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A.G. Lee, R.A. Lokhtin, E.M. Mandrik,
A.S. Medvedko, V.V. Rashenko, E.P. Semenov,
Yu.F. Tokarev

PULSE MODULATOR

FOR A DIAGNOSTIC INJECTOR

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Pulse modulator for a diagnostic injector

A.G. Lee, R.A. Lokhtin, E.M. Mandrik, A.S. Medvedko,
V.V. Rashenko, E.P. Semenov, Yu.F. Tokarev

Институт Ядерной Физики им. Г. И. Будкера
630090 Новосибирск, Россия

Abstract

The Modulator proposed was designed as a high voltage pulse power source for an injector on the basis of an arc plasma emitter [1]. Output pulse voltage of the Modulator is up to 55 kV; output current is up to 2.5 Amps. Pulse flat top voltage stability is not worse than ± 0.5%. Rise and fall time of the pulse voltage does not exceed 10 μs. Maximal pulse duration is 2 sec, pulse repetition rate is not less than 300 sec. Atmospheric air media is applied as basic insulation in this modulator. The Modulator also provides supply voltage for the second grid of the injector. For half a year the Modulator has been used as testing facility for injectors created at BINP SB RAS.

Аннотация

Предлагаемый Модулятор был разработан в качестве импульсного высоковольтного источника питания для инжектора на основе дугового плазменного эмиттера. Напряжение выходных импульсов Модулятора до 55 кВ, выходной ток до 2.5 А. Стабильность напряжения на плоской вершине импульса не хуже ± 0.5%, длительность фронта нарастания и спада импульса напряжения до 10 мкс. Максимальная длительность импульса до 2 сек., период повторения импульсов более 300 сек. В качестве высоковольтной изоляции в Модуляторе используется атмосферный воздух. Дополнительно Модулятор обеспечивает питающим напряжением управляющую сетку инжектора. В течение полугода Модулятор использовался в качестве тестового оборудования при испытаниях инжекторов, создаваемых в ИЯФ СО РАН.

1. Introduction

The diagnostic injector must be capable to inject a beam of neutral hydrogen of 50 kV energy necessary for investigations on plasma physics field. The HV Pulse Modulator is designed for powering the diagnostic injector grids. The Modulator shall meet a range of rigid requirements to the output pulse shape, operation reliability at electrical breakdowns in the load and also fire security and ecological purity of applied materials. Application of an advanced conception based on a Current loop circuit in the design of the high voltage Modulator and using high power IGBT modules made it possible to construct a modulator with the required properties.

2. HV Modulator

Main parameters of the high voltage Modulator for an Injector based on quasi stationary arc plasma emitter are presented in Table 1. The injector is intended for generation hydrogen beam of about 2 Amps current in ions.

Table 1. Electrical parameters of the Modulator

Parameter	Unit	Designed value	Attained value
Output pulse voltage	kV	Up to 55	55
Output voltage flat top stability	%	± 0.5	± 0.5
Output current	A	Up to 2.5	2.5
Voltage pulse duration or output pulse series duration	sec	0.0005 to 2	0.0005 to 2
Pulse repetition rate	sec	≥300	≥300
Pulse rise and fall time from $U=0.01\times U_{Max}$ to $U=0.99\times U_{Max}$	μs	Up to 50	up to 10*
Pause duration between pulses in series	μs	≥500	≥500

The parameter marked with «*» in the table is presented for a case when the total capacitance of the loads (supplying cables) of the Modulator does not exceed 5ηF.

The Modulator described can also generate a series of pulses with the characteristics presented in the Table. There is also an additional power output in the Modulator to supply the second grid of the injector.

The simplified basic diagram of the Modulator is presented on Fig.1. It consists of a number of sections shown on the figure. Each section is powered from a current type supply source through a current loop shown on the left part of the figure. The circuit on the comparator K and the switch VT holds voltage across the capacitor C at a necessary level. When the voltage exceeds a set threshold, the switch VT turns on and stops the capacitor C to be charged by shunting the windings of the transformer T.

