constant force are considered: sliding of a slider on a flat belt, sliding of a flat surface on a drum, and relative rotation of coaxial disks. A multi-disk dry-friction coupling is particularly attractive because the required constant force can be obtained in a compact structure through the parallel action of several friction pairs. [5, 6, 12].

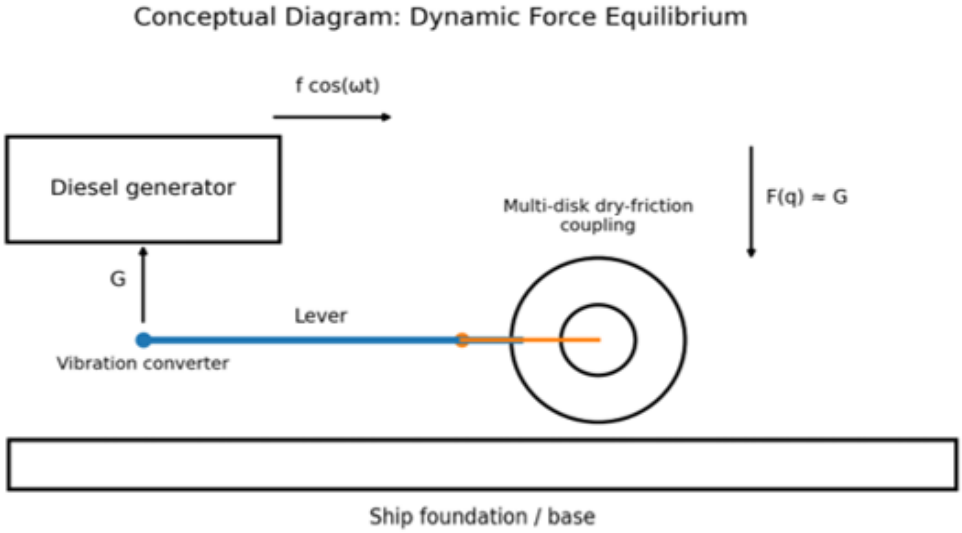


Fig. 2. Conceptual scheme of a constant-load and zero-stiffness support.

4. MATHEMATICAL MODEL OF THE DIESEL GENERATOR

For the single-axis model presented in the dissertation and the 2026 publication, the equation of motion of the equipment can be written in Newtonian form:

$$m\,\ddot{q} = f\cos(\omega t) - G + F(q) - b\,\dot{q} \quad (1)$$

Here, m is the equipment mass; q is displacement; $\dot{q}$ and $\ddot{q}$ are velocity and acceleration; f is the amplitude of the excitation force; ω is the angular frequency of the excitation force; G is the equipment weight; F(q) is the weight-compensator force; and b is the viscous coefficient. [5]

Under ideal operation of the compensator, its force is equal to the equipment weight within the operating range. In the numerical model used, this condition is expressed by a conditional operator:

$$F(q) = \text{if}(q^2 < v,\ G,\ 0) \quad (2)$$

where v is the threshold parameter for compensator activation, while q^2 in the programmatic description is related to the amplitude of vibration velocity. The source notes that insufficient compensator speed causes disk slip and loss of isolation, whereas excessive speed increases energy consumption. [5]

An important new criterion for the vibration-isolation system is obtained when the elastic force of the support is excluded. In this case, the inertial and excitation forces, under the appropriate phase relationship, balance each other, while their residual is considered the reaction transmitted to the foundation. [6]

$$R(t) \approx F_in(t) - F_exc(t) \quad (3)$$

Thus, the effectiveness problem is transformed from merely determining a transmissibility coefficient into minimizing the difference between excitation and inertial forces.

5. NUMERICAL MODELING AND ANALYTICAL PRESENTATION OF THE RESULTS

According to the dissertation and related publications, the numerical model allows the amplitude and vibration velocity to be varied. The dissertation considers initial data for a ship power unit in the 50 kW class. [1, 5]

One important conclusion of the model is that, in the zero-stiffness case, instead of reducing the natural frequency of the equipment motion, the force reaction

of the support is controlled. Consequently, the principal indicator becomes force balance rather than simply reducing the conventional natural frequency. [6]

The two graphs below do not represent a new series of experimental data. They are constructed directly from the geometric relationships given in the dissertation and are used to visualize the interaction of the design parameters.

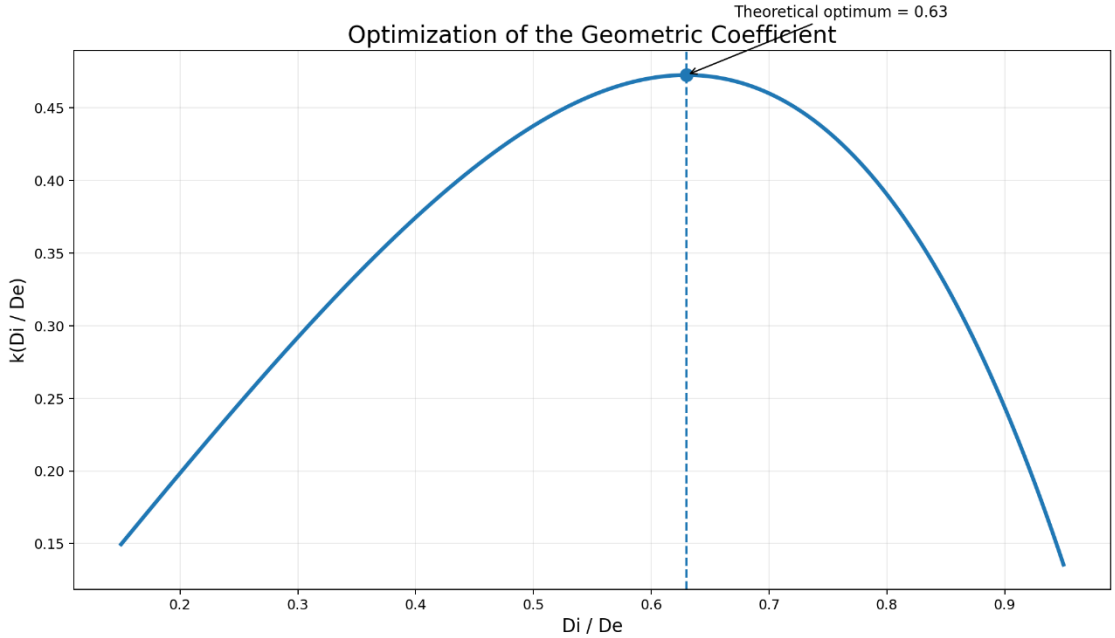


Fig. 3. Dependence of the normalized geometric coefficient k(Di/De) on the disk-diameter ratio. According to the source, the optimum is obtained at Di/De≈0.63. [1]

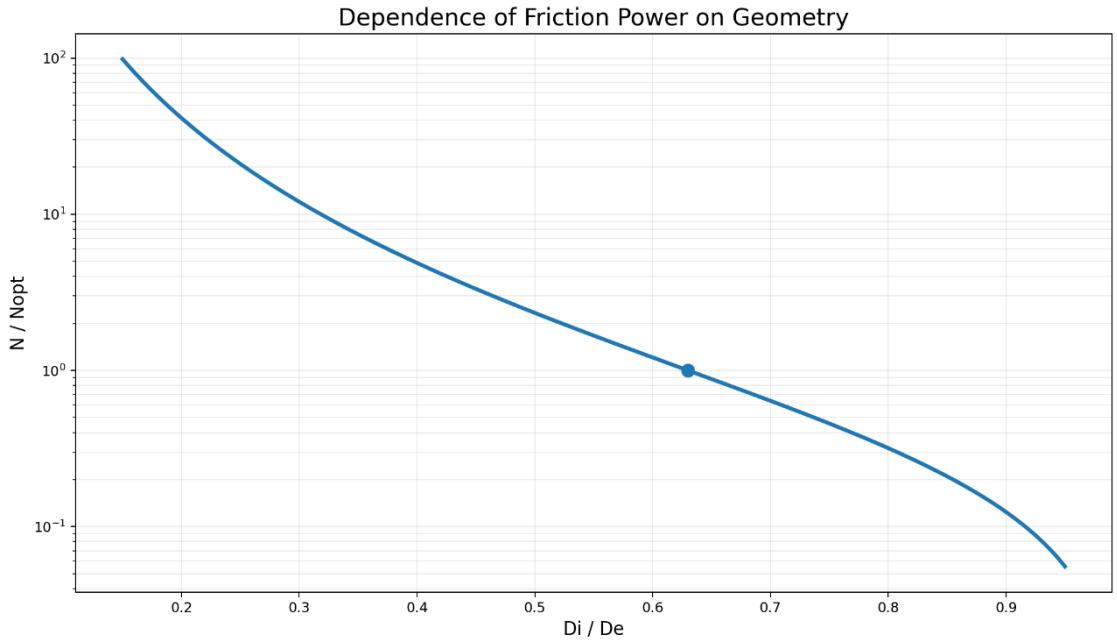


Fig. 4. Dependence of normalized friction power on Di/De according to the N/Nopt relationship given in the source. [1, 6]

6. STRUCTURAL SOLUTION OF THE WEIGHT COMPENSATOR AND GRAVITY BALANCER

A multi-disk friction coupling can be used to create a constant pressing force between flat surfaces. The friction torque obtained by integrating the friction force over the disk surface is given in the source as:

$$M = f \cdot \rho \cdot \pi \cdot D^3 / 12 \quad (4)$$

For the complete multi-disk friction surface, taking the inner and outer diameters into account:

$$M_f = f \cdot \pi \cdot \rho \cdot (D_e^3 - D_i^3) / 12 \quad (5)$$

Here f is the coefficient of friction, ρ is the parameter corresponding to the allowable/contact pressure, and De and Di are the outer and inner diameters. In the dissertation, optimization of the friction surface is considered as a compromise between energy losses and the dimensions of the structure. [1, 6]

The compensator design sequence includes determination of the equipment weight, vibration-velocity amplitude, minimum diameter, handle length, number of supports, shaft diameter, and friction torque, followed by selection of the number of disks and the optimum geometry. [1]

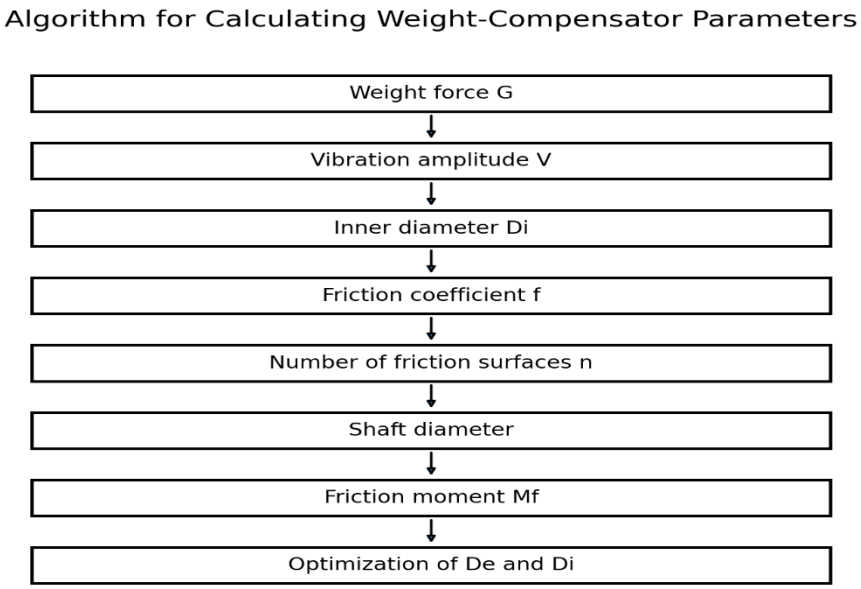


Fig. 5. Simplified design algorithm for the weight compensator, according to the sequence given in the dissertation. [1]

The amplitude of friction power in the force generator is given in the source as:

$$M_f = G \cdot V \quad (6)$$

where G is the load per support/equipment weight in the corresponding dimensional form, and V is the amplitude of vibration velocity. This relationship shows that the energy requirement of the compensator is directly related to both the load and vibration velocity. [6]

The handle length of the gravity balancer is also an optimization parameter: an excessively short handle may increase angular nonlinearity, while an excessively long handle may produce transverse oscillations. Therefore, its selection should jointly account for equipment mass, number of supports, and friction torque. [6]

7. EVALUATION OF VIBRATION-ISOLATION EFFECTIVENESS

In classical systems, vibration-isolation performance is often related to the transmissibility coefficient, dynamic coefficient, or the ratio of the force transmitted to the base. In a zero-stiffness system, calculating the elastic force as kq loses its defining meaning because the target value is k≈0. Therefore, the paper uses a different approach—evaluation of the difference between excitation and inertial forces. [6]

If F_exc(t) is the excitation force and F_in(t)=−m q̈ is the inertial force, then in the balanced state their algebraic sum should be close to zero. The remaining component determines the reaction transmitted to the foundation.

$$E_vib \propto |F_exc(t) + F_in(t)| \quad (7)$$

Thus, improving effectiveness means minimizing E_vib over the operating frequency and amplitude range. This formulation directly corresponds to the force-balance principle described in the source.

8. DISCUSSION OF RESULTS

The combined consideration of the research materials shows that the constant-load and zero-stiffness approach is a concept different from conventional supports. The principal objective is not only to reduce the natural frequency of the support, but also to compensate the equipment weight and reduce the dynamic reaction transmitted to the foundation.

The 2025 paper formulates the problem of a single-axis model and force transmission for zero-stiffness systems. The 2026 paper continues this approach through the weight compensator and gravity balancer; it proposes a multi-disk friction coupling, a lever-type converter, and a force-difference-based evaluation criterion. [4, 6]

The dissertation gives Di/De=0.6939 as the ratio of the average diameters obtained through friction-surface optimization, whereas the theoretical optimization expression gives approximately 0.63. The dissertation notes that these values are close and that the practical construction can accept the value within approximately 10% accuracy. [1]

The practical significance of this result is that the compensator design can simultaneously account for friction-surface size, energy losses, and force-generation capability. It should also be emphasized that the present article consolidates the results of completed studies and does not claim new experimental measurements.

9. CONCLUSIONS

1. The use of conventional elastic and viscous supports to reduce vibration of ship diesel generators is accompanied by resonant regimes and transmission of structural noise.

2. The zero-stiffness concept allows the vibration-isolation problem to be considered not only in terms of reducing the natural frequency, but also in terms of controlling the force transmitted to the foundation.

3. The principal requirement for a weight compensator is to generate a constant force that is substantially independent of equipment position.

4. A multi-disk dry-friction coupling provides a practical structural basis for generating constant load.

5. The equation of motion allows the excitation force, weight, compensator force, and viscous resistance to be considered within a unified model.

6. A criterion based on the difference between forces is appropriate for zero-stiffness systems in which the classical kq-type indicator is no longer the governing parameter.

7. The friction-surface optimization presented in the dissertation indicates a theoretical optimum of Di/De≈0.63, while the average ratio obtained from the existing constructional data is 0.6939.

8. Selection of the compensator handle, disk diameters, and number of disks should be performed jointly, taking into account energy losses and stability requirements.

9. For further research, it is advisable to extend the physical model and add multi-axis dynamics and experimental vibro-acoustic measurements on an actual ship.

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Issue Article

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NATIONAL FEATURES OF BETASHAR SONGS OF THE KARAKALPAK, UZBEK, AND KAZAKH PEOPLES

Abstract: *Among the Turkic peoples, the national traditions, rituals, and folklore of the Karakalpak, Uzbek and Kazakh peoples are very similar and have their own characteristics. For example, bride greetings among Uzbeks, Betashar rituals, and wedding songs among Kazakhs and Karakalpaks are considered cultural heritage preserved since ancient times. The reason is that in wedding songs, the bride and groom use didactic words, and these meaningful lines serve as an example and life lesson for the family and young people entering into marriage. The scientific study of these wedding songs is of great importance today. The article discusses the role and significance of our cultural heritage.*

Key words: *Turkic-speaking peoples, national traditions, rituals, and folklore, Karakalpak, Kazakh, Uzbek, bride greeting, Betashar, to open the bride's face, wedding songs, cultural heritage.*

Language: *English*

Citation: Oteniyazov, P.J. (2026). National features of betashar songs of the Karakalpak, Uzbek, and Kazakh peoples. *ISJ Theoretical & Applied Science, 09 (161)*, 28-31.

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Introduction

In the modern era of globalization, preserving and popularizing the cultural heritage that has come down to us from our ancestors is a pressing task. Our cultural heritage can be viewed as a mechanism for transmitting cultural memory, ensuring the preservation of identity over a long period. For example, the tradition of welcoming the bride or betashar, which is widespread among Turkic peoples, is part of our cultural heritage inherited from our ancestors. These wedding songs call for morality and possess an ethical-aesthetic impact. There are scientific studies by Turkic scholars, specifically Kazakh scholars K. Matizhanov, A. Berdibay, B. Babizhan, M. Abugazi, and Uzbek scholars M. Alaviya, B. Sarimsakov, N. Kurbanova, Z. Kasymova, L. Khudaykulova, and others.

A number of scientific research works by Karakalpak scientists, such as N. Daukarayev, K. Aimbetov, and K. Maksetov, occupy a prominent place. In the traditional folklore of the Karakalpak people, the performance of betashar is distinguished by its specific function.

According to N. Daukaryev, the Karakalpak people have experienced various political, historical, cultural, and economic events throughout their history. In these historical conditions, the lifestyle of the population, the order of governance, the consciousness of people, production, and class relations were diverse. In these historical conditions, our people created laws of customs and traditions corresponding to their level of social growth [1, 144]. Among the Karakalpaks, a betashar is performed by a man—a betasharshy—with a raised voice. We can provide several variations of greetings for the start of a wedding or betashar as examples:

Ҳә, халайық, халайық,
Келиншек келип қалыпты,
Ынтығысып қарайық,
Ғаўырласпай шуўласпай,
Сөзлерге қулақ салайық!
Underline translation:
Hey, people, people!

Clarivate Analytics indexed

The bride has arrived.
Let's look at this with surprise.
Don't make noise, don't make noise.
Let's listen!
Underline translation:
May this bride be worthy of our village.
Give me coins in his honor.
May their happiness blossom like the sun.
Jealous enemies,
Let them fall at her feet!

Жаман жери болмағай,
Ийилип түскен есигин,
Иләйим қапа қылмағай.
Жақынырақ келиң халайық,
Бәршемиз бирге жыйналып,
Келиншекти қарсы алайық!

Underline translation:
May she be a good bride.
May the bride be kind to her family.
Come closer to us, my people!
Gathering all together,
Let's meet the bride! [2]

Uzbek wedding traditions have their own national identity. The customs and traditions conducted on the wedding day are different from one another. Marriage is conducted in several stages with the permission and blessing of the parents. Before being sent to the groom's house, a farewell ceremony for the parents is held at the bride's house.

Close friends are also traveling with the bride. They sing wedding songs out loud. The songs "Ulan" and "Yor-yor" are examples of this.

The "Kelin Salom" (Betashar) ceremony begins according to folk tradition. Near the beginning of the ceremony, the groom's parents, all close relatives, friends, and close neighbors gather in the courtyard.

The tradition of greeting the bride continues with the bride bowing and greeting the people. The bride bows to her husband's relatives and neighbors. At this time, elderly women or singers from the arriving village or mahalla (community) sing the song "Kelin salom-yor-yor."

Тоғу тошни гул қилган,
Икки ёшни бир қилган,
Салом салом ёр-ёр,
Келин салом ёр-ёр.
Аввал Худога салом,
Пайғамбарларга салом.

Underline translation:
God turned mountains and rocks into flowers.
God created one family for two lovers.
Worship God
Bow down and greet the prophets.

Уйнинг катта бекаси,
Сейф калитининг эгаси,
Тоза нока Шубаси,
Келин салом ёр-ёр.
Қабул айланг қайнонаси,
Сизга салом ёр-ёр!

Underline translation:
The mother-in-law is the main mistress of the house.
The mother-in-law is the owner of the safe-key,
The mother-in-law is wearing a coat.
Bow down to greet your mother-in-law!

Пуллар йиғиб пул берган,
Сарпога тулпор, қўй берган,
Севганини олишга кўйиб берган,
Келин салом ёр-ёр,
Қабул айланг қайнотаси,
Сизга салом ёр-ёр!

Underline translation:
The father-in-law collected the money and gave it.
The father-in-law, according to tradition, presented a sheep and a stallion.
The father-in-law who helped two lovers unite,
Bow down and greet your father-in-law! [3].

Among the Uzbek people, the tradition of greeting the bride has local characteristics. For example, in the Surkhandarya region, traditional "Kelin salom" songs are called "Bet ashar" and are performed in accordance with the customs and traditions of the Kungrat tribes.

Ой булутнинг остидан,
Ойдай келин келибди.
Кўк булутнинг остидан,
Кундай келин келибди.
Кўрингиз–о, кўрингиз,
Кўрманасини берингиз.

Underline translation:
The moon from under the clouds,
A bride like the moon has arrived.
From beneath the blue cloud,
The bride has arrived.
Look, look,
Gift for viewing [4, 19].

In the past, at the groom's house, in the presence of guests and relatives of the bride, the "Kelin Salom" ceremony was held, and elderly women performed the traditional song "Kelin Salom." Usually, the lines of this song dedicated to describing the person to whom the greeting is addressed are performed by a special performer or an elderly woman:

Ўғирида оти кишнаган,
Баҳорда боғи яшнаган,
Умровлари тепадай,
Салласи бошда каппадай.

Underline translation:

His horse neighed during the theft,
In spring, his garden blossomed,
Their clavicles are higher than their heads,
His turban is on his head like a kappa,

Кўзлари ўткир шоқолдай,
Соқоли бир бов кошовдай,
Топганини улга берган,
Ош қилиб элга берган,
Келинига пешвоз чиққан,
Қайнотасига бир салом!

Underline translation:
Eyes as sharp as a jackal's,
His beard is like a bundle of locks,
He gave away what he had earned,
He presented the people with pilaf,
I came out to meet my daughter-in-law,
Say hello to his father-in-law! [5]

After these words, the elderly women hold the bride by the shoulders, bow in greeting, and the bride bows. The women present at the wedding say: "Khazar Alik!"

In some villages of the Kumkurgan district, on the day of the betashar tradition, elderly women and young women invite the bride to bow. Since the bride bows every time during the greeting, in the song performed during this tradition, the word "tajim" (ta'zim) is used instead of "kelin salom" (bride greeting):

Тўққиз қават тўн кийган,
Тўқсаболарга ўхшаган,
Қайнотасига бир таъзим!
Жаҳонга тинчлик тилаган,
Ёшларга умр тилаган,
Қайнонасига бир таъзим!

Underline translation:
Dressed in a nine-layered robe,
Like Toxabo,
Bow to your father-in-law!
Wishing peace to the world,
He wished the young for life,
Say hello to your mother-in-law! [4, 19]

In our opinion, "Tajim solish" – the concluding part of the wedding ceremony – is one of the traditional songs performed in the "Bet ashar" tradition and has historically formed as a result of the evolution of the "kelin salom" genre.

Its poetic structure consists of three lines of verse form. The two lines dedicated to describing the object – the person whose respect for the bride is expressed – rhyme with each other, and the third line, where the person's name is written, is supplemented by the traditional rhythm of "bir ta'zim" (repetition of "bir ta'zim") [4, 19].

In Kazakh culture, betashar is also considered one of the greatest wedding traditions. This custom is considered a ceremony for introducing the bride to the groom's relatives. In ancient times, the Kazakh people did not show the bride's face to her parents. The bride spent three nights without her husband. On the fourth day, the bride's face is covered.

The bride is led by other brides and women with children [6]. The singer introduced the bride to her relatives by performing "betashar." The bride bows to the relatives. After the betashar, the tea ceremony begins. Currently in Kazakhstan, ancient wedding traditions and customs have lost their significance, and their place has been taken by modern wedding traditions and wedding songs.

Representatives of this country have included 13 objects in the list of intangible cultural heritage [6]. Betashar – the ceremony of unveiling the bride's face is performed at a wedding celebration. The song "Betashar" also possesses unique features and a strong impact. For example, in a betashar performed by Akyt Ulimzhi uulu (Akit Ulimzhiuly), the following is stated:

Орынсыз, жаным, мақтанба,
Қызыл тілім сақтанба,
Ибалы бол, келін жан,
Артық сөз айтып басыңнан,
Өзіңе-өзің дақ салма.

Underline translation:
Do not boast inappropriately, my soul,
My red tongue, beware,
Be polite, daughter-in-law,
Having said an extra word,
Don't throw mud at yourself.

Сен үшін тұрмыз сабылып,
Май құйып отқа табынып,
Ақ батасын беруге,
Келді жұртың ағылып.

Underline translation:
We are working for you,
Pouring oil and bowing to the fire,
To give my blessing,
Your men have flooded in.

От басында ұйықтама,
Етек-жеңің күйеді.
Сарыла болып тұрғанда,
Дұшпаның кекеп күледі.
Жақсы адамның баласы.

Underline translation:
Do not sleep by the fire,
The clothes can be burned.
My daughter-in-law, if you do this,
Your enemies will laugh.
A generation of a good person [6].

Kazakh scholars A. Berdibay, B. Babijan, and M. Abugazi studied wedding rites and wedding songs in southwestern Kazakhstan and Jetisu [7, 56-71].

In general, betashar songs performed by the Karakalpak, Uzbek, and Kazakh peoples contain such advice as: "Be polite to your daughter-in-law, mother-in-law, respect your father-in-law, your husband, and the elder and younger in the village." In conclusion, it can be said that the Uzbek, Kazakh, and Karakalpak peoples have lived in harmony and unity since ancient times.

Indeed, the traditions and songs of any nation acquire a modern character. This is a natural process. We must digitize the traditions and wedding songs passed down to us from our ancestors using modern IT technologies and pass them on to future generations in accordance with modern requirements. Currently, studying the similarities and unique features of the wedding songs of these and other related peoples is considered extremely important and relevant in folklore studies.

