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Continued Conditioning of the Fermilab 400 MeV Linac High-Gradient Side-Couple Cavities.

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CONTINUED CONDITIONING OF THE FERMILAB 400 MEV LINAC HIGH-GRADIENT SIDE-COUPLE CAVITIES.

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Abstract

The high-energy portion of the Fermilab 400 MeV Linac is made of high gradient (37 MV/meter surface field) side-coupled cavity sections which were conditioned over a 10 month period before their installation in August of 1993. We have continued to monitor the conditioning of these cavities since that time while the cavities have been in operation, and those results are presented here. The sparking rate and the X-ray production are measured and compared with the 1992/3 pre-operational and 1993/4 early-operational measurements. These rates are consistent with a continued diminishing of these phenomena. Predictions and spark management strategies presented in earlier reports are evaluated in light of present experiences. We also have been measuring the sparking rate within this structure with and without our 50 mA peak beam. We find that the sparking rate is 20% higher with beam in the accelerator.

Introduction

During the fall of 1993, Fermilab commissioned seven side-coupled linac cavities as replacements for four of its original drift-tube cavities, resulting in a doubling of the linac's output energy. Achieving the acceleration necessary in the available space required gradients of up to 8 MV/m which led to maximum surface gradients of nearly 40 MV/m. These high fields raised concerns for RF breakdown, resulting in beam loss, and X-ray production, resulting in material degradation of surrounding components and possible personnel exposure in the conditioning area. Therefore, these two properties were monitored carefully [1, 2]. We have continued to monitor these quantities throughout their lifetime and report on them here.

The fundamental concern with RF breakdown is lost beam pulses. If the rate of RF breakdown were too high, it would impact the amount of beam delivered for p-bar production or for fixed target physics. Being the first accelerator of the Fermilab complex, it was desired that the losses be very low. The goal for the beam loss rate at the time of commissioning was 10^{-3}.

Conditioning History

The conditioning of the cavities started in the summer of 1991 in a separate shielding cave apart from the linac tunnel. The modules were placed in the cave individually and operated for a month or two until their sparking and x-ray characteristics were understood. In the fall of 1992 they were placed in the linac tunnel alongside the still running drift tube linac and operated there for about seven months. In August 1993, the old linac cavities were removed and the new ones were put into position and powered once again. From 27 August to 4 September of 1993 the new linac was commissioned with beam and has been running since.

Since it has the highest gradients, module 1 was conditioned first and has the most extensive information. Module 7, having the lowest fields, was never operated in the separate cave and has the least information. Daily logging of sparking data started in April 1994 and continues. Data were also collected during each modules initial turn-on in the separate cave, during February, and October-November of 1993.

During its initial conditioning in February of 1992, module 5's x-ray production was carefully measured. This was repeated in March of 1996.

RF breakdown

Figure 1 shows the spark rate for module 1 as a function of total accumulated pulses. The rate is shown as sparks per million RF pulses. One can see that initially there was a rapid cleanup. This cleanup has a characteristic time, τ, of of eleven days to decrease by $1/e$ with the cavities running at the nominal 15 Hz. The later measurements show that once the initial cleanup is done, a slower conditioning rate is evident.

Table 1 shows the maximum surface gradients for the modules. We assume the conditioning rate is dependent on the strength of the fields in the cavities and the quality of the surface of the high field regions. For module 1, τ of the long term conditioning is 365 days. (The cavities accumulate 1.3×10^6 RF pulses per day.) For module 3, τ is 630 days and for module 6 it is 8.8 years. Looking again at Table 1 the decrease of the sparking rate as the surface field decreases. In a previous report [1] we noted that

