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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CLIC NOTE 187

HIGH GRADIENT TESTING OF AN 11.4 GHZ ACCELERATING STRUCTURE FOR KEK / CERN LINEAR COLLIDER STUDIES

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Abstract

High gradient tests have been carried out at KEK on a CERN-built 11.4 GHz travelling-wave accelerating structure as part of a KEK/CERN collaboration on future high energy e^+e^- linear colliders. Peak and average accelerating gradients of 138 MV/m and 85 MV/m respectively were obtained after 50 hours of conditioning and were only limited by available power. The level of dark current at a field level of 50 MV/m was measured to be <1 µA.

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High gradient tests have been carried out at KEK on a CERN-built 11.4 GHz travelling-wave accelerating structure as part of a KEK/CERN collaboration on future high energy e^+e^- linear colliders. Peak and average accelerating gradients of 138 MV/m and 85 MV/m respectively were obtained after 50 hours of conditioning. The level of dark current at a field level of 50 MV/m was measured to be <1 μA.

Introduction

The accelerating section shown in figure1 was built at CERN and tested under high power (up to 55 MW) at KEK as part of a CERN / KEK collaboration on future high energy e^+e^- linear colliders. An obvious design aim for these machines is to make the main linacs as short as possible to keep the cost down - this implies high accelerating gradients; CLIC has chosen to operate at 80 MV/m, and JLC at 50-100 MV/m.

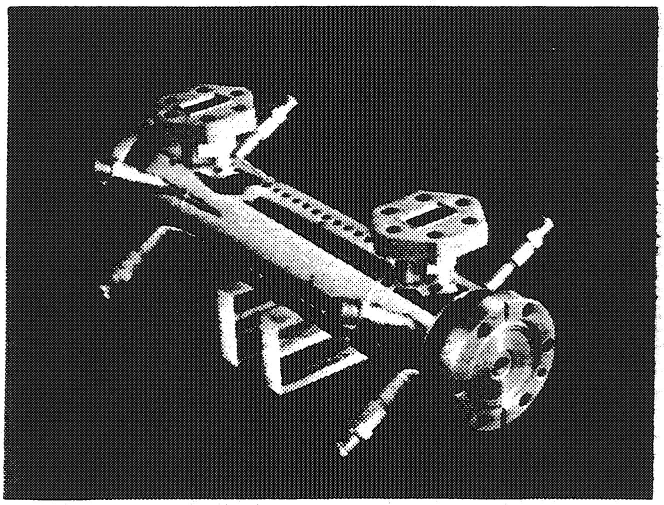

Fig.1 20-cell X-band Accelerating section

The 20-cell 11.4 GHz travelling wave section served both as a model for CLIC high gradient studies as well as a prototype for JLC studies. The operating frequency, which is 2.6 times lower than the CLIC frequency, was chosen because a high power klystron and pulse compression system has been developed for this frequency at KEK. Testing CLIC models at 11.4 GHz is more stringent than at 30 GHz because electrical breakdown thresholds decrease as the frequency is lowered.

Structure parameters

The shunt impedance of the section was chosen such that 30 MW of input power - the best estimate at the time for available power from the new X-band klystron - would produce peak accelerating gradients of 100 MV/m.
The target frequency of the constant impedance structure was chosen to be 11.424 GHz at 36.5°C in vacuum.

The structure parameters are given below
(* measured values)

Frequency	11.424 GHz
Mode	2π/3
Aperture (2a)	6 mm
Cell outer diameter (2b)	20.8 mm
a / λ	0.11
Cell length	8.745 mm
Iris thickness	2 mm
Shunt impedance	106.8 M Ω/m
Quality factor	* 6610
R'/Q	16.0 k Ω/m
Group velocity (v_g/c)	* 1.12 %
Field attenuation	* 1.64 Nepers/m
Power attenuation over section	* 0.63
Fill time	* 58 ns
Section length	0.1924 m
Number of cells	20 + 2
Ratio E_s/Ea (TW)	1.9

The peak and average accelerating gradients in the section as a function of input power are

$$Ea\ (MV/m) = 18.6 \sqrt{[P_{IN}(MW)]}$$
$$<Ea\ (MV/m)> = 16.0 \sqrt{[P_{IN}(MW)]}$$

Structure fabrication and RF tuning

The structure was fabricated using the machine-and-braze techniques developed at CERN for CLIC prototype accelerating sections [1]. The machining tolerances on all dimensions was 1-2 μm and the surface finish was < 20nm. A special feature of this fabrication technique is the use of copper-to-copper diffusion bonding to stop the flow of braze material both into the cell and out of the structure.
The section was dimple-tuned to give a phase-advance per cell of 2π/3 at 11.424 GHz. The VSWR after tuning was measured to be 1.08.