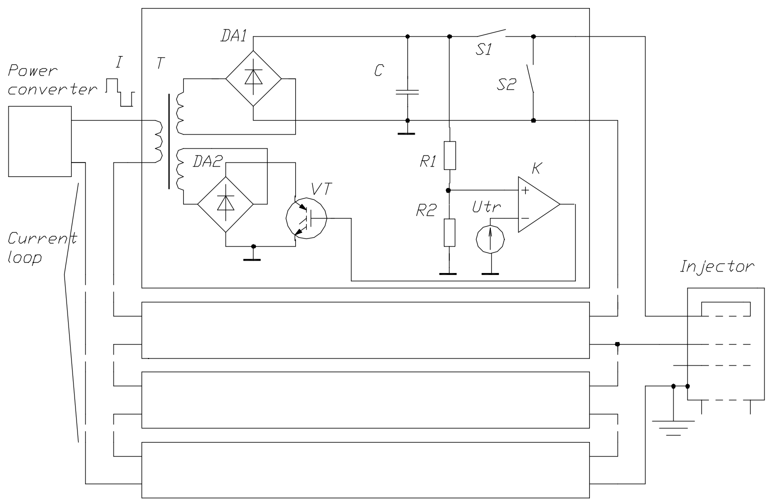


Fig.1. The simplified diagram of the Modulator.

When the Modulator is generating an output high voltage pulse the switch S1 of each section turns on and the switch S2 turns off, the capacitors C of all the sections appear to be connected in series, and their summary voltage is applied to the load. For output current to be as high as required, the powering source current must be not lower than the last one referred to the secondary winding of the step up transformers T. The primary one turn windings of the transformers in all the sections are connected in series forming so called Current loop that is fed from one Power converter. The Power converter generates AC current of a constant value. It will be presented later.

The presented Modulator's circuit differs from known ones by holding the filter capacitors voltage near the necessary level during the whole output pulse. This allows generating high voltage pulses of any duration.

The output pulse rise and fall times of the Modulator are only determined by electrical characteristics of the switches used in the sections, pulse flat top voltage stability is determined by the value of filter capacitance and switching frequency of the switch VT.

The Modulator includes two structural elements such as Sectioned rectifier and Power inverter.

The Sectioned rectifier generates two necessary output voltages powering the first and the second grids of the injector. The Power inverter provides the Current loop of the Sectioned rectifier with AC current. The inverter is a square shape current source of 25 kHz frequency and magnitude up to 600 Amps. The shape of current curve is shown on Fig.6.

3. Controllable sectioned rectifier

To construct the sectioned rectifier we used the circuit proposed in [2], on the base of a Current loop. A schematic layout of the sectioned rectifier is presented on Fig.2.

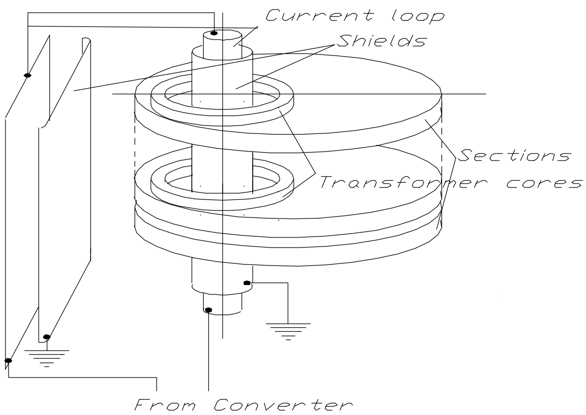


Fig.2. Schematic layout of the Controllable sectioned rectifier.

It is shown that each section includes a power step–up transformer on a ring core. The primary winding of this transformer is formed by one turn of the Current loop supplied from the Power inverter. The loop passes through the cores of all the transformers of the sections. Insulating air gap between the current loop and the sections was designed to operate under the full voltage generated by the Modulator. The conductor of the current loop and contents of the section are hidden from the air gap with smooth protecting shields, shown on the figure.

The more detailed electrical circuit of the Sectioned rectifier is presented on Fig.3. The rectifier consists of 22 sections. Each section generates power of 2.5 kV and up to 2.5 Amps. Outputs of the sections are connected in series. The number of operating sections determines the value of the total output voltage. Each section can be driven to operation through a flexible optical cable.

