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Content

Transformation of the Ukrainian cities within post-Chornobyl and Post-totalitarian 'transitional' period

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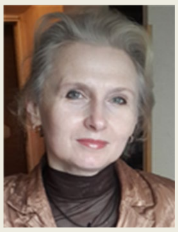

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Abstract. The study of the transformation of Ukrainian cities in the post-Chornobyl and post-totalitarian transition period highlighted a number of general development trends and regional features of the global urban process. Despite the socio-economic upheavals, Russia's military aggression and population decline, Ukraine has entered the 'human development high category' list of countries. Studies have shown that the country urbanization level continues to grow, while balancing its spatial development potential. This is evidenced by the emergence of the 'South-West Spatial Vector', the 'West Sector' and the 'Meridional Axis' of the urbanization process development. This indicates, first, the 'spatial structures memory', the presence of which allows us to interpret post-socialist transformations as a 'return to pre-socialist development trajectories' of Ukraine in common Pan-European space; secondly, on the cyclical development and reversibility of 'waves vibrational motion' of the world urban process; thirdly, the 'country urbanized space reaction' to the Russian military aggression in the East of Ukraine, the annexation of the Autonomous Republic of Crimea and part of the Donbas territories.

The specifics of the post-socialist development of the Kyiv Agglomeration reflect the new status of Kyiv and the general trend of development of the European metropolitan network, as well as the 'gravitational pattern' of spatial development, which is manifested by territorial uneven economic development and 'growth poles wave migration' from center to periphery and vice versa. The post-Chornobyl growth of the tourist attractiveness of the Chornobyl Exclusion Zone, where 80% of visitors are foreigners, will contribute to the further transformation of Ukrainian cities. In particular, air communication − the development of Kyiv and the Kyiv Agglomeration; roads − development of bordering cities in the west and south of the country, as well as cities in the areas of Pan-European transport corridors influence; railway - the development of Kyiv, Chernihiv, Slavutych; the Dnipro - Visla waterway project implementation, the pur-

pose of which is the connection of the Baltic and Black Seas - the development of city-river ports along the Dnipro and Pripyat Rivers.

Keywords: urban processes, environmental and town-planning systems, cities, settlement systems, post-totalitarian period, Chernobyl exclusion zone (area of alienation).

INTRODUCTION

35 years passed since April 26, 1986, when the Chornobyl nuclear disaster took place, which, according to the AEC (INES) International scale, was classified as the danger highest - seventh level, with the radioactive cloud covering most of Europe. Then within a 30 kilometers radius around the Chornobyl nuclear power plant more than 115 thousand of Polissya inhabitants were evacuated and more than a 2,500 sq. km territory was separated from adjacent territories and transferred to the radiation-hazardous lands category [1]. It will soon be 30 years since August 24, 1991 − the date of the declaration of independence of Ukraine. What happened to us during this period? What happened to the cities we live in?

Nowadays Ukraine adopted the Law "On the National Program of Decommissioning of the Chornobyl NPP and Shelter Transformation into an Environmentally Safe System", according to which the NPP should be liquidated by 2065. Therefore, among the topics of the great interest in the world is Chornobyl Tourism - the opportunity to visit the Chornobyl Exclusion Zone and the zone of unconditional (compulsory) resettlement for scientific and educational purposes.

The number of the Chornobyl zone visitors from 2014 to 2019 increased 15 times. According to the Center for Organizational, Technical and Information Support of Exclusion Zone Management State Enterprise' official website, 124 thousand people visited it in 2019, almost 80% of them are foreigners. Among the leading countries whose citizens visited Chornobyl: Great Britain − 18.5 thousand people, Poland − 10.4 thousand people, Germany − 9 thousand people, the United States – 6.4 thousand people, the Czech Republic – 4.6 thousand people [2, 3, 4].

Among the second 'attraction' of scientific interest in the world are the processes of urban development that are inherent in the countries that have long suffered due to communist totalitarian regimes [5, 6, 7]. Ukraine is one of these countries. In terms of population, it is the seventh (as of April 1, 2021 − 41.5 million people, excluding the temporarily occupied territory of the Autonomous Republic of Crimea) [8, 9], and in terms of area − the largest European country (603.6 thousand sq. km) [10]. The post-totalitarian transition period of the country's development, which began in 1991 on the post-Chornobyl background, after 2014 it was burdened by Russian military aggression − the occupation of the Autonomous Republic of Crimea and part of the territories in Donetsk and Luhansk regions.

Post-socialist transformations, as economic, political, institutional and ideological changes associated with the communism rejection in Central and Eastern Europe [5], are accompanied by complex and lengthy reconfigurations in many areas [11]. The projections of these changes in the urban space are the transformations of the country settlement system and the network of its populated cities. These changes in Ukrainian cities in the post-totalitarian transition period led to the layering in the 'globalization power field' of several identities: the past Soviet, national Ukrainian and the desired European [12].

As for political and democratic transformations, the transition period of Ukraine's development was marked by the revolutions of 2004 and 2013; reforming and decentralization of powers, with its transition to local self-government and transformation of the territorial-administrative system. In the socio-economic sphere, there was a transition from a planned economy to a market economy and privatization.

This has led to fundamental changes in the paradigm of urban planning (at least in practice): if during the socialist (Soviet) period it was the main subject of urban development, in the post-socialist period the state, being not the main subject that determines directions of urban development, belatedly responds to existing challenges [13].

In the demographic sphere of the country the depopulation process continues since 1993, which during the first decade occurred due to the accelerated reduction of its urban population on the background of further expansion of urban areas (Fig. 1) [14].

The environmental area of the country, based on environmental pollution problems, was marked by measures aimed at eliminating the consequences of the unprecedented in the history of mankind Chernobyl disaster [2]. These aspects of the transition period of Ukraine's development have determined the course of modern urbanization.

MATERIALS AND METHODS

The purpose of the study is to analyze the trends of urban development and transformation of Ukrainian cities in the post-Chornobyl and post-totalitarian transition period.

In the course of the work a systematic approach, methods of statistical and cartographic analysis were used, namely: the method of interval dynamic series, which is an effective means of assessing phenomena trends and patterns of development in time and space; chamber method, where the map acts as a model of the object under study and an intermediate link in the analysis of the spatial location and dynamics in the space of 'growing cities'.

Cities of Ukraine with a population of over 50 thousand people were selected for analysis; the period from 2001 to 2020 − after the first All-Ukrainian census and the 'abnormal decade' of depopulation due to the accelerated reduction of urban residents (see Fig. 1). The intermediate dates are 2014 and 2018 - the beginning of the Russian military aggression and the fourth year of the invasion.

STARTING POINT

Urban planning is a continuous and long process, which is conditioned by the transformation of spatial development systemic patterns, changing the spatial development ideology, its socio-economic basis, demographic situation, environmental factors and conditions. Management of this process, first of all, is connected with search of compromises between the purposes of development of ecological and town-planning system "population ↔ environment" at various stages and its spatial integrity level, and also constant adaptation of this development programs to new specific conditions [15, 16, 17].

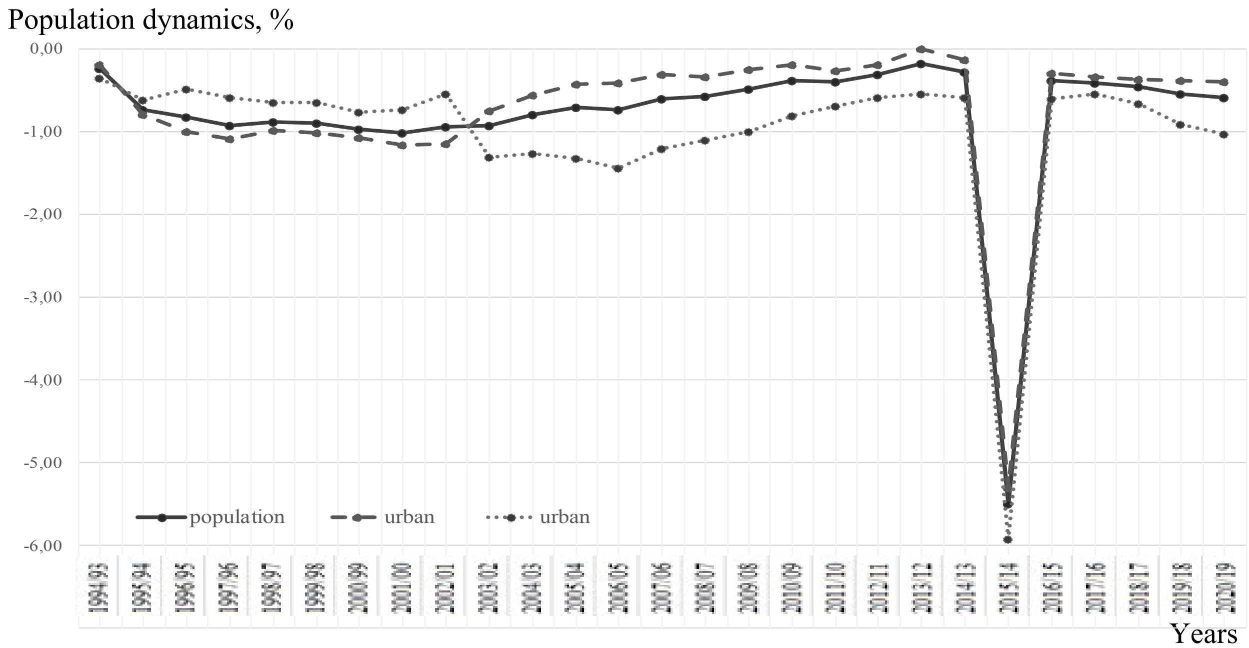


Fig. 1. The average annual population decline in Ukraine during the depopulation period from 1993 to 2020

There are general trends in urban development in a certain historical epoch [18, 19], but it is possible to identify specific regional features of the post-socialist transition period, which may later be signs of a new 'wave fluctuations' vector of the global urban process [6, 7, 20, 21, 22]. The relations between society and urbanization in the transition period function in a unique way at the levels of ideology, practice and urban change [23, p. 607].

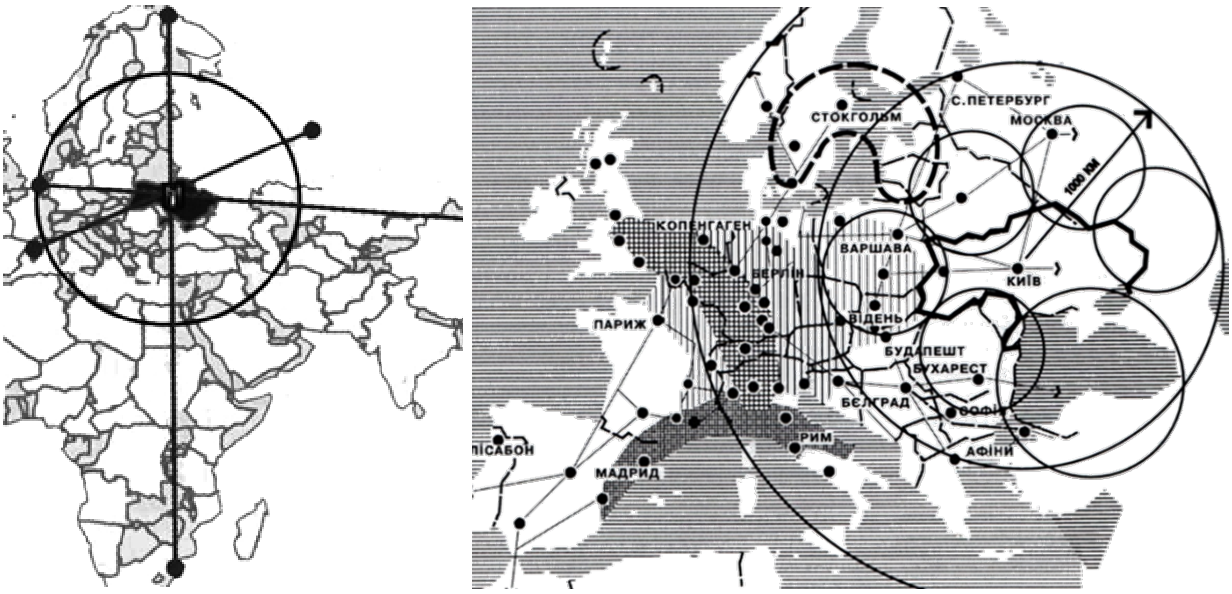
KYIV NEW GEOPOLITICAL STATUS

The contemporary Kyiv geopolitical status gives new impacts to Ukraine's movement towards consolidation with the European Community countries, it started in 1995. The new importance of the country in the Pan-European space and its multidisciplinary ties with the countries of Western Europe determines '... the need not only for political and economic integration of all countries of the European continent, but also for spatial planning' [20, p. 107]. In this context, taking into account the geographical location of Ukraine and the area of three-hour accessibility of Kyiv airports, covering almost all of Europe and North Africa (Fig. 2. a), the concept of '... Eastern European countries' planning integration of into a common European territorial structure – the concept of the 'extensive' European space organization in the long run, taking into account the general trends of political and economic process integration' (Fig. 2. b) [20, p. 107].

SOCIO-ECONOMIC AND DEMOGRAPHIC SITUATION

Regarding the socio-economic development of Ukraine, which is assessed by the UNDP annual reports on the 'human development index' (HDI takes into account the welfare of the population, life expectancy and learning). According to the UNDP Report on the human development for 2019, Ukraine is in the middle of the ranking, it ranks 88th among 189 countries [24, p. 23]. This includes Ukraine in the list of 'human development high category' countries (HDI = 0.75 [25]), despite the fact that for the period from 1990 to 2018 the welfare of the population, measured by gross national income per capita, decreased by 25.6% and since 1993 the population has been declining (see Fig. 1) [14].

That is, despite the socio-economic disturbance and Russia's military aggression, Ukraine is showing certain progress in human development. Thus, for the period from 1990 to



a *b*

Fig. 2. Kyiv airports three-hour accessibility (a) and the common Pan European planning space area of influence, by Yu. Bilokon (b)

2018, the HDI value increased by 6.4% (from 0.705 to 0.750); birth life expectancy increased by 2.1 years (from 69.9 years in 1990 to 72 years in 2018); the study years average figure − 2.2 years, the expected number of years of study - 2.7 years [25].

As for the demographic situation (in terms of population reproduction), during the period from 1990 to 2019 (not taking into account temporarily occupied territories data) birth rates in Ukraine decreased (from 12.6 to 8.1; average annual decrease − 1.26%) and mortality rates increased from 12.1 to 14.7, the average annual growth of 0.61%), which led to the population negative values acquisition natural growth rates (from + 0.5 to – 6.6) and following 1993 the country's population reduction (see Fig. 1) [14].

During the period of depopulation, which has been burdened by Russian military aggression since 2014 (occupation of the territory of the Autonomous Republic of Crimea and part of the Donbas), the population of Ukraine decreased by 19.7% (from 52.2 million in 1993 to 41.9 million in 2020, excluding the temporarily occupied territory of the Autonomous Republic of Crimea; average annual reduction − 0.73%). As for the urban population, during this period it decreased more slowly than the total population of Ukraine − by 18% (from 35.5 million people in 1993 to 29.1 million people in 2020; the average annual decrease - 0.67 %) [14].

Comparatively slower decline of the urban population (overall decline of 18 <19.7%; average annual decline of 0.67 <0.73%) indicates an overall increase in the urbanization level in Ukraine. Thus, for the period from 1993 to 2020 it increased by 1.7% (the share of urban population in 1993 − 68%, in 2020 - 69.7%) [14].

TRANSITION PERIOD URBANIZATION PROCESSES AS SOCIAL TRANSFORMATION REFLECTION

Statistical analysis of urban development processes found that in the period from 2001 to 2014 among 89 cities of Ukraine with a population of over 50 thousand people, the population grew only in 15 cities (Table 1) [26, 27]. In the period under study, among the biggest (over 800 thousand people) and big (over 500 to 800 thousand people) cities of Ukraine [28], only Kyiv grew in number (see Table 1). As for the relatively faster than in Kyiv average annual population growth (0.76%) in the cities, it should be noted that the cities of Brovary (1.07%) and Boryspil (0.88%) are part of the Kyiv Agglomeration and they are located in the first belt of Kyiv satellite cities - at a distance of 25 and 39 km, respectively; and Chornomorsk (0.81%) is one of the largest seaports in the country.

Cartographic analysis of ‘growing cities’ spatial location on the map of Ukraine showed the southern, in relation to the Kyiv Agglomeration spatial vector of average annual accelerated urban growth and ‘fading power’ of growth of the outlying ones from the capital (1.07 → 0.88 → 0.81%) (Fig. 3.a).

Population dynamics analysis of these cities in the period from 2014 to 2018 showed that among the 15 cities whose population grew in the previous period (see Table 1), only 8 cities in Ukraine continue to grow (no information is available regarding the cities of Sevastopol and Evpatoria,) (Table 2) [26, 27, 29]. The city of Irpin joined the group of growing cities in 2017 (50.4 thousand people [30]).

In the period under review, only Kyiv continues to grow among the big and biggest cities in the country (see Tables 1, 2).

Relatively faster than Kyiv (0.57%) growth in urban population (see Table 2), in the first zone of the Kyiv Agglomeration the cities of Brovary (1.24%) and Boryspil (0.68%) continue to grow; the fastest growing city is Irpin (5.3%), which is located 26 km from Kyiv, may be added to them (see Table 2).

In the period under review, compared to the previous period (see Tables 2 and 1), the growth of the city of Ivano-Frankivsk accelerated almost threefold (0.31 → 0.92%). This ‘turned’ the country spatial vector of the growing cities location from south to southwest (Fig. 3.b).

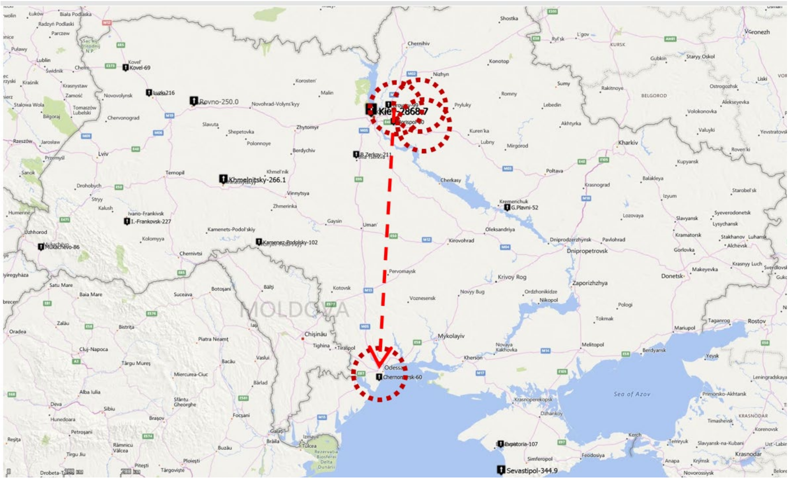
Table 1. Growing cities of Ukraine with a population of over 50 thousand people in the period from 2001 to 2014

	City	Number of available population (people)		Average annual population growth, (%)
		2001 [1]	2014	
1.	**Kyiv**	2 611 327	2 868 702	**0,76**
2.	Sevastopol	342 451	344 853	0,05
3.	Khmelnitskyi	253 994	266 095	0,37
4.	Rivne	248 813	249 912	0,03
5.	Ivano-Frankivsk	218 359	227 030	0,31
6.	Lutsk	208 816	216 076	0,27
7.	Bila Tserkva	210 128	211 205	0,04
8.	Evpatoria	105 915	107 040	0,08
9.	Kamyanets Podilskyi	99 610	102 254	0,20
10.	**Brovary**	86 839	98 874	**1,07**
11.	Mukacheve	82 346	85 487	0,29
12.	Kovel	66 401	69 032	0,30
13.	**Boryspil**	53 975	60 160	**0,88**
14.	**Chornomorsk**	54 151	59 840	**0,81**
15.	Horishni Plavni	51 740	51 958	0,03
16.	Irpin [2]	40 593	44 023	0,65

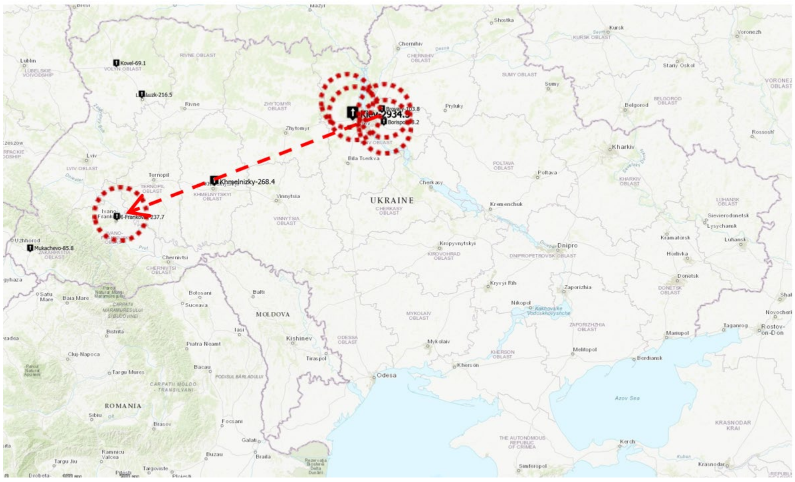
Notes:
1. according to the All-Ukrainian census of December 5, 2001
2. to be included in the group of cities under study in 2017

Table 2. Growing cities of Ukraine with a population of over 50 thousand people in the period from 2014 to 2018 (no information available on the cities of the Autonomous Republic of Crimea)

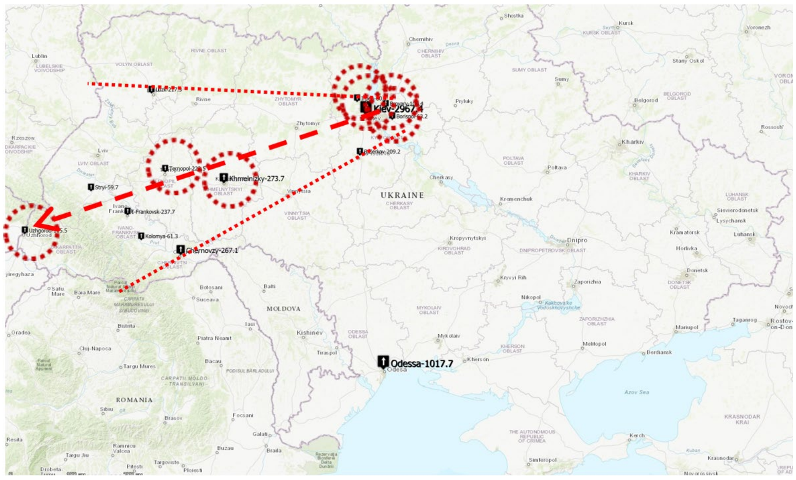
	City	Number of available population (people)		Average annual population growth, (%)
		2014	2018	
1.	**Kyiv**	2 868 702	2 934 522	**0,57**
2.	Khmelnitskyi	266 095	268 417	0,22
3.	**Ivano-Frankivsk**	227 030	237 686	**0,92**
4.	Lutsk	216 076	216 505	0,05
5.	**Brovary**	98 874	103 787	**1,24**
6.	Mukacheve	85 487	85 796	0,12
7.	Kovel	69 032	69 089	0,02
8.	**Boryspil**	60 160	61 807	**0,68**
9.	**Irpin**	44 023	**53 361**	**5,3**



a. 2001 – 2014



b. 2014 – 2018



c. 2018 – 2020

Chornobyl NPP Exclusion zone

Cities with growing populations *growing faster than Kyiv*

Spatial vector and *Urbanization process spatial sector*

Fig. 3. Cities of Ukraine with a population of over 50 thousand people where the number increased in the period from 2001 to 2020

The analysis of the cities' population dynamics in the period from 2018 to 2020 showed that in the trend of 8 cities, the population of which has been growing since 2001 (see Tables 1, 2), there are only 6 left, these are Kyiv, Khmelnytskyi, Ivano-Frankivsk, Lutsk, Brovary and Boryspil; The city of Bila Tserkva renewed its growing (see Table 1) and 6 'new growing cities' were added: Odessa, Chernivtsi, Ternopil, Uzhhorod, Kolomyia, and Stryi (Table 3) [29].

It should be noted that in the period under review, the second largest growing city of Odessa appeared for the first time (over 800 thousand people); among the growing big cities − Chernivtsi (over 250 to 500 thousand people), among the medium − Ternopil, Uzhgorod, Kolomyia and Stryi (over 50 to 250 thousand people) [28] (see Table 3).

The appearance of the second biggest city of Odessa, growing after Kyiv, testifies to certain 'spatial alignment' of the country's urban development potentials along the North-South axis (Fig. 3. c).

As is known, at the end of the 19th − beginning of the 20th century, Odessa was significantly ahead of Kyiv development in its dynamics, because then its industrial and demographic potential significantly exceeded the potential of Kyiv [19].

The emergence of five 'new growing cities' in Western Ukraine (Chernivtsi, Ternopil, Uzhhorod, Kolomyia, Stryi) in addition to the three cities that have been growing since 2001 (Khmelnytskyi, Ivano-Frankivsk, Lutsk) has significantly strengthened the south-western 'urbanization spatial vector process', which was faster than of Kyiv (0.56%); growth of Ternopil (1.1%), Khmelnytskyi (0.99%), Uzhgorod (0.66%) and the 'western spatial sector' formation of the growing cities of Ukraine with a population of over 50 thousand people (see Fig. 3.c).

Relatively faster than Kyiv (0.56%) average annual population is the growth in the cities of the Kyiv Agglomeration. In the first zone, the cities of Irpin (6.3%), Brovary (2.2%) and Boryspil (1.1%) continue to grow steadily. In addition, in the second belt of satellite cities, the city of Bila Tserkva (0.01%), located at a distance of 89 km from Kyiv, began to grow again (see Fig. 3. a, c).

The specifics of Kyiv Agglomeration first belt urban growth. In the near zone of Kyiv influence (up to 40 km) the 'gravitational tendency' continues to gain momentum of [31] acceleration the average annual population growth of the cities of Irpin (0.65 → 5.3 →

Table 3. Growing cities of Ukraine with a population of over 50 thousand people in the period from 2018 to 2020

	City	Number of available population (people)		Average annual population growth, (%)
		2018	2020	
1.	**Kyiv**	2 934 522	2 967 360	**0,56**
2.	Odessa	1 011 494	1 017 699	0,31
3.	**Khmelnytskyi**	268 417	273 713	**0,99**
4.	Chernivtsi	265 682	267 060	0,26
5.	Ivano-Frankivsk	235 355	237 686	0,50
6.	**Ternopil**	218 653	223 462	**1,10**
7.	Lutsk	216 505	217 315	0,19
8.	Bila Tserkva	209 176	209 238	0,01
9.	**Uzhorod**	113 996	115 512	**0,66**
10.	**Brovary**	103 787	108 349	**2,20**
11.	**Boryspil**	61 807	63 169	**1,10**
12.	Kolomiya	60 993	61 265	0,22
13.	Stryi	59 099	59 730	0,53
14.	**Irpin**	53 361	60 084	**6,30**

6.3%), Brovary (1.07 → 1.24 → 2.2%) and Boryspil (0.88 → 0.68 → 1.1%), which are located at a distance of 26, 25 and 39 km from Kyiv, respectively.

The accelerated growth of these satellite cities is due to the availability of jobs in the capital and lower housing costs in its suburbs. The reverse side of the 'first zone overheating' is the Kyiv Agglomeration core 'cooling', which is manifested by a 'reversible slowdown' of the average annual population growth of Kyiv (0.76 → 0.57 → 0.56%) (see table. 1, 2, 3, Fig. 3) [21, 22].

This is a manifestation of the general 'gravitational pattern' of space development [31], which is manifested in the territorial inequality of economic development of countries, and regions, disparities in income and living standards. As noted in the World Bank's 2009 World Development Report, prosperity leads to the economy 'oversaturation'; as a result of which there is an economic activity 'overflow', but only in those areas that are closely associated with prosperous areas' [32, p. 16].

This causes business activity 'overflow' from the biggest cities to the space of urban agglomerations, which in turn leads to cyclical spatial development: alternating transition from centralized to decentralized forms of settlement and the emergence of 'gravitational waves' that circularly spread from urban cities to the peripheral urban areas [31].

Both these tendencies of contemporary urban development in the near zone of Kyiv influence demonstrate this, as well as the emergence of the 'western urbanization spatial sector process' from the eight growing cities of the country in Volyn, Lviv, Ternopil, Khmelnytskyi, Ivano-Frankivsk, Zakarpattia and Chernivtsi that are in the near area of the European Union influence (see Fig. 3.c).

No doubt, these processes are a manifestation of the post-totalitarian transformation of the urbanization space of Ukraine, a projection of social transformation and the reaction of this space to the Russian military aggression in the East of the country with the annexation of the Autonomous Republic of Crimea. The strengthening of the south-western 'spatial vector' and the emergence of the western 'spatial sector' of the urbanization process (see Fig. 3) may indicate the 'memory of spatial structures', the presence of which allows to interpret post-socialist transformations as 'return to pre-socialist development trajectories' [33, p. 558; 15] of Ukraine in a common European political, economic and planning space (see Fig. 2).

The western region of Ukraine is bordering the European Union (Poland, Slovakia, Hungary, Romania), whose development is supported by the EU's spatial policy, including the new philosophy of governance [34], which directly relate to the development of metropolises and the metropolisation process [35].

In the context of balancing spatial potentials and adaptive management of sustainable development of territories, the experience of metropolisation can be useful in the post-totalitarian transition period of Ukrainian cities development.

METROPOLIS ESTABLISHMENT AND TRANSFORMATION OF HISTORICAL CITIES

The international significance and metropolitan functions concentration (organization and management, economic, information-representative, cultural, innovation-creative, transport and communication, social) gives cities the status of a metropolis. These cities are the 'poles of growth', on which depends the development of the surrounding area [35, p. 34 − 35].

According to research, the assessment of the implementation level of these functions in the cities − regional centers of Ukraine for 2005−2014 showed that Kyiv falls under the status of a regional metropolis in the European metropolitan network (see Fig. 2), and Kharkiv, Odessa, Dnipro, Donetsk and Lviv − under the status of regional metropolises as part of the national metropolitan network. The specialization of the Donetsk metropolitan functions development (until 2014) was administrative and economic; Dnipro - investment and economic; Kharkiv − educational-scientific, innovative; Odessa − political, logistical, cultural and tourist; Lviv − political, transport, cultural and tourist [35, p. 456].

As for the development of metropolitan functions in Western Ukraine regional centers, their potential is enhanced by the emergence of new types of economic activity. Realization of their potential, taking into account the features of these cities (Lutsk − mechanical engineering; Rivne − mechanical engineering, manufacturing; Uzhgorod − mechanical engineering, logistics; Ternopil − educational center, agro-industrial complex; Chernivtsi − educational center, trade; Ivano-Frankivsk − educational center, mining industry), will contribute to the inflow of additional resources (human, financial, material) [35, p. 34-36].

The effect of metropolization global processes in the post-totalitarian transition period of development of Ukrainian cities was revealed by our research (see Fig. 3).

The transformation of historical cities, the ‘crossroads of civilizations’ [34]. Now these cities face the dilemma of preserving the existing ‘spatial-planning environment’ and the need for further active use of historical and cultural potential. In historical cities monuments of different eras and styles are closely situated, coordinated and coexist, the appearance of cities reflects the patterns of the past and present. The main criterion for the transformation of such cities in modern conditions is their architectural and artistic succession and an acceptable level of reconstruction.

Cultural and architectural monuments should not be exclusively museum exhibits in the authentic environment of the historic city. They must be adapted to contemporary needs, which can be one of the radical ways to preserve them. Creative searches of Ukrainian architects in the field of reconstruction of historic cities, in particular in recent years, present a wide range of using the heritage of historic cities for various functions: cultural and educational (cinemas, exhibitions, libraries, educational centers); museum (city history museums; lifestyle museums); travelling (historical and architectural reserves, tourist services, hotels) [4].

The global attractiveness of Chornobyl tourism; the main task of which is the awareness of humanity of the nuclear catastrophe scale and its environmental and humanitarian consequences. It should be noted that the natural and architectural-landscape heritage of the exclusion zone can become an independent unique object of cultural-cognitive, research, educational-ecological, sentimental and religious (since the 18^{th} century Chornobyl was one of the Hasidism centers in Ukraine) tourism [2, 4].

CONCLUSIONS

1. Despite the socio-economic disturbance in the post-totalitarian transition period and Russia's military aggression, according to UNDP, Ukraine is among the ‘human development high category’ countries and it shows certain progress in this direction. Thus, during the period from 1990 to 2018, the human development index value increased by 6.4% (from 0.705 to 0.750).

2. Along with the population decline in Ukraine, the level of country urbanization continues to grow. Thus, during the period of depopulation - from 1993 to 2020 the population decreased by 19.7% (from 52.2 to 41.9 million people, excluding the temporarily occupied territory of the Autonomous Republic of Crimea), and the share of urban population increased by 1, 7% (from 68 to 69.7%), which is the evidence of cities ‘gravitational influence’ increase.

3. During the transitional period of development of Ukrainian cities there is a balancing of spatial development potentials of Ukraine. This is evidenced by the appearance in the south of the country following 2018 the second largest growing city after Kyiv – Odessa, and in the west - five growing cities with a population of over 50 thousand people (Chernivtsi, Ternopil, Uzhgorod, Kolomyia, Stryi), in addition to three cities that were growing after 2001 (Khmelnytskyi, Ivano-Frankivsk, Lutsk). This may help to renew the urbanization process along the North-South axis and strengthen its role in the ‘western spatial sector’ of the growing cities in Ukraine, which are the nearest to the European Union border.

4. The appearance of Kyiv − Odessa Meridional axis, the south-west 'urbanization process spatial vector', which turned out to be swifter than the Kyiv growth, with the cities of Ternopil, Khmelnytskyi, Uzhhorod and the strengthening of the 'west urbanization process spatial sector', may indicate: first, the 'memory of spatial structures', the existence of which allows us to interpret post-socialist transformations as a 'return to the pre-socialist development trajectory' of the country in a common Pan-European space; secondly, the cyclical development and movement reversibility in the 'urban process world waves'; third, the 'reaction of the urbanization space' of Ukraine to the Russian military aggression in the East of the country with the annexation of the Autonomous Republic of Crimea and part of the Donbas territories.

5. The features of the Kyiv Agglomeration post-socialist development reflect the new status of Kyiv as a regional metropolis in the European metropolitan network, and the general 'gravitational pattern' of spatial development, which is manifested in territorial inequality of economic development and 'pole growth migration'. This manifest itself in the acceleration of the average annual population growth of the cities of Irpin, Brovary and Boryspil, which are located in the Kyiv nearest area of influence (up to 40 km), and the reversible slowdown in the average annual population growth in Kyiv.

6. The post-Chornobyl growth of the Chornobyl Exclusion Zone attractiveness, where 80% of visitors are citizens from 130 countries, will contribute to the further transformation of Ukrainian cities. In particular, airway connection will positively influence the development of Kyiv and the Kyiv Agglomeration; road connection - development of west and south border cities, as well as cities in the area of influence of Pan-European transport corridors №3, №5 and №9; railway connection − development of Kyiv, Chernihiv and Slavutych; implementation of the Dnipro-Visla waterway E40 Project, the purpose of which is to connect the Baltic and Black Seas − the development of river ports on the Dnipro and Pripyat Rivers, namely: Kherson, Nova Kakhovka, Nikopol, Zaporizhya, Dnipro, Kamyanske, Kremenchuk, Cherkasy, Kyiv and Chernobyl.

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Трансформация украинских городов в пост-Чернобыльский и пост-тоталитарный «переходный» период

Николай Дёмин, Тамара Панченко, Ирина Устинова

Аннотация. Исследованием трансформации украинских городов в пост-Чернобыльский и пост-тоталитарный переходный период выявлен ряд общих тенденций развития и региональные особенности мирового урбанистического процесса. Несмотря на социально-экономические потрясения, вооруженную агрессию России и сокращение численности населения, Украина вошла в перечень стран «высокой категории человеческого развития».

