Fermi National Accelerator Laboratory

TM-1522

Application of the Argonne Advanced Acceleration Test Facility to Development for Conventional Accelerators*

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April 7, 1988

*Expansion of remarks made at the Advanced Acceleration Test Facility Workshop, Argonne National Laborabory, Argonne, Illinois, April 6-7, 1988. To be included in proceedings of same.

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

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Abstract

The Argonne Advanced Acceleration Test Facility is designed as a powerful tool to test ideas for very high gradient acceleration schemes based on direct beam excitation of plasmas, metal structures, dielectrics, *etc.* The characteristic size in these systems is $\sim$ 1 cm, corresponding to frequencies $\sim$ 10 GHz. The question addressed here is whether the special features of this facility have application as well to the development of components for the more conventional, lower frequency, accelerators now operating or under development. It is suggested that the usefulness of the facility for the development of conventional systems could be enhanced by a provision for longer time delay between driver and witness beam pulses.

1 Introduction

The Argonne Advanced Acceleration Test Facility (A^3TF) has been developed to investigate acceleration and focusing by wakefields in plasma, metal structures, dielectrics, *etc.* The scale of the devices of interest is $\sim$ 1cm, *i.e.*, the lowest rf modes are in the 10 GHz range. Wakefields at such frequencies are also of interest in existing accelerators in the contexts of beam stability and stochastic cooling. The Chemistry Division linac, which provides the beam for A^3TF has been used by Fermilab and Los Alamos in tests where lower frequencies were important also.[1] The mode structure of an L-band disk-and-washer accelerating structure was studied with beam excitation.[2] The frequency response, sensitivity, and position sensitivity of the stochastic cooling pickups for the Fermilab Antiproton Source were measured[3], and a prototype beam current pickup for the Fermilab main ring and Tevatron was evaluated.[4] It is interesting to consider whether the new facility adds to the information one can obtain for such devices. Another question is whether the properties of objects like special vacuumchamber sections, which are designed to have low coupling impedance, can be explored effectively.

*expansion of remarks made at the AATF Workshop held at Argonne National Laboratory 6–7 April 1988

The layout of the A^3TF is shown in the figure. Two beamlines divide from a partially intercepting target placed in the 21 MeV beam from Argonne's Chemistry linac. The 21 MeV branch transports more than 90% of a single bunch which has ~5 ps width isochronously to a 1 m test section. A 15 MeV bunch of about 10^{-3} of the 21 MeV intensity is also transported isochronously through a variable length line and recombined with the the high intensity bunch just before the test section. The high intensity bunch called the driver is used to excite a test object. The wakefields left by the driver accelerate and focus the following witness pulse. The variability of about two feet in the length of the 15 MeV line provides for arbitrary delay between driver and witness. The energy change of witness and driver can be simultaneously determined in a magnetic spectrometer. The spectrometer also provides a measurement of the deflection of the witness beam. The salient properties of the facility are summarized in the table. A more complete description is given in the proceedings of the last linac conference.[5] It adds to the capabilities of the Chemistry linac in five distinct ways:

- low current witness pulse separated from driver by arbitrary time separation 1.8 to -0.2 ns and arbitrary transverse (vertical) offset 0–1 cm
- momentum analysis of driver and witness
- measurement of witness deflection
- very short pulse length $\rightarrow$ 5 ps
- time-resolved momentum analysis of beam

The features combine to make a powerful tool for the study of centimeter-scale systems with large coupling impedance; they may also open new approaches to problems in evaluation of components for conventional systems.

Possible applications to component development will be discussed qualitatively. The workshop ethos is assumed to prevail so that I am not to be held accountable for some naïveté.

2 Likely Candidates for Beam Coupling Measurements

In the discussion of particular examples the following questions recur in one form or another:

- Is the object intended to couple strongly to the beam?
- What sensitivity is required?
- Is the object intended as a $\beta = 1$ structure?
- Does the object have an electrical output that provides the needed information?

- What is the frequency range of interest?
- How long do wakefields persist?
- Are physical dimensions compatible with test section and beam profile?

Besides these more or less technical questions there will be practical considerations influencing a decision on whether to make the effort required for reliable beam measurements. In many cases there will be some information available from calculation, bench tests, or extrapolation of prior experience. The interest in obtaining complementary and possibly more credible information from beam measurements will depend on how critical the component is and on the ease in making the additional measurements. The latter point is one which raises questions for the A^3TF management. For example, how much effort is justified in maintaining flexibility in arrangements at the test section? On what time scale will A^3TF and the Chemistry Division be willing to respond to requests from outside? What level of support is to be provided for interfacing and installing heterogeneous hardware? If A^3TF management contemplates developing support among a broader segment of the accelerator community, it should consider whether it risks upsetting an orderly research program in novel accelerator techniques through competition for hardware resources and diversion of manpower.

There follow hereafter remarks on various things one might reasonably want to stick in the ANL electron beam. The ordering is approximately from less to more problematic. If the logistics are not prohibitive, even quick checks of items supposed to be well understood could be useful to catch unwarranted assumptions.

2.1 Beam Pickups

For a beam current pickup, beam position monitor, or stochastic cooling electrode array the foremost question is usually how the device sees the beam. Thus, the information required is obtained from the device as built; no witness beam or driver beam spectrometry is needed. Even the pulse shortening provided by the upstream buncher is unlikely to be very important because the spectrum of any bunch that the linac produces extends well beyond the range that the electronics attached to the detector can measure. As long as the bunch shape and total charge are measured adequately the absolute value of the excitation is known to any frequency of interest. The role of the facility in this case becomes primarily that of providing control of the beam, longitudinal phase space measurement, and a convenient test section.

