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Management of complex security of enterprises using the symbolic method

The formalized description of the symbolic method (complex numbers) is presented, by means of which the complex value is determined in the form of the level of influence of causal factors on the damage caused by accidents and fires. On the example of enterprises of oil and gas complex of Russia the substantiation on use of the symbolic method by means of which there is a possibility to receive adequate results of an estimation is presented. It is proposed to use software developed with the use of the method of hierarchy analysis and pairwise comparisons, as well as the method of Bayesian Belief Network. As an output, the task of determining the complex influence weight coefficient assigned to the report on accidents and fires at the considered enterprises is solved.

Keywords: *oil and gas complex, integrated security system, symbolic method, cognitive maps, influence coefficient*

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INTRODUCTION

The article considers the problem of integrated safety management (hereinafter — ISM) at the enterprises of oil and gas complex in Russia (hereinafter — enterprises of OGC in Russia) and proposes an approach based on the use of symbolic method for its solution.

The relevance of the presented problem lies in the need for the development and improvement of new expert knowledge, the need to search for new ideas, methods and tools based on the application of a specialized approach to the analysis of accident occurrence statistics at Russian OGC enterprises, which has not been previously used in the ISM at Russian OGC enterprises. This article is a development of the basics of complex and cognitive modelling to improve the ISM at Russian OGC enterprises; it was started in the studies [1–5].

BASIC COMPONENTS FOR THE APPLICATION OF THE SYMBOLIC METHOD

The methodological basis for obtaining new knowledge is the interdisciplinary approach, it gives an opportunity for obtaining new results with the reasonable use of technologies applied in both related and distant fields of science. It is defined as the integration of two or more scientific areas, technologies, etc. [6–7]. If knowledge exists, then with theoretical justification and correct transfer from one scientific sphere to another, it can become a means for obtaining results in a new researched area. Such is the application of the symbolic method (complex numbers) [8–11], further on its basis the construction of a cognitive model to assess the existing system of integrated security (hereinafter — SIS) at Russian OGC enterprises. The mathematical apparatus of the symbolic method (complex numbers) is successfully applied in various fields, for example, to determine the magnitude of deviation of characteristics (current from voltage) in electrical engineering. The use of the method of the symbolic method (complex numbers), allows to represent the instantaneous value of the investigated characteristic in the plane through the proved relationship between trigonometric functions and the exponent. Their application makes it possible to compactly outline the sequence in the build-up and development of conditions for the occurrence of dangerous events (accidents and fires) that cause damage (material and economic, sanitary and irrecoverable losses of personnel and third parties).

In order to improve the state of SIS at Russian OGC enterprises, knowledge and experience gained from accidents and fires[1] are taken into account and attention is paid to those cases when the accident and fire occurred sequentially after each other. The analysis of cause-and-effect relationships leading to the emergence of regularities, when one dangerous event (accident or fire) became the primary factor, it became a source of damage to another interacting subsystem can be realized using the symbolic method (complex numbers).

It is reasonable to consider a complex number used for solving problems in SIS at Russian OGC enterprises as a point and as a vector. For example, there is a vector displayed on the plane as $0\bar{Z}$ (Fig. 1) and $\bar{Z}$ its complex coordinate. When it is rotated around the point 0 by the angle φ (anticlockwise), the complex coordinate will be displayed on the sinusoid as the instantaneous value of the time period displayed on the scale *t*.

A complex number can be considered as a directed vector, or as a point that belongs to a differentiated (instantaneous) time index. An important geometrical interpretation of a complex number is noted. There is a vector $0\bar{C}$ in the plane (Fig. 2) and *C* is its complex coordinate.

1 Website of the Russian Federal Service for Ecological, Technological and Nuclear Supervision. URL: https://www.gosnadzor.ru/ (accessed: 03.24.2023). (rus.).