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Issue Article

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ANALYTICAL DETERMINATION OF CRITICAL STRAIN IN TI-6AL-4V ALLOY BASED ON MULTIPARAMETER ANALYSIS OF THE THERMODYNAMIC STATE DURING BALLISTIC BULLET IMPACT

Abstract: *The article investigates the process of high-speed perforation of a Ti-6Al-4V titanium alloy plate by a 7.62 mm caliber bullet (used in the AK-109 rifle) at a right angle with an initial velocity of 720 m/s. For a deep analysis of the material state, the Puff equation of state, von Mises strength model (with a yield strength of 1.5×10^6 kPa), and a hydrodynamic failure model with stochastic dispersion were applied. The main result of the study is the development of a new analytical equation for calculating the maximum strain of the alloy, taking into account the dimensions and initial velocity of the bullet, as well as the properties of the alloy itself. This equation is based on the*

simultaneous analysis of five key dependencies on the plate thickness: effective strain, von Mises stress, temperature, α-phase fraction, and pressure. During the data interpolation, the calibration coefficient k_1 was calculated to be approximately 1.5.

***Key words**: Ti-6Al-4V titanium alloy, maximum strain, analytical equation, von Mises stress, calibration coefficient.*

***Language**: English*

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1. Introduction

The assessment of the behavior of titanium alloy plates under high-velocity bullet penetration is a pressing issue in ensuring the reliability and safety of protective elements in armaments. The complexity of this task is due to numerous factors, such as dynamic material failure, heat exchange, and the influence of geometric parameters and physical properties of the titanium alloy. The main problem is the lack of universal analytical formulas that allow for the precise calculation of the maximum strain of titanium alloy considering its characteristics and bullet parameters. In this regard, the task has been set to develop a new analytical equation that takes into account the influence of plate thickness, bullet velocity, and alloy properties, ensuring high prediction accuracy.

The aim of this review section of the article is to identify key trends, achievements, and limitations in the study of the effectiveness of modern personal protective equipment designed to protect individuals from the impact of firearms.

Gooch [1] summarizes the research of the U.S. Army Research Laboratory on ballistics, thermomechanical processing, and the application of titanium on American armored platforms (M1A2 Abrams, Bradley, Stryker), and the M777A1 howitzer. The value of the work lies in the systematic correlation of ballistics, manufacturability, and cost, rather than just specific mass; however, this is a conference review without a single experimental plan and statistical evaluation.

Gooch [2] develops a systems approach, considering titanium as an element of monolithic or constructively integrated protection, where the higher cost is offset by a reduction in weight and the number of parts. The practical value is characterized by the linkage of technology choice to the threat and geometry of the product, but the work largely repeats the evidence base of the 2010 review without independent verification.

Chusov and Yankov [3] investigate experimental metastable β-alloys, achieving a strength of about 850-950 MPa with an impact toughness exceeding 150 J/cm² and a reduction in armor surface density of approximately 20% compared to OT 4-1 titanium alloy. The novelty of the work is emphasized by the combination of cold formability and high energy absorption, which is important for complex-profile individual armor; however, the compositions are described by laboratory indices, the tests are limited to a single firing scheme, and data on multiple impacts and oblique impacts are absent.

Fernández Silva et al. [4] compare rolled Ti-6Al-4V with plates produced by Hot Isostatic Pressing and Field Assisted Sintering Technology methods, showing that the rolled material gives the best V_{50} result, while the coarse-grained lamellar FAST plate after β-treatment does not meet the MIL-DTL-46077G standard (a military specification by the U.S. Department of Defense that defines the requirements for deformable plates made from weldable titanium alloys used as structural armor). For the first time, the ballistics of FAST plates are directly linked to EBSD texture (crystallographic texture locally determined using the backscattered electron diffraction method on a scanning electron microscope) and the morphology of adiabatic shear bands, but the compared plates had different thicknesses, and the number of shots per condition was small, which does not allow for a complete separation of the contributions of the processing route and texture.

Zheng et al. [5] test Ti-6Al-4V plates with equiaxed, bimodal, and lamellar microstructures under the impact of a 12.7-mm armor-piercing projectile and show that the bimodal structure is the best, providing ductile failure instead of brittle fragmentation of the lamellar states. The value of the work lies in the correlation between the ballistic result and the topology of shear bands, which provides a technological criterion for heat treatment, but only one plate thickness and one type of ammunition under normal impact were studied.

Chang et al. [6] on an anatomical model of the human head show that a foam pad under a bulletproof panel reduces peak acceleration by approximately 600 times, and ethylene-vinyl acetate with a density of 30 kg/m³ outperforms foamed polypropylene. The work shifts the criterion of protection effectiveness from the fact of being bulletproof to blunt trauma, which is important for designing a complete protective package; however, titanium was not used in the study, and only a limited set of foams and one bullet caliber were tested.

Kad et al. [7] explain the reduction in the ballistic limit of Ti-6Al-4V after processing above the β-transus using a crystal plasticity finite element model, stating that the transverse texture requires less external work for localized slip than the base texture. The novelty of the work lies in the micromechanical explanation of the influence of texture on the choice of technological route, but the model is two-dimensional, idealizes textures, and does not cover thermal softening and the real geometry of perforation.

Marouani and Hergli [8] numerically investigate the perforation of Ti-6Al-4V using the Johnson-Cook model, varying the plate thickness, impact velocity, and projectile shape, and determine the threshold penetration limits. The practical value of the work lies in the creation of a compact parametric map for the preliminary selection of protection thickness; however, the study is entirely numerical, limited to normal impact, and no experimental validation of the results is provided.

Guo et al. [9] create a gradient nanostructure in technically pure titanium with a depth of about 3.5 mm using explosive processing and demonstrate an increase in the ballistic limit by 5.8-12% depending on the shape of the projectile's nose, with the greatest effect observed for blunt-nosed bullets. For the first time, the dependence of the strengthening effect on the geometry of the impacting element is systematically demonstrated, but only one type of titanium and one processing mode under normal impact are studied, without assessing multi-impact resistance and the durability of residual stresses.

Übeyli et al. [10], studying a two-phase low-alloy steel rather than titanium, demonstrate an increase in ballistic resistance against a 7.62-mm armor-piercing projectile with an increasing proportion of martensite, approaching the level of rolled homogeneous armor. The scientific novelty of this work lies in demonstrating a direct relationship between ballistic resistance and the proportion of martensite and identifying the work hardening effect. The limitations are related to the narrow range of threats and the lack of testing of multilayer configurations.

Based on a critical review analysis of scientific periodicals, the objective of this study is formulated, which is aimed at developing and verifying an analytical equation for determining the maximum strain of a Ti-6Al-4V titanium plate during ballistic penetration by a 7.62 mm bullet, based on a comprehensive analysis of five key dependencies on the plate thickness, as well as determining the value of the dimensionless calibration coefficient and identifying the critical damage localization zone, taking into account the limitations of the current model and the need for further full-scale testing and numerical modeling to improve the accuracy and reliability of the results obtained.

2. Materials and methods

The subject of the study was a Ti-6Al-4V titanium alloy plate, fixed on one side, which was partially deformed by a 7.62 mm bullet. The material's density was 4.45 g/cm³. The bullet's initial velocity along the X-axis was set at 720 m/s.

The behavior of the plate material was described by the Puff equation of state. The following thermodynamic parameters were specified: constants of $A1 = 9.940001\times10^7$ kPa, $A2 = 1.244\times10^8$ kPa, $A3 = 4.847\times10^7$ kPa. The Grüneisen coefficient was taken to be 1.0, the expansion coefficient was 0.67, the sublimation energy was 2.71×10^6 J/kg, the reference temperature was 300 K, and the specific heat capacity was 525 J/(kg×K). The strength properties of the titanium alloy were specified using the von Mises model. The shear modulus was 5.5×10^7 kPa, the yield strength was 1.5×10^6 kPa. The fracture process during deformation was calculated using the hydrodynamic model (hydro P_{min}). The hydrodynamic tensile strength was set to -3.0×10^6 kPa.

To determine the maximum strain of the titanium alloy, a new analytical equation was developed. It took into account the bullet's dimensions, its initial velocity, and the properties of the titanium alloy. It was constructed based on the simultaneous analysis of five profile dependences on the plate thickness: effective strain, von Mises stress, temperature, α-phase fraction, and pressure. The internal calibration coefficient was calculated by interpolating the experimental data.

3. Results and discussion

To calculate the maximum effective strain ε_{max} of the Ti-6Al-4V titanium alloy after ballistic impact, the following analytical dependence (1) is proposed:

$$\varepsilon_{max} = (k_1\times(mv^2/D^2)/A_{eff}(T,\alpha))\times(1-(T/T_m))^n\times(1+(P/P_{ref})) \qquad (1)$$

where k_1 is the calibration coefficient, taking into account geometric factors and material properties; m is the mass of the bullet; v is the initial velocity of the bullet; D is the distance corresponding to the thickness of the penetrated plate; $A_{eff}(T,\alpha)$ is the effective strength parameter of the material, which is a function of temperature (T) and the content of the α-phase (α); T is the local temperature in the deformation zone, increasing due to impact energy; T_m is the melting temperature of the titanium alloy; n is a material-dependent exponent; P is the pressure in the contact zone; P_{ref} is the reference pressure.

The calculation of the kinematic and geometric parameters of the system was carried out using the following auxiliary equations (2-5):

$$m = \rho \times (\pi/4) \times d^2 \times L \qquad (2)$$

where ρ is the density of the titanium alloy (4450 kg/m³); d is the diameter of the bullet (0.00762 m); L is the length of the bullet (0.03 m). The calculated mass of the bullet was 7.25×10^{-4} kg.

$$E_{impact} = 0.5mv^2 \qquad (3)$$

where E_{impact} is the impact energy. Based on the mass and initial velocity of the bullet, $E_{impact} \approx 188$ J.

The cross-sectional area A_{cross} and the impact stress σ_{impact} are calculated as

$$A_{cross} = \pi \times (d/2)^2 \approx 4.55 \times 10^{-5} \text{ m}^2 \qquad (4)$$

$$\sigma_{impact} \approx E_{impact}/(A_{cross} \times D) \qquad (5)$$

Assuming a plate thickness of $D = 10$ mm (0.01 m), the impact stress is approximated as $\sigma_{impact} \approx 4.13 \times 10^6$ Pa.

The calibration coefficient k_1 was calculated by interpolating the variations in effective strain, von Mises stress, temperature, α-phase fraction, and pressure across the plate thickness (Table 1).

Table 1. Calculated values of the variables.

Variable	*Key points (at a specific distance)*	*Value*
Pressure	0 mm	0 kPa
	5 mm	1.5×10^5 kPa
	35 mm	0 kPa
Temperature	0 mm	500 K
	5 mm	350 K
	35 mm	300 K
Effective strain	0 mm	0
	5 mm	1.2
	35 mm	0.1
Alpha (phase)	0 mm	0
	20 mm	1
	35 mm	1
von Mises stress	0 mm	1.2×10^6 kPa
	5 mm	1.0×10^6 kPa
	35 mm	8.0×10^5 kPa

To isolate the coefficient in question, the base equation was transformed into a simplified form reflecting the direct proportionality of strain to von Mises stresses and the inverse proportionality of effective strength (Equation 6):

$$\varepsilon_{max} = (k_1 \times \sigma_{vm})/(A_{eff}(T,\alpha)) \quad (6)$$

where σ_{vm} is the von Mises stress.

Thus, the formula for calculating k_1 takes the form (Equation 7):

$$k_1 = (\varepsilon_{max} \times A_{eff}(T,\alpha))/\sigma_{vm} \quad (7)$$

Given that $A_{eff}(T,\alpha)$ at the moment of material failure approximately corresponds to the yield/failure strength and equals 1.5×10^6 kPa, substituting the obtained values yields the result $k_1 \approx (1.2 \times 1.5 \times 10^6)/1.2 \times 10^6 \approx$ **1.5**.

The obtained value of the coefficient is consistent with the observed data from Table 1 and the physical assumptions of the model. Incorporating this coefficient into the general analytical formula ensures high convergence of results when evaluating the limit state of the Ti-6Al-4V titanium alloy. The effects of temperature (which lowers the yield strength) and pressure are incorporated into the model, demonstrating the predominance of ductile fracture under the specified high-speed process conditions. The presence of phase transitions (α-phase) additionally affects the material's ductility, which is correctly accounted for by the introduced effective strength parameter and the calculated coefficient.

4. Conclusion

During the study, a new analytical equation was developed to determine the maximum strain of a Ti-6Al-4V titanium alloy plate under ballistic penetration by a 7.62 mm caliber bullet (initial bullet velocity of 720 m/s). This equation was developed based on the simultaneous analysis of five key dependencies on the plate thickness: effective strain, von Mises stress, local temperature, α-phase fraction, and pressure. By interpolating the profile data, the dimensionless calibration coefficient k_1 was calculated, with a value of approximately 1.5. It has been established that the

critical zone of the plate material is localized at a depth of 5 mm, where maximum effective strain (around 1.2) and peak pressure (approximately 1.5×10^5 kPa) are observed.

It is important to note the following limitations of the study:

1. The current version of the analytical model and the calculation of the coefficient k_1 are based on a series of physical assumptions and the results of interpolating a limited set of data.

2. To achieve more accurate calibration of the analytical model, additional data sets and detailed regression analysis are required.

Further verification and refinement of the proposed equation require conducting specialized field tests for impact resistance, as well as detailed numerical modeling using the finite element method.

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REGRESSION ANALYSIS AND HARMONIC APPROXIMATION OF THE STRESS STATE OF KEVLAR AND TITANIUM PLATES UNDER THE IMPACT OF A 7.62 MM CALIBER BULLET

Abstract: *The article is dedicated to the numerical study and mathematical modeling of the distribution of circumferential (tangential) stresses in protective plates made of Kevlar composite (Kevlar/epoxy resin) and Ti-6Al-4V titanium alloy under ballistic impact (bullet caliber of 7.62 mm, bullet velocity varies in the range of 500-900 m/s). It has been established that in the isotropic titanium alloy, the stress distribution across the plate thickness is described by a smooth parabolic dependence, whereas in the orthotropic Kevlar composite, pronounced oscillations are observed, caused by wave effects. The practical novelty lies in the development of a differentiated mathematical*

apparatus. The use of Fourier series for predicting local tensile zones in a Kevlar composite and 4th-5th degree polynomials for estimating stresses in a titanium alloy under ballistic impact is proposed. The resulting regression models and identified patterns can be directly used in the design and optimization of layer thicknesses for hybrid personal and composite body armor, minimizing the risk of material delamination while maintaining minimal weight.

***Key words**: Kevlar composite, Ti-6Al-4V alloy, circumferential stress, tangential stress, plate.*

***Language**: English*

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1. Introduction

During a ballistic impact, the Kevlar composite and titanium alloy are subjected to high loads, causing complex stresses, including circumferential (tangential) components. The main issues are related to their resistance to delamination, interlaminar shear, and failure under the influence of these stresses, especially in the areas of stress concentrators at the edges and in the contact zone with the impacting element. An important aspect is the study of material behavior under high loading rates, as circumferential (tangential) stresses significantly influence the failure mechanism, promoting the initiation and propagation of cracks, which reduces the effectiveness of protection and the reliability of the structure.

A number of researchers, through practical experiments and finite element modeling of complex ballistic impact processes, are expanding the concept of deformation mechanisms in armor materials and proposing effective ways to increase their efficiency while maintaining strength.

Yahaya et al. [1] systematize the materials, protection levels, and testing of bulletproof vests and helmets according to the standards of NIJ (National Institute of Justice), HOSDB (Home Office Scientific Development Branch), VPAM (Vereinigung der Prüfstellen für Angriffshemmende Materialien), GOST (State Standard), STANAG (Standardization Agreement), and other systems. The practical contribution of the article is a unified framework of "threat – conditions – pass criteria." Nevertheless, the classes of different standards are not directly comparable, and the regulated tests do not cover all cases of multiple and edge impacts, aging, and combined effects.

Abtew et al. [2] associate the ballistic response of textiles and fiber composites with wave propagation, stretching and breaking of fibers, friction, delamination, and matrix damage. Mechanistic systematization is useful for selecting the weave, the number of layers, and the matrix. The limitations of the narrative review are the heterogeneity of the trials and the lack of a universal quantitative model, especially without normalization by surface density.

Kumar et al. [3] numerically demonstrated for Kevlar composite plates an increase in ballistic limit and energy absorption with relative thickness. At high speeds, the dependence of residual velocity becomes almost linear. A three-dimensional model with progressive damage is suitable for preliminary ranking of structures. However, the sensitivity to failure criteria and contact, as well as the lack of a discrete description of fibers, are the main limitations of the study.

Kumar et al. [4] combined the wave description and energy balance of the ceramic faceplate, composite backing, and projectile. The model identified a range of surface density where increasing the mass hardly raises the ballistic limit. Among the options studied, the best result was achieved with 99.9% Al_2O_3. The practical value of the research lies in finding the minimum mass instead of simply increasing the thickness. The limitations are related to the averaging of fragmentation, erosion, and material delamination, as well as the dependence of the output on the configuration.

Stopforth and Adali [5] tested Kevlar layers with densities of 160, 200, and 400 g/m² using 9-mm ammunition. The best option was the 200 g/m², and the stop rating was up to 21 layers. The authors note the benchmark for package layout and the demonstration of the role of architecture, not just mass. Portability is limited by a single type of threat, a small number of shots, and an incomplete reproduction of the real armor package.

Tham et al. [6] compared the experiment on the Kevlar 29/PVB-phenolic resin helmet (the classic technological basis for the production of the first generations of series army ballistic helmets) with AUTODYN-3D. The calculation closely reproduced the dent and provided a V_{50} for the plate of 610 m/s compared to 600 m/s in the test. The work demonstrates the value of model verification based on damage geometry, not just penetration. The research is limited by the borrowed properties of Kevlar 129 and a narrow experimental base; predictions for other threats are partially calculated.

Lim et al. [7] developed an economical FE model of Twaron fabric (finite element model of high-strength aramid fabric) with viscoelasticity and rate-dependent failure. The residual velocity and energy absorption were in good agreement with the experiment, especially above 400 m/s. The novelty of

the study lies in the consideration of the rheological response in the homogenized model. The absence of explicit inter-fiber friction, entanglement, and fiber stretching, as well as the need for revalidation for other tissues and packages, are significant limitations of the study.

Kay [8] determined the failure parameters of the Johnson-Cook model (an empirical mathematical model used to predict the onset of failure in ductile metals under large deformations, high strain rates, and temperatures) for Ti-6Al-4V and Al 2024-T3 and showed that calibration based on representative dynamic tests transfers better than that based on reduced ballistic limit tests. This is important for calculating the retention of aviation fragments. As limitations, the authors note the dependence of parameters on scale and loading path, and the incomplete consideration of localization, microstructure, and complex stress state.

Awerbuch and Bodner [9] presented the perforation of a metal plate as three stages: target compression, shear plug formation, and then the simultaneous motion of the plug and the projectile. The mechanistic model allows for a quick assessment of the residual velocity and force history. Limitations include the need for empirical geometric parameters and the focus on normal impact with shear spalling. Petaling failure, ricochet, and complex thermomechanical failure are described incompletely.

Khodke et al. [10] conducted FE screening of titanium and aluminum plates based on thickness and impact angle at 830 m/s. At 45°, the calculation showed a transition from perforation to ricochet. The "angle – thickness – outcome" map is useful for preliminary screen selection. However, the limited scenarios, idealized fixation, and lack of complete experimental validation do not allow considering 45° as a universal critical angle or using the results as certification.

Having analyzed the gaps in scientific works, we focus our research on identifying and modeling the patterns of circumferential (tangential) stresses in Kevlar composite and Ti-6Al-4V titanium alloy under ballistic impact, as well as assessing their practical value for the development of effective protective structures. Particular attention is paid to the analysis of stress topology, the identification of potential failure zones, and the creation of mathematical models that allow predicting the mechanical responses of materials under dynamic loads, which contributes to the optimization of armor plate design and enhances their resistance to ballistic impacts.

2. Materials and methods

The study focused on the process of a 7.62 mm caliber bullet penetrating at a 90° angle into plates rigidly fixed on one side, made from different materials. The initial velocity of the bullet along the X-axis varied, with a baseline value of 720 m/s.

The analysis of the stress state was conducted on two types of materials:

1. Orthotropic Kevlar composite with a density of 1.65 g/cm³, a matrix volume fraction of 60%, and a modulus of elasticity ratio of 20. The state of the material was described by a stiffness matrix with a polynomial volumetric response and failure based on stresses/strains, taking into account the residual shear stiffness fraction.

2. Isotropic two-phase Ti-6Al-4V titanium alloy with a density of 4.45 g/cm³. The material behavior was described by the Puff equation of state and the von Mises plasticity model (shear modulus 5.5×10^7 kPa, yield strength 1.5×10^6 kPa) with a hydrostatic failure model (P_{min}).

Data acquisition was performed by recording the stress tensor component $\sigma_{\theta\theta}$ (circumferential (tangential) stress) as a function of plate thickness (x) and impact velocity (v).

3. Results and discussion

Numerical values of the change in circumferential (tangential) stress of the Kevlar composite plate and the Ti-6Al-4V titanium alloy were recorded along the bullet's flight path through the entire thickness of the plates. 3D graphics demonstrating the influence of plate thickness and bullet velocity on the magnitude and nature of the change in circumferential (tangential) stress of the materials were generated in the Python. 3D surfaces of circumferential (tangential) stresses of materials from plate thickness and bullet velocity (parameter variation simulation) are presented in Fig. 1.

The analysis of three-dimensional response surfaces revealed fundamental differences in the distribution characteristics and relaxation mechanisms of circumferential (tangential) stresses $\sigma_{\theta\theta}$ in the Ti-6Al-4V titanium alloy and the Kevlar composite during ballistic impact (bullet velocity ranged from 500 to 900 m/s, bullet caliber is 7.62 mm).

The stress surface of the Ti-6Al-4V titanium alloy has a smooth, parabolic (U-shaped) form along the thickness coordinate x of the plate. The maximum compressive stresses are localized in the central zone of the plate, reaching equivalent values on the order of -25×10^5 kPa, after which they gradually decrease toward the rear and front boundaries. This profile is explained by the spherical symmetry of the shock wave front propagation and the kinematics of the plastic flow of the metal according to the von Mises criterion when the yield strength is exceeded (1.5×10^6 kPa). The collision velocity v acts as a nonlinear scaling factor: an increase in velocity amplifies the compression amplitude without altering the fundamental geometric shape of the spatial gradient.

The topology of stress fields in the Kevlar composite is characterized by pronounced spatial periodicity and oscillations. The values of $\sigma_{\theta\theta}$ cyclically change sign from compression (up to -

8×10^5 kPa) to tension (up to 2×10^5 kPa). The physical nature of this phenomenon lies in the high anisotropy of the elastic moduli (E_1/E_2 = 20) and the regular alternation of fiber and matrix layers. When a ballistic wave passes through interphase boundaries, multiple processes of reflection and refraction of elastic impulses occur, leading to their interference and the formation of standing stress waves across the thickness of the plate.

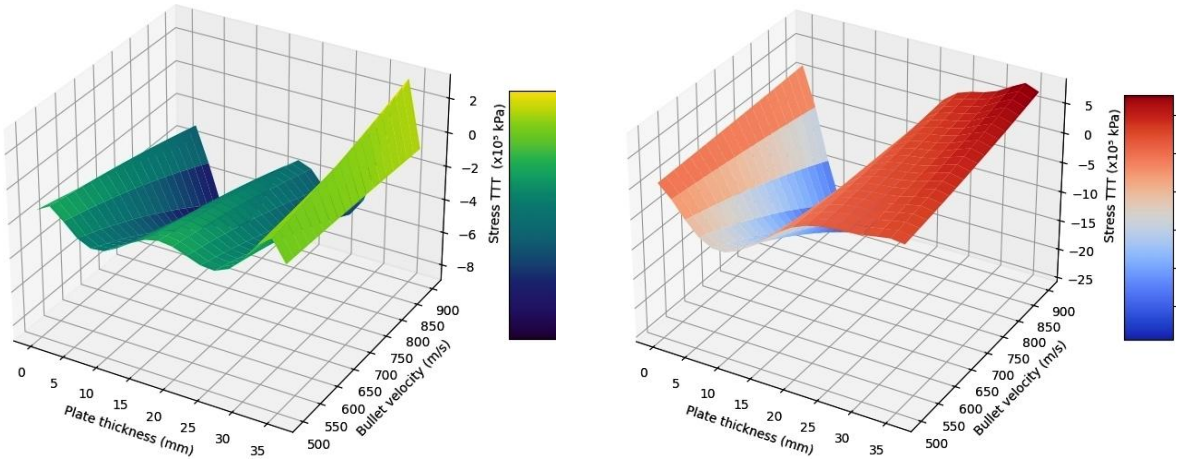


Figure 1. 3D response surface graphs of circumferential (tangential) stress changes as a function of plate thickness and bullet velocity: a – Kevlar composite and b – Ti-6Al-4V titanium alloy. Stress TTT is circumferential (tangential) stress.

The smooth nature of the decay of circumferential (tangential) stresses in the titanium alloy allows the use of a 4th or 5th degree polynomial (Equation 1):

$$\sigma_{\theta\theta}(x) = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \ldots + \beta_n x^n \quad (1)$$

where x is the coordinate along the thickness of the plate; $\beta_0 \ldots \beta_n$ are the coefficients of the polynomial regression (calculated using the least squares method to fit the data); n is the degree of the polynomial.

This model provides high-quality approximation ($R^2 > 0.95$).