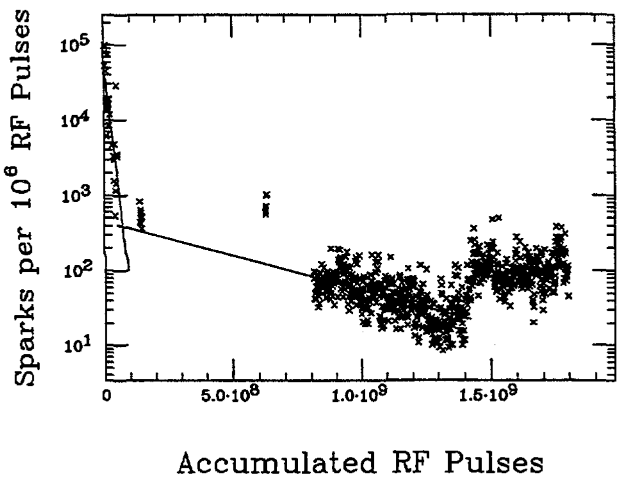

Figure 1: Spark Rate Evolution for Module 1

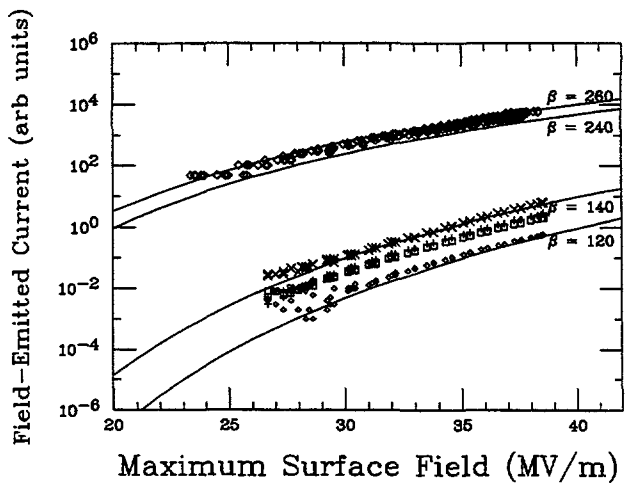

Figure 2: Beta Dependence of X-ray Production

Module	1	2	3	4	5	6	7
Max. Fld.	36.5	36.2	35.8	35.5	35.2	35.0	34.9
Spk. rt.	36	37	40	21	9	4	2

Table 1: Maximum surface field (MV/m) and average spark rate (sparks per 10^6 RF pulses) for the Fermilab Side-coupled Cavities. The spark rate is corrected for pulse length variation (see section on Pulse Length Dependence).

within a single cavity the sparking rate varied with the field to the 19.5 power. The data here indicates that more than just the field strength is at work as the reduction should only be a factor of 2.5 from module 1 to 7.

The much larger reduction evident here probably represents our learning to construct the cavities more cleanly as time passed. The tuning of the cavities also became more efficient as we gained experience. This meant that the cavities were open to the ambient air for shorter periods of time.

The above results refer to all cavity sparks recorded. The Fermilab linac pulses at 15 Hz whether or not beam is present. The question remains whether or not the presence of beam affects the sparking rate. We looked at this for data collected during a three week period of stable running in January and February of 1996. The raw sparking rate during that time was 273±15 sparks per million RF pulses. The rate of lost beam pulses during that time was 328±26 per million beam pulses. This indicates that the presence of beam increases the sparking rate by 20%.

Pulse Length Dependence

In a previous report [2] we reported on seeing a dependence between the length of the flat-top of the RF pulse and the sparking rate. We noted that the sparking rate increased as the fourth power of of the pulse length. The performance of the systems continues to be consistent with this finding. The break in Figure 1 at 1.4×10^9 shows the increase in sparking rate for module 1 when the flat top was increased from 45μsec to 80μsec. A thorough study of this phenomenon was not completed in time to produce statistically significant results for this report.

X-ray Production

At the time of initial conditioning, we made a thorough measurement of the relationship between the cavity power (and therefore the maximum surface field) and the x-ray production. Recently we repeated that measurement. Figure 2 displays the results. The topmost set of data points are the 1992 data. These were taken by a single detector placed by the middle of the module. The lower groups are the 1996 data, taken by four detectors each placed near the middle of each section of the module. The lines on the plot show the Fowler-Nordheim equation for the RF case [3].

$$j_F = \frac{5.7 \times 10^{-12} \times 10^{4.52\phi^{-0.5}}}{\phi^{1.75}}(\beta E_s)^{2.5} \times exp(-\frac{6.53 \times 10^9 \times \phi^{1.5}}{\beta E_s})$$

The lines represent different values of beta which is a measure of the enhancement of the electric field due to geometrical effects on a microscopic level compared to the measured macroscopic surface electric field. To make absolute comparisons, we would have to know the area of the emitting surfaces as a function of the field in that area. We do not know this, but we feel that the curvature of the lines and the plotted data gives an indication of the average beta of the field-emitting surfaces. The change in the shape of the plots would indicate that the effective average beta has been reduced by approximately a factor of two. In addition, comparing the actual x-ray measurements we see a reduction of an order of magnitude after the three years of running which would indicate that the area associated with these high microscopic fields is being reduced.

Summary

The new side-coupled cavities of the Fermilab linac upgrade have performed very well. The beam loss rate due to sparking of .03% is well below our target of .1%. The sparking rate continues to improve, indicating that conditioning is continuing. This is also evident in the measurements of the X-ray production. Measurements indicate that the field emission sites are getting cleaner and are getting smaller in area.

Acknowledgments

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