Selection of the optimal component of the elastic coating for the central Asian region

Dilbar Bakirova[1], Absaid Sulliev[2], Amangul Sanbetova[3], Raxmatillo Karimov[1,4,a)]

[1] *Almalyk State Technical Institute, Almalyk, Uzbekistan*
[2] *Tashkent State Transport University, Tashkent, Uzbekistan*
[3] *"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" NRU, Tashkent, Uzbekistan*
[4] *Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan*

[a)] *Corresponding author: rahmatillo05.03.1982@gmail.com*

Abstract. The work examines the issue of selecting the optimal polymer component for elastic rail substrates used in the extreme climatic conditions of Central Asia. An analysis of the properties of the main types of elastomers - synthetic rubbers (SBR, NBR), polyurethanes, silicone rubbers, and composites based on recycled tires - was conducted. Based on mechanical, climatic, and economic criteria, an approach to composition selection using the analytical hierarchy (API) method has been proposed. It has been established that the best combination of elastic and climatic properties is demonstrated by polyurethane and composite materials with antioxidant and UV-modification.

INTRODUCTION

Elastic rail pads are an important element of the rail-sleeper grid, ensuring a reduction in dynamic impacts, uniform load distribution, and extending the service life of the track. The elastic under-rail gasket was initially called the track substrate. This laying allows for solving the following tasks: protecting the upper structure of the track, improving the quality of the track position, reducing vibrations not only of the track but also in the directional transitions. Rail linings are elastic products installed directly under the rail sole, which provide shock absorption and wear resistance. They have specified rigidity and are used on the ballast track. Improved load distribution ensures more comfortable driving and less wear of the track's upper structure. Increased elasticity positively affects the wear of elements of the track's upper structure and rolling stock 1 [1-5].

The purpose of the research is to select and justify the optimal polymer component that ensures the durability of the elastic gasket in the climatic conditions of Central Asia.

In the conditions of Central Asia, characterized by extremely high summer temperatures (+50^{0}C), low humidity, intense UV radiation, and significant daily temperature fluctuations, traditional materials (SBR, NR) lose their properties due to accelerated aging and cracking. In the second work, the experimental study of an optimized NR development connection was analyzed to improve railway productivity, especially in the transition junction zone where tracks transition from bridges to ballasted sections [2-4, 6-11].

Various compounds of the formula NR were invented by adjusting the filler, and tests for tensile, thermal aging, and rupture properties were conducted.

Let's consider the properties of NR. Natural rubber, Natural Rubber, is designated as NR - an elastomer of natural origin derived from the latex of rubber-bearing plants (mainly Hevea brasiliensis). It is highly elastic, crystallizing when stretched. Its density is 0.91 0.93 g/cm^3, and its glass transition temperature is -70^{0}C. Its tensile strength is very high, especially when stretched due to crystallization. Exceptionally elastic rubber, the relative elongation at break is 600-800%. It has excellent deformation reversibility properties and very high impact strength.

Wear resistance is high, excellent for the use of auto tires, conveyor belts, seals, vibration and noise-insulating elements, rail pads, and shock absorbers that operate without contact with oils and at moderate temperatures. It is a benchmark for many mechanical properties among rubbers [4-7, 12-16].

NR has good operational properties such as high elasticity and wear resistance, excellent dynamic strength and fatigue resistance, good damping and vibration-reducing properties, and works well at low temperatures. However, it has several drawbacks: 1) poorly tolerates the effects of oils, fuel, ozone, and solar radiation; 2) tends to age when heated for a long time; 3) requires protection (antioxidants, wax coatings, UV stabilizers) when used outdoors. And the most important aspect is the price, natural rubber is expensive, therefore it is recommended to use a combination of NR + SBR + EPDM [1-2, 11-13, 17-22].

