EXPERIMENT ON RF HEATING OF THE COPPER CAVITY – THE IMITATOR OF THE CLIC HIGH-GRADIENT ACCELERATING STRUCTURE*

S.N.Sedykh, E.V.Gorbachev, A.K.Kaminsky, N.I.Lebedev, E.A.Perelstein, N.V.Pilyar, T.V.Rukoyatkina, V.V.Tarasov, JINR, Dubna, Russsia
S.V.Kuzikov, N.Yu.Peskov, M.I.Petelin, A.A.Vikharev, IAP RAS, N.Novgorod, Russia

Abstract

The facility for joint experiments of JINR-IAP RAS has been commissioned to investigate the lifetime dependence of the CLIC high-gradient accelerating structure on the surface damage by repetitive high-power RF pulses. The facility is based on the 30 GHz JINR free-electron maser, which uses an electron beam of the induction linear accelerator LIU-3000.

Intermediate optical observations of the central ring allowed us to control the process of the damage evolution. The first damage of the copper surface have been observed after $1.6*10^4$ pulses with the pulse heating of 250ºK. After $6*10^4$ pulses the damage of the surface of the oxygen-free copper cavity became strong enough to cause regular breakdowns inside the test cavity.

INTRODUCTON

The project of the compact electron-positron collider CLIC with room-temperature accelerating structure is now developed by international collaboration headed by CERN [1]. The damage of the wall of the accelerating structure due to very intensive cyclic heating by short high-power RF pulses can be one of the most severe limits on the accelerating gradient or serve as a criterion for choice the materials for structure manufacturing [2]. Several experimental groups around the world have started investigations of this effect using different methods. Collaboration of JINR and IAP RAS has developed the experimental facility creating the RF pulse heating with temperature rise more than 200ºK. The expected lifetime of the copper cavity at such high temperatures was not more than $2*10^5$ pulses.

EXPERIMENTAL FACILITY

The facility is based on the 30 GHz 20 MW free-electron maser (FEM), which uses an electron beam of the induction linear accelerator LIU-3000 [3]. Radiation spectrum width does not exceed 10 MHz at pulse duration of 180 ns, repetition rate is 0.5-1 pulse per second.

The Gaussian wave beam from the FEM output waveguide is passing through the thin diagnostic film to the symmetrical two-mirror quasi-optical transmission line. After the oversized waveguide with an input vacuum window the radiation is transformed by the input horn from the Gaussian distribution into the TE_{11} mode and then – into TE_{01} mode by a specialized mode converter. After the output horn the radiation is monitored by a detector with a dielectric waveguide and then it is fully accepted by the calorimeter (figure 1).

A specially designed test cavity- imitator of the CLIC accelerating structure - operates at the mode TE_{011} with zero electric field near the wall to prevent the inner discharge. It consists of two diaphragms and the inner ring with a rather thin edge. The most heated area is the inner edge of the ring. The quality factor of the cavity is 1500. The precise frequency matching of the cavity with the FEM oscillator can be achieved by changing the distance between the diaphragms. The test cavity module has its own vacuum system.

DATA ACQUISITION AND CONTROL SYSTEM

The distributed data acquisition system was constructed several years ago [4, 5] and it demonstrates her versatility and reliability. Recently the some new possibilities were added. The automatic stabilization sub-system [6], being exploited in test regime with local control during 1 year, is now installed inside the accelerator hall and completely switched to the remote control. The electron beam focusing system consists of 12 magnetic lenses along the accelerator and beam-line. Each magnetic lens is fed by individual stabilized current supply. Controller is connected to the PC and current supplies by means of RS-485 protocol, allowing controlling the individual lenses currents. Another new feature of the control system is an active automatic start-times control for the modulators of the induction linear accelerator. It means the local feedback between the synchronization sub-system (which was operating previously only in human-controlled regime) and modulator pulse control sub-system. The hardware core of the pulse control subsystem is a set of fast ADC with memory buffers and input multiplexors. The server program is now supplied by a module of pulse shape recognition, which calculates a time when a flat top of pulse is started. TCP server module of this subsystem is ready to send this data to the client module in synchronization subsystem. The synchronization program calculates the difference between measured value and desired one, and then sends the correction to the synchronization channel connected with corresponding modulator. The list of channels taking part in this regime can be corrected by the operator in on-line regime.