High gradient test facility

The CERN structure was tested in a high gradient test facility which was developed by KEK to evaluate the performance of X-band structures [2]. The experimental set-up is shown in figure 3. Forward, reflected and transmitted powers together with the level of the vacuum close to the structure were continuously monitored during the conditioning process. The upstream and downstream Faraday cups measured the time average values of dark current produced by the structure. The dipole analyser magnet together with an adjustable slit allowed the energy spectrum of the downstream dark current to be obtained. The transverse profile of the dark current could be seen on a TV monitor by inserting a scintillator screen into the beam tube. Five plastic scintillators placed along the length of the structure provided information on the X-ray flux.

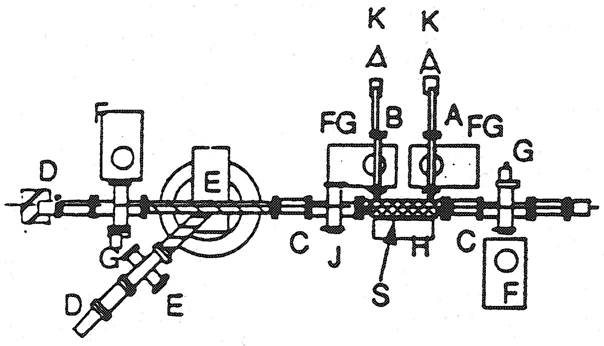

Fig.3 The X-band high gradient experimental set-up

The various components in the figure are A,B: RF monitors, C: current transformer, D: Faraday cup, E: analyser magnet and slit, F: 20 l/s ion pump, G: cold cathode gauge, H: plastic scintillator, J: profile monitor, K: TV camera, S: accelerating structure.

The conditioning process was performed in two stages. In the first stage the RF power came directly from the klystron until the output power limit of 18.5 MW was reached with pulse lengths of 100ns.

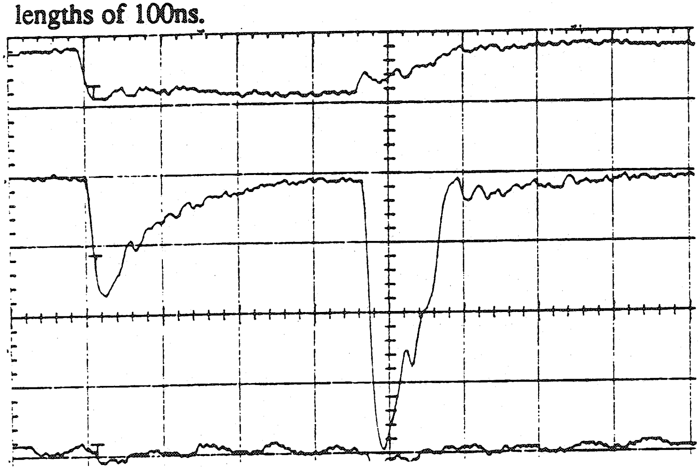

Fig.4 Voltage of compressed output power pulse

In the second stage the power was increased to 55 MW using a KEK pulse compression system [3]. A typical klystron input pulse and compressed output pulse are shown in figure 4. The compressed pulse is about 100ns long but is not flat. This makes the interpretation of measured data for the second stage of conditioning more difficult.

Conditioning and high gradient results

Figure 5 shows the conditioning history of the CERN structure. The 10^7 shots correspond to a total conditioning time of about 50 hours.