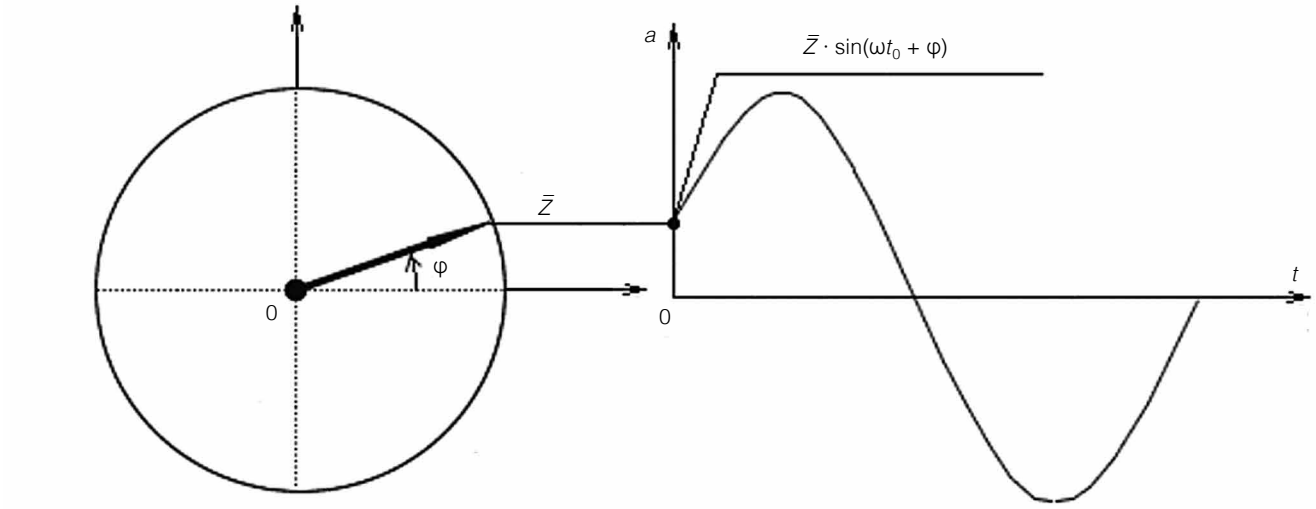

Fig. 1. Instantaneous value of a vector rotating on the plane

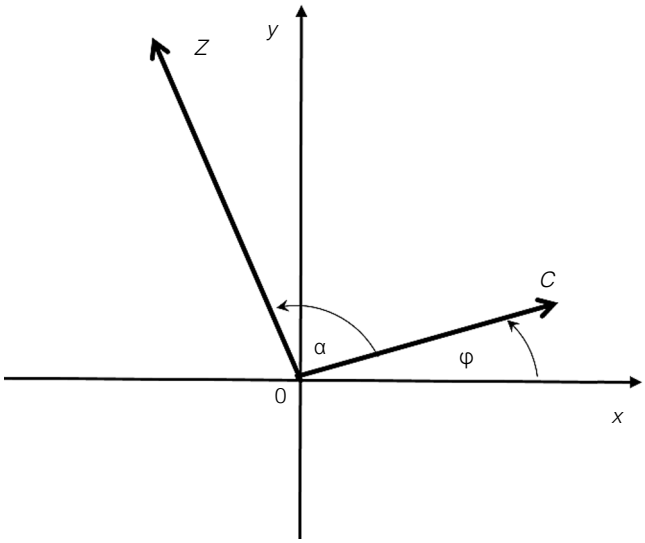

Fig. 2. Rotation of a vector on the complex plane

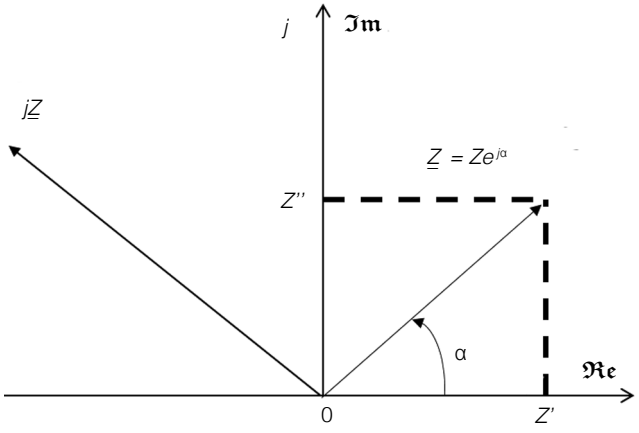

Fig. 3. Display of complex number values on the axes

When we rotate the vector around the initial point by an angle of α (anti-clockwise if α > 0, clockwise if α < 0) and stretch this vector by *n* times. As a result, a new vector $0\bar{Z}$ with complex coordinate *Z* will be obtained.