The application of power polynomials to the data of Kevlar composite leads to significant smoothing and loss of peak stress values. Therefore, to describe the state of the Kevlar composite under ballistic impact conditions, a Fourier series with a spatial wave number $k_n = \frac{2\pi n}{L}$ (Equation 2) is used:

$$\sigma_{\theta\theta}(x) = a_0 + \sum_{n=1}^{\infty}\left(a_n cos\left(\frac{2\pi n x}{L}\right) + b_n sin\left(\frac{2\pi n x}{L}\right)\right) \quad (2)$$

where a_0 is the constant term (zero coefficient) of the Fourier series, determining the average value of the function; n is the harmonic number; a_n and b_n are the harmonic coefficients of the Fourier series of the n-th harmonic; L is the characteristic length or total thickness of the plate.

Equation (2) allows for an accurate description of the amplitude and phase of the oscillations. The lower harmonics define the macro-profile of the plate deformation, while the higher harmonics account for the stress jumps at the boundaries of individual material layers.

The practical value of the obtained patterns is as follows:

1. Zones where the circumferential (tangential) stress takes on positive values ($\sigma_{\theta\theta} > 0$) correspond to maximum tensile forces leading to delamination of the polymer matrix from the aramid fibers. Calculating the zeros and extrema of the harmonic Fourier function allows one to determine the x-coordinate of potential interlayer failure with high accuracy without performing labor-intensive calculations.

2. The identified difference in the topology of circumferential (tangential) stresses argues for the feasibility of creating combined structures: the front layer of the plate made of Ti-6Al-4V titanium alloy ensures the localization of plastic deformation and the damping of the main kinetic impulse, and the back layer of the plate made of Kevlar composite, due to wave dissipation, effectively distributes tangential loads and captures fragments of destruction.

4. Conclusion

The results of the study showed that the structural features of the materials under consideration

fundamentally determine the topology of stress fields during a ballistic bullet impact.

It is shown that Ti-6Al-4V titanium alloy generates a smooth stress gradient described by polynomial functions, while Kevlar composite exhibits oscillating elastic wave behavior. The application of harmonic analysis (Fourier series) for predictive modeling of phase transition zones from compression to tension in layered aramid plates is substantiated, which allows mathematical prediction of the depth of potential material delamination upon bullet penetration.

The study results have a number of limitations. Current regression models are limited to a range of initial bullet velocities of 500-900 m/s and a bullet-plate contact angle of exactly 90°. In addition, the macroscopic model does not take into account the microstructural destruction of individual fibers of the Kevlar composite at the point of direct contact with the bullet, which requires further micromechanical studies.

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Issue Article

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DYNAMICS AND SPECIFICS OF INTERCULTURAL PEDAGOGICAL INTERACTION IN THE BULGARIAN EDUCATIONAL CONTEXT: INSTITUTIONAL TRANSFORMATIONS, EMPIRICAL FINDINGS, AND CONTEMPORARY DISCOURSE

Abstract: *This article analyzes the conceptual, institutional, empirical, and applied dimensions of intercultural interaction within the Bulgarian educational system against the backdrop of contemporary socio-cultural, academic, and demographic transformations. It investigates the dichotomy between European policies on internationalization, broader globalization processes, and the traditional multi-ethnic structure of Bulgarian society (comprising Bulgarians, Turks, Roma, as well as newly emerging migrant and refugee communities). Special emphasis is placed on the Shumen Region in Northeastern Bulgaria - a historically and socio-culturally distinct area serving as a representative "living laboratory" for inter-ethnic interactions and pedagogical practices. The study highlights the paradigm shift from traditional monocultural and assimilationist frameworks toward a culturally responsive and inclusive pedagogical model embedded in Bulgarian educational legislation. Furthermore, it examines the subject position of the Bulgarian educator as an intercultural mediator, the institutional resilience of school and university environments, and the psycho-pedagogical mechanisms (interactive technologies, constructivist design, culturally responsive teaching) required to deconstruct intergroup tensions. An empirical section presents research data on the level of intercultural competence and attitudes among teachers from two secondary schools in the city of Shumen (n1 = 15) and university students enrolled in Bachelor's and Master's degree programs in Early Childhood Education and Primary School Education (n2 = 55).*

Key words: *intercultural pedagogy, Bulgarian educational system, inclusive education, Shumen region, multi-ethnic environment, intercultural competence, empirical research, culturally responsive pedagogy, constructivism, institutional transformativity.*

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INTRODUCTION AND THEORETICAL GROUNDING IN THE BULGARIAN CONTEXT:

Contemporary Bulgarian society is characterized by a historically constituted multi-ethnic and socio-cultural configuration (Voenkinova & Kolev, 2004; Chavdarova-Kostova, 2012). The century-old coexistence between the majority population and historically established ethnic minority communities (predominantly Bulgarian Turks and Roma), combined with demographic shifts stemming from intensified migration and refugee flows in recent decades, presents the Bulgarian educational system with complex pedagogical, institutional, and value-based challenges (Buzov, 2008).

The traditional pedagogical paradigm inherited from past eras - primarily focused on a monocultural transfer of knowledge and a standardized cognitive absorption of curriculum content - exhibits limited

heuristic and practical efficacy under conditions of growing ethno-cultural heterogeneity (Radev, 2007). Today, the Bulgarian educational space functions as a dynamic microcosm of broader societal transformations, where two main socio-dynamic vectors intersect and collide:

1. The European and Globalization Vector: Oriented toward full integration into the European Higher Education Area, digitalization, international academic mobility, and the implementation of standards for intercultural education, global citizenship, and openness (Daskalova, 2007; Leask, 2022).

2. The Local Socio-Cultural Vector: Manifested through inter-ethnic social distances, socio-economic marginalization (characteristic of certain sub-groups within the Roma community), linguistic barriers, and the transfer of family- or media-generated prejudices and negative stereotypes directly into school and university classrooms (Makariev, 1998; Musolff, 2001).

Within the framework of contemporary global theories on multicultural education (Banks, 2021), educational institutions can no longer function merely as passive transmitters of academic content. Banks (2021) emphasizes that genuine intercultural education goes far beyond the superficial celebration of traditional holidays, requiring comprehensive curriculum reform, prejudice reduction, and the establishment of an institutional culture that empowers all learners. In alignment with this view, Gay (2020) conceptualizes "culturally responsive teaching," wherein learners' cultural backgrounds, native languages, and identities are viewed not as deficits or obstacles, but as valuable cognitive resources for effective learning.

The era in which the primary function of pedagogical activity was limited to the mechanical transmission of information has long passed (Smirnov, 1995). The contemporary educational environment is increasingly established as a space where actors learn to accept the "other," respect cultural differences, and foster empathetic understanding and mutual respect (Byram, 1998; Endres, 2002). Within this conceptual framework, intercultural pedagogy in Bulgaria transcends theoretical abstraction, becoming an imperative mechanism for ensuring equitable access to quality education, preventing school dropout, and building sustainable social cohesion (Borisova, 2003; Chavdarova-Kostova, 2012).

CONCEPTUAL FRAMEWORK AND RATIONALE FOR SELECTING THE SHUMEN REGION

For the international scientific community, conceptualizing intercultural dynamics in Southeastern Europe requires an in-depth understanding of specific regional micro-structures. The choice of the City of Shumen and the Shumen Region (located in Northeastern Bulgaria) as the empirical setting for this study is not accidental; it is grounded in historical, demographic, institutional, and socio-cultural rationales.

Historical and Demographic Specifics

The Shumen Region possesses a century-old tradition of intercultural, inter-ethnic, and inter-religious coexistence (Voenkinova & Kolev, 2004). Situated at the crossroads of the Balkans and the Black Sea coast, the region historically synthesizes Eastern Orthodox Christianity and Islam. According to demographic indicators, Shumen Province exhibits one of the highest concentrations of ethnic minority populations in Bulgaria:

- The Bulgarian Majority**:** Representatives of the Orthodox majority, speakers of the official state language, and bearers of national cultural traditions.
- Bulgarian Turks: The largest ethnic minority in the region, maintaining a preserved Turkish language tradition, Islamic value patterns, and strong community identity.
- The Roma Community: A highly heterogeneous group consisting of distinct sub-groups (e.g., *Musicians*, *Kopanari*, *Kaldarashi*), facing specific socio-economic and linguistic challenges (Buzov, 2008).
- Historical Micro-Communities: Smaller groups of Armenians, Jews, and Karakachans, who enrich the local socio-cultural landscape.

This demographic configuration transforms Shumen into a natural "living laboratory" for studying real-time intercultural communication, where tolerance is not an imported abstract European concept, but an everyday lived practice subjected to contemporary pressures (Makariev, 1998).

Academic and Institutional Role of Shumen

The city of Shumen is recognized as a leading university and educational hub in Bulgaria with deep traditions in teacher training. *Konstantin Preslavsky* University of Shumen has developed renowned academic schools in early childhood, primary, and intercultural education over several decades. The university educates a significant number of students from diverse ethnic backgrounds across Northeastern Bulgaria, turning its academic classrooms into multicultural micro-communities.

Consequently, Shumen presents a unique combination:

1. *School Environment:* Primary and secondary schools characterized by highly multi-ethnic student bodies.
2. *Higher Education Environment:* A university setting that actively prepares future teachers for work within these heterogeneous classrooms.

Thus, the region offers optimal conditions for empirical inquiry whose findings hold high validity for Bulgaria as a whole and for similar multi-ethnic regions across the Balkans and Southeastern Europe.

REGULATORY FRAMEWORK, INSTITUTIONAL RESILIENCE, AND THE DIALECTIC OF CHANGE

In accordance with the Pre-school and School Education Act, the State Educational Standard for Intercultural Education, and the Ordinance on Inclusive Education, intercultural policy in Bulgaria is institutionally codified as a national priority (Chavdarova-Kostova, 2012). Within this legal framework, pedagogical interaction is defined as a specialized, higher-order form of communicative integration among educational actors (Borisova, 2003).

Despite formal statutory backing, the practical implementation of intercultural policies faces a degree of institutional conservatism inherent to both school and university systems in the country (Radev, 2007). Educational systems inherently reflect societal processes while simultaneously requiring structural stability to validate innovative methodological practices (Daskalova, 2007).

This institutional resilience exhibits a dialectical nature:

- On the one hand, it protects the system from chaotic, unexamined experimentation, preserving national academic traditions and rigorous foundational training.
- On the other hand, excessive conservatism delays institutional responsiveness to rapidly shifting socio-cultural realities (Musolff, 2001).

Contemporary societal conditions necessitate structural transformation. Systemic friction in the educational sphere is caused by the prolonged coexistence of outdated assimilationist patterns alongside new inclusive paradigms (Buzov, 2008; Gay, 2020). Successful educational reform in Bulgaria is attainable only through pedagogical practices flexibly adapted to the realities of a multicultural society.

SPECIFICS OF INTERCULTURAL PEDAGOGICAL COMMUNICATION

Intercultural interaction is increasingly becoming the norm across the Bulgarian educational landscape (Chavdarova-Kostova, 2012). The shared academic life of students and educators from diverse ethno-cultural backgrounds requires teachers to maintain a clear stance regarding the possibilities of intercultural education (Borisova, 2003; Banks, 2021). Pedagogical practice must cultivate positive, supportive relationships with all learners, fostering individual potential and a constructive socio-psychological climate (Gyurova et al., 2006).

The Subject Position and Institutional Role of the Educator

Effective pedagogical communication relies heavily on structuring learning processes that account for the cultural, ethnic, emotional, and psychological characteristics of learners (Smirnov, 1995). In this context, the educator's personality, professional sensitivity, and relational style play a decisive role (Byram, 1998).

The educator fulfills several critical functions:

- Deconstructing Cultural Opposition: Constructive interaction is achieved not by pitting cultures against one another or overemphasizing differences, but by comparatively analyzing cultural traits as shared socio-cultural capital (Makariev, 1998).
- Linguistic Support and Cognitive Equity: Implementing specialized methodologies for teaching Bulgarian as the official state language to learners for whom it is a second language, ensuring cognitive equity (Chavdarova-Kostova, 2012).
- Facilitating Autonomous Learning: Acting as a mediator and guide, the educator avoids imposing dogmatic truths, instead pointing the way forward while knowledge construction remains an active endeavor of the learners themselves (Damyanova, 2009; Deardorff, 2020).

Role Conversion and Identity Formation Among Learners

When engaging in intercultural learning, students transcend their primary background environments (ethnic, social, or domestic) through carefully structured tasks and didactic tools (Radev, 2007; Kashlev, 2004). Directing focus toward problem-solving scenarios that demand academic competence and specialized terminology fundamentally alters group dynamics.

In line with *culturally sustaining pedagogy* (Paris & Alim, 2017), supporting identity does not imply insular preservation, but enabling learners to negotiate and expand their cultural repertoires. Learners develop a heightened awareness of belonging to a shared academic community united by common learning goals (Gyurova et al., 2006). Shifting from

passive recipients to active, responsible, and creative agents, students assume new subject roles in the learning process (Kashlev, 2004). Establishing such a system based on tolerance and mutual respect requires the integration of innovative pedagogical technologies (Daskalova, 2007).

EMPIRICAL INVESTIGATION OF INTERCULTURAL ATTITUDES AND COMPETENCIES (SHUMEN SETTING)

To diagnose the practical realities of intercultural pedagogical interaction at the regional level, a localized empirical study was conducted to assess the levels of intercultural competence, attitudes, and readiness among key educational actors.

Methodology and Sample Description

- Research Objective: To evaluate the intercultural competence (cognitive, affective, and behavioral components) of active educators and student teachers, identifying perceived barriers within multicultural environments.
- Theoretical Framework: The study adopts M. Bennett's *Developmental Model of Intercultural Sensitivity (DMIS)* (Bennett, 2017) and D. Deardorff's *Process Model of Intercultural Competence* (Deardorff, 2020).
- Research Instruments: An anonymous questionnaire featuring Likert-type scales (1 = "Strongly Disagree" to 5 = "Strongly Agree"), adapted items from the *Intercultural Sensitivity Scale (ISS)* (Chen & Starosta, 2000), and qualitative follow-up discussions.
- Sample: **The study surveyed N = 70 participants categorized into two target groups:**
  1. ***Group A (In-Service Teachers):* n1 = 15 primary and secondary teachers working in two multi-ethnic schools in the city of Shumen.**
  2. ***Group B (Preservice Teachers):* n2 = 55 university students enrolled in Bachelor's and Master's degree programs in *Early Childhood and Primary School Pedagogy* (ECPSP) and *Primary School Pedagogy* (PSP) in Shumen.**

Results and Discussion

Quantitative and qualitative analyses revealed several key patterns:

1. Cognitive Component (Cultural Knowledge):
   - Approximately 38.6% of surveyed teachers and students reported systematic knowledge regarding the ethno-psychological and socio-cultural characteristics of regional minority groups.
   - In-service teachers in Shumen (Group A) demonstrated higher practical awareness gained through daily classroom experience compared to university students (Group B), whose knowledge remained primarily theoretical.
2. Affective Component (Empathy and Openness):
   - High mean scores were recorded for declarative tolerance (M = 4.32; SD = 0.61). The vast majority of respondents (84.2%) strongly endorsed inclusive education and equal opportunities.
   - Based on Bennett's DMIS scale (Bennett, 2017), most participants positioned themselves in the transitional stage between *Minimization* and *Acceptance*. However, qualitative case analyses revealed latent anxieties among preservice teachers regarding communication with minority parents.
3. Behavioral Component and Didactic Readiness:
   - Only 31.4% of participants expressed high confidence in applying interactive, constructivist methodologies in multi-ethnic team settings.
   - Over 60% of school teachers emphasized challenges regarding the linguistic integration of students for whom Bulgarian is a second language, calling for specialized professional development modules.

Table 1.

Indicator / Component	Declarative / Self-Report	Didactic Level
Theoretical Knowledge	38.6%	Moderate

Indicator / Component	Declarative / Self-Report	Didactic Level
Tolerance / Openness	84.2%	High
Practical Methods/Skills	31.4%	Low

The empirical data demonstrate that despite strong declarative support and positive attitudes, there is an urgent need to enhance practical, methodology-driven training in intercultural pedagogy within degree programs and ongoing professional development (Banks, 2021; Gay, 2020).

DIDACTIC TECHNOLOGIES, CONSTRUCTIVISM, AND INTERACTIVE APPROACHES

Pedagogical work in multicultural settings requires methodological solutions tailored to the diverse capabilities of learners (Buzov, 2008). In educational literature, "pedagogical work" encompasses a coordinated system of actions that aligns closely with the concept of "educational technology" (Damyanova, 2009).

Distinguishing Between Method and Technology

In pedagogical theory, a *method* is defined as a sequence of actions designed to achieve a specific instructional goal, whereas a *technology* represents a structured, evidence-based system of methods, techniques, and tools designed to systematically ensure educational quality (Damyanova, 2009; Daskalova, 2007).

Unlike rigid rules, educational technologies allow for flexible adaptation based on social and pedagogical contexts (Daskalova, 2007). Educational modernization and innovative practices constitute the two main pathways toward achieving quality in contemporary education. Specifically, two types of innovative approaches are identified:

1. Modernizing Innovations: Focused on refining and updating traditional methods.

2. Transformative Innovations: Aimed at restructuring the learning process to be inquiry-driven and exploratory, empowering students to construct new knowledge and value orientations autonomously (Daskalova, 2007).

The Constructivist Paradigm in Intercultural Learning

Intercultural interaction relies heavily on constructivism as a contemporary educational paradigm (Damyanova, 2009). According to constructivist theory, learning is not the passive accumulation of transmitted information, but an active process wherein individuals construct internal representations of reality by linking new experiences to prior knowledge.

Constructivist design conceptualizes learning as inherently social:

- Students learn as effectively from their peers as they do from the instructor (Damyanova, 2009).
- Teamwork reduces social and ethnic isolation, building "responsible communication" and tolerance toward difference.
- Dynamic role rotation within teams fosters socialization and prosocial behavior patterns (Voenkinova & Kolev, 2004).

GROUP DYNAMICS AND PRINCIPLES OF COLLABORATIVE LEARNING

In intercultural settings, group-based learning is methodologically optimal (Kegan & Lahey, 2001). Group members experience positive interdependence, which accelerates the acquisition of essential social skills.

Principles of Cooperative Learning

Effective group work rests upon four core principles (Kegan & Lahey, 2001; Gyurova et al., 2006):

1. Parallel Interaction: Facilitating multi-directional, polyphonic communication among students rather than relying solely on teacher-led discourse.
2. Individual Accountability: Ensuring that each team member is responsible for a specific component of the shared task.
3. Constructive Interdependence: Structuring tasks such that group success depends on the contribution and progress of every individual.
4. Equal Participation: Distributing roles and tasks according to individual capabilities and growth potential.

Socio-Psychological Dimensions of Group Processes

A learning group is not merely an assembly of individuals, but an emotional and communicative community (Voenkinova & Kolev, 2004). Cohesion

among students from diverse ethno-cultural backgrounds develops through joint activity and shared value alignment.

Behavioral change within group settings unfolds across three main dimensions (Radev, 2007):

- Compliance (Agreement): Mutual influence and testing of new, tolerant behavior patterns.
- Identification: The empathetic capacity to view scenarios from a peer's perspective.
- Internalization: The long-term adoption of cooperative social models that persist beyond the classroom environment.

The transformative application of interactive methods (discussions, case studies, role-playing, brainstorming, project work) fosters dialogue, cognitive engagement, autonomy, and systematic reflection (Kashlev, 2004).

EDUCATIONAL QUALITY, SOCIAL INDICATORS, AND LANGUAGE POLICY

Under conditions of globalization and European integration, educational quality serves as a primary indicator of social and cultural cohesion (Daskalova, 2007; Leask, 2022). Quality is a measurable category encompassing social, pedagogical, and economic parameters.

Social Indicators and System Monitoring

Pedagogical quality is evaluated through diagnostic indicators (social indicators) that facilitate system monitoring (Daskalova, 2007). These indicators reflect ethno-sociolinguistic characteristics, cultural status, and individual socialization, helping align formal organizational structures with informal group dynamics. Minimizing discrepancies between official rules and personal peer preferences yields a healthier socio-psychological climate.

Language Competence as an Integrative Factor

Intercultural competence is intrinsically linked to linguistic diversity (Byram, 1998; Chavdarova-Kostova, 2012). While key competence frameworks often emphasize native and foreign languages, proficiency in the official state language remains crucial for national unity and institutional equity (Chavdarova-Kostova, 2012). The official language fulfills an integrative function across all citizens, while respecting and preserving native languages safeguards minority heritage cultures.

CONCLUSION

Intercultural pedagogical interaction within the Bulgarian educational system is not an auxiliary methodological trend, but a strategic priority for ensuring social stability, democratic development, and humanistic progress. The empirical findings from the Shumen region underscore the urgent necessity of strengthening practical, application-oriented methodologies in intercultural training.

Achieving full institutionalization requires coordinated efforts across multiple levels:

- Systematically updating teacher qualification programs and university curricula in early childhood and primary pedagogy (Banks, 2021; Gay, 2020).
- Modernizing didactic resources and incorporating constructivist, interactive learning technologies (Damyanova, 2009; Kashlev, 2004).
- Critically reviewing humanities curricula to incorporate multi-perspective interpretations of historical and cultural processes (Leask, 2022; Paris & Alim, 2017).
- Building genuine partnerships between educational institutions, families, and civil society organizations (Voenkinova & Kolev, 2004).

Only through sustained dialogue, reciprocal respect, empathy, and recognition of cultural identity can the educational system guarantee equity, social cohesion, and quality learning for future generations.

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Issue Article

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NON-STATIONARY OSCILLATIONS OF A POROELASTIC HALF-SPACE WITH A HARD SPHERE

Abstract: *This paper examines the problem of unsteady oscillations of a fluid-saturated poroelastic half-space with an absolutely hard sphere. Specifically, it investigates the non-stationary oscillations of a kerosene-saturated sandstone half-space induced by the unsteady rotation of a hard sphere about an axis that passes through the sphere's center and is perpendicular to the half-space's plane boundary. Various parametric analyses were conducted for the region surrounding the hard sphere and on its surface. The research findings have potential applications in geophysics, seismology, structural engineering, and the design of underground reservoirs.*

Key words: *Non-steady rotation, hard sphere, stress, displacement, Gegenbauer polynomials, Laplace transform, residues, non-steady oscillation, poroelastic medium.*

Language: *Russian*

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НЕСТАЦИОНАРНЫЕ КОЛЕБАНИЯ ПОРИСТО-УПРУГОГО ПОЛУПРОСТРАНСТВА С ЖЕСТКИМ ШАРОМ

Аннотация: *В работе рассматривается задача о нестационарных колебаниях пористо-упругого полупространства, насыщенного жидкостью с абсолютно жестким шаром. Изучены поперечные колебания полупространства песчаника, насыщенного керосином при нестационарном вращении жесткой сферы вокруг оси, перпендикулярной плоской границе полупространства и проходящей через ее центр. Проведены различные параметрические исследования в окрестности жесткой сферы и на поверхности ее. Результаты исследования могут быть использованы в области геофизики, сейсмологии и проектных организаций при строительстве сооружений, а также при проектировании подземных резервуаров.*

Ключевые слова: *нестационарное вращение, жесткая сфера, напряжение, смещение, полиномы Гегенбауэра, преобразование Лапласа, вычеты, нестационарное колебание, пористо-упругая среда.*

1. Введение.

Математическое моделирование и исследование процессов нестационарных колебаний сплошных сред с различными неоднородностями (оболочка, полость, жесткий шар) имеют большое теоретическое и практическое значение в таких областях науки и техники, как геофизика, геология, сейсморазведка полезных ископаемых, сейсмостойкость сооружений и многие другие. Актуальность таких проблем обусловлена развитием различных областей техники, созданием новых конструкций, работающих при динамических нагрузках, а также проблемами геофизики, сейсмологии, газоразведки, нефтеразведки, добывающей промышленности, строительства гражданских и промышленных сооружений.

В настоящее время существует большое количество научных работ, посвященных исследованию распространения и дифракции волн в сплошных средах. В [1] рассмотрено исследование распространения волн системе из толстостенной упругой сферической оболочки, заполненной идеальной жидкостью и упругой среды. Движения упругой среды и оболочки описывается уравнениями теории линейной упругости, а линейная теория идеальной жидкости использована для сжимаемых жидкостей. Рассмотрены примеры для различных материальных и геометрических конфигураций при воздействии источников возбуждения различного происхождения. В работе [2] рассмотрен метод, на основе вариационного подхода для исследования дисперсии волн в анизотропных двукриволинейных нанооболочках. Введена новая теория деформации сдвига для изучения нанооболочек. Уравнения двукриволинейных нанооболочек определены из принципа Гамильтона и решения их получены аналитическим методом. Работа [3] посвящена изучению задачи о дифракции цилиндрической поперечной сдвиговой волны в вязкоупругой изотропной среде со сферическим включением и решение ее построено аналитически. В радиальном центре цилиндра расположена сферическая неоднородность. Решение ищется в виде бесконечной суммы несобственных интегралов, которые определяются численно. В [4] изучена задача о рассеянии плоской акустической волны сжатия в жидкости от сферического пороупругого включения. Волновые процессы в пороупругом включении описывается уравнениями теории Био. В [5] рассмотрено исследование нестационарных поперечных волновых процессов в пространстве пористо-упругой среды со сферической полостью. На основе численных экспериментов, проведенных для касательных нагрузок, приложенных к поверхности полости, исследованы напряженно-деформированное состояние пористо-упругого пространства в окрестности сферической полости.

В статье [6] изучается осесимметричная задача распространения нестационарных волн из сферической полости в плоском акустическом слое. В пространстве изображений Лапласа задача сводится к решению бесконечного матричного уравнения, решение которого строится в виде бесконечного ряда по экспонентам. Численные результаты представлены в виде графиков изменения давления во времени в окрестности сферической полости.