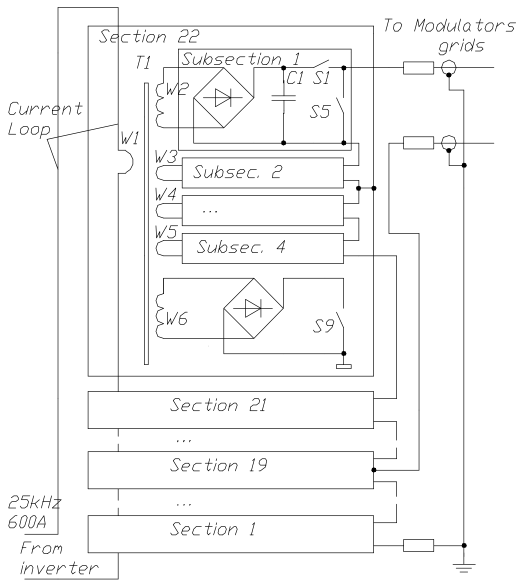


Fig.3. Layout of the Controllable sectioned rectifier.

For smooth regulation of the voltage fed to the injector grids, the 22nd and 15th sections have an option of smooth regulation their output voltage from 125V up to 2.5 kV. Level of generated voltage is set by DAC PWM signals, transmitted through additional optical cables.

Fig.3 presents one of the sections in more details. It is shown that each section consist of four subsections. The power transformer in the section has five identical secondary windings. Four of them serve for charging the four filter capacitors C1..C4 of the subsections,. The fifth winding jointly with the switch S_9 serve for stabilization their summary voltage. It is stabilized through all the time of HV pulse duration.

The stabilization process is synchronized with the AC frequency of the Current loop.

When the voltage of each section reaches the required value, the rectifier becomes ready to generate its output pulse. As initial charging process takes some time, the Power inverter starts its operation some tens milliseconds before the HV pulse starts running.

For the section to generate its output voltage, it is necessary to turn off the switches $S_5 \div S_8$ and turn on the switches $S_1 \div S_4$. As the switches, IGBT transistors BSM50GB120DN2 of SIEMENS are used.

In order to extend rise and fall time of the output pulse and make it acceptable for the injector, we made the following. Reduced driving voltage is applied to the gates of the IGBTs switching the capacitors in the sections to make the IGBTs operate as current sources that would lead to extension of the pulse edges.

4. The high frequency converter

A simplified layout of the Power converter is presented on Fig.4. The converter is constructed on the base of IGBT modules BSM400GA120DN2 of SIEMENS. The converter consists of a supply line rectifier, a filter capacitor, two current regulators coupled in parallel and a bridge converter. The current regulators are composed of IGBTs VT1, VT2 and chokes L1 and L2. Each regulator generates current of up to 300 Amps. The resistors R1 and R2 are used for measuring and stabilization their current. The summary current of both regulators is inverted into AC by the bridge converter composed of IGBTs VT3 + VT10. It is shown that each switch of the bridge consists of two IGBT modules connected in parallel.

The operating frequency of the IGBTs is 12.5 kHz for the current regulators and 25 kHz for the bridge converter.

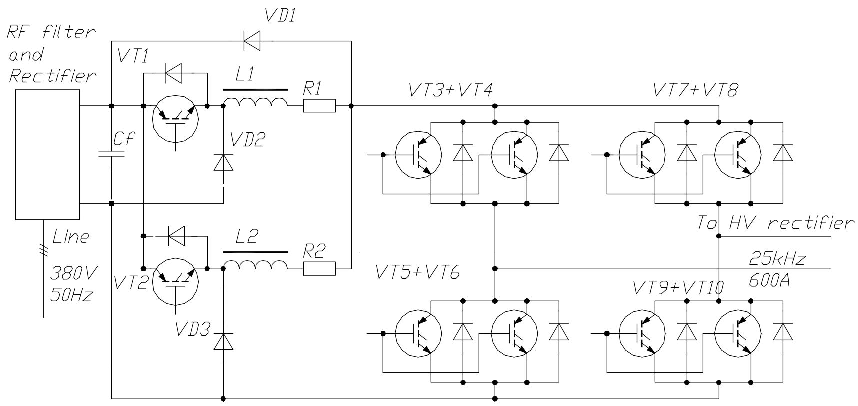


Fig.4. A simplified layout of the power converter.