Any complex number $\underline{Z}$ can be represented (Fig. 3) in algebraic form:

$$\underline{Z} = Z' + jAZ'', \quad (1)$$

trigonometrically

$$Z = Z\cos\alpha + jZ\sin\alpha, \quad (2)$$

demonstratively

$$Z = Ze^{j\alpha}, \quad (3)$$

where

$$e^{j\alpha} = \cos\alpha + j\sin\alpha, \quad (4)$$

is called the Euler formula.

A vector on the complex plane, where $j = 1$, imaginary unit, $Z' = Z\cos\alpha$ is the real part of a complex number $\underline{Z}$ (projection of the vector onto the real axis of real $\mathfrak{Re}$ values); $Z'' = Z\sin\alpha$ is the imaginary part of a complex number $\underline{Z}$ (projection of the vector onto the imaginary $\mathfrak{Im}$ axis); $Z = |\underline{Z}| = \sqrt{Z'^2 + Z''^2}$ is the modulus of a complex number.

Since $e^{\pm\frac{\pi}{2}} = \pm j$, multiplying the complex number $\underline{Z}$ by *j* will increase its argument by $+\frac{\pi}{2}$ and rotate the vector representing the complex number $\underline{A}$ by an angle $+\frac{\pi}{2}$ in the positive direction, and multiplying by (–*j*) will decrease its argument by $-\frac{\pi}{2}$ and rotate the vector by the same angle in the negative direction.

Two complex numbers having equal moduli and equal but opposite in sign arguments are called conjugates.

For a complex number $\underline{Z} = Z' + jZ'' = Ze^{j\alpha}$, the conjugate is the complex number $\underline{Z}^* = Z' - jZ'' = Ze^{-j\alpha}$, with $\underline{Z}\underline{Z}^* = Z^2$.

Conclusion: any complex number, using the expression (4), can be represented in trigonometric form:

$$Ze^{j(\omega t + \varphi)} = Z\cos(\omega t + \varphi) + jZ\sin(\omega t + \varphi). \quad (5)$$

RATIONALE FOR THE USE OF SYMBOLIC METHOD FOR SOLVING PROBLEMS IN COMPLEX SECURITY OF ENTERPRISES

To assess the factors influencing the occurrence of joint hazardous events (accidents and fires) it was necessary to analyze the data on accidents[2] and fires[3] for the period of 7 years during which there were accidents according to Rostechnadzor statistics — 412 cases; fires according to the statistics of the Ministry of Emergency Situations of Russia — 1,354 cases; deaths of employees of enterprises — 227 people were recorded, about 600 people were injured. There were 21 cases of impact on the ecological environment [2].

The symbolic method (complex numbers) is based on the use of transformations of the investigated characteristics, which are presented (see Fig. 4).

On the upper part of the graph with the axis $\mathfrak{Re}$ and $\mathfrak{Im}$ values, the areas of primary and secondary influencing factors from accidents — *I*, fires — *U*, are presented, where each of the considered hazardous events can occupy the corresponding area.

The complex value on the influence of factors causing damage from hazardous events (accidents and fires) is a vector, considered as indicators *Z* for the domain of primary factors and *C* for secondary factors, mapped to an angle of deviation φ; –φ. The angle α will be used in the calculations for the equivalent determination of the magnitude of influence on damage from hazardous events (accidents and fires). In complex form, the record can be represented as a system of equations:

$$\left.\begin{aligned} \underline{I} &= Ie^{j(\pm\pi/2\pm\varphi)} \\ \underline{U} &= Ue^{j(\pm\pi/2\pm\varphi)} \end{aligned}\right\}. \qquad (6)$$

The essence of using the symbolic method (complex numbers) is that using the above transformations it is possible to go from the system of differential equations for real functions of time to the system of algebraic equations with influencing complex indicators of damage from accidents and fires. Transition from differential equations to complex equations is carried out by replacing in them instantaneous values of primary and secondary influencing factors *I*, *U* (formulas (1)–(6)).