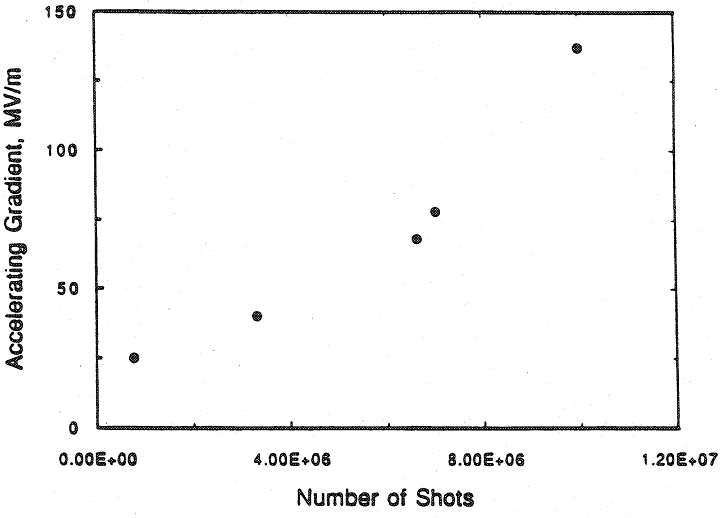

Fig.5 Conditioning history

The highest accelerating gradient achieved during the tests was 138 MV/m, limited only by the power available from the klystron with the pulse compression system in place. This maximum field occurred at the input of the section at the time of the maximum of the power pulse. After the 58 nsec fill time, the average accelerating gradient along the length of the entire section was 85 MV/m.

Figure 6 shows the results of measurements of maximum accelerating gradient obtained as a function of pulse length, taken at the end of stage 1 of the conditioning process.

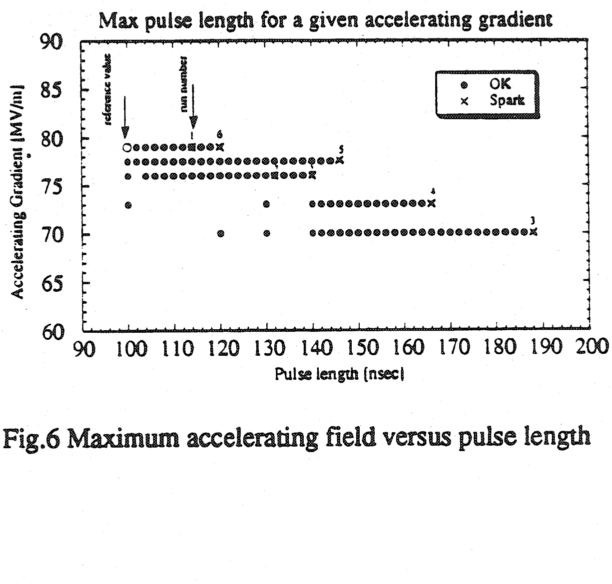

Fig.6 Maximum accelerating field versus pulse length

Data was taken by selecting an accelerating gradient then slowly increasing the pulse length until break-down occurred. Since breakdown levels are affected by conditioning history, a reference condition of 80 MV/m field, 100 nsec pulse length was re-established after each breakdown and before re-starting data taking. The data clearly show that maximum accelerating gradient decreases with increasing pulse length although the data is too limited to determine a functional dependence. The data is not inconsistent with the expected $t^{1/2}$ dependence.

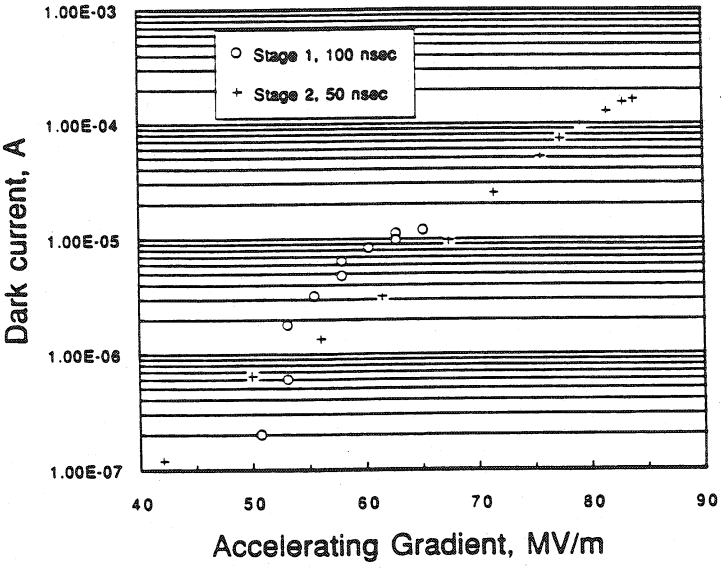

Fig.7 Peak dark current versus average accelerating gradient

The "peak" dark current plotted as a function of accelerating gradient is shown in figure 7. "Peak" refers to the dark current occurring *during* the RF pulse and is the measured Faraday cup current / (pulse length * repetition rate). The interpretation of results from the data taken during the second stage of conditioning is rather difficult due to the irregular shape of the compressed pulses. A Fowler Nordheim plot [3] derived from the stage 1 data presented in figure 7 is shown in figure 8.