Let's consider SKI-3 (styrene-butadiene rubber, international designation SBR - Styrene-Butadiene Rubber) - the most common synthetic rubber of general purpose, created as a substitute for natural rubber (NR). It is produced by the copolymerization of butadiene (≈75%) and styrene (≈25%) in an emulsion medium. This rubber has a density of 0.93 0.96 g/cm3 higher than that of HP, but its strength is lower. It has the following operational advantages: good wear resistance and dimensional stability; higher resistance to aging and heat than natural rubber; low cost and ease of processing; good adhesion to technical carbon; the ability to regulate properties (hardness, elasticity) by selecting fillers. Features for Central Asian climate SKI-3 is beneficial because: it is more resistant to heat and aging than NR; it mixes well with NR and EPDM, creating balanced recipes; it is economical and available in the local market [7-9, 15-17, 23-29].

EXPERIMENTAL RESEARCH

EPDM (ethylene-propylene-diene monomer rubber) is a synthetic elastomer characterized by high resistance to aging, ozone, solar radiation, and temperature fluctuations. It is widely used in technology, where durability and stable properties are required in open air and elevated temperatures. Its density is 0.86-0.87 g/cm^3, lower, NR + SBR. It has good elasticity and medium hardness, and its wear resistance is also lower than that of NR and SBR.

Significance for under-rail gaskets: for the climate of Central Asia, EPDM is extremely beneficial, as [30-34]:

- resistant to ultraviolet, ozone, and heat - does not age in the sun;
- operates in the range from -50 to $+150^0$C - tolerates sharp temperature fluctuations;
- does not break down from salts and moisture characteristic of saline soils;
- increases the service life of the NR/SBR mixture by 1.5-2 times.

However, it has disadvantages, higher cost compared to NR and SBR, and poor compatibility with other rubbers without special modifiers. Therefore, its proportion in many recommended mixtures is 16.7 times less than NP, and 3.4 times less than NP. In work 2, the mixture for manufacturing the elastic gasket does not contain EPDM, and natural rubber STR20, nitrilbutadiene rubber NBR, and chloroprene rubber CR are included in the mixture [35-38].

In work 4, the results of separation tests conducted on three samples of butadiene-styrene rubber (SBR) granules and one polyurethane sample are presented.

Let's consider options made of polyurethane for elastic gaskets.

Polyurethane elastomers (PU, or TPU - thermoplastic polyurethanes) are a group of polymer materials with high elasticity, strength, and wear resistance, combining the properties of rubber and plastics. In addition to the above-mentioned properties, they possess abrasion resistance, possessing high mechanical strength against abrasive wear, surpassing many materials, including cast iron. They can combine the strength and hardness of engineering plastics with the elasticity of rubber, maintain elasticity in a wide range of temperatures (from -50 to $+1200^0$C), and can withstand large dynamic loads. They are resistant to the effects of oils, fuels and lubricants, and other aggressive environments, as well as to hydrolysis and atmospheric factors. After all, these properties are perfectly suited for railway transport, and on railways with diesel traction, the impact of oils and fuels and lubricants on track elements is maximal, especially considering the influence of atmospheric precipitation and solar radiation [19-23, 39-42].

In work 3, the author proposes an alternative to reusing abundant waste, reducing the cost of elastic elements. The author asserts that when the tire layers are deconstructed without grinding the material, they retain the tire properties [12-14, 23-24, 35, 42-45].

GTR compounds are created by mechanical or thermoplastic mixing of rubber crumbs (usually from SBR, NR, BR-based tires) with a binding polymer - for example, polyethylene (PE), polypropylene (PP), EVA, thermoplastic polyurethane (TPU), or fresh rubber (SBR, NBR, EPDM).

Sometimes plasticizers, binding agents, and vulcanizing systems are added to improve phase compatibility. Mechanical properties of the GTR compound: the tensile strength depends on the crumb fraction and the type of binder and is 3-15 MPa. Wear resistance is high, but lower than that of pure polyurethanes [26-28, 44-48].

