TO THE POSSIBILITY OF LIQUID DIELECTRICS USE IN WAKEFIELD METHOD OF CHARGED PARTICLE ACCELERATION

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Possibility of use of liquid dielectrics for dielectric loaded structures for wakefield acceleration of the charged particles is investigated. Application of liquid dielectric, at its circulation through structure, allows avoiding charge accumulation in volume of dielectric, heating of dielectric, loss of properties under the influence of ionizing radiation, characteristic for firm dielectrics. At change of temperature of liquid dielectric or mixing of liquid dielectrics with various value of dielectric permeability adjustment of dielectric permeability and working frequency of structure is easily feasible.

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INTRODUCTION

The idea of use of the dielectric loaded structures for transformation of energy of an electronic bunch to electromagnetic radiation was put forward in 1947 [1].

To advantages of dielectric structures necessary to refer the maximum simplicity of their production and high electric durability that is especially important at development of short-wave area of lengths of waves. The dielectric wave guide has no strips of blackness and at small values of dielectric permeability can provide quite weak dispersion of electromagnetic waves in the wide frequency range in the field of relativistic phase speeds [2].

Now is the object of intensive experimental and theoretical study a new method of wakefield acceleration of the charged particles, using wakefields generated by the short high charge electron bunches passing through dielectric loaded accelerating structure [3, 4]. Commonly a dielectric loaded accelerating structure (DLA) is the single-layered dielectric tube with an inner vacuum channel for the passing electron beams. A dielectric cylinder is inserted into a conductive copper jacket.

Wakefield acceleration assumes the energy transfer from a high-current low-energy electron beam (driver) to a low-current high-energy accelerating beam of charged particles (witness). While passing the waveguide the driver beam generates Cherenkov electromagnetic waves (wakefields) with the longitudinal fields up to 100 MV magnitudes to be used for the witness beam acceleration.

As dielectric new types of ceramics on the basis of $Mg_xCa_{1-x}TiO_3$ (MCT ceramics), oxides of aluminum (alumina 96S), and also structure from cordierite, quartz, diamond, and others were used, but the shortcomings applied dielectrics were the reason of it, main from which are: charge accumulation, loss of properties under the influence of ionizing radiation and a dielectric overheat [5].

We propose to apply in DLA liquid dielectric that gives the chance, thanks to a channel and updating of liquid dielectric considerably to eliminate charge accumulation, loss of properties under the influence of ionizing radiation and its overheat.

1. DESIGN OF THE DLA WITH LIQUID DIELECTRIC

In Fig. 1 the scheme of flowing DLA with liquid dielectric is submitted. In a metal waveguide (1) the glass tube with lateral walls (2) is pasted. Between a glass tube and a waveguide there is a liquid dielectric which can be pumped over via the heat exchanger (3) by means of the pump (4)

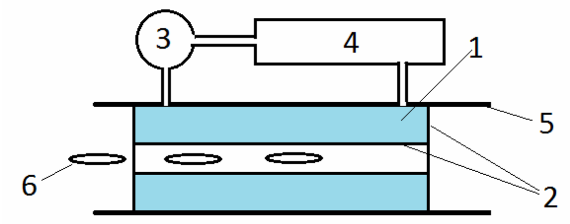

Fig. 1. Scheme of flowing dielectric structure:
1 – liquid dielectric; 2 – glass tube; 3 – heat exchanger;
4 – water pump; 5 – copper waveguide;
6 – electrons bunches

As liquid dielectric we applied the condenser oil having a smaller of dielectric losses factor (tan δ) in comparison with transformer oil. Condenser oil filled space between a copper waveguide and a glass tube.

Internal diameter of a waveguide – 8.6 cm. Diameter of the channel on an axis of structure of 2.2 cm, structure length – 23 cm. Thickness of a glass tube – 2 mm. Thanks to small glass thickness and contact with liquid dielectric, in glass there is no considerable accumulation of a charge and its temperature is equal to temperature of liquid dielectric.

Now various grades of glass with an electric durability up to 700 kV/cm, with dielectric permeability ε from 3 to 12 and high radiation stability [6] Therefore the glass tube practically doesn't worsen structure parameters are issued.

2. A TUNABLE DLA STRUCTURE WITH CONDENSER OIL

The need for frequency tuning of any accelerating structure arises from the fact that the frequency of the assembled accelerating structure will, in general, differ from the design due to various sources of error.

Volume of the dielectric material inside the metal waveguide and its dielectric constant determine the dispersion relation of the accelerating mode. Frequency errors in a DLA structure are dominantly caused by machining tolerance of the dielectric dimensions and dielectric constant heterogeneity.