5. The Modulator's voltage stability estimations

Let us estimate ripples of the output voltage in the sections, basing on the value of the filter capacitors. The current of the Current loop corresponds to the maximal output current of the modulator. In this case it can be shown that in a steady state mode the maximal level of voltage ripples at the output of the section will take place at Modulator's output current equal to a half of its maximal value. At a half output current the voltage stabilization circuit will restrict duration of the charge current with 10 microseconds in each half period of the converter frequency. Amplitude of 50 kHz frequency ripples can be estimated in this case as following:

$$\frac{\Delta U}{U} = \frac{t \cdot I}{C \cdot U} = \frac{10 \cdot 10^{-6} s \cdot 2.5A/2}{10 \cdot 10^{-6} F \cdot 625V} \approx 0.0025 = 0.25\%$$

Here: t – the current duration in a half period, I – the maximal current of the modulator, C – capacitance of subsection's capacitor, U – voltage across the capacitor.

6. Powering of the electronic circuit in the section

The circuit of a section is shown in Fig.5. The figure presents the stabilization circuit for the summary voltage across the filter capacitors of the section and the feeding circuits for other parts of the section.

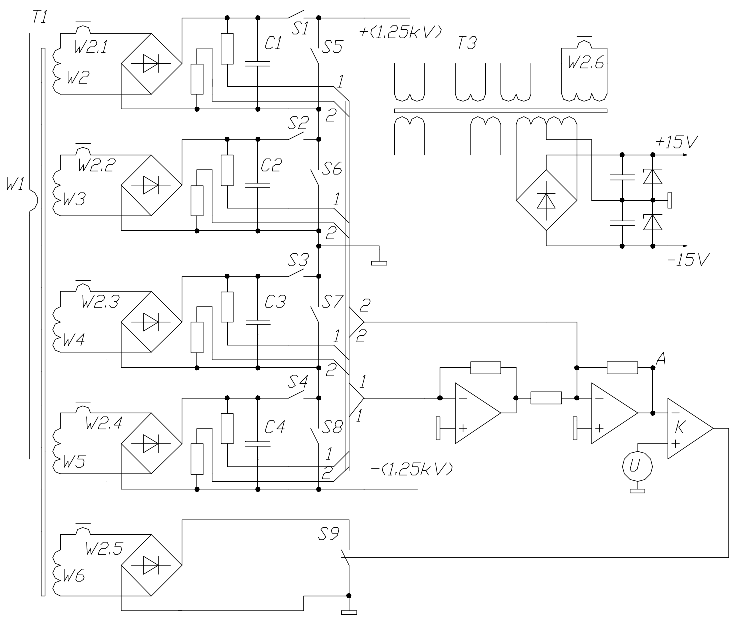


Fig.5. The stabilization circuit for the section's output voltage and supply circuit of the internal parts of the section.

As it is shown, the beginning leads of all the five secondary windings of the power transformer T1 form a single turn winding on the core of the matching transformer T2.

The transformer T2 is presented on Fig.5 as separate windings. Since current in the Current loop can be considered as of a constant value, the total current of all the primary windings of the transformer T2 and, consequently, the secondary winding of T2 and primary winding of T3 must be of a constant value as well. The secondary windings of the transformer T3 are made so that they are coupled closely. These windings provide powering of all the parts with floating potential such as some internal circuits and the drivers for the IGBT modules. Stable voltage of all the secondary windings of the transformer T3 is performed due to stabilization voltage of one feeding rectifier by using equivalent of a high power Zener diode.

Fig.5 also presents the measurement circuit for the summary filter capacitor voltage, the circuit for comparison the summary voltage and an assigned level and the switch S9 shunting one of the secondary windings of the transformer T1.

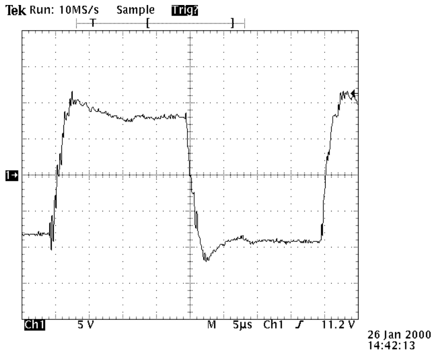
7. The protection system

The modulator is equipped with protection systems that watch operation regimes of its separate units and stop its operation if some parameters observed exceed permissible bounds. The watched parameters are voltage across the filter capacitor Cf and current values in the chokes L1 and L2 and in the IGBT modules of both regulators shown on Fig.4. In addition to this, the modulator and the injector are protected against breakdowns in the injector. If the output current of the Modulator exceeds the first threshold (about 3.5 Amps), the modulator stops generating the output pulse for 3mSec. If the injector recovers after that, the Modulator will continue its operation. If current exceeding repeats too frequently or the current exceeds the second threshold (about 6A) once, the Modulator stops operation until the next pulse series begins.