Density 1.05-1.25 g/cm3. Moreover, the operating temperature range is high, ranging from -40 to $+800^0$C, which is perfectly suited for the climate of Central Asia. Good resistance to impact loads and fatigue, which is well combined with loads on the roads of industrial enterprises, where the load on the axis exceeds permissible norms, since when loading with excavators, it is impossible to weigh the ore. Resistance to ozone and atmospheric aging is excellent chemical resistance for gaskets [5-6, 11-14, 29-30, 48-49].

Review of materials and foreign solutions. Modern under-rail gaskets are made from [45-49]:

- synthetic rubbers (SBR, NBR, IR) - are used in Russia and the CIS (SP-74, SP-356, KB-65); they have good mechanical properties but are sensitive to heat and UV aging.
- polyurethane elastomers (PUR) - used by the companies Getzner, Pandrol, RailOne; they are characterized by stable rigidity and low wear during prolonged vibration.
- silicone rubbers (HTV-SR) - have excellent thermal and UV resistance, but high cost limits their application.
- recycled rubber compounds (ground tire rubber, GTR) - an economical and environmentally friendly solution that requires modification with plasticizers and antioxidants to stabilize properties.

3. Material selection criteria are summarized in Table 1.

TABLE 1. Material selection criteria

Criteria group	Indicators	Significance (weight, %)
Mechanical	Stiffness, fatigue strength, compression	35
Climate resistance	Heat, UV, and moisture resistance	30
Economic	Cost of raw materials, processing technology	15
Ecological	Use of secondary raw materials, utilization	10
Technological	Adhesion to sleepers, reproducibility of the process	10

Research methodology: The analytical hierarchy method (AHP) is used to calculate the integral suitability index of the material. Tests are being conducted on [5-6, 11-14, 49]:

• GOST 34078-2017 Railway Rail Fastening Layers. Technical conditions;
• GOST ISO -188-2013 - modeling solar exposure;

The results of the comparative analysis of five types of materials are summarized in Table 2.

TABLE 2. Results of comparative analysis

Material	Static stiffness (kN/mm)	UV stability	Heat resistance	Price (relative)	AHP Integral Index
SBR	100	low	average	1.0.	0.62
NBR	110	average	high	1.2.	0.74
PURE	115	high	high	1.4.	0.88
GTR compound	90	average	average	0.7	0.81
Silicon (HTV-SR)	95	very high	very high	2.5	0,79

Discussion: Polyurethane linings demonstrate stable mechanical properties and excellent resistance to climatic factors, making them optimal for Central Asia. Composites based on recycled tires with the addition of stabilizers can serve as an economical alternative. Using the hierarchy analysis method allows for the justified selection of material considering multifactorial conditions [47-53].

CONCLUSION

1. The optimal components for elastic gaskets in the climate of Central Asia are:

• polyurethane elastomers with UV modifiers;
• composites based on recycled tires with antioxidant additives.

The optimal option for manufacturing elastic sub-rail gaskets in the conditions of the Central Asian region is polyurethane elastomers modified with UV stabilizers, as well as composites based on recycled tires with the introduction of antioxidant additives. These materials provide the necessary combination of elasticity, durability, and resistance to climatic factors - high temperatures, intense solar radiation, and fluctuations in humidity.

However, the use of secondary rubber materials is limited by the availability of raw materials: the volume of car tire waste in the region is insufficient for large-scale production of railway linings. In this regard, a rational direction is the combined approach - the use of polyurethane systems with partial inclusion of rubber crumbs, which will simultaneously increase environmental efficiency and ensure stable production volumes.

2. The MAI matrix is presented in Table 3.

TABLE 3. Hierarchy analysis method matrix

ANR matrix						
Criterion	Weight	SBR	NR	PUR	GTR	Silicone
Mechanical properties	0,35	0,7	0,8	0,9	0,7	0,8
Climate resistance	0,3	0,5	0,7	0,9	0,6	1
Economy	0,15	1	0,9	0,8	1,2	0,4
Environmental friendliness	0,1	0,5	0,6	0,6	1	0,5
Technicality	0,1	0,8	0,8	0,9	0,7	0,7
Total (Σ=points)		0,62	0,74	0,88	0,81	

