Nanosecond Pulse Generator Based on Comber-Type Coaxial Line with Built-in Charging Transformer

F.Ya. Zagulov, V.V. Kladukhin, S.V. Kladukhin, S.P. Khramtsov, and V.Y. Yalov

Institute of Electrophysics, UDC RAS, 106, Amundsen srt., Ekaterinburg, 620016, Russia
E-mail: laepr@iep.uran.ru

Abstract – The implementation of nanosecond generator based on a section of comber-type coaxial line charged by built-in transformer is considered. This approach can be used for reducing size of pulse generator. The experimental results are reported of the highcurrent highvoltage nanosecond pulses forming.

1. Introduction

Sections of conventional coaxial lines are widely used to form power nanosecond rectangular pulses. Tesla transformers are often used for charging forming lines.

A construction arrangement of generator that combines coaxial forming line with Tesla charging transformer was proposed in [3]. Such solution has two significant advantages: size decreasing and absence of losses caused by energy storage on transformer’s stray capacitances. This solution is widely used in generators of highcurrent nanosecond pulses such as SINUS [4], RADAN [5] etc.

It is a topical problem to combine this scheme with solutions providing the increase of formed pulse duration. The basic method of pulse duration increasing is slowing of wave velocity by using dielectric filled lines with \( \varepsilon > 1 \). Another way to slow down wave velocity is to use spiral or corrugated types of forming line.

Using spiral forming line to decrease generator length was proposed in [6], where spiral line was used for elongation of section of a conventional coaxial line with a built-in charging transformer. Interfering of an axially symmetrical EH-wave propagating in the forming line with highvoltage conical coil of transformer eliminates combining of a charging transformer and spiral line in compliance with design described in [3].

This paper discusses the implementation of nanosecond pulse generator based on corrugated forming line permits combining with charging transformer according to [3].

2. Design of generator

The combination of a transformer with a comb-type forming line based on a lack of interaction between axially symmetrical E waves propagates in this line with the conical secondary circuit coil of a charging transformer and a magnetic cores placed under the magnetotransparent conductors of the forming line. In order to make inner and outer conductors of the forming line transparent for magnetic flux of charging transformer these conductors were made as thin wires separated by dielectric gap.

A design of generator based on comber-type coaxial forming line is shown in Fig. 1.

Fig. 1. The design of generator: 1 – forming line; 2 – inductance coil of charging transformer; 3 – inner and outer magnetic cores of transformer; 4 – double-gap gas switch; 5 – coaxial port; 6 – supporting insulators; 7 – generator body

A nonuniform periodic distribution of electric and magnetic fields when waves propagate in the combertype forming line allows to consider a scheme presented in Fig. 2 as an equivalent scheme of this type of forming lines.

Fig. 2. Equivalent scheme of generator

In this figure: \( C_i – \) section capacitance, \( L_i – \) section inductance, \( C_{ai} – \) intersection capacitance. Since the periodic structure is uniform the following conditions fulfill:

\[
C_{ai} = C_{ai+1} = C_i, \quad i = 1, n-1;
\]

\[
C_i = C_{i+1} = C_j, \quad i = 1, n; \quad (1)
\]

\[
L_i = L_{i+1} = L_j, \quad i = 1, n-1.
\]

3. Forming line

Phase velocity of a sine-wave propagation in periodic structure presented by equivalent scheme in Fig. 2 can be expressed by follow relation:
and dispersion characteristics of periodic structure can be written as:

\[ \lambda = \frac{2 \pi c}{\sin \frac{\phi}{2}} \sqrt{1 + \frac{4 C_2}{C_1}} \sin \frac{\phi}{2}, \]

where \( l \) is the length of one section of structure; \( \lambda \) is the wavelength of sine-wave; \( V_\lambda \) is the phase velocity of sine-wave with wavelength equal to \( \lambda \); \( \phi \) – phase shift of on one section of periodic structure with wavelength equal to \( \lambda \), \( C \) is the velocity of light.

