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A TECHNOLOGICAL UNDULATIVE INDUCTION ACCELERATOR FOR COMMERCIAL APPLICATIONS

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The results of analysis of the electron undulative induction accelerator are presented in the paper. It is shown, in particular, that a wide spectrum of technological systems (destined for natural and wastewater purification, medicine equipment and preparations, etc.) can be constructed on the basis of undulative induction accelerator. Characteristic features of these systems are commercial attractiveness, high level of efficiency and relative compactness. One variant of design of the undulative induction accelerator is described and discussed.

Introduction

It is well-known that the problem of constructing commercially attractive technological electron accelerators remains topical till today. Systems on such a basis should possess relative compactness, be inexpensive and, at the same time, they should have high level of reliability and electromagnetic compatibility.

The main purpose of the paper is to demonstrate a real technological possibility of constructing commercial accelerators of this kind. The undulative induction accelerators (UNINAC) [1–5] are chosen as an example for such demonstration. It is proposed to use the UNINAC as a promising design basis for various electron-beam technological systems including those that are destined for sterilization and decontamination of different products etc.

The design and element basis of the UNINAC is the same as that of the linear induction accelerators (LINACs) [6]. But, in contrast to the LINACs, technological parameters of the UNINAC look much more commercially attractive. The main design peculiarity of the UNINAC is the use of a few parallel linear accelerative channels (similar to those that are used in the LINACs), which are connected with each other by special turning systems. This means that, in general, UNINAC can be classified as multi-channel (and even multi-beam) acceleration system.

General description of the undulative induction accelerator

The results of relevant comparative analysis of the modern world market of technological accelerators [7; 8] can be presented in fig. 1 (item *1*). At the same time, many commercial applications [8] require more powerful (with respect to the averaged power) sources of charged particle beams. Totality of such accelerators is illustrated in fig. 1 by item *2*.

In this connection the question arises: how to solve this problem? As it is shown in this paper, it could be achieved by means of using the UNINAC technology.

The mentioned above comparative analysis shows also the most promising commercial applications of high power electronic accelerators of the UNINAC type:

– sterilization and purification of large volumes of natural and waste water;
– processing of polymer materials;
– recycling of used rubber, including car tires;
– cleaning of industrial gases, smokes, and other gas-like wastes;
– food sterilization and pasteurization;
– decontamination of agriculture products;
– sterilization of medical materials, preparations and instrumentation.

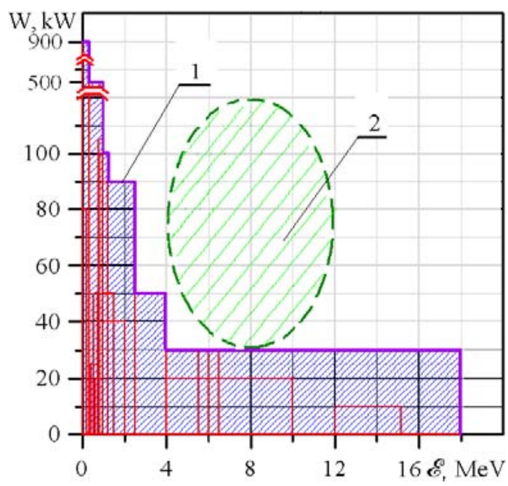


Fig. 1. The illustration for prospective area of averaged power and energy of beam for commercial electron accelerators:
1 – illustrates the area of parameters that are typical for widespread commercial accelerators today; *2* – corresponds to the analogous area, which characterizes technological possibilities of the UNINAC

The structure scheme of a simplest version of the discussed UNINAC is shown in fig. 2.

