|  |  |  |
| --- | --- | --- |
| UDC 004.622: 517.927 |  |  |

**I. V. BRYSINA, V. O. MAKARICHEV**

***N. Ye. Zhukovsky National Aerospace University “Kharkiv Aviation Institute”, Ukraine***

**ATOMIC FUNCTIONS AND THEIR GENERALIZATIONS IN DATA PROCESSING: FUNCTION THEORY APPROACH**

*The atomic function is solutions with a compact support of the linear functional differential equations with constant coefficients and linear transforms of the argument. The atomic function theory was created in the 70's of the 20th century due to the necessity to solve different applied problems, in particular, boundary value problems. One of the reasons for the appearance of atomic functions and some other classes of functions was the inability to apply such classic approximation tools as algebraic and trigonometric polynomials. V.A. Rvachev up-function is the most famous and widely applies atomic function. The development of technologies changes the existing problems and fundamentally new problems appear. Nowadays big data processing is one of the most important problems. It should be mentioned that suitable mathematical tools must be applied to obtain the desired result. This paper is devoted to the fundamentals of applications of some atomic functions and their generalizations in data processing and data reduction. In this paper, we consider the main properties of these functions from the function theory point of view and give their interpretation with respect to information processing. Smoothness, compact support, and good approximation properties are the main advantages of atomic functions. Moreover, the spaces of atomic functions and the spaces of generalized Fup-functions, which are the natural generalization of V.A. Rvachev Fup-functions, are asymptotically extremal for the approximation of periodic differentiable functions. This means that in the terms of A.N. Kolmogorov width these functions are just as effective as classic trigonometric polynomials {1, cos(nx), sin(nx)}. Hence, the replacement of discrete transforms based on trigonometric functions on similar transforms based on atomic functions and generalized Fup-functions is quite promising. For this purpose, we introduce discrete atomic transform and generalized discrete atomic transform. We also discuss the dependence of data processing results on order of smoothness and size of support of the applied functions. The theoretical justification of the application of some atomic functions and generalized Fup-functions to data processing and, in particular, data reduction is the main result of this paper.*

***Keywords:*** *data processing; data compression; atomic functions; up-function; Fup-function; generalized Fup-function; discrete atomic transform; generalized discrete atomic transform.*

**Introduction**

Theory of atomic functions appeared in the 70’s of the 20th century because of necessity to solve different applied problems, especially boundary value problems [1]. The first atomic function is V. A. Rvachev up-function

.

This function is the most famous and widely used atomic function. Later many other different atomic functions were constructed and investigated. One of the reasons for the appearance and further development of atomic functions and some other classes of new functions was the inability to use in numerical methods such classic constructive tools as trigonometric and algebraic polynomials [1].

Now fundamentally new technical capabilities have been created and science community has a significant number of totally new problems. Processing of big data is one of them.

It is well-known that complexity and efficiency of algorithms of big data sets processing depend on properties of used mathematical tools. Atomic functions combine a huge number of convenient properties. For this reason they have many different applications (note that a list of current application is presented in [4]; also comprehensive survey, which was actual at the time of writing, can be found in [5]). It should be mentioned that at the current time atomic functions are mostly used as a tool for analysis of functions of real or complex variables. But now data is often discrete (for example, digital image is a matrix). Therefore, it is the development of algorithms for discrete data processing that is one of the most important problems. Hence, the following question is quite natural: **is it rational to use atomic functions in processing of discrete data?** In this paper we get an answer on this question. For this purpose the following approach is used: we consider the main properties of some atomic functions and their generalizations from the function theory point of view and obtain the interpretation with respect to information processing.

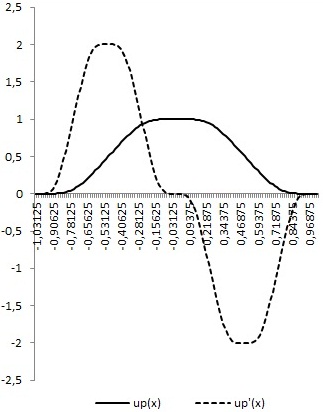


Fig. 1. The graph of up-function and its derivative

**Formulation of the problem**

Consider the space of up-function shifts

.

Approximation properties of these spaces were investigated in [1 - 3]. It was also shown that in the space  there exists a basis that consists of translates of the function

,

where  is the Fourier transform of  with a local support.

These results were generalized in [12] for the case of spaces

,

where ,  and

.