*Work is partially supported by RFBR grants: # 06-02-16418-a, # 07-02-00617-a, # 09-08-00743-a.

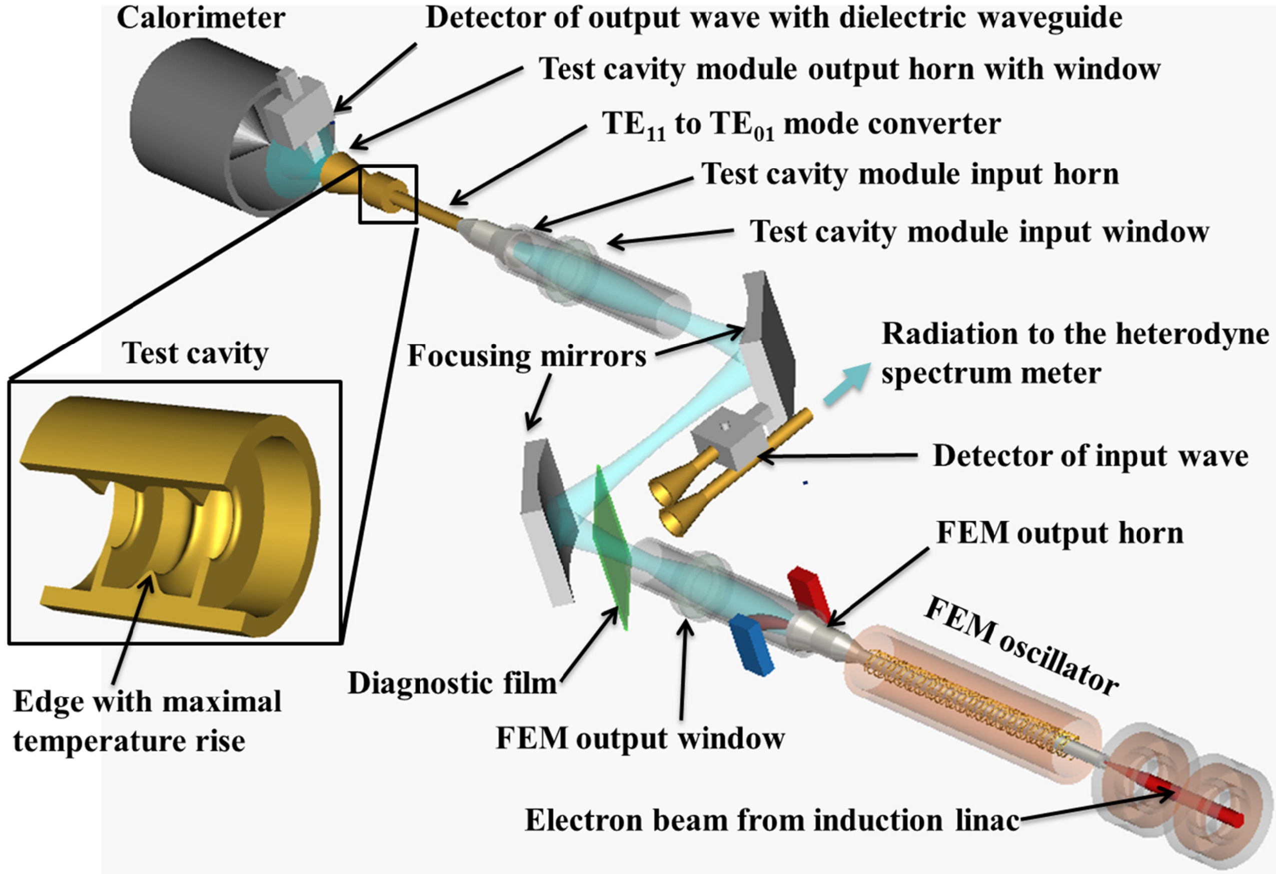

Figure 1. The layout of the experiment on 30 GHz copper cavity heating

EXPERIMENTAL RESULTS

Several full-scale experiments have been performed using created facility. Inner rings of the test cavity, which imitates the CLIC accelerating structure, have been manufactured from oxygen-free copper by turning with a diamond tool. Temporal and space variation of surface temperature inside the test cavity has been simulated numerically taking into account radiation parameters after the output horn. We have controlled a heating regime in each pulse, RF mode purity and the absence of the vacuum breakdown inside the test cavity. The maximal pulse temperature rise in different experiments was varied from 220ºK up to-250ºK with well-known decreasing along the surface according the distribution of near-surface magnetic field.