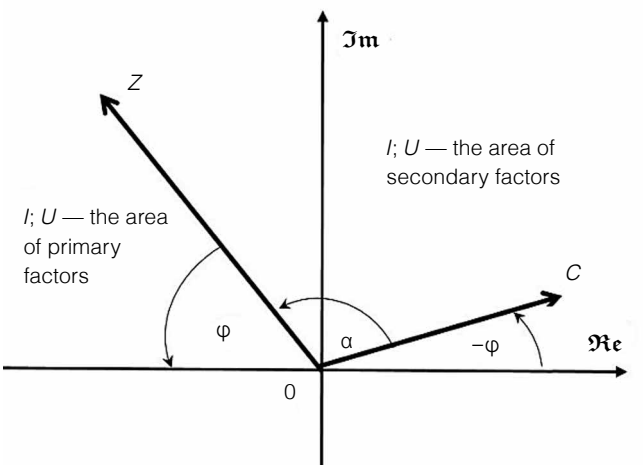

Fig. 4. Areas under consideration and characteristics displayed on the axes

In equation (6), the indicator *e,* is considered as a numerical value displayed as a level value of the influencing value of the occurrence of a hazardous event (accident and fire), its indicator is required to be determined using sound methods.

EXAMPLE ON THE USE OF THE SYMBOLIC METHOD TO ASSESS THE IMPACT OF ACCIDENTS AND FIRES ON THE INTEGRATED SAFETY OF ENTERPRISES

The total damage *U* at the enterprises of OGC of Russia was calculated through the sum of damages related to the types of its component processes of production $U_{(E, P, S, T, Ot)}$, inflicted to the objects of technosphere protection (personnel, materiel and equipment), which was evaluated taking into account quantitative indicators: human losses (sanitary and irrecoverable); by economic damage in rubles (Table 1).

$$U = F_U\{U_E, U_P, U_S, U_T, U_{Ot}\} = \\ = \sum\left[F_{U_{(E,P,S,T,Ot)}}(U_E, U_P, U_S, U_T, U_{Ot})\right]\cdot q_{(0.1-1)}, \qquad (7)$$

where *E* — extraction; *P* — processing; *S* — storage; *T* — transportation; *Ot* — other.

The framework for selecting indicators with the normalizing factor *q* is determined with the help of experts, its values are presented in Table 1.

Further, to carry out calculations using the symbolic method (complex numbers), it is proposed to use a vector-directional symmetric model (Fig. 5).

A symmetric model for assessing the influence of causal factors related to the analyzed accident reports, in the content of which are presented the areas *I* and *U* — primary and secondary factors. Each domain is equipped with a limit level measured in degrees from the axis with real $\mathfrak{Re}$ — values.

To assess the factors affecting the damage caused by accidents and fires, we used the symbolic method (complex numbers) and the programme "*Rating Data Generator for the assessment of industrial and fire safety at enterprises of the oil and gas complex of Russia*" designed to create a rating list of activities that caused

Table 1. Examination results for the use of the normalizing factor q

q	Casualties, persons	Victims, persons	Damage, thousand roubles
q = 1	> 5	> 20	> 50,000.0
q = 0.9	3 to 5	10 to 20	from 1,000.0 to 50,000.0
q = 0.8	1–2	5 to 10	from 1,000.0 to 50,000.0
q = 0.7	–	1 to 5	from 1,000.0 to 50,000.0
q = 0.6	–	–	> 50,000.0
q = 0.5	–	–	from 1,000.0 to 50,000.0
q = 0.4	–	–	from 1,000.0 to 50,000.0
q = 0.3	–	–	500.0 to 1,000.0
q = 0.2	–	–	from 500.0
q = 0.1	–	–	–

2 Information on accidents at Russian oil and gas companies. URL: https://www.gosnadzor.ru/industrial/oil/lessons/

3 Letter from the Head of FSBI VNIIPO of the Ministry of Emergency Situations of Russia "On submission of fire record cards" No. 652 1 29 11 6 dated 06.04.2020.