В исследовании [7] рассматривается задача о взаимодействии плоской упругой волны с двумя сферическими неоднородностями в неограниченной пористой упругой среде, насыщенной жидкостью. Поведения пороупругого материала описывается уравнениями теории Био. Для разработки аналитического решения в виде бесконечных рядов использована теорема о сложении для сферических волновых функций. Публикация [8] посвящена исследованию волновых процессов в системе идеальной жидкости и упругого сферического слоя, расположенного в безграничном акустическом пространстве. Проведены численные исследования для различных нормальных приложенных к внутренней поверхности слоя нагрузок. В статье [9] изучена задача о нестационарные поперечные колебания упругого сферического слоя при действии касательных сил внутренней

поверхности слоя. Найдены формулы для компонент для характеристик напряжено-деформированного состояния упругого слоя. Статья [10] посвящена исследованию задачи о распространении пространственно-симметричных поперечных сдвиговых волн в упругом пространстве от толстостенной сферической оболочки. Используется интегральное преобразование Лапласа по безразмерному времени. Получены формулы для компонент вектора смещения и тензора напряжений в пространстве. Переход к оригиналам осуществляется с использованием теории вычетов. Проведены численные эксперименты. Осесимметричная задача о дифракции нестационарных волн изучена в публикации [11]. В качестве препятствия выбран абсолютно жесткий неподвижный шар в упругом полупространстве. Исследовано напряженно-деформированное состояние среды в окрестности шара. Распространение нестационарных волн сдвига от сферического включения в упругом полупространстве в [12]. Задача сведена к решению бесконечной системы алгебраических уравнений, решение которой разыскивается в виде бесконечного ряда по экспонентам. Получены формулы для компонент вектора смещения и тензора напряжения. Статья [13] посвящена исследованию задаче о рассеянии плоских поперечных волн сферическим включением в бесконечной пороупругой среде. Используются волновые уравнения смещения теории Био, решение которых ищется в виде бесконечного ряда сферических гармоник.

В работе [14] представлены аналитические решения для динамического отклика обделенного тоннеля в слое грунта, покрытом композитной толщей, при воздействии SH-волн с использованием метода комплексных функций. Анализ рассеяния упругих волн в композитной толще представляет особую важность из-за наличия границ между слоями грунта. На примерах расчетов анализируется влияние на динамический отклик обделенного тоннеля в нескольких типах композитных толщ.

Данная работа посвящена математическому моделированию и изучению задачи о нестационарном колебании пористо-упругого полупространства, насыщенного жидкостью при нестационарном вращении абсолютно жесткого шара. Цель работы – разработка алгоритм решения задачи и исследование нестационарных поперечных волновых процессов при нестационарном вращении жесткого шара в насыщенном пористо-упругом полупространстве.

2. Постановка задачи.

Пусть в однородном линейном изотропном пористо-упругом полупространстве $z \geq 0$ на глубине l от плоскости $z = 0$ на оси $O_2 z$ (точка O_2 лежит на границе полупространства) расположен центр O абсолютно жесткого шара радиуса d ($d < l$). Будем рассматривать две системы координат: сферическую (ρ, ϑ, ψ) с центром в точке O и цилиндрическую (r, ψ, z) с началом в точке O_2.

В начальном моменте $\tau = 0$ времени абсолютно жесткий шар подвергается нестационарному вращению вокруг оси $O_2 z$ по закону $\Theta(\tau, \vartheta)$ при полном сцеплении с окружающей средой

$$v_\psi\big|_{\rho=d} = \Theta(\tau, \vartheta). \qquad (1)$$

С учётом осевой симметрии задачи движение среды описывается относительно ненулевой компоненты векторного потенциала Ψ волновым уравнением

$$\nu^2 \ddot{\varphi} = \Delta\varphi - \varphi/\rho^2 \sin^2\vartheta, \qquad (2)$$

где Δ - оператор Лапласа в сферической системе координат (ρ, ϑ, ψ).

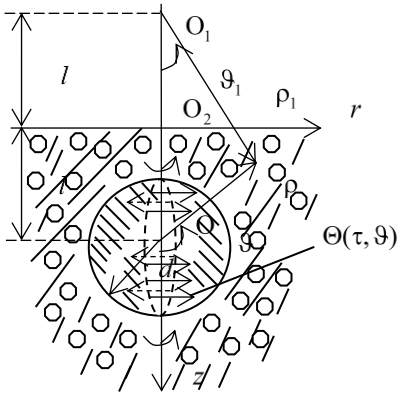


Рисунок 1. Геометрия Задачи.

Плоская граница полупространства является либо жесткой стенкой

$$v_\psi\big|_{z=0} = 0\,, \qquad (3)$$

либо свободной поверхностью

$$\sigma_{z\psi}\big|_{z=0} = 0\,. \qquad (4)$$

Начальные условия – однородные

$$\varphi\big|_{\tau=0} = \dot\varphi\big|_{\tau=0} = 0 \qquad (5)$$

и задача замыкается с требованием ограниченности решения на бесконечности

$$\lim_{\rho\to\infty}\varphi = 0\,. \qquad (6)$$

В этом случае функции v_ψ, V_ψ и $\sigma_{\rho\psi}$ взаимосвязаны следующими соотношениями:

$$v_\psi = \frac{\partial\varphi}{\partial\rho} + \frac{\varphi}{\rho}, \qquad V_\psi = \beta v_\psi\,, \qquad (7)$$

$$\sigma_{\rho\psi} = \frac{\eta-\chi}{2}\left(\frac{\partial v_\psi}{\partial\rho} - \frac{v_\psi}{\rho}\right). \qquad (8)$$

Постановка задачи приведена в следующих безразмерных величинах (штрих означает безразмерную величину)

$$\rho' = \frac{\rho}{d}\,,\ \tau = \frac{v_2 t}{d}\,,\ \varphi' = \frac{\varphi}{d^2}\,,\ \nu = \frac{v_2}{v_2^*}\,,\ v'_\psi = \frac{v_\psi}{d}\,,$$

$$V_\psi = \frac{V_\psi}{d}\,,\ \sigma'_{\rho\psi} = \frac{\sigma_{\rho\psi}}{H}\,,\ \beta = -\kappa_{12}/\kappa_{22}\,,\ \chi = \frac{A}{H}\,,$$

$$\eta = \frac{P}{H}\,,\ H = P + 2Q + R\,,\ P = A + 2N\,,$$

где v_ψ, V_ψ - компоненты вектора смещения скелета и жидкости соответственно; $\sigma_{\rho\psi}$ - компонент тензора напряжения; A и N - упругие константы скелета среды; R - давление, приложенное к жидкости; Q - величина сцепления между твердыми и жидкими компонентами; κ_{12} - коэффициент динамической связи между твердыми и жидкими компонентами; κ_{22} - эффективная масса жидкости при её относительном движении; v_2 - скорость распространения поперечных волн в среде (ниже везде штрих в обозначениях безразмерных величин опущен).

3. Метод решения.

Начально-краевая задача (1)-(6) решается с применением интегрального преобразования Лапласа по времени τ и методом неполного разделения переменных [15]. В пространстве изображений потенциал φ^L, компоненты v_ψ^L, V_ψ^L вектора смещения и $\sigma_{\rho\psi}^L$ тензора напряжения представим в виде бесконечных рядов по полиномам Гегенбауэра $C_{n-1}^{3/2}(\cos\vartheta)$ [16, 18].

В пространстве изображений решение уравнения (2) с учётом условия ограниченности (6) записываем в виде:

$$\varphi^L = \varphi_1^L + \varphi_2^L\,, \qquad (10)$$

$$\varphi_1^L = -\frac{\sin\vartheta}{\sqrt{\rho}}\sum_{n=1}^{\infty} B_n^L(s) K_{n+1/2}(\rho\nu s) C_{n-1}^{3/2}(\cos\vartheta)\,,$$

$$\varphi_2^L = -\frac{\sin\vartheta_1}{\sqrt{\rho_1}}\sum_{n=1}^{\infty} E_n^L(s) K_{n+1/2}(\rho_1\nu s) C_{n-1}^{3/2}(\cos\vartheta_1)\,.$$

Здесь $B_n^L(s)$ и $E_n^L(s)$ - произвольные функции; ρ_1, ϑ_1, ψ_1 - дополнительная сферическая система координат, полученная переносом вдоль оси O_2z центра O исходной сферической системы в точку O_1, симметричную точке O относительно плоскости $z=0$.

Далее ограничимся задачей о распространении от сферической полости осесимметричных сдвиговых волн при наличии жесткой стенки (условия (3)) или при свободной границе полупространства (условия (4)).

Учитывая связь координат ρ, ϑ и ρ_1, ϑ_1 на границе полупространства

$$\rho\big|_{z=0} = \rho_1\big|_{z=0}\,,\ \vartheta\big|_{z=0} + \vartheta_1\big|_{z=0} = \pi\,, \qquad (11)$$

а также свойства многочленов Гегенбауэра [16, 18]

$$C_{n-1}^{3/2}(-x) = (-1)^n C_{n-1}^{3/2}(x)\,, \qquad (12)$$

из граничных условий (3), (4) получаем связь между функциями $B_n^L(s)$ и $E_n^L(s)$:

$$B_n^L(s) = \pm(-1)^n E_n^L(s)\,. \qquad (13)$$

Здесь и далее верхний знак соответствует жесткой стенке, а нижний – свободной границе полупространства.

Теперь подставляя (13) в (10) и используя теорему сложения [17] для функций Бесселя второго рода $J_{n+1/2}(x)$, а также выражения этих функций через элементарные [18], представляем изображение потенциала в виде следующего ряда:

$$\varphi^L = -\sin\vartheta\sum_{n=1}^{\infty}\varphi_n^L(\rho,s)\,C_{n-1}^{3/2}(\cos\vartheta)\,, \qquad (14)$$

где

$$\varphi_n^L(\rho,s) = \frac{1}{\rho^{n+1}(\nu s)^n}\Big[R_{n0}(\rho\nu s)E_n(s)e^{-rvs} +$$

$$+W_{n0}(\rho\nu s)\sum_{p=1}^{\infty}U_{np}(s)E_p(s)e^{-2lvs}\Big], \qquad (15)$$

$$W_{n0}(s) = R_{n0}(-s)e^{s} - R_{n0}(s)e^{-s}\,,$$

$$U_{np}(s) = \frac{\pm(-1)^p(2n+1)}{2n(n+1)}\sum_{\sigma=|p-n|}^{p+n} b_\sigma^{(n1p1)}\frac{R_{\sigma0}(2lvs)}{(2lvs)^{\sigma+1}}$$

где $b_\sigma^{(n1p1)}$ - коэффициенты Клебша-Гордона [17].

Аналогично (14), изображения перемещение v_{ψ}^{L}, напряжение $\sigma_{\rho\psi}^{L}$ и заданную функцию Θ^{L} раскладывая в ряды по полиномам Гегенбауэра, приходим следующим выражениям и граничному условию относительно коэффициентов рядов:

$$v_{\psi n}^{L}=\frac{\partial\varphi_{n}^{L}}{\partial\rho}+\frac{\varphi_{n}^{L}}{\rho},\ \sigma_{\rho\psi n}^{L}=\frac{\eta-\chi}{2}\left(\frac{\partial v_{\psi n}^{L}}{\partial\rho}-\frac{v_{\psi n}^{L}}{\rho}\right), \tag{16}$$

$$v_{\psi n}^{L}\Big|_{r=1}=\Theta_{n}^{L}(s). \tag{17}$$

Далее, с учётом (15) из формул (16) приходим к следующим выражениям коэффициентов $v_{\psi n}^{L}$, $\sigma_{\rho\psi n}^{L}$:

$$v_{\psi n}^{L}=-\frac{(\nu s)^{-n}}{\rho^{n+2}}\left[R_{n3}(\rho\nu s)E_{n}(s)e^{-\rho\nu s}+\right.$$
$$\left.+W_{n3}(\rho\nu s)U_{n}(s)\right], \tag{18}$$

$$\sigma_{\rho\vartheta n}^{L}=\frac{(\eta-\chi)s^{-n}}{2\rho^{n+3}\nu^{n+2}}\left[R_{n4}(\rho\nu s)E_{n}(s)e^{-\rho\nu s}+\right.$$
$$\left.+W_{n4}(\rho\nu s)U_{n}(s)\right], \tag{19}$$

$$W_{nm}(s)=R_{nm}(-s)e^{s}-R_{nm}(s)e^{-s},\ m=\overline{3,4},$$
$$R_{n3}(s)=R_{n1}(s)-2R_{n0}(s),$$
$$R_{n4}(s)=R_{n2}(s)-R_{n0}(s),$$
$$U_{n}(s)=\sum_{p=1}^{\infty}U_{np}(s)E_{p}(s)e^{-2l\nu s}.$$

Здесь $R_{nk}(s)$ - полиномы параметра s, $k=\overline{0-2}$ [5, 8].

Подставляя (18) в граничное условие (17), получим бесконечную систему линейных алгебраических уравнений относительно неизвестных функций $E_{n}^{L}(s)$, которую запишем в виде матричного уравнения:

$$\mathbf{N}(s)\mathbf{E}(s)t^{2}+\mathbf{G}^{(1)}(s)\mathbf{E}(s)y+$$
$$+\mathbf{G}^{(2)}(s)\mathbf{E}(s)yt^{2}=\mathbf{\Theta}(s)t, \tag{20}$$
$$y=e^{-2l\nu s},\ t=e^{-\nu s}.$$

Здесь $\mathbf{N}(s)$ - бесконечная диагональная матрица с элементами $N_{n}(s)$; $\mathbf{G}^{(l)}(s)$ - бесконечные матрицы элементов $G_{np}^{(l)}(s)$ $(l=1,2)$; $\mathbf{\Theta}(s)$ - бесконечный вектор-столбец с элементами $\Theta_{n}(s)$; $\mathbf{E}(s)$ - бесконечный неизвестный вектор-столбец с компонентами $E_{n}^{L}(s)$, а функции $N_{n}(s)$, $G_{np}^{(l)}(s)$ и $\Theta_{n}(s)$ в зависимости от типа граничных условий на включении имеют вид

$$N_{n}(s)=R_{n3}(d\nu s),\ \Theta_{n}(s)=-d^{n+2}(\nu s)^{n}\Theta_{n}^{L}(s),$$
$$G_{np}^{(1)}(s)=N_{n}(-s)U_{np}(s),$$
$$G_{np}^{(2)}(s)=N_{n}(s)U_{np}(s).$$

Решение матричного уравнения (20) разыскиваем в виде бесконечного ряда по экспонентам

$$\mathbf{E}(s)=\sum_{i,j=0}^{\infty}\mathbf{e}_{ij}(s)y^{i}t^{-j-1}, \tag{21}$$

где $\mathbf{e}_{ij}(s)$ - бесконечные векторы-столбцы с элементами $e_{ij}^{(n)}(s)$.

Подставляя ряд (21) в уравнение (20) и приравнивая коэффициенты левой и правой частей при одинаковых степенях переменных y и t (ряд в правой части содержит только один ненулевой член), получаем рекуррентную систему уравнений относительно функций $e_{ij}^{(n)}(s)$ и соответствующие начальные условия к ним

$$e_{ij}^{(n)}(s)=\sum_{p=1}^{\infty}U_{np}(s)e_{i-1,j+1}^{(p)}(s)-$$
$$-\frac{N_{n}(-s)}{N_{n}(s)}\sum_{p=1}^{\infty}U_{np}(s)e_{i-1,j-1}^{(p)}(s),\ (i\geq 1,\ j\geq 1),$$
$$e_{i0}^{(n)}(s)=\sum_{p=1}^{\infty}U_{np}(s)e_{i-1,0}^{(p)}(s),\qquad (i\geq 1),$$
$$e_{i1}^{(n)}(s)=0,\ (i\geq 0), \tag{22}$$
$$e_{0j}^{(n)}(s)=0,\qquad (j\geq 1),$$
$$e_{00}^{(n)}(s)=\Theta_{n}(s)/N_{n}(s).$$

Эти соотношения позволяют определить все искомые изображения без использования редукции бесконечной системы уравнений. Анализ рекуррентных соотношений показывает, что изображения есть рациональные функции параметра преобразования Лапласа s, который дает возможность вычислять их оригиналы, а следовательно, и оригиналы коэффициентов перемещения и напряжения в среде с помощью вычетов из теории функций комплексных переменных [19].

Окончательные формулы для изображений коэффициентов рядов по полиномам Гегенбауэра искомых функций следуют из (18) и (19):

$$v_{\psi n}^{L}(\rho,s)=-\frac{1}{\rho^{n+2}(\nu s)^{n}}\sum_{i,j=0}^{\infty}\left[R_{n3}(\rho\nu s)e_{ij}^{(n)}(s)t^{\rho}+\right.$$
$$\left.+W_{n3}(\rho\nu s)\sum_{p=1}^{\infty}U_{np}(s)e_{ij}^{(p)}(s)y\right]y^{i}t^{-j-1}, \tag{23}$$

$$\sigma_{\rho\psi n}^{L}(\rho,s)=\frac{(\eta-\chi)s^{-n}}{2\rho^{n+3}\nu^{n+2}}\sum_{i,j=0}^{\infty}\left[R_{n4}(\rho\nu s)e_{ij}^{(n)}(s)t^{\rho}+\right.$$
$$\left.+W_{n4}(\rho\nu s)\sum_{p=1}^{\infty}U_{np}(s)e_{ij}^{(p)}(s)y\right]y^{i}t^{-j-1}.$$

С помощью вычетов определяются оригиналы последних формул [19], которые с рядами полиномов Гегенбауэра позволяют получить основные решения задач.

4. Численные результаты и сравнения.

Для примера рассматривается нестационарное колебание полупространства песчаника, насыщенного керосином при нестационарном вращении жесткого шара. Параметры песчаника, насыщенного керосином заданы с величинами $A = 4.026 \cdot 10^8$ Па, $N = 2.493 \cdot 10^8$ Па, $R = 0.672 \cdot 10^8$ Па, $Q = 0.295 \cdot 10^8$ Па, $\beta_0 = 0.26$, $\rho_s = 2.6 \cdot 10^3$ кг/м^3, $\rho_f = 0.82 \cdot 10^3$ кг/м^3, $\rho_{12} = -0.0019 \cdot 10^3$ кг/м^3, которому соответствует следующие безразмерные величины: $\beta = 0.0088331$, $\gamma = 1$, $\eta = 0.8772$, $\chi = 0.392$. Центр жесткой сферы расположен на расстоянии $h = 1.5$, плоская граница полупространства – свободная поверхность (4). Абсолютно жесткая сфера вращается вокруг оси $O_2 z$ по закону $\Theta(\tau, \vartheta) = \tau e^{-\tau} H(\tau)$ при полном сцеплении с окружающей средой, где $H(\tau)$ - функция Хевисайда.

Результаты численных экспериментов представлены в виде графиков изменения компонент $\sigma_{\rho\psi}$, $\sigma_{\vartheta\psi}$ тензора напряжения и v_ψ перемещения по безразмерному времени τ. Числовые результаты получены с учётом семи членов рядов по полиномам Гегенбауэра.

Графики, приведенные на рис. 2, демонстрируют изменение компоненты $\sigma_{\rho\psi}$ напряжения в точках среды: $\rho = 1$, $\vartheta = \pi/2$ (кривая 1), $\rho = 1.2$, $\vartheta = \pi/2$ (кривая 2) и $\rho = 1.4$, $\vartheta = \pi/2$ (кривая 3). На рис. 3 построены кривые, характеризующие изменения компоненты $\sigma_{\vartheta\psi}$ напряжения по времени в различных точках окружающей среды: $\rho = 1$, $\vartheta = \pi/4$ (кривая 1), $\rho = 1.2$, $\vartheta = \pi/4$ (кривая 2) и $\rho = 1.4$, $\vartheta = \pi/4$ (кривая 3).

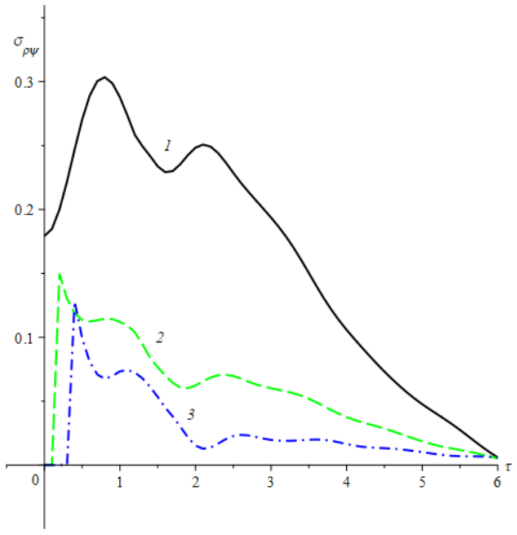


Рисунок 2. Изменения тангенциального $\sigma_{\rho\psi}$ напряжения по времени.

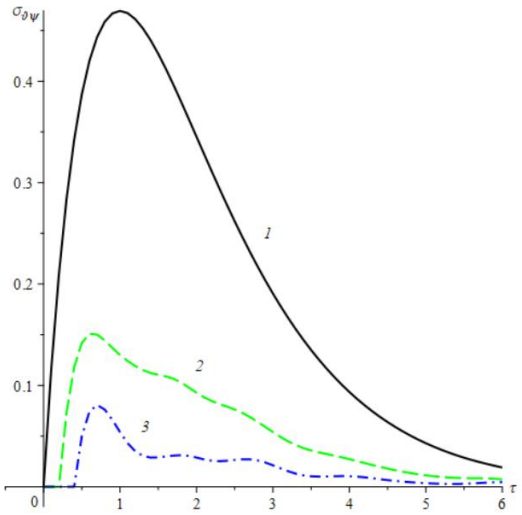


Рисунок. 3. Изменения компоненты $\sigma_{\vartheta\psi}$ напряжения по времени.

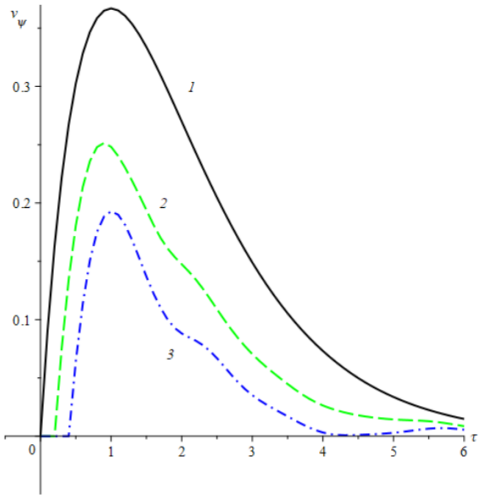


Рисунок 4. Изменение перемещения v_ψ по времени.

Рис. 4 показывает графики изменения компоненты v_ψ перемещения в точках полупространства: $\rho = 1$, $\vartheta = \pi/4$ (кривая 1), $\rho = 1.2$, $\vartheta = \pi/4$ (кривая 2) и $\rho = 1.4$, $\vartheta = \pi/4$ (кривая 3).

5. Заключение.

В данной работе мы изучали нестационарные колебания пористо-упругого полупространства, насыщенного жидкостью с абсолютно жестким шаром. Мы решали соответствующую начально-краевую задачу и исследовали нестационарный волновой процесс в насыщенном жидкостью пористо-упругом полупространстве.

В частности, наши выводы сводятся к следующему:

- разработан алгоритм решения задачи о нестационарном колебании пористо-упругого полупространства, насыщенного жидкостью при вращении абсолютно жесткого шара.
- найдены точные формулы для компонент смещения и тензора напряжений.
- получены численные результаты, которые представлены в виде графиков. Графики показывают, что с приходом волны появляется скачок. С увлечением расстояния уменьшаются скачки.

Результаты исследования могут быть использованы для проектирования при строительстве сооружений, а также при строительстве подземных резервуаров.

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Issue **Article**

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THE COGNITIVE MODEL OF DEVELOPMENT SYMPTOMS OF PARKINSON'S DISEASE

Abstract: *A cognitive model of the development of symptoms of Parkinson's disease in people with anxiety has been developed. The initial data on the manifestations of symptoms of 9 diseases are taken from the verbal model from the report[1]. Sense and numerical variables and restrictions have been introduced in the form of strict inequalities:* $2*c^2_{21}<c^2_{11}$, $2*c^2_{31}<c^2_{11}$, $2*c^2_{41}<c^2_{11}$, $2*c^2_{51}< c^2_{11}$, $2*c^2_{61}<c^2_{11}$, $2*c^2_{71}<c^2_{11}$, $2*c_{28} < c^2_{11}$, $2*c^2_{91}< c^2_{11}$. *These constraints were successfully used to solve the Optimization Problem. Verbal values of y-variables were determined, representing extracted tacit knowledge about disease symptoms. Based on the initial 9 z-events, the model determined (learned) the values of 9 y-events, independent in meaning. The new y-events received a substantive and quantitative justification as a set of diseases. The meanings of these y-variables were found, which are extracted hidden knowledge about the symptoms of diseases. Subsets from the original 9 z-events Using 9 subsets, the model added (learned) the meanings of 9 y-events that were independent in meaning. New y-events are meaningfully and quantitatively substantiated as sets of diseases. Manifestations of y-events are model-implemented, their formulaic and phraseological representations are justified, and the mutual dynamics of the curves are visualized in graphs and correspond to the expected. New 9 formulas were calculated, where each y-disease formula has z-symptoms of several z-diseases. For y-diseases, it is necessary to develop your own set of drugs that treat only these z-diseases and Parkinson's disease and do not affect the other bunch of z-diseases from the other y-disease (out of 9 model independent y-diseases). This original idea requires practical implementation in medical and pharmaceutical projects. The variables introduced into the model are endowed with mathematical and statistical properties, and the parameters are constant. They are modeled in the Optimization Problem and depend on the number of variables and on the indicator value c11=0.53. Both uncorrelated (y-) and correlated (z-) variability are multiplied by their "weights" - the strength of the factor manifestation. Interesting knowledge was gained after visualization. The most meaningful (the dispersion of the semantic variable* $disp(y_1)=3.000$ *immeasurably exceeds the dispersion of each other semantic variable) is sense(*y_1*). The semantic equation* $meaning(y_1)=meaning(z_1)*0.5300+meaning(z_2)*(-0.1835)$ *has a solution* $meaning(y_1)$*, depending on 2 known meanings* $meaning(z_1$, $meaning(z_2)$*, phrases which are given above in the source data of the model. Summarizing the meanings of 3 phrases and confirming 3 phrases with semantic and numerical data relating to their semantic equation* $meaning(y_1)=meaning(z_1)*0.5300+meaning(z_2)*(-0,1835)$*.The meaning was found (*y_1*)="random manifestation (with variability* $disp(y_1)=3.000$*) of symptoms of Parkinson's disease in people "with anxiety" (with strength* $c^2_{11}=0.5300)^2$ *give non-random (due to the medical treatment measures taken within project[1]) random manifestation of decreasing symptoms of depression" (with strength* $c^2_{21}=(-0.1835)^2$*). The result of the project is the manifestation of decreasing symptoms of depression" in people (with strength* $c^2=(-0.1835)^2$*) numerically evaluates the project, and our cognitive model extracted hidden knowledge from the original data. Original solutions when formalizing the symptoms of diseases require practical implementation in medical and pharmaceutical projects. Visualization of the mutual dynamics of curves (representing variability values for z- and y-variables from matrices* Z_{m9} *and* Y_{m9}*) regarding "weights" (derived from* C_{99}*). Visualizing the z- and y-variability values in a model comprising 9 z-variables and 9 y-variables revealed distinct dynamics in the modeled values of unmeasured indicators representing disease symptom manifestations. Each new y-event (manifestation of the y-disease) is substantiated both quantitatively and conceptually. The informational*

manifestations of these events have been numerically implemented and justified, with their formulaic, verbal, and visual representations displayed in the graphs.