Исследования показали, что уровень урбанизации в стране продолжает расти, при этом происходит балансировка потенциалов ее пространственного развития. О чем свидетельствует появление «меридиональной оси», «юго-западного пространственного вектора» и «западного сектора» развития урбанизационного процесса в Украине.

Отмеченное может указывать, во-первых, на «память пространственных структур», наличие которых позволяет интерпретировать постсоциалистические трансформации как «возвращение к досоциалистическим траекториям развития» Украины в едином Пан-Европейском пространстве; во-вторых, о цикличности развития и реверсивности «колебательного движения волн» урбанистического процесса; в-третьих, о «реакции урбанизированного пространства» страны на российскую вооруженную агрессию на востоке Украины с оккупацией АР Крым и части территорий Донбасса.

Специфика постсоциалистического развития Киевской Агломерации отражает новый статус Киева и общую тенденцию развития европейской метрополитарной сети, а также «гравитационную закономерность» освоения пространства, которая проявляется территориальной неравномерностью экономического развития и «волновой миграцией полюсов роста» от центра к периферии и обратно.

Пост-чернобыльский рост туристической атрактивности Чернобыльской зоны отчуждения, 80% посетителей которой иностранцы, может содействовать дальнейшей трансформации украинских городов. В частности, авиасообщение – развитию Киева и Киевской Агломерации; автомобильное – развитию приграничных городов запада и юга страны, а также городов в зонах влияния Пан-Европейских транспортных коридоров; железнодорожное – развитию Киева, Чернигова, Славутича; реализация проекта Днепровско-Вислянского водного пути, назначением которого является соединение Балтийского и Черного морей – развитию городов-речных портов вдоль рек Днепр и Припять.

Ключевые слова: урбанистические процессы, эколого-градостроительные системы, города, системы расселения, пост-тоталитарный период, зона отчуждения Чернобыльской АЭС.

Synthesis of Arts in Soviet Architecture: stages of development, main directions, causes of their occurrence

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Abstract. The history of the Soviet Union, its socio-economic, socio-political and socio-cultural life is unique in comparison with other countries. The USSR was created on the model of social development, expressed by European and Russian Utopian socialists and was grounded in the classics of Marxism-Leninism. So, the system of government, economic conditions and cultural activities of a society built on the hegemony of the proletariat was a long-running social experiment that conditioned the life of the Soviet people and influenced other countries as well.

The experiment of a country with total state property envisaged that the party leadership assumed responsibility for defining all spheres of political life - both internal and interstate relations - and inevitably formed unified programs of cultural activity and social development, managed them, and financed and tightly controlled their implementation. The Soviet people, the so-called "working masses", were forced to live and act under uniform rules. Depending on the planning of the political, economic and social life of the party leadership throughout the existence of the USSR, the country went through several stages, which differed in the directions of forming an architectural and urban planning environment that had to meet the tasks of state and ideological character. Familiarizing yourself with this unique experience and finding the reasons for its formation is important for understanding the trends of social development in the twentieth century.

Keywords: Soviet Union, Ukraine, socio-cultural activities, influence of political and economic conditions, architecture and urban planning.

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THE INTRODUCTION

It is known that for a complete idea of the depth and essence of the impact of cultural heritage on social development, it is necessary to study the historical heritage, analyze its value for the present, look for reasons for its formation in the past. Due to the length of time consideration, you can see a complete picture of cultural dynamics and forecast it for the future.

During the existence of our country in the USSR, together with it, Ukraine has undergone joint processes of economic development and state formation. It is important to study the parallels of the socio-historical and cultural development of the country in order to find the identity of architectural and cultural development and to justify the causes of Ukrainian identity when they exist, as well as to find out the ways of using the synthesis of arts in Ukrainian architectural and construction practice, which has always contributed to enhancing the desired effects in formation of architectural and urban planning environment.

THE PURPOSE OF THE RESEARCH

So, *the object of this study* is the synthesis of arts in the architecture of Soviet Ukraine. *The subject* is the role and directions of the use of art synthesis in the architecture of Soviet Ukraine. *The purpose of scientific research* is to identify the causes of the use of art synthesis in different historical periods of political and economic development of Ukraine and to establish their role and main directions.

THE METHODS OF THE RESEARCH

Research methodology – the causation between the political and economic situation, foreign and domestic policy directions and socio-cultural activities; comparative analysis of the consequences of the formation of architectural heritage using the synthesis of arts at different stages of socio-historical development of our country in the Soviet era.

THE RESULTS AND DISCUSSION

The connection between the periods of historical, political and economic development of the country and socio-cultural activity of the population on the example of developing the principles of creating an architectural and urban planning environment has been proved in many author's publications [1 – 4] and many others. They identify the main phases of political and economic development of our country during its existence in the USSR, which are caused by foreign and domestic political activity - these are: the first after 1917 - the stage of search for directions of optimization in the system of government and management, which was distinguished by diversity proposals, even going back for a while to the old forms of the capitalist economy (the so-called NEP) - 1920s - 1932; the stage of establishing a totalitarian system of government headed by a leader and with total state property, characterized by the construction of socialism (the so-called «Stalinist» period) - 1937 - 1953 and the stage of a collegial system of government based on a one-party system headed by the Secretary-General. At that time, in 1955 - 1985, attention was paid to social programs and the direction of building further economic development – communism – was being worked out.

Each of these stages of socio-political and economic development was preceded by transitional stages, which were characterized by the search for new directions, understanding of certain state-social needs, the gradual transition to changes in management systems and corresponding changes in the directions of formation of architectural and urban planning environment. All of them that are listed the three main and three transitional stages *have shown signs of centralization of the management system* in the orientation of planning, financing, implementation of the system of control over the implementation of the planned programs and the system of responsibility and punishment for failure to meet the scheduled time and amount of tasks.

The state-party government, which took responsibility for resolving all economic issues, disseminated the principles of social ideologization, which was reflected in various areas of cultural activity, including the means of creating an architectural and urban planning environment.

The latter became the most prominent object of propaganda of state ideology, which not only was formed on the basis of state-ideological programs, but also forced the population to constantly be surrounded by symbols of totalitarianism.

So, let's consider the main directions of formation of architectural and urban planning environment, corresponding to the three stages of political and economic development of the USSR and Ukraine that was in it. *The first stage* of the search for directions of political and economic development was characterized by a variety of proposals of representatives of different architectural schools, in each of which experts tried to prove the priority of their direction among others in order to determine the correspondence to the Soviet-socialist goal. These were representatives of the old classical school; of eclecticism, which prevailed in the pre-October times and, following the tradition of «architecture of choice» by A. Ikonnikov's definition [5], provided an opportunity to freely interpret the artistic and aesthetic image of an architectural structure by architectural means; efforts were made to create a purely Ukrainian school on a national basis, which caused the greatest concern on the part of the authorities. M.S. Ilchenko notes: «In the 1920s, the avant-garde trend in Soviet architecture was a colorful mosaic consisting of many currents, groups and schools that professed different artistic principles and set different creative tasks. Many of these groups lacked a solid theoretical platform or clear setup and were therefore forced to navigate between more influential currents, periodically joining one or the other community of architects» [6]. Among them, the direction of architectural formation generated by the Russian Revolution had a special status, it was too straightforward to reflect the symbolic and ideological content of a new type of state. This is constructivism, which by its industrial forms, transferred to the social environment, was doomed to embed in the public opinion the idea of a new socio-political system resulting from the victory of workers and peasants. That is why the process of intensifying the design and construction of various clubs and palaces as centers of cultural and mass work (the palaces of communism, Soviets, labor, workers, railways, arts, pioneers, etc.) [7] has unfolded, which did not stop in the following periods.

Analyzing the experience of constructivism in the construction of buildings, we can conclude that the architectural form in this direction of styling was chosen as a solid monumental image of the undeniable victory of workers during the Soviet times (see Fig. 1, *a, b, c*). As history of architecture proves, monumentality does not need decorativeity, it should impress with its laconic large-scale forms. So, constructivism was not characterized by the use of small-sized decorative parts. Rather, the decorative shape was determined by horizontal lines, which were supposed to reflect the idea of the dynamics of social life (Fig. 1, *d*) and complex combinations of geometrically simple volumes (Fig. 1, *e*). The symbolic content of the architecture of constructivism over time began to manifest itself in the formation of buildings that resembled technical achievements or symbolized signs of statehood of a new type. This was especially characteristic of the Russian Federation (there is a construction in the form of a plane, an opera house in Rostov-on-Don – in the form of a tractor, and an opera house in Arkhangelsk – in the form of a huge grandstand, Fig. 1, *h*, same, factory-kitchen in Samara displays the sickle and hammer). What we define as a synthesis of the arts in architecture can be determined in relation to the direction that is viewed as the Soviet-ideological symbolism of a large-scale architectural form. In Ukraine, the manifestations of symbolism in the form of a building were much more modest (for example, the facade of the Railway Culture Palace in Kharkov has a surface like an accordion; in Fig. 1, *f, g,* the notorious building of Ukrainian writers destroyed by Soviet power in Kharkiv - under the name «Word» has the form of the letter «C».

The second stage of the formation of Soviet architecture, which coincides with the time of a new period of economic and political development, is the stage of embodiment of pseudo-classicism in the architectural and urban environment, and after the Second World War, for the well-known reasons, due to the so-called «victory over fascism», pseudo-empire that was based on the prototype of the eclecticism of the Russian Empire (see Fig. 2, *a, b, d*).

The transition from horizontal division of the facade in constructivism to the vertical one, characteristic of the newly chosen direction in architecture, took place against the backdrop of fierce criticism of the authors of architectural works by representatives of the party elite. It was about a «boxed» monotonous architecture, about the desire to show the «mechanization» of the public space, about the discrepancy between the theme of technization in architecture to the living human being [6 – 8]. Yes, Russian researcher Selivanova O.N. writes that the avant-garde (constructivism) in this new context was viewed twice in retrospect, because it denied the notion of physicality in general, and in addition, the new era judged it by its own standards presenting constructivist buildings as ill, defective ordismembered dead bodies [8]. She,

Searching for a new architecture for workers
Beginning of 1920 – beginning of 1930s

Forming of buildings

Decorative form and its elements

Form symbolism as content

Fig.1. Examples of new building architecture for workers in the style of constructivism: *a* – project of the House of Books erected on the site of the Central Department Store, str. Khreshchatyk, 44, Kyiv, Holovproject, 1930s; *b* – Derzhprom, Sq. Svoboda, Kharkiv, arch. S.S. Serafimov, S.M. Kravets, M.D. Felger, 1925 – 1928; *c* – Main Post Office, Sq. Pryvokzal'na, 2, Kharkiv, arch. A. Mordvinov, 1927 – 1929; *d* – 1st doctor's house, str. V. Zhytomyrska, 17, Kyiv, arch. P. Alyoshin, 1928 – 1930; *e* – project of Dynamo restaurant, Petrovska alley, 3, Kyiv, arch. J. Karakis, P. Savich, 1932; *f* – *g* – apartment building of the writers «Word», str. Kultura, 9, Kharkiv, arch. M. Dashkevich, 1926 – 1930: house facade and aerial view; *h* – factory kitchen of plant named after Maslennikov, Samara, Russia, arch. K. Maximova, 1932.

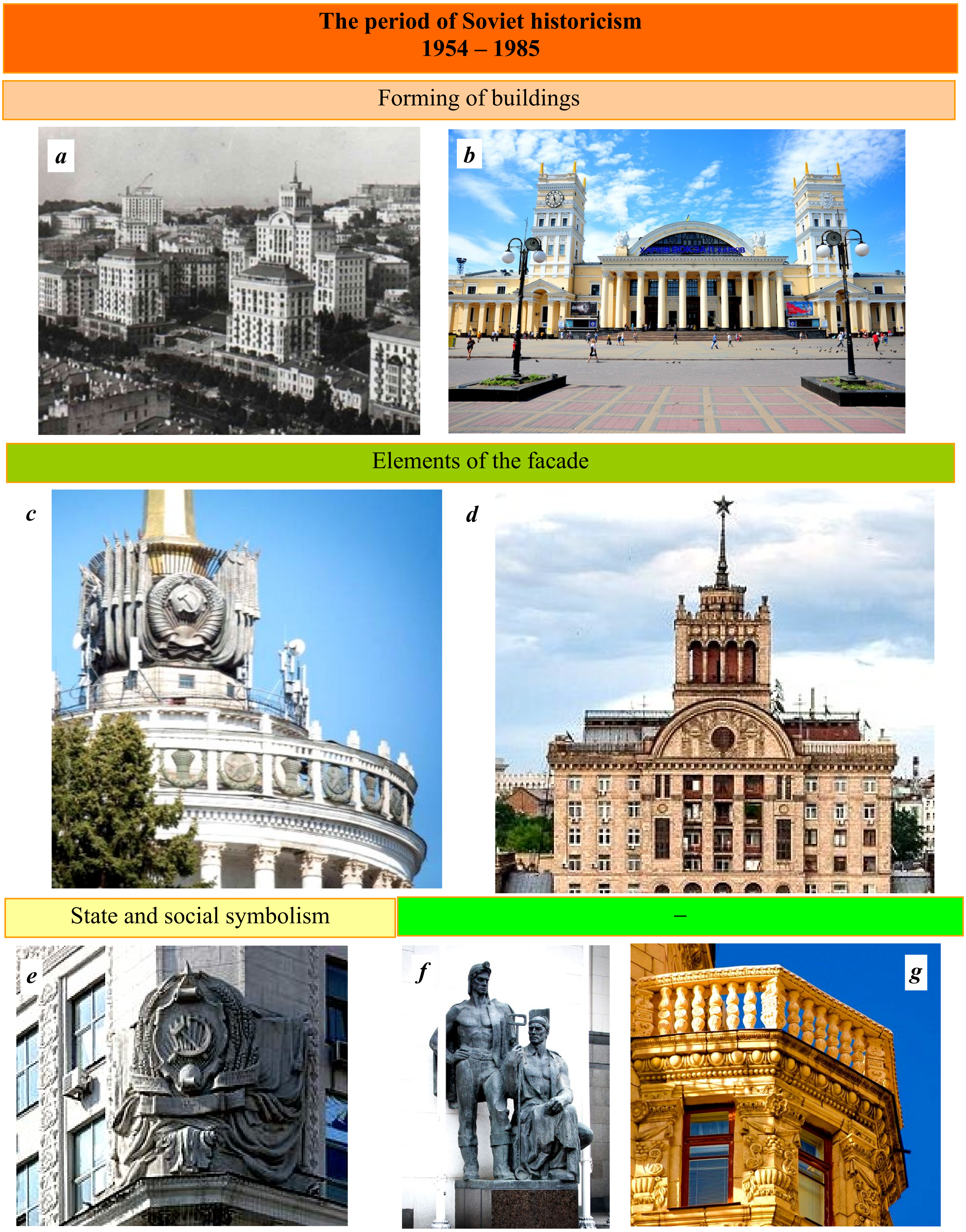

Fig.2. Examples of the shaping of buildings and the synthesis of the arts as a means of state and social symbolism in the period of historicism: *a* – panorama of buildings on the str. Khreschatyk, Kyiv; *b* – Railway station, Kharkiv, arch. G Voloshin et al., 1952; *c* – VDNH, main pavilion, Kiev, arch. B. Gégerine, 1949; *d* – building on the str. Khreshchatyk, No. 25, Kyiv; *e* – building on Sq. Of the Constitution, Kharkiv, arch. V. Petit, Y. Chebotaryova, V. Kostenko, 1947 – 1950; *f* – sculptures at the entrance to the Verkhovna Rada, Kiev, arch. V. Zabolotny; *g* – bay window of house № 23, str. Khreschatyk, Kyiv.

quotes the famous Soviet urban planner M. Milyutin: «If the creation of new forms of human beings depended on constructivists, they would have exposed all his skeleton, tendons, nervous system, and intestines. What is the job of such an architect to create artistic images?» Thus, the eclecticism of architecture was in keeping with the contemporary needs of the Soviet state at the time – to create an ideologically designed environment through various means. When working on the compositional fantasies of the Palace of Communism, Ya. Chernikhov wrote: «Architecture, as the art of spatial forms, as an image constantly visible and tangible, is one of the powerful factors for convincing propaganda of the great ideas of communism. Undoubtedly, the heroics of the Stalin era will find in architectural structures that expressive and laconic image that puts forward a special category of compositional interpretations of spatial forms. Magnificence and pomp, rise and triumph, joy and happiness, power and strength...» [7]. The «heroics of the Stalin era» coincided with the deification of the leader, at least the main professional editions of architecture in every way emphasized this, reflecting on the great inspirer of Soviet architecture, who "created the doctrine of socialist realism - the principle and creative method of the Soviet art, about a galaxy of architects, who «guided by ideas – ideas of Marxism-Leninism... They are the creators of the best examples of Soviet architecture, characterized by high ideology and partisanship, ... full conformity of ideological content and artistic form, critical development of the classical heritage of the past, the most progressive national traditions of their people» [9]. The Bulletin of the Academy of Architecture of the USSR for the 1950s prints the editorial article «Under the glorious banner of Soviet democracy», the content of which resembles an essay on the personality of the Generalissimos: «Stalin! – It is the most expensive and most native name for all the Soviet people and the workers of the whole world, which is spoken with love and pride in all corners of our vast homeland... For us, Soviet people, there is no the most dear and most native person than our leader and teacher Joseph Stalin» [10].

In order to justify the applied architectural forms and details borrowed from the historical heritage of the Russian Empire (which were not even hidden, and in print publications it was possible to meet praiseworthy reviews on works of artists of classical architecture [9]), in the architecture of buildings began to spread symbolic signs of the new power and its economic and political system. That is, the mass use of state and social symbols (state in the form of attributes of power – state and republican coats of arms – Fig. 2. *c, e* – stars, flags, sickle and hammer as signs of the working-peasant power; social – the tools of labor, the sun with rays, ribbons, flowers that symbolized the happy life of the people in the Soviet socialist state). In the pre-war period of «Stalinism» in architecture, one can find the use of the theme of happy life of workers, which was decorated with reliefs depicting people in the process of work and rest. Over time, this tendency in some examples began to turn into significant in size and complex in number of used decorative elements of the composition, which contained vases, balusters (Fig. 2, *g*), capitals of pilasters and more.

After World War II, sculptures of a large size of an individual appear in work or sportswear with certain tools in their hands, which adorned the facades of buildings and personified the Soviet people. In Kyiv, such examples of sculpture use are: the building of the Verkhovna Rada of Ukraine, separate dwellings of the so-called «Stalin» time, and the central street of Kyiv – Khreschatyk – according to the reconstruction project it was to be transformed into a museum of cement figures, according to O. Mokrousova [11]). The sculptures were used not only in the decoration of the facades of buildings – in their completion as the most significant place, at the base near the entrance – closer to the conditions of perception (Fig. 2, *f*), but also as dominant elements in symmetrically constructed large-scale compositions of architectural and spatial organization of urban centers and town-planning ensembles. Here, the sculpture was already detached from a separate building, spatially was reinforcing the emphasis in the structureof the town-planning ensemble, becoming the main landmark in creating a single composition, which revealed the main content that glorified power, the state, the conditions of Soviet life (see materials of competitive projects after the Second World War [12]).

Thus, the Stalinist state system actively used the synthesis of arts in the form *of plastic arts* to enhance the effect of decoration of architecture, focused on a clearly defined ideological direction, from their decorative qualities and ending with large compositions of several figures or too large in size of a single figure. On the one hand, there was the simplicity of the structure of the spatial organization on the basis of axial symmetry, on the other, the complexity of constructing the most architectural form with variations in accordance with the chosen theme of classical architecture and the imaginative conditions of perception of the sculptural composition, which was arranged and allowed it to be viewed from different points of space, in the light and shade that changed position during the day mode. This was increasing the overall impression and met the conditions of formation on the basis of increased decorative at the time.

In parallel with the implementation of a course designed by the party to «creatively rethink classical heritage» in Soviet architecture, which was adopted at the First Congresses of Architects of the Soviet Union and Ukraine in 1937 [13, p. 9], according to which specialists and scientists of the Academies of Architecture of the USSR and Ukraine continued to work hard, Ukrainian architects were looking for ways to improve construction in the direction of economic housing structure, development of typical industrial products and new construction materials. This was also determined by the tasks of the party leadership. These very first works on the industrialization of construction constituted the experience which in the following helped to define a new course in construction, proclaimed by the Resolution of the Central Committee of the CPSU and the Council of Ministers of the USSR «On Combating Surpluses in Architecture» [14], and in full to create a base, on which began the formation of a school of typical design and construction in the USSR and Ukraine.

Thus, *the transition to the third stage* in Ukrainian practice can be considered as important work in the field of construction technology and the search for economic housing, which occurred in parallel with the implementation of grandiose ambitious projects of the Stalin era [15 – 17].

Orientation by the Secretary General of the CPSU Central Committee, M. Khrushchev, to social programs [18], which arose from familiarity with the experience of a lifestyle in European countries, has led to a kind of revolution in architecture, urban planning and construction. The scale of reform in the Soviet Union and Ukraine is impressive, as well as the number of new design and research institutes and building organizations that have emerged. The presence of any decorative details in the shaping of architecture has since been crushed by criticism. The consequences of such an attitude by the authorities to the architectural heritage of the previous period of «Stalin centralization» contributed to the bitter disappointment and recognition of these years of decoration (Stalin's empire) as terrible for the architecture of the time (according to M. Barshch) (quoted by M.S. Ilchenko [6]). The main thesis for new directions of understanding of architectural formation and approach to creation of architectural form became economy, which envisaged extreme simplicity and possibility of industrial execution. In Khrushchev's time, there were appeared compositions made of ceramics on the first objects of public service, which were information-filled planes according to the functional purpose of the building. The announced new policy in architecture and construction was completely opposed to the previous era. The emphasized asceticism of the forms and the mass of typical housing and the extraordinary pace of construction aimed at promoting the ideas of the invincibility of the Soviet state, the greatness, the advantages of the socialist type of economy, which can all – «catch up and overtake» the leading states of the world.

The harsh reality of the post-Stalinist time eventually morphed into a direction that purportedly continued the idea of restraint in shaping. But at the same time, the USSR formed a socialist camp from part of the European countries, the Council for Mutual Economic Assistance, the Warsaw Pact as a military union of states, and international cultural ties with the formation of relevant organizations were spreading. The leadership of the Soviet Union led the newly formed interstate alliances. The practice of cultural contacts between the USSR and the countries of the socialist camp automatically led to the borrowing of methods of creating an architectural and urban planning environment, typical construction, methods of forming the artistic image of buildings, and so on. Due to the expansion of the spatial and territorial range of Soviet influence onto the culture of other peoples and the leading role of the Soviet country in resolving purely professional issues regarding the reconstruction of historical centers of cities, three-tier service system, organization of transport routes, etc., the USSR exerts pressure onto the leadership of friendly states through any manifestation of their independence in the directions of formation of architectural and urban planning environment [19].

Orientation to improve the architectural formation, that was proclaimed by the Resolution of the CPSU Central Committee and the Council of Ministers of the USSR in 1969 [20], contributed to the diversity of forms (Fig. 3, *a, b*), the spread of vertical division on the facade as elements of neoclassicism in representative buildings (Palace of Congresses) and the extraordinary spread of *plane arts* as an additional way of expressing the state-ideological essence of the Soviet state (Fig. 3, *c, d*). The mosaic was especially widespread (Fig. 3, *e*). A rather expensive means of synthesizing the arts in stingy rationalist forms of architecture reflected the plots of state grandeur, ideological content, and social propaganda. Mosaics over time have become an invariable attribute of Soviet architecture, giving ideological content to any structure, even urban and suburban bus stops, they constantly reminded of the joyful present and the expected bright future by their presence in the lives of the working masses.

THE CONCLUSIONS

Thus, the ideological component of a totalitarian Soviet state at all stages of its development was an indispensable feature of architecture. At the first post-October stage, it was a specific form of constructivism born in Soviet Russia that cannot be confused with European functionalism. As the main idea of the emergence of functionalism was contained, in addition to improving the living conditions of the society, in the fight against the negative effects of the spontaneously formed state of gigantic cities, due to the emergence of industrial territories in their suburbs, that surrounded the city with ring, prevented their connection with the natural environment and their further growth, facilitated the compacting of buildings and the formation of slums. That is, the program of functionalists was defined as the primary tasks of solving functional, social and sanitary-hygienic problems [21].

The stylistic trend was non-state, cosmopolitan. Constructivism, on the contrary, provided new, not existing architectural tools in order to demonstrate the ideology of workers and peasants in the architectural and urban environment.

In the second and third stages, the means of artistic expressiveness of the state-ideological direction were increased decoration of forms, the extraordinary spread of state and social symbolism and the means of art synthesis: in the Stalin period, it was the plastic arts, and later – the plane arts.

Finally, a comparison should be made between the Russian and Ukrainian legacies of the Soviet era. When Ukraine was part of the USSR, did she have any differences in the formation of the architectural and urban planning environment at that time, carefully following the orders of one-party power from Moscow? So! Studying the experience of design and construction of the Russian Federation and Ukraine and comparing them with each other allows us to draw the following conclusions.

1. The Russian artists were quicker to respond to the tasks, accomplish them with scope, were more inclined to convey the main

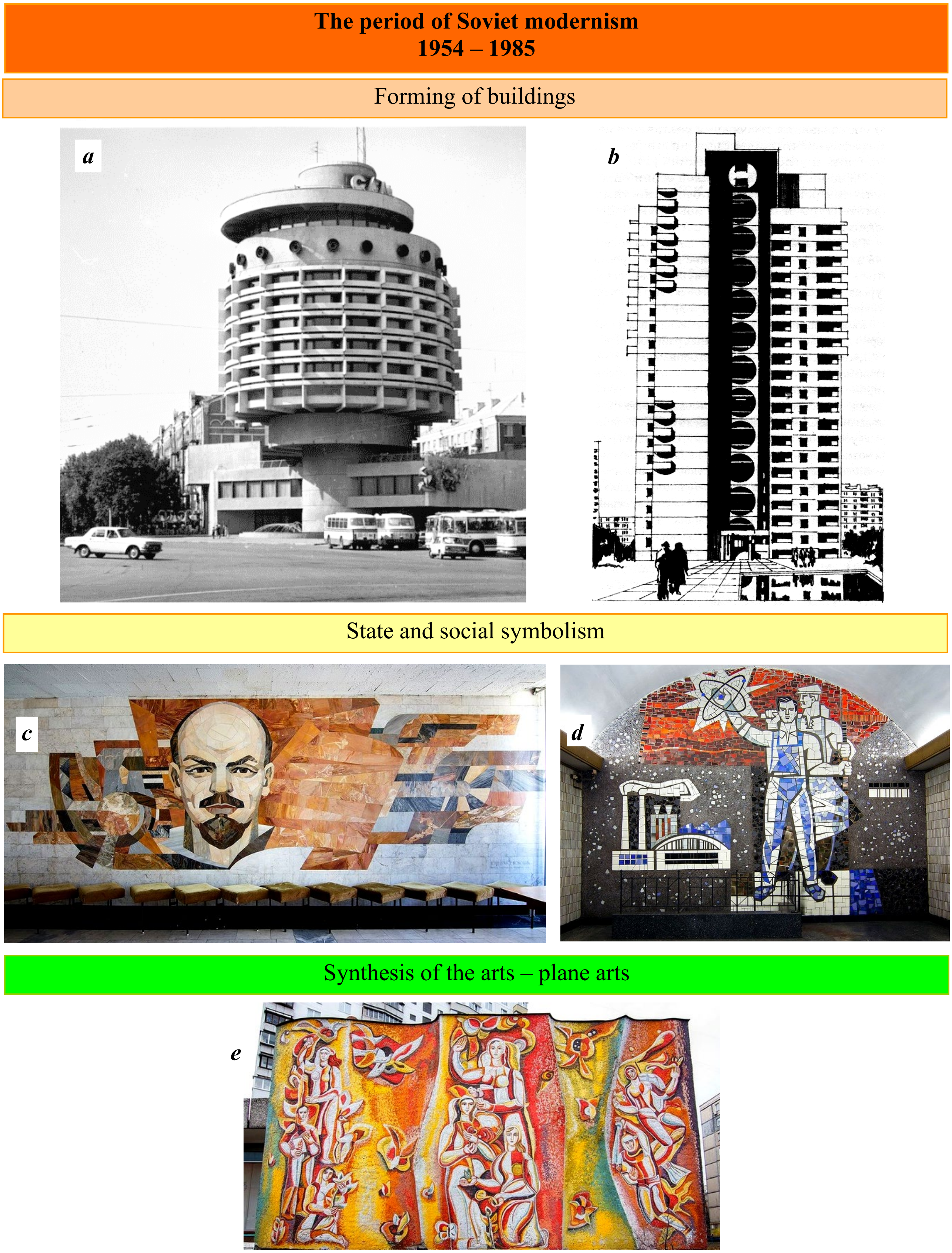

Fig.3. Examples of the Formation of Buildings and the Synthesis of the Arts as Means of State and Social Symbolism in Ukrainian Architecture of the Modernist Period: *a* – Salute Hotel, Kyiv; *b* – facade of a 22-storey large panel apartment building of the APVS series on the str. Mostytska in Kyiv; *c* – panel – photo by E Nikiforov; *d* – panel in the interior of the Bolshevik subway (now called Shulyavka), Kyiv, Avt. I. Litovchenko, 1963, Peremoha avenue, 1967 – 1968, photo by E. Nikiforov; *e* – mosaic in a residential complex in Kyiv.

ideological thought and to implement it in the architectural and spatial organization. This is confirmed by competitive projects and completed structures (examples are Moscow skyscrapers [22 – 24]).

In Ukraine, the party-defined tasks were performed on a smaller scale and slower. Most likely, the reason was not only the periphery of the territory of Ukraine relative to Moscow, but also the mentality of Ukrainians, differences in their psychology, probably the conditions of territorial density of habitation, as psychologists point out [25, 26], the perception of orders from above as a pressure on a freedom-loving people.

2. At the first post-revolutionary stage of cultural development of the newly created state, a series of projects of Kharkiv as the first Ukrainian capital of workers was an example of the implementation of new trends in architecture and real construction in Soviet Ukraine. These are separate buildings, erected as variations on the theme of industrial architecture, the workers' village of KhTZ and the Metropolitan center of power on Sq. Dzerzhinsky (now the Freedom Square). Ukrainian architects sought perfection and reality in architectural solutions in accordance with the latest social needs, both in the functional part and in the artistic-figurative form.

All of these facilities, which were built in accordance with the revolutionary ideology of creating an environment for workers, have changed in appearance due to the length of construction and the emergence of new requirements for architecture. This is a testament to the further refusal of the use of functionalism in urban planning and constructivism in the architecture of buildings due to changes in policy and ideological tasks.

3. The plasticity of Stalinist architecture during the second period of socio-cultural development in Ukraine compared to Russia was relatively moderate. Large-scale compositions for the reconstruction of the capital (Kyiv), proposed in the competitive projects of Soviet architects (Russian), have not been implemented. Numerous sculpture groups on Khreshchatyk, which had to demonstrate the state majesty and happiness of the Soviet people, disappeared from the project immediately after the death of the Generalissimos, and in Kharkov and Kiev architects abandoned the tower completions that Stalin so loved.

4. In the third stage, the Russian mosaic panel prototypes had the emphasized ideological content, in Ukraine, they rather acquired the trait of folk art, became models of national culture, which received a negative assessment of state power, but it was welcomed by the Ukrainian people.

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Синтез искусств в советской архитектуре: этапы развития, главные направления, причины их появления

Людмила Бачинская

Аннотация. История Советского Союза, его социально-экономической, социально-политической и социально-культурной жизни является уникальной в сравнении с другими странами. СССР был создан по модели общественного развития, сформулированной еще европейскими и российскими социалистами-утопистами, и обоснован классиками марксизма-ленинизма. Поэтому система правления, экономические условия и культурная деятельность общества, построенного на гегемонии пролетариата, была продолжительным социальным экспериментом, который обусловил жизнедеятельность советского народа и повлиял на другие страны.

Эксперимент страны с тотальной государственной собственностью предполагал, что партийная верхушка брала на себя ответственность определять все сферы политической жиз-

ни – и внутриполитической, и межгосударственные отношения – и неминуемо формировала единые программы культурной деятельности и общественного развития, руководила ими, осуществляла финансирование и жесткий контроль за их выполнением. Советский народ,. так называемые «трудящиеся массы» были вынуждены жить и действовать по единым правилам В зависимости от планирования партийным руководством политико-экономической и общественной жизни в течение всего существования СССР страна пережила несколько этапов, которые отличались по основным направлениям формирования архитектурно-градострои-тельной среды. Среда должна была отвечать заданиям государственно-идеологического характера. Ознакомление с этим уникальным опытом и поиск причин его создания является важным для понимания тенденций общественного развития в XX столетии.

Ключевые слова: Советский Союз, Украина, социально-культурная деятельность, влияние политико-экономических условий, архитектура и градостроительство.

Investigation of the relationship between the strength limit and the long time fatigue of steel reinforcements of reinforced concrete structures

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Abstract. The results of experimental studies have shown a strong effect of diffusion hydrogen on the static and cyclic parameters of crack resistance of reinforcing steel. It was found that with increasing flooding, especially when the hydrogen content exceeds 5 cm^3/100g, both static strength and long-term strength (fatigue) decrease sharply. Moreover, these areas of hydrogen solution in reinforcing steel are characterized by a viscous nature of fracture, while for heavily flooded reinforcement (from 5 to 12 cm^3/100g) is characterized by brittle fracture by the mechanism of microcracking in the hardened (martensite or troostite structure). The analysis of the obtained experimental results allowed to determine the optimal hydrogen content in the reinforcing steel (3…5 cm^3/100g), the excess of which can cause a decrease in the crack resistance of the reinforcement during long-term operation, especially in corrosive environments.

The mechanism of hydrogen influence on crack resistance of metal at static and alternating loading which consists in diffusion and dislocation movement of hydrogen in structure of a reinforcing core that as a result that causes strong flooding of steel and its embrittlement is offered. It is established that carbon and low-alloy sieves, which are characterized by ferritic-pearlitic and sorbitol structure provide high resistance, especially to long-term fatigue, and the transition to steels with a structure of martensite or tempered (transient structure of bainite) structure of bainite sharply reduces reinforcing steel, which makes it impossible to use in the manufacture of reinforcement involved in reinforced concrete structures designed for long-term operation (more than 50…60 years). Thus, the obtained diagram

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can be recommended to designers of reinforced concrete structures for hydraulic purposes, as it greatly facilitates the reasonable choice of reinforcement in the development of reinforced concrete structures for responsible and long-term use.

Keywords: crack resistance, flooding, fatigue, cyclicity, fittings.

Introduction. It is known that the fatigue process begins with the plastic deformation of the surface layers of the metal fittings. Moreover, the displacement of dislocations under conditions of re-alternating loads is observed at loads below the elastic limit of the metal. The rate of local plastic deformation during cyclic deformation is several orders of magnitude higher than the rate of deformation under static loading. Dislocation slip begins in grains with a favorable orientation near stress concentrators. As the number of cycles in the surface layers increases, the density of dislocations and the number of vacancies increases. When the base number of N_R cycles is reached, a surface reinforced layer Af metal with a large number of germinal cracks is formed, the size of which does not reach a critical value. Increasing the number of cycles cannot cause further development of fracture in such a layer. Only when the stresses exceed the endurance limit of the crack reach a critical length, after which the process of their discharge into the main crack begins with the spread of the latter. The results of experimental studies indicate a strong effect of diffusion hydrogen on static and cyclic parameters of crack resistance. It was found that with increasing flooding, especially when the hydrogen content exceeds 5 cm^3/100g, both static strength and long-term strength (fatigue) decrease sharply. Moreover, for these areas of hydrogen solution in reinforcing steel is characterized by a viscous nature of fracture, while for heavily flooded reinforcement (from 5 to 12 cm^3/100g is characterized by brittle fracture by the mechanism of microfission in the hardened (martensite or troostite structure). Allowed to determine the optimal hydrogen content in reinforcing steel (3…5 cm^3/100g), the excess ofwhich will reduce the crack resistance of reinforcement during long-term operation, especially in corrosive environments. The results of the research confirm the above data. bainite structure y sharply reduces the crack resistance of reinforcing steel, which makes it impossible to use in the manufacture of reinforcement involved in reinforced concrete structures designed for long-term operation (more than 50…60 years). Thus, the obtained diagram can be recommended to designers of reinforced concrete structures for hydraulic purposes, as it greatly facilitates the reasonable choice of reinforcement in the development of reinforced concrete structures for responsible and long-term use.

