THE RECENT JINR ADVANCES IN TECHNOLOGY DEVELOPMENT ON LINEAR ACCELERATORS

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Abstract

JINR actively participates in ILC project. JINR physicists are taking part in several fields of activity in ILC: works on beam diagnostics, photo injector prototype, and laser system for electron source, participating in design and construction of cryomodules, laser metrology, etc. Moreover Joint Institute is officially approved candidate for possible hosting of ILC in the region near Dubna. All above mentioned topics are discussed in the presented report.

BEAM DIAGNOSTICS

The free electron laser FLASH has been in operation at DESY since the year 2000. The electron energy now reaches 1 GeV, rms bunch length is 50 μm, the FWHM radiation pulse duration is about 30 fs, the normalized emittance is 2 π·mm·mrad, the bunch charge is 1 nC, the peak power is up to 1 GW, the peak brilliance is of 10^{28} ph/s/mrad2/mm2/(0.1%bw).

The MCP detector [1-3] developed by the JINR-DESY collaboration for FLASH facility is used for measurement of statistical properties of the radiation allowing determination of the pulse length. Key element of the detector is a wide dynamic MCP which detects scattered radiation from a target. With four different targets and MCPs in combination with optical attenuators, the present FLASH detector covers an operating wavelength range 6 -100 nm, and a dynamic range of the radiation intensities, from the level of spontaneous emission up to the saturation level of SASE FEL.

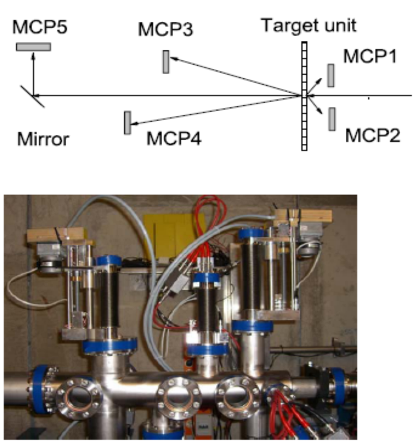

Figure 1: Layout of the MCP detector.

The gold target is perfect for the wavelength range above 10 nm, however its reflectivity falls dramatically for shorter wavelengths, and different targets and geometries of the detector are used. We added three more targets to gold mesh: two iron meshes, and one copper mesh (Fig.1). This helps us to operate the detector in a range below 10 nm.

A bunched electron beam of extremely high quality is needed in the XFEL project to get coherent radiation in subnanometer wavelength. JINR proposes to design Hybrid Pixel Array Detector on basis of GaAs (Cr) detectors (Fig. 2) [4]. The technology of the pixel detector with resolution of 50 μm was developed on basis of the JINR-Toms State University GaAs (Cr) sensors and the Medipix chips.

Figure 2: Spectrometric detector based on GaAs (Cr) pixel censor with 256×256 channels of 50 μm resolution and Medpix chip.

ACCELERATOR COMPLEX FOR ULTRAVIOLET LITHOGRAPHY

JINR actively develops the project aimed at construction of accelerator complex for applications in nanoindustry, mainly for extreme ultraviolet lithography using kW-scale Free Electron Laser light source [5, 6]. The project involves the construction of a 0.7 GeV superconducting linear accelerator (based on XFEL-type cryomodule) to produce coherent FEL radiation for extreme ultraviolet nanolithography at a wavelength of 13.5 nm and an average radiation power of 0.5 kW.

The application of kW-scale FEL source permits to realize EUV lithography with 22 nm, 16 nm resolutions and beyond. The project for construction of an accelerator and FEL complex for EUV lithography is based on the technology realized on FEL FLASH. Present analysis [6] shows that this technology holds great potential for increasing the average power of a linear accelerator and the efficiency of conversion of electron kinetic energy into light.

HOLLOW PHOTOCATHODE CONCEPT FOR E-GUN

Photocathode is the key device for high-quality electron bunches generation. Such bunches are needed as initial electron source in contemporary linear accelerators. In all cases there are several important parameters: fast response time, quantum efficiency, long lifetime, low thermal emittance, minimal effect on RF properties of the accelerating system.

