ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ
АКАДЕМИЯСЫ» РҚБ

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

ХАБАРЛАРЫ

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
КАЗАХСТАН»

NEWS

OF THE NATIONAL ACADEMY
OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN

SERIES

OF GEOLOGY AND TECHNICAL SCIENCES

2 (470)

MARCH – APRIL 2025

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

«ҚР ҰҒА» РҚБ Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).

Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *Геология, гидрогеология, география, тау-кен ісі, мұнай, газ және металдардың химиялық технологиялары*

Мерзімділігі: жылына 6 рет.

http://www.geolog-technical.kz/index.php/en/

«Известия РОО «НАН РК». Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: *геология, гидрогеология, география, горное дело и химические технологии нефти, газа и металлов*

Периодичность: 6 раз в год.

http://www.geolog-technical.kz/index.php/en/

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, hydrogeology, geography, mining and chemical technologies of oil, gas and metals*
Periodicity: 6 times a year.
http://www.geolog-technical.kz/index.php/en/

NEWS of the National Academy of Sciences of the Republic of Kazakhstan
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 2. Number 470 (2025), 21–41

https://doi.org/10.32014/2025.2518-170X.488

UDC 778.64

Y.A. Altay, B.B. Bazarbay*, B.N. Absadykov, G.K. Berdibaeva, S.A. Kalmaganbetov, 2025.
Kazakh National Research Technical University named after K.I. Satbayev, Almaty, Kazakhstan.
E-mail: b.bazarbay@satbayev.university

METHOD OF IDENTIFYING FACTORS INFLUENCING DEFECT FORMATION IN SELECTIVE LASER MELTING OF HEAT-RESISTANT ALLOY USING ACOUSTIC EMISSION METHOD

Yeldos A. Altay – PhD, Candidate of technical sciences, Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan, e-mail: y.altay@satbayev.university, ORCID ID: 0000-0002-3736-0291;
Bauyrzhan B. Bazarbay – PhD, Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan, e-mail: b.bazarbay@satbayev.university, ORCID ID: 0000-0002-7387-1654;
Bakhyt N. Absadykov – Doctor of Technical Sciences, associate professor, Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan, e-mail: b.absadykov@satbayev.university, b_absadykov@mail.ru, ORCID ID: 0000-0001-7829-0958;
Gulmira K. Berdibaeva – PhD, associate professor, Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan, e-mail: g.berdibayeva@satbayev.university, ORCID ID: 0000-0002-2976-8561;
Sanzhar A. Kalmaganbetov – Master of Technical Sciences, Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan, e-mail: s.kalmaganbetov@satbayev.university, ORCID ID: 0009-0001-9248-4086.

Abstract. *Relevance.* Acoustic emission systems and complexes are currently considered a sensitive method for detecting forming defects. However, defect detection in selective laser melting of heat-resistant alloys using acoustic emission becomes challenging under the influence of noise. The impact of noise significantly complicates the identification of factors influencing the defect formation process, and it also makes it much harder to interpret the parameters of acoustic emission that characterize the state of the object under control. *Objective.* Study of filtering methods in case of extraneous influences to improve the reliability of the results of recording acoustic signals and improve the identification process. *Methods.* This article presents the results of the implementation of the developed method of cascade digital filtering. The method is based on high-frequency digital filters, approximated by a second-order Butterworth polynomial model. Amplitude, time, and frequency fragments of acoustic emission signals, which characterize the defect formation process during the manufacturing of products, are highlighted. A relationship between the measurements of the signal's amplitude parameters, the laser power of the system, and the nitrogen content in the heat-resistant alloy is established. The dependence of the laser power and nitrogen content percentage is approximated using the least squares method and visualized based on a scatter plot. *Results and conclusions.* The developed relationship describes and characterizes the influence of the listed factors on the defect formation process, and its adequacy is confirmed by calculating the coefficients of determination and significance. It is shown that the application of the cascade filtering method for signal identification significantly increases the effectiveness of the acoustic emission method. The developed cascade filtering method can also be applied when studying the acoustic properties and stresses caused by the physical fields of various rocks.

Keywords: acoustic emission, defect formation control, additive manufacturing, direct laser deposition, filtration, laser power, chromium-nickel alloy.

Е.А. Алтай, Б.Б. Базарбай*, Б.Н. Абсадыков, Г.К. Бердибаева, С.А. Калмаганбетов, 2025.

Қ.И. Сәтбаев атындағы Қазақ Ұлттық Техникалық Зерттеу университеті, Алматы, Қазақстан.

E-mail: b.bazarbay@satbayev.university

ЫСТЫҚҚА ТӨЗІМДІ ҚОРЫТПАНЫ ТІКЕЛЕЙ ЛАЗЕРЛІК БАЛҚЫТУ КЕЗІНДЕ АҚАУЛАРДЫҢ ПАЙДА БОЛУЫНА ӘСЕР ЕТЕТІН ФАКТОРЛАРДЫ АКУСТИКАЛЫҚ ЭМИССИЯ ӘДІСІМЕН АНЫҚТАУ

Алтай Ельдос Алтайұлы – PhD, техника ғылымдарының кандадаты, Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті, Алматы, Қазақстан, e-mail: y.altay@satbayev.university, ORCID ID: 0000-0002-3736-0291;

Базарбай Бауыржан Бакытбекұлы – PhD, Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті, Алматы, Қазақстан, e-mail: b.bazarbay@satbayev.university, ORCID ID: 0000-0002-7387-1654;

Абсадыков Бахыт Нарикбаевич – техника ғылымдарының докторы, қауымдастырылған профессор, Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті, Алматы, Қазақстан, e-mail: b.absadykov@satbayev.university, b_absadykov@mail.ru, ORCID ID: 0000-0001-7829-0958;

Бердибаева Гульмира Куанышбаевна – PhD, қауымдастырылған профессор, Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті, Алматы, Қазақстан, e-mail: g.berdibayeva@satbayev.university, ORCID ID: 0000-0002-2976-8561;

Калмаганбетов Санжар Арманулы – Техника ғылымдарының магистрі, Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті, Алматы, Қазақстан, e-mail: s.kalmaganbetov@satbayev.university, ORCID ID: 0009-0001-9248-4086.

Аннотация. *Өзектілігі.* Акустико-эмиссионды жүйелер мен кешендер бүгінгі таңда пайда болатын ақауларды анықтаудың сезімтал әдісі ретінде қарастырылады. Дегенмен, жылуға төзімді қорытпаны таңдамалы лазерлік балқыту кезінде акустикалық эмиссия әдісімен ақауларды анықтау бөгде әсерлердің ықпалынан күрделене түседі. Бөгде әсерлердің ықпалы дефект пайда болуына әсер ететін факторларды анықтауды едәуір қиындататын болса, акустикалық эмиссияны тіркеу кезінде оның параметрлерін интерпретациялау да айтарлықтай қиындық туғызады. *Мақсат.* Акустикалық эмиссия сигналдарын тіркеу нәтижелерінің сенімділігін арттыру және идентификация процесін жақсарту үшін бөгде әсерлер кезінде сүзгілеу әдістерін зерттеу. *Әдістері.* Бұл мақалада каскадтық сандық сүзгілеу әдісін іске асыру нәтижелері қарастырылған. Әдістің негізіне екінші ретті Баттерворстың полиномдық моделімен апроксималанған жоғарғы жиіліктердің сандық сүзгілері алынған. Өнімдер өсіру процесін сипаттайтын акустикалық эмиссия сигналдарының амплитудалық, уақыттық және жиілік фрагменттері бөлінген. Сигналдың амплитудалық параметрлерін өлшеу мен лазер қондырғысының сәулелену қуаты және жылуға төзімді қорытпадағы азот мөлшері арасындағы тәуелділік анықталған. Лазер сәулелену қуаты мен азоттың пайыздық мөлшерінің тәуелділігі ең аз квадраттар әдісімен апроксималанып, скаттограмма негізінде визуализацияланған. *Нәтижелер мен қорытындылар.* Дамыған тәуелділік аталған факторлардың дефект пайда болу процесіне әсерін сипаттап, оны анықтайды, оның сәйкестігі анықтама коэффициенттері мен маңыздылықты есептеу арқылы расталған. Каскадтық сүзгілеу әдісін сигналдарды идентификациялау үшін қолдану акустикалық эмиссия әдісінің тиімділігін айтарлықтай арттыратыны көрсетілген. Дамыған каскадтық сүзгілеу әдісі түрлі тау жыныстарының физикалық өрістері туғызған акустикалық қасиеттер мен кернеулерді зерттеуде де қолданылуы мүмкін.

Түйін сөздер: акустикалық эмиссия, ақаулардың пайда болуын бақылау, аддитивті өндіріс, тікелей лазерлік өсіру, сүзгілеу, лазер қуаты, хром-никель қорытпасы.