***Key words**: multisense equation with known and unknown semantic variables, symptoms of Parkinson's disease, semantic formula of the disease.*

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ИНФОРМАЦИОННАЯ И КОГНИТИВНЫЙ УРОВНИ ОПИСАНИЯ СИМПТОМОВ БОЛЕЗНИ ПАРКИНСОНА

***Аннотация**: Разработана когнитивная модель развития симптомов болезни Паркинсона у людей, страдающих тревожностью. Исходные данные о проявлениях симптомов 9 заболеваний были взяты из словесной модели, представленной в отчете[1]. Были введены смысловые и числовые переменные, а также ограничения в форме строгих неравенств $2*c^2_{21}<c^2_{11}$, $2*c^2_{31}<c^2_{11}$, $2*c^2_{41}<c^2_{11}$, $2*c^2_{51}< c^2_{11}$, $2*c^2_{61}<c^2_{11}$, $2*c^2_{71}<c^2_{11}$, $2*c_{28}<c^2_{11}$, $2*c^2_{91}<c^2_{11}$. Эти ограничения были успешно использованы при решении Оптимизационной Задачи. Были определены словесные значения y-переменных, представляющие собой извлеченные скрытые знания о симптомах заболеваний. На основе исходных девяти z-событий модель определила (научилась) значения девяти y-событий, независимых по смыслу. Новые y-события получили содержательное и количественное обоснование как совокупности заболеваний. Реализовано моделирование проявлений y-событий, обосновано их представление в виде формул и фраз, а взаимная динамика кривых визуализирована на графиках и соответствует ожидаемым результатам. Были рассчитаны 9 новых формул, в которых каждая формула «y-заболевания» включает симптомы (z-симптомы) ряда «z-заболеваний». Для таких «y-заболеваний» необходимо разработать специализированный набор препаратов, воздействующих исключительно на соответствующие «z-заболевания» и болезнь Паркинсона, но не затрагивающих группы «z-заболеваний», характерные для других «y-заболеваний» (из числа 9 модельных независимых «y-заболеваний»). Эта оригинальная идея требует практической реализации в рамках медицинских и фармацевтических проектов. Введены смысловые, числовые переменные, системы смысловых уравнений с семантическими переменными (в виде фраз, передающих смысл z-, y-переменных). ограничения, Введены смысловые, переменные. Введены числовые коэффициенты-измерители величин сил взаимосвязей между переменными. Найдены (смоделированы) числовые значения отклонений от 0 вправо\влево изменчивости z_{ik} z-переменных, умноженных на «веса» c_{kj}. Сумма произведений $z_{ik}c_{kj}$, $k=1,\ldots, 9$, образует новую y-переменную, при $j=1,\ldots, 9$ y-переменные образуют некоррелированное множество. Найдены смысли y-переменных (равных сумме соответствующих смыслов z-переменных), являющихся извлеченными знаниями об z-симптомах y-новых симптомах развития болезни Паркинсона. Разработана систа из 9 многосмысловых уравнений с 18 семантическими переменными: смысл(y_1),…, смысл(y_9), смысл(z_1),…,смысл(z_9). Фразы 9 семантических переменных (решений) суть знания (новые извлеченные), уравнения познают смысли, парные числовые связи, силы проявлений семантических переменных. Визуализация взаимных динамик кривых (значений изменчивостей z-, y-переменных из матриц Z_{m9},Y_{m9}) знаний о «весах» (из C_{99}). Визуализация значений z-, y-изменчивостей в модели с 9 z-переменными, 9 y-переменными показала разные динамики модельных значений неизмеряемых показателей проявлений симптомов болезни. Каждое новое y-событие (проявление y-болезни) количественно и по смыслам обосновано. Информационные проявления событий численно реализованы, обоснованы, а их формульное, фразеологическое, визуализированное виды отображены на графиках. Описания поведений кривых соответствуют ожидаемому. Введенные в модель переменные наделены математическими и статистическими свойствами, а параметры постоянны. Они смоделированы в Оптимизационной Задаче и зависят от количеств переменных и от значений 3-х индикаторов. Как некоррелированные (y-), так коррелированные (z-) изменчивости умножаются на свои «веса» - силы проявления фактора. Получены интересные знания, видимые после визуализации. Самым информативным (дисперсия смысловой переменной с дисперсией 3.000 неизмеримо превосходит дисперсию каждой другой числовой переменной) является смысл(y_1). Смысловое уравнение смысл(y_1)=смысл(z_1*0,5300+смысл(z_2)*(-0,1835) имеет решение смысл(y_1), зависящее от 2-х известных смыслов смысл(z_1), смысл(z_2), фразы которых приведены выше в исходных данных модели. Суммируя смыслы 3-х фраз и подтверждая 3 фразы смысловыми и числовыми данными, относящими к их смысловому уравнению смысл(y_1)=смысл(z_1)*0,5300+смысл(z_2)*(-0,1835). Найден смысл(y_1)=««случайное проявление (с изменчивостью disp(y_1)=3.000) симптомов болезни Паркинсона у людей «с тревожностью» (с силой $c^2_{11}=0,5300)^2$ дают неслучайное (обусловленное проделанными медицинскими лечебными мероприятиями в рамках проекта[1]) случайное проявление убывающих симптомов депрессии» (с силой c^2_{21}=(-*

0,1835)^2) Результат проекта - проявление убывающих симптомов депрессии» у людей (с силой $c^2 = (-0,1835)^2$) числе) численно оценивает проект, а наша когнитивная модель извлекла скрытые знания из исходных данных. Оригинальные решения при формализации симптомов болезней требуют практического воплощения в медицинских, фармацевтических проектах.

Ключевые слова: *многосмысловое уравнение с известными и неизвестными семантическими переменными, симптомы болезни Паркинсона, смысловая формула болезни.*

Введение

Мединформатика – это прикладная медико-техническая наука, являющаяся результатом перекрестного взаимодействия медицины и информатики: медицина поставляет комплекс задач и методы, а информатика обеспечивает числовые средства-приемы в едином методическом подходе, основанном на системе задача–модели-методы. Медицинский уровень описания болезни Паркинсона развивается успешно, а информационному и когнитивному уровням описания симптомов болезней не исследуются медиками, не сотрудничающие с специалистами информатики. Внедрение в медицинскую практику роботов с искусственным интеллектом кардинально меняет уровни восприятия симптомов болезни Паркинсона. Ниже дано новое описание симптомов болезни Паркинсона. Медицинские знания - это выводы, сформированные и воссозданные в науках о здоровье. База знаний медицинских наук в настоящее время весьма разнообразна.

В настоящей статье выявлена другая «информатика болезней», отличающаяся от общей статистики: «За последние 25 лет распространенность болезни Паркинсона выросла вдвое. В 2019 г. численность лиц, страдающих болезнью Паркинсона, оценивалась на уровне свыше 8,5 миллиона человек. Согласно текущим оценкам, в 2019 г. болезнь Паркинсона привела к утрате 5,8 миллиона лет жизни, скорректированных на инвалидность (DALY), что на 81% больше, чем в 2000 г., и стала причиной смерти 329 000 человек (рост на 100% по сравнению с 2000 г.)». Мы ниже выявили скрытые знания, узнали. «Исследование выявило связь между тревожностью и развитием болезни Паркинсона. Люди в возрасте старше 50 лет, испытывающие тревогу, склонны в два раза чаще болеть болезнью Паркинсона, чем их сверстники, не испытывающие тревоги». Об этом в воскресенье, 30 июня, сообщила газета The Washington Post со ссылкой на исследование, опубликованное в British Journal of General Practice».

«Исследователи сравнили группу из 109 тыс. человек 50 лет и старше из Великобритании, у которых был диагностирован первый эпизод тревожности в период с 2008 по 2018 год, с группой из 987 тыс. человек без симптомов тревоги. По словам ученых, которые занимались этой работой, за десятилетие болезнь Паркинсона развилась у 331 пациента с диагнозом «тревожность», средний срок развития болезни после постановки этого диагноза — 4,9 года. Исследователи пришли к выводу: вероятность проявления болезни Паркинсона (с силой проявления c^2_{11}) у людей «с тревожностью **(**смысл(z_1)**)** была в два раза выше, чем вероятность у тех людей, кто не имеют тревожность, но страдают депрессией **(**смысл(z_2)), нарушениями сна (смысл(z_3)), усталостью (смысл(z_4)), когнитивными расстройствами (смысл(z_5)), низким кровяным давлением (смысл(z_6)). https://vfokuse.mail.ru/article/issledovanie-vyyavilo-svyaz-mezhdu-trevozhnostyu-i-razvitiem-bolezni-parkinsona-61738655/

«Симптомы заболевания имеют тенденцию усиливаться с течением времени. Заболевание неизлечимо, но его симптомы можно ослабить при помощи различных видов терапии и лекарственных средств. Наиболее распространенные симптомы болезни Паркинсона включают тремор, болезненные непроизвольные сокращения мышц и речевые нарушения. Причина заболевания не установлена, но риск его развития выше у людей, у которых имеются родственники с болезнью Паркинсона. Риск заболевания может повышаться в результате загрязнения воздуха и контакта с пестицидами и растворителями. https://www.who.int/ru/news-room/fact-sheets/detail/parkinson-disease «Болезнь Паркинсона – заболевание головного мозга, которое затрудняет двигательную активность и вызывает психические нарушения, расстройства сна, боли и другие проблемы со здоровьем». (https://www.who.int/ru/news-room/fact-sheets/detail/parkinson-disease). Группа людей из 109 тыс. человек у которых наряду развитием болезни Паркинсона был диагностирован первый эпизод тревожности**.** У категории людей (987 тыс. человек) болезнь Паркинсона присутствует без проявления симптомов тревоги. Кто не имеет симптомов тревожности страдают еще 5 видами болезней, как подчеркнуто в статье. Каждая из 5 болезней имеет другое значение вероятности проявления. Число так связанных болезней равно 6. Каждая из 6 болезней в нашей модели рассматривается как отдельное событие (z-переменная) среди связанных событий (коррелированных z-переменных). Количество связанных событии равно 6, сумма 6 вероятностей

проявления равна 1:

Восприятие изменчивости проявлений симптомов тревоги и сопутствующих 8 z-болезней проведем через моделирование случайных чисел. Все требования к таким опытам в естественной среде выполнены, и мы должны иметь результат – таблицы случайных данных, соответствующих заданным смыслам случайных проявлений симптомов z-болезней и новым найденным смыслам симптомов новых y-болезней. Не имея ничего, кроме словесной модели отчета о результатах исследовани[1], разработаем познающую (когнитивную) модель, использующую смыслы 9 связанных с болезнью Паркинсона (с проявлением симптомов тревоги) z-болезней, смыслы которых заданы в исходных данных модели, но не известны изменчивости проявлений симптомов z-болезней.

С точки зрения информатики медицина не является конкретной наукой, то есть в медицинских знаниях мало прослеживается количественных законов, выраженных в формулах.

Ниже выведены 9 формул, где каждая формула y-болезни имеет симптомы нескольких z–болезней, а для y-болезни нужно разрабатывать свой комплекс лекарств, лечащих только эти z–болезни, не влияющие на букет z–болезней из другой y-болезни (из 9 модельных независимых y-болезней). Эта оригинальная идея требует практического воплощения в медицинских, фармацевтических проектах.

Болезнь Паркинсона может начаться с самых разнообразных симптомов. При этом симптоматика может быть связана как с нарушениями двигательной, мыслительной активности, так и функциями, которые, на первый взгляд, не связаны с нервной системой, а касаются работы пищеварительного тракта и даже носа.

Какие же симптомы чаще всего беспокоят страдающих болезнью Паркинсона? Имеются разные словесные описания симптомов. Рассмотрим словесную модель из отчета https://vfokuse.mail.ru/article/issledovanie-vyyavilo-svyaz-mezhdu-trevozhnostyu-i-razvitiem-bolezni-parkinsona-61738655/

Исходные данные

Исходные данные о проявлениях симптомов 9 болезней взяты из словесной модели отчета https://vfokuse.mail.ru/article/issledovanie-vyyavilo-svyaz-mezhdu-trevozhnostyu-i-razvitiem-bolezni-parkinsona-61738655/ сформулируем в терминах явления «болезнь Паркинсона»:

1) симптомы болезни с смыслом(z_1)=«проявление симптомов болезни Паркинсона у людей «с тревожностью»;

2) симптомы болезни с смыслом(z_2)=«депрессия»;

3) симптомы болезни с смыслом(z_3)=« нарушения сна»;

4) симптомы болезни с смыслом(z_4)=«усталость»;

5) симптомы болезни с смыслом(z_5)=« когнитивные расстройства»;

6) симптомы болезни с смыслом(z_6)=«низкое кровяное давление, тремор, болезненные непроизвольные сокращения мышц и речевые нарушения»;

7) симптомы болезни с смыслом(z_7)=«тремор, болезненные непроизвольные сокращения мышц и речевые нарушения»;

8) симптомы болезни с смыслом(z_8)=«ригидность»;

9) симптомы болезни с смыслом(z_9)=«нарушение равновесия».

В излагаемую ниже модель введены 9 семантических переменных (9 фраз смыслов) зависимых факторов (симптомов), им соответствуют модельно вычисленные коррелированные 9 числовые z-переменные, равные значениям отклонений вправо/влево от 0 (z-изменчивости проявлений z-симптомов). Величины сил проявлений z-симптомов должны удовлетворять ограничениям: например, симптом болезни «усталость» проявляется с силой c^2_{41}, в 2 раза меньшей, чем сила проявления c^2_{11} симптомов болезни Паркинсона у людей с тревожностью». Для заданных 9 имен-смыслов требуется найти значения модельных z-переменных, для которых моделируются числовые значения и требуется найти смыслы модельных y-переменных и их модельные значения (равные линейным комбинациям значений модельных z-переменных) с учетом модельных сил проявлений симптомов. Ограничения из пунктов 1)-9) взяты из отчета , они имеют вид следующих строгих неравенств, применяемых ниже при решении Оптимизационной Задачи: $(2*c^2_{21}<c^2_{11})$, $(2*c^2_{31}<c^2_{11})$, $(2*c^2_{41}<c^2_{11})$, $(2*c^2_{51}<c^2_{11})$, $((2*c^2_{61})<c^2_{11})$, $((2*c^2_{71})<c^2_{11})$, $((2*c^2_{81})<c^2_{11})$, $((2*c^2_{91})<c^2_{11})$. Мы не можем применять не строгие неравенства вида $(2*c^2_{21}\le c^2_{11})$, $(2*c^2_{31}\le c^2_{11})$, $(2*c^2_{41}\le c^2_{11})$, $(2*c^2_{51}\le c^2_{11})$,…, $((2*c^2_{91})\le c^2_{11})$, ибо в программе-таблице из надстройки «Поиск решения» ЭТ Excel избегаем одинаковости значений для $(c^2_{21}=c^2_{11})$, $(c^2_{31}=c^2_{11})$, $(c^2_{41}=c^2_{11})$, $(c^2_{51}=c^2_{11})$,…, $c^2_{91}=c^2_{11}$.

В разработанной ниже модели мы моделируем матрицу псевдособственных векторов C_{99}, в которой компоненты 1-ого псевдособственного вектора $\mathbf{c_1}=(c_{11},c_{21},c_{31},c_{41},c_{51},\ldots,c_{91})^T$ обладают свойством $c^2_{11}+c^2_{21}+c^2_{31}+c^2_{41}+c^2_{51}+c^2_{91}\neq 1$, $c^2_{11}+c^2_{12}+c^2_{13}+c^2_{14}+c^2_{15}+\ldots c^2_{19}=1$.

Эти неравенства являются главными как в словесной модели из отчета, так и в нашей когнитивной модели.

Задача: разработать систему из 9 смысловых уравнений с 18=9+9 семантическими переменными смысл(y_1),…, смысл(y_9), смысл(z_1), …,смысл(z_9). Смысловые уравнения должны удовлетворять матричному смысловому равенству вида смысл(Z_{m9})=смысл($Y_{m9}C^T_{99}$), где смысл(Z_{m9})=смысл(z_1)⊕…⊕смысл(z_9), смысл($Y_{m9}\mathbf{C}^T_{99}$)=смысл($Y_{m9}\mathbf{c}^T_1$)⊕…⊕ смысл($Y_{m9}\mathbf{c}^T_9$). Элементы матрицы C^T_{99} равны 9 элементам первых 9 строк $\mathbf{c}^T_1$, …, $\mathbf{c}^T_9$ матрицы индикаторов C_{99}, а ее i-ая строка $\mathbf{c}^T_j$ имеет компоненты, равные компонентам матрицы индикаторов C_{99}:c^T_j=(c_{j1},c_{j2},…,c_{j9}), i=1,…,9. Этому матричному смысловому равенству соответствует математическое матричное равенство для числовых переменных вида: $Z_{m9}=Y_{m9}C^T_{99}$.

Применяемая система многосмысловых уравнений

Многосмысловое уравнение для y-переменной, смысл ее равен неизвестной сумме известных смыслов заметных z-переменных. Суммирование известных смыслов заметных п «весу» z-переменных, правильно отражает добавление нового отсутствующего знания к известному знанию: соблюдается принцип линейного мышления человека. Человек не умеет умножать знание, прибавляет знание к известному, либо исправляет ранее добытое. Но для исправления неправильного надо извлечь знание, заменяющее неправильное знание. В теории искусственного интеллекта популярен «принцип линейного мышления». Матричное смысловое равенство вида смысл(Z_{m9})=смысл($Y_{m9}C^T_{99}$), где смысл(Z_{m9})=смысл(z_1)⊕…⊕смысл(z_9), смысл ($Y_{m9}\mathbf{C}^T_{99}$)=смысл($Y_{m9}\mathbf{c}^T_1$)⊕…⊕смысл($Y_{m9}\mathbf{c}^T_9$) точно соответствует принцип линейное числовое равенство на соответствие мышления человека. Хотя смысловое равенство первично, но для него проверяется числовое равенство на соответствие смысловому равенству. Линейное числовое равенство удовлетворяет смысловому линейному конструированию многосмысловых линейных уравнений, где линейность выражена через слагаемые фразы, образующую новую осмысленную фразу. Важную роль имеет этапы введения числовых параметров, переменных, функций связи, индикаторы присутствия знаний, которые проверяются разработчиком модели на соответствие реальным свойствам реальных многомерных объектов разных типов. Тип объектов, их свойства отражается в смыслах свойств объектов [2-8]. Суммы смыслов свойств (z-переменных) объекта могут образовать новый смысл y-переменной (равной неизвестной сумме известных смыслов z-переменных) или не образовать новый смысл, если не использовать контексты фраз смыслов z-переменных. В многомерной математической модели (она является вторичной, первична матричная смысловая модель) переменные делятся на 2 вида: известные имена-смысли z-переменных: смысл(z_1),…,смысл(z_9) и неизвестные имена-смыслы y-переменных смысл (y_1),…,смысл(y_9). Количество 9 z-переменных равно количеству дисперсий disp(y_1)=λ_1, disp(y_2)=λ_2,…,disp(y_9)=λ_9. В соответствии с значениями λ_1, λ_2,…,λ_9, взятыми из пары смоделированных матриц (C_{99},Λ_{99}) проставляются числовые параметры c_{11},…, c_{99} в нижеприведенные 9 уравнений из системы многосмысловых уравнений. Не проводим удаления слагаемых с «весами» c_{ij}, если даже их величины не удовлетворяют критерию быть индикатором скрытых знаний [11,14], поэтому количество слагаемых в уравнениях с неизвестными новыми смыслами смысл(y_1), смысл(y_2),…,смысл(y_9) не сокращаются. Более «короткие» суммы смыслов приведены для осмысливания читателем статьи. Для конструирования 9 фраз для 9 новых смыслов (новых семантических y-переменных) новый_смысл(y_1), ..., новый_смысл(y_9), дополняющих числовыми величинами (измерителями степени важности, изменчивости проявлений симптомов) исходные смыслы смысл(z_1),…, смысл(z_9) применялись методы смыслового преобразования исходных семантических переменных в новые семантические переменные. Это – сложная и трудозатратная особенность когнитивного моделирования.

Требуемые фразы, отражающие смыслы неизвестных 9 новых смыслов y-переменных, можно сконструировать, если смоделировать:

а) пару матриц собственной структуры (Λ_{99},C_{99}), где C_{99} – матрица псевдособственных векторов [9], $C_{99}C^T_{99}=I_{99}$, $C^T_{99}C_{99}\neq I_{99}$, $\Lambda_{99}=diag(\lambda_1,\ldots\lambda_9)$, $tr(\Lambda_{99})=\lambda_1+\ldots+\lambda_9=9$, условие упорядоченности $\lambda_1\geq\ldots\geq\lambda_9\geq 0$ не требуется;

б) матрицы значений некоррелированных изменчивостей Y_{m9}, коррелированных изменчивостей (отклонений от 0) Z_{m9}, соответствуют своим системам многосмысловых уравнений с известными и неизвестными семантическими (смысловыми) переменными.

Иное название [9-12] элементов матрицы C_{99} введено в статьях [1-9], оно отражает смысл «весов», моделируемых в нашей модели, наш метод моделирования отличается от методов из [2-9].

Новые моделируемые 2 матрицы в нашей модели должны обладать свойствами: ортогональная (не ортонормированная) матрица C_{99} собственных векторов $\mathbf{c_j}$=(c_{1j},c_{2j}…c_{9j})^T,

расположенных по столбцам матрицы $C_{99}=[c_1|c_2|\ldots|c_9]$ согласована со своим спектром Λ_{99} неиспользуемой нами ковариационной матрицы $W_{99}=(1/m)Z^T_{m9}Z_{m9}$, $\Lambda_{99}=diag(3.0000,0.6000, 0.6000, 0.8000, 0.8000, 0.8000, 0.8000, 0.8000, 0.8000)$ В решаемой ниже Оптимизационной Задаче: $(I_{99},I_{99})=>(C_{99}, \Lambda_{99})$ (другие методы смотрите в [9-15]) целевая функция отличается от ранее применявшейся функции: $\lambda_1+\ldots+\lambda_9=9$, теперь это равенство является функцией ограничений при изменяемых значениях 9*9+9 элементов 2-х матриц C_{99}, Λ_{99}, $C^T_{99}C_{99}\neq I_{99}$, $C_{99}C^T_{99}=I_{99}$. Моделируемые ниже случайные матрицы U_{m9} и Y_{m9} такие, что подчиняются соотношениям Обратной Модели Анализа Главных Компонент [16-17]: $(1/m)U^T_{m9}U_{m9}=I_{99}$, $Y_{m9}=U_{m9}\Lambda^{1/2}_{99}$, $Z_{m9}=Y_{m9}C^T_{99}$, в матрице Y_{m9} элементы j–го столбца $y_{1j},y_{2j},\ldots,y_{mj}$ (формула j-ой y-переменной имеет вид $y_{ij}=z_{i1}*c_{1j}+z_{i2}*c_{2j}+\ldots+z_{i9}*c_{9j}$, j=1,…,9) имеют среднее арифметическое, равное нулю: $(1/m)(y_{1j}+y_{2j}+\ldots+y_{mj})=0$ и дисперсию равную λ_j: $(1/m)(y^2_{1j}+y^2_{2j}+\ldots+y^2_{mj})=\lambda_j$, сумма дисперсий равна 9: $\lambda_1+\ldots+\lambda_9=9$. Матрицы $Y_{m9}=U_{m9}\Lambda^{1/2}_{99}$, $Z_{m9}=Y_{m9}C^T_{99}$ в таком порядке моделируются, интерпретируются как многомерные выборки [17]. В нашей модели мы моделируем не стандартизованные ($C^T_{99}C_{99}\neq I_{99}$) коррелированные z-переменные, они являются многомерными данными, объединенных в матрицу Z_{m9}, в которой элементы j–го столбца $z_{1j},z_{2j},\ldots,z_{mj}$ (j-ая переменная, j=1,…,9) имеют среднее арифметическое равное нулю: $(1/m)(z_{1j}+z_{2j}+\ldots+z_{mj})=0$, и дисперсию не равную 1: $(1/m)(z^2_{1j}+z^2_{2j}+\ldots+z^2_{mj})\neq1$, но сумма дисперсий z-переменных не равна 9. Все элементы матрицы C_{99} интерпретируются как индикаторы знаний [10-12]. Матрица Y_{m9}, в которой элементы j–го столбца y_{1j}, $y_{2j},\ldots,y_{mj}$ (j-ая y-переменная, j=1,…,9) имеют среднее арифметическое равное нулю: $(1/m)(y_{1j}+y_{2j}+\ldots+y_{mj})=0$, и дисперсию равную λ_j: $(1/m)(y^2_{1j}+y^2_{2j}+\ldots+y^2_{mj})=\lambda_j$, сумма дисперсий равна 9: $\lambda_1+\ldots+\lambda_9=9$. Матрица Y_{m9}, интерпретируется как многомерная выборка. Им соответствуют (в нашей модели) не стандартизованные коррелированные z-переменные – модельные данные, объединенные в матрицу Z_{m9}, в которой элементы j–го столбца $z_{1j},z_{2j},\ldots,z_{mj}$ (j-ая z-переменная, j=1,…,9) имеют среднее арифметическое равное нулю: $(1/m)(z_{1j}+z_{2j}+\ldots+z_{mj})=0$ и дисперсию, не равную 1: $(1/m)(z^2_{1j}+z^2_{2j}+\ldots+z^2_{mj})\neq1$, сумма дисперсий не равна 9 (как бывает в ПМ АГК [17]). Матрица Z_{m9} интерпретируется как многомерная не стандартизованная выборка.