The new concept is proposed [7]: hollow photocathode – transparent for the laser beam cathode made like a washer with the width of 4-6 mm with a cone or cylinder aperture in the middle (Fig. 4). Work surface of the photocathode is the cone (or cylinder) generatrix. In the case of a cone obliquity is 1:50. Outcome diameter is ~2 mm.

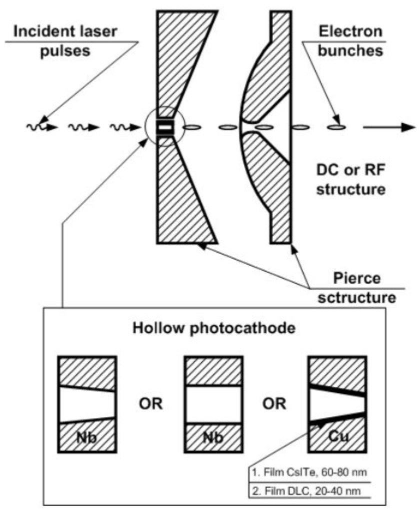

Figure 4: Scheme of the hollow photocathode.

Backside irradiation radically simplifies laser beam targeting on emitting surface, accelerator equipment adjustment and allows photocathode work surface laser cleaning.

Preliminary emission characteristics of photocathode (Nb, Ø10 mm disk 1 mm thick, normal hade) investigations were done. Radiant flux density (intensity) was changed from 0.8 MW/cm^2 to 4.1 MW/cm^2 for unfocused beam and from 3.2 MW/cm^2 to 16.4 MW/cm^2 for focused beam, cathode surface was laser cleaned. During unfocused beam irradiation up to obtainable intensity no thermoemission was observed.

Investigations have shown that hollow photocathode usage radically simplifies laser beam targeting on emitting surface, accelerator equipment adjustment and allows photocathode working surface laser cleaning. Quantum efficiency of investigated hollow photocathodes is at least ten times more than QE of solid ones.

HIGH AVERAGE POWER LASER

To provide ILC format beam for Super-conducting Test Facility (STF) at KEK (Japan), an electron source based on photo-cathode L-band RF gun was developed. The laser system for this source [8] consists from Yb fiber oscillator, macro-pulse profiler, Nd:YLF amplifier and Harmonic Generations. The laser system is initially developed at Institute for Applied Physics (IAP, Nizhny Novgorod, Russia) in collaboration with JINR (Dubna) and moved to KEK-STF, Japan for the experiment. Aim of STF at KEK is demonstrating technologies for International Linear Collider (ILC). In STF, one full RF unit, which is composed from one klystron, three Cryomodules, and 24 RF cavities, will be developed and beam acceleration test will be made.

It was confirmed that the system performance meets the basic requirements as the driver for the STF photo-cathode injector. Currently, the laser is a stand-alone system and any synchronization to master signal is not implemented at all. The laser system meets the basic ILC requirements: one macro-pulse contains 2439 micro pulses with 369ns bunch spacing; the macro-pulse is repeated in 5Hz; the micro-pulse energy is 1.9μJ, which corresponds to 4.3nC assuming 1.0% quantum efficiency of cathode.Synchronization to master RF signal is easily made by a phase-lock loop with the signal of PMO measured by Photo-Diode, which is already in use and the fast control by the piezo cylinder. STF will perform the beam acceleration test in 2012.

4TH GENERATION CRYOMODULE DESIGN

Explosion welding of bimetallic tubes

JINR (Dubna) in collaboration with RFNC (Sarov, Russia), INFN (Pisa) and FNAL are working on the design of fourth-generation cryomodule for the ILC. Scientists from Dubna proposed to substitute titanium (Ti) helium-supply pipe of the Dewar vessel by the stainless steel (SS) pipe – such construction can essentially reduce accelerators costs. The key problem is to create the Ti-SS transition element, because it's heavily problematic to joint Ti pipe with SS pipe by the traditional welding methods. The problem has been solved by the RFNC (Sarov) explosion welding method. A technology for production of bimetallic Ti-SS *tubular* transition elements by the explosion welding method has been developed and implemented for the first time**.** The world first sample created by the explosion joint has been presented to an international scientific community at the Milan ILC-meeting, 2006, and met the enthusiastic approval (Fig. 5).