It is known [1 – 5] that the resistance of the metal to fatigue failure is characterized by the limit of endurance (fatigue), ie it is the highest stress that can withstand the metal without failure at any number of cycles. The limit of endurance is most often determined in tests with alternating symmetrical cycle (R=-1) , and therefore the endurance limit is denoted by σ_{-1}.

As a rule, the endurance limit is limited to 10^7 cycles (this number of cycles is called the test base). Thus, it can be noted that the endurance limit is the maximum cycle stress that can withstand the material without destruction at the base number of cycles (for ferrous metals, this base is 10^7 cycles). Then on fatigue curves it is possible to find such important indicator, as durability at fatigue under which accept number of cycles of loading which maintains steel at destruction at a certain pressure.

It is known from the literature [1] that the endurance limit in metal correlates well with the mechanical properties of metals. Thus, the value of σ_{-1} is on average (0.4…0.6) σ_B – for carbon and alloy steels; (0.3…0.5) σ_B – for bronze and brass. This characteristic can be similarly compared with Brinell hardness: $\sigma_{-1} = (0.128 \ldots 0.156)$ HB – for carbon steels; (0.168…0.222) HB – for alloy steels; $\sigma_{-1} = 0.19$ HB – for aluminum alloys.

It is known from modern fracture mechanics [2…4] that with increasing number of cycles at any stresses above the endurance limit in metal, the following processes occur sequentially:

1) plastic deformation;

2) the formation of cracks, the cells of which are non-metallic inclusions (HB);

3) gradual development of some of them with the predominant spread of the main crack;

4) rapid final destruction.

The process of fatigue begins with the plastic deformation of the surface layers of the metal fittings. Moreover, the displacement of dislocations under conditions of re-alternating loads is observed at loads below the elastic limit of the metal. The rate of local plastic deformation during cyclic deformation is several orders of magnitude higher than the rate of deformation under static loading. Dislocation slip begins in grains with a favorable orientation near stress concentrators. As the number of cycles in the surface layers increases, the density of dislocations and the number of vacancies increases. When the base number of N_R cycles is reached, a surface reinforced layer of metal with a large number of germinal cracks is formed, the size of which does not reach a critical value. Increasing the number of cycles cannot cause further development of fracture in such a layer. Only when the stresses exceed the endurance limit of the crack reach a critical length, after which the process of their discharge into the main crack begins with the spread of the latter.

Formulation of problems and relevance of the topic. The ultimate stresses at which the process begins, for example, hydrogen sulfide fracture (HSF), are recommended as criteria for comparing the stability of different reinforcing steels [5, 6]. One of the important factors influencing the resistance to HSF is the composition and structure of steel. Yes, carbon has a significant effect on HSF. It is known [6, 7] that with increasing amount of carbon the tendency of hardened steels to HSF increases due to increasing internal stresses. Hydrogen diffusing into the metal, even in small quantities (2…3 cm^3/100g) does not cause sufficient for the development of cracks of local plastic deformations in strong metal. It is believed that steel loses its visco-plastic characteristics at a hydrogen content in the range of 7…12 cm^3/100g [8]. However, as established in [9], hydrogen fragility can occur with a small amount of absorption (absorbed) hydrogen. Thus, in steel with a tensile strength of 1600 MPa, doped with 0.7% Cu, 0.25% Mo, 0.8% Nb and 0.025% Al, a decrease in plastic properties (δ) was observed from 45 to 3% at the level of flooding 0.03 cm^3/100g.

In our opinion, this phenomenon can be explained with the involvement of the sorption-electrochemical mechanism of long-term strength (fatigue) [10].

Static (hydrogen) fatigue is caused by sorption processes:

1) diffusion of hydrogen into the defects of the crystal lattice of the metal;

2) adsorption of hydrogen by the inner surfaces of the crystal structure;

3) the pressure of moly hydrogen in the reservoirs;

4) weakening of the bonding forces between atoms in the crystal lattice of the metal.

That is, even with sufficient viscosity and ductility of the metal (for example, low-alloy steel – 08Г2С, 15ХСНД), due to the adsorption of hydrogen in microdefects (microcapillaries, pores), the formation of microcracks is facilitated due to low resistance of brittle material.

Analysis of the literature shows that according to modern physical and mechanical ideas about the nature of static fatigue of the metal there is a critical concentration of hydrogen, which sharply weakens the cohesive bonds in the crystal lattice, ie the rupture of interatomic bonds. According to the developed diffusion model of hydrogen segregation, the critical value of hydrogen depends on the grade of steels, stress state, operating conditions. In our case (underground sewer system) the critical level of hydrogen in the fittings is approximately 5…6 cm^3/100g [11]. This volume is sufficient to dramatically accelerate the process of nucleation and development of cracks (submicrocracks). Therefore, appropriate measures are required to influence the dislocation mechanism of hydrogen delivery into the valve structure.

It is established [5…7] that the distance between the sliding strips of dislocations is $(10^{-6} \dots 10^{-4})$ cm; the amount of slip is $(10^{-7} \dots 10^{-5})$ cm. The critical tangential stress is $\tau = (10^{-5} \dots 10^{-7})\mu$, where μ is the shear modulus equal to $(1 \dots 11)10^{4}$ MPa. Normal stress (perpendicular to the sliding plane) $\sigma = (10^{-5} \dots 10^{-7})\mu$. Theoretical lattice strength (shear strength in a perfect crystal) is taken as $\sigma_T = \mu/30$. It is assumed that the dislocations can be concentrated in some places, forming a cellular structure (subgrain). The size of subgrains (blocks) is equal $(10^{-7} \dots 10^{-5})$ cm.

In the calculations, the stress required to break the adhesion forces in the metal is taken equal to 85 MPa. It should be taken into account that in the structure of reinforcing steels the diffusion of hydrogen is facilitated by the presence of microdefects, dislocations, temperature-pressure gradient and variable loads (force factor).

It was found that the predominant amount of diffusion hydrogen is concentrated in traps, and the binding energy of atoms with them is approximately HB ≈ 58.6 kJ/mol [3]. At the same time, its concentration in the crystal lattice matrix decreases to $10^{2} \dots 10^{3}$ cm^{-3}, and in $N_{B(P)}$ traps. Under such conditions, at temperatures below 300…320K, almost all hydrogen is captured by dislocations and traps, and the concentration in the lattice matrix is almost zero.

As noted above (according to the text), the critical concentration of hydrogen depends on the stresses in the steel and is largely determined by the structural composition. Therefore, to determine the delayed destruction by the mechanism of hydrogen embrittlement, causing static (hydrogen) fatigue, a binary combination of critical values of hydrogen concentration and mechanical stresses is required. The critical concentration of hydrogen is created under the influence of the three-dimensional space of the tensile stress field of the directed (collective) diffusion of hydrogen. The period during which the critical value is reached $(C_{cr}+\sigma_{cr})$ corresponds to the incubation period of microcracking growth. There are different views on the mechanism of nucleation and propagation of cracks caused by hydrogen embrittlement, but the hypothesis of molecular pressure of hydrogen is the most noteworthy, ie the main cause of high pressure hydrogen in non-continuous metal reinforcement, which causes high internal stresses. Moreover, on a microscale, the action of hydrogen can be manifested not so much in embrittlement as in the plasticization of the metal.

On a macro-scale, embrittlement looks like a reduction in the fracture stress due to local plastic flow and the destruction of metal microvolumes at the crack tip.

The mechanism of hydrogen-initiated nucleation of the microcrack and its subsequent growth involves a series of the following frequent processes:

– discharge of hydrogen ions on the surface of the body (blocks, dislocation traps, non-metallic inclusions, phases of introduction, etc.) as a result of the cathodic reaction [10]:

$$2H^{+} + e^{-} \rightarrow [2H] ,$$
$$\downarrow$$
$$[H]_{Me} \quad (H_2)\uparrow,$$

where $[H]_{Me}$ – the concentration of dissolved atomic hydrogen in the metal, (H_2) – its concentration in the gas phase;

– penetration and transportation (by diffusion or dislocation mechanism) of hydrogen atoms in the region with high stress concentration, ie to the vertices of microcracking;

– ensuring the growth of microcracks as a result of hydrogen-induced decrease in the ductility of the flooded metal.

In [5], it was proved that hydrogen on atomically pure surfaces of submicrocracks forms a layer of anions resulting in a change in the energy state of the surface and hence the behavior of submicrocracks in the stress field. hydrogen on the movement of dislocations This peculiarity of the dislocation mechanism of hydrogen transport is due to the abnormally high coefficient of its diffusion and relatively low binding energy with dislocations.

It is known from the literature that microcracks form atomically pure surfaces on which hydrogen released from dislocations is chemisorbed. Thermodynamic calculations using the Gibbs equation show [2, 4] that hydrogen adsorption sharply reduces surface energy, especially at low concentrations on the surface 6.0…7.5 J/cm^2 [9]). If you take into account the actual energy consumption for the destruction of iron (≈10…20 J/cm^2), such a change will be very sensitive.

In addition, the formation of microcracks on the outskirts of collisions of dislocations is facilitated by stresses which at a distance of 1 μm from the core of the dislocation are equal (for helical dislocation according to Hooke's law) [3]:

$$\tau_{\chi\Theta} = (G_{Fe}+b)/(2\pi r) = $$
$$= (0.8\cdot10^{12}+2.5\ 10^{-8})/\ (2\pi\cdot10^{-4}) = $$
$$= 0.32\ 10^{8}\ \text{dyn/cm}^2 = 32\ \text{N/mm}^2.$$

Here G_{Fe} = 0.8·10^{12} dyn/cm^2 – modulus of elasticity of iron; b =2.5·10^{-8} cm – Burger's vector; r = 1 μm = 10^{-4} см – distance to the core of the dislocation; Θ i χ – coordinates of a cylindrical system in which the χ axis is directed along the line of dislocation. According to the formula, the stresses decrease inversely proportional to the distance from the dislocation nucleus.

Dimension b/2π = $y_{\Theta\chi}$ – relative shift.

The total theurgy of the elastic deformation of the helical dislocation per unit of its length is equal to:

$$V_{helical} = (G\cdot b^2)/4\pi)\cdot \ln R/V_O = $$
$$= 0.5\cdot10^{12}\ (3\cdot10^{-8})^2/4\pi\cdot\ln(1/(5\cdot10^{-8})) = $$
$$= 6\cdot10^{-4}\ \text{erg/cm}^2\cdot\text{erg/interatomic distance} = $$
$$= 12.5\cdot10^{7}\ \text{eV/interatomic distance.}$$

This is a very large energy, and therefore it contributes to the formation of microcracks in the presence of a catalyst - hydrogen. Let's calculate the effective mass of dislocations, attributed to a unit of its length (for helical dislocation):

$$m_{e\phi} = b^2\cdot\gamma/2 = $$
$$= \{(2.5\cdot10^{-8})^2\cdot7.85\}/2 = 2.45\cdot10^{-15}\ \text{g/cm},$$

where γ = 7.85 g/cm^3 – metal density.

As in 1 cm of length of dislocation keeps within 5·10^{-8} – interatomic distances, a=2.5Ă (angstrom) = 2.5·10^{-8} cm),

$$\text{Then } m_{ef} = (2.45\cdot10^{-15})/(1/1.25\cdot10^{-8}) = $$
$$= 6.1\cdot10^{-23}\ \text{(g/interatomic distance).}$$

The mass of 1 Fe atom is equal

$$m = M/(6.02\cdot10^{23}) = 56/(6.02\cdot10^{23}) = $$
$$= 9.3\cdot10^{-23}\ \text{g},$$

where M is the atomic weight equal to 1 g-atom.

Therefore, the effective mass of the dislocation at one interatomic distance is approximately equal to the mass of one atom. This indicates that the work of crack formation and growth due to high stresses and dislocation mobility is reduced in the presence of hydrogen adsorbed on the crack surface.

Rapid diffusion and propagation of cracks requires rapid diffusion of hydrogen atoms, if we take the rate of propagation of cracks $V_{r.tr}$= = 10^{-2} cm/s, which is proportional to the velocities of dislocations in ferritic-pearlitic steels, which include reinforced concrete reinforcement, and the coefficient of diffusion hydrogen, for example in α-Fe D_H ≈ 10^{-4} cm^2/c, and as a criterion for estimating the propagation of the microcrack parameter X^{-2} = $2D_H\cdot t$, where t is time, it follows that for a certain period of time t at $V_{p.tr}$ = 10^{-2} cm/s mobility of hydrogen atoms is sufficient, even when D_H ≈ 10^{-6} cm^2/s.

The process of formation of fatigue cracks takes only 5…10% of the operation time of structures until the final destruction. The rest of the term falls on the origin and gradual growth of cracks, most of which eventually slow down or completely suspend their development (due to the strengthening of the metal in places of concentrated stresses near the top of the crack). Only those cracks which have rather big length and sharp top receive the further development. One of them can lead to the final destruction of the reinforced concrete structure.

It should be noted that the reduction in the amount of cement in the steels of reinforcing bars with a service life is according to X-ray diffraction analysis of about 30…35% and electron microscopic data - about 20…25%. It should be borne in mind that cementite is easily decomposed under the action of hydrogen atoms:

$$Fe_3C \leftrightarrow 3Fe + C\ (24.3 \pm 2.01),\ kJ;$$
$$C + 2H_2 \leftrightarrow CH_4 + (75.42 \pm 0.84),\ kJ.$$

In general, this process is described by the reaction

$$Fe_3C + 2H_2 \leftrightarrow 3Fe + CH_4.$$

Atomic hydrogen easily appears at interaction of hydrogen sulfide which is contained even in insignificant amount of the stored technological environment (for example, sewage waters, with metal of reinforced concrete reinforcement):

$$4Fe + 6H_2S = 2Fe_2S_3 + 12H.$$

In the process of deformation on the surface of the armature metal or the surface of the microcavity, active centers are formed, in which the dissociation of hydrogen molecules and the penetration of atomic hydrogen into the depth of the armature metal takes place.

Decarburization of reinforcing steels takes place over a long period of time, which is facilitated by the temperature-pressure mode of transport of sewage in underground systems. Since under such conditions the mobility of carbon atoms in ferrite is low, the main hydrogen reaction takes place in the pearlitic grain. The diffusion coefficients of carbon and hydrogen in α-Fe are as follows (temperature 20°C):

– for hydrogen – $15 \cdot 10^{-5}$ cm^2/s;

– for carbon –$2 \cdot 10^{-17}$ cm^2/s.

The accumulation of the reaction products (methane and atomic hydrogen, which recombines into molecules) takes place initially in the pores and microcavities, in the boundary volumes of the grains of the armature metal. Atoms of impurities and cavities are concentrated along the grain boundaries, which promotes the creation of segregation, especially sulfur, as a result of which the boundary regions of the grains are also enriched with carbon. In addition, the grain boundaries are energetically metastable.

The pressure of moly hydrogen in such can reach large values, resulting in stresses exceeding the cohesive strength of reinforcing steel of reinforced concrete structures, which often leads to the formation of microcracks in the metal, and in general to the degradation of reinforcing steels.

It should be noted that the analysis of literature sources of domestic and foreign researchers does not provide an unambiguous answer to the question of the influence of hydrogen and alternating stresses on the embrittlement of reinforcing steel of different brands, and the results of experimental studies are usually obtained in different conditions different external factors, and therefore characterized by contradictions, making them difficult to compare and draw final conclusions, although the problem of degradation of reinforced concrete structures is relevant and, moreover, is important for the construction industry of Ukraine, resulting in additional experimental and theoretical studies.

The goal of the work – study of hydrogen crack resistance of reinforcing rods of reinforced concrete structures of long service life in aggressive environments.

Methods of experimental research, materials, criteria and equipment. The object of research was reinforcing steel of the following grades: 5; 35ГС; 20ГС; 08Г2С; 15ХСНД; Х18Н9, ie steel carbon, low-alloy, which had a structure of ferritic-perlite, sorbitol and troostite and martensitic with a coefficient of endurance K_V = 0.40…0.50. The effect of hydrogen on the endurance limit and static strength limit was investigated on samples of steel grade 20ГС which before experiments were flooded to the required level in special chambers with hydrogen medium. The hydrogen content in steel samples cut from reinforcing bars was determined by vacuum melting on a chromatographic unit VH-6 company Gereus (Germany) [10, 11]. The duration of flooding of the samples was about 72…78 hours, depending on the required volume of flooding.

Samples of cylindrical shape with a length of 162 mm, of which the working part was 50 mm, and the diameter of the capture – 70 mm of the working part – 10 mm, which allowed the fittings with a diameter of 32 mm (Fig. 1).

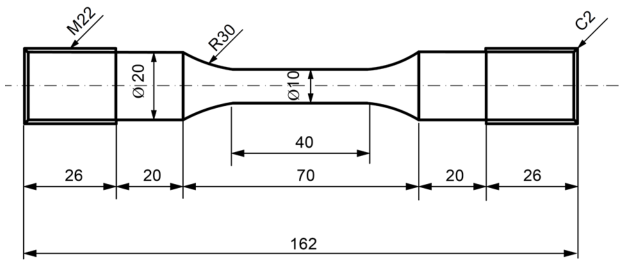

Fig. 1. Samples for fatigue strength tests (multi-cycle tests)

The samples perceived the deformation of the bend with axial compression-tension. The baseline test for prolonged fatigue was N = 10^7 cycles.

After fabrication, the reinforcement samples were subjected to different heat treatment modes depending on the steel grade and obtaining the desired type of structure. The samples were polished with a grinding skin with a grain size of 3/0, and then subjected to tempering in a vacuum chamber at 620°C for 30 min to remove residual stresses. The samples were tested on the setpoint of the model "Instron" (UK). The tests were performed on a bend with zero average voltage and a cycle frequency of 20 Hz. The tests were performed in air. The impact of the aggressive environment was absent. We add that the tests were performed in accordance with the requirements of the Specification of the International Association of Corrosive (Specification TenquizOil and Gas Plant // ProzessPlant.-Lurgi code: 65102-00-MAL-TENGUIZ II. Specification №.SPC-62900-XP-007). Fractographic and metallographic studies were performed using an electron scanning microscope model Jeol-35SF (Japan). A fragment of the reinforcing rods, from which the samples for flooding were cut, followed by a test for long-term strength and factual studies, is shown in Fig. 2.

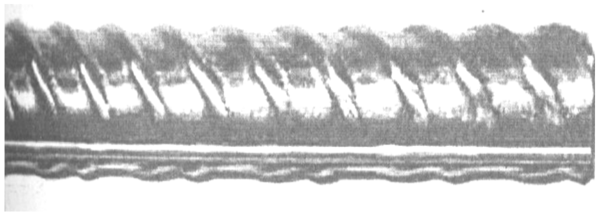

Fig. 2. Fragment of experimental reinforcement of reinforced concrete structure

***Research* results and their discussion.** The results of experimental studies are shown in Fig. 1 and 2. The data in Fig. 1 indicate a strong effect of diffusion hydrogen on static and cyclic parameters of crack resistance. It can be seen (see Fig. 1) that with increasing flooding, especially when the hydrogen content exceeds 5 cm^3/100g, both static strength and long-term strength (fatigue) decrease sharply. Moreover, these areas of hydrogen solution in reinforcing steel are characterized by a viscous nature of fracture, while for heavily flooded reinforcement (from 5 to 12 cm^3/100g is characterized by brittle fracture by the mechanism of microfission in the hardened (martensite or troostite structure). experimental results allowed to determine the optimal hydrogen content in reinforcing steel (3…5 cm^3/100g), the excess of which will reduce the fracture toughness of reinforcement during long-term operation, especially in corrosive environments. (according to the text).

The results of the research presented in Fig. 3 confirm the data of Fig. 4. It can be seen from Fig. 4 that carbon and low-alloy sieves, which are characterized by ferritic-pearlitic and sorbitol structure provides high resistance primarily to prolonged fatigue, and the transition to steels with a structure of martensite or tempered (bainite transition jet) sharply reduces bainite structure. crack resistance of reinforcing steel, which makes it impossible to use in the manufacture of reinforcement involved in reinforced concrete structures designed for long-term operation (more than 50…60 years). Thus, the obtained diagram can be recommended to designers of reinforced concrete structures for hydraulic purposes, as it greatly facilitates the reasonable choice of reinforcement in the development of reinforced concrete structures for responsible and long-term use.

Steels with a tempering sorbitol structure have the highest survivability. This is due to the low growth rate of the fatigue crack due to the high ductility of the metal (see Fig. 4) and the presence of a developed substructure of the ferritic phase of sorbitol. The dislocation walls that separate the ferrite grains serve as barriers to the fatigue crack, which causes it to change direction in a zigzag pattern and spend more energy and time growing to a critical size. In addition, steel after heat treatment for tempering sorbitol becomes insensitive to the appearance of stress concentrators and accidental shock load.

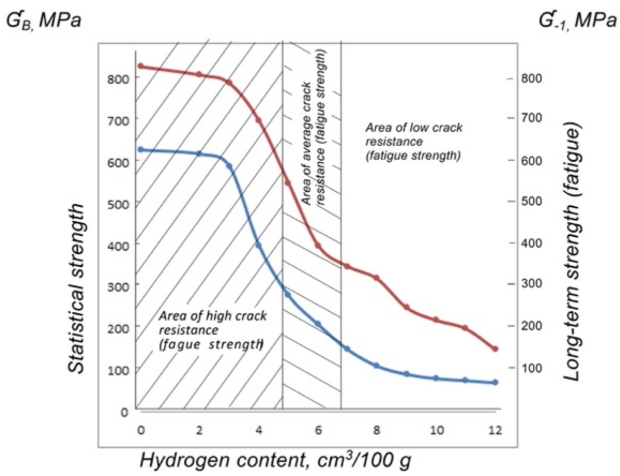

Fig. 3. Graphs of dependence of fatigue strength (σ_{-1}) and static strength (σ_B) on the hydrogen content in the reinforcement samples. Reinforcing steel grade 20ГС. Test base N=10^7 cycles. Designation: the red line refers to the static axis strength and the blue line refers to the axis of fatigue strength (σ_{-1})

Steel heat-treated on cane or tempering martensite has a higher σ_{-1}, but its significant resistance to the formation of fatigue cracks is neutralized by increased sensitivity to surface quality. In addition, high-strength steels are characterized by low resistance to cracking.

Thus, the operating conditions require a special combination of high resistance to the formation of fatigue cracks and high resistance to its propagation, which is almost impossible to provide in reinforcing steel using alloying and heat treatment. This problem is solved by the use of surface hardening technologies (surface plastic deformation, chemical-thermal treatment, surface hardening) for low- or medium-carbon steels treated with the structure of tempering sorbets. The result is steels with a strong surface and a viscous plastic core.

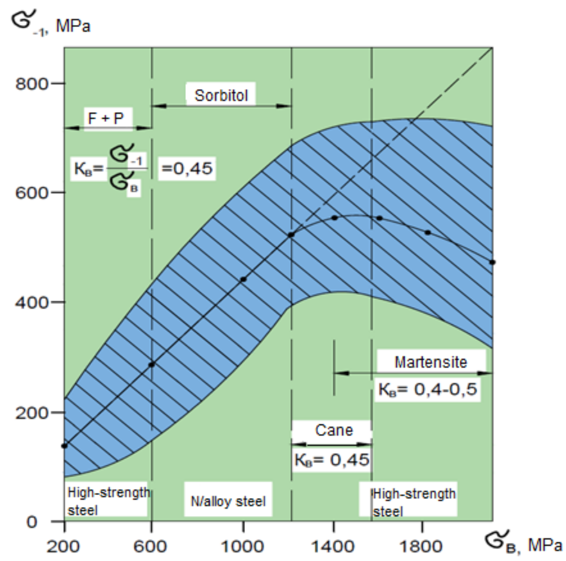

Fig. 4. Influence of the type of reinforcing steel structure on its endurance limit (σ_{-1}.) Designation: K_V - coefficient of endurance; σ_B - tensile strength; σ_{-1} - limit of fatigue strength (endurance); F - ferrite; P - perlite

At surface hardening two mechanisms of increase of cyclic durability are used, in particular there is an increase in resistance to deformations of surface layers of metal and there are residual compressive stresses interfering with emergence and development of fatigue cracks. Combined with external stresses, compressive stresses reduce the level of dangerous tensile stresses on the surface.

The efficiency of the application of surface hardening methods increases with increasing stress concentration. The most effective is the combination of different hardening methods (chemical-thermal treatment, HFC hardening) with surface deformation because the latter additionally (by 10…20%) increases the hardness of the surface layers and the level of residual compressive stresses. It is recommended to use a surfactant that prevents the development of the process of adsorption fatigue. It should be noted that most technologies of surface hardening of reinforcement have a positive effect on its wear resistance and cyclic durability.

In the process of heat treatment, reinforcing steel has undergone all stages of austenitic transformation. In particular, as is known, the pearlitic transformation of supercooled austenite is crystallization in nature, its mechanism is diffusion [3, 4]. This follows from the fact that austenite is almost homogeneous in terms of carbon concentration, decomposes with the formation of ferrite (almost pure iron) and cementite with a content of 6.6% C, ie a mixture of phases with different concentrations of carbon (Fig. 5).

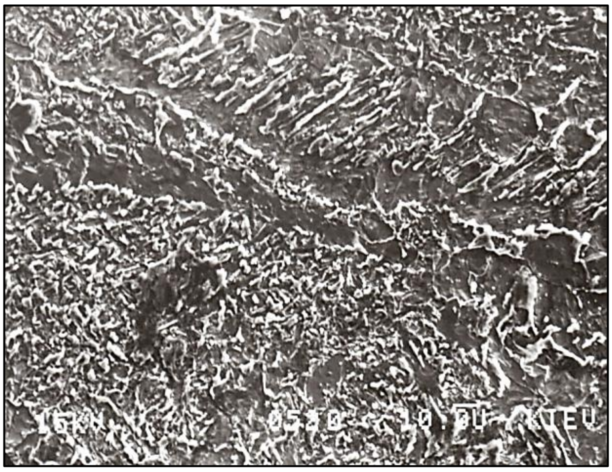

Fig. 5. Structure of perlite and cementite needles (Fe_3C) in the decay of austenite reinforcing steel (20ХСНДА) – (x500)

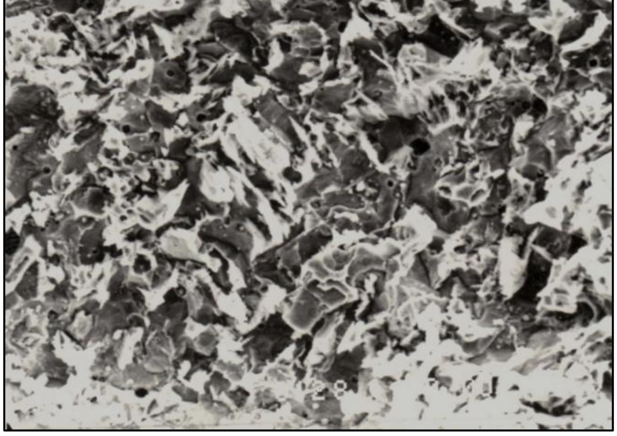

Fig. 6. Microstructure of martensite and residual austenite of reinforcing steel (x600)

The main phase is martensite (Fig. 6).

The growth of the cementite germ is due to the diffusion of carbon from the adjacent volumes of austenite. This eventually leads to its transformation into ferrite. At the same time there is an increase in the thickness of the plates of ferrite and cementite (see Fig. 4). Thus, on the surface of the formed pearlite grain there are also germs of cementite with a different orientation. This process continues until the collision of individual grains and the transformation of all austenite. Moreover, the lower the decay temperature of austenite, the more dispersed is the ferrito-cementite mixture (Fig. 7, 8).

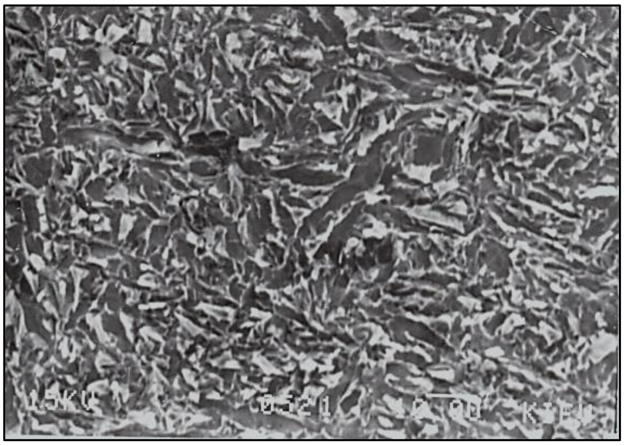

Fig. 7. The effect of temperature on the formation of the structure (fine) sorbitol during the decay of austenite (transformation at 650…680ºC)

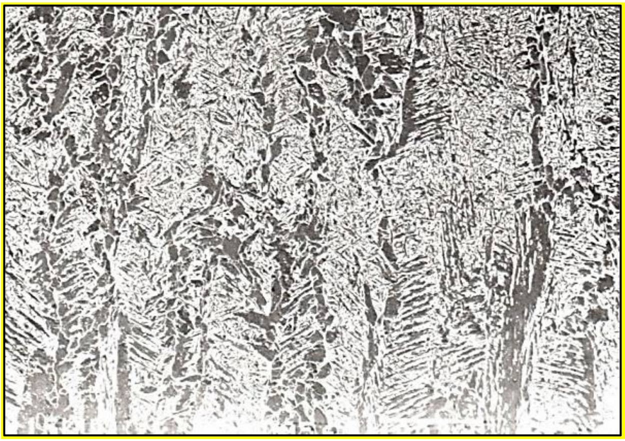

Fig. 8. The structure of sorbitol of reinforcing steel 20ХСНДА during the decay of austenite (conversion temperature – 400…599ºC) – (x1500)

It should be noted that the degree of dispersion is usually characterized between the lamellar distance Δ, under which take the average sum of the thicknesses of the plates of ferrite and cementite. It should be noted that the thickness of carbide plates is determined by the mobility of carbon atoms, which depends on temperature. It is established [2…4] that with a large supercooling (up to temperatures of 500…550ºC) a more dispersion mixture called cane is formed (Fig. 9).

At magnifications of the order of 1,500 times or more, this is clearly visible on the electron microscope. The authors of this work found that the distance between the plate in perlite is 0.5…1.2 μm, sorbitol ≈0.35 μm and trostite ≈0.2 μm (see Fig. 9).

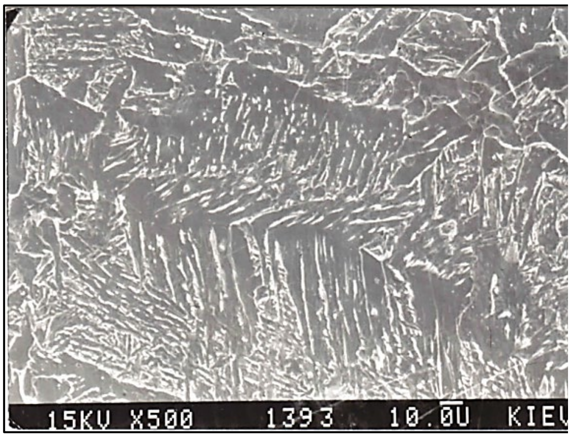

Fig. 9. Microstructure of the rebar of reinforcing steel 20ГС (x1600)

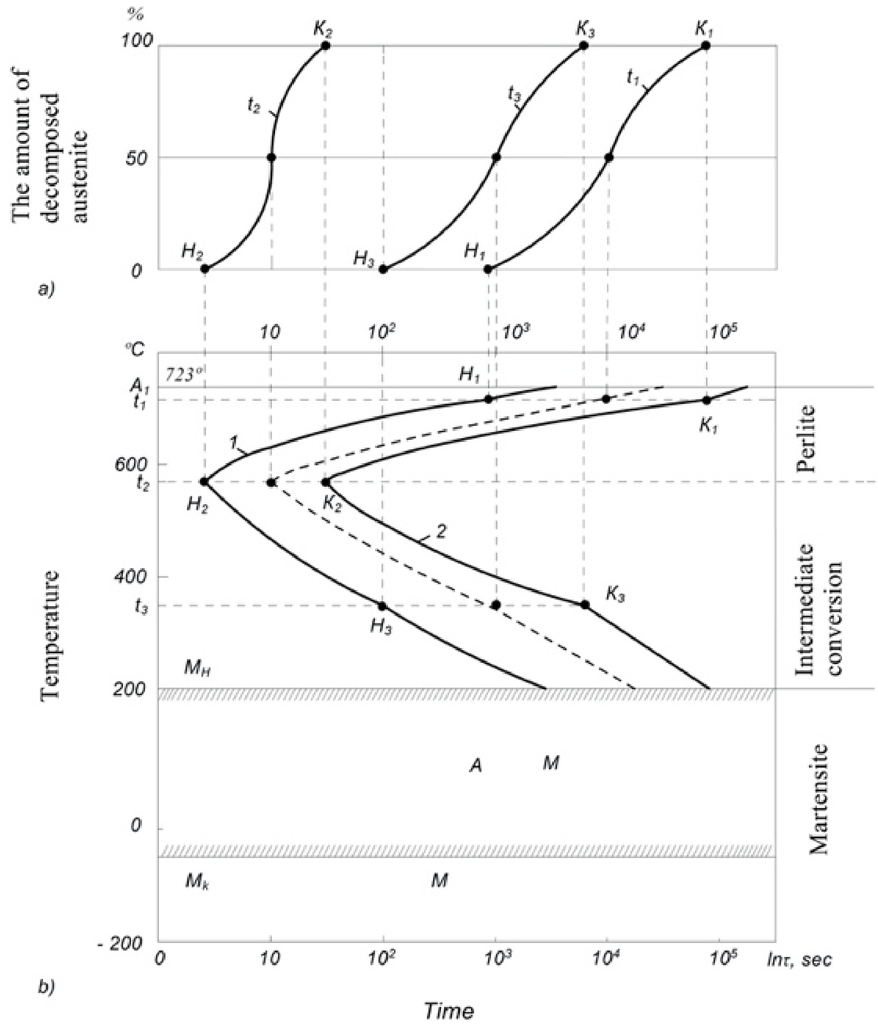

Fig. 10. Construction of the diagram of isothermal transformation of supercooled austenite for reinforcing steel 20ГС. Notation: a) kinetic curves; b) diagram of isothermal transformation of austenite

It is known [5, 6] that the intermediate transformation takes place at low cooling temperatures of austenite 400…200ºC, when the diffusion of iron atoms is almost impossible, and the diffusion of carbon atoms is relatively easy. Therefore, the diffusion process of ferrite formation becomes impossible, and the formation of iron carbide and its separation from austenite and ferrite can occur [3, 4]. Therefore, the kinetics of the intermediate transformation and the structures formed in this case have features of both diffusion (pearlitic) transformation and non-diffusion (martensitic) transformation.