Е.А. Алтай, Б.Б. Базарбай*, Б.Н. Абсадыков, Г.К. Бердибаева, С.А. Калмаганбетов, 2025.
Казахский национальный исследовательский технический университет имени К.И. Сатпаева, Алматы, Казахстан.
E-mail: b.bazarbay@satbayev.university

МЕТОД ИДЕНТИФИКАЦИИ ФАКТОРОВ, ВЛИЯЮЩИХ НА ДЕФЕКТООБРАЗОВАНИЕ ПРИ СЕЛЕКТИВНОМ ЛАЗЕРНОМ ПЛАВЛЕНИИ ЖАРОПРОЧНОГО СПЛАВА МЕТОДОМ АКУСТИЧЕСКОЙ ЭМИССИИ

Алтай Ельдос Алтайулы – PhD, Кандидат технических наук, Казахский национальный исследовательский технический университет имени К.И. Сатпаева, Алматы, Казахстан, e-mail: y.altay@satbayev.university, ORCID ID: 0000-0002-3736-0291;

Базарбай Бауыржан Бакытбекулы – PhD, Казахский национальный исследовательский технический университет имени К.И. Сатпаева, Алматы, Казахстан, e-mail: b.bazarbay@satbayev.university, ORCID ID: 0000-0002-7387-1654;
Абсадыков Бахыт Нарикбаевич – доктор технических наук, ассоциированный профессор, Казахский национальный исследовательский технический университет имени К.И. Сатпаева, Алматы, Казахстан, e-mail: b.absadykov@satbayev.university, b_absadykov@mail.ru, ORCID ID: 0000-0001-7829-0958;
Бердибаева Гульмира Куанышбаевна – PhD, ассоциированный профессор, Казахский национальный исследовательский технический университет имени К.И. Сатпаева, Алматы, Казахстан, e-mail: g.berdibayeva@satbayev.university, ORCID ID: 0000-0002-2976-8561;
Калмаганбетов Санжар Арманулы – магистр технических наук, Казахский национальный исследовательский технический университет имени К.И. Сатпаева, Алматы, Казахстан, e-mail: s.kalmaganbetov@satbayev.university, ORCID ID: 0009-0001-9248-4086.

Аннотация. *Актуальность.* Акустико-эмиссионные системы и комплексы на сегодняшний день считаются чувствительным методом обнаружения формирующихся дефектов. Однако обнаружение дефектов при селективном лазерном плавлении жаропрочного сплава методом акустической эмиссии становится сложным при влиянии помех. Влияние помех существенно усложняет идентификацию факторов, влияющих на процесс дефектообразования, а также при регистрации акустической эмиссии существенно затрудняет интерпретацию ее параметров, характеризующих состояние объекта контроля. *Цель.* Изучение методов фильтрации при посторонних воздействиях для повышения достоверности результатов регистрации акустических сигналов и улучшения процесса идентификации. *Методы.* В данной статье рассмотрены результаты реализации разработанного метода каскадной цифровой фильтрации. В основу метода положены цифровые фильтры верхних частот, аппроксимированные полиномиальной моделью Баттерворта второго порядка. Выделены амплитудные, временные и частотные фрагменты акустических сигналов эмиссии, характеризующие процесс дефектообразования при выращивании изделий. Установлена зависимость между измерениями амплитудных параметров сигнала и мощностью излучения лазера установки, и содержанием азота в жаропрочном сплаве. Зависимость мощности излучения лазера и процентным содержанием азота аппроксимирована методом наименьших квадратов и визуализирована на основе скатрограммы. *Результаты и выводы.* Разработаная зависимость описывает и характеризует влияние перечисленных факторов на процесс дефектообразования, адекватность которой подтверждена вычислением коэффициентов детерминации и значимости. Показано, что применение метода каскадной фильтрации для идентификации сигналов существенно повышает результативность метода акустической эмиссии. Разработанный метод каскадной фильтрации также может быть применен при изучении акустических свойств и напряжений, вызванных физическими полями различных пород.

Ключевые слова: акустическая эмиссия, контроль дефектообразования, аддитивное производство, прямое лазерное выращивание, фильтрация, мощность лазера, хром-никелевый сплав.

Introduction. With the development of additive manufacturing (AM), there is an increasing need to apply control methods for products manufactured using additive technologies (AT) at all stages of their life cycle (Kovalevich, 2023; Kaplan, 2018). This is due to the fact that the reliability and operational characteristics depend on the presence of structural inhomogeneities and imperfections in products made using AT (Kovalevich, 2023). The main types of defects in metallic products produced by AT include cracks, porosity, lack of fusion, non-metallic inclusions, local and general layer displacement, and excessive roughness. For metallic AM products, cracks and porosity are the most critical since they can lead to product failure under operational loads. The occurrence of these types of defects is especially characteristic of direct laser growth (DLG).

DLG is one of the promising methods of AM. Its distinctive feature is the manufacturing of products and prototypes from various materials (Litunov, 2016). The essence of the DLG method lies in the layer-by-layer sequential melting of metal powder using laser radiation (Litunov, 2016). Various spherical metal powders based on zinc, bronze, steel, titanium, chromium, nickel, etc., are used as cladding materials (Litunov, 2016; Wei, 2022). It is essential to emphasize that both the properties of the powder material and the characteristics of the DLG process affect the product quality and defect formation (Yang, 2022; Popkova, 2015; Smirnov, 2018; Kaplan, 2018): the technological properties of the powder material and the technological parameters of DLG, primarily laser energy, laser beam scanning speed, and platform temperature used for DLG.

It has been established that in DLG, the power of laser radiation contributes significantly to the selective melting of metal powders (Popkova, 2015; Kaplan, 2018). Therefore, the main factors determining the quality of DLG products are laser radiation power, powder properties, and laser path speed (Kaplan, 2018). It should also be noted that the laser radiation power at various stages of DLG directly affects the state of the metal powder melt and the solidification of the molten metal, which has a significant impact on the type and size of the defects formed, whose characteristics may also depend on the technological properties of the metal powders (Yang, 2022; Barat, 2019; Altay, 2022; Absadykov, 2022). Heat-resistant chrome-nickel alloys, such as EP648, EP74, (Yang, 2022; Chernova, 2017; Rastegaeva, 2018) are the most widely used for manufacturing products. According to numerous studies (Yang, 2022; Barat, 2019; Altay, 2022; Chernova, 2017; Rastegaeva, 2018), these alloys differ in fractional composition, the mass fraction of chemical elements, particle morphology, and other characteristics. Selecting the most suitable metal powder in terms of corrosion resistance, heat resistance, plasticity, and particle morphology (not exceeding 50 μm (Smirnov, 2018; Chernova, 2017; Rastegaeva, 2022) for AM products using the DLG method is a non-trivial task. Despite the identified features of AM product manufacturing, it is crucial to choose a heat-resistant metal powder for a specific task, and non-destructive monitoring of defect formation in growing products is a relevant and important issue that requires a comprehensive approach.

Studies (Kovalevich, 2023; Kaplan, 2018; Smirnov, 2018; Smirnov, 2019) have proposed acoustic and optical methods to control the defect formation process in tested products. The most promising method for monitoring internal defects, namely crack formation and porosity occurring during the layer-by-layer melting of powder material, is the acoustic emission (AE) method, which is sensitive to internal structural rearrangements in product materials during manufacturing (Smirnov, 2018; Smirnov, 2019).

The optical method for monitoring the defect formation process is also considered promising and especially important for detecting surface and subsurface defects in manufactured products. Therefore, experimental studies aimed at investigating the defect formation process in AM products using the AE method are relevant and promising for ensuring non-destructive testing.

The practical application of the AE method is complicated by the inevitable influence of noise (Tempelman, 2022) on the informative component of AE signals (Pandiyan, 2021), which significantly reduces the signal-to-noise ratio and complicates the search for associations between AE parameters and AE sources (Rastegaev, 2018). To overcome this challenge, this article justifies the application of a previously developed polynomial digital filtering method for AE signals based on a high-pass filter (HPF) (Pandiyan, 2021; Makhutov, 2020), approximated by a second-degree Butterworth polynomial (n = 2). This method ensures stable filtering of real AE signals with the required filter quality indicators (transient time, overshoot, gain coefficient) (Pandiyan, 2021), confirmed by the placement of root loci (zeros and poles) within the unit circle on the right side of the complex plane.

The choice of this method is justified by the possibility of high-precision filtering with minimal distortion of the informative component of the AE signal shape (Rastegaev, 2018), as well as its resistance to noise interference (Pandiyan, 2021; Rastegaev, 2018; Makhutov, 2020) when presenting filtered signals in the frequency-time domain.

One of the ways to present the results of AE data processing after filtering is frequency-time signal analysis (Tempelman, 2022). The need for frequency-time analysis (Frolov, 2015) methods arises from the ability to visualize high-frequency components of AE signals over time and low-frequency components by frequency. Fourier, wavelet, and Hilbert-Huang transformations are widely used for frequency-time processing of AE signals (Frolov, 2015). These methods are analytically interconnected (Frolov, 2015), but depend on the properties of the analyzed signal.