In particular, it was proved that shifts of the function



where  is the Fourier transform of , constitute a basis of the space .

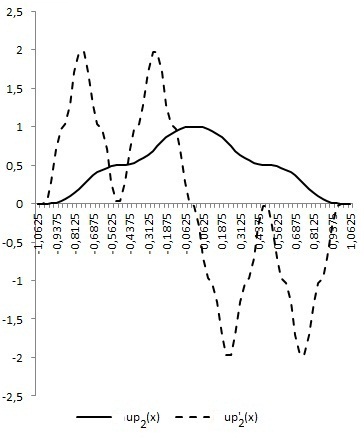


Fig. 2. The graph of  and its derivative

Consider the function

,

where F(t) is the Fourier transform of the positive even function  with a support , ,  and . The function  is called generalized Fup-function and  is its mother function [6, 7].

Generalized Fup-function is a natural generalization of V. A. Rvachev Fup-functions and .

It follows from [1 – 3, 6 – 8] that ,  and the spaces of generalized Fup-functions shifts combine the following advantages:

1) these spaces are asymptotically extremal for approximation of periodic differentiable functions;

2) the spaces  are extremal for approximation of periodic differentiable functions;

3) these spaces have a locally supported bases;

4) elements of these spaces have high order of smoothness.

This implies that atomic functions ,  and generalized Fup-functions are convenient for applications, in particular, for construction of different numerical methods. In other words, from function theory point of view these functions are excellent mathematical tools.

**The aim of this paper** is to prove the efficiency of ,  and generalized Fup-functions in discrete data processing.

**Discrete data transform**

The spaces of atomic functions and generalized Fup-functions can be easily used for representation of real or complex variable functions. Let us introduce the following scheme of discrete data representation.

We consider the case of one-dimensional of real-valued data.

Let  be some data. The value of  can be the result of measuring a certain indicator. For example,  is the temperature or the exchange rate at the i-th moment in time.

Let us construct the function  such that the data  is a set of values of this function. For this purpose it is sufficient to construct the scale of the independent variable .

By  denote some segment. Let , where  and .

Further, denote by  the space of atomic functions  or .

Finally, let the system of functions  be a basis of the space .

Using classic decomposition procedure, we can find the function

 (1)

such that

 (2)

for any .

Note that the set of atomic coefficients  uniquely identifies the data set .

In this way we construct the procedure for the transformation of some discrete data  into atomic coefficients . We call this procedure the **discrete atomic transform** (DAT) and the set of coefficients the **DAT-coefficients**. If  is a space of generalized Fup-functions, we call this procedure the **generalized discrete atomic transform**.

It is obvious that the basis  of the linear space  can be chosen in different ways. The simplest approach is to choose atomic wavelets or generalized atomic wavelets, which were constructed in [4, 9 – 11], as a basis. In this case we get wavelet expansion of the discrete data .

In the same way we can construct DAT-procedure and generalized DAT-procedure for representation of complex-valued and multi-dimensional discrete data .

**Dependence of data processing complexity on the support of the basic functions**

In the previous section we introduced the special numerical scheme that can be used for discrete data processing. It is evident that the following questions are of particular interest:

1) what is the complexity of DAT and generalized DAT procedures?

2) what is the complexity of algorithm for obtaining initial data?

It is obvious that complexity of these algorithms principally depends on the properties of the basis .

Existence of the locally supported basis in the spaces of atomic functions and generalized Fup-functions is a convenient feature of these spaces. For instance,

 (3)

and the system of functions

 (4)

is a basis of the space  [1, 3];

 (5)

and the system

 (6)

constitutes a basis in the space  [12];

finally,

 (7)

and spaces of these generalized Fup-functions have a basis

 (8)

(actually, the spaces of generalized Fup-functions are constructed as a linear span of the system (8) [8]).

To obtain DAT-coefficient  we put  for  in expansion (1). Using (2), we get the system of linear algebraic equations. If (4), (6) or (8) is a basis of the space , then it follows from (3), (5) and (7) that matrix of this system is band. Hence, complexity of solution is . In other words, the algorithm of transform of  into the coefficients  has linear complexity in the size of initial data. This means that **DAT and generalized DAT procedures have linear complexity in the size of data**. By the same argument, **complexity of the inverse procedure is also linear**. Indeed, to obtain the value  we should put  in (1). From (3), (5) and (7) it follows that the most part of the terms on the right side of equality (1) is equal to zero. So, we need to calculate the sum of several terms.

