MULTY-BEAM KLYSTRONS WITH REVERSE PERMANENT MAGNET FOCUSING SYSTEM AS THE UNIVERSAL RF POWER SOURCES FOR THE COMPACT ELECTRON ACCELERATORS

I.A. Frejdovich, P.V. Nevsky, V.P. Sakharov, M.Yu. Vorob'ev, FSUE "R & P Corp. "Toriy", Moscow, Russia
E.A. Knapp, W.P. Trower, World Physics Technologies Inc., Blacksburg, VA, USA
H. Yamada, A. Kleev, Photon Production Ltd, Kioto, Japan
A.S. Alimov, V.I. Shvedunov, Skobeltsyn Institute of Nuclear Physics Moscow State University, Moscow, Russia
Yu.D. Chernousov, I.V. Shebolaev, V.I. Ivannikov, Institute of Chemical Kinetics and Combustion, SB RAS, Novosibirsk, Russia
Yu.N. Gavrish, V.M. Nikolaev, D.V. Efremov Scientific Research Institute of Electrophysical Apparatus, St. Petersburg, Russia

Abstract

Parameters of serially produced and being developed multi-beam klystrons (MBK) for particle accelerators are given. Some specific applications are described.

SERIAL MB KLYSTRONS

Compact relocatable and mobile installations with local radiation shielding occupy essential part of electron accelerators market. They are used for defectoscopy, radiotherapy, sterilization, for control of different objects by methods of intrascopy, radiography and tomography and for other applications. Due to strengthening of the struggle with terrorism, with contraband of the fissile and explosive materials, with smuggling of the narcotics, interest to such installations has been grown essentially during several last years. Typical compact electron accelerator for these applications has energy up to 6 MeV and beam power 1-3 kW.

Traditional RF sources for discussed accelerators are magnetrons with permanent magnet focusing, for example, S-band magnetron M5193 produced by EEV with pulsed/average output RF power up to 3 MW/3 kW, or X-band magnetron PM-1100X with pulsed/average output RF power up to 1.8 MW/1.5 kW, produced by CTL. The magnetron advantages are low weight and small dimensions, low operating voltage, relatively low cost. However their pulsed and average power are insufficient for number of applications, output RF signal amplitude and phase stability is low, phasing of several magnetrons operating in the same installation is difficult. Low voltage MBK amplifiers with periodic permanent magnet focusing system (PPMFS) with field reverses developed at FSUE "Toriy", Moscow, Russia since end of 80-th can successfully replace magnetrons and single beam klystrons. The main parameters of these MB klystrons are given in Table 1. The low cathode voltage (2-3 times lower as compared with single beam analogues) and compact low weight PPMFS, which is integral part of the device, are distinguishing features of the MB klystrons. Klystrons are capable to operate in any spatial position and can operate in the moving state. Use of the MBK permits to decrease accelerators dimension, weight and cost and make it possible to build relocatable and mobile installations. Photos of pulsed and continuous wave (CW) MB klystrons are given at Figs. 1 and 2.

The compact input power sources have been developed by Institute of Chemical Kinetics and Combustion, SB RAS, Novosibirsk, for these MB PPMFS klystrons (Fig. 3). There are two variants of RF source: with operating frequency 2450 MHz and 2856 MHz. RF source contains the solid-state transistor cascade for preliminary amplification in CW mode to the minimum level of 1 W and two subsequent RF amplifier cascade modules with the use of vacuum triodes operating in pulsed mode. These sources provide output pulse power up to 200W, average power up to 2W, pulse long up to 30μs. Weight of sources is not more 7 kg.

Table 1: The main parameters of serially produced MB klystrons.