For example, wavelet transformation allows the analysis of nonlinear and non-stationary segments of signals (Frolov, 2015) and their representation in the form of wavelet scalograms, the use of which expands the visualization capabilities of AE control data (Tempelman, 2022; Frolov, 2015). Therefore, in this study, wavelet scalograms are used to present AE signal processing results in the frequency-time domain.

This study presents the results of AE monitoring of pore and crack formation processes in products during their DLG using polynomial cascade filtering of registered noisy AE signals followed by frequency-time analysis. The study also provides a statistical assessment of the influence of various DLG modes and the composition of alloy powder on defect formation.

The goal of the research is to improve the effectiveness of processing and analyzing AE signals in defect formation control through the application of polynomial digital filtering, as well as to develop a model of the influence of selected factors on the diagnostic parameter of AE.

A statistical model characterizing the influence of various laser radiation power modes and the chemical composition of spherical EP648 alloy powder was developed using regression analysis (Isametova, 2022 a). The choice is due to the operability and high sensitivity of this method to the analyzed control data (Frolov, 2015), as well as the absence of requirements for special training of samples obtained during control.

Methods and materials.

Technological properties of powders used in AM. In the production of AM products operated under high-temperature conditions, heat-resistant chrome-nickel alloys are widely used (Yang, 2022; Barat, 2019; Rastegaeva, 2022; Frolov, 2015). Based on the analysis of studies (Frolov, 2015; Isametova, 2022 b), the main characteristics of the alloys were identified using the methods presented in Fig. 1.

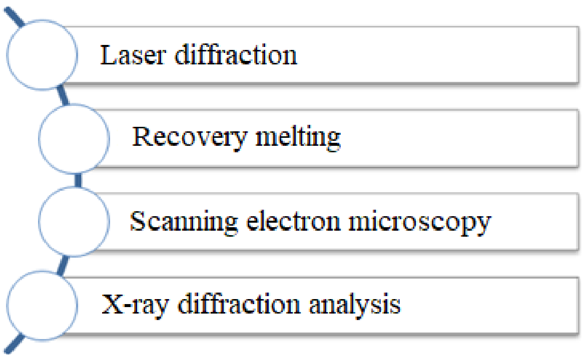


Fig. 1. Methods for assessing the technological properties of alloys

As a result of the analysis of the technological properties of various heat-resistant alloys (Yang, 2022; Chernova, 2017; Rastegaeva, 2022; Frolov, 2015), it was established that the powder samples have a single-phase austenitic structure with a face-centered cubic crystal lattice due to the presence of alloying elements: chromium over 18% and nickel — 8%. Due to the content of alloying elements and low oxygen content, the EP648 powder, unlike EP741, is resistant to corrosion, plastic deformation, and high temperatures (Chernova, 2017; Rastegaeva, 2022; Frolov, 2015), which justifies the choice of this particular alloy. The particle size (diameter) of this spherical powder does not exceed 50 μm (Chernova, 2017), which contributes to a narrow particle size distribution (Smirnov, 2018) and reduces the porosity of the manufactured products (Kaplan, 2018). However, the EP648 alloy powder contains nitrogen in the range of 0.109 to 0.111%, which may contribute to the formation of cracks in the finished product (Rastegaeva, 2022), a factor that must also be considered when manufacturing products using the DLG method. The influence of the composition of spherical alloy powders on manufactured products was also noted in studies. For the subsequent stages of the research, the choice of EP648 (due to the nitrogen content) as a predictor affecting the crack formation process is substantiated. Thus, the analysis of studies (Yang, 2022; Barat, 2019; Rastegaeva, 202; Frolov, 2015) devoted to the evaluation of chrome-nickel alloys showed that the most corrosion-resistant, ductile, and heat-resistant material is EP648, therefore, this study focuses on it for further research.

Registration and analysis of noisy AE signals. For AE monitoring, the SCAD 16.10 acoustic emission system with a set of AE transducers PK 0.1-0.7 was used as a measuring instrument. DLG was performed using the ILIST-L robotic setup (Frolov, 2015), which consists of a production chamber, a two-axis rotator, a cladding head, a robotic manipulator, a powder preparation and feeding system, and a cladding nozzle. During the layer-by-layer growth of products, AE signals were recorded directly during laser growth.

As part of the experimental studies, five samples in the form of parallelepipeds were grown under different laser radiation power modes/values: 800, 1000, 1200, 1400, and 1600 W. Each sample was grown on an aluminum substrate fixed on the worktable in the production chamber of the ILIST-L robotic setup (Fig. 2) under the cladding head. AE events were recorded sequentially during the growth of each sample. A total of 20 real AE signals were registered throughout the sample growth process.

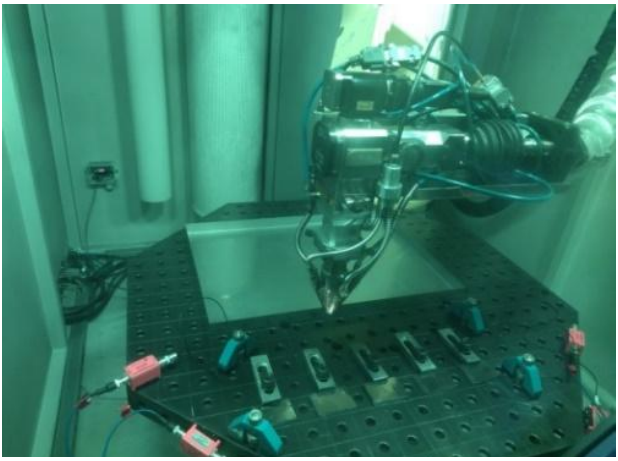
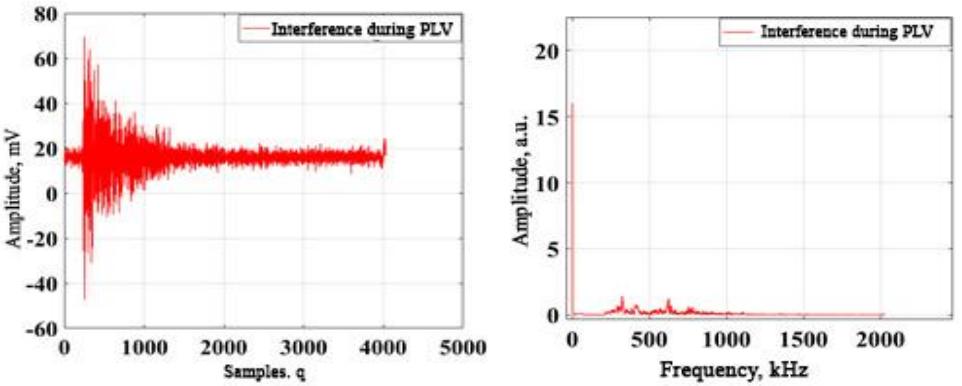


Fig. 2. External view of the experimental setup

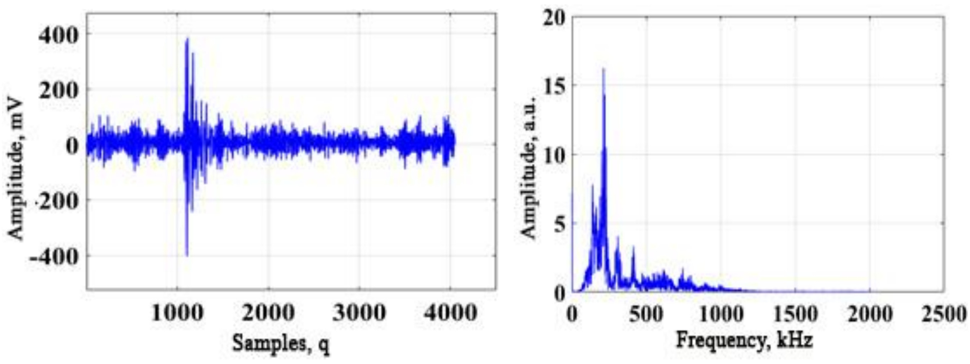
To isolate the informative component from noise, a signal generated by the movement of the robotic manipulator of the DLG setup was recorded in advance (this noise most significantly distorts the informative component). Figure 3 shows the amplitude-time diagram of the noise during DLG (a; q — samples) and its frequency spectrum (b).



a) b)

Fig. 3. Noise generated during DLG: a) time-domain diagram; b) frequency spectrum

Figure 4 illustrates the characteristics of one of the noisy AE signals during DLG (a — before filtering; b — frequency spectrum). A joint analysis of the frequency spectra justified the choice of the filter cutoff frequency for processing and further analysis of AE signals.



a) b)

Fig. 4. AE signal shape during DLG: a) before filtering; b) frequency spectrum

A comparative analysis of the characteristics of the registered signals presented in Figures 3 and 4 revealed that the frequency component above 1000 kHz corresponds to noise, while the component ranging from 90 to 250 kHz is informative. The obtained results of the experimental evaluation of the frequency of the informative signal component and noise are consistent with the findings of the study (Frolov, 2015), which noted that the frequency of signals characterizing the crack formation process can range from 100 to 250 kHz.