Применяемая система многосмысловых уравнений состоит из 9 смысловых уравнений с 18=9+9 семантическими переменными смысл(y_1),…,смысл(y_9), удовлетворяющих матричному смысловому равенству вида смысл(Z_{m9})=смысл($Y_{m9}C^T_{99}$), где смысл(Z_{m9})=смысл(z_1)⊕…⊕смысл(z_9), смысл($Y_{m9}\mathbf{C}^T_{\mathbf{99}}$)=смысл($Y_{m9}\mathbf{c}^T_{\mathbf{1}}$)⊕смысл($Y_{m9}\mathbf{c}^T_{\mathbf{2}}$)⊕ …⊕ смысл($Y_{m9}\mathbf{c}^T_{\mathbf{9}}$).

Таблица 1. Модельная матрица C_{99} псевдособственных векторов Λ_{88} =diag(3.0000,0.6000, 0.6000,0.8000, 0.8000, 0.8000,0.8000,0.8000,0.8000)

	c1	**c 2**	**c 3**	**c 4**	**c 5**	**c 6**	**c 7**	**c 8**	**c 9**
z1	0.5300	0.3462	0.3462	0.3462	0.3462	0.0000	0.3462	0.0000	0.3462
z2	-0.1835	1.0000	-0.1199	0.0000	0.0000	-0.0096	0.0000	0.0000	0.0000
z3	0.0000	0.0000	1.0000	-0.1199	0.0000	-0.0029	0.0000	0.0000	0.0000
z4	0.0000	0.0000	0.0000	1.0000	-0.1199	-0.0029	0.0000	0.0000	0.0000
z5	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
z6	0.0000	0.0000	0.0000	0.0000	-0.0003	1.0000	0.0000	0.0000	0.0000
z7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
z8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
z9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
c_{99}	0.3146	1.1199	1.1342	1.1342	1.1342	1.0001	1.1199	1.0000	1.1199

Оптимизационная Задача

Оптимизационная Задача использует ограничения , сформулированные в словесной модели. Они сужают значения сил проявлений 9

z–факторов. Согласно применяемой гипотезе Матричное смысловое равенство вида смысл(Z_{m9})=смысл($Y_{m9}C^T_{99}$) требует моделирования матриц (C_{99},Λ_{99}), Z_{m9}, Y_{m9}, где C_{99} -матрица собственных векторов, чисел Λ_{99} - матрица собственных чисел, матрицы $Y_{m9}=U_{m9}\Lambda^{1/2}_{99}$, $Z_{m9}=Y_{m9}C^T_{99}$ моделируются, интерпретируются как многомерные выборки – изменчивостей [17]. Элементы j–го столбца y_{1j}, y_{2j},…,y_{mj} (j-ая y-переменная, j=1,…,9) имеют среднее арифметическое равное нулю: (1/m)($y_{1j}+y_{2j}+ \dots +y_{mj}$)=0, и дисперсию равную λ_j: (1/m)(y^2_{1j}, $+y^2_{2j}+\dots+y^2_{mj}$)=λ_j. матрица псевдособственных векторов C_{99} таких, что выполняются условия: $C_{99}C^T=I_{99}$, $C^T_{99}C_{99}=\neq I_{99}$, $\Lambda_{99}=diag(\lambda_1,\dots\lambda_9)$, $tr(\Lambda_{99})=\lambda_1+\dots+\lambda_9=9$, , Введем в излагаемую ниже модель 9 семантических переменных (9 фраз смыслов) зависимых факторов (симптомов), им соответствуют модельно вычисленные коррелированные 9 числовые z-переменные, равные значениям отклонений вправо/влево от 0 (изменчивости проявлений симптомов). К заданным 9 именам-смыслам модельных z-переменных, добавим ограничения, взятые из отчета. Они имеют вид строгих неравенств: ($2*c^2_{21}<c^2_{11}$), ($2*c^2_{31}<c^2_{11}$), ($2*c^2_{41}<c^2_{11}$), ($2*c^2_{51}<c^2_{11}$), (($2*c^2_{61}$) $<c^2_{11}$), (($2*c^2_{71}$) $<c^2_{11}$), (($2*c^2_{81}$)$<c^2_{11}$), ($2*c^2_{91}$) $<c^2_{11}$. Мы не можем применять не строгие неравенства вида ($2*c^2_{21}\leq c^2_{11}$), ($2*c^2_{31}\leq c^2_{11}$), ($2*c^2_{41}\leq c^2_{11}$), ($2*c^2_{51}\leq c^2_{11}$),…, ($2*c^2_{91}$) $\leq c^2_{11}$, ибо в программе-таблице из надстройки «Поиск решения» ЭТ Excel избегаем одинаковости значений для ($c^2_{21}=c^2_{11}$), ($c^2_{31}=c^2_{11}$), ($c^2_{41}=c^2_{11}$), ($c^2_{51}=c^2_{11}$),…, $c^2_{91}=c^2_{11}$.

Модельная матрица C_{99} служит индикатором наличия скрытых знаний сформируем для будущей пары матриц (C_{99}, Λ_{99}) 2 диагональные единичные матрицы (I_{99}, I_{99}). Они являются начальными значениями для (C_{99}, Λ_{99}). Применяемая процедура GRD2 (из надстройки “Поиск решения”) после последовательных приближений преобразует матрицы (I_{99},I_{99}) в матрицы (C_{99},Λ_{99}). Для процедуры GRD2, необходимы функции ограничений, помогающие процедуре GRD2 уменьшить работу при поиске решения (матриц C_{99},Λ_{99}). Решается Оптимизационная Задача: (I_{99},I_{99})=>(C_{99},Λ_{99}), ее целевая функция имеет вид $\lambda_1+\dots+\lambda_9=9$. Было опасение, что процедура GRD2 откажется искать решение (C_{99},Λ_{99}). Используем ограничения: $\lambda_1+\dots+\lambda_9=9$ при изменяемых значениях 9*9 элементов матрицы C_{99}, имеющей ограничения на свои элементы: $C^TC\neq I_{99}$, $C_{99}C^T_{99}=I_{99}$, $\Lambda_{99}=diag(\lambda_1,\dots\lambda_9)$, $tr(\Lambda_{99})=\lambda_1+\dots+\lambda_9=9$, но без ограничений на монотонность: $\lambda_1\geq\dots\geq\lambda_9\geq0$. Особенности матриц псевдособственных векторов C_{99} и собственных чисел состоят в том, что они позволяют моделировать как коррелированные z-переменные (с дисперсиями, большими 1), так и некоррелированные y-переменные (с дисперсиями, меньшими 1). Мы получили одну y-переменную, в 3 раза более изменчивую, чем каждая из 9 z-переменных, из 8 y-переменных, что показывает существенность извлеченного знания (). Сильно изменчивые z-переменные (z_2, z_3, z_3, z_5, z_9) через формулу передают заметные ненулевые дисперсии y-переменной y_1. Значения z-переменных (z_1, z_2, z_3, z_4, z_5,…, z_9) являются многомерными данными, объединенных в матрицу Z_{m9}, в которой элементы j–го столбца z_{1j},z_{2j},…,z_{mj} (j-ая переменная, j=1,…,9) имеют среднее арифметическое равное нулю: (1/m)($z_{1j}+z_{2j}+\dots+z_{mj}$)=0, и дисперсию не равную 1: (1/m)($z^2_{1j}+z^2_{2j}+\dots+z^2_{mj}$) ≠1,сумма дисперсий не равна 9.

Смысл доминирующего y-фактора модели симптомов болезни Паркинсона

Информационными объектами когнитивной модели болезней, связанных с болезнью Паркинсона (с проявлением симптомов тревоги), являются:

1. Модельная пара матриц (C_{99},Λ_{99}): матрица собственных чисел Λ_{99}, матрица псевдособственных векторов C_{99} таких, что выполняются условия: $C_{99}C^T=I_{99}$, $C^T_{99}C_{99}=I_{99}$, (Λ_{99})=diag($\lambda_1,\dots\lambda_9$), $tr(\Lambda_{99})=\lambda_1+\dots+\lambda_9=9$, Λ_{99}=diag(3.0000, 0.6000, 0.6000, 0.8000, 0.8000, 0.8000, 0.8000, 0.8000, 0.8000).

Известные смысловые переменные смысл (z_1), …, смысл(z_9) в модели используются для нахождения новых смыслов для модельных y-переменных y_1 , y_2 , y_3 ,…,y_9 , которые управляют соответствующими числовыми 9 z-переменными (z_1,z_2,…,z_9).

3.Девять смысловых уравнений: смысл(y_1)= смысл(z_1*0,5300+смысл(z_2)*(-0,1835);
смысл(y_2)=смысл(z_1)*0,3462+смысл(z_2)*1,0000;
смысл(y_3)=смысл(z_1)*0,3462+смысл(z_2)*(-0,1199)+z_3*1,0000;
смысл(y_4)=смысл(z_1)*0,3462+смысл(z_2)*0,0000+ смысл(z_3)*(-0,1199)+смысл(z_4)*1,0000;
смысл(y_5)=смысл(z_1)*0,3462+смысл(z_2)*0,0000+ смысл(z_3)*0,0000+смысл(z_4)*(-0,1199)+ смысл(z_5)*1,0000;(-0,0003);
смысл(y_6)=смысл(z_1)*0,0000+смысл(z_2)*(-0,0096)+смысл(z_3)*(-0,0029)+смысл(z_4)*(-0,0029)+смысл(z_5)*0,0000+смысл(z_6)*1,0000;
смысл(y_7)=смысл(z_1)*0,3462+(z_7)*1,0000;
смысл(y_8)=смысл(z_8)*1,0000;
смысл(y_9)=смысл(z_1)*0,3462+смысл(z_9)*1,0000(-0,1259)+смысл(z_5)*1,0000;

После удаления слагаемых с нулевыми параметрами имеем короткие формулы: смысл(y_6)=смысл(z_2)*(-0,1124)+смысл(z_3)*(-

0,0720)+смысл(z_4)*(-0,0063)+смысл(z_6)*1,000;
смысл(y_7)=смысл(z_1)*(0,3548)+смысл(z_7)*1,00;
смысл(y_8)=смысл(z_8)*(1,0000);
смысл(y_9)=смысл(z_1)*(0,3548)+смысл(z_9)*1,0000.

Системе из 9 смысловых равенств соответствует система из 9 числовых алгебраических равенств:
$y_1=z_1*0.5300+z_2*(-0.1835)+z_3*$ 0.0000;
$y_2=$ $z_1*0.3462+$ $z_2*1.0000$;
$y_3=$ $z_1*0.3462+z_2*(-0.1199)+z_3*1.0000$;
$y_4=$ $z_1*0.3462+z_2*0.0000+z_3*(-0.1199)+z_4*1.0000$;
$y_5=z_1*0.3462+z_2*0.0000+z_3*0.0000+z_4*(-0.1199)+$ $z_5*1.0000$;
$y_6=z_1*0.0000+z_2*-0.0096+z_3*(-0.0029)+z_4*(-$ $0.0029)+z_5*0.0000+$ $z_1*1.0000$;

Ненулевые дисперсии (их 9 штук) $\lambda_1=3.0000$, $\lambda_2=0{,}6000$, $\lambda_3=0{,}6000$, $\lambda_4=0{,}8000$, $\lambda_5=0{,}8000$, $\lambda_6=0{,}8000$, $\lambda_7=0{,}8000$, $\lambda_8=0{,}8000$, $\lambda_9=0{,}8000$ делятся на 2 группы: 1-ая состоит из одной резко доминирующей дисперсии $\lambda_1=3.0000$, 2-ая группа образована из 8 дисперсий, значения которых меньше 1, что означает низкую их значимость по сравнению с смыслами z-переменных, смысловую близость «весов» к 0 при смыслах смысл(y_2) ,…,смысл(y_9). Смысловая переменная смысл(y_1) имеет доминирующую значимость в соответствии с дисперсией disp(λ_1)=3.0000. Смысл(y_1) является (по значимости) доминирующим смыслом, а семантическая переменная является существенным ресурсом скрытых знаний. Остальные смысловые переменные смысл(y_2),…,смысл(y_9) являются источниками постоянно проявляемых симптомов. Иначе говоря, изменчивости этих 8 y-переменных модели равны 0, их смысли постоянны во всех интервалах времени. Здесь в измышлениях (по поводу моста между смыслами и числами) мы привели обоснование: ”числовая переменная, имеющая нулевую дисперсию, является постоянной переменной с значениями, равными малой по величине константе 0”. Сравнив относительные доли 3/9=1/3 и [6/9]/8=[2/3]/8=1/12 дисперсий, назначим 8 дисперсиям переменных $y_2,\ldots,y_9$ нулевые значения. Для числового спектра Λ_{99}=diag(3.0000, 6000, 0.6000, 0.8000, 0.8000, 0.8000, 0.8000, 0.8000, 0,8000) соответствующая корреляционная матрица, имеет ранг, практически равный 1=9-8. А Корреляционная матрица, имеющая ранг, равный 1 имеет матрицу главных компонент (значений y-переменных), состоящую из одного столбца (с дисперсией, равной размерности корреляционной матрицы). В нашей модели только для смыслов смысл(y_1), смысл(y_2),…,смысл(y_9) из смысловых уравнений применяем критерий односмысловости. В математической модели числа $\lambda_1,\ldots\lambda_9$ равны значениям дисперсий алгебраических формул y–изменчивостей $y_{i2},y_{i1},y_{i3},y_{i9}$, i=1,…,36. Других значений не удалось получить при решении Оптимизационной Задачи с одним индикатором (управляющим параметром, соответствующим смыслом y-переменных y_1 ,…,y_9) и ограничениям ($2*c^2_{21}<c^2_{11}$), ($2*c^2_{31}<c^2_{11}$), ($2*c^2_{41}<c^2_{11}$), ($2*c^2_{51}<c^2$), (($2*c^2$)$<c^2_{11}$), ($2*c^2_{71}<c^2_{11}$), $2*c^2_{81}<c^2_{11}$, $2*c^2_{91}<c^2$ из словесной модели. Из вычисленных в рамках модели элементов матрицы C_{99}, содержащей 9*9=81 индикаторов используются все (в том числе 1 назначенный экспертом) индикаторов наличия модельных знаний. Эти извлеченные знания, как показано на Рисунках 1-9, адекватны ожидаемым знаниям. До момента конструирования новых смыслов 9 y–переменных эти знания были скрытыми.

Познающая модель смогла извлечь скрытые знания.

3.Каждая из 9 смысловых формул из пункта 3 когнитивно сконструирована из смыслов 9 неизмеряемых и зависимых друг от друга z-показателей. Девять y–изменчивостей переменных попарно (y_{1i},y_j), i*j, не коррелируют друг с другом: $(y_1,y_2)=corr(y_2,y_3)=corr(y_1,y_3)=\ldots=corr(y_8,y_9)=0$, так как $\lambda_{12}=\lambda_{23}=\ldots=\lambda_{89}=0$. Эти равенства – формальное выражение исходной словесной гипотезы модели: y–переменные по смыслам не влияют друг на друга.

3. Коррелированные смысли 9 z-показателей являются входными данными модели, они сформулированы в пункте «Исходные данные» статьи.

4.Один исходный индикатор $corr(z_1,y_1)=c_{11}=0{,}53$ отражает приемлемое значение, удовлетворяющее 8 неравенствам, взятых из словесной модели , они согласуются с значениями модельных 81-3=78 индикаторов, формально найденных при решении Оптимизационной Задачи. В индикаторе $corr(z_1,y_1)=c_{11}=0.53$ отражена *причина* для *следствий*: от одного индикатора (наименьшая априорная информация для модели, исключающая подсказку для познающей модели) сконструированы ниже конкретные фразы смыслов 9 y–показателей.

6.Модельные матрицы Y_{m9}, Z_{m9} (Таблицах 5 и 6) (полученные путем вычисления по алгоритму и путем компьютерного моделирования случайных матриц V^0_{m9}, U_{m9} удовлетворяют равенствам алгебраической системы уравнений, соответствуют найденным выше 9 многосмысловым уравнениям.

Конструирование смыслов 9 y-переменных из системы 9 многосмысловых уравнений для силы проявлений симптомов болезни

Паркинсона и сил проявлений симптомов 8 z-болезней

— Рассмотрим факты и сведения, которые воспроизводят явления физиологичного, анатомического характера, непосредственно касающихся болезни Паркинсона (z-болезней). Элементами конструирования каждого смысла (из 9 y-факторов) является подмножество смыслов, выбранное (для рассматриваемого y-смысла) из множества 9 z-факторов:

смысл(z_1)=«проявление болезни Паркинсона у людей «с тревожностью» происходит с силой c^2_{11};

смысл(z_2)=«депрессия» проявляется с силой c^2_{12}, в 2 раза меньшей, чем силы проявления болезни Паркинсона у людей без тревожности;

смысл(z_3)=« нарушения сна» проявляется с силой проявления c^2_{31} , в 2 раза меньшей, чем сила проявления c^2_{11} болезни Паркинсона у людей с тревожностью;

смысл(z_4)=«усталость» проявляется с силой c^2_{41}, в 2 раза меньшей, чем сила проявления c^2_{11} «болезни Паркинсона у людей с тревожностью»;

смысл(z_5)=«когнитивные расстройства» проявляется с силой c^2_{51} – в 2 раза меньшие, чем сила проявления c^2_{11} «болезни Паркинсона у людей с тревожностью»;

смысл(z_6)=« низкое кровяное давление» проявляется с силой c^2_{61} , в 2 раза меньшей, чем сила проявления c^2_{11} «болезни Паркинсона у людей с тревожностью». тремор, болезненные непроизвольные сокращения мышц и речевые нарушения;

смысл(z_7)=«тремор» проявляется с силой c^2_{71}, в 2 раза меньшей, чем сила проявления c^2_{11} «болезни Паркинсона у людей с тревожностью»;

смысл(z_8)=«ригидность» проявляется с силой c^2_{81} , в 2 раза меньшей, чем сила проявления c^2_{11}«болезни Паркинсона у людей с тревожностью»;

смысл(z_9)=«нарушением равновесия» проявляется с силой c^2_{91} , в 2 раза меньшей, чем сила проявления c^2_{11} «болезни Паркинсона у людей с тревожностью». Дисперсии 9 y-факторов: λ_1=3.0000, λ_2=0,6000, λ_3=0,6000, λ_4=0,8000, λ_5=0,8000, λ_6=0,8000, λ_7=0,8000, λ_8=0,8000, λ_9=0,8000. Дисперсии 9 z-факторов не равны 1, ибо значения z-переменных получены при преобразовании матрицей C_{99} псевдособственных векторов: dsp{z_1}=3,6239; dsp{z_2}=12,6085; dsp{z_3}=27,6112; dsp{z_4}=48,8110; dsp{z_5}=75,7990; dsp{z_6}=108,7986; dsp{z_7}=147,7983; dsp{z_8}=192,7977; dsp{z_9}=243,7968. Если матрица C_{99} являлась матрицей собственных векторов, то дисперсии 9 z-факторов были бы равны 1. Для системы смысловых уравнений с ненулевыми параметрами («весами») при смысловых переменных найдем фразы смыслов смысл(y_1), смысл(y_2), смысл(y_3), смысл(y_4), смысл(y_5), смысл(y_6), смысл(y_7), смысл(y_8), смысл(y_9), каждая из которых равна своей сумме смыслов (умноженных на параметры-компоненты псевдособственных векторов из матрицы C_{99}) из множества {смысл(z_1),…,смысл(z_9)}.

Уравнения системы имеют вид:
смысл(y_1)=смысл(z_1*0,5300+смысл(z_2)*(-0,1835)+смысл(z_3)*0,0000;
смысл(y_2)=смысл(z_1)*0,3462+смысл(z_2)*1,0000;
смысл(y_3)=смысл(z_1)*0,3462+смысл(z_2)*(-0,1199)+z_3*1,0000;
смысл(y_4)=смысл(z_1)*0,3462+смысл(z_3)*(-0,1199)+смысл(z_4)*1,0000;
смысл(y_5)=смысл(z_1)*0,3462+смысл(z_4)*(-0,1199)+смысл(z_5)*1,0000;
смысл(y_6)=смысл(z_6)*1,0000;
смысл(y_7)=смысл(z_1)*0,3462+z_7*1,0000;
смысл(y_8)=смысл(z_8)*1,0000;
смысл(y_9)=смысл(z_1)*0,3462+ смысл(z_9)*1,0000.

Смысловым уравнениям системы смысловых переменных соответствуют следующие числовые равенства:

y_1=z_1*0,5300+z_2*(-0,1835)+z_3*0,0000;

y_2=z_1*0,3462+z_2*1,0000;

y_3=z_1*0,3462+z_2*(-0,1199)+z_3*1,0000;

y_4=z_1*0,3462+z_2*0,0000+z_3*(-0,1199 z_4*1,0000;

y_5=z_1*0,3462+z_4*(-0,1199)+z_5*1,0000(-0,0003) 0,0000;

y_6=z_1*0,0000+z_2*-0,0096+z_3*(-0,0029)+z_4*(-0,0029)+z_5*0,0000+z_6*1,0000;

y_7= z_1*0,3462 + z_7*1,0000;

y_8=z_8*1,0000;

y_9= z_1*0,3462+ z_9*1,0000.

Будем конструировать фразы смыслов для смыслов 9 y–переменных, начиная с y–переменной с нулевой дисперсией, в порядке возрастания величины дисперсии. Восемь y–переменных имеют приблизительно нулевые дисперсии, они являются постоянно действующими факторами-симптомами болезни Паркинсона. Одна y–переменная имеет доминирующую дисперсию, а ее смысл должен содержать фразу «…проявление симптомов болезни Паркинсона у людей «с тревожностью», так как из исходных данных видно: суммы фраз смыслов 9 z–переменных словесно выражают знания об «…проявлениях симптомов болезни Паркинсона. Результаты из Таблицы подтверждают это: болезнь Паркинсона у людей «с тревожностью» смысл y–переменной y_1

дополняют фразу смысла(z_1). Содержат извлеченные скрытые знания, представляющие собой особо ценные «цифровые» знания. Рассмотрим смысловое уравнение смысл(y_9)=смысл(z_1)*(0,3548)+смысл(z_9)*1,0000. Начнем с фразы, присущей смыслу z–переменной z_9 (λ_9=0,8000) с наибольшим «весом» c_{99}=1.0000. Фраза «проявление симптомов болезни Паркинсона у людей «с тревожностью» с силой $c^2_{19}=(0,3548)^2$ дает многократное «нарушение равновесия» с силой $c^2_{91}=1.0000^2$». Так как $c^2_{19}+c^2=1$, то сила проявлений симптомов при «событии z_1» в 3 раза вырастут по силе при наступлении «события z_9, симптомы которого проявятся с силой $c^2_{91}=1.0000^2$. Такова могучая сила события «проявление симптомов болезни Паркинсона у людей «с тревожностью». Здесь мы сконструировали новый смысл(y_9)=«постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» дает многократное «нарушение равновесия». 2-ая постоянное событие «y_8». Его смысл передается фразой смысл(y_8)=«постоянная ригидность» проявляется при «болезни Паркинсона у людей с тревожностью»». Конструируется этот смысл просто из смыслового уравнения смысл(y_8)=смысл(z_8)*1,0000). Смысл третьего постоянного события из его смысловой формулы смысл(y_7)=смысл(z_1)*0,3462 +(z_7)*1,0000. Фраза «проявление симптомов болезни Паркинсона у людей «с тревожностью» с силой $(0,3462)^2$ дает многократное «проявление симптомов тремора с силой $c^2_{71}=1.0000^2$». Смысл(y_7)= «постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» дает многократное «проявление симптомов тремора». Смысл 4-го постоянного события из его смысловой формулы смысл(y_6)=смысл(z_2)*(-0,0096)+смысл(z_3)*(-0,0029)+смысл(z_4)*(-0,0029)+смысл (z_6)* 1,0000. В смысловой формуле отсутствуют симптомы z–факторов z_1,z_5,z_7,z_8,z_9. Очень малые силы симптомы z–факторов z_2,z_3,z_4 относительно силы симптома z_6 $c_{61}=1.0000^2$ позволяет упростить фразу смысла(y_6). Смысл(y_6)=«постоянное низ кое кровяное давление» у людей с «болезнью Паркинсона, испытывающих тревожность». С примечанием: «при очень малых по силе симптомах –факторов z_2, z_3, z_4».

Смысл 5-го постоянного события конструируем из его смысловой формулы смысл(y_5)=смысл(z_1)*0,3462++смысл(z_4)*(-0,1199)+смысл(z_5)*1,0000. Фраза, передающая смысл(y_5)=«постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» (с силой $(0,3462)^2$), а также постоянное уменьшение симптомов=«усталости» (с силой $c_{45}=(-0,1199)^2$) дают постоянное многократное «проявление симптомов «когнитивные расстройства» (с наибольшей силой $c^2_{55}=1.0000^2$)». Смысл 6-го постоянного события сконструируем из его смысловой формулы смысл(y_4)=смысл(z_1) *0,3462+смысл(z_3)*(-0,1199)+смысл(z_4)*1,0000. Фраза, передающая смысл(y_4)=«постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» (с силой $c^2_{14}=(0,3462)^2$), а также постоянное уменьшение симптомов «нарушения сна» (с силой $c^2_{34}=(-0,1199)^2$) дают постоянные симптомы «усталости» (с силой $c^2_{44}=(1.000)^2$))». Смысл 7-го постоянного события сконструируем из его смысловой формулы смысл(y_3)= смысл(z_1)*0,3462+смысл(z_2)*(-0,1199)+ z_3*1,0000.