If we choose atomic wavelets or generalized atomic wavelets as a basis of the linear space , we obtain just the same situation. It was shown in [4, 9 - 11] that these wavelets are locally supported functions. Therefore discrete atomic transform and generalized atomic transform of the data  into the coefficients  have linear complexity. Also, the inverse procedures are the algorithms with a linear complexity.

Processing of multi-dimensional data using atomic functions and their generalizations has the same convenient feature.

**Influence of approximation properties   
on the data representation**

Allocating useful information from initial data is one of the data processing problems. It is often required that the extracted data adequately represent the initial information [12 – 15]. Obviously, the efficiency of such extraction algorithms depends on many factors, in particular, on the approximation properties of the applied mathematical tools.

For example, algorithm JPEG is de-facto a standard for compression of digital images. In this algorithm, compression is achieved due to the fact that most of the quantized coefficients, which are obtained using discrete cosine transform (DCT), are equal to zero. This means that a few DCT-coefficients describe all information. This important property is based on the well-known approximation properties of trigonometric polynomials .

It was proved in [1 – 3, 6, 8] that the best approximation of wide classes of periodic differentiable functions by spaces of linear combinations of atomic functions ,  and generalized Fup-functions  almost coincides with the corresponding A.N. Kolmogorov width (we note also that in some cases the value of best approximation is equal to the width). This means that in the terms of A.N. Kolmogorov width these functions are just as effective as classic trigonometric polynomials. Hence, it is enough to operate with an insignificant number of DAT or generalized DAT coefficients in the process of data analysis. So, **DAT-coefficients and generalized DAT-coefficients are convenient tools for processing of discrete data**.

**Dependence of data representation   
on the order of smoothness**

The wide use of classic trigonometric polynomials is due to many factors. The following one is the most important: there are many physical processes and phenomena, which are well described using trigonometric functions.

But in some cases, application of  and  leads to undesirable effects. These functions are analytic. For this reason processing of data with smooth changes using trigonometric functions is so useful. For example, application of discrete cosine transform in JPEG algorithm allows achieving a high compression ratio. At the same time, it can be easily checked that if we recompress JPEG-image using JPEG algorithm, we get degradation in quality or increase the file size. What is the reason for this effect? The answer is quantization of DCT-coefficients. Indeed, this procedure is used to obtain integer numbers instead of real-valued DCT-coefficients. But in the process of decompression we get data with less smooth changes. So, the decompressed image is less analytical than the original one. This yields that JPEG recompression becomes less effective.

Atomic functions  and  are **not** analytic. Moreover, these functions are non-quasianalytic (for more details see, for example, [2]). By construction, order of smoothness of the generalized Fup-function depends on the properties of the mother function. For example, if the mother function  is non-quasianalytic, then  is non-quasianalytic too. Therefore, application of atomic functions and generalized Fup-functions to processing of data with low order of smoothness is quite promising.

Besides, it was shown in [1, 6, 8] that there exists almost trigonometric basis in the spaces of atomic functions and generalized Fup-functions. This means that these spaces are just as good approximation tools as trigonometric polynomials. Combining this with the previous conclusion, we see that **application of DAT-procedure and generalized DAT-procedure is much more effective than discrete cosine transform**.

**Application perspectives**

In this section we consider some actual problems that can be solved or partially solved using DAT and generalized DAT.

As it was shown above, DAT and generalized DAT procedures can be effectively used instead of DCT. Hence, it is quite natural to use them, for example, in lossy data compression (notice that a detailed discussion of application of atomic functions  to lossy image compression is presented in [16]). For this purpose the following scheme can be used:

1) preliminary data processing (for example, RGB-to-YCrCb transformation, block splitting procedure etc.);

2) discrete atomic transform (or generalized discrete atomic transform);

3) quantization of DAT-coefficients (or generalized DAT-coefficients);

4) lossless compression of quantized coefficients.

Another application is an analysis of time series. For this purpose generalized atomic wavelet expansion, which was introduced in [4], can be used.

This is a partial list of practical applications. It is clear that investigation of all possible applications of discrete atomic transform and generalized discrete atomic transform is a topic for a special research.