According to numerous studies (Tempelman, 2022; Makhutov, 2020; Frolov, 2015), the frequency of AE signals from pore formation is below 100 kHz. This justifies the selection of the lower (up to 100 kHz) and upper (up to 250 kHz) boundaries of the frequency range for tuning two HPFs to isolate AE signals of crack formation, pore formation, and suppress noise at frequencies localized above 250 kHz.

Processing and analysis of AE signals registered during defect formation. AE signal processing was carried out in two stages. Stage 1 included the calculation and analysis of HPF transfer functions, the development of a cascade bidirectional filtering scheme to isolate AE signals from defects, and their visualization in the frequency-time domain. Stage 2 involved the analysis and evaluation of the AE diagnostic parameter characterizing the defect formation process.

Stage 1. The calculated transfer functions of continuous Butterworth HPFs and their bilinear transformation are presented in Table 1.

Table 1. Transfer function of the calculated high-pass filters

Cascade of filters	**Transfer functions of HPF (where HPF stands for High-Pass Filters)**	
	Continuous, W(s)	Discrete, W(z)
HPF at fc = 100 kHz	$\frac{s^2}{s^2+0{,}06364\,s+0{,}002025}$	$\frac{0{,}9687\,z^2-1{,}937\,z+0{,}9687}{z^2-1{,}936\,z+0{,}9384}$
HPF at fc = 250 kHz	$\frac{s^2}{s^2+0{,}1768\,s+0{,}01563}$	$\frac{0{,}9155\,z^2-1{,}831\,z+0{,}9155}{z^2-1{,}824\,z+0{,}8382}$

Note: *s* is the complex variable of the continuous transfer function of the filter; *z* is the complex variable of the discrete transfer function of the filter.

The analysis of quality indicators showed that the digital HPFs, tuned to cutoff frequencies of 100 and 250 kHz, are stable, with a gain coefficient of 0.7 at the cutoff frequencies. The pole roots and zero roots of the calculated filters are localized at the pole loci p1,2 = 0.968 ± 0.0308i for fc = 100 kHz and p1,2 = 0.912 ± 0.080i for fc = 250 kHz, as well as at the zero loci at z = 0.999 ≈ 1. The analysis confirms the localization of the HPF transfer function roots within the unit circle, specifically on the right side of the complex z-plane, and the filters are considered stable for performing cascade filtering of real AE signals.

The cascade bidirectional filtering was implemented in the MatLab software version R2017b according to the block diagram presented in Fig. 5.

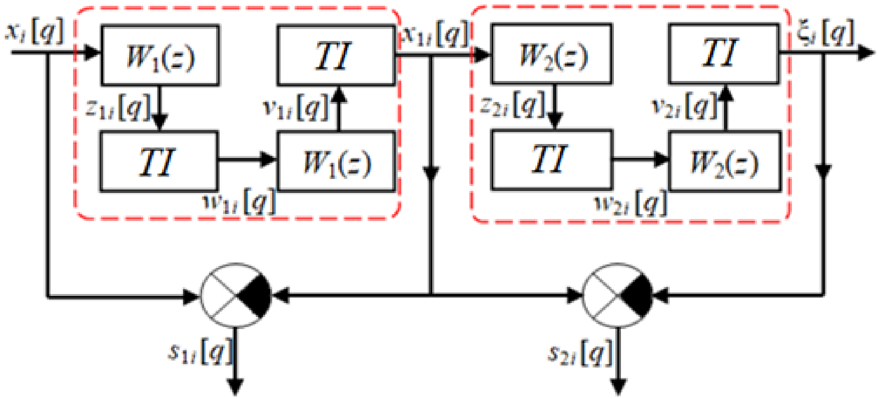


Fig. 5. Block diagram of processing for extracting AE signals from pore formation and crack formation.

According to the developed block diagram, during bidirectional filtering, the input sequence of noisy AE signals *i* is processed by filters $z_{1i}[q]$ and $z_{2i}[q]$ of the first and second sequences in the forward direction. Then, using the time inversion block (TI), the order of samples $w_{1i}[q]$ and $w_{2i}[q]$ of the filtered signals is reversed. The resulting AE signal samples *i* are processed in the reverse direction $v_{1i}[q]$ and $v_{2i}[q]$ using $W_1(z)$ and $W_2(z)$, and the final time inversion at the output of the TI block reverses the order of the samples again. At the TI block output, the distortions introduced by the filters mutually compensate, forming the corresponding signals.

The introduction of the «adder-subtractor» block ensures the formation of defect-specific signals, for example, the signal $s_{1i}[q]$ characterizes the process of pore formation, while $s_{2i}[q]$ corresponds to crack formation. The signals $\xi_i[q]$ represent only high-frequency noise affecting the AE parameter characteristics. The separation of AE signals into $s_{1i}[q]$ and $s_{2i}[q]$ also allows for a quantitative assessment of the ratio of these informative signals to the noise $\xi_i[q]$, similar to the signal-to-noise ratio (SNR) described in (Rastegaev, 2018). The calculated indicators characterize the improvement in signal processing quality at the output of each cascade filter sequence. The result of the SNR evaluation is shown in Fig. 6 as a Tukey diagram, illustrating the increased effectiveness of AE signal processing.

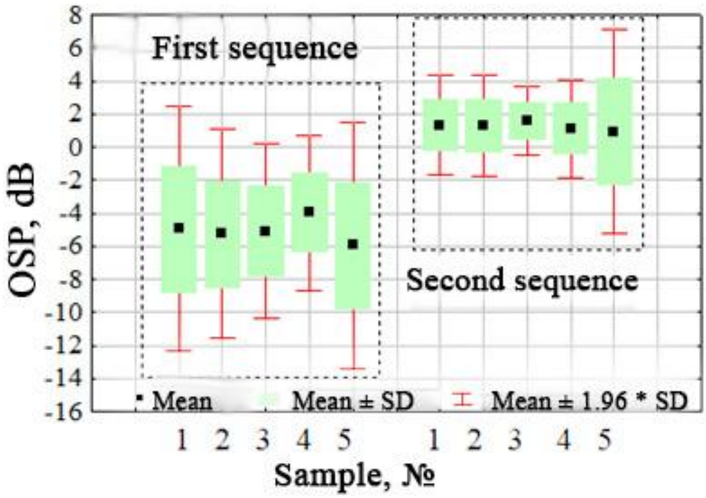


Fig. 6. Diagram of the OSP indicator assessment

Discussion of the results.

The results of cascade filtering showed that the average SNR value at the HPF output increases, confirming the distinguishability of this indicator's values and the improvement in signal processing efficiency. At the same time, the distinguishability of the experimental SNR indicator values at the output of each HPF is confirmed by T-test statistics (Table 2; M — mathematical expectation, SD — standard deviation, p — statistical significance coefficient), where AE control data from defects are presented as groups (first and second sequence).

Table 2. Difference in the OSP indicator values at the output of each sequence in the filter cascade

Sample, №	First sequence M±STD, dB.	Second sequence M±STD, dB.	p - value
1	-4,957±3,779	1,335±1,519	0,034
2	-5,267±3,222	1,298±1,574	0,015
3	-5,093±2,699	1,593±1,058	0,013
4	-3,959±2,396	1,119±1,518	0,007
5	-5,949±3,808	0,938±3,168	0,001

Note:
M – mathematical expectation, STD – standard deviation.
The indicators are statistically significant at $p < 0.1$.

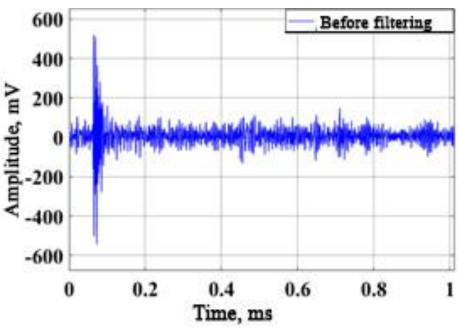
The mean SNR value for each sample, calculated at the output of the first sequence of cascade filters, is statistically significantly different from the mean SNR value of the second sequence. It should be noted that the negative SNR indicator at the output of the first sequence of cascade filters is due to the lower amplitude of the isolated AE signal compared to the amplitude of the noise.

As noted in (Rastegaev, 2018), a negative or low value of the indicator, characterizing noise suppression at the output of the cascade filters for low-amplitude signals of complex form and structure, is explained by the fact that the amplitude of the measured AE signals (Makhutov, 2020) is lower than the amplitude of the noise (Tempelman, 2022). This also confirms the validity of the assessment of this indicator.