In general, the mechanism of intermediate transformation is as follows. In the intermediate temperature range, the supercooled austenite undergoes transformation (decay) after some incubation period. Initially, there is a diffusion redistribution of carbon inside the austenite, which leads to the formation of volumes of austenite enriched and depleted of carbon (see Fig. 10). Areas of carbon-depleted austenite undergo a non-diffusion transformation γ → α. In the non-diffusion transformation γ → α, only the lattice type (FCC → BCC) changes without changing the location of the carbon

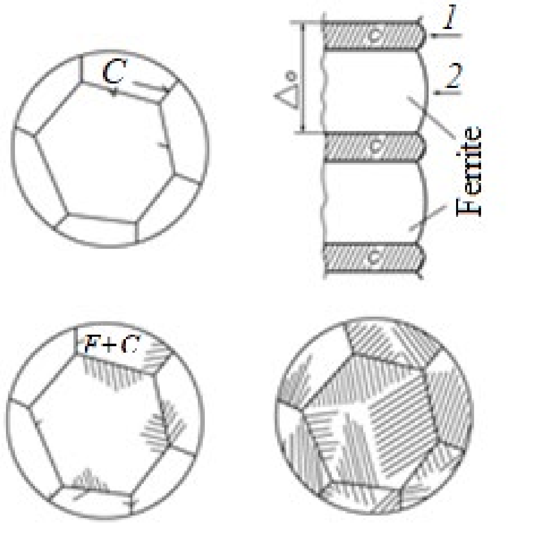

Fig. 11. Schematic representation of the origin and growth of pearlite grain. Designation: C - cementite; F + C - ferrite plus cementite; 1 - high concentration of carbon (6.67%); 2 - low carbon concentration (0.002%); Δ_o - between the plate distance

atoms in austenite. Therefore, as a result of such transformation, a supersaturated solid α-solution (martensite) is formed, which is an unstable structure and decomposes into a ferritic-cementite mixture at isothermal exposure. Thus, as a result of the intermediate transformation, a structure is formed, which consists of a mixture of α-phase and carbide (cementite), which is called bainite (see Fig. 1), and sometimes needle cane. Thus, the intermediate transformation of austenite combines the diffusion redistribution of carbon in austenite with the non-diffusion (martensite) transformation γ → α. It should be noted that in the upper bainite is concentrated mainly the structure of sorbitol similar to the structure of

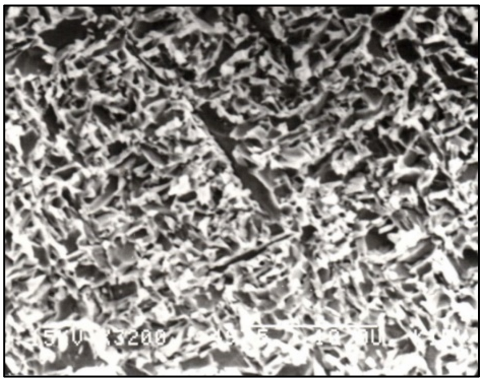

Fig. 12. Microstructure of bainite of reinforcing steel 20ГС (x1000)

perlite, and in the lower bainite carbide particles are located inside the plate of the α-phase (Fig. 11).

The above data are confirmed by the microstructure of bainite grain (Fig. 12).

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Исследование взаимосвязи предела прочности и долгосрочной усталости стальноиј укрепления железобетонных конструкций

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Аннотация. Результаты экспериментальных исследований показали сильное влияние диффузионного водорода на статические и циклические параметры трещиностойкости арматурной стали. Было обнаружено, что с увеличением затопления, особенно когда содержание водорода превышает 5 см^3/100 г, как статическая прочность, так и длительная прочность (усталость) резко снижаются. Причем эти участки раствора водорода в арматурной стали характеризуются вязким характером разрушения, тогда как для сильно обводненной арматуры (от 5 до 12 см^3/100 г) характерно хрупкое разрушение по механизму микротрещин в закаленной (мартенситной или трооститовой) стали. Анализ полученных экспериментальных результатов позволил определить оптимальное содержание водорода в арматурной стали (3…5 см^3/100 г), превышение которого может вызвать снижение трещиностойкости арматуры при длительной эксплуатации, особенно в агрессивных средах.

Предложен механизм влияния водорода на трещиностойкость металла при статическом и

знакопеременном нагружении, который заключается в диффузии и перемещении дислокаций водорода в структуре армирующего стержня, что в результате вызывает сильное заливание стали и увеличения ее хрупкости. Установлено, что углеродные и низколегированные стали, характеризующиеся ферритно-перлитной и сорбитовой структурой, обеспечивают высокую стойкость, особенно к длительной усталости, и переходу на стали со структурой мартенсита или отпуска (переходная структура бейнита). Структура бейнита резко снижает прочность арматурной стали, что делает невозможным использование ее при изготовлении арматуры для железобетонных конструкций, рассчитанных на длительную эксплуатацию (более 50…60 лет). Таким образом, полученная схема может быть рекомендована проектировщикам железобетонных конструкций гидротехнического назначения, так как значительно облегчает разумный выбор арматуры при разработке железобетонных конструкций ответственного и длительного использования.

Ключевые слова: трещиностойкость, затопление, усталость, цикличность, арматура.

Stabilization of the process of mechanized pulsed-arc welding

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Abstract. The main disadvantage of the mechanized arc welding process in shielding gases with short circuits is the spatter during melting of the electrode metal and its transfer to the weld pool, which affects the productivity of the process, reducing it. Its elimination is possible through the implementation of the controlled transfer of molten electrode metal into the weld pool. The implementation of such a transfer and the control of the processes that take place in the arc gap to a large extent determine the conditions for the qualitative formation of the deposited metal, the stability of the process, the magnitude of the loss of electrode metal and the manufacturability of the processes of arc welding in shielding gases. At the present stage of development of welding technologies, controlled transfer of electrode metal is possible due to the pulsed nature of arc burning. In this case, one of the main methods for increasing the efficiency of the process is to limit the maximum value of the short circuit current by increasing the inductive resistance of the welding circuit.

The research aimed to determine the effect of the rate of rising of the welding current during a short circuit on the stability of the welding arc. It was found that an increase in the current growth rate, starting from 1.23 kA/s to 50 kA/ s, leads to a decrease in the average duration of short circuits by at least 10 times. At the same time, the average frequency of short circuits increases by more than 2 times, from 36...38 s^{-1} to 80...86 s^{-1}. The reason for this is the increase in the values of the electrodynamics' Lorentz force, the action of which leads to the compression of the liquid metal bridge of the drop (pinch effect) due to an increase in the short circuit current. At the same time, there is a violation of the stability of the pulse process, and this is reflected in an increase in the average frequency of arc breaks by more than 30 times from 0.33 s^{-1} to 10 s^{-1}. An increase in the energy parameters of the welding process led to a decrease in the average frequency of short circuits (2...3 times) and their average duration (2 times). The reason for this should be considered a change in the type of transfer of liquid metal – the welding process with short circuits has turned into a mixed process in which, along with short circuits, a droplet transfer of electrode metal is observed.

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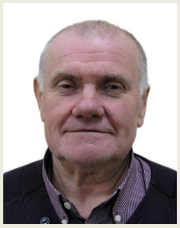

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Keywords: mechanized arc welding in shielding gases, arc stability, controlled transfer, current source, inductive resistance, short-circuit current rise rate.

INTRODUCTION

It is known that mechanized arc welding in shielding gases with short circuits (s.c.) is performed at moderate values of the welding current (up to 180...220 A) and a relatively low voltage (18...24 V) on the arc. The main disadvantage of the process is spattering during melting of the electrode metal and its transfer to the weld pool, which affect the productivity of the process, reducing it [1, 2]. Authors of publications [3 – 6], devoted to the improvement of technological processes of shielded-gas arc welding, based on theoretical and practical searches, came to the conclusion that the elimination of drawbacks is possible through the implementation of the controlled transfer of molten electrode metal into the weld pool. The implementation of such a transfer and the control of the processes that take place in the arc gap to a large extent determine the conditions for the qualitative formation of the deposited metal, process stability, the amount of electrode metal losses and the manufacturability of the processes of arc welding in shielding gases [7 – 9]. At the present stage of development of welding technologies, controlled transfer of electrode metal is possible due to the pulsed nature of arc burning [10 – 13].

When pulsed-arc welding, one of the main methods for increasing the efficiency of the process is to limit the maximum value of the short circuit current by increasing the inductive resistance L in the welding circuit [14 – 16]. The parameters of the inductive resistance of the welding circuit determine the current growth rate v_c during short-circuit, on which depends $I_{s.c.}^{max}$, the stability of the welding process and spatter of the electrode metal [1, 17, 18]. Under the stable behaviour of the pulse-arc welding process, we will consider such a process in which there is no violation of the welding arc burning. A sign of violation of the arc burning will be the transition of the power source to open-circuit voltage, which will be recorded by the information-measuring system when registering the instantaneous values of current and voltage on the arc.

PURPOSE AND METHODS

Based on the features of mechanized arc welding, the aim of the research was to determine the influence of the value of the welding current growth rate during a short circuit on the stability of the welding arc.

It should be noted that in a pulse power supply, there is a structurally absent inductor that regulates the value of v_c, and, accordingly, the maximum value of the short circuit current $I_{s.c.}^{max}$. To control these parameters, it is provided that the so-called virtual inductance L_V is numerically laid in the controller at the program level, which determines the reaction rate of the source to a change in current in the "source-arc" circuit.

In connection with this feature, before performing experimental studies, the relationships between L_V and v_c were determined using a computerized information-measuring system (IMS) [19]. For this, the inverter [20] was connected to the ballast rheostat according to the circuit in Fig. 1. When the circuit breakers were closed at 50 A, and then at 100 A at different L_V values, the analogue-digital converter IMS recorded a current jump from 50 A to 150 A using a connected current transformer.

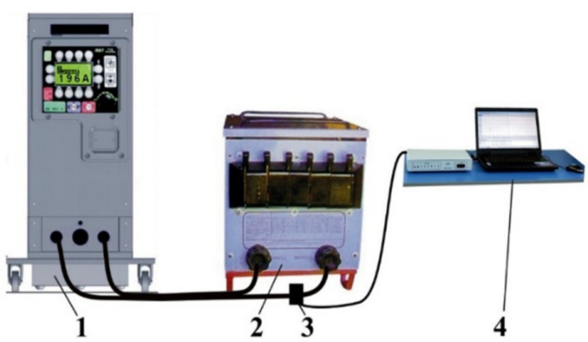


Fig. 1. Connection diagram of devices for determining the dependence of the value of v_c from the parameter L_V: 1 – power supply LET-500, 2 – ballast rheostat, 3 – current transformer, 4 – information-measuring system IMS 2007

During operation, the IMS recorded the instantaneous values of the current flowing in the inverter-rheostat circuit, after which the time interval at which the current increased from 50 to 150 A was determined from the oscillogram (Fig. 2).

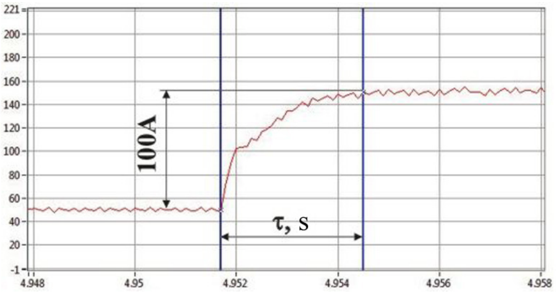


Fig. 2. An example of current oscillograms for determining the current growth rate from 50 to 150 A. τ is the current growth time by 100 A

The value of v_c calculated according to a simple formula: v_c = 100 [A] / τ [s]. Depending on the value of L_V, τ changed. The calculation results of v_c for different values of L_V are shown in Table 1.

Table 1. The calculated values of v_c for different values of the parameter L_V

L_V, conventional units	v_c, kA/s	L_V, conventional units	v_c, kA/s
9	50,0	21	1,23
12	35,7	24	0,35
15	11,4	27	0,22
18	4,15	30	0,06

The implementation of the experimental work involved surfacing on a plate with programming the inverter operation mode at different values of L_V= 9, 12, 15, 18, 21, 24, 27, 30. For this purpose, current-voltage characteristics (CVC) No.1 and No.2 were placed in the inverter (Fig. 3) and set the pulse mode with a frequency of f = 25 Hz and a duty cycle of C = 2.

Plate material – steel of strength class X70, wire – Sv08G2S with a diameter of 1.2 mm, wire feed speed V_W = 5.1 m/min., shielding gas – Ar + CO_2, welding speed V = 30 cm/min.

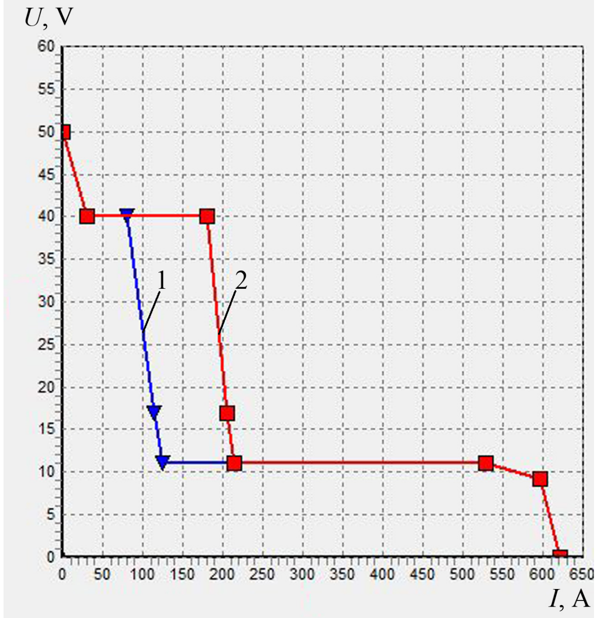


Fig. 3. CVC of a pulsed process with a frequency f = 25 Hz to determine the effect of the growth rate of the welding current v_c arc stability: 1, 2 – inverter operation according to *I–V* characteristics No.1 and *I–V* characteristics No.2, respectively

The heat input Q for each experiment was calculated using the well-known formula in which the values of I_{AV} and U_{AV} were determined by statistical processing of instantaneous values of current and voltage by the information-measuring system IMS 2007:

$$Q = \frac{60 \cdot I_{av} \cdot U_{av}}{V} \cdot \eta , \qquad (1)$$

where V – welding speed (cm/min.), η = 0.7.

RESULTS AND EXPLANATIONS

The results of the analysis of the data recorded by the computerized IMS, and conclusions regarding the stability of the pulse process are shown in Table 2.

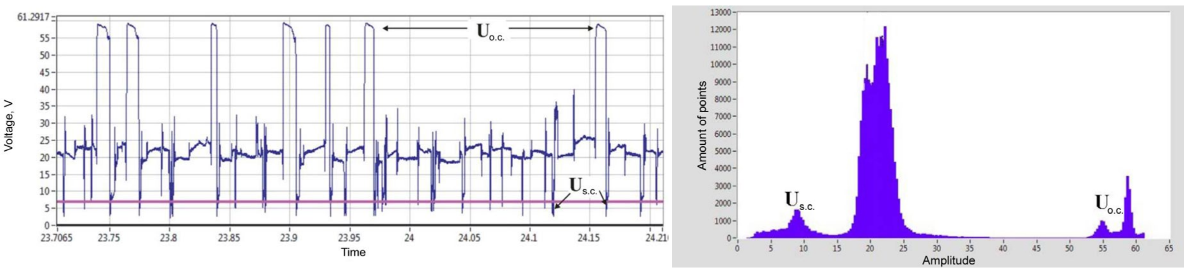
Evaluation of all recorded oscillograms of the arc voltage and their statistical processing shows that the value of L_V significantly affects the stability of the pulse process during the transfer of metal with short circuits (Fig. 4).

Table 2. Modes of the pulse-arc process at different values of L_V

N	L_V	v_c, kA/s	I_{AV}, A	U_{AV}, V	Q, kJ/sm	$I_{s.c.}^{max}$, A	Note
1	9	50,0	161	23,1	5,207	467	Arc interruption
2	12	35,7	169	22	5,205	467	Arc interruption
3	15	11,4	167	22,9	5,354	460-467	Arc interruption
4	18	4,15	172	22,25	5,358	430-435	Reduction of the arc interruption
5	21	1,23	172	21,8	5,249	350-360	Reduction of the arc interruption
6	24	0,35	173,5	21,8	5,295	330-350	No arc interrup-tion
7	27	0,22	175,1	21,56	5,285	200-270/ 270-330	No arc interrup-tion
8	30	0,06	172,1	21,94	5,286	200-260/ 270-330	No arc interrup-tion

So, at L_V = 9...18, which corresponds to the values of the welding current rise rate v_c = 50.0...4.15 kA/s, non-uniform breaks in the welding arc burning are observed. On oscillograms, this is reflected in the operation of the switching power supply at open-circuit voltage $U_{OC} \approx 60$ V (Fig. 4, a-d). An increase in the value of L_V to conventional values of 24...30, which due to the inverter control system significantly reduces the value of v_c, Leads to the fact that the process of arc burning is much more stable, almost without breaks (Fig. 4, e-k). On the histogram, this is displayed by a sharp decrease in the number of instantaneous values of the power supply operation at U_{OC}.

When analysing the oscillograms of the welding current and the statistical processing of the *I–U* characteristics of the process (Fig. 5), it was found that a decrease in the value of v_c leads to a significant limitation of the maximum value of the short circuit current. So, for example, at v_c = 35.7 kA/s (Fig.5, a), there is, in addition to the already identified violations in the stability of continuous arc burning (I_W = 0, $U_A = U_{OC}$), a wide range of the spread of the



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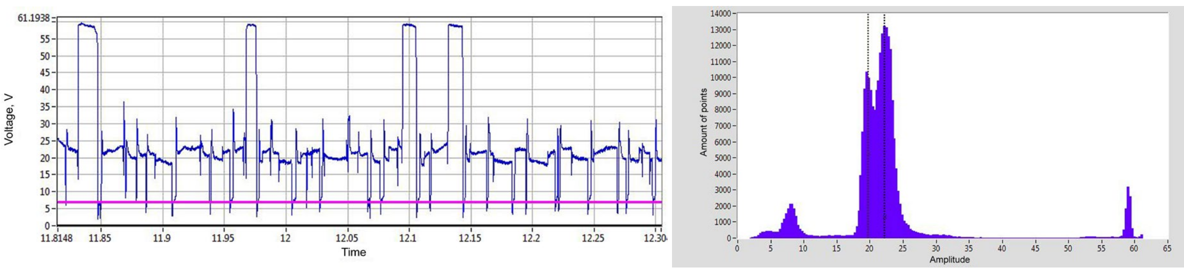
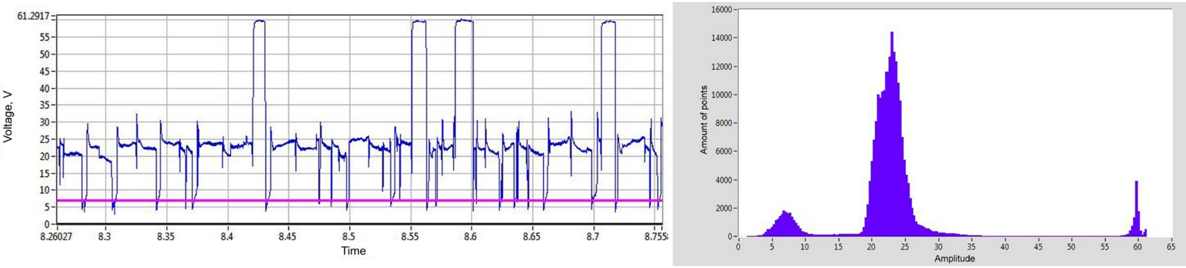


b

Fig. 4 (beginning). Oscillograms and histograms of the arc voltage at different L_V values: a – 9 (v_c = 50 kA/s); b – 12 (v_c = 37.5 kA/s); c – 15 (v_c = 11.4 kA/s); d – 18 (v_c = 4.15 kA/s); e – 21 (v_c = 1.23 kA/s); f – 24 (v_c = 0.35 kA/s); g – 27 (v_c = 0.22 kA/s); h – 30 (v_c = 0.06 kA/s). U_{SC} – instantaneous voltage values during short circuit, U_{OC} – instantaneous voltage values when the power source is working at open circuit voltage



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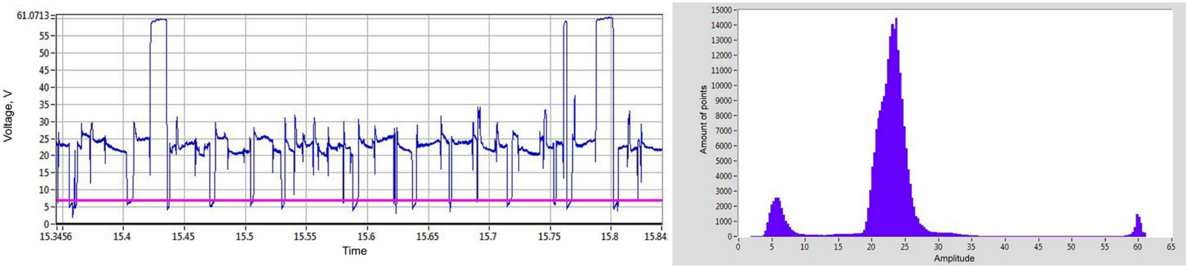

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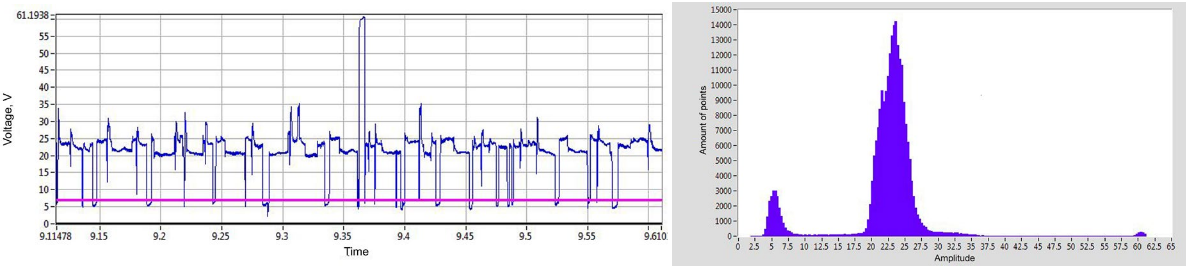

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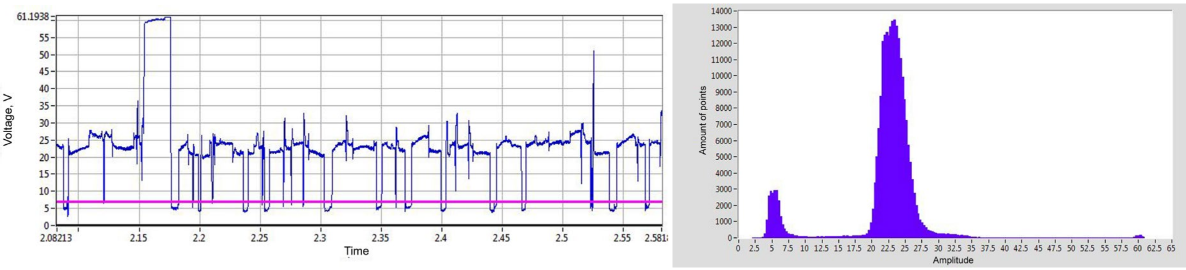

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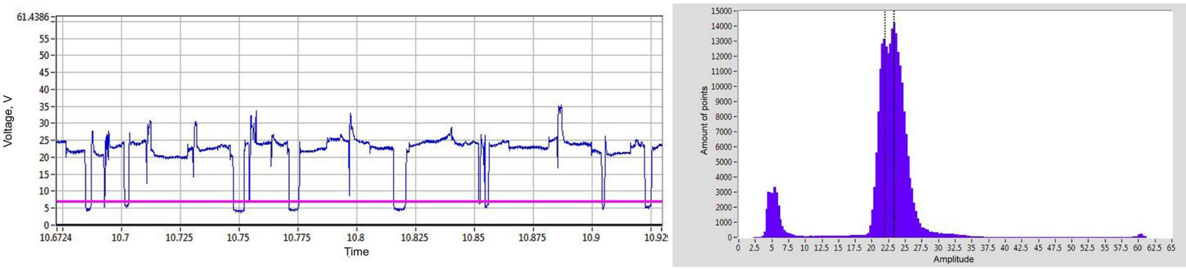

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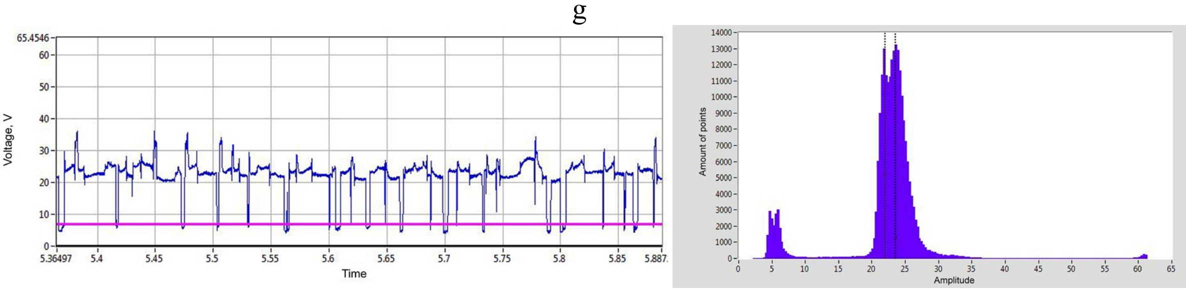


h

Fig. 4 (the end). Oscillograms and histograms of the arc voltage at different L_V values instantaneous values I_{SC} = 120...465 A zone. The maximum value of the short circuit current in many cases was $I_{\text{s.c.}}^{\max} = 467$ A. When surfacing, this was reflected in a high sputtering of molten metal.

A gradual increase in virtual inductance to L_V = 24 ... 30 (ν_c = 0.35 ... 0.06 kA/s) led to a significant change in the quality of the pulse process (Fig. 5, f-h). The maximum short circuit current decreased by 130 A to $I_{\text{s.c.}}^{\max}$ = 330...350 A and the zone of dispersion of instantaneous values was I_{SC} = 200...330 A.

The entire zone of instantaneous values I_{SC} is divided into two ranges: the first – 200...260 A and the second 270...350 A. It can be assumed that the first range corresponds to a short circuit at the time of operation of the power supply according to CVC No.1, and the second – according to CVC No.2.

Statistical processing of instantaneous values of the welding current showed that an increase in the current growth rate ν_c, starting from 1.23 kA/s and up to 50 kA/s, leads to a decrease in the average short-circuit duration by at least 10 times (Fig. 6, a). At the same time, the average frequency of short circuits increases more than 2 times – from 36...38 s^{-1} to 80...86 s^{-1}. The reason for this is the increase in the values of the electrodynamics' Lorentz force, the action of which leads to the compression of the liquid metal bridge of the droplet (pinch effect) due to an increase in the magnitude of the I_{SC}. Energy characteristics of the pulsed process for different ν_c did not

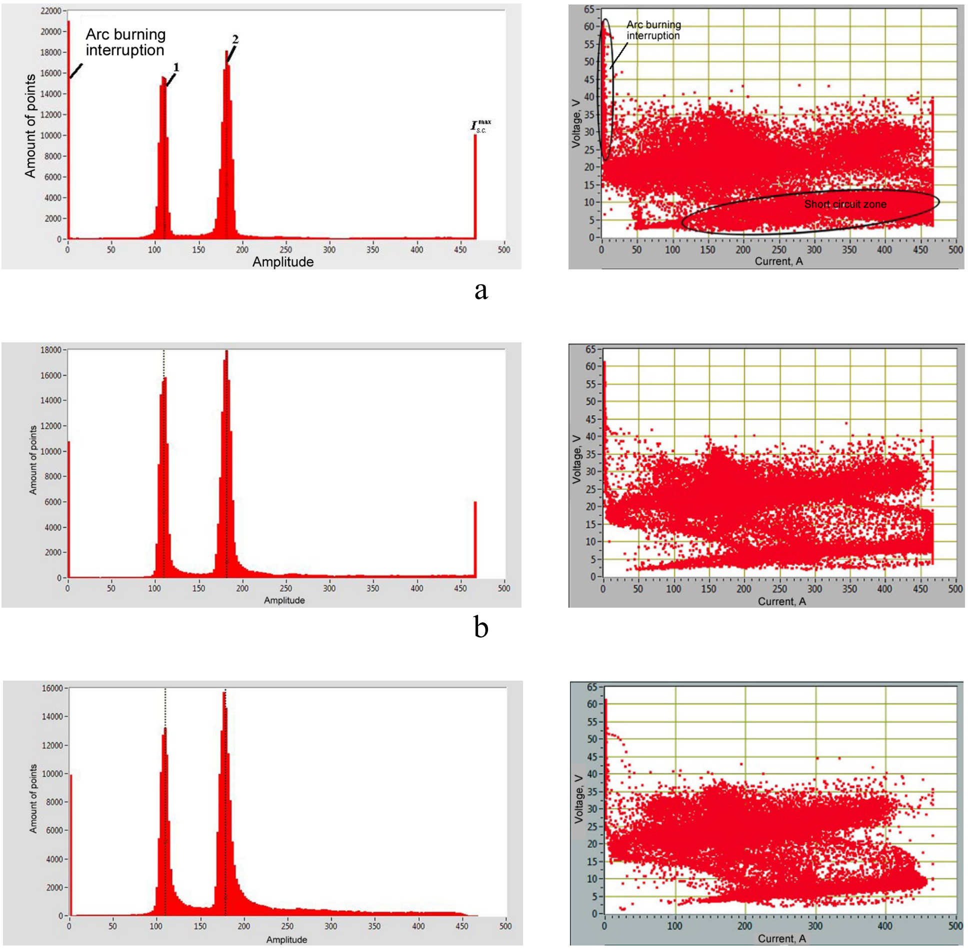
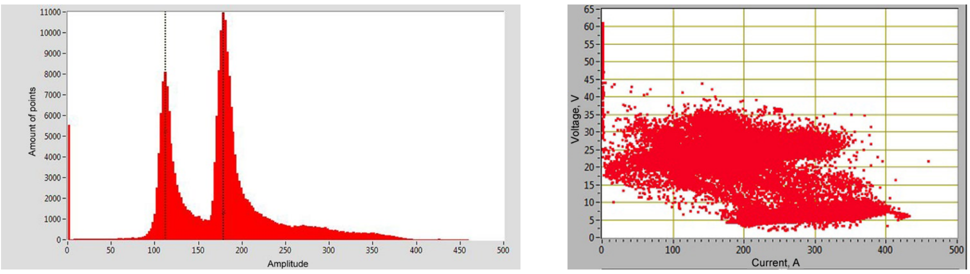


Fig. 5 (beginning). Histograms of the welding current and the current-voltage characteristic of a pulsed process with short circuits at different L_V values: a – 9 (ν_c = 50 kA/s); b – 12 (ν_c = 37.5 kA/s); c – 15 (ν_c = 11.4 kA/s); d – 18 (ν_c = 4.15 kA/s); e – 21 (ν_c = 1.23 kA/s); f – 24 (ν_c = 0.35 kA/s); g – 27 (ν_c = 0.22 kA/s); h – 30 (ν_c = 0.06 kA/s). 1, 2 – inverter operation according to *I–V* characteristics No.1 and No.2, respectively



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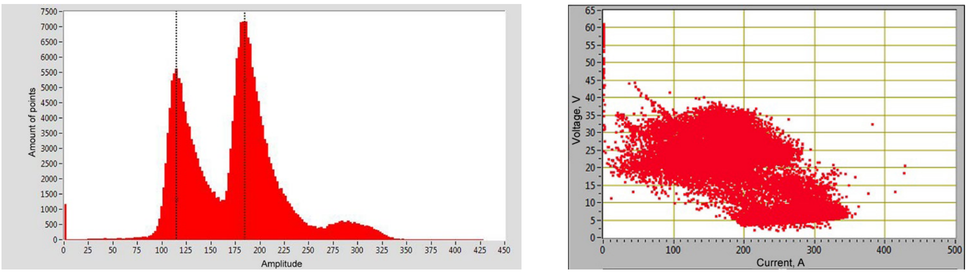

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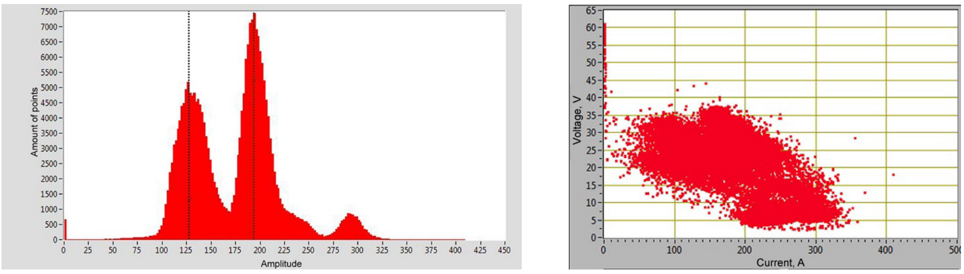

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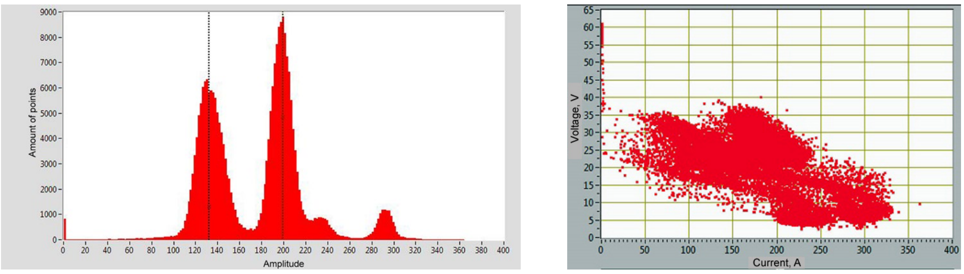

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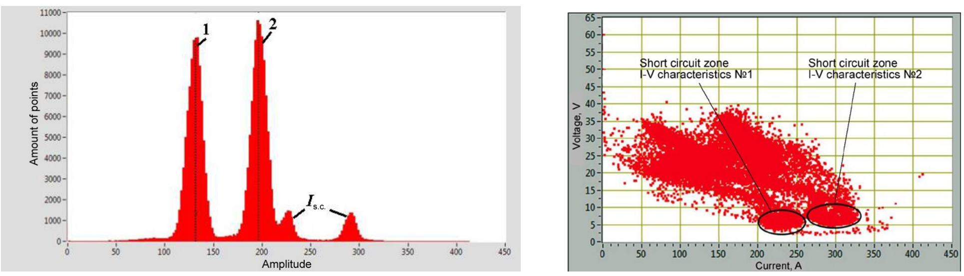

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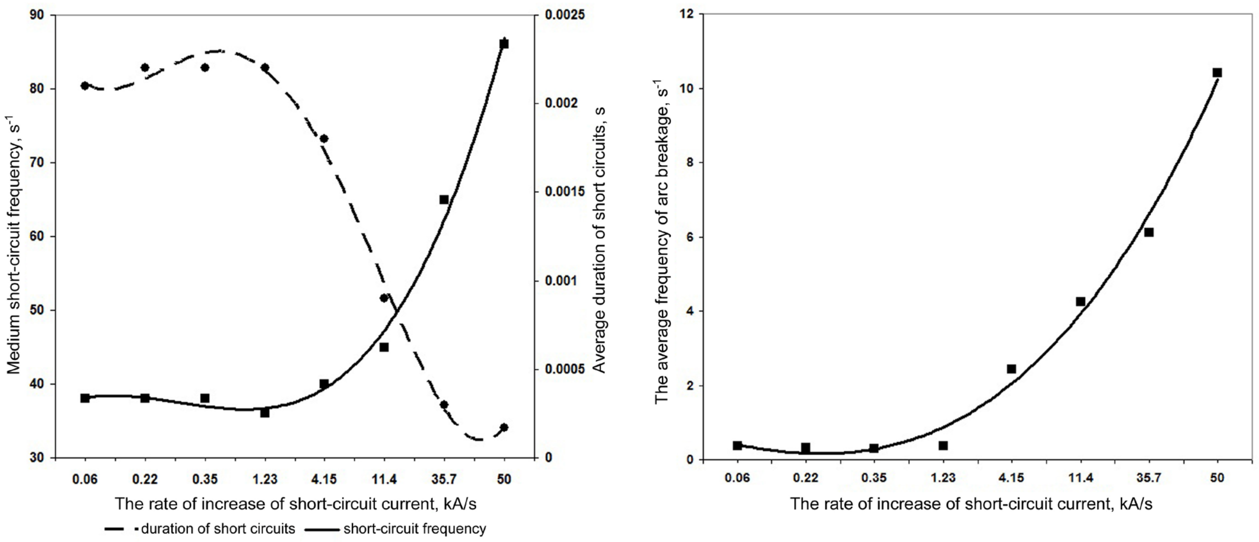
Fig. 5 (the end). Histograms of the welding current and the current-voltage characteristic of a pulsed process with short circuits at different L_V values



a b

Fig. 6. The influence of the short-circuit current growth rate on: a – the average frequency and duration of short-circuit; b – the stability of the pulse-arc welding process

change significantly since the values of I_{AV} and U_{AV} remained at the same level (160...170 A, 21...22.5 V), the heat input Q was in the range of 5.20...5.35 kJ/cm.