Klystron	KIU-111	KIU-168	KIU-147	KIU-147A	KU-399A	KU-399
Operating frequency, MHz	2450±5	2856±5	2450±5	2856±5	2450±5	2450±5
Output pulsed power, MW	6	6	5	6	-	-
Average output power, kW	6	6	25	25	50	25
Efficiency, %	45	45	45	45	65	55
Amplification, dB	50	50	50	50	42	40
Cathode voltage, kV	50	52	50	53	15	10
Weight with PPMFS, kg	80	80	85	87	40	36

Figure 1: Pulsed MB klystron KIU-168

Figure 2: CW MB klystron KU-399A

Figure 3: RF source

APPLICATIONS

Klystrons listed in Table 1 are used in 18 different type accelerators which were developed and are produced in Russia and other countries. In our report we describe MB klystrons application in four types of new generation compact electron accelerators which could not be built with their parameters using other type klystrons or magnetrons..

UEL-15-100D

Linear electron accelerator UEL-15-100D [1] (Fig. 4) with beam energy up to 16 MeV and average beam current up to 100 μA based on KIU-111 klystron is serially produced by STC LUTs at D.V. Efremov Scientific Research Institute of Electrophysical Apparatus, St. Petersburg, and is used for non-destructive testing and inspection of large-scale steel products and for customs control of large-scale containers using methods of radiography, intrascopy and tomography.

The klystron KIU-111 is used in this accelerator as an RF amplifier terminal stage with automatic control system tuning RF driver frequency to accelerating structure resonance frequency. Klystron is isolated from accelerating structure by circulator. Electron accelerator Linatron 600A with close beam parameters is fed by single beam klystron with focusing solenoid. Weight of this accelerator is 2900 kg, while UEL-15-100D weight is 1100 kg, which is achieved by the use of PPMFS MBK.

Figure 4: UEL-15-100D

70 MeV Race-Track Microtron

A compact rugged 70 MeV, 5-10 mA beam current compact race-track microtron (RTM) (Fig. 5) has been built by World Physics Technologies Inc. USA [2] to field nitrogen camera, which images nitrogen concentrations for explosives detection. RTM has several unique features: ~1 T rare-earth end magnets; a narrow rectangular biperiodic accelerating structure with RF quadrupole focusing; klystron KIU-147A operating in self-oscillation mode without a precision RF generator, a circulator, frequency and temperature stabilization systems. Such mode of operation is possible due to high electrical and thermal margin of safety of the klystron output window, which can withstand against 20 MW pulsed and 70 kW average power.

Figure 5: 70 MeV RTM

High Average Power CW Linac

A compact 1.2 MeV beam energy, 60 kW average power CW electron accelerator for radiation technologies has been developed at Skobeltsyn Institute of Nuclear Physics MSU, with the support of World Physics Technologies Inc. USA [3]. Two klystrons KU-399A operating in self-oscillation mode provides accelerator wall-plug efficiency approaching to 40%.

Light Source MIRRORCLE-20 (6X)

A compact light source MIRRORCLE-20 (6X) (Fig. 6), has been developed by Photon Production Laboratory, Ltd., Japan, for the equipment with local shielding. consist of the classical microtron, which is used as an injector to the storage ring. The electron energy at the microtron output is 20MeV (6MeV) and the pulse beam current is 100mA. The diameter of the electron orbit in the storage ring is about 30cm.The microtron is fed by pulsed KIU 111 klystron while for feeding a synchrotron cavity CW klystron KU-399 phased with microtron klystron is used. The MIRRORCLE 20 is used as a synchrotron radiation source while MIRRORCLE-6X as a X-ray source.

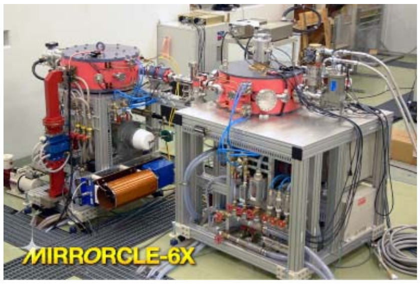

Figure 6: Compact light source MIRRORCLE-20 (6X)

PROSPECTIVE MB KLYSTRONS

We also consider prospective directions for development of the high power pulsed and CW MB klystrons for accelerators. Increase of operating frequency is the most perspective direction permitting to build more compact accelerators. Parameters of prospective MB klystrons with PPMFS are given in Table 2.