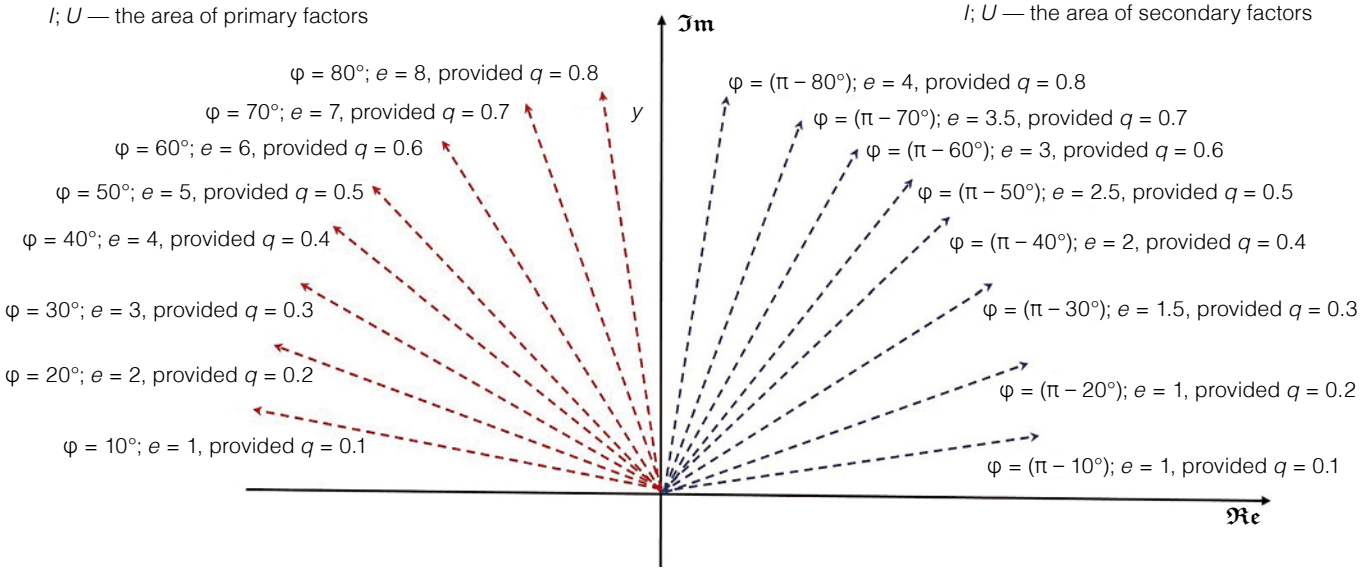

Fig. 5. Symmetric model for determining the assessment of the influence of factors

the occurrence of dangerous events (accidents and fires)[4] [13]. The general rating list can be specified for each of the directions of functioning of the production process considered for the enterprises (*E*; *P*; *S*; *T*; *Ot*). In addition, each of the activities presented in the list can be analyzed using the programme "Netica", which will provide an output for each cause — the indicator of recurrence for the period under study. Further, for each report from the generated sample of accident and fire statistics, it will be possible to determine its own estimated level of impact on damage. An example with a fragment of indicator selection is presented (see Table. 2 and Fig. 6).

The results presented in the table are reflected in the vector diagram (Fig. 6), taking into account the peculiarity of the frequency of recurrence of events during the study period (i.e. during the year).