Смысл(y_3)=«постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» (с силой $c^2_{13}=0,3462)^2$ и постоянное проявление симптомов депрессии» (с силой $c^2_{23}=(-0,1199)^2$) дают постоянные проявления симптомов ««нарушения сна» (с силой $c^2_{13}=1,0000)^2$». Смысл 8-го постоянного события: смысл(y_2)=смысл(z_1)*0,3462+ смысл(z_2)*1,0000.

Фраза смысла(y_2) обосновывается смысловыми и числовыми данными: «постоянные проявления (с силой $c^2_{12}=0,3462^2$) симптомов «болезни Паркинсона, испытывающих тревожность» дают постоянные проявления «депрессии» (с силой $c^2_{22}=1.0000^2$). Смысл (y_2)=«постоянные проявления симптомов болезни Паркинсона, испытывающих тревожность» дают постоянные 100%-ые проявления «депрессии».

Самым информативным (дисперсия смысловой переменной disp(λ_1)=3.000 неизмеримо превосходит дисперсию каждой другой (из Таблицы 4) смысловой переменной), является смысл(y_1). Смысловое уравнение смысл(y_1)=смысл(z_1)*0,5300+смысл(z_2)*(-0,1835) имеет решение смысл(y_1), зависящее от 2-х известных смыслов смысл(z_1), смысл(z_2), фразы которых приведены выше в исходных данных модели. Суммируя смысли 3-х фраз и подтверждая 3 фразы смысловыми и числовыми данными, относящими к их смысловому уравнению смысл(y_1)=смысл(z_1*0,5300+смысл(z_2)*(-0,1835) +смысл(z_3)*0,0000, имеем смысл (y_1)=«случайное проявление (с изменчивостью disp(λ_1)=3.000) симптомов болезни Паркинсона у людей «с тревожностью» (с силой

c^2_{11}=0,5300)^2 дают неслучайное (обусловленное проделанными медицинскими лечебными мероприятиями в рамках проекта[1]) случайное проявление убывающих симптомов депрессии» (с силой c^2_{21}=(-0,1835)^2). Результат проекта - проявление *убывающих* симптомов депрессии» у людей (с силой c^2_{21}=(-0,1835)^2) численно оценивает проект, а наша когнитивная модель извлекла скрытые знания из исходных данных.

Таблица 2. Извлеченные знания об 9 у-ситуациях развития симптомов болезни Паркинсона

№	% дисперсии	Смыслы независимых у–факторов, зависящих от смыслов z-факторов	Дисперсии z-факторов	Выводы
9	0/9=0,00%	смысл(y_9)=«постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» дает многократное «нарушение равновесия»	ddsp{z_1}=3,6239; dsp{z_9}=243,7968	Постоянно проявляемый у-фактор y_9
8	0/9=0,00%	смысл(y_8)=«постоянная ригидность» проявляется (с силой c^2_{88}=1,0^2) при «болезни Паркинсона у людей с тревожностью»	dsp{z_8}=192,7977	Постоянно проявляемый у-фактор y_8
7	0/9=0,00%	смысл(y_7)=«постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» дает многократное «проявление симптомов тремора»	ddsp{z_1}=3,6239; dsp{z_7}=147,7983	Постоянно проявляемый у-фактор y_7
6	0/9=0,00%	Смысл(y_6)=«постоянное низкое кровяное давление» у людей с «болезнью Паркинсона, испытывающих тревожность»	dsp{z_4}=48,8110; dsp{z_6}=108,7986	Постоянно проявляемый у-фактор y_6
5	0.00/9= 0000%	смысл(y_5)=«постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» (с силой c^2_{15}=(0,3462)^2), а также постоянное уменьшение симптомов=«усталости» (с силой c^2_{45}= (-0,1199)^2) дают постоянное многократное «проявление симптомов «когнитивные расстройства» (с наибольшей силой c^2_{55}=1.0000^2)»	ddsp{z_1}=3,6239; dsp{z_4}= 48,8110; dsp{z_5}=75,7990;	Постоянно проявляемый у-фактор y_5
4	0.00/9= 0000%	смысл(y_4)=«постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» (с силой c^2_{14}=(0,3462)^2), а также постоянное уменьшение симптомов «нарушения сна» (с силой c^2_{34}=(-0,1199)^2) дают постоянные симптомы «усталости» (с силой c^2_{44}=(1.000)^2))»	ddsp{z_1}=3,6239; dsp{z_3}=27,6112; dsp{z_4}= 48,8110;	Постоянно проявляемый у-фактор y_4
3	0.00/9= 0000%	смысл(y_3)=«постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» (с силой $c^2$13=0,3462)^2 и постоянное проявление симптомов депрессии» (с силой c^2_{23}=(-0,1199)^2) дают постоянные проявления симптомов ««нарушения сна» (с силой c^2_{13}=1,0000)^2»	ddsp{z_1}=3,6239; dsp{z_2}=12,6085; dsp{z_3}=27,6112.	Постоянно проявляемый у-фактор y_3
2	3.00/9= 0000%	Смысл(y_2)=«постоянные проявления симптомов болезни Паркинсона, испытывающих тревожность» дают постоянные 100%-ые проявления «депрессии»	ddsp{z_1}=3,6239	Постоянно проявляемый у-фактор y_2

1	3.0000/9 =33.3%	смысл(y_1)=««случайное проявление (с изменчивостью disp(λ_1)=3.000) симптомов болезни Паркинсона проявляются у людей «с тревожностью» (с силой c^2_{11}=0,5300)^2 дают неслучайное (обусловленное проделанными медицинскими лечебными мероприятиями в рамках проекта),случайное проявление убывающих симптомов депрессии» (с силой c^2_{21}=(-0,1835)^2)».	ddsp{z_1}=3,6239; dsp{z_2}=2,0890.	проявление убывающих симптомов депрессии у людей, модель численно оценивает проект, модель извлекла скрытые знания из исходных данных.

Краткий пересказ смысла(y_1) yandex.

Случайное проявление симптомов болезни Паркинсона

- Симптомы болезни Паркинсона проявляются у людей с тревожностью:
- Сила связи между тревожностью и симптомами составляет 0,5300.

Неслучайное проявление симптомов.

- Симптомы убывают у людей в состоянии депрессии.
- Сила связи между депрессией и симптомами составляет (-0,1835).

Медицинские лечебные мероприятия.

- Медицинские мероприятия в рамках проекта могут влиять на проявление симптомов.
- Эти мероприятия могут быть причиной неслучайного проявления симптомов

Моделирование числовых матриц Y_{m9}. Z_{m9} y- и z–отклонений для системы из 9 многосмысловых уравнений

Отдельно моделировались матрицы U_{m9} и Y_{m9} [17] такие, что $(1/m)U^T_{m9}U_{m9}=I_{99}$,$Y_{m9}=U_{m9}\Lambda^{1/2}_{99}$, Λ_{99}=diag(3.0000,0.6000,0.6000,0.8000,0.800,0,0.8000,0.8000,0.8000,0.8000),затем моделировалась матрица $Z_{m9}=Y_{m9}C^T_{99}$. Матрица значений z-переменных $z_1,z_2,z_3,\ldots,z_9$ $Z_{m9}=Y_{m9}C^T$, C^T $C_{99}I_{99}$,$C_{99}C^T_{99}=I_{99}$. Легко вычисляется в ЭТ Excel. Матрицы Z_{m9} и Y_{m9} содержат модельные значения неизмеряемых изменчивостей (отклонений от 0), соответствующих неизмеряемым факторам. Матрица Y_{m9} обеспечивает случайность будущих значений y- и z–отклонений. Матрицы Z_{m9}, Y_{m9} приведены в Таблицах 5 .

Таблица 3. Вид таблицы-программы Оптимизационной задачи: ($I_{99}I_{99}$)=>(C_{99} Λ_{99}) в модели с 9 z-переменными, 9 y-переменными

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	
z_1	0.5300	0.3462	0.3462	0.3462	0.3462	0.0000	0.3462	0.0000	0.3462	1.0000
z_2	-0.1835	1.0000	-0.1199	0.0000	0.0000	-0.0096	0.0000	0.0000	0.0000	1.0000
z_3	0.0000	0.0000	1.0000	#####	0.0000	-0.0029	0.0000	0.0000	0.0000	1.0000
z_4	0.0000	0.0000	0.0000	1.0000	-0.1199	-0.0029	0.0000	0.0000	0.0000	1.0000
z_5	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	1.0000
z_6	0.0000	0.0000	0.0000	0.0000	-0.0003	1.0000	0.0000	0.0000	0.0000	1.0000
z_7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	1.0000
z_8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	1.0000
z_9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000
	0.3146	**1.1199**	**1.1342**	**1.1342**	**1.1342**	**1.0001**	**1.1199**	**1.0000**	**1.1199**	9.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
lam	**3.0000**	**0.6000**	**0.6000**	**0.8000**	**0.8000**	**0.8000**	**0.8000**	**0.8000**	**0.8000**	9.0000
c_{11}	**0,53**		1,00000							

Таблица 6. Матрица Y_{m9} y–изменчивостей

	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9
1	1.1309	0.2253	0.4569	-0.7079	-1.0924	-1.0089	-0.0637	-2.0496	-0.7849
2	-3.3990	-0.5916	-0.6309	0.9416	-1.5517	-1.8390	0.0539	0.5450	-0.7958
3	-1.2076	-0.1278	-0.5628	-0.1343	-1.1792	0.5980	1.5721	1.2457	0.1581
4	0.6166	0.9877	0.8074	0.1900	-1.0374	-0.5560	-0.5894	-0.2319	1.0562
5	1.3531	-0.9330	0.4247	-1.0127	0.3808	-0.3082	1.1688	0.7153	-0.5584
6	1.5741	0.3819	0.8296	1.0884	0.9279	-0.1355	-1.7426	0.5184	-0.6977
7	-0.7495	0.2835	-0.4798	0.3628	0.8009	-0.0462	1.6032	0.2639	0.0336
8	0.1824	0.4935	-0.0603	-1.1871	-0.1293	-0.6828	-1.3810	-1.4948	-1.3514
9	-0.6067	-0.2554	0.5702	0.1312	0.1698	1.8704	0.1545	1.1165	-0.6765
10	-2.5773	0.7678	0.4538	-0.1365	-0.2387	0.2839	-0.5574	-1.4625	0.5778
11	4.2004	0.6005	0.3390	-0.7807	0.9820	-1.0203	0.8085	0.9541	0.4405
12	2.5000	-1.1625	-0.7087	1.7329	-0.2533	-0.2115	0.1213	-0.6872	0.0362
13	1.6766	0.7861	0.0332	1.2259	-1.6650	0.8303	0.5316	-0.7601	0.9812
14	2.0953	0.2797	1.2638	-1.1874	-0.0456	0.7722	1.1024	-0.7361	-1.1152
15	1.2350	-2.0616	0.7225	0.5036	-0.4776	1.1114	-0.3036	0.5010	-1.1260
16	2.3847	1.1847	-0.5778	0.5983	0.8597	-0.5931	-0.2957	0.2980	-0.4826
17	-2.5558	0.6776	1.2578	0.3264	-0.4850	0.8275	1.2631	-0.4285	0.6587
18	-1.2228	0.1923	-1.2514	-0.5667	0.3246	-0.9482	-0.5558	0.8928	1.4673
19	-0.2063	-1.3377	1.5236	1.1760	0.1495	-1.1563	-0.5815	0.2409	0.0134
20	-0.0580	-0.5178	0.3459	-0.6451	0.9046	0.4240	-1.7463	-0.5802	1.5854
21	-0.9268	-0.6868	-1.2009	-0.3503	1.1545	0.7440	-0.3820	-0.7983	-1.5013
22	-0.3720	0.7034	-0.9521	1.2509	1.3819	0.9781	0.0735	-0.8255	0.7426
23	0.4008	-0.7778	0.7764	0.6821	0.8677	0.2529	-0.7143	1.1422	1.2135
24	1.4108	0.3710	-0.9126	-1.0163	-1.1759	0.7188	-1.5479	0.5927	-0.4337
25	-0.6208	-0.2301	-0.1383	-1.2696	1.1120	0.3755	0.9579	-0.1735	0.2964
26	-3.8143	0.4559	0.7628	-0.9537	0.6694	1.0819	-0.0842	0.3917	-0.0788
27	1.7109	-0.1697	-0.8345	0.1789	0.5357	-0.0159	1.0694	-0.5198	0.6104

28	-0.5539	-1.6699	-0.2605	-1.6295	-1.0891	0.0895	0.1365	-1.0508	1.0371
29	-1.7367	-0.0173	0.0875	1.8434	0.4760	-0.7261	0.7078	-1.5656	-1.0117
30	-2.4602	0.3814	-0.0225	-0.3242	-0.2016	-0.7248	-1.3499	1.5851	-0.7941
31	0.3305	0.9297	-0.1815	-0.2211	0.4571	1.0002	-0.3836	0.1243	-0.8154
32	-0.4775	-0.8278	-1.7779	0.0210	0.5642	0.2282	-0.2842	-0.4579	0.6423
33	-1.0557	0.1226	0.9235	-0.4016	1.1078	-2.1557	0.6865	0.1546	1.0604
34	-0.5007	0.8691	-0.5265	0.3234	-0.2320	-0.4910	0.8091	1.1219	-1.7421
35	1.5386	0.0943	-0.4992	-1.0241	-1.4513	-0.7876	0.2370	0.6967	0.3822
36	0.7609	0.5789	-0.0004	0.9726	-1.5208	1.2204	-0.4940	0.7219	0.9718
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	3.0000	0.6000	0.6000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000

Таблица 7. Матрица Z_{m9} z–изменчивостей

	z_1	z_2	z_3	z_4	z_5	z_6	z_7	z_8	z_9
1	-0.2736	2.4420	3.9372	3.9493	4.5619	5.7766	7.8523086	6.9973	9.39284389
2	-4.5902	-7.2963	-10.9354	-12.4631	-18.5466	-22.2324	-23.738902	-26.6468	-31.3865604
3	-1.2866	-2.4813	-4.1712	-4.8251	-7.2171	-6.6471	-6.8809661	-8.4150	-10.7101377
4	0.8534	2.1295	2.6360	2.7824	2.0456	3.1440	3.7268431	4.7010	6.60571986
5	0.9278	1.7252	4.6062	4.3549	7.1461	7.8101	10.640384	11.5399	11.6193119
6	2.8943	3.4319	5.4218	7.2740	8.7983	9.3087	9.2760019	13.1111	13.4691368
7	-0.2871	-1.1575	-2.7715	-2.7309	-2.9464	-4.5433	-3.6430374	-5.7317	-6.711495
8	-0.7865	0.8720	0.6311	-0.4401	0.7826	0.4115	-0.1043009	-0.0357	0.29007451
9	0.5936	-1.5552	-1.2711	-2.3215	-2.8639	-1.7701	-4.0926942	-3.7374	-6.13718131
10	-2.5512	-4.4439	-7.2626	-10.4179	-13.1252	-15.1798	-18.598448	-22.0808	-22.6178244
11	4.6827	8.9704	13.0367	15.9061	21.9840	24.1818	30.211248	34.5573	38.2440731
12	1.8397	3.9245	6.5844	11.7640	12.2469	14.7888	17.621579	19.3131	22.5366035
13	1.9770	4.1274	4.9137	8.1296	6.7181	10.8906	12.268024	12.6529	16.0708133
14	2.2666	4.3114	7.6896	7.1969	10.4307	13.3438	15.769215	16.0260	17.7421849
15	0.9596	0.3110	4.3639	5.4974	5.6971	8.5213	8.341097	10.3806	9.98857564
16	3.2152	6.0291	6.5063	10.0357	12.7832	13.7147	16.397115	19.3755	20.9795551

17	-1.6780	-4.5927	-6.4511	-9.8411	-13.2640	-14.5072	-16.627589	-20.8750	-22.3435819
18	-1.6571	-2.0942	-4.8493	-5.4942	-5.7896	-8.2853	-9.1155921	-8.8898	-9.53814302
19	-0.2458	-1.9217	0.7671	0.3363	-0.8820	-2.3941	-2.0254779	-1.4094	-1.84316885
20	-0.1770	-0.6794	0.2479	-0.9868	0.6145	0.0755	-2.1524456	-1.0444	1.06315888
21	-1.4470	-2.4037	-3.9415	-4.1981	-3.4796	-4.8173	-6.8697526	-8.2128	-9.84267952
22	0.6354	0.0640	-2.2210	-0.4058	-0.4783	-1.2547	-2.5307897	-3.8018	-2.60575772
23	1.2768	-0.0717	1.8963	2.1806	2.8717	2.6574	2.0912863	4.3486	4.82063838
24	0.9866	3.2950	3.4395	4.7656	5.8779	9.1837	8.327392	11.8788	12.2630907
25	-0.7752	-1.4586	-1.8496	-3.8871	-1.9918	-3.3495	-3.3874375	-5.1397	-5.29048991
26	-2.8969	-7.2746	-10.5689	-16.2944	-18.4022	-21.8043	-26.784422	-30.1229	-34.4076996
27	1.3940	3.3523	4.2769	6.9584	9.0903	10.2494	13.045816	13.1675	16.0087246
28	-2.8031	-2.7473	-1.7272	-3.7148	-3.8587	-3.2336	-3.7408793	-5.4821	-3.94810031
29	-1.7060	-3.4942	-5.3416	-5.1585	-8.2076	-11.1466	-11.449331	-15.4594	-16.6422327
30	-2.1500	-4.5293	-7.3621	-10.1388	-12.5026	-15.4859	-18.571304	-18.0965	-22.9359172
31	1.2314	1.6028	0.8336	1.0431	2.1095	2.9829	1.9297072	2.7681	2.15891782
32	-1.4087	-1.5720	-3.2137	-1.9574	-1.8234	-2.6372	-3.6268444	-4.2782	-3.6554495
33	-1.1193	-2.0787	-2.1893	-4.7509	-4.1706	-8.4902	-6.7033219	-8.2909	-8.44073183
34	0.0277	-0.0646	-2.0661	-1.6503	-2.7357	-3.4954	-2.6960524	-2.8840	-6.24869884
35	0.5273	3.2389	4.2416	5.3064	6.2416	8.4444	11.007088	13.0053	14.2294153
36	1.5502	2.0890	2.1622	4.1949	2.2837	5.7863	4.8322373	6.8090	7.81980442
	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001	-0.0001	-0.0001	-0.0001
	3.6239	12.6085	27.6112	48.8110	75.7990	108.7986	147.7983	192.7977	243.7968

Визуализация знаний о величинах z-, y-изменчивостей проявлений 9 z-симптомов , 9 y-болезней

Точки на кривых (Рисунки 1-7) показывают заметные (измеряемые величинами весов проявлений) взаимные динамики, “скачки-падения» точек переменных из 9 числовых уравнений. На Рисунке 7. показаны взаимные динамики z-изменчивостей 2-х z–факторов и y-изменчивости y–фактора y_1 ($y_1=z_1*0{,}5300+z_2*(-0{,}1835)$). Так как сила проявления смысла (z_1) заметно проявлена: $c^2_{11}=corr^2(z_1,y_1)=0{,}5300)^2$, то динамики кривых “$z_1$” ,“$y_1$“ близки, что визуально отображает близость фразы смысла(z_1) и фразы смысла(y_1). Фраза смысла(y1) добавляет к смыслу(z_1) обосновывающие числа: $corr^2(z_1,y_1)=(0{,}5300)^2$, $corr^2(z_2,y_1)=(-0{,}1835)^2$, противоположно влияющих на случайную динамику изменчивости y-фактора y_1 с новым смыслом=«случайные проявления (с наибольшей изменчивостью $disp(\lambda_1)=3.000$) симптомов болезни Паркинсона у людей «с тревожностью» проявляются (с силой $c^2_{11}=corr^2(z_1,y_1)=(0{,}5300)^2$ через случайное проявление убывающих

симптомов депрессии» (с силой $c^2_{21}=corr^2(z_2,y_1)=(-0,1835)^2$)» и возрастающих симптомов болезни Паркинсона у людей «с тревожностью» (с силой $c^2_{11}=corr^2(z_1,y_1)=(0,5300)^2$»). Из 9 дисперсий - переменных 8 дисперсий близки к 0: Λ_{99}=diag(3.0000,0.6000,0.6000,0.8000,0.8000,0.8000,0.8000,0.8000,0.8000), существенные знания дает одна y-переменная y_1 (смотрите выше), имеющая большую дисперсию $disp(\lambda_1)$= 3.0000.

Каждая динамика (Таблицы 1-6) y-переменных y_2, y_3,...,y_9, постоянно проявленных 8 y-факторов (за 35 интервалам времени) тесно связана с z–фактором z_1 с доминирующим весом (Рисунки 1-7). Визуализация динамик факторов медицинских ситуаций отличается от визуализаций динамик факторов из других предметных областей [1-17]. Рисунки 1-7 визуализируют значения 35 чисел (относящихся к 35 интервалам времени) из столбцов Таблиц 6 и 8. Извлеченные знания из смыслов 9 y-показателей (ситуаций) симптомов болезни Паркинсона у людей «с тревожностью визуализированы в системе координат вес фактора-изменчивость фактора-время, стимулирующую продолжение исследований.

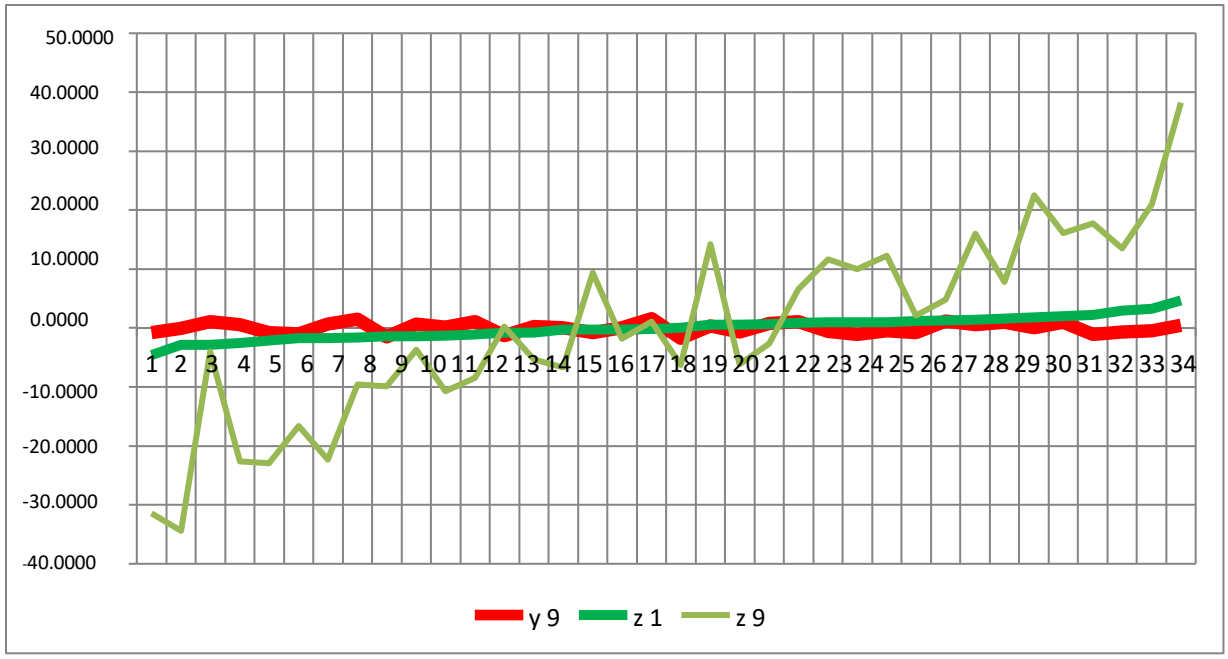


Рисунок 1. Взаимная динамика 2-х изменчивостей z_1, z_9, влияющих на постоянную динамику y-изменчивости фактора y_9 со смыслом «постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» дает многократное «нарушение равновесия»

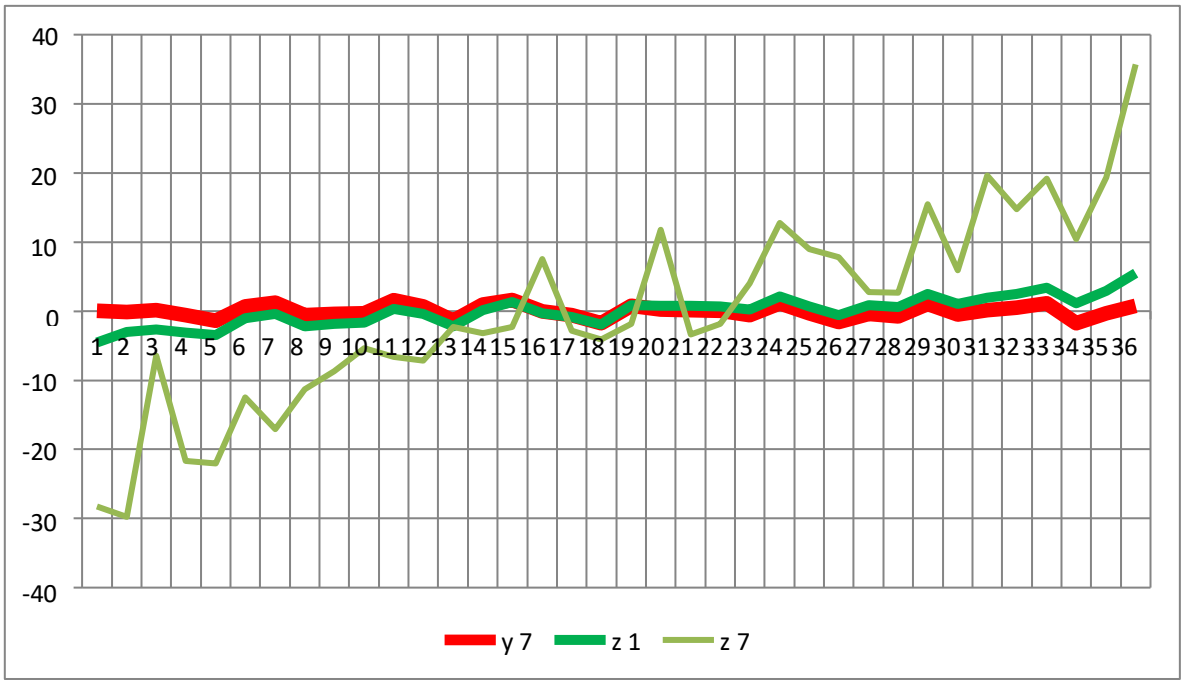


Рисунок 2. Взаимная динамика 2-х изменчивостей z_1, z_7, влияющих на постоянную динамику y-изменчивости фактора y_7 (смысл(y_7)=смысл(z_1)*0,3462 +z_7)*1,0000) со смыслом «постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» дает многократное «проявление симптомов тремора»