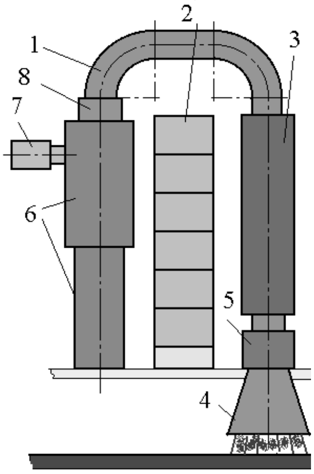


Fig. 2. General design arrangement of the considered two-channel one-beam UNINAC:
1 – the solenoids for E-beam transportation (including sections of the turning system); *2* – the pulsed power supply blocks; *3* – the acceleration section; *4* – the funnel-open sharpening for the electron beam; *5* – the output system (including the magnetic system for beam expansion); *6* – the sections of the electron injection; *7* – the vacuum pump; *8* – the forming solenoid

Project parameters of the considered UNINAC are provided in tab. 1.

Table 1

Project parameters of the considered UNINAC

Parameter	Value
Beam current (peak), kA	1,0
Output beam energy, MeV	5,0
Total voltage of Injector (peak), kV	600
Diameter of beam, mm	80
Axial electric field, kV/m	1000
Pulse duration, ns	100
Inductor's primary voltage, kV	25
Magn. core diameters (int./ext.), mm	150 / 280
Inductors efficiency	0,44
Vacuum system productivity, liter/s	350
Total mass of magnetic cores per section for 100 kV, kg	57,4
Field of the focusing solenoid, T	0,09
A number of turning solenoids	2
Magnetic induction swing, T	1,5
Rate of remagnetization, T/ms	15
Power of beam (average), kW	50
Diameter of vacuum channel, mm	90
Number of acceleration sections	5
Number of cores per section	8
Material of magnetic cores	MetGlas 2605 CO

The general view of system for purification of waste and natural water, constructed on the basis of this UNINAC is shown in fig. 3.

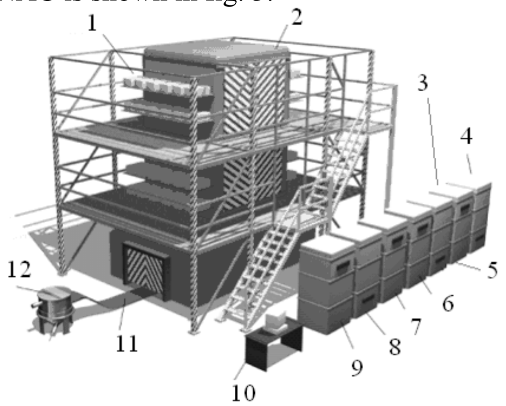


Fig. 3. General design arrangement of the UNINAC-system for water purification (50kW averaged power, 5MeV beam energy):
1 – pulse power supply block; *2* – radiation protection; *3* – water cooling; *4* – gas cooling; *5* – thyratrons power supply; *6* – charging unit; *7* – relay block of control system; *8* – power supply unit for focusing solenoid; *9* – auxiliary electronics and current sources block; *10* – working place for the operator; *11* – gutter; *12* – tank with the waste water

In general, the accelerator is rather a complex electrical engineering system, which consists of a number of design elements and blocks. Let's discuss some key elements and blocks of the proposed UNINAC.

The injectors block

The standard injector design is used that is traditional for the LINAC [6]. The structure scheme of injector is shown in fig. 4.

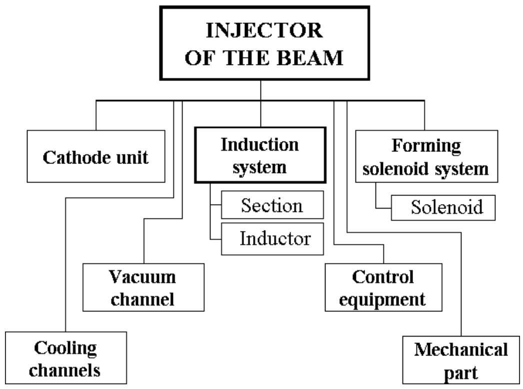


Fig. 4. The structure of the injector block

The sketch of this system is illustrated in fig. 5, 6.
The parameters of the proposed injector block are given in tab. 2. The acceleration section consists of four induction blocks, each of them is accomplished in the form of induction LINAC-block. The structure of the acceleration section is shown in fig. 7.
This block consists of several subsections. A general view of a single subsection is presented in fig. 8.