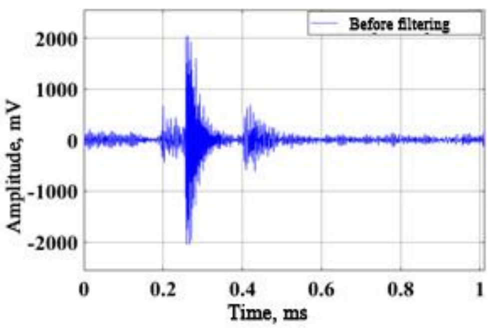
The distinguishability of the maximum amplitude values of AE signals obtained from pores and cracks is clearly visible in Fig. 7 (a–d — Sample № 1; e–k — № 5). The analysis results showed that AE signals from pores (Fig. 7, b and f) and cracks (Fig. 7, c and j) differ in form and characteristics from each other, as well as from the noisy signal (Fig. 7, a and e). At the same time, the maximum amplitude of the signals in Sample № 5 is significantly higher than in Sample № 1. The AE signal shape for all samples is similar to the form of the discrete acoustic emission signal, while the shape of the isolated noise signal (Fig. 7, d and k) contains a mixture of acoustic and continuous noise, which is due to the movement of the robotic manipulator and the effect of laser radiation power at various DLG stages, consistent with the results in (Frolov, 2015).

The analysis of the frequency-time characteristics of the signals shown in Fig. 8 (a–d — Sample № 1; e–k - № 5) demonstrated that at the output of digital filters, AE signals from pore formation (Fig. 8, c and j) and crack formation (Fig. 8, e and k) are identified, where their informative component (Fig. 8, a and d) is ‘masked’ by noise.

The wavelet scalogram of informative AE signals from pores and cracks (Fig. 8, b and f, as well as c and j) differs from the wavelet scalogram of the original signal, as filtering increases processing efficiency. It is worth noting that the frequency-time domains in the noise signal diagrams (Fig. 8, a and d, as well as e and k) coincide. This confirms the correctness of all filtering procedures implemented within the developed cascade bidirectional filtering scheme.



a)



e)

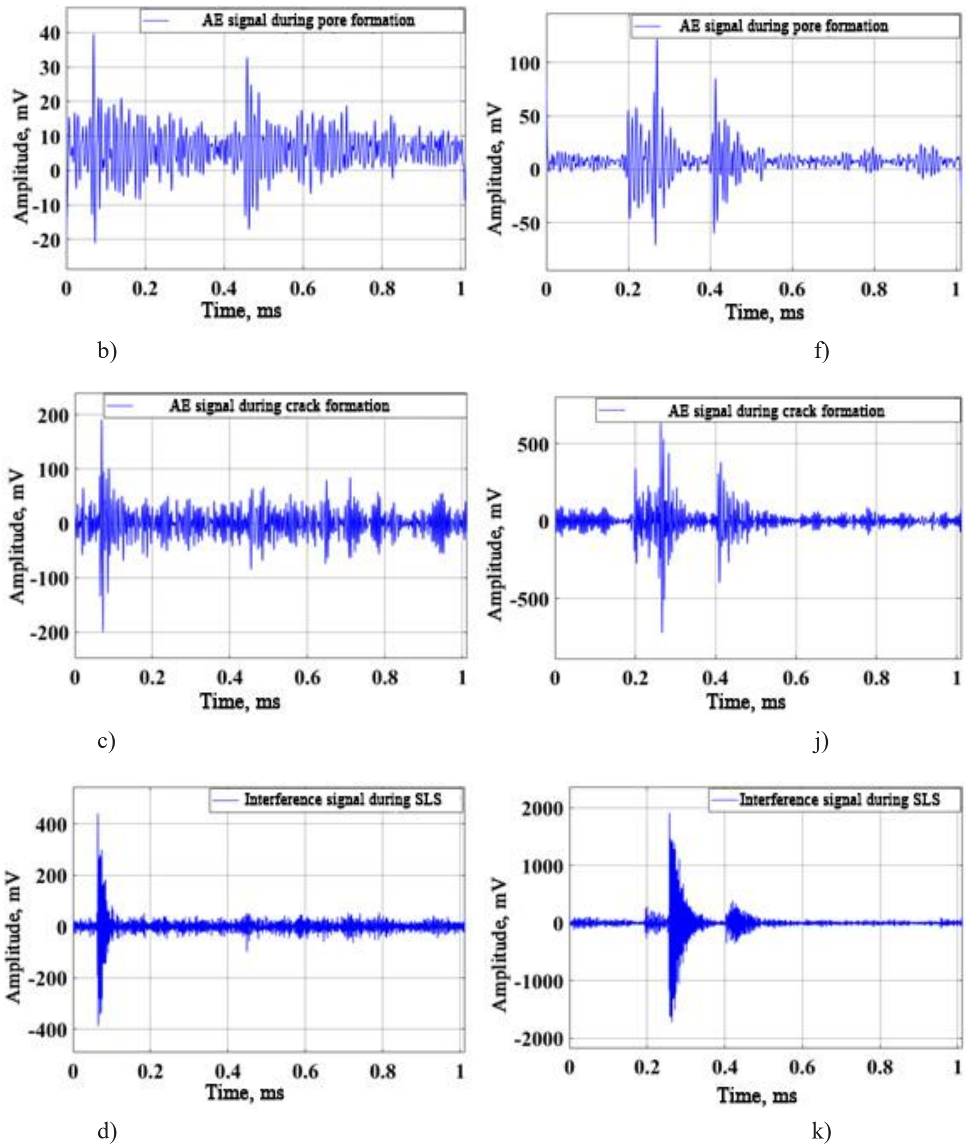


Fig. 7. Amplitude-time characteristic of AE signals:
a) – d) sample №1; e) – k) sample №5.

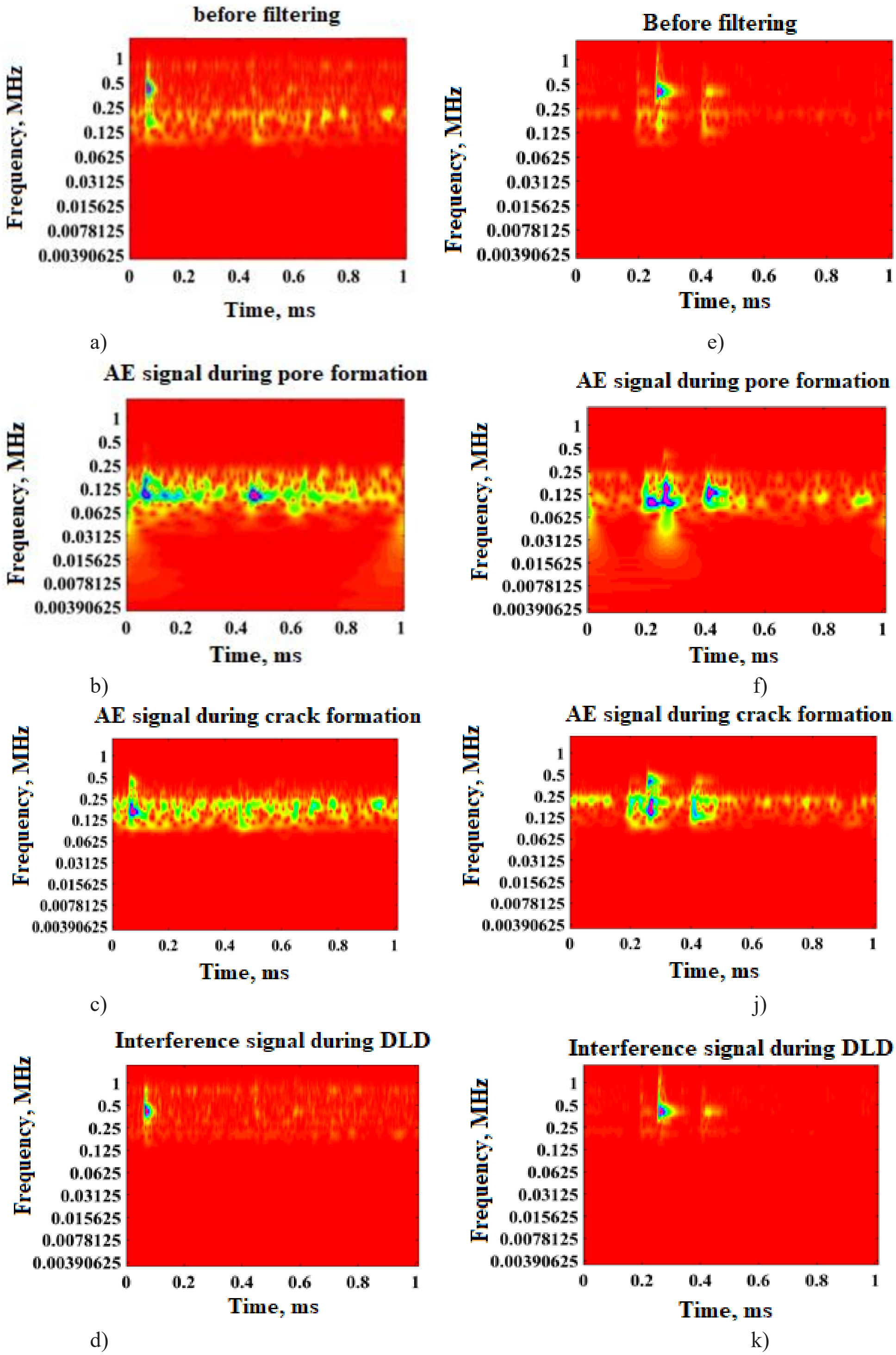


Fig. 8. Time-frequency characteristic of AE signals: a) – d) sample №1; e) – k) sample №5.