**Conclusions**

In this paper we have introduced discrete atomic transform and generalized discrete atomic transform that can be used in discrete data processing. It have been shown that

1) DAT-procedure and generalized DAT-procedure have linear complexity in the size of initial data;

2) DAT-coefficients and generalized DAT-coefficients are convenient for discrete data processing and analysis;

3) procedures, which are inverse to DAT and generalized DAT, have linear complexity;

4) application of DAT-procedure and generalized DAT-procedures is much more promising than DCT-procedure.

We also have presented some possible applications of DAT-procedure and generalized DAT-procedures.

In general, the main result of the current paper is a fundamental justification of application of atomic functions ,  and generalized Fup-functions  to the processing of discrete data and lossy data compression.

**Contributions of authors:** conceptualization, methodology – **Makarichev Victor;** formulation of tasks, analysis **– Makarichev Victor, Brysina Iryna;** development of model,software,verification **– Makarichev Victo, Brysina Iryna;** analysis of results, visualization **– Brysina Iryna;** writing – original draft preparation, writing – review and editing **– Brysina Iryna.**

**Conflict of Interest**

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

**Financing**

The research was conducted without financial support.

**Data availability**

The manuscript has no associated data.

**Use of Artificial Intelligence**

The authors confirm that they did not use artificial intelligence methods while creating the presented work.

**Acknowledgement**

The authors are grateful to professor V. A. Rvachev for his attention to their research.

All the authors have read and agreed to the published version of this manuscript

**References (GOST 7.1:2006)**

*1. Рвачёв, В. Л. Неклассические методы теории приближений в краевых задачах [Текст] /   
В. Л. Рвачёв, В. А. Рвачёв. – К. : Наукова думка, 1979. – 196 с.*

*2. Rvachev, V. A. Compactly supported solutions of functional-differential equations and their applications [Text] / V. A. Rvachev // Russian Math. Surveys.   
– 1990. – Vol. 45, No. 1. – P. 87 – 120.*

*3. Rvachev, V. A. On approximation by means of the function up(x) [Text] / V. A. Rvachev // Sov. Math. Dokl. – 1977. – Vol. 233, No. 2. – P. 295-296.*

*4. Brysina, I. V. Generalized atomic wavelets [Text] / I. V. Brysina, V. O. Makarichev // Radioelectronic and Computer Systems. – 2018. – Vol. 85, No. 1. – P. 23-31.*

*5. Теория R-функций и актуальные проблемы прикладной математики [Текст] / Ю.Г. Стоян, В. С. Проценко, Г. П. Манько, И. В. Гончарюк,   
Л. В. Курпа, В. А. Рвачев, Н. С. Синекоп, И. Б. Сироджа, А. Н. Шевченко, Т. И. Шейко. – К. : Наукова думка, 1986. – 264.*

*6. Makarichev, V. A. Approximation of periodic functions by mups(x) [Text] / V. A. Makarichev // Math. Notes. – 2013. – Vol. 93, No. 6. – P. 858-880.*

*7. Brysina, I. V. On the asymptotics of the generalized Fup-functions [Text] / I. V. Brysina, V. A. Makarichev // Adv. Pure Appl. Math. – 2014. – Vol. 5,   
No. 3 – P. 131-138.*

*8. Brysina, I. V. Approximation properties of generalized Fup-functions [Text] / I. V. Brysina, V. A. Makarichev // Visnyk of V. N. Karazin Kharkiv National University, Ser. “Mathematics, Applied Mathematics and Mechanics”. – 2016. – Vol. 84. – P. 61-92.*

*9. Макаричев, В. А. Об одной нестационарной системе бесконечно дифференцируемых вейвлетов с компактным носителем [Text] / В. А. Макаричев // Вісник ХНУ, Сер. «Математика, прикладна математика і механіка». – 2011. – № 967, вып. 63.   
– С. 63-80.*

*10. Brysina, I. V. Atomic wavelets [Text] /   
I. V. Brysina, V. A. Makarichev // Radioelectronic and Computer Systems. – 2012. – Vol. 53, No. 1. – P. 37-45.*

*11. Makarichev, V. A. The function mups(x) and its applications to the theory of generalized Taylor series, approximation theory and wavelet theory [Text] /   
V. A. Makarichev // Contemporary problems of mathematics, mechanics and computing sciences: collection of papers / V. A. Makarichev ; editors: N. N. Kizilova, G. N. Zholtkevych. – Kharkiv : Apostrophe, 2011.   
– P. 279-287.*

*12. Kuan-Ching Li (eds.). Big data management and processing [Text] / Kuan-Ching Li, Hai Jiang,   
A.Y. Zomaya (eds.). – Chapman and Hall / CRC, 2017. – 487 p.*

