STUDIES OF THERMAL FATIGUE CAUSED BY RF PULSED HEATING

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Abstract

A future linear collider with a multi-TeV level of energies of the collided particles in the center of masses is naturally associated with high frequencies and a high power RF level. One of the interfering factors in this way is an effect of copper damage due to multi-pulse mechanical stress caused by high-power microwaves. In order to get new information about this effect, we started an experiment with the test cavity fed by 30 GHz FEM oscillator (15-20 MW, 100-200 ns, 0.5 - 1 Hz). Now we finished the second phase of this experiment where the test cavity was irradiated by 0.1 millions of RF pulses with temperature rise ~50° C in each pulse. The third phase is the experiment with the temperature rise ~150° C and 1 million pulses. In the next planned experiment with 36 GHz magnetron (0.1-0.15 MW, 1-2 mks, 0.01 - 1 kHz) we are going to investigate the thermal fatigue in most interesting for collider application region of temperatures (30-50 C). It is expected that these two experiments will supply necessary statistical information for the developed theory of the thermal fatigue in order to extrapolate lifetime numbers to other values of the temperature rise and pulse duration.

INTRODUCTION

A future warm linear collider with multi-TeV level of energies of the collided particles in the center of masses is naturally associated with high RF frequencies and a high power level. One of the interfering factors in this way is an effect of copper damage due to multi-pulse mechanical stress caused by high-power microwaves [1]. This effect was experimentally observed at 11 GHz [2].

EXPERIMENT WITH 30 GHz FEM OSCILLATOR

In order to get new information about thermal fatigue at 30 GHz, we started a new experiment with the test cavity fed by 30 GHz FEM oscillator (15-20 MW, 100-200 ns, 0.5 - 1 Hz) [3-4]. The FEM output wave is the circular polarized Gaussian beam. This wavebeam is transported to the test cavity using a pair of confocal mirrors, the receiving horn, and the TE_{11} (rotating) to TE_{01} mode converter (Fig. 1-3). All these components, excepting the mirrors, are assembled in the vacuum evacuated vessel, separated from air by quartz resonant windows. Behind the output window of the system the special equipment (receiving detector, calorimeter, low power Q-meter) was installed.

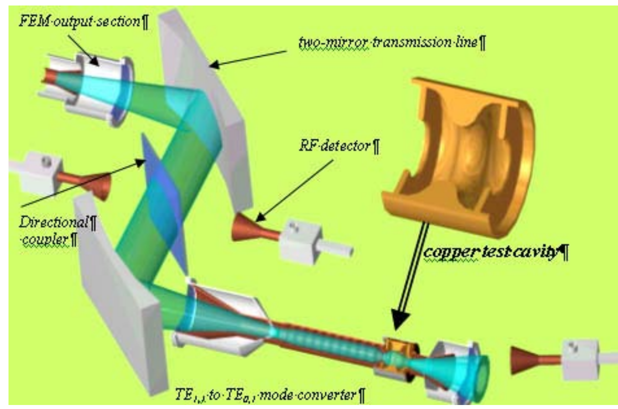

Figure 1: Scheme of 30 GHz experimental set-up.

The test cavity operates with the axis-symmetrical TE_{011} mode (Fig. 2). The loaded Q-factor equals Q_l=1200. In accordance with calculations the incident 25 MW pulse of t=200 ns duration causes 375° C temperature rise at central part of the cavity (H_{max}=1.1 MA/m). For this calculation it is assumed that frequency bandwidth of the pulse $\delta\omega$ is much less than ω/Q_l, where ω is an operating frequency. The measured frequency bandwidth (10-20 MHz) satisfies this condition.

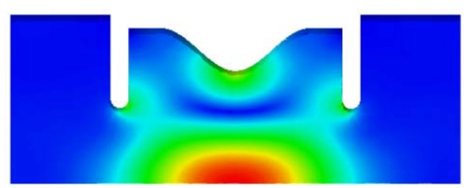

Figure 2: Magnetic field distribution at the used TE_{011} test cavity.

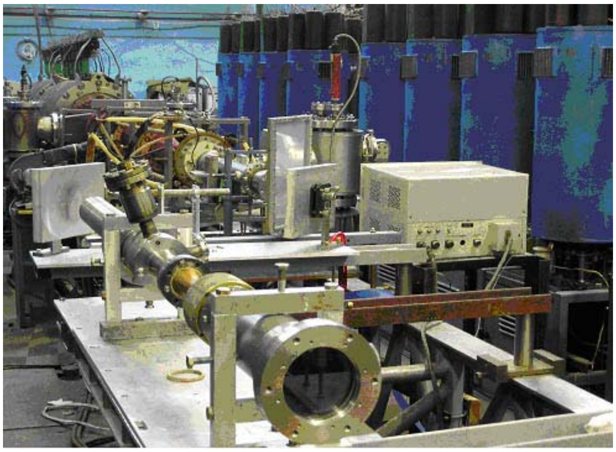

Figure 3: Photograph of experimental set-up.

Now we finished the second phase of this experiment where the test cavity was irradiated by 10^5 RF pulses. Unfortunately, transmission efficiency was less than the expected value because of breakdown in air which was regularly observed behind FEM's window (Fig. 4). In particular, we detected only 4-7 MW power of the beam transmitted through the test cavity (Fig. 5), the pulse duration ~70 ns was also limited by the mentioned breakdowns.

Figure 4: Breakdown in air at FEM output.

That is why, the temperature rise about 50° C was achievable during this phase of the experiment (Fig. 6). Of coarse, so small temperature with 10^5 pulses did not render any influence on the test cavity. Note that in Figs. 4-5 only 10% of total number received pulses is submitted.

