

ULTIMATE ABILITIES OF CONVENTIONAL POSITRON SOURCES

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Abstract

Significant increasing of desired luminosity for future e^+e^- colliders leads to corresponding enlargement of positron production rate. Conventional technology of positron production has not reached yet its technical limits. Experimental study in order to find out these limits for basic subsystems of positron source is presented.

INTRODUCTION

With the advent of first linear accelerators in the middle of last century these machines were used for production and acceleration of positron beams. The first successful acceleration of positron beam was reported from Mark III accelerating system at Stanford [1]. Many linac based e^+ sources were built in subsequent years with significant improvements of beam intensity and quality. But the basic concept of these sources remained practically unchanged [2]. In this concept a high-energy electron beam from driving linear accelerator is focused on a thick target of high Z material, generating an electromagnetic shower in it. A part of shower positrons escapes from the target with a large spread in energy and angles. So only a small fraction of these positrons is guided by magnetic matching device into a following linear accelerator. The first part of this linac is immersed into longitudinal magnetic field of a long solenoid. This field provides transverse focusing for positrons with a large transverse momentum. Quadrupoles mounted on accelerating structure are used downstream of the long solenoid. These quadrupoles have alternating polarity for magnetic field gradient and form so-called FODO structure. A sketch of linac based positron source is shown in Fig. 1.

POSITRON PRODUCTION TARGET

For particular value of driving electron beam energy, an optimum length of positron production target exists [2]. This optimum length corresponds to the maximum of positrons density in the electromagnetic shower as it leaves the target. Space, energy and angle distributions of positrons after the target with an optimum length have a weak dependence upon the energy of primary electron beam within the range from 0.3 GeV up to 30 GeV [3]. This fact makes easier the analysis and comparison of positron sources with different energy of driving electron

beam.

Thermal stability of positron production target under the heating energy deposition from the electromagnetic shower is the most important problem. Thermal damage of the target limits the intensity of driving electron beam and, hence, the intensity of secondary positron beam. This damage comes from the excess of mechanical stress limit for solid elements of target assembly.

Driving electron beam may consist of one or few intense and very short bunches usually called as a bunch train, or macro pulse. Driving electron linac produces these macro pulses with some repetition rate. In such a way, the particular time structure of the beam can be varied and depends on the particular application. But for most target designs and driving beam structures the working area for target subsystem can be defined in terms of two parameters. The first parameter is related to negative stress limit reached while the shock wave travels through the solid part of the target assembly (dynamic limit). Intense driving electron bunch or bunch train generates this wave. The second parameter corresponds to the maximum DC power density allowed for particular target design (static limit). Both parameters depends upon the power density in driving electron beam and, hence, upon the electron beam size on the target. However, the positron beam size at the exit of the target with optimum length is practically the same for any diameter of driving beam less than 1 mm. So the optimum driving electron beam transverse size on the target can be fixed at the level of 1 mm (FWHM).

The following time scales can be applied for different processes took place in a short electron bunch interaction with the target: energy deposit (up to 100 ps), time response for temperature (up to few ns) and stress (up to 300 ns). So 100 ns can be chosen as the maximum time duration for the bunch train, which generates shock waves with maximum efficiency. Finally, it is possible to define the first parameter as $J=E*N/S$, where E is driving electron beam energy in GeV, N is the maximum number of incident electrons in 100 ns time interval, S is the transverse cross section of driving electron beam (mm^2). The second parameter can be defined as DC power (kW) in driving electron beam with 1 mm transverse size on the target. These two parameters form 2-D plot (see Fig.2)

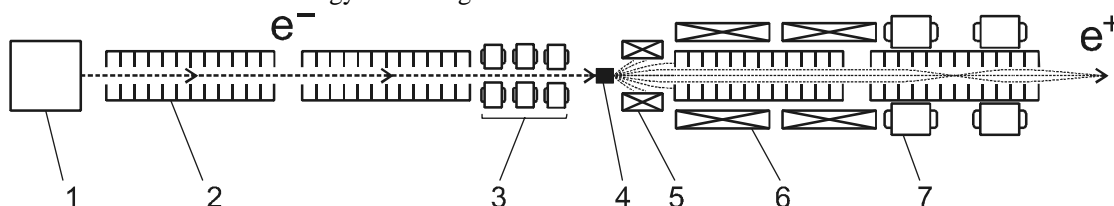


Figure 1: 1 — electron source, 2 — accelerating structure, 3 — focusing triplet, 4 — positron production target, 5 — magnetic matching device, 6 — solenoid, 7 — quadrupole lens.