Table 2

Parameters of the injector

Parameter	Value
Current intensity in the bunch, A	1000
Frequency of bunch repetition, Hz	100
Perveance of bunch, $A \cdot V^{-3/2}$	$1,2 \cdot 10^{-5}$
Gun power, kW	~5
Diameter of bunch in the channel, cm	8

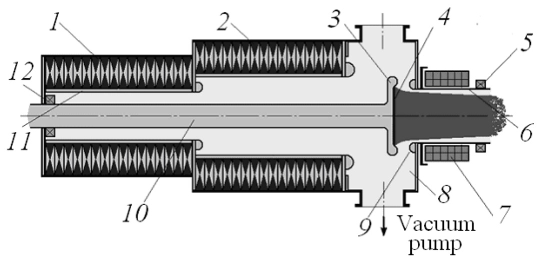


Fig. 5. The draft of the injector block:
1, *2* – pulsed transformer; *3* – cathode unit; *4* – cathode; *5* – beam solution sensor; *6* – beam pipeline; *7* – forming solenoid; *8* – vacuum chamber; *9* – anode; *10* – cathode stem; *11* – insulation tubes; *12* – pulsed current sensor

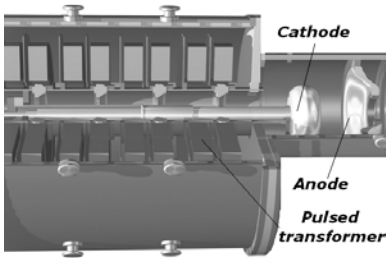


Fig. 6. The general view of the injector block fragment

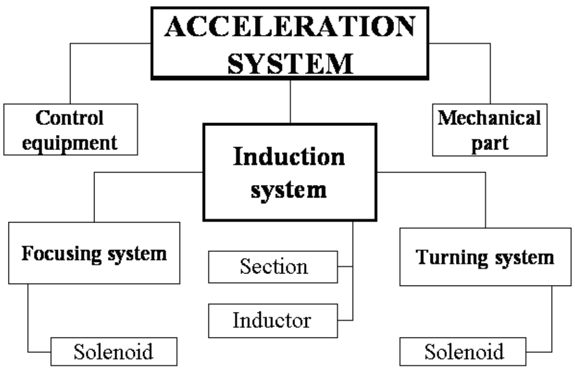


Fig. 7. Structure of the acceleration section

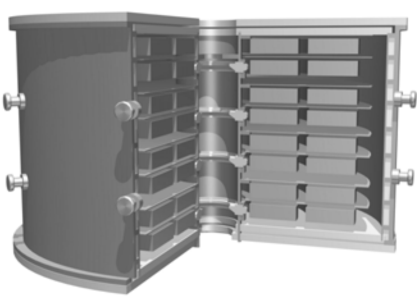


Fig. 8. The general view of induction block section

Its design parameters are given in tab. 3.

Table 3

Parameters of the induction block and the output parameters of the feeding system

Parameter	Value
Total number of inductors	200
Magnetic induction swing, T	1,5
Bunch duration nc	100
Rate of remagnetization, T/μs	15
Number of work channels	2

The control of the beam position and characteristics is provided for all stages of the acceleration process. Therein, the average synchrotron radiation power is remarkable enough ($W_{rad} \sim 0,2$ W). It is proposed to use information about this radiation (spectral and angular distribution of power) for the diagnostics of the electron beam parameters, especially within the turning system.

The feeding system

Technological conditions of the UNINAC use imply high stability of the electron beam power from one pulse to another. Numerical estimations show that the requirements for the non-stability of the charging voltage should not be higher than 1–2 % in our case. Taking this into account, the feeding system is constructed on the basis of double forming lines. The structure of the feeding system is shown in fig. 9.