*13. Gonzalez, R. C. Digital image processing [Text] / R. C. Gonzalez, R. E. Woods. – Prentice Hall, 2008. – 977 p.*

*14. Salomon, D. Handbook of data compression [Text] / D. Salomon, G. Motta, D. Bryant. – Springer, 2010. – 1370 p.*

*15. Tsay, R. S. Analysis of financial time series [Text] / R. S. Tsay. – John Wiley and Sons, 2010.   
– 714 p.*

*16. Makarichev, V. O. Application of atomic functions to lossy image compression [Text] / V. O. Makarichev // Theoretical and applied aspects of cybernetics. Proceedings of the 5th International scientific conference of students and young scientists. – Kyiv : Bukrek, 2015. – P. 166-175.*

**References (BSI)**

1. Rvachev, V. L., Rvachev, V. A. *Neklassicheskie metody teorii priblizhenii v kraevykh zadachakh* [Nonclassical methods of approximation theory in boundary value problems]. Kyiv, “Naukova dumka” Publ., 1979. 196 p.

2. Rvachev, V. A. Compactly supported solutions of functional-differential equations and their applications. *Russian Math. Surveys*, 1990, vol. 45, no. 1, pp. 87-120.

3. Rvachev, V. A. On approximation by means of the function up(x). *Sov. Math. Dokl*. 1977, vol. 233, no. 2, pp. 295-296.

4. Brysina, I. V., Makarichev, V. A. Generalized atomic wavelets. *Radioelectronic and Computer Systems*, 2018, vol. 85, no. 1, pp. 23-31.

5. Stoyan, Yu. G., Protsenko, V. S., Man’ko, G. P., Goncharyuk, I. V., Kurpa, L. V., Rvachev, V. A., Sinekop, N. S., Sirodzha, I. B., Shevchenko, A. N., Sheiko, T. I. *Teorija R-funkcij i aktual’nye problemy prikladnoj matematiki* [Theory of R-functions and current problems of applied mathematics]. Kyiv, “Naukova dumka” Publ., 1986. 264 p.

6. Makarichev, V. A. Approximation of periodic functions by mups(x). *Math. Notes*, 2013, vol. 93, no. 6, pp. 858-880.

7. Brysina, I. V., Makarichev, V. A. On the asymptotics of the generalized Fup-functions. *Adv. Pure Appl. Math.*, 2014, vol. 5, no. 3, pp. 131-138.

8. Brysina, I. V., Makarichev, V. A. Approximation properties of generalized Fup-functions. *Visnyk of V. N. Karazin Kharkiv National University, Ser. “Mathematics, Applied Mathematics and Mechanics”*, 2016, vol. 84, pp. 61-92.

9. Makarichev, V. A. Ob odnoi nestatsionarnoi sisteme beskonechno differentsiruemykh veievletov s kompaktnym nositelem [On the nonstationary system of infinitely differentiable wavelets with a compact support]. *Visnyk KhNU, Ser. “Matematika, prikladna matematika and meckhanika”*, 2011, no. 967, pp. 63-80.

10. Brysina, I. V., Makarichev, V. A. Atomic wavelets. *Radioelectronic and Computer Systems*, 2012, vol. 53, no. 1, pp. 37-45.

11. Makarichev, V. A. The function mups(x) and its applications to the theory of generalized Taylor series, approximation theory and wavelet theory. *Contemporary problems of mathematics, mechanics and computing sciences*, Kharkiv, “Apostrophe” Publ., 2011, pp. 279-287.

12. Kuan-Ching Li, Hai Jiang, Zomaya, A. Y. (eds.). *Big data management and processing*, Chapman and Hall / CRC, 2017. 487 p.

13. Gonzalez, R. C., Woods, R. E. *Digital image processing*, Prentice Hall, 2008. 977 p.

14. Salomon, D., Motta, G., Bryant, D. *Handbook of data compression*, Springer, 2010, 1370 p.

15. Tsay, R. S. *Analysis of financial time series*, John Wiley and Sons, 2010, 714 p.

16. Makarichev, V. O. Application of atomic functions to lossy image compression.*Theoretical and applied aspects of cybernetics.Proceedings of the 5th International scientific conference of students and young scientists,* Kyiv, “Bukrek” Publ., 2015, pp. 166-175.

