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WAKEFIELD MEASUREMENTS OF SLAC LINAC STRUCTURES AT THE ARGONNE AATF

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Abstract

Damped and detuned linac structures designed to minimize the effects of wakefields excited by $e^{\pm}$ bunch trains in future linear colliders are presently under investigation at SLAC. This paper describes the results of measurements of both longitudinal and transverse wakefields performed at the ANL Advanced Accelerator Test Facility with two SLAC-built X-Band disk-loaded waveguides: a conventional 30-cavity long constant-impedance structure and a non-conventional 50-cavity long structure along which the iris and spacer diameters have been varied so as to stagger-tune the HEM_{11} mode frequency by 37%. The results are shown to be in excellent agreement with computations made by KN7C [1], TRANSVRS [2], TBCI [3], and LINACBBU [4].

I. WAKEFIELD CALCULATION FOR FUTURE LINEAR COLLIDER STRUCTURES

Among many parameters, the design of accelerator structures for future linear colliders is constrained by undesirable effects produced by short- and long-range wakefields. These wakefields are of two types, longitudinal which produce energy spread, and transverse which produce cumulative emittance growth. The short-range fields affect particles within a single bunch while the long-range ones affect particles from bunch to bunch. In this paper, we concern ourselves with the long-range wakefields. Indeed, machines in the TeV energy range will require trains of at least 10 bunches, spread over hundreds of RF cycles per pulse, because single-bunch colliders cannot reach the desired luminosities of 10^{33}-10^{34} cm^{-2}sec^{-1} unless the single-bunch populations exceed 10^{11} $e^{\pm}$. At these levels, the single-bunch effects become very difficult to control. While the short-range wakefields are only a function of the iris diameter and number of disks, the effect of long-range wakefields depends on their coherence and attenuation. At the present time, it is believed that their control will be achieved by a combination of built-in "decoherence," i.e., detuning of high-order modes (HOM), and damping by letting them escape into lossy outer regions where they can be attenuated without affecting the fundamental accelerating mode. The damping technique has been described in an earlier paper [5].

Within certain limitations, wakefields can be calculated by existing computer programs: in the time domain, via TBCI for cylindrically symmetric cavities, and MAFIA for three-dimensional cases; through field-matching techniques, via KN7C for monopoles, and TRANSVRS for higher even-poles. LINACBBU computes wakefields from an input set of mode frequencies, loss factors k, and Q's.

From these, it is possible to calculate the wake potential, i.e., the time-varying integrated effect of the wakefields of a driving bunch on a trailing test particle or another bunch. To gain confidence in these calculations, two practical SLAC-built structures were tested at the Argonne Advanced Accelerator Test Facility and the results compared with theoretical predictions.

II. THE EXPERIMENTS AT THE ARGONNE AATF

The characteristics of the two SLAC structures which were tested at the Argonne National Lab AATF are given in Table 1 and Table 2, respectively.

Table 1. Constant-Impedance Disk-Loaded Structure

Fundamental frequency (GHz)	11.424
Iris diameter 2a (cm)	0.750
Cavity diameter 2b (cm)	2.117
a/λ	0.143
Disk thickness t (cm)	0.146
Length (cm)	26.25
Phase shift per cavity	$2\pi/3$
Normalized group velocity (v_g/c)	0.033
Shunt impedance (MΩ/m)	98

Table 2. HEM_{11}-Detuned 50-cavity Disk-Loaded Structure

Iris diameter 2a range (cm)	1.22 - 0.83
Cavity diameter 2b range (cm)	2.72 - 2.01
Disk thickness (cm)	0.159
Cavity height (cm)	0.794
HOM_{11} frequency range (GHz)	11.4 - 16.7
Fractional detuning	37%

The first structure was a complete copper section which had been tested earlier in the Relativistic Klystron program at LLNL [6]. The second structure was a simple array of 50 aluminum cylinders and disks (made out of sheet metal) stacked inside a concentric S.S. vacuum pipe. The dimensions of the 50 cavities in the range given in Table 2 were chosen to fit a Gaussian HEM_{11} frequency population of the form $p(f) \propto \exp[-(f-f_0)^2/2\sigma_f^2]$ where f_0 is the center frequency (14.45 GHz) and $\sigma_f = 1.07$ GHz is the standard deviation. The goal of distributing the frequency population in such a manner