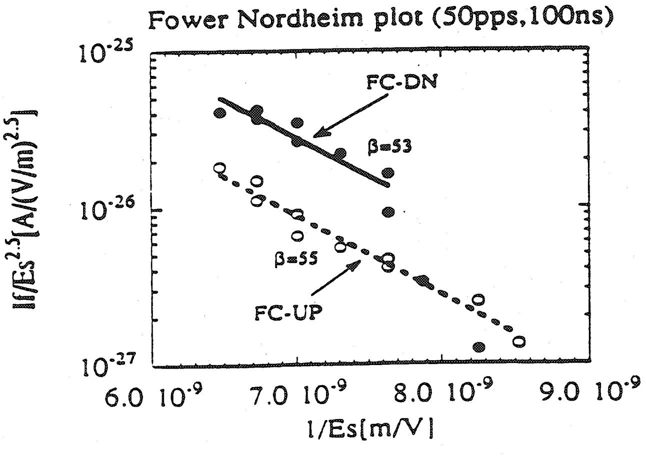

Fig.8 Fowler-Nordheim plot

Although the Fowler Nordheim β values of around 50 are similar to those reported for other 11.4 GHz structures [2,4] the dark current levels shown in figure 7 are somewhat lower. Such a result can be explained if the diamond machined surface of the CERN structure has similar, but fewer, emission sites compared to a normally machined surface. Unfortunately no independent test of this hypothesis is available.

The energy spectra of the dark current for various pulse lengths, figure 9, are very complex and difficult to interpret. However, the measured dark current energy cutoff of 11 MeV implies an average accelerating gradient of 61 MV/m, a result consistent with that expected from an RF input power of 15 MW.

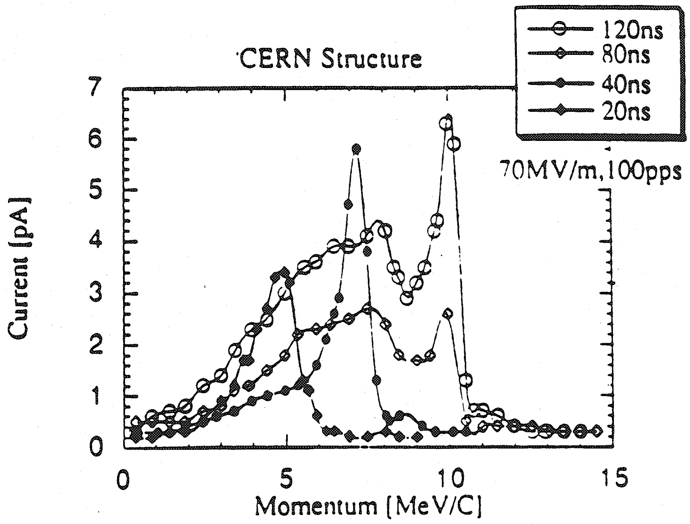

Fig.9 Energy spectra of dark current

Measurements at SLAC [4] have shown that dark current depends on the rise time of a power pulse. This is because a sharper input pulse has a frequency spectrum with larger high frequency components. The higher frequencies have lower phase velocity (phase velocity decreases with increasing frequency in a forward wave structure) and are consequently more efficient at capturing dark current.

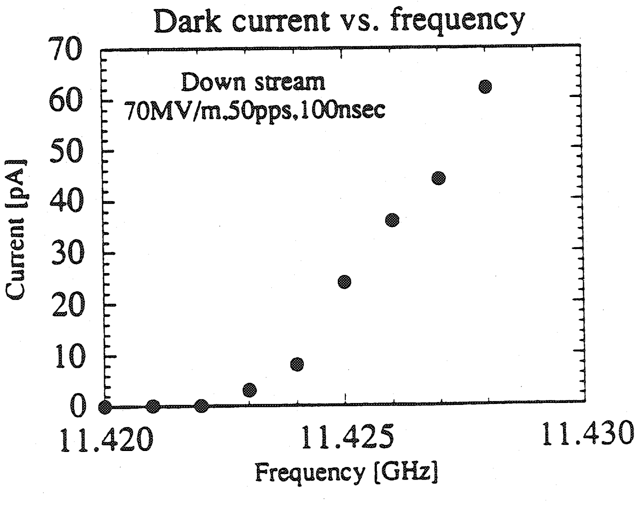

Fig.10 Dark current dependence on frequency

Unfortunately it was not possible to vary the rise time of the power pulse in a well controlled way in this experiment, so the effect was studied instead by varying the carrier frequency and measuring the dark current. Figure 10 qualitatively shows the expected frequency dependence of dark current capture in the neighbourhood of the $2\pi/3$ mode.

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