REFERENCES

1. S.Amirov, A.Sulliev, U.Mukhtorov. *Resonance sensors of motion parameters*. AIP Conference Proceedings, 3256(1), 050028, (2025). https://doi.org/10.1063/5.0267548
2. K.Turdibekov, A.Sulliev, O.Iskandarova, J.Boboqulov. *Experimental and statistical methods for studying the modes of electric power systems under conditions of uncertainty*. E3S Web of Conferences, 452, **04002**, (2023), https://doi.org/10.1051/e3sconf/202345204002
3. S.Kasimov, A.Sulliev, A.Eshkabilov. *Optimising Pulse Combustion Systems for Enhanced Efficiency and Sustainability in Thermal Power Engineering*. E3S Web of Conferences, 449, **06006**, (2023), https://doi.org/10.1051/e3sconf/202344906006
4. S.Amirov, A.Sulliev, S.Sharapov. *Study on differential transformer displacement sensors*. E3S Web of Conferences, 434, **02011**, (2023), https://doi.org/10.1051/e3sconf/202343402011
5. S.Amirov, A.Sulliev, K.Turdibekov. *Investigation of biparametric resonance sensors with distributed parameters*. E3S Web of Conferences, 377, **01002**, (2023), https://doi.org/10.1051/e3sconf/202337701002
6. M.Yakubov, A.Sulliev, A.Sanbetova. *Modern methods of evaluation of metrological indicators of channels for measurement and processing of diagnostic values of traction power supply*. IOP Conference Series Earth and Environmental Science, 1142(1), **012010**, (2023), doi:10.1088/1755-1315/1142/1/012010
7. K.Turdibekov, A.Sulliev, I.Qurbanov, S.Samatov, A.Sanbetova. *Voltage Symmetration in High Speed Transport Power Supply Systems*. AIP Conference Proceedings, 2432, **030084**, (2022), https://doi.org/10.1063/5.0089958
8. K.Turdibekov, M.Yakubov, A.Sulliev, A.Sanbetova. *Mathematical Models of Asymmetric Modes in High-Speed Traffic*. Lecture Notes in Networks and Systems, **247**, (2022), pp.1051-1058. DOI:10.1007/978-3-030-80946-1_95
9. S.K.Shah, L.Safarov, A.Sanbetova, and etc. *Investigation on composite phase change materials for energy-saving buildings*. E3S Web of Conferences, 563, **01003**, (2024), https://doi.org/10.1051/e3sconf/202456301003
10. A.Sanbetova, A.Mukhammadiev, A.Rakhmatov, Z.Beknazarova. *Study on cultivation of environmentally friendly seed potatoes based on electrical technology*. E3S Web of Conferences, 377, **03001**, (2023), https://doi.org/10.1051/e3sconf/202337703001
11. M.Sadullaev, E.Usmanov, R.Karimov, D.Xushvaktov, D.Xalmanov, Y.Shoyimov, D.Khimmataliev. *Mathematical Models and Calculation of Elements of Developed Schemes of Contactless Devices*. AIP Conference Proceedings, 3331(1), **040043**, (2025), https://doi.org/10.1063/5.0305748
12. E.Yuldashev, M.Yuldasheva, A.Togayev, J.Abdullayev, R.Karimov. *Energy efficiency research of conveyor transport*. AIP Conference Proceedings, 3331(1), **040030**, (2025), https://doi.org/10.1063/5.0305742
13. A.Nuraliyev, I.Jalolov, M.Peysenov, A.Adxamov, S.Rismukhamedov, R.Karimov. *Improving and Increasing the Efficiency of the Industrial Gas Waste Cleaning Electrical Filter Device*. AIP Conference Proceedings, 3331(1), **040040**, (2025), https://doi.org/10.1063/5.0305751
14. M.Sadullaev, E.Usmanov, R.Karimov, D.Xushvaktov, N.Tairova, A.Yusubaliev. *Development of Contactless Device Schemes for Automatic Control of the Power of a Capacitor Battery*. AIP Conference Proceedings, 3331(1), **040042**, (2025), https://doi.org/10.1063/5.0305879