Earlier in [7] it was offered to carry out fine tuning of dielectric permeability of firm dielectrics, a way change of temperature of dielectric, but uniform on volume change of temperature of firm dielectric a complex challenge, besides such changes are quite inertial. Much more simply, in our opinion to change and maintain stable temperature of liquid dielectric when using the scheme shown in Fig. 1.

Dielectric permeability of condenser oil was determined at full filling with oil of section of a rectangular waveguide by two values of lengths of waves in a waveguide: without dielectric and with dielectric [8]. At value of magnetic permeability μ = 1 length of a wave in the wave guide which has been completely filled with dielectric - λd is defined from:

$$\lambda_d = \lambda_0 / \left(\varepsilon - \frac{\lambda_0^2}{\lambda_c^2}\right)^{-\frac{1}{2}} \quad (1)$$

Where λ_0 – wave length in free space, λ_c – the critical length of a wave.

From here dielectric permeability is equal:

$$\varepsilon = \frac{\lambda_0^2(\lambda_c^2 + \lambda_d^2)}{\lambda_c^2 \lambda_d^2} \quad (2)$$

The measuring line with a waveguide 23·10 mm^2, raised on a wave of the H_{10} type with a critical length of a wave λ_c = 4.6 cm was used. Wave length without oil was equal in the short-circuited measuring line λ_w = 6.4 cm, (that corresponds to wave length in free space λ_0 = 3.74 cm), and when filling line with condenser oil it decreased to λ_d=3.065 cm (at a temperature of 20°C). Counted from (2) value of dielectric permeability makes ε = 2.15.

For research of dependence of dielectric permeability of condenser oil from temperature values of its dielectric permeability were measured in range of temperatures of 10…60°C.

Results of measurements are presented in Fig. 2.

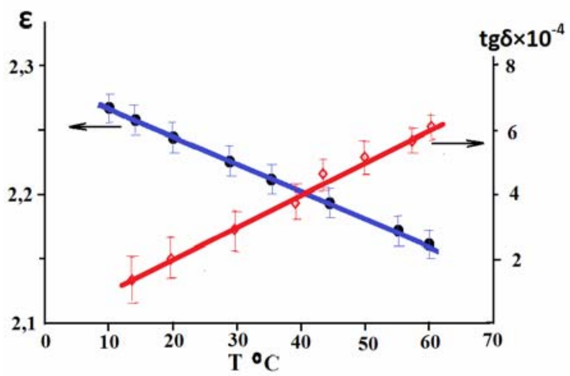

Fig. 2. Dependence of dielectric permeability and tangent of angle of losses of condenser oil from temperature

In the same drawing dependence of dielectric losses factor of condenser oil on temperature is presented. The dielectric losses factor was defined from a ratio [8]:

$$tg\delta = 2E_{min}/\pi E_{max}. \quad (3)$$

E_{min}, E_{max} value of intensity of fields in the minimum and maximum amplitude standing wave in measuring line.

Linear change of dielectric permeability of condenser oil from temperature does possible to carry out simple and fast frequency trim of DLA. For our DLA $\Delta f/\Delta T \approx 2$ MHz/°C.

Application of liquid dielectrics also allows carrying out smooth change of dielectric permeability in wide range when mixing liquid dielectrics with various value ε. In Fig. 3 dependence of dielectric permeability of a mix of condenser and castor oils is presented at the various contents castor oil in mix.

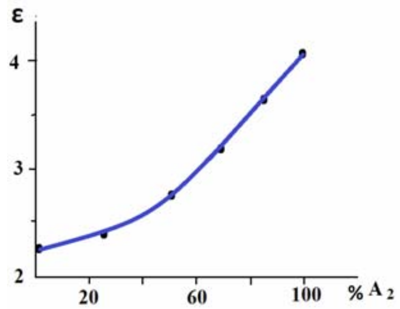

Fig. 3. Dependence of dielectric permeability of a mix of condenser and castor oil on the content of castor oil in a mix

In case of application of a mix of liquid dielectrics the scheme of a supply of dielectric structure becomes complicated, but there is an opportunity considerable (several times) changes of dielectric constant and working frequency of DLA

3. EXPERIMENT

Experimental researches on excitation of wakefields by sequence of clots of relativistic electrons in slowing-down structure with liquid dielectric were carried out.