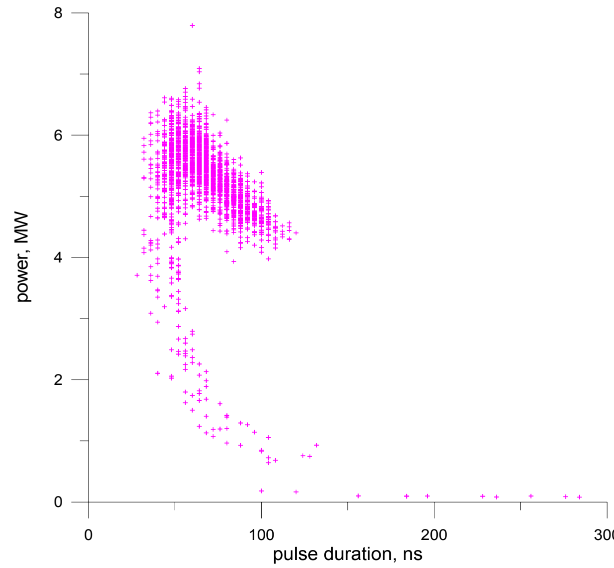

Figure 5: Statistical distribution of the transmitted RF pulses.

The third phase of the experiment will include a modified transmission line, an improved test cavity, and 10^6 total number of RF pulses. A new transmission line operates with 1.6 times bigger cross-section of the Gaussian beam in order to avoid any breakdown. A new test cavity has 2 times higher loaded Q-factor and more sharp edge where maximum magnetic field is achieved. The "belt' width is 0.3 mm. These two factors allow increasing by ~3 times the temperature in a surface of the cavity. Finally, we anticipate getting the information about thermal fatigue under ~150° C.

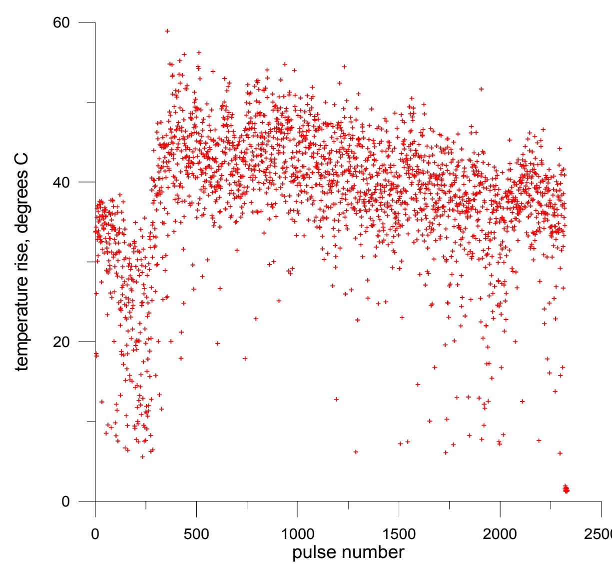

Figure 6: Statistical distribution of temperatures.

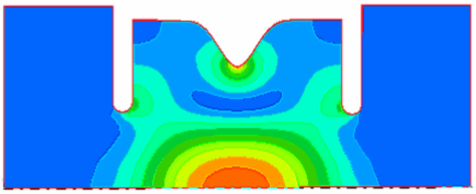

Figure 7: Magnetic field distribution at new TE_{011} test cavity.

EXPERIMENT BASED ON 36 GHz MAGNETRON

In the next planned experiment with 36 GHz magnetron (0.1-0.15 MW, 1-2 μs, 10^{-2} - 1 kHz) we are going to investigate the thermal fatigue at region of temperatures 20-50° C, which is most interesting in viewpoint of collider ‘s application.

The 36 GHz magnetron has approximately 100 times less output power in comparison with the 30 GHz FEM oscillator. However, an insufficiency of power is compensated by longer RF pulses and much higher repetition rate as well. The last circumstance is very important, because in accordance with theoretical predictions a number of pulses needed to destroy copper surface is given by [5]:

$$N_f = \frac{C}{\exp\left(\zeta \cdot \sqrt{\tau} \cdot \Delta T^2\right) - 1}, \qquad (1)$$

where ΔT is a temperature rise, τ is a pulse duration, C and ξ are constants. The less temperature rise, the more pulses are necessary in order to observe the fatigue. Therefore, high repetition rate is absolutely important in order to get the necessary statistical information during a foreseeable time.

The RF power of magnetron in a form of TE_{01} mode of circular cross-section waveguide is launched by means of a horn into an oversized waveguide (Fig. 8). In a middle of this waveguide the formed wavebeam has a plane phase front and comes off walls. This allows using a thin dielectric film under 45° as a directional coupler in order to control the incident as well as the reflected powers. These powers are coupled with receiving horns in air by means of big quartz windows which provide also additional mode selectivity of whole feeding system.

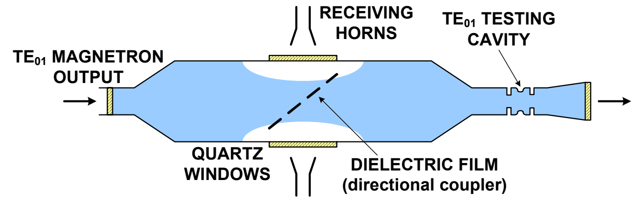

Figure 8: Scheme of 36 GHz experimental set-up.

The second receiving horn feeds the TE_{011} test cavity which is similar to the previously described ones. The mentioned cavity has the loaded Q-factor 3000 and a thin “belt” (0.2 mm) where the temperature reaches enough high value.

CONCLUSION

Two experiments to study thermal fatigue near 150°C and 30°C of temperature rises correspondingly are being carried out. It is expected that these two experiments will supply necessary statistical information for the developed theory of the thermal fatigue in order to extrapolate the lifetimes to other values of the temperature rise, pulse duration, and frequency.

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