Statistical analysis also confirmed the conclusion (Fig. 6, b) that the increase in v_c leads to a violation of the stability of the pulse process and this is reflected in an increase in the average frequency of arc breakage by more than 30 times from 0.33 s^{-1} (for v_c = 0.06...1.23 kA/s) to 10 s^{-1} (for v_c = 50 kA/s).

To determine how the growth of the welding current v_c affects the stability of the pulsed process if it is necessary to increase the heat input Q, additional experimental and theoretical studies were carried out. To do this, the *I*–*V* characteristic was placed in the inverter (Fig. 7), in which the falling sections of the *I*–*V* characteristics No.1 and No.2 (in the range of 40 – 11 V) were shifted in the direction of increasing the welding current by 100 A compared to the previous version programming the power source (see Fig. 3). The pulse process was carried out with a frequency f = 25 Hz, the welding speed V = 30 cm/min., the wire feed speed V_W = 7.7 m/h, the shielding gas –Ar + CO_2.

The results of processing these data by a computerized information-measuring system are shown in Table 3.

An analysis of the obtained data and their comparison with the results of previous experiments (Fig. 6, a) showed that an increase

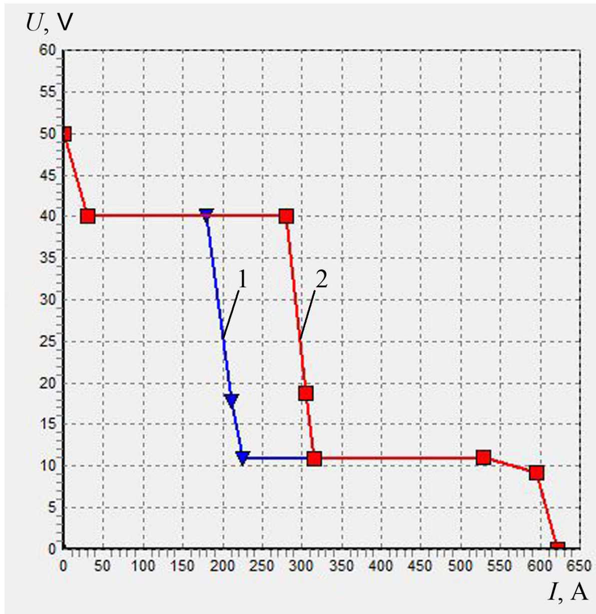


Fig. 7. Current-voltage characteristics of the pulse process to determine the effect of the growth rate of the welding current v_c on the stability of arc burning at heat input Q = 7.8...8.0 kJ/cm. 1, 2 – inverter operation according to *I*–*V* characteristics No.1 and No.2, respectively

Table 3. Welding modes and data processing results

N	L_V	v_c, kA/s	I_{AW}, A	U_{AW}, V	Q, kJ/sm	$I_{s.c.}^{max}$, A	Average frequency of short circuits, s^{-1}	Short circuit average duration, s	Note
1	9	50,0	220	25,8	7,946	467	27	0,00021	No arc breaks
2	12	35,7	220	25,9	7,977	467	26	0,00050	
3	15	11,4	225	24,5	7,717	450	25	0,00080	
4	18	4,15	223	25,4	7,930	410	22	0,00089	
5	21	1,23	223	25,5	7,961	390	20	0,00090	
6	24	0,35	222	25,9	8,050	385	17	0,00096	
7	27	0,22	225	25,0	7,875	385	21	0,00098	
8	30	0,06	225	24,9	7,843	385	22	0,00094	

in the energy parameters of the pulsed-arc welding to the level of I_{EW} = 220...225 A, U_{EW} = 24.5...25.9 V, Q ≈ 7.9...8.0 kJ/cm led to changes in the parameters that characterize the process of pulse welding with short circuits. A sharp decrease in the average frequency of short circuits (2...3 times) and their average duration (2 times) took place. The reason for this should be considered that the increase in energy indicators changed the type of transfer of liquid metal – the welding process with short circuits (Fig. 8a) turned into a mixed process [15], in which, along with short circuits, a droplet transfer of electrode metal is observed (Fig. 8b). In the latter case, part of the molten metal flows into the weld pool in small drops, while the short circuit time is much shorter (3...5 times) than with a conventional short circuit. As a result of this, the arc voltage remains at the level of U_{SC} > 12...15 V and does not have time to decline to the accepted values of U_{SC} = 5...10 V.

Since the IMS 2007 statistically calculates the cases of short circuit for the condition U_{SC} = 5...10 V and does not take into account larger voltage values, the calculated average frequency of short circuits is lower.

Processing oscillograms of the welding current and voltage showed that pulse-arc welding proceeds stably without disturbances in the welding arc burning in the entire range of the control value L_V = 9...30 (v_c = 50.0...0.06 kA/s).

CONCLUSIONS

1. The increase in the inductance of the power source, which due to the control system of the inverter significantly reduces the slew rate of the short circuit current, leads to stabilization of the pulse-arc welding process with short circuits.

2. An increase in the growth rate of the short circuit current v_c, starting from 1.23 kA/s to 50 kA/s, leads to a decrease in the average duration of the short circuit by at least 10 times. At the same time, the average frequency of short circuits increases more than 2 times.

3. An increase in the energy indices of pulse-arc welding led to a sharp decrease in the average frequency of short circuits (2...3 times) and their average duration (2 times). As a result, the process proceeds stably without disturbances in the burning of the welding arc in the entire range of changes in the inductance of the power source.

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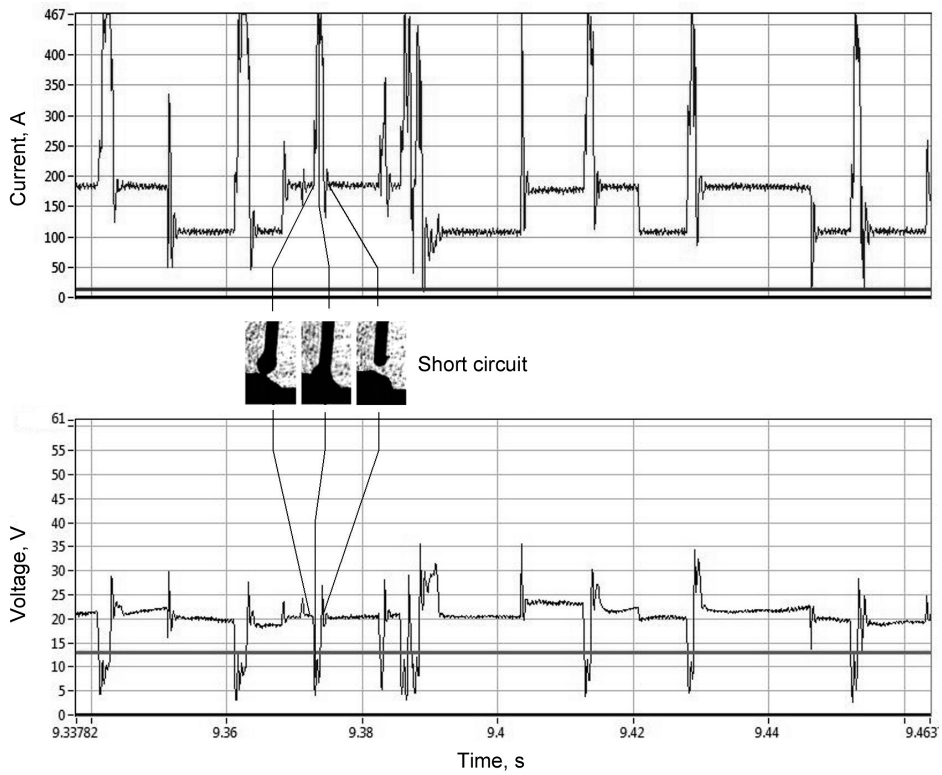
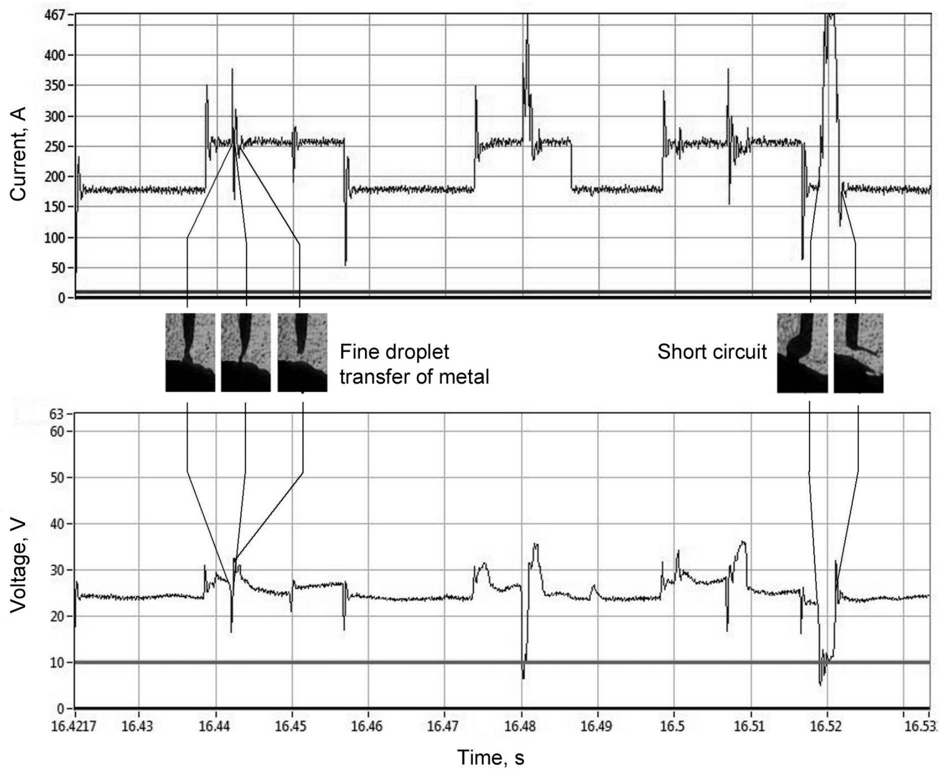


a)



b)

Fig. 8. Oscillograms of current and voltage of the pulse process at v_c = 50 kA/s: a – process with short circuit (Q = 5.207 kJ/cm); b – mixed process (Q = 7.946 kJ/s)

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Стабилизация процесса механизированной импульсно-дуговой сварки

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Аннотация. Главным недостатком процесса механизированной дуговой сварки в защитных газах с короткими замыканиями является разбрызгивание при плавлении электродного металла и его переносе в сварочную ванну, что сказываются на производительности процесса, снижая ее. Его устранение возможно путём реализации управляемого переноса расплавленного электродного металла в сварочную ванну. Реализация такого переноса и контроль процессов, которые проходят при этом в дуго-

вом промежутке, в значительной степени определяют условия качественного формирования наплавленного металла, стабильность процесса, величину потерь электродного металла и технологичность процессов дуговой сварки в защитных газах. На современном этапе развития сварочных технологий управляемый перенос электродного металла возможен за счет импульсного характера горения дуги. При этом одним из основных приёмов повышения эффективности процесса является ограничение максимальной величины тока короткого замыкания за счет увеличения индуктивного сопротивления в сварочной цепи.

Цель проведенных исследований – определение влияния величины скорости роста сварочного тока при к.з. на стабильность горения сварочной дуги. Установлено, что увеличение скорости роста тока, начиная с 1,23 кА/с до 50 кА/с, приводит к уменьшению средней продолжительности короткого замыкания не менее чем в 10 раз. Одновременно с этим увеличивается средняя частота коротких замыканий более чем в 2 раза, с 36 ... 38 $с^{-1}$ до 80 ... 86 $с^{-1}$. Причина этого заключается в росте значений электродинамической силы Лоренца, действие которой приводит к сжатию перемычки жидкого металла капли (пинч-эффект) вследствие увеличения величины тока короткого замыкания. При этом наблюдается нарушение стабильности импульсного процесса и это отражается в увеличении средней частоты обрывов дуги более чем в 30 раз с 0,33 $с^{-1}$ до 10 $с^{-1}$. Увеличение энергетических показателей процесса сварки привело к уменьшению средней частоты коротких замыканий (в 2 ... 3 раза) и средней продолжительности к.з. (в 2 раза). Причиной этого следует считать изменение типа переноса жидкого металла – процесс сварки с короткими замыканиями превратился в смешанный процесс, в котором наряду с короткими замыканиями наблюдается мелкокапельный перенос жидкого металла.

Ключевые слова: механизированная дуговая сварка, защитные газы, стабильность горения, сварочная дуга, управляемый перенос, источник тока, индуктивное сопротивление, скорость роста сварочного тока, короткое замыкание.

Improvement of the calculation and experimental method of evaluation of carbonization of reinforced concrete structures of sewerage underground systems

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Abstract. Carbonization of concrete leads to a decrease in the alkalinity of concrete, an increase in the number of hydrogen ions in the pores, is one of the main factors that lead to corrosion of reinforcement, the formation of cracks and the subsequent reduction of load-bearing capacity of structures. The study of the depth of carbonization of concrete is to determine the pH of the pore liquid at different depths. There are devices with automatic maintenance of a given concentration of carbon dioxide, to determine the diffusion permeability of concrete to carbon dioxide, based on data on the rate of neutralization (carbonization) of concrete with carbon dioxide. Basically, this method is intended for use in the development of technology and design of concrete composition, providing long-term maintenance of structures in non-aggressive and aggressive gaseous environments, as chips are not prepared immediately before the test and after reaching the design age are placed in the installation with reagents for 7 days. But to determine the carbonization directly on the construction site or object often use the pH method, i.e. the indicator method of pH determination. To assess the concentration of hydrogen ions used acid-base indicators - organic substances – dyes, the color of which depends on the pH from the obtained results the algorithm of definition of depth of carbonization consists in the following actions. The improved formula of definition of depth of carbonization of concrete taking into account degree of aging and corrosion damages for what in the final formula the corresponding coefficients k_{st} and k_{kor} are entered: hcarb = $\{(2D{\star}C{\star}\tau) / (m_o{\star}k_{st}\ {\star}k_{kor})\}$ 1/2, where the effective diffusion coefficient of CO_2 in the concrete of the existing reinforced concrete structure, which is determined by the condition $D = (m_o{\star}\delta_2) / (2C{\star}t\ )$. The thickness of the neutralized layer δ is determined exper-

imentally on an existing structure using a physico-chemical method (phenolphthalein solution or using depth gauges. .Concentration of CO_2 in air C should be determined by chemical analysis of air samples taken directly from the structure or take ≈ 0.03%. Re. the ability of concrete mo is determined by the formula $m_o = 0.4$ (C⋆p⋆f), taking the amount of cement, kg per $1m^3$, respectively, the strength of concrete. neutralization of concrete is equal to f = 0.5.

Keywords: carbonization, corrosion, reinforcement, concrete, hydraulic engineering, diffusion.

INTRODUCTION

Carbonization (neutralization) of concrete is a process of interaction with carbon dioxide (CO_2) which results in the formation of calcium carbonate with a reduced pH of the liquid phase of concrete and the loss of passive action on concrete reinforcement (Fig. 1, 2) [1 − 4].

Moreover, the passive state is a state of the metal in which the speed of the anode process is very limited, ie corrosion is virtually absent.

Influence of chlorides − 65% carbonization − 5…6% poor quality mortar – 3…4% frost destruction − 5% fatigue of structures − 5% construction and installation defects – 18…20% This is more clearly illustrated in Fig. 3 [3, 4].

Despite the fact that carbonization occupies only 5…6% of destruction, but its prevalence in recent years in underground sewer-hydraulic reinforced concrete structures has led to the need for urgent study of this important problem for the construction industry [4, 5].

According to the analysis of literature sources which are devoted to the problem of carbonization, the main characteristic responsible for the kinetics of carbonization is the diffusion permeability of carbon dioxide CO_2 into concrete.

According to Fick's first law, we have

$$Q = - D \cdot (dc/d\delta), \quad (1)$$

where Q is the amount of transferred substance that is proportional to the gradient of its concentration d_c/d_δ; D is the coefficient of proportionality or diffusion coefficient cm^2/s (it is assumed that the diffusion coefficient does not depend on the gas concentration and time) [7].

The change in concentration with time dc/dδ at point (x) in linear diffusion is determined by Fick's second law

$$dc/dt = D \cdot (d2c/d\delta 2). \quad (2)$$

Assuming that the concentration of CO_2 in the pores of concrete varies linearly from the value of the concentration in the environment to zero in the zone of chemical interaction, and that the concentration gradient for small time intervals is constant, we can determine the effective diffusion coefficient by the formula

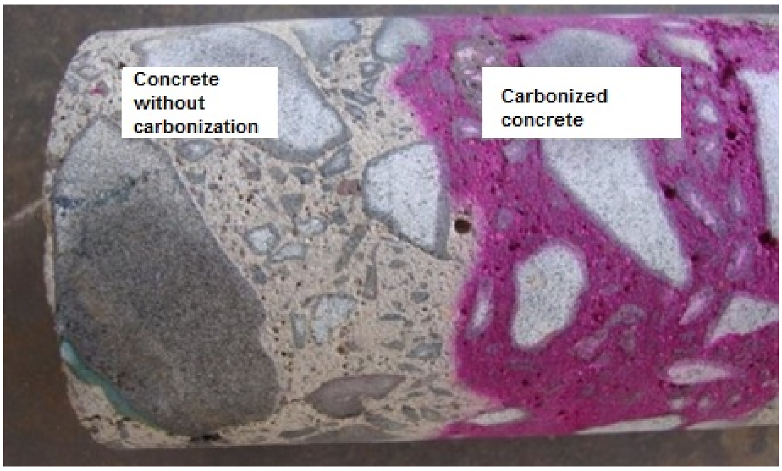

Fig. 1. A concrete sample is taken from the reinforced concrete structure of the underground sewer system

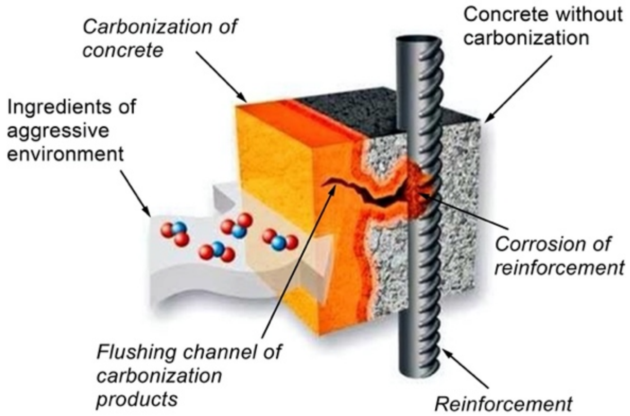

Fig. 2. Schematic representation of the occurrence of corrosion of reinforcing steel

$$D = (m_o\ 2\delta_2/2C \cdot t), \quad (3)$$

where D is the effective gas diffusion coefficient in concrete cm^2 / s; mo is the reactivity of concrete or the volume of gas absorbed per unit volume of concrete. This value depends on the mineral composition, consumption and degree of hydration of cement and the pore structure of cement stone; δ is the thickness of the neutralized concrete layer, mm; t − duration of gas action on concrete, s; C is the concentration of CO_2 in the air in relative terms by volume.

The reactivity of concrete to carbon dioxide can be determined approximately by the formula

$$m_o = 0.4\ (C \cdot p \cdot f), \quad (4)$$

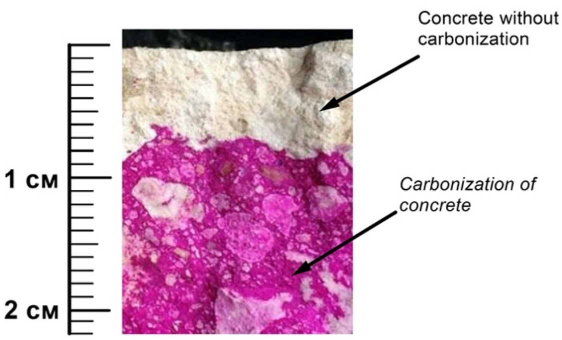

Fig. 3. Scheme of measuring the depth of carbonization

where C is the amount of cement kg per 1 m^3 of concrete; p is the number of basic oxides in the cement in terms of CaO in relative terms by weight. Accepted in the calculations according to the chemical analysis of cement; f is the degree of neutralization of concrete equal to the ratio of the number of basic oxides that reacted with the acid gas to their total amount in the cement.

Since in practice it is often necessary to note the diffusion permeability of existing reinforced concrete structures, for which it is almost impossible to directly determine the parameters C, p, f, they can be determined approximately by the following assumptions. Since the strength of concrete depends on the amount of cement, kg per 1 m^3, you can roughly take C for concrete:

B25 (M300) − 300 kg; B30 (M400) − 400 kg; B40 (M500) − 500 kg. The concrete strength of the existing reinforced concrete structure can be determined by non-destructive methods.

If it is impossible to perform chemical analysis of cement, the value of p can be taken taking into account the composition of Portland cement [7, 8]:

$$CaO = 58\text{-}72\%\ MgO = 5\%\ Na_2O = \\ = 1\text{-}2\%\ K_2O = 1\text{-}2\%,$$

i.e. the value of p can be taken equal to the average height ≈ 0.7.

In addition, we can assume that the degree of neutralization of concrete f, in which carbonization occurs, based on the conditions of a linear drop in CO_2 concentration from the value of the concentration in the environment near the concrete surface to zero in the chemical interaction zone is f = 0.5.

It should be noted that in many scientific works [9, 10] where problems of carbonization of concrete are considered and models of forecasting of its depth of penetration into concrete are offered the main lack, in particular, in such models consequences of aging and corrosion of elements of concrete and reinforcement that obviously overestimates results. theoretical calculations. This shortcoming can be eliminated by entering in the calculation models of the aging coefficients kst and k_{kor} corrosion damage [11] k_{kor}.

Table 1 shows the values of the coefficients kst and kkor for reinforced concrete structures of sewer systems depending on the service life (from 0 to 50 years).

Table 1. The value of the coefficients of aging k_{st} and corrosion k_{kor} reinforced concrete structures depending on the service life in underground sewers

Coefficients	Service life of structures, years				
	10	20	30	40	50
K_{st}	0.7	0.6	0.55	0.5	0.45
K_{kor}	0.85	0.76	0.65	0.6	0.55
k_{Σ}	0.595	0.456	0.38	0.3	0.25

Note: $k_{\Sigma} = k_{st} \times k_{kor}$ is the total degradation coefficient of reinforced concrete structures of sewer systems

Given the above, the formula for determining the depth of carbonization will be as follows:

$$h_{karb} = \{(2D \cdot C \cdot \tau) / (m_o \cdot k_{cт} \cdot k_{kor})\}\ 1/2; \quad (5)$$

Then, using the data of Table 1, according to formula (5) we calculate the depth of carbonization of concrete of long service life. The results of the calculation are summarized in Table 2. Attention is drawn to the low error (not more than 5…6%), which indicates the adequacy of the theoretical calculations of physical and mechanical processes that accompany the carbonization of concrete during the long life of reinforced concrete structures of underground sewerage [12].

Test methods:

- preparation of an alcoholic solution of the indicator 1% alcoholic solution is used: (1 gram of the drug is dissolved in 80 ml of ethyl alcohol and water is added to a volume of 100 ml) [11];

- the indicator is applied on a fresh section of concrete made on an experimental structure or on a sample of concrete powder drilled from different depths from several holes. In the pH range from 8.2 to 10, the color of the indicator changes from colorless to red-purple. It is believed that when the pH of the pore fluid in the concrete around the reinforcement decreases to 10, the concrete loses the ability to reliably protect the reinforcement from corrosion and in the presence of oxygen (oxidized) and moisture (electrolyte) corrosion of the reinforcement can begin. The depth of the carbonization zone from the surface of the structure is measured with a caliper [12].

Thus, it can be emphasized that carbon dioxide CO_2, which is in the atmosphere, primarily penetrating into the pores of concrete, tends to neutralize the highly alkaline environment in the presence of moisture, thereby weakening its protective effect against reinforcement. This process is called carbonization concrete − is a complex reaction of conversion of calcium hydroxide into calcium carbonate, which in a simplified form can be written [12]:

$$Ca\ (OH)\ 2 + CO_2 + H_2O = CaCO_3 + 2H_2O.$$

THE RESULTS OF EXPERIMENTAL AND THEORETICAL RESEARCH AND THEIR DISCUSSION

Table 1 shows the values of the coefficients of aging and corrosion of structures and Table 2 shows the data for determining the depth of carbonization of concrete depending on the service life of the reinforced concrete structure.

The carbonization process consists of a number of intermediate stages, starting from the surface of the concrete structure from the moment of its manufacture and attenuating as carbon dioxide penetrates into the concrete through open pores.

Table 2. Calculated and experimental values of carbonization depth of reinforced concrete structures of underground sewer structures

Depth of carbonization, mm	The service life of structures is years				
	10	20	30	40	50
h_{teor}	7.7	20.17	36.3	61.3	91.9
h_{exp}	9.1	18.7	33.6	58.7	88.87

Note: The error between theoretical (calculated) and experimental values of the depth of carbonization is not more than 5…6% allowed in engineering calculations

During the reactions, the pH value of the porous liquid of concrete decreases from the initial values of 12.5 to a level below 9. With limited access of air, iron is not passivated in alkaline solutions having a pH below 11.3 − 11.8. Carbonization of concrete is completely completed at pH values of about 9. At such pH values there is a depassation of reinforcing steel (destruction of the protective film), resulting in a risk of corrosion of the reinforcement.

Carbonization of concrete leads to a decrease in the alkalinity of concrete, an increase in the number of hydrogen ions in the pores, is one of the main factors that lead to corrosion of reinforcement, the formation of cracks and subsequent reduction of load-bearing capacity of structures. The study of the depth of carbonization of concrete is to determine the pH of the pore liquid at different depths. There are devices with automatic maintenance of a given concentration of carbon dioxide, to determine the diffusion permeability of concrete for carbon dioxide, based on data on the rate of neutralization (carbonization) of concrete with carbon dioxide. Basically, this method is intended for use in the development of technology and design of concrete composition, providing long-term maintenance of structures in non-aggressive and aggressive gaseous environments, as samples are not prepared immediately before testing and after reaching design age are placed in the installation with reagents for 7 days. However, the pH method, i.e. the indicator method for determining pH, is often used to determine carbonization directly on a construction site or site. To assess the concentration of hydrogen ions used acid-base indicators − organic substances − dyes, the color of which depends on the pH of the medium, in this case using phenolphthalein $C_{20}H_{14}O_4$.

CONCLUSIONS

Based on the above, we can conclude the following:

1 The proposed algorithm for determining the depth of carbonization, which consists in the following steps:

Improved formula for determining the depth of carbonization of concrete, taking into account the degree of aging and corrosion damage, for which the final formula introduced the appropriate coefficients k_{st} and k_{kor}: $h_{karb} = \{(2D \cdot C \cdot \tau) / (m_o \cdot k_{st} \cdot k_{kor})\}$ 1/2, where the effective diffusion coefficient of CO_2 in the concrete of the existing reinforced concrete structure, which is determined by the condition $D = (m_o \cdot \delta_2) / (2C \cdot t)$.

2. The thickness of the neutralized layer δ is determined experimentally on an existing structure using a physicochemical method (phenolphthalein solution or using depth gauges).

3. The concentration of CO_2 in the air C must be determined by chemical analysis of air samples taken directly from the structure or take ≈ 0.03%.

4. The reactivity of concrete mo is determined by the formula $m_o = 0.4$ (C·p·f), taking the amount of cement, kg per $1m^3$, according to the strength of concrete. The amount of basic oxides in cement in terms of CaO to take the average values of p ≈ 0.7. Moreover, the degree of neutralization of concrete is taken equal to f = 0.5.

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Улучшение расчетно-экспериментального метода оценки карбонизации железобетонных конструкций подземных систем канализации

Михаил Сукач, Валерий Чигарев, Иван Чеботар

Аннотация. Карбонизация бетона приводит к снижению щелочности бетона, увеличению количества ионов водорода в порах, является одним из основных факторов, приводящих к коррозии арматуры, образованию трещин и последующему снижению несущей способности. вместимость конструкций. Исследование глубины карбонизации бетона заключается в определении pH поровой жидкости на разной глубине. Существуют устройства с автоматическим поддержанием заданной концентрации углекислого газа, позволяющие определять диффузионную проницаемость бетона для углекислого газа на основе данных о скорости нейтрализации (карбонизации) бетона углекислым газом. В основном этот метод предназначен для использования при разработке технологии и конструкции бетонного состава, обеспечивающего длительное обслуживание конструкций в неагрессивных и агрессивных газовых средах, так как стружка не готовится непосредственно перед испытанием и после достижения проектного возраста помещают в установку с реагентами на 7 суток. Но для определения карбонизации прямо на стройплощадке или объекте часто используют pH-метод, то есть индикаторный метод определения pH. Для оценки концентрации ионов водорода используются кислотно-основные индикаторы − органические вещества − красители, цвет которых зависит от pH. По полученным результатам алгоритм определения глубины карбонизации состоит в следующих действиях. Усовершенствованная формула определения глубины карбонизации бетона с учетом степени старения и коррозионных повреждений, для чего в окончательную формулу вводятся соответствующие коэффициенты k_{st} и k_{kor}: $h_{carb} = \{(2D \cdot C \cdot \tau) / (m_o \cdot k_{ст} \cdot k_{kor})\}$ 1/2, где эффективный коэффициент диффузии CO_2 в бетоне существующей железобетонной конструкции, который определяется условием $D = (m_o \cdot \delta_2) / (2C \cdot t)$. Толщина нейтрализованного слоя δ определяется экспериментально на существующей конструкции с помощью физико-химического метода (раствор фенолфталеина или с помощью глубиномеров. Концентрация CO_2 в воздухе C должна определяться химическим анализом проб воздуха, взятых непосредственно из конструкции, либо взять ≈ 0,03% Re. Способность бетона m_o определяют по формуле $m_o = 0,4\ (C \cdot p \cdot f)$, принимая количество цемента, кг на 1м^3, соответственно прочность бетона. Нейтрализация бетона равна f = 0,5.

Ключевые слова: карбонизация, коррозия, армирование, бетон, гидротехника, диффузия.

Project development and marketing in the global oil and gas industry – a constellation of stakeholders co-creating strategic value for the industry

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Abstract. Project development and marketing on large oil and gas projects (LOGPs) by engineering-procurement-construction (EPC) contractors respond to massive capital investment (CAPEX) undertakings by oil and gas industry owners and takes on multi-lateral interactions carried out by a dozen of actors proactively participating in the EPC contractors' business ecosystem created to remain competitive toward owner companies, which form of project marketing is different from a straight forward contractor – owner interaction found in the other branches of contracting industry. Most of such interactions are based on strategic trust among the relevant members built over decades of heavy win-win transactions.

This study has found the actors that compose the project development and marketing cycle in LOGPs, explored dominant logics of EPC contractor's project development and marketing, and analysed how primary actors in LOGP development and implementation co-create strategic values for both the respective corporations, and sustainable overall industry growth.

Keywords: project development and marketing, large oil and gas projects (LOGP), strategic trust based value co-creation, hard vehicle and soft vehicle of contractor competitiveness

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BACKGROUND

This study addresses project development and marketing by the tier-one global EPC (engineering, procurement and construction) contractors operating in midstream-downstream, onshore oil and gas projects. The unit of analysis of this research is EPC contractors' project development and marketing of large oil and gas projects (hereafter referred to as LOGPs) amounting to US $150 million and larger in investment costs.

International Energy Agency' World Energy Outlook (IEA, 2015) estimated that the global oil and gas industry was expected to invest US$ 25 trillion from 2015 to 2040 in development projects which stands at US $1.02 trillion average per year. This expected oil and gas development investment volume has been drastically reduced in 2020 and 2021 due to two reasons: the drastically reduced demand for fuel caused by the prolonged COVID-19 Pandemic and accelerated global policy on energy transition by which oil and gas major companies have frozen a considerable part of oil and gas development spending (as of May 2021). Yet the fact that this industry is a typical capital intensive industry remains unchanged. Although projects in the industry include also small and medium sized projects up to around US$150 million, a salient characteristic therein resides in a relatively large number of LOGPs including mega projects exceeding one billion US$ in investment costs. Merrow refers to mega projects in the oil and gas industry as those which are US$ one billion and larger in terms of constant-of-2003 $ terms (Merrow, 2012). According to E&Y report on mega oil and gas projects (E&Y, 2016), 365 mega projects, here with US$1 billion and larger costs too, were counted as of 2016.

As most recent (2016) in-depth research on modelling success of large oil and gas projects, Redda (2016) defines large oil and gas projects (LOGP) in excess of US$150 million. This study uses Redda's term LOGP to typically handle oil and gas capital investment projects which are frequently referred to as "CAPEX" projects as well.

This study addresses contractors' project development and marketing by the tier-one EPC contractors regularly or often occupying the top ten positions in Engineering News-Record's Top 100 International Contractors − EPC division published annually (ENR, 2018) who almost exclusively handle mega oil and gas projects (idem). Some authors in this literature review describe the LOGP EPC community as rather exclusive, dominated by few players on both owner side and tier-one contractor side, and forming an entrance barrier (Mohammad & Price, 2006: Berends, 2007; Tanaka 2014); this, however, is not a result of entrance barrier policy but owing to the natural law of the LOGP EPC business, e.g. the strictly high requirements of chemical plant technology, highly experienced and EPC specific technical personnel and proactive project formation capability based on time-honoured stakeholder networking, all embodied in contractors' track records and reliability brand, that cannot be acquired in one decade or so. Also noted is that the EPC industry has a highly narrow allowance for errors in project management.

The literature review and EPC industry review indicate that the global oil and gas capital investment industry embraces a constellation of actors focusing on owners and EPC contractors, of which primary resources are dedicated to the industry over the past seven decades. This tradition has bonded the actors strongly, founded on the agency theory of B2B marketing (Banerjee et al. 2012), the convention of mutual rule setting and coordination (Thévenot. L, 2001), cross-fertilization and co-prospering ultimately directed the sound growth of the total capital investment industry; the author's analysis is that the project development and marketing on LOGPs is value co-creating (Vargo and Lusch, 2004) activities among echelons of actors in both a cascading direction with the prime EPC contractor at the top and the bottom-up direction toward the owner company at the top.

The objectives of this study are to find the actors that compose the project development and marketing cycle in LOGPs, explore dominant logics of EPC contractor's project development and marketing, and analysed how primary actors in LOGP development and implementation co-create strategic values for both the respective corporations, and sustainable industry overall growth on the foundation of strategic trust.

The main research question (MRQ) is: Is project development and marketing on large oil and gas projects (LOGPs) broad-ranging, multi-faceted, and highly structured interactions among the relevant capital investment industry members who co-create strategic values for, both the respective industry members and the industry overall?