One feature of our experiments was the investigation of the dynamics of the surface damages appearance and development. We had controlled visually the surface of the inner ring after $1.6*10^4$, $3.2*10^4$, $4.8*10^4$ and $6*10^4$ pulses using optical microscope. After the experiment each ring has been cut into 6 sectors and investigated carefully by electron microscope. The first damages of a copper surface were observed after $1.6*10^4$ pulses [7]. After $6*10^4$ pulses the damage of the surface of the oxygen-free copper cavity became considerable enough to cause regular breakdowns inside the test cavity.

CONCLUSION

The experimental facility have been created consisting of the linear induction accelerator LIU-3000, the 30 GHz free-electron maser with the output power 15-20 MW, the wave transmission line, the diagnostics of an electron beam and RF radiation, the modernized system of data acquisition and control. The goal of these experiments was a correct choice of the material for the accelerating structure of the future electron-positron collider CLIC.

The distributed data acquisition system was constructed several years ago and demonstrated her versatility and reliability. Recently the some new possibilities were added, such as a remote control of the magnetic lenses power supplies and an active automatic start times control for the modulators.

The series of experiments have been fulfilled to investigate a copper cavity damages due to the repetitive action of the high-power RF radiation. A damage of a copper surface was observed after $1.6*10^4$ pulses with the pulse heating of 220ºK -250ºK. After $6*10^4$ pulses with a temperature rise of 250°K the surface of the oxygen-free copper cavity has been damaged strong enough to initiate the regular breakdowns inside the cavity.