Stage 2. At this stage, it was revealed that an increase in DLG laser power in the tested samples leads to a rise in the number of pores and cracks, significantly affecting the AE parameters. This influence is clearly visible in Figures 9 and 10 (a — before processing; b — AE from pore formation; c — AE from crack formation), where the maximum AE amplitude for Sample № 5 (Fig. 10) is considerably higher than for Sample № 1 (Fig. 9). This also demonstrates the distinguishability of AE amplitude when compared with the pre-filtering results (Table 3).

Table 3. Amplitude AE characteristics by channels

Sample	**Before processing** M±STD, mV	**Pore formation** M±STD, mV	**Crack formation** M±STD, mV	**Interference** M±STD, mV
1	2402,000±1217,335 $p = 0{,}029^*$	632,068±467,251 $p = 0{,}073^*$	418,181±292,325 $p = 0{,}064^*$	155,288±695,665 $p = 0{,}020^*$
	$p = 0{,}019^{**}$		$p = 0{,}024^{**}$	$p = 0{,}048^{**}$
2	1712,500±706,873 $p = 0{,}016^*$	467,817±132,935 $p = 0{,}005^*$	422,652±93,120 $p = 0{,}002^*$	993,767±453,865 $p = 0{,}022^*$
	$p = 0{,}024^{**}$		$p = 0{,}026^{**}$	$p = 0{,}011^{**}$
3	2000,750±794,011 $p = 0{,}015^*$	492,749±216,329 $p = 0{,}019^*$	428,969±504,904 $p = 0{,}013^*$	106,367±440,299 $p = 0{,}016^*$
	$p = 0{,}013^{**}$		$p = 0{,}015^{**}$	$p = 0{,}013^{**}$
4	2205,750±995,030 $p = 0{,}021^*$	600,711±101,621 $p = 0{,}001^*$	504,904±116,576 $p = 0{,}003^*$	131,271±586,070 $p = 0{,}020^*$
	$p = 0{,}045^{**}$		$p = 0{,}046^{**}$	$p = 0{,}022^{**}$
5	2433,500±1492,962 $p = 0{,}047^*$	872,869±914,056 $p = 0{,}012^*$	646,229±688,105 $p = 0{,}015^*$	164,222±107,397 $p = 0{,}055^*$
	$p = 0{,}032^{**}$		$p = 0{,}036^{**}$	$p = 0{,}032^{**}$

Note.
* - difference in the average amplitude values between channels,
** - difference in amplitude before and after the implementation of the filtering method.

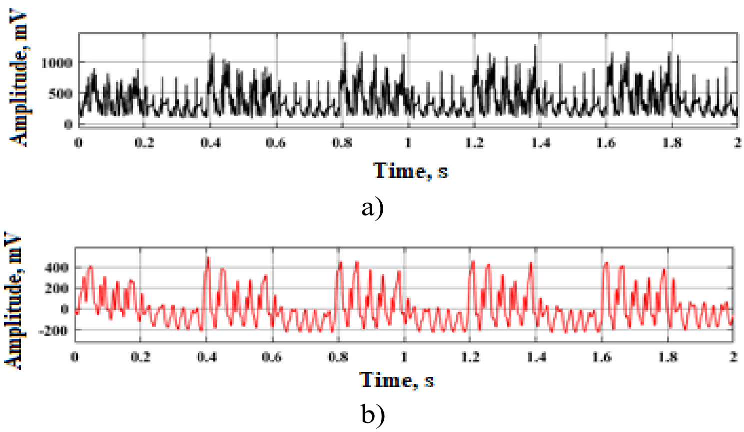


Fig. 9. Changes in AE amplitude over time. Sample №1:
a) before processing; b) AE from pore formation.

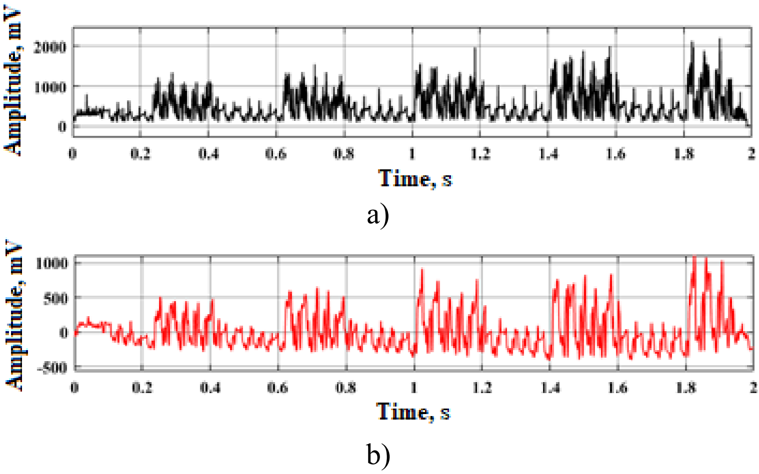
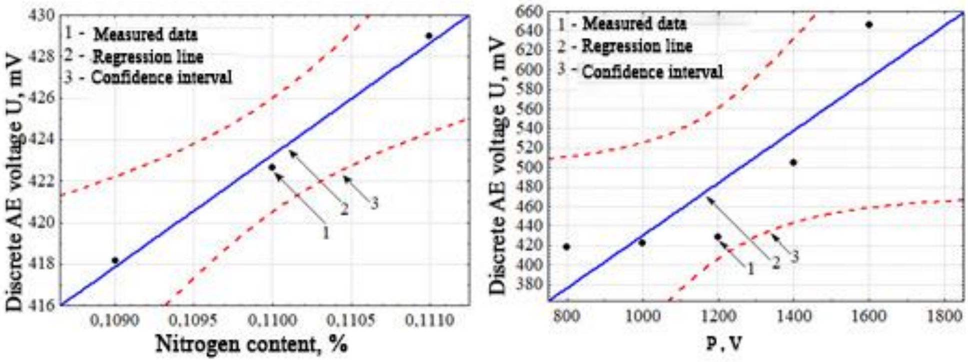


Fig. 10. Changes in AE amplitude over time. Sample №5:
a) before processing; b) AE from pore formation.

From Table 3, it is evident that the mean value of the measured AE signals for each channel during the control of each sample statistically significantly differs from the mean value of signals in other groups. The difference in the mean values of noisy and filtered signals is due to the high efficiency of the digital filtering method. Table 3 also shows that the AE amplitude increases from sample to sample, which is attributed to the restructuring of the internal material structure. Consequently, the discrete AE signal characterizes the crystallization process of the EP648 alloy under the influence of laser radiation power at various DLG stages.

It is known (Rastegaev, 2018) that the presence of defects in the crystal lattice (CL) or the destruction of internal structural bonds in products causes irreversible displacements of adjacent CL bonds. Moreover, the strength and stability of structural bonds in the CL largely depend on the nature of the defects (Tempelman, 2022). At the same time, the presence of defects in the CL of products may not be the sole factor affecting the AE signal characteristics. The amplitude of discrete AE may also be significantly influenced by the nitrogen impurity content in the spherical EP648 powder, with a close relationship between these parameters allowing the identification of defect formation causes in the produced products.

Assessment of DLG factors influencing defect formation. A significant impact on the quality of manufactured products is exerted by laser radiation power (Fig. 11, b) and the percentage of nitrogen N in the EP648 powder (Fig. 11, a).



a) b)

Fig. 11. Graphs of the dependence of the discrete AE amplitude on: a) nitrogen content percentage; b) laser power

The nature of the graphical dependencies shown in Fig. 11 and the results of the correlation-regression analysis presented in Table 4 indicate that the percentage of nitrogen content and laser radiation power have a statistically significant effect on the amplitude of discrete AE.

Table 4. Results of correlation-regression analysis

Factor	Association	Conclusion
Laser power	Before processing: r=0,292, R2=0,085, p=0,632	
	After processing: r=0,874, R2=0,765, p=0,052	Affects 76%
Nitrogen content percentage	Before processing: r= - 0,579, R2=0,335, p=0,606	
	After processing: r=0,995, R2=0,990, p=0,062	Affects 99 %

The results of the correlation-regression analysis (see Table 4) also indicate that before applying the developed cascade processing scheme, the presence of noise resulted in a weak and negative statistically insignificant correlation, which increased two to three times after filtering.