METHODOLOGY

This study is a qualitative and exploratory exercise to find the logic of project development and marketing on LOGPs and identify how it differs from project marketing in other contracting industry. This article is founded on a working paper "EPC project marketing in the global oil and gas industry - a constellation of stakeholders co-creating strategic value for both enterprises and sustainable industry overall growth: case study" submitted by the first author to EDEN Doctoral Seminar 2018 − Perspectives on Projects organised by SKEMA Business School on August 21st to 23rd, 2018 in Lille, France (Tanaka, H., 2018).

The research is first founded on the author (Tanaka)'s employment experience in the global contractor side of the oil and gas industry for 42 years, with 20 relevant project management articles being published in a variety of ways, which provides us with an ethnographic lens for this study, and on review of 60 literature items on project development, project marketing and other theoretical lenses, and oil and gas capital investment industry specific literatures and data in ten domains (idem).

On this theoretical foundation of the subject, we have conducted an analytical study for sense-making logics of project development and marketing on LOGPs by way of finding further evidence, secondary data and Web data such as analysis of tier-one EPC contractors' project news releases and profiling the recently completed and ongoing EPC joint venture LOGPs to construct the logic, and co-relating qualitatively the factors found to support the logics under construction.

The study has culminated in a conceptual model of project development and marketing for recommendation to the oil and gas capital investment industry, and identified further research recommendation.

LITERATURE REVIEW

Construction Industry Institute (1994) published its extensive research on capital

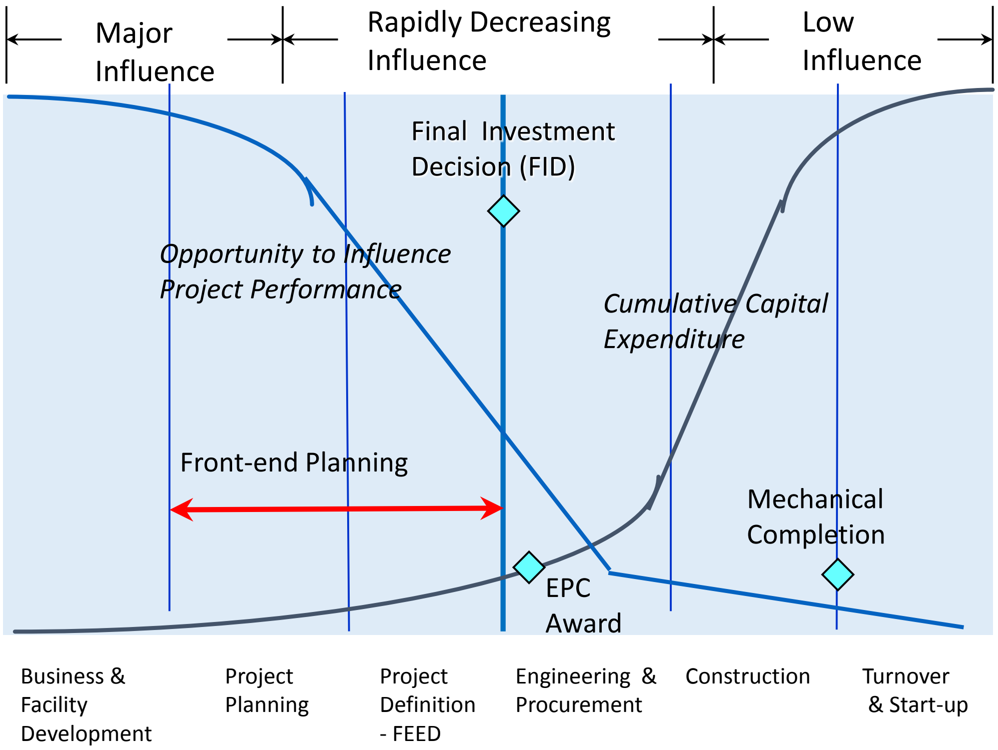

Fig. 1. Opportunity for Influence on Project Performance - Impact of Front-end Planning

investment industry project development under the title of Pre-Project Planning which has now been renamed as Front-end Planning. Pre-project planning, or front-end planning, is defined as the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chances for a successful project. The process begins when a validated project concept has been identified during the business planning process and ends when a decision has been made whether or not to authorize funding for the execution of the project. The research has drawn three conclusions:

- Pre-project planning is an owner-driven process that must be tied closely to business goals;
- Pre-project planning is a complex process that must be adapted to the business needs of the owner company, tailored to specific projects, and applied consistently to all projects in order to gain full benefits;
- Corporate goals and guidelines for both pre-project planning and the project must be well-defined and aligned among project participants. Alignment requires involvement of operations, business, and project management early in the pre-project planning process.

The findings of the PPP research include influence and cost expenditure curves in Fig.1.

The PPP study has revealed that many projects, both large and small, failed due to lack of careful planning in the upfront and warns it is too late that right project management of EPC is in place if against ill-defined or low quality plans. The graph shows two curves based on research findings: one, from left bottom to right above is so-called cumulative capital expenditure curve; the other, from up left to right bottom is a curve representing roughly opportunity to influence project performance at a given progress point of the project.

The opportunity curve drops sharply toward the award of an EPC contract. The research suggests that 80% of the project performance is potentially determined within the 20% progress of the project in its entire cycle down to mechanical completion. Therefore front-end planning prior to EPC is crucially important.

Later a graduate research by a middle manager of a European major oil company has been conducted on the correlation of quality of front-end planning and overall project value realization (Hutchison & Wabeke, 2006). The research used actual project data to demonstrate the value of front-end planning. The correlation is summarised in Fig. 2. In the extreme right, projects surveyed are categorized into four. Clearly, projects which had good project definition coupled with good project execu-

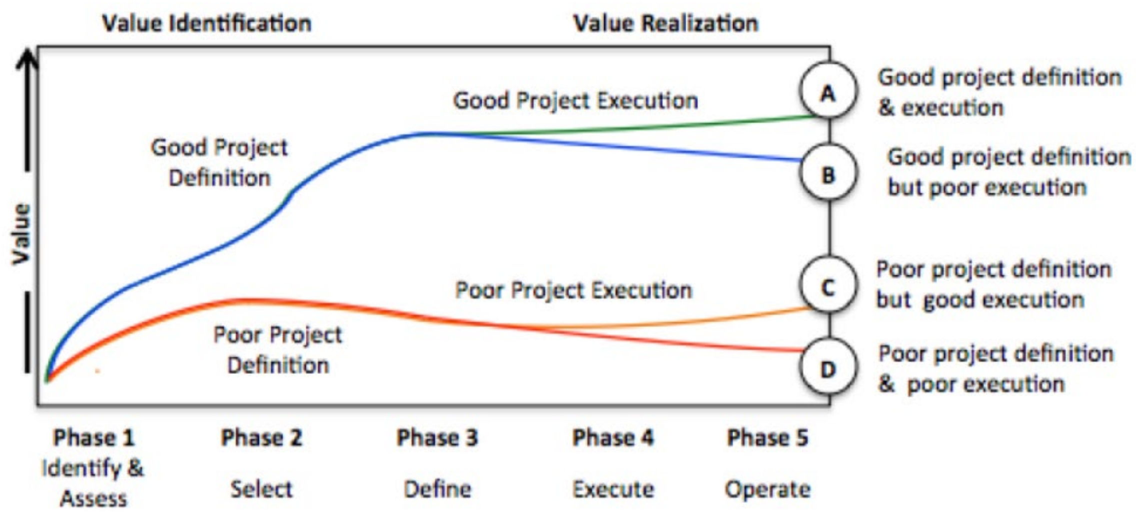

Fig. 2. Influence of Project Development Quality on the Value of a Project (after Hutchison & Wabeke)

tion is the best in project value realization, and the reverse, poor plus poor is the worst, and interestingly, projects having good definition but poor execution is much better in value realization than well executed but poorly defined projects.

Project marketing constitutes one school of the Nine Schools of Project Management proposed in “Perspectives in Projects” (Turner, J.R., Hueman, M., Anbari, F.T., & Bredillet, C.N., 2010).

The marketing school argues that the various stakeholders of the project need to be persuaded to be part of the project and support its objectives and that the project marketing school therefore focuses on interaction between stakeholders, alignment of strategic and tactical components, project advocacy, and customer relationship management. Project marketing elements include:

- Negotiating the fuzzy front-end;
- Structuring the project solution;
- Managing stakeholder relationships;
- Identifying interrelationships of marketing and project management in specific types of projects;
- Identifying and communicating value;
- Creating and exchanging value.

Project marketing researchers (Cova et al, 2002; Skaates & Tikkanen, 2003; Lecoeuvre-Soudain & Deshayes, 2006; and Blomquist & Wilson, 2007) suggest that while project management deals with organizational and management issues, project marketing deals with sales and marketing issues of projects.

Project marketing focused on a customer based approach helps build and maintain long-lasting relationships with key clients avoiding short term opportunism. Cova et al (2002) proposed a three stage model for project marketing: 1) independent of any project, 2) pre-tender, and

3) tender preparation. According to this view, the goal of the project marketing process is to win the contract. However project marketing is a continuous process that occurs during the realisation and project follow up phases as well. The follow up phase which occurs after the project has been delivered is very crucial since this determines client satisfaction, key account development, and its success will reduce the discontinuity of project activities (Lecoeuvre-Soudain, & Deshayes, 2006; Cova et al, 2002). Vargo & Lusch (2004) suggest the client gets no benefit until the output works. For this reason Lecoeuvre-Soudain & Deshayes (2006) added a fourth phase to the project marketing process, the post project phase, giving four phases of project marketing:

1) Pre-project marketing: The project does not exist yet, but the supplier anticipates the customer’s requirements, develops themes for the potential bid, and maintains the relationship with the client;

2) Marketing at the start of the project: The supplier starts with co-construction of rules beside and within the network of influential relationships;

3) Ongoing project marketing: The client and contractors proceed with re-negotiation, modifications, follow-up, and meetings following one another with constant relationship exchanges until the end of the project;

4) Creating the conditions for future projects: The supplier maintains the relationship with the client, through logistics support and “sleeping relationships” which enables it to manage discontinuity in project business and prepare for future projects. ¥

Lecoeuvre-Soudain & Deshayes (2006) suggested that there are six foci of project marketing: ¥

a. Relationship management (Rel);

b. Trust (Tru);

c. Collaboration (Col) ;

d. Communication (Com) ;

e. Training (Tra);

f. Going with (providing mentoring, coaching and support) (Gwi).

Going with is identifying the customer’s true requirement and working with the client to provide a solution to their requirement. Turner and Lecoeuvre (2017) take a perspective of the service dominant logic, (Vargo & Lusch, 2004). The focus is on marketing with the client, collaborating with them to produce and sustain value for the client. The contractor collaborates with the client so that it can draw upon resources that contractor provides to:

- Co-create value networks and processes, (relationships);
- Co-create conversation and dialogue, (communication);
- Co-create value propositions, (collaboration);
- Co-create service offerings, (requiring trust).

Turner and Lecoeuvre (2017) argued that project marketing is a portfolio management.

Tikkanen H., Kujala J. and Artto K. proposed The Four Portfolios Framework as a marketing strategy of a project-based firm (2007). The framework consists of the relationship portfolio management for the customer relationship portfolio and network relationship portfolio, and the project portfolio management comprising the sales and delivery project portfolio and the offering development project portfolio.

CHARACTERISING THE OIL AND GAS CAPITAL INVESTMENT INDUSTRY

To profile the characteristics of the oil and gas capital investment industry which is the unit of analysis of this project development and marketing study, we have reviewed the articles of Yao and Ning (2002), Mohammad & Price (2006), Berends (2007), Eweje (2012), Tanaka (2006b, 2014) and Redda (2016) who all are researchers belonging to or have come from the oil and gas industry. Eweje, Tanaka and Redda's works are based, in turn, on other industry researchers' work on broad oil and gas industry artefacts. Initially 39 profiles were extracted from the article review, and selected 26 characteristic key words which were mentioned more than twice, were selected. The selected characteristics and density of agreement are shown in Table 1.

Large oil and gas projects (LOGPs) are vehicles of corporate strategy implementation for oil and gas companies. Due to their cumulative huge investment costs (US $1.1 trillion per year, as of 2015), LOGPs represent massive undertakings and require significant stretch of corporate resources, hence as a whole are an important economic activity. LOGPs require a dense focus on front-end works up to final investment decision (FID) lasting for a time period equalling to half of the EPC phase and, once sanctioned, span a long project cycle with the EPC phase taking four years or longer to complete. Mega grade LOGPs, in excess of US$ one billion in investment costs, are mostly developed by owner joint ventures, and are implemented by plural EPC contractors, often forming an EPC joint venture(s), under multi-country sources of financing, located at a geographically challenging site, undertaken by globally dispersed EPC contractor teams, and operated by using project resources procured from throughout the world. Due to the huge size and CAPEX, a long period of time of existence, and global nature of project formation, LOGPs are exposed to changes in P.E.S.T.L.E. (political, economic, social, technological, legal, and environmental) factors and may exert significant political, economic, environmental, or social influence in the project host country.

Due to the interplay of all these important project development and execution factors, including phase overlaps, so many interfaces, activity interdependence, the project execution environment is highly complex and is exposed to all imaginable uncertainty and even by wicked risk (Kämpf Metal., 2011).

EPC contractors play a key role in the development and implementation of LOGPs as project stakeholder formation, front end engineering design (FEED) defining the project, plant systems integration, plant technology integration and project resources integration are all left to EPC contractors. Hence, they must master complexity and robust risk management.

THE BUSINESS ECOSYSTEM FOR LOGPS

The oil and gas capital investment project community, as seen from a prime EPC contractor, consists of such primary actors as

Table 1. Comparative review on characteristics of LOGPs

Characteristics of Large Oil & Gas Projects	Berends (2007)	Mohammad & Price (2006)	Yao & Ning (2002)	Tanaka (2014)	Eweje (2012) - Compounded views	Redda (2016)
Vehicle of corporate strategy implementation					o	o
Huge investment costs	o	o		o	o	o
Massive undertakings – scale, magnitude – an	o	o			o	
Mostly multi-projects seen as a program				o	o	
Significant stretch on the corporate resources					o	
Multiple sponsors or owner joint venture partners				o	o	
Multi contractors from multi countries				o	o	
EPC contractors playing a key role in the	o					o
Long project lifecycle, usually over five years	o			o	o	o
A significant number of stakeholders co-creating	o			o	o	o
Significant challenge to the stakeholders				o	o	
Finance engineering				o	o	o
Higher levels of uncertainty/risk	o	o			o	
Uncertainty in accurate prediction of desired			o			
Uncertainty associated with long project period	o			o		
Exposure to shift in PESTLE factors				o		
Risk of scope change or cancellation				o		
Logistic challenges, especially on mega projects at				o	o	
High environmental risk				o	o	
Robust risk management				o	o	
High complexity – objectives, project organization	o		o	o	o	o
Dense focus on front-end works (up to final				o	o	
A challenging project location					o	
Geographically dispersed teams				o		o
An inadequate supply of resources						
Multi vendors from multi countries				o		
Spasmodic delivery/supply schedules		o				
Work fragmentation			o			
Tens of thousands on-site workforces from multi				o		
Extensive infrastructure requirements						
Higher technology, new or alternative technology		o		o		
Larger number of engineering disciplines (seven to		o				
Socio-economic & political interest in the host					o	
Attention of NGO and the media					o	
Significant political, economic, environmental, or					o	
Difficult regulatory constraints					o	
Direct and indirect impacts on the environment				o	o	
Direct and indirect socio-politico-economic				o	o	o
High level of corporate and public attention					o	o

the EPC prime contractor (ecosystem leader), the owner, EPC joint venture partner(s), ECA - export credit agency, large commercial banks, government agencies of the project export (contractor's home) country, government agencies of the host country, process technology suppliers, equipment & materials vendors, construction subcontractors, and communities around the project site(s) (Tanaka, 2006a; 2006b).

The business ecosystem theory (Moore 1996) posits that a business ecosystem is an economic community supported by interacting organisations; the company holding a leadership role is valued by the community because it enables members to move toward shared visions to align their investments – this refers to the platform services theory (Iansiti & Levien, 2004), – and to find mutually supportive roles. This theory very well explains the business domain of the EPC community for LOGPs in which in addition to the relationship with the owner, there are multi actor interactions for value co-creation founded on strategic trust – leverage theory (idem), namely, the EPC contractor and its business associates in plural directions – and dominant chains of eco system actors are tightly structured and connected so that substandard performance of one actor in the ecosystem can constitute a bottleneck in successful completion of an LOGP - bottleneck theory (idem), eventual target of project marketing success and well-functioning or overall health (idem) of the oil and gas investment industry.

The roles of the respective actors of the ecosystem in terms of fulfilling functions in capital investment projects, degree that each actor's business is dedicated to the oil and gas industry and the type of impact of each actor's participation in capital investment projects as well as their positions in the EPC contractor's project marketing chain, are portrayed based on Tanaka (2006a) and general EPC industry practice, in Table 2.

Lecoeuvre-Soudain & Deshayes (2006) proposed six foci to measure dependency and relationship between the actors in project marketing. They are Relationship management (Rel), Trust (Tru), Collaboration (Col), Communication (Com), Training (Tra) and Going with (providing mentoring, coaching and support) (Gwi). Considering that the EPC contractor's project development and marketing for LOGPs is not just enabled by the bilateral marketing relationship between the contractor and the owner – for instance, an LOGP is not materialized by a contractor not having access to an ECA; many of LOGPs need technology licensor(s)' participation in the project; mega projects pricing US$1 billion and larger need a joint venture EPC partner (s) who are otherwise competitors; EPC bid competitiveness depends on quotation competitiveness of major equipment vendors and core construction subcontractors founded on multi-lateral marketing relationship, the authors have analysed the relationship between the 11 actors in the EPC contractor's ecosystem posited above as depicted in Table 3.

Those relations labelled as “Tru” (trust) or “Col (collaboration)” are considered as most critical from the viewpoint of first stage of project developing and marketing success, or wining an EPC contract. Those relations are the EPC contractor's transaction/relation with the owner, joint venture partner (an EPC contractor ally), export credit agency (ECA), commercial banks joining a syndicated loan with the ECA and the government agency (s) of plant exporting country.

THE PROJECT DEVELOPMENT AND MARKETING PRACTICE ON LARGE OIL AND GAS PROJECTS

The first questions that we should ask regarding the practice of project development and marketing by the EPC contractor for LOGPs is: what are the phases of an LOGP as seen from the owner's project lifecycle, and how does the EPC contractor's project development and marketing activities fit in in the owner's cycle of project development, implementation and post-completion commercial operation?

Table 2. Actors in large oil & gas capital investment projects marketing ecosystem

Actor	Function in capital investment projects	Degree of dedication to the oil & gas industry	Type of impact of participation in capital investment projects	Position in EPC contractor's project marketing chain
EPC prime contractor (leader role in the ecosystem)	Provides professional EPC services to the owner to help realise the owner's new capital asset and soft value	Very high (it takes other non-oil and gas plants)	As the agency theory dominates, the primary agent to perform the project on behalf of the owner	Principal of project development and marketing on LOGPs
Owner	Invests and owns the plant for additional corporate capital value	Full	Project not existent without an owner	Direct client of contractor marketing
EPC joint venture partner(s)	Provides, together with the EPC contractor, professional EPC services to the owner to help realise the owner's new capital and soft value	Very high (it takes other process plant and infrastructure projects as well)	As the agency theory dominates, the primary agent, together with the EPC contractor, to perform the project on behalf of the owner	Partner of project marketing to the EPC contractor toward the owner
Export credit agency(s) (ECAs)	Provides government-funded loan or covers risks on project funds provided by own country's banks	Very high due to magnitude of LOGPs	Indispensable in most of LOGPs in developing and emerging economies	Where ECA loan is prerequisite, decisive enabler; where not, maintain "silent relationship"
Large commercial banks	Provides project loans as part of fund required to build the plant	High at a bank division in charge of project finance	Indispensable for all mega projects and most of LOGPs	Ditto
Government agencies of the project export (contractor) country	Supports own country's prime contractor and ECAs	Part of important national industry promotion policies	Impact varies with type of government involvement; high where ECA loan is provided	Facilitator in the backyard of EPC contractor's project development and marketing
Government agencies of the project host country	Provides government permits to construct the plant; supports the owner company in financing transactions with foreign ECA(s)	Part of important national industry promotion policies	Impact varies with type of government involvement; high where sovereign guarantee is needed for loan repayment	Regulatory agency that affects post-contract award project marketing
Technology suppliers	Provides process technology for the plant	Full (specialized in oil and gas)	Except for open art technology, high but there is alternation among like technologies exists	Facilitator of marketing
Vendors	Supplies to the EPC contractor equipment, machinery or materials	Very high (oil & gas vendors are almost fenced)	Indispensable as function but alternation among vendors exists	Enabler in tender preparation stage (competitive quotes) & EPC phase
Construction subcontractors	Supplies construction services to EPC contractor	High except civil and building subcontractors	Indispensable but alternation among subcontractors exists	Ditto
Communities around the project site(s).	Provides community support to project construction or affect construction in a variety of way	N/A	May defer start, obstruct or crush construction; conversely protects the site project for smooth construction execution	Maintains silent relationship during bid preparation and a possibly communicate with during site operation phase on community sustainability

Tanaka (2006b, 2014), Eweje (2012) and Merrow (2012) described the phases of an LOGP all from the owner's cycle. The three authors used slightly different nomenclatures but phasing is basically same. Fig. 3 delineates Tanaka's LOGP phases and density of project marketing effort on both the EPC contractor side and the Owner side; the density scale is for image.

explore detailed feasibility and later definition of the project, culminating with final investment decision (FID) or withdrawal, or postponement of the investment decision. Project definition work, referred to as front-end engineering design (FEED) in the second half of this phase, is usually undertaken with the owner employing a global EPC contractor. Obviously, the EPC contractor

Table 3. Matrix of project marketing relationships among the actors of LOGP

	Contractor	Owner	JV Partner	ECA	Banks	Govt. - Exp	Govt. - Host	Technology	Vendors	Subcontr.	Community
EPC Contractor		Tru	Col, Tru	Col, Tru	Col, Tru	Col, Tru	Rel	Col	Col	Col (Tra)	Com
Owner	Tru		Tru	Rel	Rel.	Rel.	Rel	Col or Rel	N/A	N/A	Com
EPC JV Partner	Tru	Col, Tru		Col, Tru	Col, Tru	Col, Tru	Rel	Col	Col	Col (Tra)	Com
ECA	Rel	Col, Tru	N/A		Col, Tru	Col, Tru	Rel	N/A	N/A	N/A	N/A
Comm. Banks	Rel	Col, Tru		Col, Tru		Col, Tru	Rel	N/A	N/A	N/A	N/A
Govt. - Export Ctr.	Rel	Col,Tru	N/A	Col, Tru	Com		Col	N/A	N/A	N/A	N/A
Govt. - Host Ctr.	Col, Tru	Rel	Col	Rel	Com	Col		N/A	N/A	N/A	N/A
Technology Supplie	Rel	Col	Col	N/A	N/A	N/A	N/A		N/A	N/A	N/A
Vendors	N/A	Col	Col	N/A	N/A	N/A	N/A	N/A		Com	N/A
Subcontractors	Com	Col	Col	N/A	N/A	N/A	Com	N/A	Com		Com
Site Community	Rel	Com, (Tra)	Com	N/A	N/A	N/A	Com	N/A	N/A	Com, (Col)	

Note: a code within a parenthesis indicates training requirement depending on local content clause of the contract

Project Marketing Foci Code after Lecoeuvre-Soudain & Deshayes (2006)

1. Relationship management (Rel)
2. Trust (Tru)
3. Collaboration (Col)
4. Communication (Com)
5. Training (Tra)
6. Going with (providing mentoring, coaching and support) (Gwi)

Tanaka (2006) described the four phases and the authors have analysed the EPC contractor's project marketing in the respective phase as follows (Tanji, N., Tanaka, H. and Bushuyev S. (2014).

The Project Development Phase aims at project conception as business and strategic analysis of the project value. During this phase, an owner carries out basic data gathering, project need screening against the corporation's business strategy, and evaluating basic conditions for materializing the potential project. This phase is basically conducted confidentially by the owner and the contractor's project marketing function endeavours to sense some sort of project smell.

The Front-end Planning Phase is a preamble to project execution and is intended to

(s) who performs FEED work would be in a considerably favourable position in the bidding to the EPC work coming thereafter. The EPC bidding takes place after the completion of FEED and contractors' all out efforts are expended for proposal success.

The **Project Execution Phase** is most frequently called the **EPC Phase**. As the phase term indicates, engineering, procurement of equipment and materials to compose the plant and site construction of the plant is carried out with project management directing and integrating total project efforts. The successful completion of the project is the most eloquent vehicle of project marketing for the contractor company and the contractor makes all required efforts to complete the project according to prime contract terms.

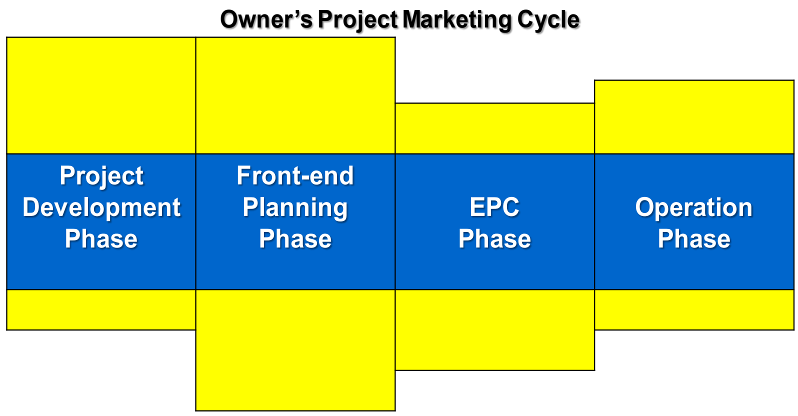

Fig. 3. Project phases and project marketing density cycle

The Operation and Maintenance Phase on the plant completed is the owner's responsibility. However, the EPC contractor stands by for the owner's call on any problems and difficulty on the plant according to warranty clauses, or 'trust' relationship for a year or two. All these post plant completion relationship with the owner provides a vital source of marketing for a future new contract to the contractor.

There is a match of the EPC contractor's project development and marketing efforts on this oil and gas industry specific context of project lifecycle to the four-stage view of the project marketing life-cycle proposed by Er, et al. (2019) in that in 1), Pre-receipt of invitation to tender: all the major EPC contractors maintain early marketing coverage of the market or potential market countries; it provides a feasibility study, a key ground work for project development for the owner, as a separate contract; and conduct front end engineering design(FEED) to firm project definition on behalf of the owner on all the LOGPs; in 2), Tender preparation and contract negotiation: this is core of the EPC contractor's project marketing efforts, consuming 10 to 15% of available person-hours (undisclosed industry data) of a contractor; in 3), Project delivery: this cycle is a mainstay business of the EPC contractor company; and in 4), Post project: as discussed earlier, contractors consider this as a valuable opportunity for marketing for new contracts.

Assuming that EPC contractors' primary success is wining contracts, we have collected survey results and have done an additional survey on owners' contractor proposal evaluation criteria or contractor self-evaluated proposal success factors. The tabulated results are given in Table 4.

The surveys searched are U.S.A. consulting company Transmar Consult's owner survey on contactor evaluation criteria cited in Oil and Gas Journal June 14, 2003 issue (Oil and Gas Journal, 2003) from 1995 to 2005; U.S.A. owner and contractor, and Japanese contractor surveys on contractor evaluation criteria in 2004, originally conducted by Construction Industry Institute and Ministry of Economy, Trade and Industry of Japan, respectively (Tanaka, 2006a), and analysis of tier-one EPC contractors (two USA, two Japanese and one European)' news releases on new projects on LOGPs constituted by 228 projects from 2009 to the first quarter of 2018, conducted by the first author.

The evaluation criteria are compounded from the four sources of survey. Those ranked in the top three are shown in bold letters. The tabulation indicates that the ranking is considerably consistent among the same survey (series) but is not so much among the surveys.

This is judged to have been caused by differences in the purposes of asking questions, differences in given criteria to rank, and differences in time surveys were conducted. Nevertheless, contractor's price is one of the top-ranked, and those criteria related to the contractor's structural capability (hard marketing vehicle), e.g. quality of contractor key personnel, project management capability and experience in the same plant, same geographical area (country) and same client, were ranked in the upper side. Joint venture strength, which is typical soft vehicle of project development and marketing, is found only in the 2018 contractor new project releases survey; the background is that news releases pertain to the five global tier-one contractors and they are active players of mega projects and use the JV delivery method quite ordinarily. From the argument of the rest of this article, it is obvious that the contractor's price (as marketing strength) is a result of a balanced combination of the structural capability, or the author-labelled hard marketing vehicle and the EPC contractor's business ecosystem constructing ability, the soft marketing vehicle.

As analysed from the characterisation and cycle of project marketing discussed above, we have extracted five dominant logics of the EPC contractor's project development and marketing for LOGPs.

Logic 1: Mastering characterization of the complex, dynamic and risky market

As reviewed in Section 4, LOGP project development and execution are exposed to all imaginable uncertainty and even wicked risk, including changes in P.E.S.T.L.E. factors. As the EPC contractor plays a key role in the development and implementation of LOGPs, e.g. project implementation scheme formation, front end engineering design (FEED) defining the project, plant systems integration, plant technology integration and project resources integration are all left to

Table 4. Tabulated results of multi-source surveys on evaluation criteria ranking for EPC contractors' proposals

Tabulated Results of Multi-source Surveys on Evaluation Criteria for EPC Contractors' Proposals									
	2018 EPC Contractor Web survey	2004 US/Japan Survey			Transmar Consult Survey (cited in Oil & Gas Journal, July 2003) - Owners only				
	2 USA, 2 Japanese, 1 European co's.	US Owner	US Contractor	Japan Contractor	2005	2003	2001	1997	1995
Contractor Proposal Evaluation Criteria	Total number key words asked for ranking								
	11	*7*	*7*	*5*	*17 (selected top 10)*				
Project Management Capability	9	N/A	**1**	**3**	**2**	**1**	**2**	**2**	**2**
Contractors' Price / Commercial Terms	Not mentioned as self-explanatory	**1&3**	**3**	**2 &5**	5	**2**	**3**	**3**	6
Quality of Contractor Key Personnel	included in Experience	N/A	**2**	**1**	**1**	**3**	**1**	**1**	**1**
Project Control Systems	included in Project Management	N/A	N/A	N/A	7	4	4	8	**3**
Detailed Engineering Capability	included in Experience	N/A	N/A	N/A	4	5	6	10	5
Construction Capability	included in Experience	N/A	N/A	N/A	**3**	6	8	5	7
Experience with Similar Work	**1**	N/A	N/A	N/A	6	7	5	7	8
Experience with Same Client	**3**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Experience with Same Geographic Are	**2**	N/A	N/A	N/A	8	8	7	9	10
Responsiveness & Flexibility	N/A	N/A	N/A	N/A	11	9	10	6	4
Safety Performance	N/A (self-explanatory	**2**		4	N/A	N/A	N/A	N/A	N/A
Shorter Delivery Time	10	N/A	N/A	N/A	Included in Project Control Systems				
Joint Venture Strength	5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
High engineering capability, Innovative solution	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

EPC contractors, the EPC contractor must have structured risk identification and mitigation capabilities toward the EPC ecosystem being built and the project exterior environment. The contractor's proposal naturally must have incorporated risk responses.

Logic 2: Building consistently the EPC contractor's structural capability

The EPC contractor's sufficiency of structural capability (Cova & Salle, 2007), labelled as SSC, comprehends volume of contracting business and financial stability, track record on the same type of the plant, the same client and the same country, safety, security, health and environment (SSH&E) policy, project execution and management capability demonstrated from past projects as well as proposed for a particular project, access to an export credit agency and to large commercial banks investing in projects and having robust network with equipment suppliers and construction subcontractors throughout the world (ENAA, 1996). SSC can only be built by decades of painstaking practice and successful delivery of LOGPs and proven mutually beneficially transactions between the owner and the EPC contractor.

Logic 3: Constructing proactively the EPC contractor's ecosystem for a specific LOGP

EPC contractors form a project specific business ecosystem (Moore, 1996; Insati & Levin, 2004) and fulfil the leader role in extracting proper value of the respective ecosystem players and co-create overall value for the relevant EPC project with the owner company since LOGPs are vehicles of corporate strategy implementation for oil and gas companies, e.g. ability to deliver projects for superior cash-flow, operational excellence, increased production via projects, maximising resource and asset value, maximising value-chain returns, demonstrated technological innovation (Tanaka, 2006a; Tanaka, 2006b; Eweje, 2012: Redda, 2016).

Project development and marketing on LOGPs is no longer the mere transaction between an EPC contractor and an owner. Project marketing is multi-faceted and time-consuming potential value co-creation activities as discussed in Section 5. Construct of the EPC contractor ecosystem is core of the soft vehicle of LOGP marketing.

Logic 4: Holding a deeper insight into total project development and marketing success on LOGPs

Successful project development and marketing for LOGPs is total project cycle efforts for the EPC contractors and is expressed as Layer 1 (in the bottom) Sufficiency of structural capabilities (SSC); Layer 2 Success of proposal (SPR); Layer 3 Success of project output (SPOP), and Layer 4 Success of project outcome (SPOC). SSC is argued in Logic 2. Winning a contract (SPR) endows the EPC contractor with an opportunity to complete the project on behalf of the owner thereby attaining the contractor's direct business objectives. Delivering the EPC project (SPOP) meeting the contract conditions, marks the EPC contractor's success of services, reinforcing its portfolio of contractor track record. When the owner has achieved project outcome, or strategic goals embodied in the project, it would ferment deeper trust in the EPC contractor who has engineered and built the plant. Maintaining responsive post-project completion relationship with the owner is highly important.

Logic 5: Following a structured path to LOGP EPC contract award

The oil and gas capital investment industry is a mature industry which has proven business practices, formality of owner-contractor relationship, and market segmentation by sizes of projects. On the assumption that tier-one EPC contractors can evenly complete the LOGP, marketing competition should eventually focus on cost offerings as owners say that owners' evaluation criteria of contractor proposals is for the lowest conditioned (and qualified) price (undisclosed international oil company, 1996). All the pre-EPC marketing efforts should be concentrated to hammering out a competitive price while allowing for project risk. One acceleration route to LOGP award is to secure a front-end engineering design (FEED) contract defining the project definition for the owner to seek final investment decision (FID) and as basis of EPC bidding.

As argued by Tikkanen et al. (2006) and posited by Turner & Lecoeuvre (2016), we have affirmed that the project development and marketing for LOGPs is part of portfolio management.

NEW EPC CONTRACT STRATEGY AND ITS IMPACT ON PROJECT MARKETING

Mohammad and Price (2004) discussed the arrival of innovative contract procurement strategies; Turner (2007) introduced partnering in projects whereby the owner and the contractor work together in a spirit (and in a contractual arrangement) of partnership, whereby they cooperate to achieve a mutually beneficial outcome; and Tanaka (2006b) enumerated strategic alliance between the owner and contractor operating in an amalgamated project organization format for totally shared work, profit and loss, and liability; partnering; unincorporated joint ventures (JVs) of EPC contractors who share the totality of project work, profit and loss and liability as new forms of LOGP EPC delivery.

According to the analysis of 228 web-based new project releases for the past ten years up to the first quarter of 2018 issued by the two USA, two Japanese and one European tier-one contractors, conducted by the first author (Tanaka, 2018), an absolute majority of recently completed and ongoing LNG and refinery projects have used or are using the JV format, there are 11 cases of partnering, but strategic alliance, often found in the 1990's, has not exited over the past ten year up to 2018. It can be inferred that the EPC contractor should market the project to its targeted EPC contractor partner before doing it to the owner and that partnering requires higher "trust" (Lecoeuvre-Soudain, L. & Deshayes, P., 2006).

