30 GHZ TEST FACILITY FOR EXPERIMENTAL STUDY OF ACCELERATING STRUCTURE DAMAGE DUE TO THE PULSE HEATING

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Abstract

The fatigue lifetime with respect to RF pulse heating is a problem of linear colliders. Experimental facility for scaling investigation of the fatigue damage for CLIC project has been developed at JINR, Dubna. It is based on 30 GHz / 20 MW / 200 ns. FEM oscillator with Bragg resonator which has been developed by the JINR-IAP collaboration. The paper presents an overview of FEM, the testing resonator, RF power transportation system, RF diagnostics as well as preliminary experimental results.

1 INTRODUCTION

The breakdown threshold and the pulse heating by the RF magnetic field give rise to the main limitation of the maximal accelerating gradient at the operating frequency of 10–35 GHz. Physical and technical peculiarities of these phenomena and corresponding restrictions are discussed in [1,2]. Up to date only a few amount of experimental data on the effect of the pulsed RF heating on the collider life time is available, belonging to the frequency range about 11 GHz [2].

Obtaining the similar experimental data is of importance for the CLIC project [3] (operating frequency 30 GHz). To solve this problem a special test facility is designed and manufactured at JINR (Dubna) jointly with IAP RAS (N.Novgorod). The required conditions are to be reproduced in the model experiment.

In this paper the features of the chosen facility scheme are described and preliminary experimental results are presented.

2 FEM OUTPUT PARAMETERS

The JINR–IAP FEM oscillator created at JINR on the base of the induction linac LIU-3000 (0,8 MeV, 220 A, 250 ns) will be used as the 30 GHz source of the test facility. The FEM magnetic system contains helical wiggler and solenoid. The regime of reversed guide magnetic field is realized in the oscillator [4]. The distributed feedback is provided by a Bragg resonator with a shift of the corrugation phase [4,5].

The significant technical modification of the oscillator was managed to provide the required FEM parameters: operating frequency about 30 GHz, power of RF radiation about 20–25 MW, RF pulse duration of 150–200 ns, frequency spectrum width of 0.1%, amplitude and pulse duration reproducibility about 90%, repetition rate of 0.5–1 Hz. It was designed and manufactured new assembly of the FEM resonator which was pressed out from thin-walled stainless tube instead of the previous one from the set of duralumin tubes. For precise measurements of the frequency and spectrum the RF signal was attenuated to milliwatt level. For resonance frequency measurements a heterodyne and a band-pass filter were used.

The signals from the detector were registered in series each of 500 pulses. During the experiments it has been measured 10500 pulses. Four characteristics were defined for every pulse: average power <*W*>, pulse duration <τ>, energy in pulse $\varepsilon = \int W dt$ and the temperature factor determined as $\xi = \int (W/\sqrt{t}) dt$ [2]. For each series the data were processed statistically, the averaged values and RMS dispersion were calculated.

The main results on the FEM oscillator investigation are presented in Figs.1–3.

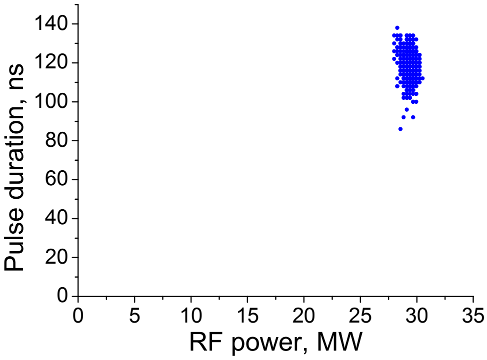

Figure 1: Power-duration distribution.

Fig.1 illustrates the stability of the RF power and pulse duration at the short series. One can see from the Fig. 1 that the required pulse duration at the nominal power and frequency are larger than 120 ns.

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In Fig. 2 the maximal pulse duration (more than 230 ns) with the power of 23 MW is illustrated. Trace 1 corresponds to power detector signal, trace 2 was measured by detector with 30 MHz band-pass filter.