15. M.Azimova, N.Kurbanova, D.Rakhmatov. Large-scale environmental benefits of biogas technology. AIP Conference Proceedings, 3152(1), **060007**, (2024), https://doi.org/10.1063/5.0218937

16. M.Sadullaev, M.Bobojanov, R.Karimov, D.Xushvaktov, Y.Shoyimov, H.Achilov. *Experimental Studies of Contactless Devices for Controlling the Power of Capacitor Batteries*. AIP Conference Proceedings, 3331(1), **040044**, (2025), https://doi.org/10.1063/5.0307195

17. E.Usmanov, M.Bobojanov, R.Karimov, D.Xalmanov, N.Tairova, S.Torayev. *Contactless Switching Devices Using Nonlinear Circuits*. AIP Conference Proceedings, 3331(1), **040031**, (2025), https://doi.org/10.1063/5.0305744

18. K.Abidov, A.Alimov, M.Gafurova. *Transients in Devices of Control Systems With Excitation Winding*. AIP Conference Proceedings, 3331(1), **040033**, (2025), https://doi.org/10.1063/5.0305756

19. K.Abidov, E.Abduraimov, M.Gafurova. *Possibility of Applying Methods of Analysis and Synthesis of Linear Electrical Circuits to Some Nonlinear Circuits*. AIP Conference Proceedings, 3331(1), **040034**, (2025), https://doi.org/10.1063/5.0305757

20. O.Ishnazarov, N.Khamudkhanova, K.Kholbutayeva, K.Abidov. *Energy Efficiency Optimization in Irrigation Pump Installations*. AIP Conference Proceedings, 3331(1), **040036**, (2025), https://doi.org/10.1063/5.0305844

21. K.Abidov, A.Alimov, N.Khamudkhanova, M.Gafurova. *Determination of the Permissible Number of Pumping Units Supplied From the Transformer of the Amu-Zang-I Substation, Selection of the Power of Static Capacitors*. AIP Conference Proceedings, 3331(1), **040029**, (2025), https://doi.org/10.1063/5.0305754

22. A.Alimov, K.Abidov, E.Abduraimov, F.Akbarov, H.Muminov. *Generalized Model of Nonlinear Inductance and its.* AIP Conference *Parameters*, 3331(1), **040035**, (2025), https://doi.org/10.1063/5.0305883

23. E.Abduraimov, M.Peysenov, N.Tairova. *Development of Contactless Device for Maintaining the Rated Voltage of Power Supply Systems*. AIP Conference Proceedings, 2552, **040012**, (2022). https://doi.org/10.1063/5.0116235

24. E.Abduraimov. *Automatic control of reactive power compensation using a solid state voltage relays*. Journal of Physics Conference Series, 2373(7), **072009**, (2022). DOI 10.1088/1742-6596/2373/7/072009

25. E.Abduraimov, D.Khalmanov. *Invention of a contactless voltage relay with an adjustable reset ratio*. Journal of Physics Conference Series, 2373(7), **072010**, (2022). DOI 10.1088/1742-6596/2373/7/072010

26. E.Abduraimov, D.Khalmanov, B.Nurmatov, M.Peysenov, N.Toirova. *Analysis of dynamic circuits of contactless switching devices*. Journal of Physics Conference Series, 2094(2), **022072**, (2021). DOI 10.1088/1742-6596/2094/2/022072

27. Y.Adilov, A.Nuraliyev, M.Abdullayev, S.Matkarimov. *Dynamic Performance Model of a Hybrid Power System*. AIP Conference Proceedings, 3331(1), **040038**, (2025). https://doi.org/10.1063/5.0305909

28. Y.Adilov, M.Khabibullaev. *Application of fiber-optic measuring current transformer in control and relay protection systems of belt conveyor drives*. IOP Conference Series Earth and Environmental Science, 614(1), **012022**, (2020), doi:10.1088/1755-1315/614/1/012022