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was to obtain an exponentially decaying envelope of the wake potential in the time domain. With a total number of cavities N (50), the frequency difference Δf from cavity to cavity was given by $\Delta f = (2\pi)^{1/2} \sigma_f/N \exp (f-f_0)^2/2\sigma_f^2$. A short program was used to calculate all the cavity dimensions centered around f_0 within a $\pm 2.5\ \sigma_f$ range. Note that the resulting structure was not a true accelerator in that the fundamental mode was not fitted to be synchronous with the velocity of light. This was not important since the goal of the experiment in this case was to study the decoherence rate or decay of the HEM_{11} and other higher-order modes as a function of time.

The two experiments were carried out sequentially at Argonne within a period of several months. The AATF, which is shown schematically in Fig. 1, has been described at an earlier conference [7].

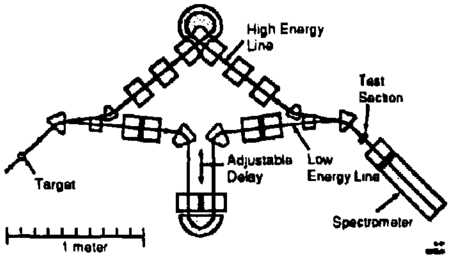

Figure 1. Plan view of the Advanced Accelerator Test Facility at Argonne. Beam line magnets are dipoles (shaded) or quadrupoles (open).

The sections to be tested are inserted, under vacuum, in the shown location, and the wake potentials are obtained by varying the time separation between the driving bunch and the witness bunch within a range of 0 and 1 nsec. A vertical-bend double-focusing spectrometer measures the energy variation of the witness bunch in the vertical plane and its horizontal position in the horizontal plane: the former yields the longitudinal wake potential, the latter gives the transverse potential as the structure is carefully swept in the horizontal plane by means of a remotely controlled carriage. The $\Delta p/p$ resolution is ~ 0.1%, the $\Delta p_\perp$ resolution is ~ 15 keV (~ 1 mrad). Fast electronic frame-grabbers digitize the beam spots in the focal plane, and a data processing program yields the analyzed data.

The experimental results for the longitudinal and transverse wake potentials of the constant-impedance structure are shown in Figs. 2 and 3 together with the computer predictions from KN7C and TRANSVRS, using 32 and 30 modes, respectively. We see that agreement is very good. For example, the measured transverse wake potential amplitude of 60 MV/nc/m^2 for a cavity with length of 0.875 cm and a full transverse offset of 0.375 cm, taking into account Gaussian bunches, gives an amplitude of 3.8V/pc/cell which is very close to the calculated value (4V/pc/cell). It is also interesting to note the excellent agreement of the experimental frequencies obtained from a Fast Fourier Transform with the calculated frequencies (see Fig. 4).

In the case of the second structure, we only show experimental data for the transverse wake potential since the structure was not designed to be an accelerator (see bottom of Fig. 5).

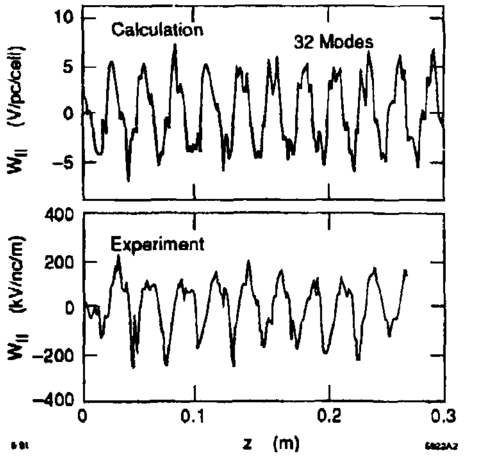

Figure 2. Longitudinal wake potential for the 30-cavity X-Band disk-loaded structure ($a/\lambda = 0.143$). TOP: Calculation by KN7C from a sum of 32 modes ($\sigma_z = 0$) for one cell. BOTTOM: Measurement result at AATF ($\sigma_z \approx 2.5$ mm) per unit length.