In facing the 'existential crisis' of capital programme delivery (European Construction Institute, 2018), however, closer owner and contractor alignment is voiced (idem) and there has occurred an industry initiative to renovate the structures of capital program (FEED + EPC) delivery for reducing transaction costs in the EPC chain (Construction Industry Institute, 2018). There is situational evidence to favour the JV EPC format and partnering but no hard data to substantiate the benefit is available yet. Possible impact on project marketing by the emerging initiative of re-structuring the capital program is not known yet; it should take years before any effect is found.

CONCLUSION AND FURTHER RESEARCH RECOMMENDATION

The findings of this research have responded to the main research question (MRQ) all positively in Sections 4 to 7. Project development and marketing of LOGP:

- depends on multi-faced and highly structured interactions among the capital investment industry members which is based on strategic trust; such relationship is represented by an EPC business ecosystem; and
- the EPC business ecosystem co-creates strategic values for, both the respective industry members and the industry overall.

In conclusion, we propose the model of LOGP project development and marketing.

The EPC contractor's project development and marketing for LOGPs is founded on both, a hard vehicle and a soft vehicle as depicted in Fig. 4.

The hard vehicle represents the EPC contractor's structural capability comprehending global level business volume and financial stability; track records on plants, clients and project host countries; structural services efficiency and project completion reliability

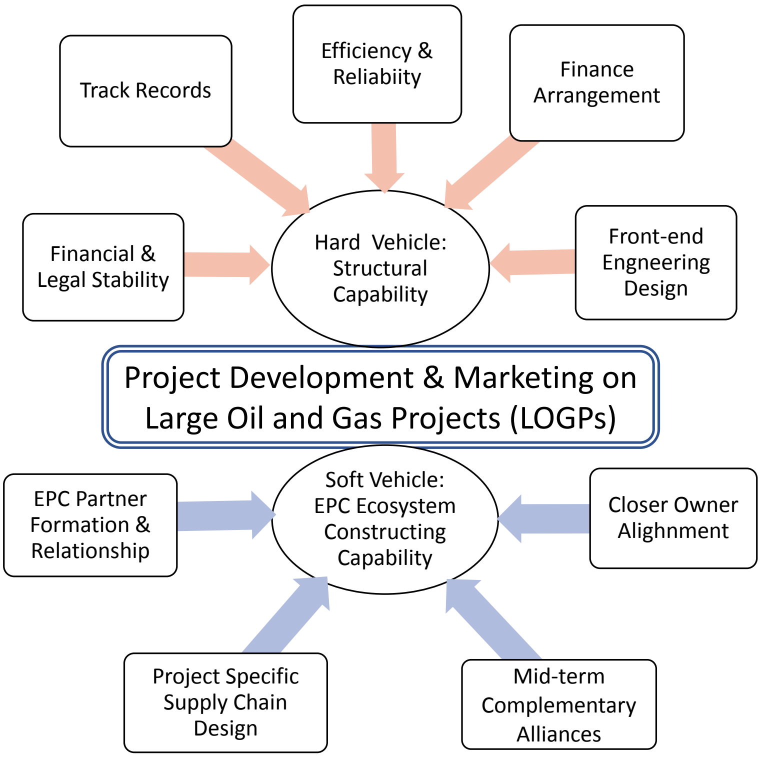

Fig. 4. EPC contractor's project development and marketing model for LOGPs

– this is the EPC contractor's brand based on past hard achievement; access to financing institutions for arranging for financing; and the capability to perform front-end engineering design (FEED) on behalf of the owner which basic designs the plant and defines other key parameters of the project enabling the owner to make final investment decision (FID).

The soft vehicle concerns variable marketing elements which all depend on strength of strategic trust, and can be represented as the EPC contactor's business ecosystem construct for a specific LOGP. The soft vehicle develops and maintains mutually beneficially collaborative relationships with a small number of industry colleague EPC contractors, and for each project, selects a partner during a pre-proposal phase to win a bid; designs a supply chain of detailed design centres, plant component vendors and services/construction subcontractors out of registered vendor and subcontractor lists; find and conclude mid-term business alliance agreements with EPC contractors and/or fabricators who have demonstrated strength in certain expertise; and collaborate with owners on plant technology innovation and initiatives for transaction (supply chain) cost reduction for the sound existence of the EPC industry – this is an investment for the future.

The research has been conducted based on literature review, analysis of existing, time series of industrial research data, and authors' additional data collection by way of web analysis. As the secondary data accessed were contributed by researchers in the EPC industry mostly as part of industry research institutes' funded research, the authors feel the confidence level is considerably high. Yet, as the EPC industry is moving quite fast in struggling with volatility of the market and ever-increasing sizes and complexity of LOGPs, it would be worthwhile organising a more structured research on this subject by accessing top-level practitioners of project marketing and project management on both the EPC contractors side and the owners side, and preferably senior staff of EPC industry research institutes.

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One approach to the axisymmetric problem of impact of fine shells of the S.P. Timoshenko type on elastic half-space

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Abstract. Refined model of S.P. Timoshenko makes it possible to consider the shear and the inertia rotation of the transverse section of the shell. Disturbances spread in the shells of S.P. Timoshenko type with finite speed. Therefore, to study the dynamics of propagation of wave processes in the fine shells of S.P. Timoshenko type is an important aspect as well as it is important to investigate a wave processes of the impact, shock in elastic foundation in which a striker is penetrating. The method of the outcoming dynamics problems to solve an infinite system of integral equations Volterra of the second kind and the convergence of this solution are well studied. Such approach has been successfully used for cases of the investigation of problems of the impact a hard bodies and an elastic fine shells of the Kirchhoff-Love type on elastic a half-space and a layer. In this paper an attempt is made to solve the axisymmetric problem of the impact of an elastic fine spheric shell of the S.P. Timoshenko type on an elastic half-space using the method of the outcoming dynamics problems to solve an infinite system of integral equations Volterra of the second kind. It is shown that this approach is not acceptable for investigated in this paper axisymmetric problem. The discretization using the Gregory methods for numerical integration and Adams for solving the Cauchy problem of the reduced infinite system of Volterra equations of the second kind results in a poorly defined system of linear algebraic equations: as the size of reduction increases the determinant of such a system to aim at infinity. This technique does not allow to solve plane and axisymmetric problems of dynamics for fine shells of the S.P. Timoshenko type and elastic bodies. This shows the limitations of this approach and leads to the feasibility of developing other mathematical approaches and models. It should be noted that to calibrate the computational process in the elastoplastic formulation at the elastic stage, it is convenient and expedient to use the technique of the outcoming dynamics problems to solve an infinite system of integral equations Volterra of the second kind.

Keywords: impact, elastic, elastic-plastic, half-space, axisymmetric problem, fine, spherical shell, S.P. Timoshenko.

INTRODUCTION

The approach [1 – 5] for solving problems of dynamics, developed in [6 – 8, 10], makes it possible to determine the stress-strain state of elastic half-space and a layer during penetration of absolutely rigid bodies [1, 2, 7, 8, 10] and the stress-strain state of elastic Kirchhoff–Love type fine shells and elastic half-spaces and layers at their collision [3 − 6]. This led to the feasibility of developing other mathematical approaches and models. In [9, 11 – 14], a new approach to solving the problems of impact and nonstationary interaction in the elastoplastic mathematical formulation [15 – 19] was developed. In non-stationary problems, the action of the striker is replaced by a distributed load in the contact area, which changes according to a linear law [20 – 22]. The contact area remains constant. The developed elastoplastic formulation makes it possible to solve impact problems when the dynamic change in the boundary of the contact area is considered and based on this the movement of the striker as a solid body with a change in the penetration speed is taken into account. Also, such an elastoplastic formulation makes it possible to consider the hardening of the material in the process of nonstationary and impact interaction.

The solution of problems for elastic shells [23 – 26], elastic half-space [27 – 29], elastic layer [30], elastic rod [31, 32] were developed using method of the influence functions [33]. In [23] the process of non-stationary interaction of an elastic cylindrical shell with an elastic half-space at the so-called "supersonic" stage of interaction is studied. It is characterized by an excess of the expansion rate areas of contact interaction speed of propagation tension-compression waves in elastic half-space. The solution was developed using influence functions corresponding concentrated force or kinematic actions for an elastic isotropic half-space which were found and investigated in [33].

In this paper, we investigate the approach [3 – 6] for solving the axisymmetric problem of the impact of a spherical fine shell of the S.P. Timoshenko type on an elastic half-space.

It is shown that the approach [1 – 4], after the reduction of the infinite system of Volterra integral equations of the second kind [5 – 7, 10] and discretization using the Gregory methods for numerical integration and Adams for solving the Cauchy problem, a poorly defined system of linear algebraic equations is obtained for which the determinant of the matrix of coefficients increases indefinitely with increasing size of reduction.

PROBLEM FORMULATION

A thin elastic spherical shell, moving perpendicular to the surface of the elastic half-space $z \geq 0$, reaches this surface at time t=0. We associate with the shell, as shown in Fig. 1, a movable spherical coordinate system $r'\varphi'\theta$, where φ' – is the longitude of the radius vector r, θ – is the polar angle. The shell penetrates into the elastic medium at a speed $v_T(t)$, $(0 \leq t \leq T)$, the initial penetration rate is $V_0 = v_T(0)$, T – the time during which the shell interacts with the half-space. The shell thickness h is much less than the radius R of the middle surface of the shell ($h/R \leq 0{,}05$).

Let us denote by $u_0(t,\theta)$, $w_0(t,\theta)$, $p(t,\theta)$, $q(t,\theta)$ the tangential and normal displacements of the points of the middle surface of the shell and the radial and tangential components of the distributed external load, which acts on the shell. With the half-space we associate a fixed cylindrical coordinate system $r\varphi z$, the Oz axis is directed deep into the medium, φ – is the polar angle. Angle θ is plotted from the positive direction of the Oz axis. The physical properties of the half-space material are characterized by elastic constants: volumetric expansion module K, shear modulus μ and density ρ. An elastic medium with constants K, μ, ρ will be associated with a hypothetical acoustic medium with the same constants K, ρ, wherein $\mu = 0$. Under C_p, C_S, C_0 we mean the speed of longitudinal and transverse waves

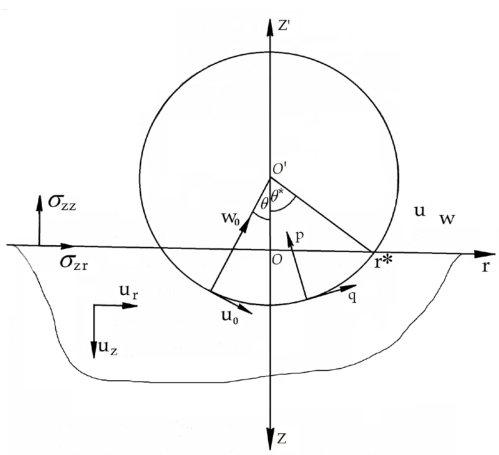

Fig. 1. Scheme of the system spherical shell – half space

in an elastic half-space and the speed of sound in the considered hypothetical acoustic medium.

Let's introduce dimensionless variables:

$$t' = \frac{C_0 t}{R},\ r' = \frac{r}{R},\ z' = \frac{z}{R},\ u_i' = \frac{u_i}{R},$$
$$u_0' = \frac{u_0}{R},\ w_0' = \frac{w_0}{R},\ \sigma_{ij}' = \frac{\sigma_{ij}}{K}, \quad (1)$$
$$v_T' = \frac{v_T}{C_0},\ w_T' = \frac{w_T}{R},\ p' = \frac{p}{KR^2},$$
$$q' = \frac{q}{KR^2},\ M' = \frac{M}{\rho R^3}.\ (i, j = r, \varphi, z)$$
$$\beta^2 = \frac{C_S^2}{C_0^2} = \frac{\mu}{K},\ \alpha^2 = \frac{C_p^2}{C_0^2} = \left(1 + \frac{4\mu}{3K}\right),$$
$$C_0^2 = \frac{K}{\rho},\ b^2 = \frac{\beta^2}{\alpha^2} = \frac{3\mu}{3K + 4\mu}.$$

where $\mathbf{u} = (u_r, u_\varphi, u_z)$ – is the vector of movement of points of the environment; σ_{zz}, σ_{rz} – nonzero components of the stress tensor of the medium; M – is the shell running mass; $v_T(t)$, $w_T(t)$ – speed and movement of the shell as a solid. In what follows, we will use only dimensionless quantities, so we omit the dash. The elastic half-space and the spheric shell are in a state of axisymmetric deformation.

Differential equations (of the S.P. Timoshenko type) describing the dynamics of spherical shells and considering the shear and inertia of rotation of the transverse section, due to (1), take the following form [34, pp. 297, 307]:

$$\frac{1}{1-\nu_0^2}\frac{\partial^2 u_0}{\partial\theta^2} + \frac{\text{ctg}\theta}{1-\nu_0^2}\frac{\partial u_0}{\partial\theta} + \frac{2(1+\nu_0)k_s + 1 - \nu_0}{2(1-\nu_0^2)k_s}\frac{\partial w_0}{\partial\theta} -$$
$$-\frac{\nu_0 + (1-\nu_0)\cos^2\theta}{(1-\nu_0^2)\sin^2\theta}u_0 + \frac{\Phi}{2(1+\nu_0)k_s} = \gamma_0^2\frac{\partial^2 u_0}{\partial t^2} - q,$$
$$\frac{1}{2(1+\nu_0)k_s}\frac{\partial^2 w_0}{\partial\theta^2} - \frac{1}{1-\nu_0}\frac{\partial u_0}{\partial\theta} + \frac{\text{ctg}\theta}{2(1+\nu_0)k_s}\frac{\partial w_0}{\partial\theta} +$$
$$+\frac{1}{2(1+\nu_0)k_s}\frac{\partial\,\Phi}{\partial\theta} - \frac{\text{ctg}\theta}{1-\nu_0}u_0 - \frac{2}{1-\nu_0}w_0 +$$
$$+\frac{\text{ctg}\theta}{2(1+\nu_0)k_s}\Phi = \gamma_0^2\frac{\partial^2 w_0}{\partial t^2} - p, \quad (2)$$
$$\frac{\partial^2\Phi}{\partial\theta^2} + \text{ctg}\theta\frac{\partial\Phi}{\partial\theta} - \frac{E_0 h R^2}{2(1+\nu_0)k_s D}\frac{\partial w_0}{\partial\theta} -$$
$$-\frac{(1-\nu_0)k_s D(2\nu_0 + (1-\nu_0)\sin 2\theta) + E_0 h R^2 \sin^2\theta}{2(1+\nu_0)k_s D\sin^2\theta}\Phi =$$
$$= \eta_0^2\frac{\partial^2\Phi}{\partial t^2},$$

where

$$\gamma_0^2 = \frac{\rho_0 k_1 C_0^2}{E_0},\ \eta_0^2 = \frac{\rho_0 h^3 C_0^2 k_r}{12D},\ k_1 = 1 + \frac{h^2}{12R^2},$$
$$k_r = 1 + \frac{3h^2}{20R^2},\ D = \frac{E_0 h^3}{12(1-\nu_0^2)},\ k_s = \frac{5}{6},$$

where Φ – angle of rotation of the normal section to the middle surface, k_S – shear ratio, D – cylindrical stiffness, ν_0, E_0, ρ_0 – Poisson's ratio, Young's modulus and density of the shell material, p и q – respectively, the radial and tangential components of the distributed load acting on the shell, R – is the shell radius.

The motion of an elastic medium is described by scalar potential φ and non-zero component of vector potential ψ, which satisfy the wave equations [1 – 4]:

$$\Delta\varphi = \frac{\partial^2\varphi}{\alpha^2\partial t^2},\ \Delta\psi = \frac{\partial^2\psi}{\beta^2\partial t^2},$$
$$\Delta \equiv \frac{\partial^2}{\partial r^2} + \frac{\partial}{r\partial r} + \frac{\partial^2}{\partial z^2}. \quad (3)$$

Physical quantities are expressed in terms of wave potentials as follows [5 – 8]:

$$u_r = \frac{\partial\varphi}{\partial r} - \frac{\partial\psi}{\partial z},\ u_z = \frac{\partial\varphi}{\partial z} + \frac{\partial\psi}{\partial r} + \frac{\psi}{r},$$
$$u_\varphi = 0,\ \sigma_{zz} = (1-2b^2)\frac{\partial^2\varphi}{\partial t^2} +$$
$$+2\beta^2\left(\frac{\partial^2\varphi}{\partial z^2} + \frac{\partial^2\psi}{\partial r\partial z} + \frac{\partial\psi}{r\partial z}\right), \quad (4)$$
$$\sigma_{r\varphi} = \sigma_{\varphi z} = 0,$$
$$\sigma_{rz} = 2\beta^2\frac{\partial^2\varphi}{\partial r\partial z} + \frac{\partial^2\psi}{\partial t^2} - 2\beta^2\frac{\partial^2\psi}{\partial z^2},$$
$$\sigma_{rr} = (1-2b^2)\frac{\partial^2\varphi}{\partial t^2} + 2\beta^2\left(\frac{\partial^2\varphi}{\partial r^2} - \frac{\partial^2\psi}{\partial r\partial z}\right),$$

If the shear modulus μ is set equal to zero $\mu = 0$, then the equations of motion of the elastic medium will be the equations of acoustics.

Let us consider the initial stage of the process of impact of elastic shells on the surface of an elastic half-space [3 − 6], when no plastic deformations occur and the depth of the shell penetration into the medium is small.

The problem of interaction of elastic shells with an elastic half-space is solved in a linear formulation, therefore, we linearize the boundary conditions [1, 2, 7, 8, 10]: we transfer the boundary conditions from the perturbed surface to the undisturbed surface of the bodies that are deformed. We assume that there is no friction between the elastic half-space and the penetrating body, or the slippage condition is valid.

As can be seen from Fig. 1, the projections of the functions u_0, w_0, p and q on the *or* and *oz* axes will be equal:

$$
\begin{aligned}
&\mathrm{pr}_{Z'} w_0(t,\theta) = w_0(t,\theta)\cos\theta,\\
&\mathrm{pr}_{Z'} u_0(t,\theta) = u_0(t,\theta)\sin\theta,\\
&\mathrm{pr}_{Z'} p(t,\theta) = p(t,\theta)\cos\theta,\\
&\mathrm{pr}_{Z'} q(t,\theta) = q(t,\theta)\sin\theta,\\
&\mathrm{pr}_{r} w_0(t,\theta) = -w_0(t,\theta)\sin\theta,\\
&\mathrm{pr}_{r} u_0(t,\theta) = u_0(t,\theta)\cos\theta,\\
&\mathrm{pr}_{r} p(t,\theta) = -p(t,\theta)\sin\theta,\\
&\mathrm{pr}_{r} q(t,\theta) = q(t,\theta)\cos\theta.
\end{aligned}
$$

Then, in the *zor* coordinate system, the displacements u_z, u_r and stresses σ_{zz} and σ_{rz} at the surface points of the contact area will be written as:

$$
\begin{aligned}
&u_z(t,r,0) = w_T(t) - f(r) - w_0(t,\theta)\cos\theta -\\
&-u_0(t,\theta)\sin\theta,\\
&u_r(t,r,0) = -w_0(t,\theta)\sin\theta +\\
&+u_0(t,\theta)\cos\theta,\\
&\sigma_{zz}(t,r,0) = -p(t,\theta)\cos\theta -\\
&-q(t,\theta)\sin\theta,\\
&\sigma_{rz}(t,r,0) = -p(t,\theta)\sin\theta +\\
&+q(t,\theta)\cos\theta,\\
&p(t,\theta) = -\sigma_{zz}(t,r,0)\cos\theta - \sigma_{rz}(t,r,0)\sin\theta, \quad |\theta| < \theta^*,\\
&q(t,\theta) = -\sigma_{zz}(t,r,0)\sin\theta + \sigma_{rz}(t,r,0)\cos\theta, \quad |\theta| < \theta^*,
\end{aligned}
\tag{5}
$$

where $w_T(t)$ – displacement of the shell as a rigid body, the function $f(x)$ describes the shell profile, $2\theta^*$ as can be seen from Figure 1, the size of the shell sector in contact with the half-space. In the case of a spherical shell:

$$
f(r) = 1 - \sqrt{1 - r^2}.
$$

The kinematic condition that determines the half-size of the contact area $x^*(t)$ is written as follows:

$$
w_T(t) - f(r) - u_z(t,r,0) - w_0(t,\theta)\cos\theta -
$$

$$
-u_0(t,\theta)\sin\theta = \begin{cases} 0, & \text{if} \quad r \le r^*(t), \\ \varepsilon < 0, & \text{if} \quad r > r^*(t), \end{cases}
$$

We assume that the contact area is simply connected region, and this statement is equivalent to the fact that the stresses normal to the contact area are compressive:

$$
\sigma_{zz}\big|_{z=0} < 0, \quad r < r^*(t).
$$

Based on (4), the boundary conditions in the absence of friction in the contact zone can be formulated as follows:

$$
\begin{aligned}
&\left.\frac{\partial u_z}{\partial t}\right|_{z=0} \equiv V(t,r) = v_T(t) - \frac{\partial w_0(t,\theta)}{\partial t}\cos\theta -\\
&-\frac{\partial u_0(t,\theta)}{\partial t}\sin\theta, \quad r < r^*(t),\\
&\sigma_{zz}\big|_{z=0} = 0; \quad r > r^*(t), \quad \sigma_{zr}\big|_{z=0} = 0, \quad r > 0.
\end{aligned}
\tag{8}
$$

The initial conditions for potentials and – are zero:

$$
\varphi\big|_{t=0} = \left.\frac{\partial\varphi}{\partial t}\right|_{t=0} = 0, \quad \psi\big|_{t=0} = \left.\frac{\partial\psi}{\partial t}\right|_{t=0} = 0. \tag{9}
$$

For the problem of impact of an elastic shell on an elastic half-space, the velocity and displacement of the impacting body are found from the equation of motion by integrating it.

The equation of motion of a shell of mass M for the problem of impact with an initial velocity V_0 has the form:

$$M\frac{d^2w_T(t)}{dt^2}=-P(t), \quad (10)$$

$$v_T(t)\big|_{t=0}=V_0, \quad w_T(t)\big|_{t=0}=0, \quad (11)$$

$$P(t)=-2\pi\int_0^{r^*(t)} r\sigma_{zz}(t,r,0)dr. \quad (12)$$

The condition for the absence of disturbances ahead of the front of longitudinal waves and the condition for damping of disturbances at infinity are valid.

$$\varphi\big|_{\rho_1>\alpha t+C_\alpha}=0, \quad \psi\big|_{\rho_1>\alpha t+C_\alpha}=0, \quad (13)$$

$$\varphi\big|_{\rho_1\to\infty}\to 0, \quad \psi\big|_{\rho_1\to\infty}\to 0, \quad (14)$$

where $\rho_1=r^2+z^2, \quad C_\alpha=\text{const}.$

SOLUTION ALGORITHM

Since the impact process is short-term, the perturbation region at each moment of time t is finite. Restricting ourselves to a finite interval of interaction time $(0\le t\le T)$, it is possible to select a region of a half-space, which by the time moment T covers the entire zone of disturbances. From this point of view, for times $(0\le t\le T)$, the elastic half-space can be replaced by an elastic half-cylinder $(r\le l;\ z\ge 0)$, the boundaries of which do not reach the perturbations by the time T.

$$l=\alpha T+r^*(T).$$

Thus, for times $(0\le t\le T)$, the considered problem is reduced to a nonstationary problem for a half-cylinder with mixed boundary conditions at its end. To represent the displacement vector as:

$$u=\text{grad}\varphi+\text{rot}\psi, \quad \text{div}\psi=0,$$

on the lateral surface of the half-cylinder, we select, for example, the conditions for sliding termination:

$$u_r\big|_{r=l}=0, \quad \sigma_{zr}\big|_{r=l}=0, \quad (15)$$

or

$$u_z\big|_{r=l}=0, \quad \sigma_{rr}\big|_{r=l}=0. \quad (16)$$

Consider the initial - boundary value problem (2), (3), (8) – (11). Let us represent the normal $w_0(t,\theta)$ and tangential $u_0(t,\theta)$ displacements of the points of the middle surface of the shell and the radial $p(t,\theta)$ and tangential $q(t,\theta)$ components of the distributed external load acting on the shell in the form of series in Legendre polynomials and their derivatives.

$$w_0(t,\theta)=\sum_{n=0}^{\infty}w_{0n}(t)P_n(\cos\theta), \quad (17)$$

$$u_0(t,\theta)=\sum_{n=1}^{\infty}u_{0n}(t)P_n^1(\cos\theta), \quad (18)$$

$$p(t,\theta)=\sum_{n=0}^{\infty}p_n(t)P_n(\cos\theta), \quad (19)$$

$$q(t,\theta)=\sum_{n=1}^{\infty}q_n(t)P_n^1(\cos\theta), \quad (20$$

$$\Phi(t,\theta)=\sum_{n=1}^{\infty}\Phi_n(t)P_n^1(\cos\theta). \quad (21)$$

In the space of Laplace transformants with parameter s, the transformants of functions Φ, w_0 , u_0 , p , q will, due to (17) – (21), have the form:

$$w_0^L(s,\theta)=\sum_{n=0}^{\infty}w_{0n}^L(s)P_n(\cos\theta), \quad (22)$$

$$u_0^L(s,\theta)=\sum_{n=1}^{\infty}u_{0n}^L(s)P_n^1(\cos\theta), \quad (23)$$

$$p^L(s,\theta)=\sum_{n=0}^{\infty}p_n^L(s)P_n(\cos\theta), \quad (24)$$

$$q^L(s,\theta)=\sum_{n=1}^{\infty}q_n^L(s)P_n^1(\cos\theta), \quad (25)$$

$$\Phi^L(s,\theta)=\sum_{n=1}^{\infty}\Phi_n^L(s)P_n^1(\cos\theta), \qquad (26)$$

We apply to the system of equations (2) the Laplace transform in the variable t with the parameter s and substitute their equalities (22) – (26). Equating the coefficients at the same $P_n(\cos\theta)$ and $P_n^1(\cos\theta)$ we obtain the relations connecting the components of the expansion into series of functions Φ^L, w_0^L, u_0^L , p^L and q^L.

$$w_{0,0}^L(s)=\frac{p_0^L(s)}{\gamma_0^2 s^2+2/(1-\nu_0)}, \qquad (27)$$

$$w_{0,n}^L(s)=Q_{11}^L(n,s)p_n^L(s)+Q_{12}^L(n,s)q_n^L(s),$$
(28)

$$u_{0,n}^L(s)=Q_{21}^L(n,s)p_n^L(s)+Q_{22}^L(n,s)q_n^L(s),$$
(29)

$$\Phi_n^L(s)=Q_{31}^L(n,s)p_n^L(s)+Q_{32}^L(n,s)q_n^L(s),$$
(30)

where

$$Q_{ij}^L(n,s)=\frac{\Delta_{ij}(s)}{\Delta(s)},\ (i=1,2,3;\ j=1,2;\ n=\overline{1,\infty}),$$

$$\Delta_{11}(n,s)=\left(\frac{n(n+1)}{1-\nu_0^2}-\frac{1}{1-\nu_0}+\gamma_0^2 s^2\right)\times, \\ \times\left(n(n+1)-1+\nu_0+R_R+\eta_0^2 s^2\right),$$

$$\Delta_{21}(n,s)=\left(R_R+\left(\frac{2(1+\nu_0)k_s}{1-\nu_0}+1\right)(n(n+1)-\right. \\ \left.-1+\nu_0+R_R)+\eta_0^2 s^2\right)\Big/\left(2(1+\nu_0)Dk_s\right),$$

$$\Delta_{12}(n,s)=\frac{n(n+1)}{1-\nu_0}\left(n(n+1)-1+\nu_0+R_R+\eta_0^2 s^2\right),$$

$$\Delta_{22}(n,s)=-\frac{n(n+1)R_R}{2(1+\nu_0)k_s}+\left(\frac{n(n+1)}{2(1+\nu_0)k_s}+\right. \\ \left.+\frac{2}{1-\nu_0}+\gamma_0^2 s^2\right)\left(n(n+1)-1+\nu_0+R_R+\eta_0^2 s^2\right),$$

$$\Delta_{31}(n,s)=\frac{R_R}{h}\left(-n(n+1)+\frac{1}{1+\nu_0}+\gamma_0^2 s^2\right),$$

$$\Delta_{32}(n,s)=-\frac{n(n+1)R_R}{(1-\nu_0)h},\ R_R=\frac{R^2E_0h}{2(1+\nu_0)Dk_s},$$

$$\Delta(s)=-\eta_0^2\gamma_0^4\left(s^6+\overline{A}_a s^4+\overline{B}_b s^2+\overline{C}_c\right),$$

$$\overline{A}_a=\frac{1}{\gamma_0^2}\left(\frac{n(n+1)}{1-\nu_0^2}+\frac{n(n+1)}{2(1+\nu_0)k_s}+\frac{1}{1+\nu_0}+\right. \\ \left.+\frac{2}{1-\nu_0}\right)+\frac{1}{\eta_0^2}\left(n(n+1)-1+\nu_0+\frac{R^2E_0h}{2(1+\nu_0)Dk_s}\right),$$

$$\overline{B}_b=\frac{1}{\eta_0^2\gamma_0^4}\left(\eta_0^2\left(\frac{n(n+1)}{1-\nu_0^2}-\frac{1}{1+\nu_0}\right)\left(\frac{n(n+1)}{2(1+\nu_0)k_s}+\right.\right. \\ \left.+\frac{2}{1-\nu_0}\right)+\gamma_0^2\left(\frac{n(n+1)}{1-\nu_0^2}+\frac{n(n+1)}{2(1+\nu_0)k_s}+\frac{1}{1+\nu_0}+\right. \\ \left.+\frac{2}{1-\nu_0}\right)\left(n(n+1)-1+\nu_0+\frac{R^2E_0h}{2(1+\nu_0)k_s}+\frac{2}{1-\nu_0}\right)- \\ -\frac{n(n+1)}{2(1+\nu_0)Dk_s}\left(\frac{\eta_0^2}{(1-\nu_0)^2}\left(2(1+\nu_0)k_s+1-\nu_0\right)+\right. \\ \left.\left.+\frac{\gamma_0^2R^2E_0h}{2(1+\nu_0)Dk_s}\right)\right),$$

$$\overline{C}_c=\frac{1}{\eta_0^2\gamma_0^4}\left(\left(\frac{n(n+1)}{1-\nu_0^2}-\frac{1}{1+\nu_0}\right)\left(\left(\frac{n(n+1)}{2(1+\nu_0)k_s}+\right.\right.\right. \\ \left.+\frac{2}{1-\nu_0}\right)\left(n(n+1)-1+\nu_0+\frac{R^2E_0h}{2(1+\nu_0)Dk_s}\right)- \\ \left.-\frac{n(n+1)R^2E_0h}{4(1+\nu_0)^2Dk_s^2}\right)+\frac{n(n+1)}{2(1-\nu_0^2)k_s}\times \\ \times\left(\frac{R^2E_0h}{2(1+\nu_0)Dk_s}-\left(\frac{2(1+\nu_0)k_s}{1-\nu_0}+1\right)\times\right. \\ \left.\left.\times\left(n(n+1)-1+\nu_0+\frac{R^2E_0h}{2(1+\nu_0)Dk_s}\right)\right)\right).$$

Then applying the inverse Laplace transform to (27) – (30), by the theorem on the convolution of the originals of two functions, we have:

$$\dot{w}_{0,0}(t)=\frac{1}{\gamma_0^2}\int_0^t p_0(\tau)\cos\left(\frac{t-\tau}{\gamma_0\sqrt{(1-\nu_0)/2}}\right)d\tau, \quad (31)$$

$$\dot{w}_{0,n}(t)=\int_0^t p_n(\tau)Q_{11}(n,t-\tau)d\tau+ +\int_0^t q_n(\tau)Q_{12}(n,t-\tau)d\tau, \quad (32)$$

$$\dot{u}_{0,n}(t)=\int_0^t p_n(\tau)Q_{21}(n,t-\tau)d\tau+ +\int_0^t q_n(\tau)Q_{22}(n,t-\tau)d\tau, \quad (33)$$

$$\dot{\Phi}_n(t)=\int_0^t p_n(\tau)Q_{31}(n,t-\tau)d\tau+ +\int_0^t q_n(\tau)Q_{32}(n,t-\tau)d\tau, \ (n=\overline{1,\infty}), \quad (34)$$

where

$$Q_{ij}(n,t)=4\left[(\Delta_r R_{ij}+\Delta_i I_{ij})\mathrm{ch}(r_0 t)\cos(\sigma_0 t)+ +(\Delta_i R_{ij}-\Delta_r I_{ij})\mathrm{sh}(r_0 t)\sin(\sigma_0 t)\right]\Big/\left(\Delta_r^2+\Delta_i^2\right)+ +\frac{2\Delta_{ij}(n,s_1^2)\left(\mathrm{H}(s_1^2)\mathrm{ch}(s_1 t)+\mathrm{H}(-s_1^2)\cos(s_1 t)\right)}{\Delta'(s_1^2)},$$

where H(x) – Heaviside function,

$r_0=(r^2+\sigma^2)^{1/4}\cos(\varphi/2)$,

$\sigma_0=(r^2+\sigma^2)^{1/4}\sin(\varphi/2), \ \ \varphi=\mathrm{arctg}(\sigma/r)$,