## *Поступила в редакцию 15.06.2026, рассмотрена на редколлегии 00.00.2026*

**АТОМАРНІ ФУНКЦІЇ ТА ЇХ УЗАГАЛЬНЕННЯ В ОБРОБЦІ ДАНИХ:   
ТЕОРЕТИКО-ФУНКЦІОНАЛЬНИЙ ПІДХІД**

***І. В. Брисіна, В. О. Макарічев***

Атомарна функція – це розв'язок з компактним носієм лінійного функціонально-диференціального рівняння з постійними коефіцієнтами та лінійними перетвореннями аргументу. Теорія атомарних функцій виникла у 70-х роках 20-го сторіччя через необхідність розв'язувати різноманітні прикладні проблеми, зокрема крайові задачі. Однією з причин виникнення атомарних функцій та багатьох інших класів функцій є неможливість використання таких класичних засобів наближення, як алгебраїчні та тригонометричні поліноми. Однією з найбільш відомих атомарних функцій є up-функція В. О. Рвачова. З розвитком технічних засобів змінювалися існуючі проблеми та виникали принципово нові. Так, зараз однією з найбільш важливих проблем є обробка великих об'ємів даних. При цьому ефективність алгоритмів здебільшого залежить від властивостей математичного апарату, що використовується. Ця стаття присвячена базовим принципам застосування деяких атомарних функцій та їх узагальнень в обробці даних та стисненні інформації з втратами якості. У роботі ми розглянемо основні теоретико–функціональні властивості цих функцій та надамо їх інтерпретацію стосовно обробки інформації. Основними перевагами атомарних функцій є гладкість, компактність носія та гарні апроксимаційні властивості. Окрім того, простори атомарних функцій та узагальнених Fup-функцій, які є цілком природним узагальненням Fup-функцій В. О. Рвачова, асимптотично екстремальні для наближення періодичних диференційованих функцій. У термінах поперечника за А. Н. Колмогоровим це означає, що ці функції так само ефективні, як і класичні тригонометричні поліноми {1, cos(nx), sin(nx)}. Тому заміна дискретних перетворень, що базуються на тригонометричних функціях, на відповідні перетворення, які будуються за допомогою атомарних функцій та узагальнених Fup-функцій, є перспективною. З цією метою ми вводимо у розгляд дискретне атомарне перетворення та узагальнене дискретне атомарне перетворення. Ми також розглянемо залежність результатів обробки даних від порядку гладкості та розміру носія. Основним результатом роботи є теоретичне обґрунтування ефективності атомарних функцій та узагальнених Fup-функцій в обробці даних та стисненні інформації.

**Ключові слова:** обробка даних; стиснення інформації; атомарні функції; up-функція; Fup-функція; узагальнена Fup-функція; дискретне атомарне перетворення; узагальнене дискретне атомарне перетворення.

**Брисіна Ірина Вікторівна** – канд. фіз.-мат. наук, доцент, доцент кафедри вищої математики і системного аналізу, Національного аерокосмічного університету ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

**Макарічев Віктор Олександрович** – канд. фіз.-мат. наук, доцент кафедри вищої математики і системного аналізу, Національного аерокосмічного університету ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

**Brysina Iryna Victorivna** – PhD in Physics and Mathematics, Associate Professor of Department of Higher Mathematics and System Analysis, National Aerospace University "Kharkov Aviation Institute", Kharkov, Ukraine,   
e-mail: iryna.brysina@gmail.com.

orcid.org/0000-0000-0000-0000, [Scopus Author ID: 00000000000](http://www.scopus.com/inward/authorDetails.url?authorID=27867503300&partnerID=MN8TOARS), [ResearcherID: M-0000-0000](http://www.researcherid.com/rid/V-4024-2017)

https://scholar.google.com.ua/citations?user=0000000000000000

**Makarichev Victor Olexandrovych** – PhD in Physics and Mathematics, Associate Professor of Department of Higher Mathematics and System Analysis, National Aerospace University "Kharkov Aviation Institute", Kharkov, Ukraine, e-mail: iryna.brysina@gmail.com.

orcid.org/0000-0000-0000-0000, [Scopus Author ID: 00000000000](http://www.scopus.com/inward/authorDetails.url?authorID=27867503300&partnerID=MN8TOARS), [ResearcherID: M-0000-0000](http://www.researcherid.com/rid/V-4024-2017)

https://scholar.google.com.ua/citations?user=0000000000000000