8. Experimental results

Duration of the Modulator output pulse presented on Fig.7 is about 2 sec. The slight rise of the current curve indicates a change of the load resistance that is caused by its heating.

It can be seen short distortions on the curves of Modulators voltage pulses caused by interference in measurement circuits.



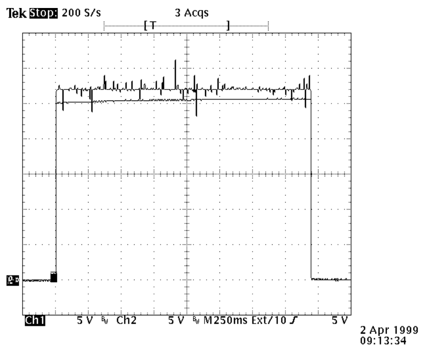
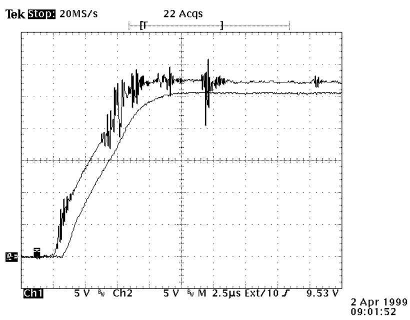


Fig.6. The Current loop current curve at 400 A/div. (Time scale is 5 μs/div).

Fig.7. The Modulator output voltage (the upper curve) at 10 kV/div, the Modulator output current (the lower curve) at 0.5A/div (Time scale is 250 ms/div).



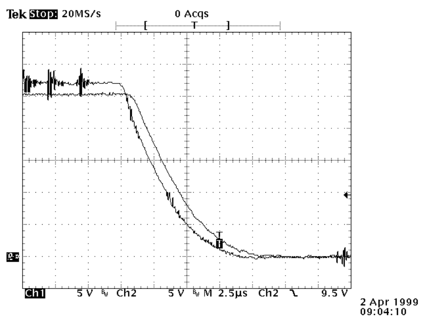


Fig.8. The front edge of the voltage (upper) at 10 kV/div and current (lower) at 0.5A/div of the Modulator pulse. (Time base is 2.5μs/div).

Fig.9. The back edge of the voltage (upper) at 10 kV/div and current (lower) at 0.5A/div of the Modulator pulse. (Time base is 2.5μs/div).

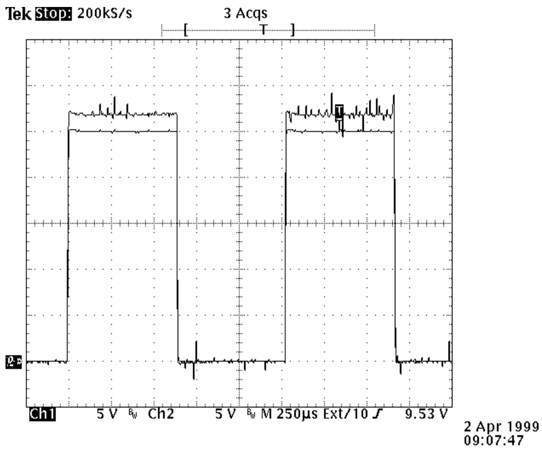


Fig.10. The fragment of a pulse series. The voltage (upper) at 10 kV/div and current (lower) at 0.5 A/div of the Modulator pulse (time scale is 250 μs/div).

9. Conclusions

The modulator is used for testing diagnostic injectors and components of injectors being developed at the Institute from the summer of 1999. The results of its operation jointly with the Diagnostic injector are presented in [1].

Fig.11 presents a photo of the modulator. It locates in two cabinets $570\times650\times2100\ \mathrm{mm}^3$ and $780\times1000\times1850\ \mathrm{mm}^3$ in size. The left cabinet on the photo comprises the power converter; the right one comprises the sectioned rectifier.

Fig.11. The Modulator's photo.

References

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2. *Lee, Ye. M. Mandrik, A. S. Medvedko, Yu. F. Tokarev.* The current type hight voltage converter for Klystron Modulator. VII International Workshop on Linear Colliders, Zvenigorod, Russia, Sept. 29 Oct.3, 1997.