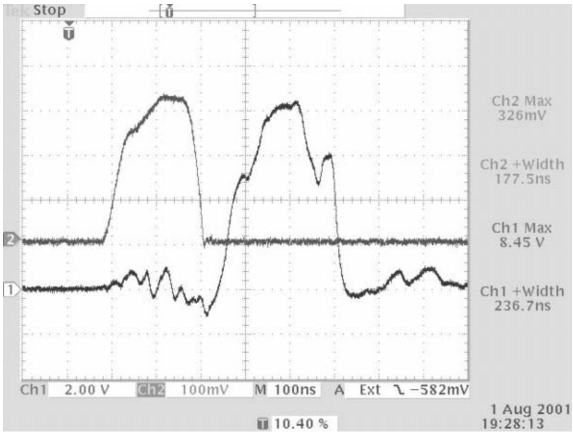

Figure 2: RF power pulses with and without filter.

In Fig. 3 the distribution of the pulses versus temperature factor measured in the short series is presented.

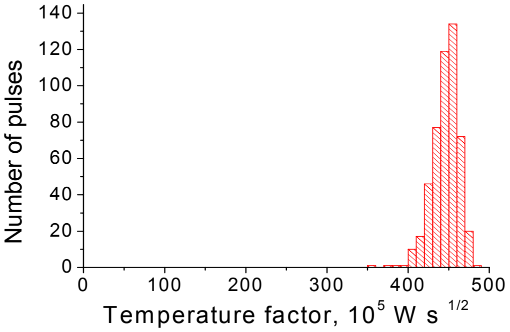

Figure 3: Distribution of the temperature factor.

The obtained RF pulse duration is close to the duration of the flat top of the linac voltage pulse. As it follows from Fig. 3 FWHM of the measured pulses gets into the demanded 10% interval in amplitude and duration values. The spectrum width of the measured signals was about 30–40 MHz, i.e. about 0.1%. The long-term stability should be improved.

3 ELECTRODYNAMIC STRUCTURE FOR STUDYING PULSE RF HEATING

The output radiation power of the existing FEM oscillator is considerably lower than the value required for powering the CLIC full-scale accelerating structure. So, in order to investigate the copper degradation undergoing 30 GHz pulsed heating, a special high-Q cavity with large local surface magnetic field is selected. The cavity surface is composed of two cones with a slot between these bases. Although there is the possibility of the precise FEM oscillator frequency tuning to fit to the accelerating structure, in our case the suitable frequency tuning is provided by the cavity slot variation. The 1 mm change of the cavity length results in ~1.5% change of its eigen-frequency and is followed with ~40% change of Q-factor.

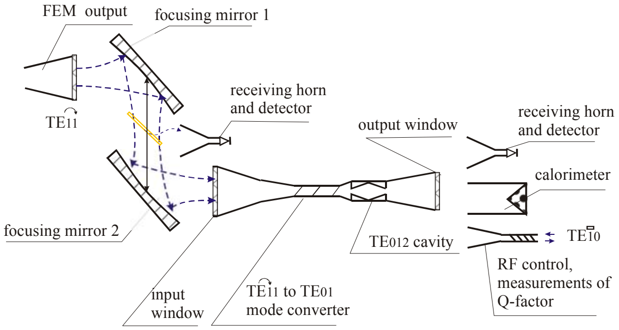

Figure 4: Scheme of the experimental layout.

As the operating mode of the cavity we chose the TE_{01} mode capable of providing also high breakdown threshold because of absence of electric field at the metallic surface.

The performed calculations showed that 30 GHz pulse power of 25 MW and duration of 100 ns provides a local surface heating of 215°C and 420°C for the cavity quality factors of 650 and 1200 respectively. On the other hand, the choice of testing cavity with the high Q-factor value sets a severe demands on a spectrum of the FEM oscillator. The scheme of the experimental layout is shown in Fig. 4.