The periodic structure under study is a low-pass filter with a bandwidth determined by a phase shift \( \phi = \pi \), which is matched by cutoff wavelength \( \lambda_{min} = \frac{\pi c}{L C (1 + \frac{4 C_2}{C_1})}. \)

The following variance relation determines a velocity spread influencing on leading and trailing edges of pulse:

\[ \beta = \frac{c}{V_\lambda} = \frac{2 \pi \phi}{4 \pi \sin \frac{\phi}{2}} \sqrt{1 + \frac{4 C_2}{C_1}} \sin \frac{\phi}{2}. \]

A pulse duration is determined by group velocity corresponds to velocity of propagation of pulse wave spectrum major part

\[ \tau_{pulse} = \frac{2Z}{V_G}, \]

\[ V_G = \frac{V_\lambda}{1 + \frac{\lambda}{V_\lambda} \frac{dV_\lambda}{d\lambda}}. \]

The generator implementation uses a forming line with a length \( Z \approx 1200 \text{ mm} \) with the following parameters: \( C_s = C_l \approx 10 \text{ pF} \), \( L_l \approx 10 \text{ nH} \), \( l \approx 60 \text{ mm} \).

Simulated dispersion characteristic for this forming line is shown in Fig. 3. Only waves fulfill to condition \( \lambda > \lambda_{min} \approx 68 \text{ cm} \) can propagate in this forming line, and waves with wavelength greater then \( 2\lambda_{min} \) has a slight phase velocity spread. In the forming line under discharge the following formula can be used to determine group velocity

\[ V_G = V_{\lambda_{min}} = \frac{\pi}{\phi_{\lambda_{min}}} l c = 0.55 c. \]

According to this formula if \( Z = 200 \text{ mm} \), then

\[ \tau_{pulse} = 2Z/V_G = 16 \text{ ns}. \]

The results of the simulation of the output pulse shape and amplitude for two different load (1) \( R_{load} = 35 \Omega \) and (2) \( R_{load} = 45 \Omega \) are shown in Fig. 4, where \( U_{FL} \) – charging voltage of forming line.

4. Charging transformer

A uniformity of charge of \( C_l \) is provided by relation:

\[ L_2 > \sum_{i=1}^{n} L_i \text{ & } L_2 \gg L_i. \]

Result from this that

\[ \left( L_1 - M \frac{L_2}{L_i} \right) \gg \sum_{i=1}^{n} L_i. \]

Duration of charging process that conforms to achieve of the first maximum of voltage on the forming line, can be calculated using the following formula:

\[ T_{ch} = \pi L_1 (1 - k) \frac{C_1 C_2}{C_1 + C_2}. \]

Dynamic behavior and efficiency of forming line charging process are determined by four parameters:

\[ Q_1 = \frac{1}{R_1} \sqrt{\frac{L_1}{C_1}}, \quad Q_2 = \frac{1}{R_2} \sqrt{\frac{L_2}{C_2}}, \quad k = \frac{M}{\sqrt{L_1 L_2}}, \quad \alpha = \frac{L_2 C_1}{L_1 C_2}. \]

where

\[ C_2 = \sum_{i=1}^{n} C_i, \]

\[ Q_j \] is the quality factor of primary circuit of transformer; \( Q_j \) is the quality factor of primary circuit of transformer; \( k \) is the coupling coefficient of circuits; \( \alpha \) is the mismatch of circuits natural frequencies.

The generator implementation uses Tesla transformer with the following characteristic parameters: \( Q_1 = 17, Q_2 = 18, k = 0.95, \alpha = 1 \). These parameters are conformed to the efficiency of energy transfer from primary circuit capacitance to the FL capacitance

\[ \eta = \frac{C_i u_2^2 (U_{ch})}{C_2 u_2^2 (0)} = 60\%. \]
5. Experimental results

The FL charging process parameters were measured by means of capacitive divider allocated on an outer conductor of FL. The oscillogram in Fig. 5 shows changing of voltage on FL during charge and discharge after closing the switch. Apparently, charge time is about 23 μs. The efficiency of energy transfer from the capacitors to primary circuit of charging transformer ($C_1$) to capacitance of FL

$$C_2 = \sum_{i=1}^{n} C_{n}$$

is $\eta = 60\%$.

![Fig. 5. The voltage on the forming line](image)

6. Conclusion

Use of the comber-type coaxial lines is a way to decrease linear size of power rectangular pulse generators. Combination of charging transformer with forming line enables decreasing of weight and size of generators and helps to avoid energy losses related with charge of stray capacitances of highvoltage circuits. Use of comber-type forming lines with widely used oil insulation (with $\varepsilon \approx 2.3$) makes it possible to achieve velocity factor $\beta \approx 4$ at insignificant worsening of pulse shape.

A good agreement of simulation and experimental results proves the validity of use of generator equivalent scheme.

References