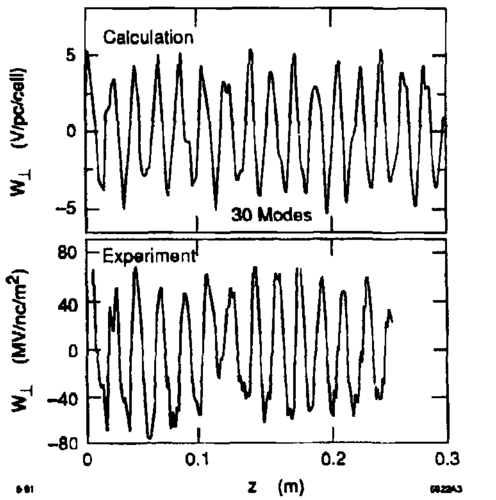

Figure 3. Transverse wake potential for the 30-cavity X-Band disk-loaded structure ($a/\lambda = 0.143$). TOP: Calculation by TRANSVRS from a sum of 30 modes ($\sigma_z = 0$, full offset = 0.375 mm) for one cell. BOTTOM: Measurement result at AATF ($\sigma_z \approx 2.5$ mm) per unit length.

The top of the figure shows the result of a theoretical calculation obtained by using LINACBBU as discussed in Ref. [8]. In this calculation, the wake function per unit length is simulated by summing the modes over the 50 frequencies present in the 50 cells. The amplitudes of all the modes are assumed to be equal. The actual propagation from cavity to cavity is neglected. Note also that in the real structure, the amplitude of the individual wakefields increases towards the output end of the structure since the transverse fields vary as a^{-3}. Despite these shortcomings of the model, we see that the temporal agreement between theory and experiment is excellent.

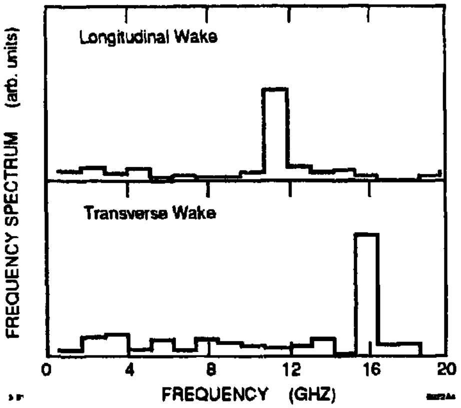

Figure 4. Frequency spectra of measured longitudinal (top) and transverse (bottom) wake potentials for the 30-cavity X-Band disk-loaded structure ($a/\lambda = 0.143$)

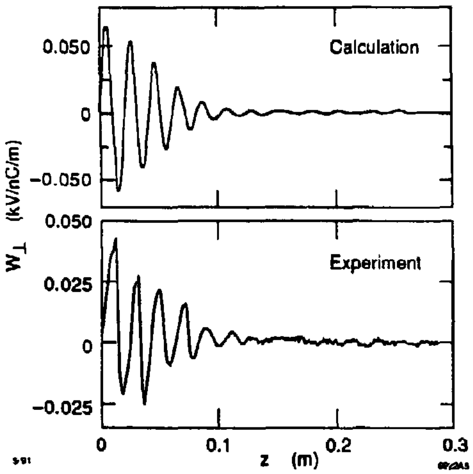

Figure 5. Transverse wake potential for the HEM_{11}-detuned 50-cavity disk-loaded structure. TOP: Calculation by LINACBBU ($\sigma_z = 0$). BOTTOM: Measurement result at AATF ($\sigma_z \approx 2.5$ mm).

III. CONCLUSIONS

The agreement between wakefield computer programs and experiments done on two SLAC structures at the Argonne AATF is very satisfying. It gives confidence in our ability to design structures and verify their behavior in a realistic physical environment. It opens the way to testing future structure designs which will incorporate both detuning and damping as well as fabrication errors, and which may therefore be too complicated to model with the required accuracy. In this regard, it would be very desirable if the AATF could be upgraded to allow an even larger time separation between the driving and the witness bunch, maybe as large as 3 nsec!

IV. ACKNOWLEDGEMENTS

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