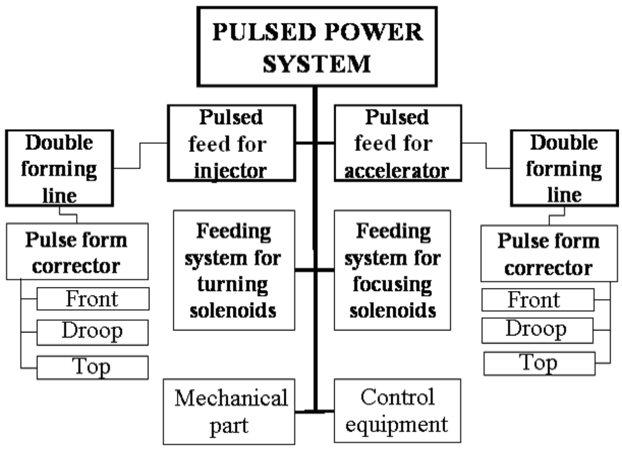


Fig. 9. Structure of the feeding system

Its principal electric scheme is shown in fig. 10.

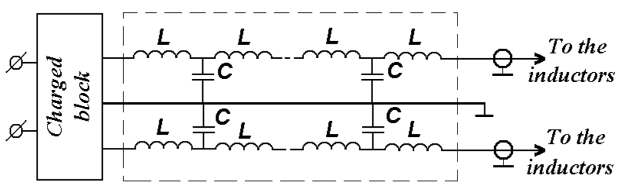


Fig. 10. Principal scheme of the feeding system

Parameters of the discussed scheme are shown in tab. 4.

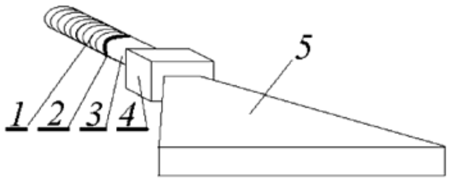
Table 4

Parameters of the feeding system

Parameter	Value
Input voltage, V	380
Output voltage, kV	25
Charging period of time, ms	2
Pulse duration, ns	100
Pulse repetition rate, Hz	125
Non-stability of the output voltage, %	1
Mean power, kW	15
Mass, kg	80

Output system for the electron beam

The drawing of the output system is provided in fig. 11.



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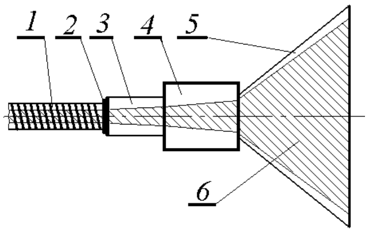


b

Fig. 11. The output system for the electron beam:
a – isometric view; *b* – view from above:
1 – the output part of acceleration channel; *2* – the connector assembly; *3* – the input vacuum assembly of the output system; *4* – the quadruple magnetic lenses; *5* – trapeziform vacuum chamber; *6* – the electron beam in the output

The system includes the quadruple magnetic lenses and trapeziform vacuum chamber as the main design elements. The magnetic field distribution within the quadruple systems in the output systems is shown in fig. 12.

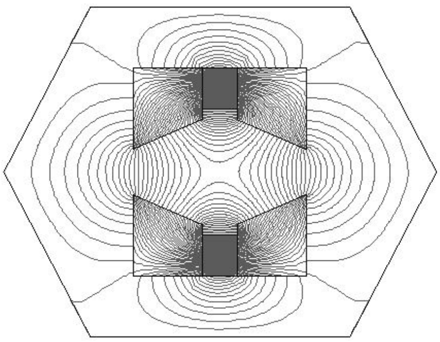
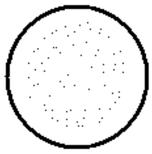


Fig. 12. Magnetic field distribution within the quadruple system in the output system

Some results of the computer modeling electron beam behavior within the output system are illustrated in fig. 13.