The MBK PPMFS can also be used to feed multi-section superconducting linear accelerators. CW PPMFS MBK operating at frequency 1498 MHz has been designed [5] according to DOE solicitation (Fig. 7).

Table 2: The prospective PPMFS MB klystrons.

Klystron	1	2	3
Operating frequency, MHz	5712±5	9300±5	5712±5
Output pulsed power, MW	5	2.5	-
Average output power, kW	5	3	15
Cathode voltage, kV	50	40	9
Cathode pulsed current, A	250	130	-
Average cathode current, A	0.25	0.16	3.5
Number of beam	40	30	12
Efficiency, %	45	45	55
Amplification, dB	45	45	40
Weight with PMFS, kg	70	45	30
Number of focusing field direction reverses	1	1	1

Klystron output power is regulated within 9 – 15 kW by changing the beams current with constant cathode voltage. Klystron efficiency stays close to 70% when output RF power is varied from 15 to 9 kW and current is varied from 2.6 to 1.7 A. Klystron design is close to the design of KU-399, it has 18 beams and uses magnetic system and collector of KU-399 klystron. Cathode voltage is 7 kV, cathode current 2.7 A. The cathode current emission density does not exceed 2 A/cm^2 and its lifetime is estimated to be not less than 30,000 hours. We consider that such RF source is optimal for feeding superconducting accelerating structures.

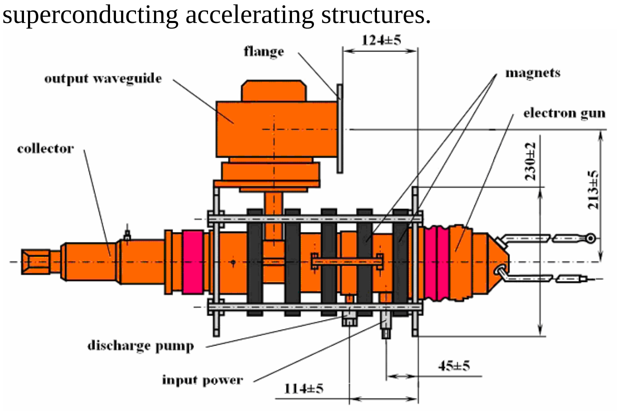

Figure 7: 1498MHz 15kW CW MB klystron with PPMFS.

REFERENCES

[1] http://niiefa.spb.ru/res/stc/luts/indexe.html

[2] V.I. Shvedunov, A.N. Ermakov, I.V. Gribov, E.A. Knapp, G.A. Novikov, N.I. Pakhomov, I.V. Shvedunov, V.S. Skachkov, N.P. Sobenin, W.P. Trower and V.R. Yajlijan, A 70 Mev racetrack microtron, NIM A550, 2005, pp. 39-53

[3] A.S. Alimov, D.I. Ermakov, B.S. Ishkhanov, E.A. Knapp, V.I. Shvedunov, and W.P. Trower, CompactIndustrial High-Current Electron LINACs, in Proceedings of the 2000 European Particle Accelerator Conference, J.L. Laclare, W. Mitaroff, Ch. Petit-Jean-Genaz, J. Poole, and M. Regler eds. (World Scientific, Singapore, 2000) pp..803-805.

[4] H. Yamada, T. Ozaki, Y. Sakai, D. Hasegawa, Y. Kitazawa, I. Tohyama, A.I. Kleev and G.D. Bogomolov, Successful beam injection to the smallest synchrotron and brilliant x-rays production, in Proceedings of Second Asian Particle Accelerator Conference, pp.100-102.

[5] I.A. Freydovich, E.A. Knapp, P.V. Nevsky, V.P. Sakharov, V.I. Shvedunov, W.P. Trower and M.Yu. Vorobyev, A variable high-power multi-beam klystron design, NIM A539, 2005, pp. 63-73.