Figure 5. The world first sample of Ti-SS bimetallic transition element prepared to the leak tests in INFN.

The achieved welded joint area shearing strength of the welded joint is ≈ 500 MPa; macro-defects such as cracks, spills and peelings were not found. Small and evenly distributed micro-defects (interstices, intermetallides) not forming big aggregations do not influence the working capacity of the welded joints [9, 10].

The results of the leak rate measurements in JINR, INFN and FNAL feet each other: $7.5 \cdot 10^{-10}$ Torr·l/s – at room temperature, $7.5 \cdot 10^{-9}$ Torr·l/s – at cryogenic temperature and less then $5 \cdot 10^{-10}$ Torr·l/s – at pressure 6.5 atm [11-13].

Basing on the explosion welding achievements in the bimetallic Ti-SS transitions collaboration decided to improve the cryomodule design – to substitute the titanium cryomodule cover by the stainless steel one using Nb-SS bimetallic transition element (Figure 6).

Figure 6. The world first sample of Nb-SS bimetallic transition element at the leak tests in FNAL.

The world first four samples of the Nb-SS joints were made in Sarov in 2010. Samples were researched and tested in Dubna, Sarov and Pisa [14]. The metallographic analysis did not reveal any structural anomalies of the welded components: in the narrow Nb–SS contact zone 0.2÷0.25 mm wide microrigidity of ≈ 4.4 GPa arises. The leak rate measured in Sarov was ≈ $7.5 \cdot 10^{-10}$ Torr·l/s. After thermal cycling and exposure to ultrasound in Pisa the upper limit of the leak rate for all test joints was found to be ≈ $2.3 \div 3.8 \cdot 10^{-10}$ Torr·l/s. Leak measurements in FNAL did not show leaks at the detector sensitivity ≈ $7.5 \cdot 10^{-11}$ Torr·l/s after six thermal cycles in liquid nitrogen.

Electron bean welding of the bimetallic transition element with Nb tube (at the temperature of 2400^{O}C) demonstrated leaks in the Nb-SS welded joint area. Using the annealing process before electron-beam welding showed the total relax of the internal stresses in the materials. Leak rate measurements of the annealed bimetallic samples demonstrated a good result: the leak was not detected on the sensitivity level of ≈ $3.5 \cdot 10^{-9}$ Torr·l/s.

Design of the cavity connections

The design of the connection of the Nb cavity end flanges with the beam pipe using a new conical flange and a quick disconnect system (Figure 7), producing by Garlock company, has been proposed in Pisa and studied with Dubna participation.

Numerical simulations of this connection using a different types of gasket have been carried out and the optimal geometrical parameters of the seal decreasing residual deformation have been determined [15, 17]. New design of the cavity connections has successfully tested in INFN cryogenic laboratory [16] at room temperature and liquid nitrogen temperature (77 K), the measured leak level is < 10^{-9} Torr·l/s.

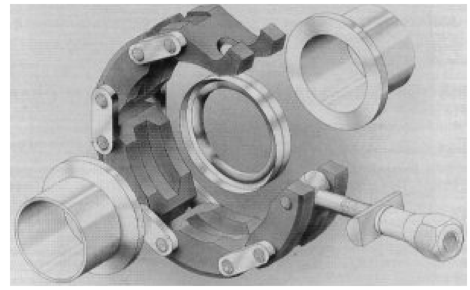

Figure 7. Garlock quick disconnect system.

This flange assembly simplifies the design, reduces the assembly time by an order of magnitude, and is expected to decrease the accelerator vacuum chamber length.

ILC SITING INVESTIGATIONS

One of the possible sites for ILC location is the territory near Dubna, where Joint Institute for Nuclear Research is placed [18]. JINR in collaboration with The State Specialized Projecting Institute (GSPI) has performed the preliminary complex engineering prospecting on the territory of the supposed ILC route [19].

The obtained data (geological structure and hydro-geological conditions, geotechnical soil properties, weak development or absence of adverse natural and engineering-geological processes) presented in GSPI Soil Boring Report supports the positioning of a site near Dubna and supports a near surface design solution.

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