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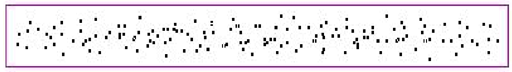

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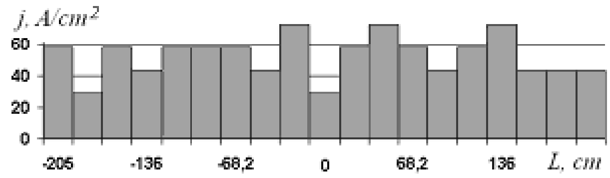

c

Fig. 13. Beam current distribution in the input (*a*) and the output (*b*) of the output system and bar chart of the electron beam density in the output of output system (*c*)

Prospects of further modernization and development of the UNINAC technology

Our nearest purpose for the next design of UNINAC is reduction of general power losses while increasing the useful output power at the same time. We plan to attain this due to further optimization of the electrical and design parameters including:

– increasing efficiency sufficiently due to the reduction of strength of the longitudinal electrical field and the choice of core material with smaller local losses (for instance, METGLAS 2705 M);

– increasing the pulse duration from 0,1 μs to ~ 0,3 μs leads to the smaller rate of remagnetization d*B*/d*t*; in turn, it leads to reduction of the local energy losses in the core material, and, as a result, to growth of the efficiency;

– use the of the multi-channel scheme allows to work with the weaker longitudinal electric field and, at the same time, to keep high efficiency and relatively small characteristic sizes of the accelerator.

The project characteristics of the system for sterilization and purification of wastewater based on the UNINAC

The system for purification of wastewater is chosen as an illustration example of potential properties of the proposed UNINAC. The system consists of two subsystems: mechanical water purification (the first subsystem) and the subsystem for radiation purification (the second subsystem). If necessary, the system may contain three subsystems (plus the subsystem for biological purification) that depends on specific requirements to the output water quality.

The first and last subsystems are described in detail in the well-known special literature. Therefore, we will focus on the second sub-system only. It is cleared that the water output parameters after purification and disinfecting, which are given in tab. 5, could be really attained.

Table 5

Water quality after purification and disinfection in the proposed system

Parameter	Water after the mechanical purification	Water after purification and disinfection by the radiation method
Oxidation, mg/l	200,4	24,4
Weighed obj., mg/	0,047	0,03
CDO, mg O_2/l	800	40
NO^{-2} mg/l	3	4
NO^{-3}, mg/l	2,2	1
NH_3, mg/l	20	0,8
General Nitrogen, mg/l	23,2	7,7
PH	7,5	7,05
Transparency, cm	3,5	30
SO_4^{2-}, mg/l	842	111
Cl, mg/l	174,83	28,01
BDO, O_2/l	96	8
Microbes number	1,1 million on ml	4 on ml

Therein, the first column shows parameters of the water, which is entered into the system for radiation purification and disinfection after the mechanical and biological purification. The project parameters of the proposed system seem to be close to the well-known analogous systems. However, the proposed variant looks more attractive for practice owing to a number of its advantages. Including, relatively small total system sizes (i.e., the system could be relatively compact), relatively low working voltage (25 kV on the inductor, in comparison with ~5 MV in the equivalent electrostatic systems of the same class). It should also be added that the undulative induction accelerator is characterized by the low level of the external electrical fields (i.e. it possesses good electromagnetic compatibility) without decreasing the intensity within the acceleration channels. All this makes the proposed project very promising for practical realization.

Conclusion

As shown in this paper, the sterilization and purification systems on the basis of presented undulative induction electron accelerator are very interesting for commercial use in the civil industry.

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Технологічні ондуляторні індукційні прискорювачі для комерційного застосування

Подано результати проектування ондуляторного індукційного електронного прискорювача. Показано можливість створення високоефективних, компактних систем комерційного призначення, у т.ч. для знезараження стічних і природних вод на базі даного класу прискорювачів. Проведено проектний аналіз основних блоків запропонованого прискорювача та наведено загальні параметри цих блоків.

В.В. Кулиш, В.Т. Чемерис, И.В. Губанов, В.Н. Крыжановский

Технологические ондуляторные индукционные ускорители для коммерческого использования

Представлены результаты проектирования ондуляторного индукционного электронного ускорителя. Показана возможность создания высокоэффективных, компактных систем коммерческого назначения, в т.ч. для обеззараживания сточных и природных вод на базе ускорителей данного класса. Проведен проектный анализ основных блоков предлагаемого ускорителя и приведены общие параметры этих блоков.