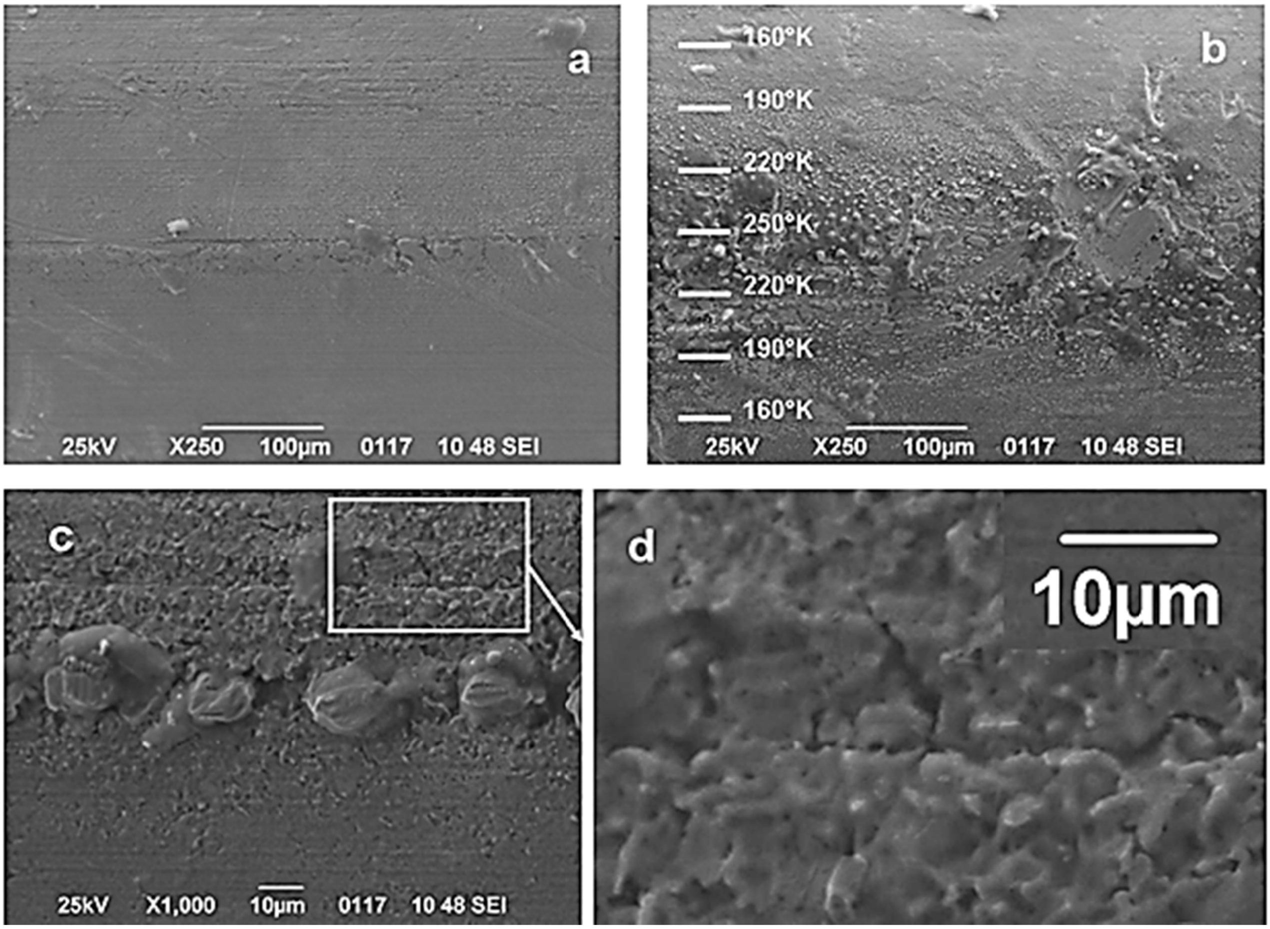

Figure 2. Scanning microscope image of the central ring surface before irradiation (a) and after = $4.8*10^4$ pulses with temperature rise up to 250°K (b). Images (c) and (d) show cracks observed after $6*10^4$ pulses with temperature rise up to 250°K.

The experimental results obtained using the facility can be useful not only for correct choice of the material for the CLIC accelerating structure, but for development of high-power microwave generators of any types if the magnetic field near the wall causes its high pulse heating [8].

REFERENCES

[1] I.Wilson - The compact linear collider CLIC – CERN AB-2004-100, CLIC Note 617, Dec. 2004, 12pp.

[2] D.P.Pritzkau, R.H.Siemann – Experimental study of RF pulsed heating on oxygen free electronic copper – Physical review special topics – accelerators and beams, 2002, vol. 5, p. 112002.

[3] A.V.Elzhov, N.S.Ginzburg, A.K.Kaminsky et al. - Test facility for investigation of heating of 30 GHz accelerating structure imitator for the CLIC project. - Nuclear Instruments and Methods in Physical Research, A, Volume A528, 2004, pp.78-82.

[4] N.I.Lebedev, A.V.Pilyar, N.V.Pilyar, et al. - Data acquisition system for lifetime investigation of CLIC accelerating structure - Dubna, Proceedings of NEC`2005, Dubna, JINR, 2006, pp.181-187.

[5] D.E.Donets, N.I.Lebedev, T.V.Rukoyatkina, S.N.Sedykh - Distributed control systems for modernization of JINR linear accelerators and HV power supplies of polarized deuteron source POLARIS – Proceedings of NEC'2007, Dubna: JINR, 2008.-pp.181-186.

[6] E.V.Gorbachev, V.V.Tarasov, A.A.Kaminsky, S.N.Sedykh - The Focusing Magnetic Field Stabilization System for LIU-3000 Accelerator – Proceedings of NEC'2007,- Dubna, JINR, 2008, pp.29-30.

[7] Yu.Yu.Danilov, N.S.Ginzburg, I.I.Golubev et al. - First full-scale result in CLIC-JINR-IAP RAS experiment on 30 GHz copper cavity heating -:Strong Microwaves: sources and applications, IAP RAS, Nizhny Novgorod, 2009, v.1, pp.230-235.

[8] M.Petelin, A.Fix – Comparison of metals in their steadiness to pulse-periodic microwave heating fatique – Vacuum Electronics Conference, 2009, IVEC 2009, p.163-164.