For evaluation of the report No. 1 with organizational measures (Table 2) the indicator put off on the axis of imaginary Im values from the area of primary factors will correspond to 0.9, and from the area of secondary factors will correspond to the indicator 0.45. To determine the value of influence of *Z* causal factors of organizational

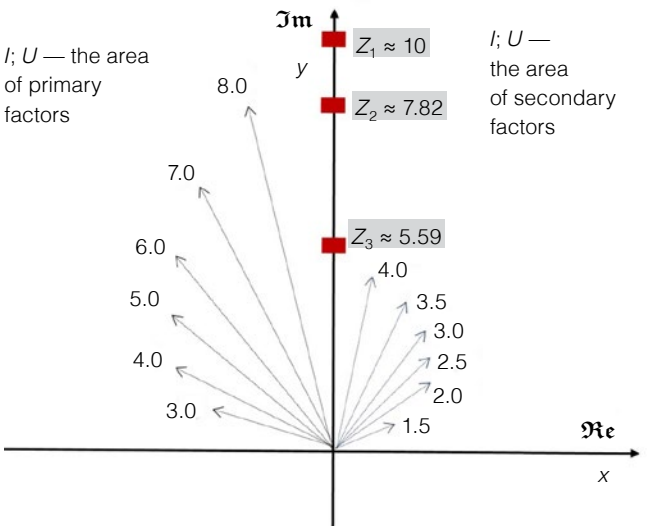

Fig. 6. Model showing the results of the integrated assessment indicators

Table 2. Information with reports on organizational and technical causes of damage from accidents

Date	Enterprise	Organizational reasons	Casualties, pers.	Injured, pers.	Damage, thousand roubles	Regulatory coefficient *q*	Repetition rate (per period)*
19.04. 2019	PJSC Nizhnekamskneftekhim TAIF Group of Companies	Violation of the procedure for carrying out preparatory work for scheduled repairs of process equipment …	4	13	4,200.0	0.9	1
06.02.2015	LLC LUKOIL-Perm, LLC Universal Stroy, OJSC LUKOIL	Violation of the technology of construction and installation works at an operating field gas pipeline	–	1	1,466.0	0.7	1
18.06.2017	SUE MR Mosoblgaz, Mytishchimezhraygaz	Work in the protection zone of an underground gas pipeline without written permission from the organization operating the gas distribution network	–	–	899.0	0.3	3

** for each increase in the frequency of occurrence of a hazardous event >1, one level rank higher from the domain of primary and secondary factors of the vector-directional symmetric model is added.*

4 Gvozdev E.V., Migalchinskiy N.M., Koldin T.E., Sinyakin D.S. State Registration Certificate for Computer Software No. 2023611653, Russian Federation. Rating data maker for evaluation of industrial and fire safety at enterprises of oil and gas industry of Russia. No. 2023610660; appl. 01.16.2023; publ. 01.24.2023. (rus.).

causes on the level of inflicted damage (Fig. 6) it is advisable to perform an algebraic calculation according to the formula:

$$Z = \sqrt{A_1^2 + A_2^2}, \quad (8)$$

where A_1 and A_2 are indicators with results taken from the areas of primary and secondary factors affecting damage.

Estimated indicators in the form of coefficients affecting the level of damage caused by accidents for reports No. 1–3 are presented below (see Table 2), where:

$$Z_1 = \sqrt{9^2 + 4.5^2} \approx 10.0;$$

$$Z_2 = \sqrt{7^2 + 3.5^2} = 7.82;$$

$$Z_3 = \sqrt{5^2 + 2.5^2} = 5.59.$$

CONCLUSION

The article substantiates the possibility of using the symbolic method (complex numbers) to solve problems in the management of SIS at Russian oil and gas companies. An example proving the adequacy of using the method described in the article in practice is presented.

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Управление комплексной безопасностью предприятий с использованием символического метода

Представлено формализованное описание символического метода (комплексных чисел), с помощью которого определяется комплексная величина в виде уровня влияния причинно-следственных факторов на наносимый ущерб от аварий и пожаров. На примере предприятий нефтегазового комплекса России представлено обоснование по использованию символического метода, с помощью которого имеется возможность получить адекватные результаты оценки. Предложено использовать программное обеспечение, разработанное с применением метода анализа иерархий и попарных сравнений, а также метода Байесовских сетей доверия. На выходе решается задача по определению комплексного весового коэффициента влияния, закрепленного за отчетом об авариях и пожарах на рассматриваемых предприятиях.