$r=-((A+B)/2+\overline{A}_a/3), \ \ \sigma=\sqrt{3}(A-B)/2$,

$s_1^2=A+B-\overline{A}_a/3, \ \ A=(-q'/2+Q^{1/2})^{1/3}$,

$B=(-q'/2-Q^{1/2})^{1/3}, \ \ Q=(p'/3)^3+(q'/2)^2$,

$q'=2(\overline{A}_a/3)^3-\overline{A}_a\overline{B}_b/3+\overline{C}_c$,

$p'=-\overline{A}_a^2/3+\overline{B}_b, \ \ r_1=r^2-\sigma^2, \ \ \sigma_1=2r\sigma$,

$$R_{11}=\eta_0^2\gamma_0^2 r_1+\left(\eta_0^2\left(\frac{n(n+1)}{1-\nu_0^2}-\frac{1}{1-\nu_0}\right)+ +\gamma_0^2(n(n+1)-1+\nu_0+R_R)\right)r+ +\left(\frac{n(n+1)}{1-\nu_0^2}-\frac{1}{1-\nu_0}\right)(n(n+1)-1+\nu_0+R_R),$$

$$I_{11}=\eta_0^2\gamma_0^2\sigma_1+\left(\eta_0^2\left(\frac{n(n+1)}{1-\nu_0^2}-\frac{1}{1-\nu_0}\right)+ +\gamma_0^2(n(n+1)-1+\nu_0+R_R)\right)\sigma,$$

$$R_{12}=\frac{n(n+1)}{1-\nu_0}(n(n+1)-1+\nu_0+R_R+\eta_0^2 r),$$

$$I_{12}=\eta_0^2\frac{n(n+1)}{1-\nu_0}\sigma,$$

$$R_{21}=\frac{1}{2(1+\nu_0)Dk_s}\left(\left(\frac{2(1+\nu_0)k_s}{1-\nu_0}+1\right)\times \times(n(n+1)-1+\nu_0+R_R+\eta_0^2 r)-R_R\right),$$

$$I_{21}=\eta_0^2\left(\frac{1}{1-\nu_0}+\frac{1}{2(1+\nu_0)k_s}\right)\sigma,$$

$$R_{22}=\eta_0^2\gamma_0^2 r_1+\left(\eta_0^2\left(\frac{n(n+1)}{2(1+\nu_0)k_s}+\frac{2}{1-\nu_0}\right)+ +\gamma_0^2(n(n+1)-1+\nu_0+R_R)\right)r+ +\left(\frac{n(n+1)}{2(1+\nu_0)k_s}+\frac{2}{1-\nu_0}\right)(n(n+1)-1+\nu_0+R_R)- -\frac{n(n+1)R_R}{2(1+\nu_0)k_s},$$

$$I_{22}=\eta_0^2\gamma_0^2\sigma_1+\left(\eta_0^2\left(\frac{n(n+1)}{2(1+\nu_0)k_s}+\frac{2}{1-\nu_0}\right)+ +\gamma_0^2(n(n+1)-1+\nu_0+R_R)\right)\sigma,$$

$$R_{31}=\frac{R_R}{h}\left(-n(n+1)+\frac{1}{1-\nu_0}+\gamma_0^2 r\right),$$

$$I_{31}=\gamma_0^2\frac{R_R}{h}\sigma, \ \ R_{32}=-\frac{R_R}{h}n(n+1), \ \ I_{32}=0,$$

$$\Delta'(s)=-\eta_0^2\gamma_0^4\left[6s^4+4\overline{A}_a s^2+2\overline{B}_b\right],$$

$$\Delta_r=-\eta_0^2\gamma_0^4\left[6r_1+4\overline{A}_a r+2\overline{B}_b\right],$$

$$\Delta_i=-\eta_0^2\gamma_0^4\left[6\sigma_1+4\overline{A}_a\sigma\right].$$

$$w_{0,0}(t)=\frac{1}{\gamma_0}\int_0^t p_0(\tau)\sin\left(\frac{t-\tau}{\gamma_0\sqrt{(1-\nu_0)/2}}\right)d\tau,$$

$$w_{0,n}(t)=\int_0^t p_n(\tau)\tilde{Q}_{11}(n,t-\tau)d\tau+ +\int_0^t q_n(\tau)\tilde{Q}_{12}(n,t-\tau)d\tau, \quad (35)$$

$$u_{0,n}(t)=\int_0^t p_n(\tau)\tilde{Q}_{21}(n,t-\tau)d\tau+ \quad (36)$$

$$+\int_0^t q_n(\tau)\tilde{Q}_{22}(n,t-\tau)d\tau,$$

$$\Phi_n(t)=\int_0^t p_n(\tau)\tilde{Q}_{31}(n,t-\tau)d\tau+$$

$$+\int_0^t q_n(\tau)\tilde{Q}_{32}(n,t-\tau)d\tau,\ \ (n=\overline{1,\infty}),$$

where

$$\tilde{Q}_{ij}(n,t)=4\Big[(\delta_r R_{ij}+\delta_i I_{ij})\mathrm{sh}(r_0t)\cos(\sigma_0 t)+$$

$$+(\delta_i R_{ij}-\delta_r I_{ij})\mathrm{ch}(r_0t)\sin(\sigma_0 t)\Big]\Big/\left(\delta_r^2+\delta_i^2\right)+$$

$$+\frac{2\Delta_{ij}(n,s_1^2)\left(\mathrm{H}(s_1^2)\mathrm{sh}(s_1t)+\mathrm{H}(-s_1^2)\sin(s_1t)\right)}{(s_1\Delta'(s_1^2))},$$

$$\delta_r=r_0\Delta_r-\sigma_0\Delta_i,\ \ \delta_i=\sigma_0\Delta_r+r_0\Delta_i.$$

We apply to the system of equations (2) the Laplace transform in the variable t (s is the transformation parameter) and the Fourier method of separation of variables, considering the evenness in x of the potential and the oddness of the potential , and require the satisfaction of condition (13) – (14). Then, in the space of Laplace transformants, we obtain the following representations for wave potentials [5]:

$$\varphi^L(s,r,z)=\sum_{n=0}^{\infty}A_n(s)\exp\left(-z\sqrt{\frac{s^2}{\alpha^2}+\lambda_n^2}\right)J_0(\lambda_n r),$$

$$\psi^L(s,r,z)=\sum_{n=0}^{\infty}B_n(s)\exp\left(-z\sqrt{\frac{s^2}{\beta^2}+\lambda_n^2}\right)J_1(\lambda_n r),$$

(37)

where λ_n – the eigenvalues of the problem, which are determined from conditions (15) taking into account (4) and are the roots of the equality

$$J_1(\lambda_n l)=0,\quad (n=\overline{0,\infty}).$$

In (37) $A_n(s)$ and $B_n(s)$ are determined from the boundary conditions. It follows from representations (37) and relations (4) that the sought-for functions on the surface of a half-space are represented as series in the system of eigenfunctions of the problem.

$$u_z(t,r,0)=\sum_{n=0}^{\infty}u_{zn}(t)J_0(\lambda_n r),$$

$$u_r(t,r,0)=\sum_{n=1}^{\infty}u_{rn}(t)J_1(\lambda_n r),$$

$$\sigma_{zz}(t,r,0)=\sum_{n=0}^{\infty}\sigma_{zn}(t)J_0(\lambda_n r),$$

$$\sigma_{zr}(t,x,0)=\sum_{n=1}^{\infty}\sigma_{zrn}(t)J_1(\lambda_n r).$$

Just as in [1 – 5], the dependence between the harmonics of the vertical component of the velocity and normal stresses on the surface of the half-space is determined [6 – 8, 10]:

$$\sigma_{zn}(t)=-\alpha\left(V_n(t)+\int_0^t V_n(\tau)F(t-\tau)d\tau\right),$$

(38)

where

$$F_n(t)=-\alpha\lambda_n J_1(\alpha\lambda_n t)+2b\beta\lambda_n\left\{\beta^2\lambda_n^2t^2(\bar{J}_0(\alpha\lambda_n t)-\right.$$
$$-\bar{J}_0(\beta\lambda_n t)-J_1(\alpha\lambda_n t)+J_1(\beta\lambda_n t))+\beta\lambda_n\ t\times$$
$$\times(bJ_0(\alpha\lambda_n t)-J_0(\beta\lambda_n t))+(2-b^2)\bar{J}_0(\alpha\lambda_n t)-$$
$$\left.-\bar{J}_0(\beta\lambda_n t)\right\},$$

where $J_0(t)$, $J_1(t)$ – Bessel functions of the first kind of zero and first order, respectively, and the function $\bar{J}_0(t)$ is defined as follows:

$$\bar{J}_0(t)=\int_0^t J_0(\tau)d\tau.$$

Further, we will satisfy the mixed boundary conditions (8). From (8), (38) we obtain the following representation for the vertical component of the velocity on the surface of the half-space:

$$\sum_{n=0}^{\infty}V_n(t)J_0(\lambda_n r)=\mathrm{H}(r^*-r)\times$$
$$\left\{v_T(t)-\dot{w}_0(t,\theta)\cos\theta-\dot{u}_0(t,\theta)\sin\theta\right\}- \quad (39)$$
$$-\mathrm{H}(r-r^*)\sum_{n=0}^{\infty}J_0(\lambda_n r)\int_0^t V_n(\tau)F_n(t-\tau)d\tau.$$

Substituting (22) and (23) into (39) with allowance for $r = \sin\theta$, arising from geometric considerations in the zone of the contact region, and representing both parts of (39) in the form of series in $J_0(\lambda_n r)$, we obtain an infinite system of Volterra integral equations (ISVIE) of the second kind regarding to unknown harmonics velocity on the surface of the half-space $(n = \overline{0,\infty})$:

$$V_n(t) + \sum_{m=0}^{\infty} \alpha_{mn}^{(4)}(r^*) \int_0^t V_m(\tau) F_m(t-\tau) d\tau +$$

$$+ \sum_{m=0}^{\infty} \left[\alpha_{mn}^{(5)}(r^*) \dot{w}_{0m}(t) + \alpha_{mn}^{(6)}(r^*) \dot{u}_{0m}(t) \right] \times$$

$$\times \int_0^t V_m(\tau) F_m(t-\tau) d\tau = C_n(r^*) v_T(t),$$

where

$$\alpha_{mn}^{(4)}(r^*) = \frac{1}{N_n^2} \int_{r^*}^{l} r J_0(\lambda_m r) J_0(\lambda_n r) dr,$$

$$\alpha_{mn}^{(5)}(r^*) = \frac{1}{N_n^2} \int_0^{r^*} r\sqrt{1-r^2} P_m\left(\sqrt{1-r^2}\right) J_0(\lambda_n r) dr,$$

$$\alpha_{mn}^{(6)}(r^*) = \frac{1}{N_n^2} \int_0^{r^*} r^2\sqrt{1-r^2} \frac{\partial}{\partial r} P_m\left(\sqrt{1-r^2}\right) J_0(\lambda_n r) dr,$$

$$C_n(r^*) = \frac{1}{N_n^2} \int_0^{r^*} r J_0(\lambda_n r) dr, \quad N_n^2 = \int_0^{l} r \left(J_0(\lambda_n r)\right)^2 dr.$$

The functions $\dot{w}_{0m}(t)$, $\dot{u}_{0m}(t)$ and $\dot{\Phi}_n(t)$ are determined from relations (31) – (34), but they involve unknown functions $p_n(t)$ and $q_n(t)$. Let us deal with their exclusion, for this we use conditions (6), (7), which can be rewritten using (38) in the form:

$$\sum_{n=0}^{\infty} p_n(t) P_n(\cos\theta) = \alpha \mathrm{H}(\theta^* - |\theta|) \cos\theta \times$$

$$\times \sum_{n=0}^{\infty} J_0(\lambda_n \sin\theta) \left(V_n(t) + \int_0^t V_n(\tau) F_n(t-\tau) d\tau \right),$$

$$\sum_{n=0}^{\infty} q_n(t) P_n^1(\sin\theta) = \alpha \mathrm{H}(\theta^* - |\theta|) \sin\theta \times$$

$$\times \sum_{n=0}^{\infty} J_0(\lambda_n \sin\theta) \left(V_n(t) + \int_0^t V_n(\tau) F_n(t-\tau) d\tau \right).$$

Using the orthogonality of the polynomials and the associated Legendre polynomials, we obtain the relations establishing the relationship between the harmonics of the series expansions of the functions p, q and V:

$$p_n(t) = \sum_{m=0}^{\infty} \gamma_{mn}^{(3)}(\theta^*) \left(V_m(t) + \int_0^t V_m(\tau) F_m(t-\tau) d\tau \right),$$

$$q_n(t) = \sum_{m=0}^{\infty} \gamma_{mn}^{(4)}(\theta^*) \left(V_m(t) + \int_0^t V_m(\tau) F_m(t-\tau) d\tau \right),$$

where

$$\gamma_{mn}^{(3)}(\theta^*) = \frac{\alpha}{\bar{N}_n^2} \int_0^{\theta^*} \cos\theta \sin\theta P_n(\cos\theta) J_0(\lambda_m \sin\theta) d\theta,$$

$$\gamma_{mn}^{(4)}(\theta^*) = \frac{\alpha}{\tilde{N}_n^2} \int_0^{\theta^*} \sin^2\theta P_n^1(\cos\theta) J_0\left(\lambda_m \sin\theta\right) d\theta,$$

$$\bar{N}_n^2 = \int_0^{\pi} \sin\theta \left(P_n(\cos\theta)\right)^2 d\theta,$$

$$\tilde{N}_n^2 = \int_0^{\pi} \sin\theta \left(P_n^1(\cos\theta)\right)^2 d\theta.$$

Thus, the final form of the resolving ISVIE of the second kind will be as follows:

$$V_n(t) + \sum_{m=0}^{\infty} \alpha_{mn}^{(4)}(r^*) \int_0^t V_m(\tau) F_m(t-\tau) d\tau +$$

$$+ \sum_{m=0}^{\infty} \alpha_{mn}^{(5)}(r^*) \sum_{k=0}^{\infty} \int_0^t \gamma_{km}^{(3)}(\theta^*(\tau)) \Big(V_k(\tau) +$$

$$+ \int_0^{\tau} V_k(\xi) F_k(\tau-\xi) d\xi \Big) Q_{11}(m, t-\tau) d\tau +$$

$$+ \sum_{m=0}^{\infty} \alpha_{mn}^{(5)}(r^*) \sum_{k=0}^{\infty} \int_0^t \gamma_{km}^{(4)}(\theta^*(\tau)) \Big(V_k(\tau) +$$

$$+ \int_0^{\tau} V_k(\xi) F_k(\tau-\xi) d\xi \Big) Q_{12}(m, t-\tau) d\tau +$$

$$+ \sum_{m=0}^{\infty} \alpha_{mn}^{(6)}(r^*) \sum_{k=0}^{\infty} \int_0^t \gamma_{km}^{(3)}(\theta^*(\tau)) \Big(V_k(\tau) +$$

$$+\int_0^{\tau} V_k(\xi)F_k(\tau-\xi)d\xi\Bigg)Q_{21}(m,t-\tau)d\tau+$$
$$+\sum_{m=0}^{\infty}\alpha_{mn}^{(6)}(r^*)\sum_{k=0}^{\infty}\int_0^t \gamma_{km}^{(4)}(\theta^*(\tau))\big(V_k(\tau)+ \qquad (40)$$
$$+\int_0^{\tau} V_k(\xi)F_k(\tau-\xi)d\xi\Bigg)Q_{22}(m,t-\tau)d\tau=$$
$$=C_n(r^*)v_T(t),\quad (n=\overline{0,\infty}).$$

To solve the problem, when the shell penetration velocity $v_T(t)$ is a predetermined function, it is sufficient to numerically implement equations (40).

The expression for the reaction force of the elastic half-space (12), using (38), can be rewritten as:

$$P(t)=-2\pi\int_0^{r^*(t)} r\sigma_{zz}(t,r,0)dr=\alpha\pi r^*(t)\times$$
$$\times\left\{v_T(t)r^*(t)+2\sum_{n=0}^{\infty}\frac{J_1(\lambda_n r^*)}{\lambda_n}\int_0^t V_n(\tau)F_n(t-\tau)d\tau\right\}.$$

The equation of motion of the shell (10) with the initial conditions takes the form:

$$M\frac{dv_T(t)}{dt}=-\alpha\pi r^*(t)\big\{v_T(t)r^*(t)+$$
$$+2\sum_{n=0}^{\infty}\frac{J_n(\lambda_n r^*)}{\lambda_n}\int_0^t V_n(\tau)F_n(t-\tau)d\tau\bigg\}. \qquad (41)$$

To solve the problem of impact with an initial velocity V_0, the system of equations (40) must be supplemented with the equation of motion (41).

The contact area is determined considering the rise of the medium from the condition:

$$\delta_{1j}v_T t+\delta_{2j}\int_0^t v_T(\tau)d\tau-f(r^*)-$$
$$-\sum_{n=0}^{\infty}J_0(\lambda_n r^*)\int_0^t V_n(\tau)d\tau- \qquad (42)$$
$$-\sqrt{1-r^{*2}}\sum_{n=0}^{\infty}P_n\left(\sqrt{1-r^{*2}}\right)\times$$
$$\times\sum_{m=0}^{\infty}\int_0^t\Big[\gamma_{mn}^{(3)}(\arcsin r^*(\tau))\tilde{Q}_{11}(n,t-\tau)+$$
$$+\gamma_{mn}^{(4)}(\arcsin r^*(\tau))\tilde{Q}_{12}(n,t-\tau)\Big]\times$$
$$\times\left(V_m(\tau)+\int_0^{\tau}V_m(\xi)F_m(\tau-\xi)d\xi\right)d\tau-$$
$$-r^*\sqrt{1-r^{*2}}\sum_{n=0}^{\infty}P_n^1\left(\sqrt{1-r^{*2}}\right)\times$$
$$\times\sum_{m=0}^{\infty}\int_0^t\Big[\gamma_{mn}^{(3)}(\arcsin r^*(\tau))\tilde{Q}_{21}(n,t-\tau)+$$
$$+\gamma_{mn}^{(4)}(\arcsin r^*(\tau))\tilde{Q}_{22}(n,t-\tau)\Big]\times$$
$$\times\left(V_m(\tau)+\int_0^{\tau}V_m(\xi)F_m(\tau-\xi)d\xi\right)d\tau=$$
$$=\begin{cases}0, & \text{if } r<r^*(t)\\ \varepsilon<0, & \text{if } r>r^*(t)\end{cases}.$$

where $\delta_{ij}=\{0,\text{ if } i\neq j;\ 1,\text{ if } i=j\}$ – Kronecker symbol. Index j=1 corresponds to the case when the body penetrates into the medium at a speed varying according to a predetermined law (setting 1); if the velocity of the penetrating body is known only at the initial moment of time $t=0$, and at subsequent moments is determined from the equation of motion (statement 2), then j=2. If we exclude the fourth term in relation (42), then we obtain a condition from which the boundary of the contact region is determined without considering the rise of the medium.

NUMERICAL SOLUTION

The size of reduction N of the ISVIE of the second kind will be chosen from considerations of practical convergence.

The integrals were calculated using the method of mechanical quadratures, in particular, the symmetric Gregory quadrature formula for equidistant nodes. The Cauchy problem for the differential equation (41) was solved by the Adams method (closed-type formulas) [1 – 5] of order m_1 with a local truncation error

$O(\Delta t^{m_1+1})$ [6 – 8, 10]. As a result of discretization, we obtain a system of linear algebraic equations (SLAE). Calculations have shown that with an increase in the reduction size *N*, the determinant of the SLAE matrix increases indefinitely. The SLAE is poorly defined: as the reduction size *N* tends to infinity, the value of the determinant of the SLAE matrix also tends to infinity. This is due to the fact that the kernels $Q_{11}(n,t)$, $Q_{22}(n,t)$ in (32), (33) have asymptotic $\exp(O(n))$ in the parameter *n*, $\tilde{Q}_{11}(n,t)$ and $\tilde{Q}_{22}(n,t)$ in (35) and (36) have asymptotic $O\left(1/n\right)\exp(O(n))$ in the parameter *n*. Methods of Tikhonov regularization and orthogonal polynomials do not work to neutralize such an exponential singularity. The approach [1 – 5] for solving problems of dynamics makes it impossible to study the impact of elastic shells of the S.P. Timoshenko type and elastic bodies on an elastic foundation [6 – 8, 10]. In addition, this approach makes it possible to determine the stress-strain state only on the surface of the medium into which the striker penetrates.

CONCLUSIONS

As a result of an attempt to solve the axisymmetric problem of the impact of a spherical fine shell of the S.P. Timoshenko type on the surface of an elastic half-space, applying the method of reduction of dynamic problems to infinite systems of Voltaire's equations of the second kind, the limitations of this technique were revealed. This technique does not allow solving plane and axisymmetric problems of dynamics for refined shells of the S.P. Timoshenko type and elastic bodies.

To solve [9, 11 – 14] the problems of impact and nonstationary interaction [15 – 19], the elastoplastic formulation [20 – 22] can be used. It should be noted that to calibrate the computational [1] process in the elastoplastic formulation at the elastic stage, it is convenient and expedient to use the technique [1 – 5] for solving the problems of dynamics, developed in [6 – 8, 10].

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Один подход к осесимметричной задаче удара оболочек типа С. П. Тимошенко об упругое полупространство

Владислав Богданов

Аннотация. Уточненная модель С.П. Тимошенко позволяет учесть вращение и инерцию такого вращения поперечного сечения оболочки. Возмущения распространяются в оболочках типа С.П. Тимошенко с конечной скоростью. Поэтому изучение динамики распространения волновых процессов в тонких оболочках типа С.П. Тимошенко является важным аспектом, так же как важно исследование волновых процессов удара в упругом основании, в которое проникает ударник. Хорошо изучены метод сведения решения задач динамики к решению бесконечной системы интегральных уравнений Вольтерра второго рода и сходимость этого решения. Такой подход успешно применялся для случаев исследования задач об ударе твердых тел и упругих тонких оболочек типа Кирхгофа – Лява об упругое полупространство и слой. В данной работе сделана попытка решения осесимметричной задачи об ударе упругой тонкой сферической оболочки типа С.П. Тимошенко об упругое полупространство методом сведения задач динамики к решению бесконечной системы интегральных уравнений Вольтерра второго рода. Показано, что такой подход неприемлем для исследуемой в данной статье осесимметричной задачи. Дискретизация с использованием методов Грегори для численного интегрирования и Адамса для решения задачи Коши для полученной бесконечной системы уравнений Вольтерра второго рода приводит к решению плохо определенной системы линейных алгебраических уравнений: при увеличении порядка редукции определитель такой системы стремиться к бесконечности. Данная методика не позволяет решать плоские и осесимметричные задачи динамики для тонких оболочек типа С. П. Тимошенко и упругих тел. Это показывает ограничения такого подхода и объясняет необходимость разработки других математических подходов и моделей. Следует отметить, что для калибровки вычислительного процесса в упругопластической постановке на упругой стадии удобно и целесообразно использовать технику сведения задач динамики для решения бесконечной системы интегральных уравнений Вольтерра второго рода.

Ключевые слова: удар, упругость, упругопластичность, полупространство, осесимметричная задача, тонкая сферическая оболочка, С.П. Тимошенко.

The twentieth century science paradoxes

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Abstract. The isolation of hypothetical theories from the realities of living matter has caused mysticism to penetrate scientific theories. With mystical thinking, the idea of using an analytical method to solve cognitive problems does not occur. Dialectical logic, in contrast to mysticism, states the opposite: any problematic tasks of cognizing the vital processes and phenomena of the universe are solvable exclusively in an analytic way, with the only method. The author created a universal and formal theory of solving intellectual (i.e., having no previously known algorithms for solving) problems associated with the knowledge of the vital functions of natural and man-made processes in any phenomena of the universe - the Kondratenko method of axiomatic modeling, the effectiveness of which is achieved by correctly setting the problem and solving it purely formal method. The correctness of the statement of the problem means, first of all, the recognition of the failure of all hypothetical (not confirmed by the results of full-scale experimentation with the subject of knowledge) theories. This requirement, in particular, to the mathematical tools used to solve problems of cognition, it revealed paradoxes in the foundations of mathematics, which are discussed in the article.

At present, in the natural and applied sciences in most publications, i.e. more than 90% associated with the construction of formal theories in these sciences, the proof of theorems is carried out: *firstly*, in a meaningful way, which contradicts the urgent requirement of philosophers of science to use exclusively formal evidence, which is a criterion for assessing the correctness and reliability of evidence; *secondly*, in substantive evidence in 95% of cases, an exclusively standard list of tautologies is used, which by definition is incorrect for the purpose of proving theorems on phenomena and processes of the universe based on exclusively true axioms obtained as a result of full-scale experimentation with these phenomena and processes. The article deals with the paradox in the classical approach to proving theorems, which consists in the inappropriateness of generally accepted stereotypical tautologies of classical mathematics for proving theorems.

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INTRODUCTION

In the last decade, interest in the sciences studying the human brain has grown tremendously. Publications on neurobiology today have quantitatively surpassed publications on physics and mathematics. Since ancient Egypt, people were eager to look into the human brain, but today the growing interest in the processes of human thinking, I think, is dictated by harsh necessity. The demand for this kind of knowledge is dictated not so much by the rapid development of world science as by “dead ends” and stagnation in the previous scientific century. The need for states economic growth in times of crisis, their fierce competition in the international arena for leadership and the disharmony of the development of modern civilization are forcing to seek new ways for the intensive development of society. There are no such proposals from science today. There is a fair hope that having understood the processes of human thinking, science will indicate the right path for further scientific and civilizational development. However, success requires more than just finding new ways. In my opinion, competently conducted "work on mistakes" of the previous period of science development is no less effective. And I propose starting this work from the basics: from the foundations of mathematics, rightfully called the queen of all sciences [1 – 5], which will serve the purpose of this article.

Man, by definition, is a "homo sapiens", since his genome contains a complex of inherited genes that implement biological tools of rational activity (BTRA) [6, 7]. The BTRA is capable of not only operating with the so-called signaling information, but also performing a complex of computational operations on it, dictated by the full human body functioning [8 – 11]. Intelligence assets are accumulated throughout a person's life in the process of learning knowledge, skills and abilities. Assets are stored in the knowledge base attached to the BTRA. The base itself consists of two sections. In the first section, realistic knowledge is stored, used exclusively to control the real life of a person. The second section contains abstract knowledge used exclusively for abstract rational activity. For example, dreams, fantasies. BTRA requires a high-speed associative search engine serving both of the above knowledge base sections. Knowledge of the BTRA architecture gives us reason to be guided by the requirement to use exceptionally realistic knowledge in solving problematic tasks related to predicting the evolution of the vital processes of real processes in the universe. However, it is known that there are forecasting technologies based on hypothetical theories. The concept "hypothetical" means in this context 100% isolation from field experimentation. The isolation of hypothetical theories from the realities of living matter has caused mysticism to penetrate scientific theories. This will be discussed not only in this article, but in subsequent ones, as well as in my previous articles on this topic. Unfortunately, there are many examples of this. A reasonable explanation of the situation in science in general, and in mathematics in particular, is impossible to find, since biological sciences, coupled with cognitive science, have practically learned the secrets of human rational thinking, based on field experimentation and rejecting hypothetical theories in principle, as theories that contradict human BTRA capabilities [12 – 15]. Any mathematical statement, if it is not a postulate, must be proved. It is proved in a formal way, i.e. without the subjective influence of a person on the result of evidence.

Relevance of the topic. At present, in the natural and applied sciences in most publications, i.e. more than 90% associated with the construction of formal theories in these sciences, the proof of theorems is carried out:
- firstly, in a meaningful way, which contradicts the urgent requirement of philosophers of science to use exclusively formal evidence, which is a criterion for assessing the correctness and reliability of evidence;
- secondly, in substantive evidence in 95% of cases, an exclusively standard list of tautologies is used, which by definition is incorrect for the purpose of proving theorems on phenomena and processes of the universe based on exclusively true axioms obtained as a result of full-scale experimentation with these phenomena and processes.

The task formulation. The article analyzes commonly used standard list of tautologies:

- modus ponens: $A \wedge (A \Rightarrow B) \Rightarrow B$ (1)
- modus tollens: $((A \Longrightarrow B) \Lambda \neg B) \Longrightarrow \neg A$ (2)
- syllogism:
- $((A \Longrightarrow B) \Lambda (B \Longrightarrow C)) \Longrightarrow (A \Longrightarrow C)$ (3)
- counter position: $(A \Longrightarrow B) \Longrightarrow$
  $\Longrightarrow (\neg B \Longrightarrow \neg A)$ (4)

METHOD FOR SOLVING THE PROBLEM

Proof of the unsuitability of the modus ponens rule for proving theorems.

Modus ponens formula rules, see (1):

$$A\wedge(A\Rightarrow B)\Rightarrow B,$$

in classical mathematics, it is invariant to the initial truth values of the component subformulas A and B. And even more invariant, to the A and B subformulas components, if these subformulas are composite. The modus ponens rule itself does not declare the elementary nature of the A and B subformulas.

However, in real life, researchers have to work when formulating and proving theorems on the phenomena of the universe exclusively with axioms (facts of full-scale experimentation with these phenomena), which in the foundations of mathematics received two alternative names:

• elementary logical formulas
• single letter disjoints.

And so, when the modus ponens formula: $A\wedge(A\Rightarrow B)\Rightarrow B$ (1) is being alone only with single letter clauses, it not only does not indicate a bright way to obtain the conclusion of the truth of the premises in a purely theoretical way, but it also poses the problem solver that, in proving the theorems, the truth of both logical variable A and logical variable B, so that there is no conflict with the predicate logic semantics of the language, functionally fully represented in the following Table 1:

Table 1

X	Y	$\neg$X	X ∧ Y	X ∨ Y	X ⇒ Y	X ⇔ Y
И	И	Л	И	И	И	И
И	Л	Л	Л	И	Л	Л
Л	И	И	Л	И	И	Л
Л	Л	И	Л	Л	И	И

Indeed, in this case, the first line shows that the formula (1) receives the true value for all true premises and the true conclusion of the theorem.

However, the semantics of the language of first-order predicate logic indicates that formula (1) can also get *true* value for truth values of single letter clauses corresponding to lines 3 and 4 of the language semantics Table 1. This corresponds to the complete absurdity in the proof of the theorems, since false single letter disjunctions reflecting the meaning of specific real axioms obtained in the course of field experimentation are unacceptable in the premises of the theorems. In the case of the modus rule, the theorem should be considered incorrectly formulated. But formulating correctly any theorem within the framework of the modus rule definition of freedom degrees is fundamentally impossible.

Thus, another insoluble paradox is generated in the beginnings of mathematics. True, there is only one correct way out of this paradox, but it will bury the modus ponens rule itself forever. The way out is to limit the number of degrees of freedom when defining operands in a modus ponens rule. As the operands of this rule, exclusively true axioms should be used, functionally fully characterizing all the admissible states of the observed phenomenon in the universe, and obtained only in the process of full-scale experimentation with this phenomenon. Moreover, this requirement should equally apply both to axioms acting as premises in the theorem, and to axioms acting as conclusions in the theorem. But even with such a limitation that allows us to correctly formulate the theorem, it is still impossible to obtain a proof of the theorem conclusion truth from the truth of the conjunction of its premises in a purely theoretical formal way [3]. For the reasons related to incomplete cognition by the international scientific community of the human psyche, which (cognition), according to optimistic estimates, can be completed no earlier than in 500 years.

The complete knowledge of the human psyche will reveal the secret of nature, in particular, about living matter, concerning (the secret) of a rigid relationship at the molecular level between two components [4]:

1) information on this matter, on the one hand, from which the higher mental functions of the central nervous system of a person are operated (including mathematical and graphic operations), including consciousness, thinking, imagination, perception, memory and scientific creativity;

2) investigated biological matter on the other hand, involved in this operation.

The disclosure of the mentioned secret will leave no room for use in theories of false hypothetical axioms, since any of the axioms will have material evidence of its truth or falsehood.

The requirement to disclose the mentioned mystery additionally follows from the postulates given below in order to confirm their truth, since they (postulates) are the keys in molecular biology and normal physiology and determine the basic foundation for the existence of a biological form of matter:

- ✓ the postulate of the trinity of bioorganic matter, chemical energy and molecular information of living matter, declaring not only the nature of heredity, but also in general, the nature of all the rational activity of individuals, together with their reflex activity in the process of knowing the environment of existence;
- ✓ the postulate of interdependence between the main components of living matter: information, structure, energy and function in various biological processes;
- ✓ a postulate stating that for living forms of matter, reflection is a condition for ensuring the unity of the organism and the external environment, without which the existence of a living form is impossible;
- ✓ a postulate stating that information, just like chemical energy, reveals complete affinity for living matter at its elementary level. Indeed, all biochemical elements of biological molecules represent that elementary form of organic matter, with the help of which biological codes of molecular information are formed and transmitted;
- ✓ a postulate stating that information, in a philosophical sense, is neither matter nor energy – it is only a property of matter.

In molecular biology, information acquires its physical embodiment and meaning already at the level of molecular units of biological information (letters or symbols) that are used in a living cell to encode and program biological molecules. It follows that information in molecular biology is not an abstract concept, but an objective property and, moreover, the very content and essence of living matter. Biological molecules and structures, as carriers of the just mentioned types of information, are constantly in informational interaction with each other and the control center of the individual psyche. Therefore, all of them may well be recognized as informational "entities".

Thus, only a rigid relationship at the molecular level between information subject to operation and the biological matter involved in this operation allows the correct formal proof of theorems in the process of scientific knowledge of this matter.

A similar approach to information, in which it (information) is identified as an objective property of each specific matter, bearing the burden of the content and essence of matter and transforming at the molecular level into matter itself, should also be developed in the process of cognition of inanimate matter.

As we have just seen, the modus ponens rule does not provide the possibility of obtaining a purely theoretical formal way of proving the truth of the conclusion of a theorem from the truth of the conjunction of its premises. Therefore, at present, the truth of all axioms, both in premises and in the conclusions of theorems, has to be determined solely by field experimentation.

It would seem that in such a situation, a formal proof of the theorems should be reasonably abandoned. But this is permissible only if one neglects the control of the logical thinking correctness of the problem solver in the case of his reasoning with a logical consequence in the structure of the "premise-conclusion" statement. This correctness is checked exclusively by the formal derivability of the conclusion truth from the conjunction of premises truth, based on the syntax and semantics of the formal language of this formal theory. That is why philosophers of science require precisely the formal proof of theorems in all formal theories [16 – 19].

CONCLUSION

The modern proof is carried out on the standard stereotype of the generalized logical formula (3) created by the author [3] of any theorem, which is represented by writing the entire theorem with abstract logical variables as the premise (left side) of the generalized theorem, and recording one or more interpretations of this theorem (obtained in the field experiment) as a conclusion to a generalized theorem.

The formal derivability of any interpretation of this formula from an abstract formula establishes two facts [20 – 22]:

• the fact of correct thinking in the formulation and solution of a specific task problem;

• the fact of an objective and correct proof of the truth of the formulated theorem.

Similar considerations indicate the unsuitability of the modus tollens rule, see (2):

$$((A \Rightarrow B) \wedge \neg B) \Rightarrow \neg A,$$

to prove the theorems, since the formula (2) can get the true value eve – for truth values of one-liter clauses corresponding to lines 1, 2 and 4 of the language semantics Table 1, which *corresponds* to the complete absurdity in proving the theorems.

Similar considerations indicate the unsuitability of the syllogism rule, see (3):

$$((A \Rightarrow B) \wedge (B \Rightarrow C)) \Rightarrow (A \Rightarrow C),$$

to prove the theorems, since the formula (3) can get the true value even for truth values of single letter clauses corresponding to lines 1 – 4 of the language semantics table, which corresponds to the complete absurdity in proving the theorems.

Similar considerations indicate the inappropriateness of the counterposition rule, see (4):

$$(A \Rightarrow B) \Rightarrow (\neg B \Rightarrow \neg A),$$

to prove the theorems, since the formula (4) can get the true value even for the truth values of single letter clauses corresponding to lines 1 – 4 of the language semantics Table 1, which corresponds to the complete absurdity in proving the theorems.

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Парадоксы науки двадцатого века

Виктория Кондратенко

Аннотация. Оторванность гипотетических теорий от реалий живой материи стала причиной проникновения мистики в научные теории. При мистическом мышлении идея применения аналитического метода решения задач познания в голову не приходит. Диалектическая логика в отличие от мистики утверждает обратное: любые проблемные задачи познания жизнедеятельности процессов и явлений мироздания разрешимы исключительно аналитическим путём, при этом единственным методом. Автором создана универсальная и формальная теория решения интеллектуальных (т.е. не имеющих заранее известных алгоритмов решения) задач, связанных с познанием жизнедеятельности естественных и рукотворных процессов в любых явлениях мироздания – метод аксиоматического моделирования Кондратенко, эффективность которого достигается путём корректной постановки задачи и её решения чисто формальным методом. Корректность постановки задачи означает, прежде всего, признание несостоятельности всех гипотетических (не подтверждённых результатами натурного экспериментирования с предметом познания) теорий. Это требование, в частности, и к математическому инструментарию, используемому для решения задач познания, выявило парадоксы в основаниях математики, рассмотрению которых посвящена статья.

В настоящее время в естественных и прикладных науках в большинстве публикаций, т.е. более 90%, связанных с построением формальных теорий по этим наукам, доказательство теорем осуществляется:
*во-первых***,** содержательным способом, что противоречит настоятельному требованию философов науки использовать исключительно формальное доказательство, которое является критерием оценки корректности и достоверности доказательства; *во-вторых,* при содержательном доказательстве в 95% случаев используется исключительно стандартный перечень тавтологий, который по определению некорректен для целей доказательства теорем о явлениях и процессах мироздания на основе исключительно истинных аксиом, полученных в результате натурного экспериментирования с этими явлениями и процессами. Рассмотрен парадокс при классическом подходе к доказательству теорем, состоящий в непригодности общепринятых стереотипных тавтологий классической математики для доказательства теорем.

Ключевые слова: аксиоматическое моделирование, искусственный интеллект, математическая логика, мышление, формализация.

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on the other hand (hereinafter − the Author(s)), who altogether referred to as the Parties, guided by the Civil Code, the Law of Ukraine "On Copyright and Related Rights", other legislative and regulatory acts of Ukraine, entered into this Agreement as follows.

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