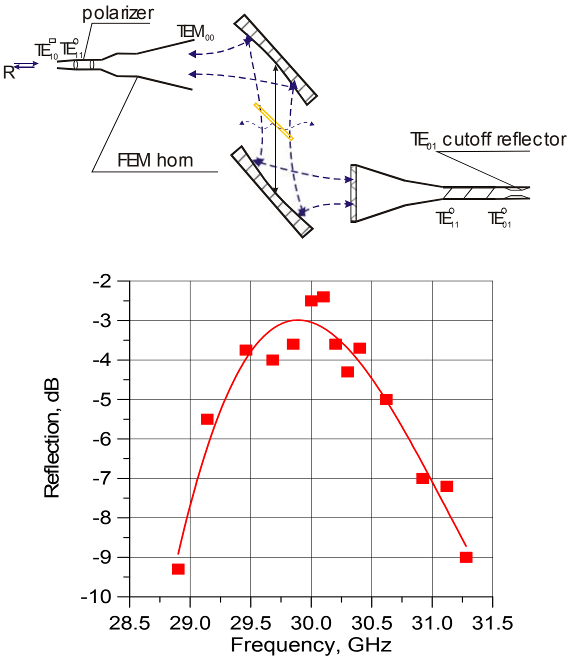

Figure 5: The results of the cold measurements of the transmissing line and the measuring scheme.

The FEM power is transformed from TE_{11} mode to Gaussian beam at the FEM output to reduce the wave beam divergence in the transmission system. By means of two elliptical mirrors the beam is matched to the input window of the resonator. A dielectric plate allows us to measure the incident and reflected RF power without disturbance of the wave beam at the FEM output. The inverse Gaussian beam transformation and the $TE_{11}\rightarrow TE_{01}$ mode converter are used to enter the radiation into the testing cavity.

The results of the cold measurements of the transmission line together with the flow plan is represented in Fig. 5 at the wide frequency band. In this case the reflective signal was registered and the cavity was replaced by the cut-off reflector. The similar measurements of the mode converter and testing cavity (Fig.6) were fulfilled at the narrow frequency band.

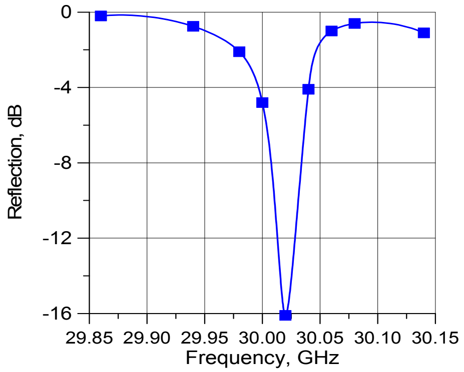

Figure 6: The results of the cold measurements of the mode converter and testing cavity.

One can see from these figures that the designed and manufactured transmission line has very small attenuation in the operating frequency range.

At present the complete transmission line is mounted and matched with the FEM oscillator (Fig.7).

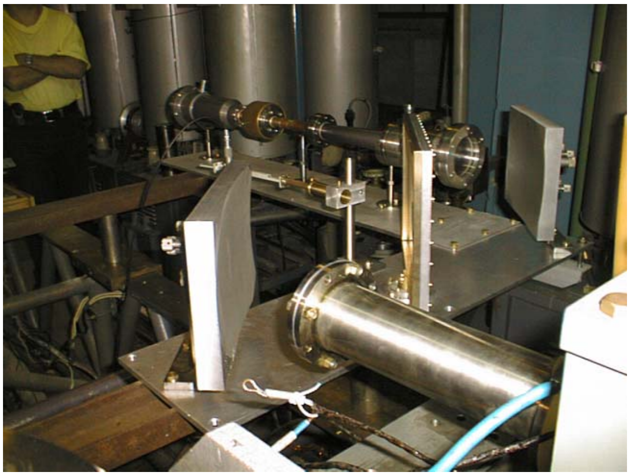

Figure 7: Scheme of the setup for investigation of the heating of the TE_{01} cavity.

4 CONCLUSIONS

An experimental facility for investigating the effect of copper degradation due to heating by pulsed 30 GHz radiation had been created.

The 30 GHz FEM was upgraded. The registration and analysis of more than 10^4 pulses of the microwave radiation of the FEM oscillator have been carried out. The required parameters: frequency band – 0.1%, pulse duration ~ 150 ns and good short-term stability are reached. The long-term stability is under consideration. A special high-Q cavity was designed and manufactured. The results of the cold measurements demonstrate the suitable parameters of the whole system.

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