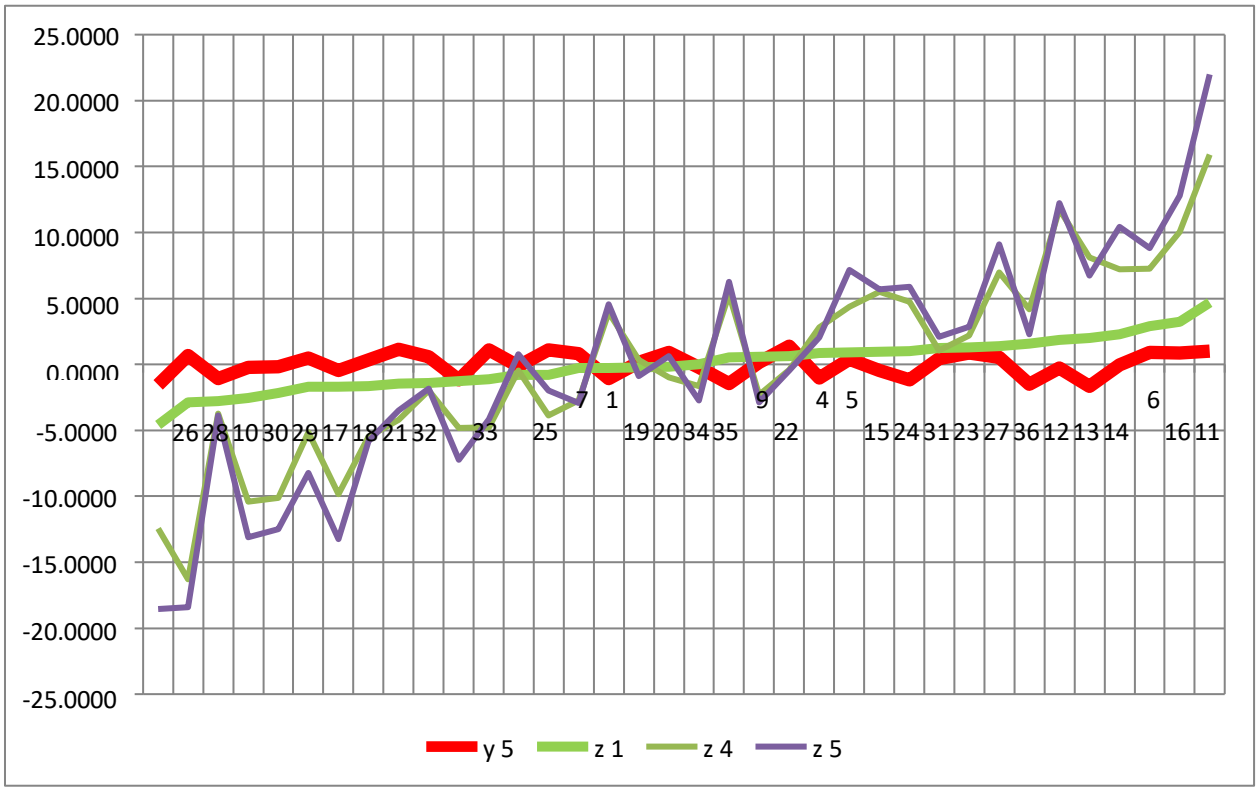


Рисунок 3. Взаимная динамика 3-х z -изменчивостей z_1, z_4, z_5, влияющих на постоянную динамику y-изменчивости фактора y_5 со смыслом «постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» (с силой $(0,3462)^2$), а также постоянное уменьшение симптомов=«усталости» (с силой c_{45}=)*$(-0,1199)^2$) дают постоянное многократное «проявление симптомов

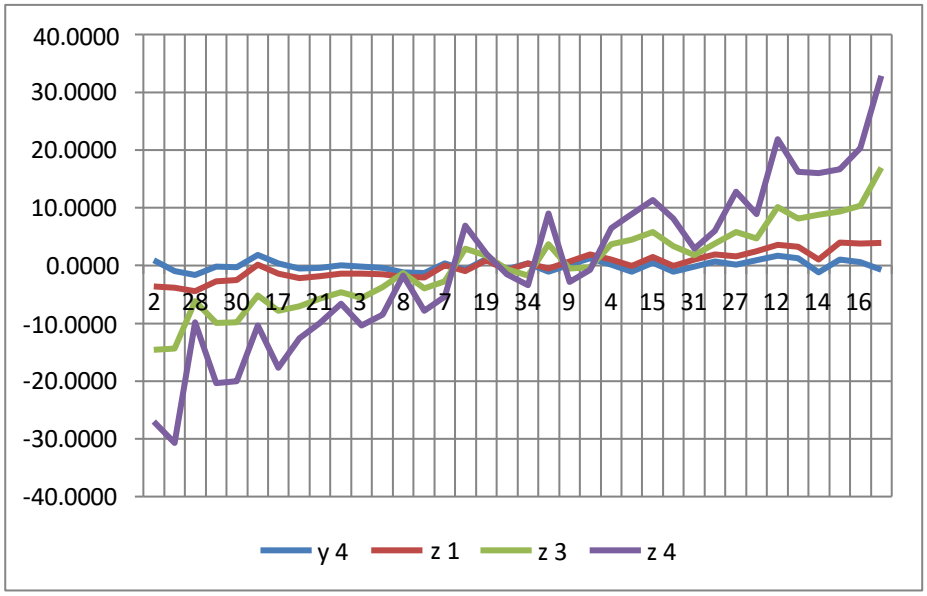


Рисунок 4. Динамика 3-х z-изменчивостей z_1, z_4, z_5, влияющих на постоянную динамику y-изменчивости фактора y_4 смысл(y_4)=смысл(z_1)*0,3462+смысл(z_3)*(-0,1199)+смысл(z_4)* 1,0000 со смыслом «постоянное низкое кровяное давление» у людей с «болезнью Паркинсона, испытывающих тревожность»

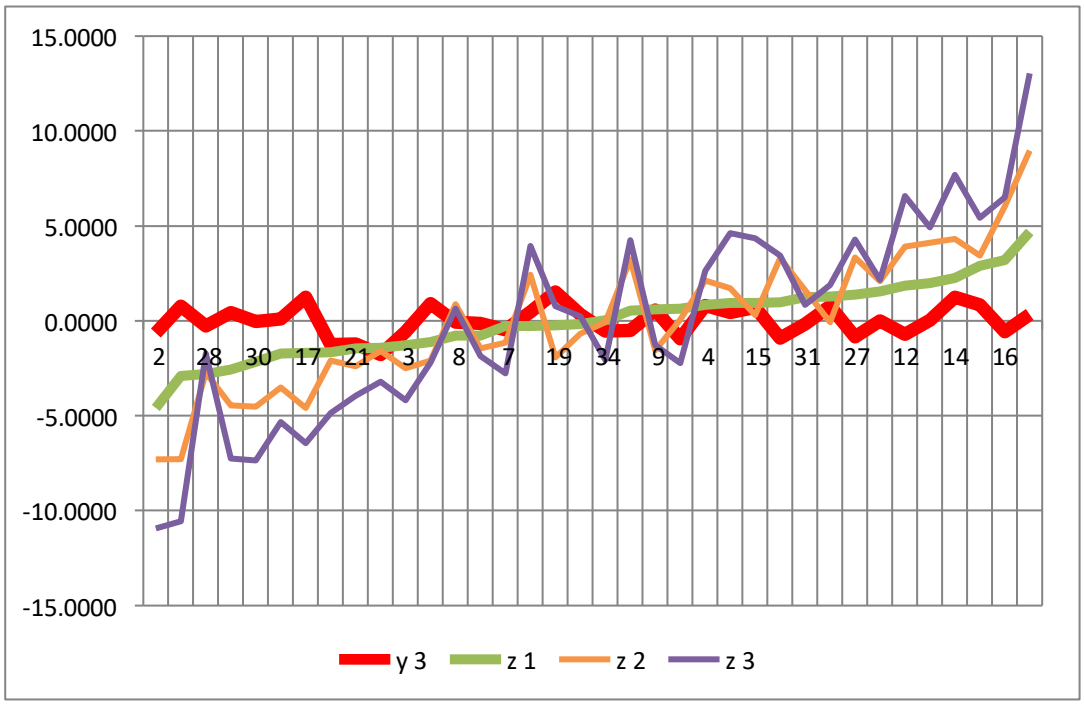


Рисунок 5. Взаимная динамика y-изменчивости фактора y_3 («постоянное проявление симптомов болезни Паркинсона у людей «с тревожностью» (с силой $c^2_{13}=0,3462)^2$ и постоянное проявление симптомов депрессии» (с силой $c^2_{23}=(-0,1199)^2$) дают постоянные проявления симптомов ««нарушения сна» (с силой $c^2_{13}=1,0000)^2$») и 4-х z-изменчивостей факторов z_1,z_2,z_3, z_4

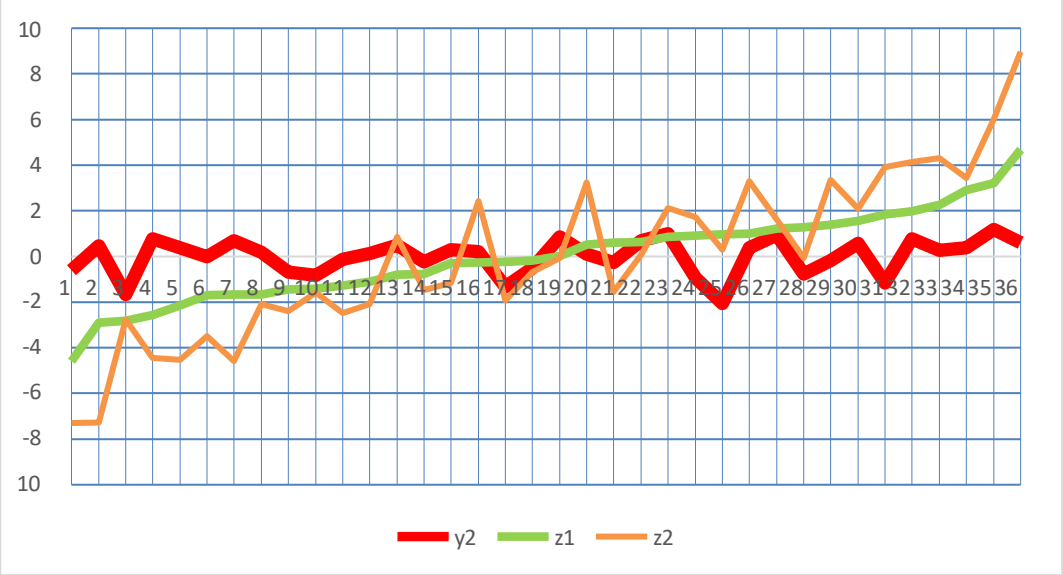


Рисунок 6. Взаимная динамика y-изменчивости фактора y_2 (смысл(y_2)=смысл(z_1)*0,3462+ смысл(z_2)*1,0000) и 2-х z-изменчивостей факторов z_1, z_2, влияющих на случайную динамику y-изменчивости фактора y 2 со смыслом «постоянные проявления симптомов болезни Паркинсона, испытывающих тревожность» дают постоянные 100%-ые проявления «депрессии»

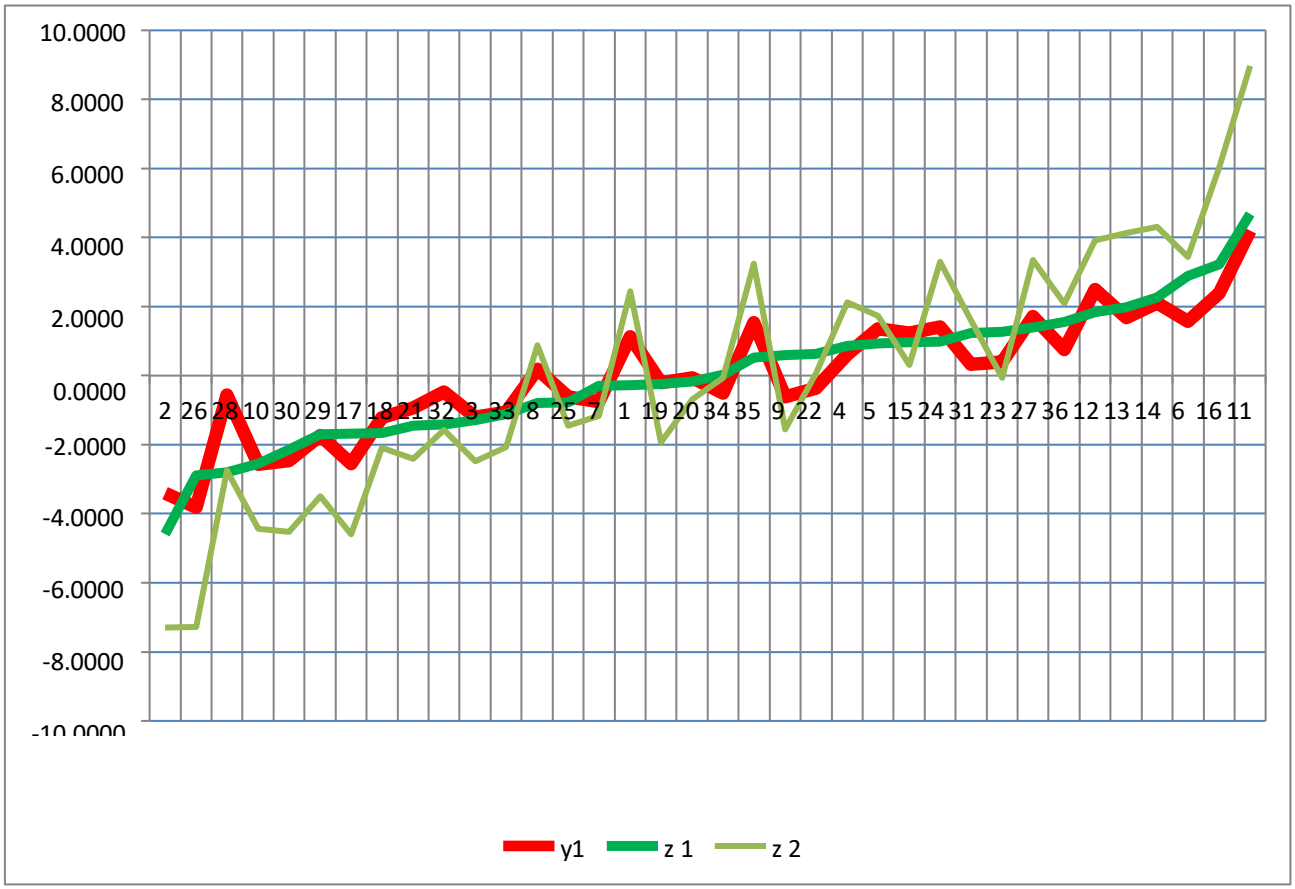


Рисунок 7. Взаимная динамика 2 изменчивостей z –факторов z_1, z_2, влияющих на случайную динамику изменчивости y-фактора y_1 с новым смыслом «случайное проявление (с изменчивостью disp(λ_1)=3.000) симптомов болезни Паркинсона у людей «с тревожностью» (с силой c^2_{11}=0,5300)^2 дают неслучайное (обусловленное проделанными медицинскими лечебными мероприятиями в рамках проекта[1]) случайное проявление убывающих симптомов депрессии» (с силой c^2_{21}=(-0,1835)^2)»

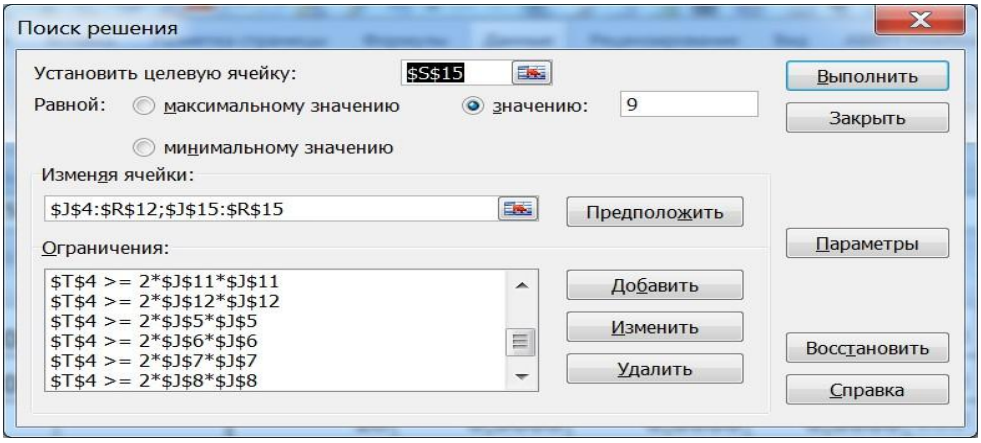


Рисунок 8. Окно надстройки «Поиск решения» с операторами таблицы-программы решения оптимизационной Задачи: (I_{88},I_{88})=>(C_{88}, Λ_{88})

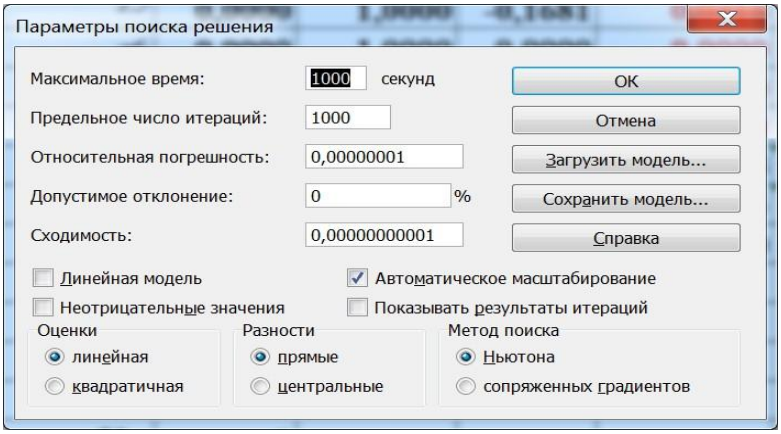


Рисунок 10. Параметры поиска решения (C_{99}, Λ_{99}) в таблице-программе решения Оптимизационной Задачи: (I_{99},I_{99})=>(C_{99}, Λ_{99})

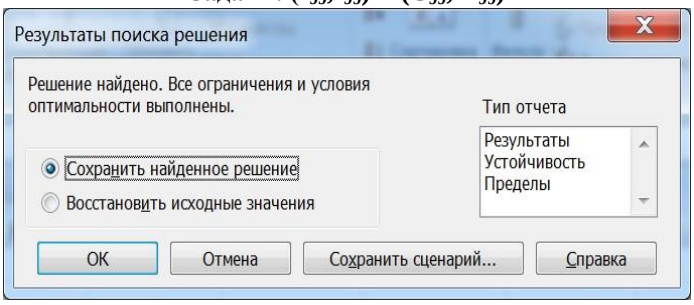


Рисунок 11.

Заключение

Разработана Когнитивная модель развития симптомов болезни Паркинсона у людей «с тревожностью». Исходные данные о проявлениях симптомов 9 болезней взяты из словесной модели из отчета[1]. Введены смысловые, числовые переменные, ограничения, имеющие вид строгих неравенств: $(2*c^2_{21}<c^2_{11})$, $(2*c^2_{31}<c^2_{11})$, $(2*c^2_{41}<c^2_{11})$, $(2*c^2_{51}<c^2_{11})$, $(2*c^2_{61}<c^2_{11})$, $(2*c^2_{71}<c^2_{11})$, $(2*c^2_{81}<c^2_{11})$, $(2*c^2_{91}<c^2_{11})$, они удачно применены выше при решении Оптимизационной Задачи. Введены числовые коэффициенты-измерители величин сил взаимосвязей между z- и y- изменчивостями симптомов болезней. Найдены (смоделированы) числовые значения z_{ik} отклонений от 0 вправо\влево изменчивости z-переменной, умноженных на «веса» c_{kj} проявлений k-ой z-переменной. Сумма произведений $z_{ik}c_{kj}$, k=1,…, 9, образует новую y-переменную с номерами j=1,…, эти 9 y-переменные образуют некоррелированное множество, соответствующее набору симптомов болезни, каждому набору соответствует свое смысловое уравнение, из семантического решения которого изливается новое цифровое знание. Извлеченные знания предназначены для использования при лечении. Найденные смыслы y-переменных, являются извлеченными скрытыми

знаниями об симптомах болезни Паркинсона (с симптомом тревожности). Используя 9 z-событий модель добавила (познала) смыслы 9 независимых по смыслу y-событий. Новые y-события по смыслам и количественно обоснованы как наборы болезней. Проявления y-событий модельно реализованы, обоснованы их формульное, фразеологическое представления, визуализированы на графиках взаимные динамики кривых соответствует ожидаемому. Разработана система из 9 смысловых уравнений с 18 семантическими переменными: смысл(y_1),…, смысл(y_9), смысл(z_1),…,смысл(z_9), удовлетворяющих матричному смысловому равенству вида смысл(Z_{m9})=смысл($Y_{m9}C^T_{99}$), где смысл(Z_{m8})=смысл(z_1)⊕…⊕смысл(z_9), смысл($Y_{m9}\mathbf{C}^T_{\mathbf{99}}$)=смысл($Y_{m9}\mathbf{c}^T_{\mathbf{1}}$)⊕смысл($Y_{m9}\mathbf{c}^T_{\mathbf{2}}$)⊕ …⊕смысл($Y_{m9}\mathbf{c}^T_{\mathbf{9}}$). Этому матричному смысловому равенству соответствует числовое матричное равенство для числовых z-, y-переменных, смоделированных в виде матриц: $Z_{m9}=Y_{m9}C^T_{99}$. Девять семантические решения–знания (новые извлеченные знания), познают смыслы, парные связи, силы проявлений семантических переменных.

Вычислены новые 9 формул, где каждая формула y-болезни имеет z-симптомы нескольких z–болезней. Для y-болезни нужно разрабатывать свой комплекс лекарств, лечащих только эти z–болезни и болезнь Паркинсона и не влияющие на другой букет z–болезней из другой y-болезни (из 9 модельных независимых y-болезней). Эта оригинальная идея требует практического воплощения в медицинских, фармацевтических проектах.

Визуализация взаимных динамик кривых (значений изменчивостей z-, y-переменных из матриц Z_{m8},Y_{m9}) знаний о «весах» (из C_{99}) и z-, y-изменчивостях в модели с 9 z-переменными, 9 y-переменными показала динамики модельных значений неизмеряемых показателей [2-17] проявлений симптомов болезни Паркинсона. Введенные в модель переменные наделены математическими и статистическими свойствами, а параметры постоянны. Они смоделированы в Оптимизационной Задаче и зависят от количеств переменных и от значения индикатора c_{11}=0.53. Как некоррелированные (y-), так коррелированные (z-) изменчивости умножаются на свои «веса» - силы проявления фактора. Получены интересные знания после визуализации.

Самым информативным (дисперсия смысловой переменной disp(λ_1)=3.000 неизмеримо превосходит дисперсию каждой другой смысловой переменной) является смысл(y_1). Смысловое уравнение смысл(y_1)=смысл(z_1*0,5300+ смысл(z_2)*(-0,1835) имеет решение смысл(y_1), зависящее от 2-х известных смыслов смысл(z_1), смысл(z_2), фразы которых приведены выше в исходных данных модели. Суммируя смыслы 3-х фраз и подтверждая 3 фразы смысловыми и числовыми данными, относящими к их смысловому уравнению смысл(y_1)=смысл(z_1*0,5300+ смысл(z_2)*(-0,1835)+ смысл(z_3)*0,0000, имеем смысл(y_1)=««случайное проявление (с изменчивостью disp(λ_1)=3.000) симптомов болезни Паркинсона у людей «с тревожностью» (с силой c^2_{11}=0,5300)^2 дают неслучайное (обусловленное проделанными медицинскими лечебными мероприятиями в рамках проекта[1]) случайное проявление убывающих симптомов депрессии» (с силой c^2_{21}=(-0,1835)^2). Результат проекта - проявление *убывающих* симптомов депрессии» у людей (с силой c^2_{21}=(-0,1835)^2) численно оценивает проект, а наша когнитивная модель извлекла скрытые знания из исходных данных.

Изложенную структуру ситуаций, в которых модель познала неизвестные скрытые знания, можно применить для субъектов (профессор, студент), если изменить исходные данные –z-ситуации для учителя заменить на z-ситуации, присущие университетам.

Ригинальные решения при формализации симптомов болезней требуют практического воплощения в медицинских, фармацевтических проектах.

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