The correlation and statistical significance coefficients between laser radiation power and discrete AE amplitude were $r = 0.874$ at $p = 0.052$, and between the percentage of nitrogen content and discrete AE amplitude — $r = 0.995$ at $p = 0.062$. Comparing these data with the dependencies shown in Fig. 11, it can be concluded that an increase in nitrogen content in the EP648 powder and laser radiation power at various DLG stages leads to a rise in the discrete AE amplitude, characterizing the defect formation process. The correlation coefficient between the predictor and the dependent variable exceeded 0.8, which, according to Chaddock's scale, is considered a very high and non-random relationship, since $p < 0.1$.

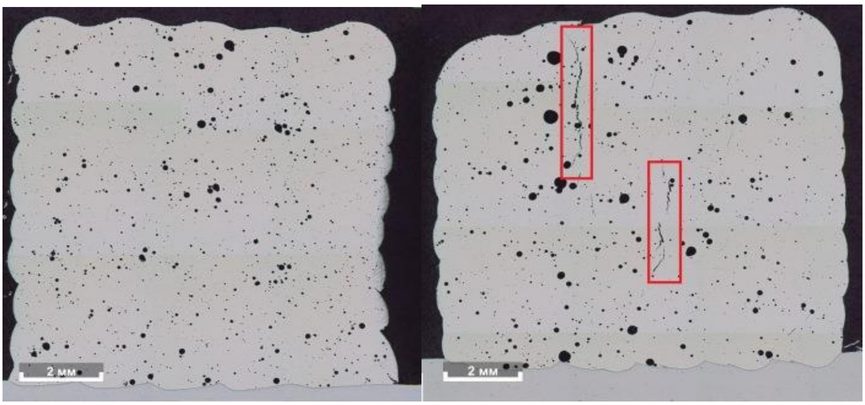
In this study, a correlation analysis was also conducted between the amplitude of discrete AE caused by pore formation, crack formation, and noise. The results showed a non-random, high correlation between the AE amplitudes during pore formation and crack formation, with r = 0.896, R^2 = 0.804, and p = 0.039. The presence of this relationship characterizes structural transformations in the sample material.

It is important to highlight the absence of a clear, statistically insignificant relationship between the amplitudes of discrete AE caused by defects and the influence of noise. As noted in (Frolov A.V., 2015), AE transducers in the 250–400 kHz range show resonant frequencies stemming from a dominant frequency of 160 kHz, caused by noise arising from the movement of the robotic manipulator in the DLG setup. The lack of a strong relationship, with r = 0.211 (for pore formation) at p = 0.435 and r = 0.103 (for crack formation) at p = 0.597 between discrete AE amplitude and noise, supports the conclusion that the frequency components of informative discrete AE signals differ from those of noise components, indicating that the processes are not correlated.

The correlation relationship affecting the amplitude of discrete AE from defects is described by the linear regression model equations (P — power, N — percentage of nitrogen content):

- for laser power: U = 0.269P + 161.179 with r = 0.874, R^2 = 0.765, p = 0.052;
- for nitrogen content: U = 5394N + 170.072 with r = 0.995, R^2 = 0.990, p = 0.062.

The result of the regression analysis suggests that an increase in laser power by 1 W is expected to raise the amplitude by 0.269 mV. Consequently, an increase in nitrogen content by 1% is projected to increase the discrete AE amplitude by 5.394 V. Metallographic analysis of microsections of the produced samples confirmed the influence of these factors on the formation of cracks and pores. Figure 12 presents images obtained from the metallographic analysis of microsections of samples № 1 (a) and № 5 (b).



a) b)

Fig. 12. Metallographic results: a) sample №1; b) sample №5

The presence of cracks is clearly visible in the microsection of Sample No. 5, which was grown at P = 1600 W. Furthermore, the presence of voids in the microsections confirms the formation of pores caused by the particle morphology (50 μm) of the spherical EP648 powder. The influence of alloy powder particle size on pore formation has been confirmed in previous studies (Kaplan, 2018).

Conclusion.

This article presents the results of acoustic emission (AE) monitoring of defect formation in samples produced using the DLG method. To process AE control data, a cascade filtering method is proposed. The results of method validation showed that:

— the signal-to-noise ratio (SNR) value after filtering averages above 1.5 dB, characterizing the stability of AE signals against noise interference;

— a threefold increase in the correlation coefficient between laser radiation power and discrete AE amplitude, as well as between nitrogen content and discrete AE amplitude after filtering, highlights the effectiveness of the processing method;

— laser radiation power and the percentage of nitrogen in the initial powder material influence the defect formation process.

References

Absadykov B.N., Bazarbay B.B., Isametova M.E., Mashekova A.S. Analysis of a new filament making mel pressing device. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2022, Vol. 4, No. 454, pp. 6 – 15. https://doi.org/10.32014/2022.2518-170X.196. (in Eng.).

Altay Y.A., Fedorov A.V., Stepanova K.A. Proc. of the 2022 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering, St. Petersburg, 2022, pp. 1320–1326. (in Eng.).

Barat V.A. Razvitiye metoda akusticheskoy emissii za schet avtomatizatsii obrabotki dannykh, povysheniya pomekhoustoychivosti i dostovernosti obnaruzheniya treshchinopodobnykh defektov metallokonstruktsiy [Development of the Acoustic Emission Method by Automating Data Processing, Increasing Noise Immunity and Reliability of Detection of Crack-Like Defects in Metal Structures]. Extended abstract of Doctor's thesis, Moscow, 2019, 40 p. (in Russ.)

Chernova V.V. Razrabotka metodiki akustiko-emissionnogo kontrolya defektov na ranney stadii ikh razvitiya v izdeliyakh iz kompozitsionnykh materialov [Development of a Technique for Acoustic Emission Monitoring of Defects at an Early Stage of Their Development in Products Made of Composite Materials]. Extended abstract of candidate's thesis, Tomsk, 2017, 21 p. (in Russ.)

Frolov A.V., Muhina I.Yu., Duyunova V.A., Uridiya Z.P. Proceedings of VIAM, 2015, no. 9, pp. 57–63. (in Russ.)

Isametova, M., Absadykov, B., Bazarbay, B., Smailova, G. (2022). Development of the design and technology of extrusion of metal-polymer mixtures for the production of feedstocks. Eastern-European Journal of Enterprise Technologies, 4 (1 (118)), 23–33. doi: https://doi.org/10.15587/1729-4061.2022.259532 (in Eng.).

Isametova M.E., Martyushev N.V., Karlina Y.I., Kononenko R.V., Skeeba V.Y., Absadykov B.N. Thermal Pulse Processing of Blanks of Small-Sized Parts Made of Beryllium Bronze and 29 NK Alloy. Materials, 2022, 15(19), 6682. https://doi.org/10.3390/ma15196682. (in Eng.).

Kaplan M.A., Kirsankin A.A., Smirnov M.A., Kalaida T.A., Sevostyanov M.A. Novyye materialy i perspektivnyye tekhnologii [New Materials and Advanced Technologies]. Collection of materials of the 4th Interdisciplinary Scientific Forum with International Participation, 2018, pp. 130–131. (in Russ.)

Kaplan M.A., Kirsankin A.A., Smirnov M.A., Sevostyanov M.A. Novyye materialy i perspektivnyye tekhnologii [New Materials and Advanced Technologies]. Collection of materials of the 4th Interdisciplinary Scientific Forum with International Participation, 2018, pp. 131–132. (in Russ.)

Kovalevich A.S., Kinzhagulov I.Yu., Stepanova K.A., Kuzivanov D.O. Journal of Instrument Engineering, 2023, no. 2(66), pp. 139–147, DOI: 10.17586/0021-3454-2023-66-2-139-147. (in Russ.)

Litunov S.N., Slobodenyuk V.S., Melnikov D.V. Omsk Scientific Bulletin, 2016, no. 1(145), pp. 12–17. (in Russ.)

Popkova I.S. Sbornik XVI mezhdunarodnoy nauchno-tekhnicheskoy Ural'skoy shkoly metallovedov-molodykh uchenykh [Collection of the XVI International Scientific and Technical Ural School of Metallurgists and Young Scientists]. Part. 2, Ekaterinburg, 2015, pp. 276–279. (in Russ.)

Rastegaeva I.I., Rastegaev I.A., Agletdinov E.A. The comparison of the main time-frequency transformations of spectral analysis of acoustic emission signals. Frontier Materials and Technologies, 2022, no. 1, pp. 49–60. (in Eng.).

Smirnov M.A., Kaplan M.A., Kirsankin A.A., Kalaida T.A., Sevostyanov M.A. Novyye materialy i perspektivnyye tekhnologii [New Materials and Advanced Technologies]. Collection of materials of the 4th Interdisciplinary Scientific Forum with International Participation, 2018, pp. 307–310. (in Russ.).

Smirnov M.A., Kaplan M.A., Sevostyanov M.A. IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2018, vol. 347, 012033. (in Eng.).

Smirnov M.A., Kaplan M.A., Kirsankin A.A., Kalaida T.A., Nasakina E.O., Sevostyanov M.A. IOP Conference Series: Materials Science and Engineering, 2019, vol. 525, 012076. (in Eng.).