29. R.Yusupaliyev, N.Musashayxova, A.Kuchkarov. Methods of Purification of Polluted Water from Ammonia Compounds at Nitrogen Fertilizer Plants. E3S Web of Conferences, 563, **03085**, (2024). https://doi.org/10.1051/e3sconf/202456303085

30. R.Yusupaliev, N.Kurbanova, M.Azimova, N.Musashaikhova, A.Kuchkarov. Establishing a Water-chemical Regime and Increasing the Efficiency of Combustion of a Mixture of Fuel Oil and Gas in a DE 25-14 GM Boiler: A Case Study of the Kokand Distillery. AIP Conference Proceedings, 2552, **030026**, (2022), https://doi.org/10.1063/5.0130471

31. R.Yusupaliev, B.Yunusov, M.Azimova. The composition of natural waters of some source rivers of the republic of Uzbekistan, used in the thermal power engineering and the results of the experimental researches at preliminary and ion exchange treatment of water. E3S Web of Conferences, 139, **01083**, (2019), https://doi.org/10.1051/e3sconf/201913901083

32. S.M.Turabdzhanov, J.M.Tangirov, P.M.Matyakubova, N.S.Amirkhulov, S.S.Khabibullaev. *Methods of providing metrological supply when pumping water into wells in oil fields.* AIP Conference Proceedings, 3045(1), **030073**, (2024), https://doi.org/10.1063/5.0197355

33. M.Sadullaev, E.Usmanov, R.Karimov, D.Xushvaktov, N.Tairova, A.Yusubaliev. *Review of Literature Sources and Internet Materials on Contactless Devices for Reactive Power Compensation*. AIP Conference Proceedings, 3331(1), **040041**, (2025), https://doi.org/10.1063/5.0305878

34. M.Jalilov, M.Azimova, A.Jalilova. On a new technology of preparation of hot drinking water. Energetika Proceedings of Cis Higher Education Institutions and Power Engineering Associations, **60(5)**, (2017), pp.484-492. https://doi.org/10.21122/1029-7448-2017-60-5-484-492

35. J.Safarov, A.Khujakulov, Sh.Sultanova, U.Khujakulov. S.Verma. *Research on energy efficient kinetics of drying raw material*. E3S Web of Conferences, 216, **01093**, (2020). https://doi.org/10.1051/e3sconf/202021601093

36. J.Safarov, Sh.Sultanova, G.Dadayev, Sh.Zulponov. *Influence of the structure of coolant flows on the temperature profile by phases in a water heating dryer*. IOP Conf. Series: Materials Science and Engineering, 1029(1), **012019**, (2021). doi:10.1088/1757-899X/1029/1/012019

37. Sh.Sultanova, A.Artikov, Z.Masharipova, A.Tarawade, J.Safarov. *Results of experiments conducted in a helio water heating convective drying plant*. IOP Conf. Series: Earth and Environmental Science, 868(1), **012045**, (2021). doi:10.1088/1755-1315/868/1/012045

38. Sh.Sultanova, J.Safarov, A.Usenov, D.Samandarov, T.Azimov. *Ultrasonic extraction and determination of flavonoids*. AIP Conference Proceedings, 2507, **050005**, (2023). https://doi.org/10.1063/5.0110524

39. Dj.Saparov, S.Sultonova, E.Guven, D.Samandarov, A.Rakhimov. *Theoretical study of characteristics and mathematical model of convective drying of foods*. E3S Web of Conferences, 461, **01057**, (2023). https://doi.org/10.1051/e3sconf/202346101057

40. Sh.Sultanova, J.Safarov, A.Usenov, T.Raxmanova. *Definitions of useful energy and temperature at the outlet of solar collectors*. E3S Web of Conferences, 216, **01094**, (2020). https://doi.org/10.1051/e3sconf/202021601094