Ключевые слова: *нефтегазовый комплекс, система комплексной безопасности, символический метод, когнитивные карты, коэффициент влияния*

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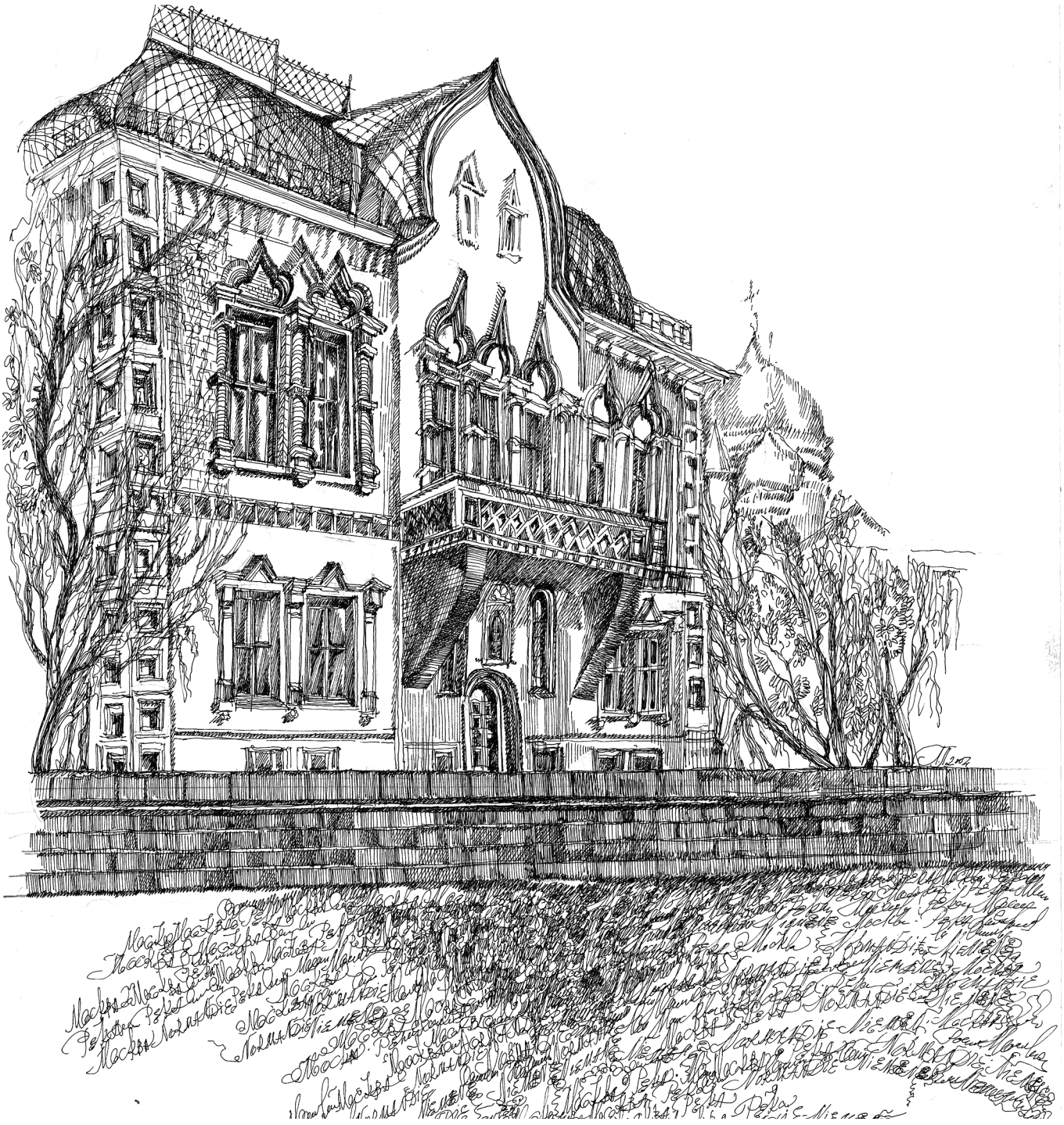

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