with different areas available for different kinds of positron production targets. The first kind of target is the stationary solid-state WRe target cooled by water. The second one is rotating WRe target cooled by thermal radiation. And the third one is liquid lead target with BN windows. All calculations were done for 6 GeV energy of driving electron beam.

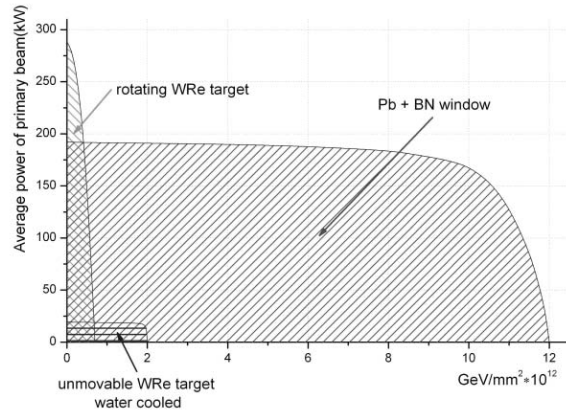


Figure 2: Areas available for different kinds of positron production targets.

Estimations for liquid lead target were performed on the base of experimental data obtained from the prototype of the system, developed in BINP [4]. For rotating WRe target estimations were done using practical experience with prototype of rotating high power target (50 kW in DC) built and successfully tested in BINP in the framework of ISTC Project #2257 [5].

The application area for liquid lead target with BN windows is limited by thermo-mechanical properties of these windows. Open liquid lead jet cannot be used together with high vacuum RF accelerating system. Rotating WRe target cooled by thermal radiation has to operate at the target temperature (around 2000 °C), at which the mechanical properties of WRe alloy degrade. The maximum practical rotation speed for this kind of targets is limited by the value of 3000 rpm. The vertical scale on Fig. 2 reflects the total DC power in driving electron beam with the energy of 6 GeV. In such a way, the real heating power deposition in the target will be about 5 times less.

MATCHING DEVICE

The transverse size of positron beam at the exit face of the target is significantly smaller than the aperture of the following accelerating structure. Thus there is a possibility to enlarge the positron beam size and reduce the angle spread for positrons. It helps to extend the capture of positrons at least 5 times. This manipulation with positron beam can be done by magnetic focusing lens usually called as matching device. There are three kinds of matching devices that are used in linac based positron sources: Quarter Wave Transformer (QWT), Flux Concentrator (FC), and Lithium Lens (LL)[2]. QWT is a

pulsed coil. Positron production target is placed at the entry of this coil. The length and the magnetic field of this coil are adjusted in order to maximize the capture of positrons. Lithium lens has azimuthal magnetic field generated by direct current parallel to the axis of the positron production system. The focusing ability of both QWT and LL is very selective at the initial energy of positrons. From this point of view FC is much better and provides good matching for positrons within wide energy range. This is why FC used in linac based positron sources provides at least double number of positrons in comparison with QWT and LL. FC is the most effective at the maximum magnetic field value of about 10 T. For the best result this high field value should be combined with a good axial symmetry of FC magnetic field. Matching device of FC type, meeting all these conditions, was designed and successfully tested on VEPP-5 Injection complex at BINP [6]. The common feature of all these matching devices is the pulse regime of operation. The time interval of proper magnetic field existence cannot be very long, and bunch train duration must be less than this interval. So the maximum time interval for the magnetic field of a good quality can be chosen as one of key parameters of matching device. Maximum magnetic field value should be the second key parameter. Fig. 3 presents the 2-D plot with areas available for different matching devices. The advantage of Lithium lens is the possibility of operation with long pulse (up to 1 ms).