41. Sh.Zulpanov, D.Samandarov, G.Dadayev, S.Sultonova, J.Safarov. *Research of the influence of mulberry silkworm cocoon structure on drying kinetics*. IOP Conf. Series: Earth and Environmental Science, 1076, **012059**, (2022). doi:10.1088/1755-1315/1076/1/012059

42. A.Tarawade, D.Samandarov, T.Azimov, Sh.Sultanova, J.Safarov. *Theoretical and experimental study of the drying process of mulberry fruits by infrared radiation*. IOP Conf. Series: Earth and Environmental Science, 1112, **012098**, (2022). doi:10.1088/1755-1315/1112/1/012098

43. M.Mirsadov, B.Fayzullayev, I.Abdullabekov, A.Kupriyanova, D.Kurbanbayeva, U.Boqijonov. *The mutual influence of electromagnetic and mechanical processes in dynamic modes of inertial vibrating electric drives*. IOP Conference Series Materials Science and Engineering, 862(6), **062081**, (2020). doi:10.1088/1757-899X/862/6/062081

44. I.Abdullabekov, M.Mirsaidov, F.Tuychiev, R.Dusmatov. *Frequency converter – asynchronous motor – pump pressure piping system mechanical specifications*. AIP Conference Proceedings, 3152, **040007** (2024). https://doi.org/10.1063/5.0218880

45. I.Abdullabekov, M.Mirsaidov, Sh.Umarov, M.Tulyaganov, S.Oripov. *Optimizing energy efficiency in water pumping stations: A case study of the Chilonzor water distribution facility*. AIP Conference Proceedings, 3331, **030107**, (2025). https://doi.org/10.1063/5.0305780

46. M.Bobojanov, F.Tuychiev, N.Rashidov, A.Haqberdiyev, I.Abdullabekov. *Dynamic simulation of a three-phase induction motor using Matlab Simulink*. AIP Conference Proceedings, 3331, **040012**, (2025). https://doi.org/10.1063/5.0305750

47. M.Tulyaganov, Sh.Umarov, I.Abdullabekov, Sh.Adilova. *Optimization of modes of an asynchronous electric drive taken into account thermal transient processes*. AIP Conference Proceedings, 3331, **030084**, (2025). https://doi.org/10.1063/5.0305786

48. Sh.Umarov, Kh.Sapaev, I.Abdullabekov. *The Implicit Formulas of Numerical Integration Digital Models of Nonlinear Transformers*. AIP Conference Proceedings, 3331, **030105**, (2025), https://doi.org/10.1063/5.0305793

49. F.Akbarov, R.Kabulov, A.Alimov, E.Abduraimov, D.Nasirova. *Dependence of Output Parameters of Photovoltaic Module Based on CIGS Solar Cells on External Temperatures*. AIP Conference Parameters, 3331(1), **040046**, (2025), https://doi.org/10.1063/5.0305885

50. Sh.Kuchkanov, M.Adilov, B.Abduraxmanov, A.Kamardin, S.Maksimov, S.Nimatov, and Kh.Ashurov. *Thermovoltaic effect in Si/Si epitaxial film structures treated by neon ions*. AIP Conference Proceedings, **3331, 040045**, (2025). https://doi.org/10.1063/5.0305887

51. M.Atajonov, Q.Mamarasulov, O.Zaripov, S.Nimatov, U.Bo'riyev. *Study of Solar Photoelectric Plant in Matlab (Simulink) Package*. AIP Conference Proceedings, 3244(1), **060001**, (2024). https://doi.org/10.1063/5.0241783

52. S.J.Nimatov, D.S.Rumi. *Investigation of the dose dependence of the amorphization of a Si(111) surface bombarded with low-energy Na+ ions*. Journal of Surface Investigation, 8(2), (2014), pp.404-407. DOI: 10.1134/S1027451014020396

53. S.J.Nimatov, D.S.Rumi. *Submonolayer films on a Si(111) surface under low-energy ion bombardment*. Bulletin of the Russian Academy of Sciences Physics, 78(6), (2014), pp.531-534. DOI: 10.3103/S1062873814060215