Tempelman J. R., Wachtor A.J., Flynn E.B., Depond P.J., Forien J.B., Guss, G.M., Matthews M.J. Additive Manufacturing, 2022, vol. 55, 102735. (in Eng.).

Pandiyan V., Drissi-Daoudi R., Shevchik S., Masinelli G., Le-Quang T., Loge R., Wasmer K. Virtual and Physical Prototyping, 2021, vol. 16, pp. 481–497. (in Eng.).

Rastegaev I.A., Merson D.L., Rastegaeva I.I. Aktual'nyye problemy metoda akusticheskoy emissii [Actual Problems of the Acoustic Emission Method]. Collection of materials of the All-Russian Conference, Togliatti, 2018, pp. 103– 104. (in Russ.)

Makhutov N.A., Sokolova A.G., Vasil'ev I.E., Chernov D.V., Skvortsov D.F., Bubnov M.A., Ivanov V.I. Russian Journal of Nondestructive Testing, 2020, no. 12(56), pp. 960–970. (in Eng.).

Wei Q., Xie Y., Teng Q., Shen M., Sun S., Cai C. Chinese Journal of Mechanical Engineering: Additive Manufacturing Frontiers, 2022, vol. 1, pp. 100055. (in Eng.).

Yang G., Xie Y., Zhao S., Qin L., Wang X., Wu B. Chinese Journal of Mechanical Engineering: Additive Manufacturing Frontiers, 2022, pp. 100037. (in Eng.).

CONTENTS

K.M. Akishev, K.Sh. Aryngazin, A.K. Tleulessov, O.V. Vyshar, V.I. Karpov
DIGITAL TRANSFORMATION OF PRODUCTION PROCESSES OF ENTERPRISES FOR THE PRODUCTION OF CONSTRUCTION PRODUCTS....5

Y.A. Altay, B.B. Bazarbay, B.N. Absadykov, G.K. Berdibaeva, S.A. Kalmaganbetov
METHOD OF IDENTIFYING FACTORS INFLUENCING DEFECT FORMATION IN SELECTIVE LASER MELTING OF HEAT-RESISTANT ALLOY USING ACOUSTIC EMISSION METHOD....21

N. Amirgaliyev, D. Burlibayeva, A. Musakulkyzy
LONG-TERM DYNAMICS OF TOXIC COMPOUNDS INFLOW OF THE ZHAIYK RIVER TO TERRITORY OF KAZAKHSTAN AND THEIR DOWNSTREAM TRANSFORMATION....42

A.S. Apatenko, S.I. Nekrasov, N.S. Sevryugina, N.I. Kozhukhova, E.A. Begimkulova
OPTIMIZATION OF THE PROCESS OF CARGO DELIVERY OF AGRO-INDUSTRIAL COMPLEX THROUGH THE INTRODUCTION OF NEURAL NETWORKS....58

K.A. Vassin, N.S. Buktukov, N.U. Aldiyarov, K.A. Ozhikenov, O.N. Tkachenko
JUSTIFICATION FOR CHANGES IN THE DESIGN OF THE ROCK-BREAKING ELECTROMAGNETIC HAMMER FOR ITS ENHANCED EFFICIENCY....70

O.N. Didmanidze, M.Yu. Karelina, R.V. Klyuev, N.V. Martyushev, D.V. Serdechnyy
APPLICATION OF ARTIFICIAL INTELLIGENCE AND MODERN TECHNOLOGIES IN GEOMONITORING TO IMPROVE THE EFFICIENCY OF THE MINING INDUSTRY UTILISING THE EARTH'S RESOURCES....84

G.Zh. Zholtayev, Z.T. Umarbekova, A.A. Antonenko, M.A. Mashrapova, G.M. Karatayeva
PROSPECTS FOR EXPANDING GOLD RESERVES IN THE BAKYRCHIK ORE DISTRICT IN EASTERN KAZAKHSTAN....97

V.V. Kazantseva, D.S. Ozhigin, V.N. Dolgonosov, S.B. Ozhigina, P.P. Grossul
ASSESSMENT OF THE ACCURACY OF THE GEOMETRIC SCHEME OF GCPS WHEN CREATING DSM USING UAV...110

A.E. Kachaev, T.N. Orekhova, V.V. Strokova, E.A. Shkarpetkin, A.O. Belyaev
IMPROVING THE DESIGN OF A PNEUMATIC MIXER FOR THE PRODUCTION OF MULTI-COMPONENT MIXTURES.................................125

K. Kozhakhmet , A.R. Kushakov, F.A Kushakov, M.M. Kurbonova, M.K. Aripova
STRATIGRAPHIC SUBDIVISION OF THE PALEOGENE DEPOSITS OF THE KARAKATA DEPRESSION OF KYZYLKUM...137

O. Kurmanbayev, A. Koishygarin, G. Jangulova, G. Madimarova, Z. Sarsembekova
CONCEPT OF STATIC MEASUREMENT PROCESSING AT THE FABRICHNY BASE STATION...152

M. Nurpeissova, A. Umirbayeva, N. Tursynbayev, N. Donenbayeva, N. Bakyt
ASSESSMENT OF DEFORMATION AND RADIATION STATE OF ADJACENT TERRITORIES OF THE DEPOSIT "KARAZHYRA".................166

Y. Nugman, A. Mustafa, R. Kaiyrov, M. Sagyntai, Zh. Turgunov
MOBILE 3D PRINTER WITH MECHANICAL PROCESSING FOR MANUFACTURING MINING EQUIPMENT PARTS......................................180

E.O. Orynbassarova, B. Adebiyet, A. Yerzhankyzy, N. Sydyk, A. Ilyasova
APPLICATION OF REMOTE SENSING METHODS FOR THE IDENTIFICATION OF IRON OXIDE ZONES AT THE KYZYLKIYA DEPOSIT...197

N.V. Palianova, Alexandr V. Dolzhenko, Andrei E. Naumov, E.N. Tsyganko, E.V. Komar
POLLUTION OF ABANDONED COAL MINES: ASSESSMENT OF SCALE AND MONITORING USING MODERN TECHNOLOGIES...209

M.V. Ponomareva, Ye.V. Ponomareva, Ye.D. Shirokaya, A.T. Tungushbayeva
ANALYSIS OF THE USE OF THE PYTHON PROGRAMMING LANGUAGE FOR GEOLOGICAL MODELING OF SOLID MINERAL DEPOSITS...225

B.T. Ratov, V.L. Khomenko, M. T. Biletskiy, S.T. Zakenov, Z.Sh. Makhitova
MODERNIZATION OF WATER WELL DRILLING TECHNOLOGY WITH DRILLING FLUID REVERSE CIRCULATION..237

T.K. Salikhov, Y.S. Kabiyev, B.B. Doskenova, H. Onal, Zh.B. Akhmetzhanov
RESEARCH OF THE SOIL COVER ECOSYSTEM IN THE WEST KAZAKHSTAN REGION ON THE BASIS OF REMOTE SENSING AND GIS-TECHNOLOGY...253

G.E. Sakhmetova, B.K. Uralov, R.A. Shinibekova, K.T. Sherov, M.R. Sikhimbayev
COMPARATIVE ANALYSIS OF AMPLITUDE-MODULATION TYPE FREQUENCY CONVERTERS..277

A.Z. Tairov, M. Leman, A. Tolekova, D.U. Abdibekov, T.E. Sorokina
HYDROCHEMISTRY AND ION FLOW DYNAMICS OF SYR DARYA TRANSBOUNDARY RIVER WITHIN KAZAKHSTAN.................................290

Publication Ethics and Publication Malpractice in the journals of the National Academy of Sciences of the Republic of Kazakhstan

For information on Ethics in publishing and Ethical guidelines for journal publication see http://www.elsevier.com/publishingethics and http://www.elsevier.com/journal-authors/ethics.

Submission of an article to the National Academy of Sciences of the Republic of Kazakhstan implies that the described work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see http://www.elsevier.com/postingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The National Academy of Sciences of the Republic of Kazakhstan follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct (http://publicationethics.org/files/u2/New_Code.pdf). To verify originality, your article may be checked by the Cross Check originality detection service http://www.elsevier.com/editors/plagdetect.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the National Academy of Sciences of the Republic of Kazakhstan.

The Editorial Board of the National Academy of Sciences of the Republic of Kazakhstan will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайтах:

www:nauka-nanrk.kz

http://www.geolog-technical.kz/index.php/en/

ISSN 2518-170X (Online),

ISSN 2224-5278 (Print)

Директор отдела издания научных журналов НАН РК *А. Ботанқызы*

Редакторы: *Д.С. Аленов, Ж.Ш.Әден*

Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 15.04.2025.

Формат 70x90$^{1}/_{16}$. Бумага офсетная. Печать – ризограф.

14,5 п.л. Заказ 2.

РОО «Национальная академия наук РК»

050010, Алматы, ул. Шевченко, 28, т. 272-13-19