Along a structure axis with liquid dielectric the sequence from 6000 bunches of relativistic electrons, created by means of the linear resonant accelerator was injected. Energy of electrons – 4.5 MeV, a charge of each bunch – 0.16 nC, the frequency of following of bunches – 2805 MHz.

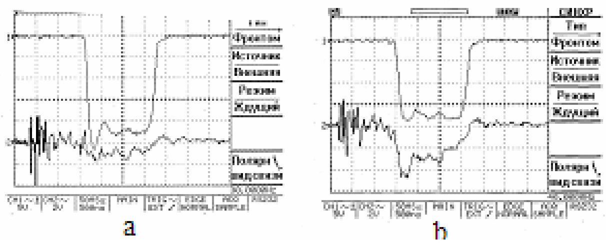

Fig. 4. Oscillograms of Ez of a component of a raised wakefields (above) a) DLA with the fluoroplastic; b) with DLA with liquid dielectric. On the bottom oscillograms the current of electrons getting on walls of a waveguide is shown

In Fig. 4 (the top oscillograms) E_z values of a component of the raised wakefields registered by the microwave oven by a probe which settled down at an output end of a waveguide at dielectric application from fluoroplastic (see Fig. 4,a) and with condenser oil (see Fig. 4,b) are presented.

On the bottom oscillograms the current of electrons getting on walls of a waveguide is shown.

In DLA with liquid dielectric amplitude of a longitudinal component of a wakefields is close to field amplitude in DLA from fluoroplastic.

The increase in current at a waveguide in a case with liquid dielectric is caused by increase of size of a cross component of a wakefield, but if in case of structure with fluoroplastic these electrons collect in volume of dielectric, at application of liquid dielectric the charge flows down on a copper waveguide of Fig. 4 (the bottom oscillogram).

CONCLUSIONS

Application of liquid dielectric in DLA thanks to its channel and hashing allows to avoid charge accumulation in volume of dielectric, heating of dielectric, loss of properties under the influence of ionizing radiation, characteristic for firm dielectrics. There is a possibility of expeditious control of working frequency of DLA at change of temperature of liquid dielectric or mixing of liquid dielectrics with various value of dielectric permeability.

Big prospect for application in DLA structures have, fluororganic liquids, for example fluororganic liquids C_8F_{16} with dielectric permeability $\varepsilon = 2$, tg $\delta < 10^{-4}$, $\rho > (10^{12}...10^{15})$ Ohm·m and with the electric durability of 500 kV/cm. Fluororganic liquids it isn't combustible, aren't toxic and don't mix up with water [9].

Application of liquid dielectrics will allow to expand considerably DLA use for wakefield acceleration and allows avoiding charge accumulation in volume of dielectric, heating of dielectric, loss of properties under the influence of ionizing radiation.

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О ВОЗМОЖНОСТИ ПРИМЕНЕНИЯ ЖИДКИХ ДИЭЛЕКТРИКОВ В КИЛЬВАТЕРНОМ МЕТОДЕ УСКОРЕНИЯ ЗАРЯЖЕННЫХ ЧАСТИЦ

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Исследуется возможность использования жидких диэлектриков в замедляющих структурах для кильватерного ускорения заряженных частиц. Применение жидкого диэлектрика, при его циркуляции через структуру, позволяет избежать накопления заряда в объеме диэлектрика, нагрева диэлектрика, потери свойств под воздействием ионизирующего излучения, характерных для твердых диэлектриков. При изменении температуры жидкого диэлектрика или смешивании жидких диэлектриков с различным значением диэлектрической проницаемости легко осуществима регулировка диэлектрической проницаемости и рабочей частоты структуры.

ПРО МОЖЛИВІСТЬ ЗАСТОСУВАННЯ РІДКИХ ДІЕЛЕКТРИКІВ ДЛЯ КІЛЬВАТЕРНОГО ПРИСКОРЕННЯ ЗАРЯДЖЕНИХ ЧАСТИНОК

В.О. Кисельов, А.Ф. Лінник, І.М. Оніщенко, В.І. Приступа

Досліджується можливість використання рідких діелектриків у сповільнюваних структурах для кільватерного прискорення заряджених часток. Застосування рідкого діелектрика, при його циркуляції через структуру, дозволяє уникнути нагромадження заряду в об'ємі діелектрика, нагрівання діелектрика та втрати властивостей під впливом іонізуючого випромінювання, характерних для твердих діелектриків. При зміні температури рідкого діелектрика або змішуванні рідких діелектриків з різним значенням діелектричної проникності легко здійснити регулювання діелектричної проникності та робочої частоти структури.