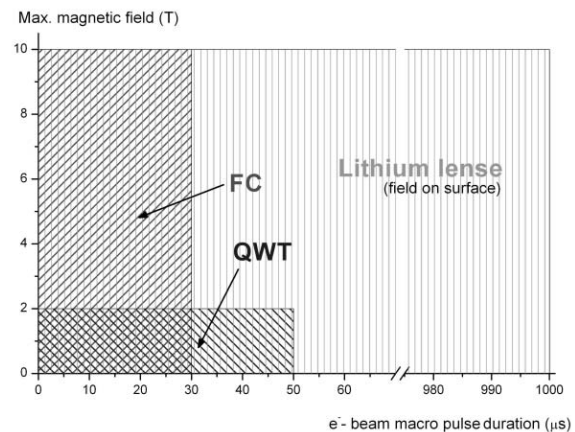


Figure 3: Areas available for different matching devices.

ACCELERATING SYSTEM

Accelerating gradient at the initial part of positron linac affects significantly to the number of accelerated positrons. Fig. 4 shows the dependence of positron capture efficiency upon the value of accelerating gradient. Calculations were done for L-band system (1.3 GHz). Another very important parameter is a macro pulse duration, which is actually restricted by particular frequency. Systems operated at higher frequency have smaller pulse duration and smaller aperture available for positron acceleration. Also maximum positron bunch length suitable for further acceleration should be smaller

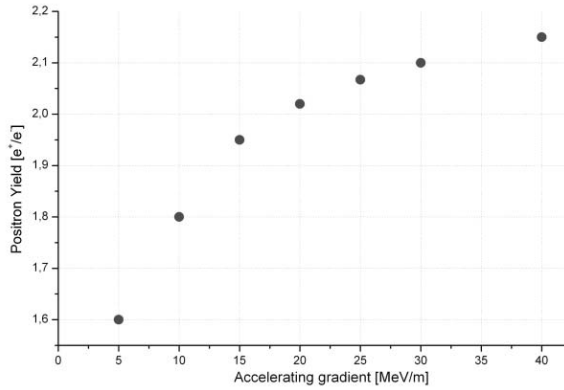


Figure 4: Dependence of positron capture efficiency upon the value of accelerating gradient. Driving e- bunch length 0.3 mm. Acceleration of positrons up to 9 GeV. Different acc. gradient at first 100 MeV only.

for systems with higher frequency. In such a way, moving to higher frequencies one can gain only in accelerating gradient and lose in all other parameters. Thus positron production rate will decrease with frequency rising.

Unfortunately, modern intense positron sources cannot utilise superconducting accelerating structures due to high heating power deposition in the structure body coming from neutron flux and electromagnetic shower. For warm copper structures the high gradient means the high input RF power. So proper powerful klystrons should be available for particular frequency band. Recent development of high power L-band klystrons allows reaching the accelerating gradient of up to 15 MeV/m [7]. It is only twice less than the maximum practical accelerating gradient for S-band (30 MeV/m at 2.8 GHz). The major advantage of L-band system is the operation with long macro pulse (up to 1 ms). Fig. 5 presents the positions of L-band and S-band positron accelerating systems on the accelerating gradient–beam macro pulse duration plot.

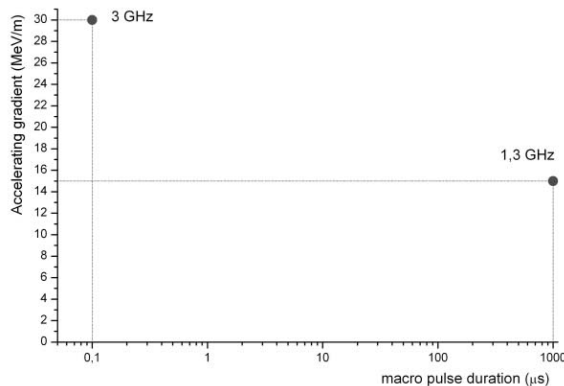


Figure 5: Accelerating gradient vs beam macro pulse duration for L-band and S-band.

CONCLUSION

Existing positron sources, which are in operation, haven't reached yet the limits of their application areas. So significant improvements in some directions are possible in the near future. It may lead to about one order of magnitude increase in positron production rate for best existing installations. Conventional positron production technology still has some reserves for such up-to-date projects as International Linear Collider (ILC) and Super B-factory.

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