Charge sensitivity, position sensitivity, and the character of reflections can all be measured in a direct and obvious way. Electronics similar to that used before the construction of A^3TF can be used.[1] Because 1 nC per ps is 1 kA, the measurements, although straightforward in principle, require care to avoid spurious coupling through the electronics, cabling, *etc.* When the response above a few hundred MHz is important, the beam excitation technique becomes especially attractive because wire excitation substantially alters the system measured.

For short pickups the match between beam velocity in the test and in the application is unlikely to be an issue, but for cooling arrays the design β has to be close to one.

2.2 Accelerating Structures

The development of an optimum accelerating structure for a linac is a search in a many-dimensional parameter space by a combination of calculation and hardware modeling/prototyping. For the major modes the agreement between calculation and resonances measured in a prototype is generally very good, and even the results of three dimensional calculations for the effect of coupling slots, stems, *etc.* are often reasonably close. Detailed calculations are a major project, however, and the characterization of all modes in a complex structure by low level rf measurements is difficult. Thus, there are likely to be uncertain identifications and some modes found by one means not seen by the other. In this situation the existence of a third technique, even if it too has significant limitations, is attractive as a way to resolve discrepancies.

If the structure to be tested is designed for $\beta = 1$ the analysis of witness momentum change and deflection translates rather directly into performance characteristics. However, if one wants to interpret the response as a sum of various modes one needs the measurements of the wakefields extending many wavelengths behind the driver. When the structure is for lower β, the modal analysis is the only way to extract information. Beam excited modes can of course be detected by using probes in the structure and its rf input port, but the absolute value of the coupling impedance is not directly accessible. Even so, information from probes is likely to be interesting as supplementary data even when results can be obtained with the witness beam.

The witness technique can not be as sensitive to weakly excited modes as low level rf measurement is. Nevertheless, it has a special advantage, *viz.*, the capability of studying the deflecting modes in a direct way. By passing the driver through the structure well off axis dipole (and higher) modes are strongly excited. The ability to favor excitation of one or another mode symmetry should be helpful in clarifying mode identification and evaluating deflecting mode impedance. The facility will measure transverse wake potential directly. By rotating the structure the beam dipole can be oriented to find the effect of asymmetries like supports, coupling slots, mode suppressors, *etc.* This is an area in which both low level rf measurements and calculations are tricky.

2.3 Vacuumchamber and Miscellaneous Devices

Generally the vacuumchamber and the miscellaneous devices put into it will be designed for low coupling to the beam, but objects like fast kickers will unavoidably introduce significant impedance. Because of complex shapes and sometimes because of the presence of ferrites *etc.* the properties of special devices can be difficult to calculate. If the coupling impedance of a single such device is large enough to cause difficulty a beam measurement at A^3TF should be sensitive enough to measure it. However, if one wants to measure the effect of distributed items like bellows or the beampipe itself which become significant only in aggregate, there generally will not be sufficient sensitivity to get useful information from pieces short enough to fit in the test section. Nonetheless there are indirect approaches by which A^3TF can add to the understanding of low-impedance structures. The structure of interest can be replaced by a test structure which exaggerates in an understandable way the features expected to contribute to beam coupling. The exaggeration may increase the size of a perturbation or the number of times it occurs in a given length. The interpretation of results from a perturbation repeated several times in a short space must take proper account of coherent excitation (interference). From a measurable result one can attempt to extrapolate directly to the original case of interest. A more indirect but, one hopes, ultimately more fruitful approach is to use A^3TF to give results for a variety of similar cases that can be calculated. If a computer program or method of calculation can be validated for a variety of cases similar to one that can not be measured directly, the results of a calculation using that method has greatly enhanced credibility. For this reason one hopes that there will be a program of comparison between calculation and measurements carried out at A^3TF for code validation. Eventually it may become possible to rely on calculation in a much wider range of situations.

There is an old topic at Fermilab which may be acquiring some new significance in relation to proposed high intensity medium energy accelerators like the European Hadron Facility. To reduce eddy current heating and high frequency mode losses these machines are being designed with costly dielectric vacuumchambers internally coated with a pattern of conducting strips. In the Fermilab Booster the beampipe was simply eliminated so that the beam interacts directly with the magnet laminations. Perhaps to the surprise of some this works rather well. For beam current $\sim$ 200 mA the penalty is primarily something less than 100 kV of extra rf required and no indication of serious beam dynamics problems. There have been at least four analytical treatments of Booster $Z_{||}$ which use differing techniques to get generally similar results.[6],[7],[8],[9] There have also been beam observations observations and wire measurements of Booster magnets in rough qualitative agreement with the calculations. The observations do not carry the comparison to very high frequency, however. Because the structure is very lossy the wakefields should be rather short range and probably of less significance for low frequency instability than the large magnitude suggests. If the dynamic consequences of disposing of the vacuumchamber were known to be manageable from reliable measurement, the designers of the new machines might happily buy the necessary increment in rf with a fraction of the savings.

3 Conclusions and Suggestions

There are both specific applications and problems of general interest to the designers and operators of accelerators of conventional design which can be addressed by experiments at A^3TF. Beam detectors, accelerating structures, special devices, and validation of numerical techniques have been cited. However, for conventional accelerators the frequencies of interest typically extend well below 1 GHz and resonant Q's may be such that wakefields persist for milliseconds. Therefore, the single most useful addition to the present facility for these problems would be a provision for much longer delays between driver and witness. Simply the ability to put a second bunch in an arbitrarily chosen bucket following the first driver would go far in meeting this need because the availability of a small range of negative delays in addition to the standard positive delay of the witness would make it possible for a witness produced by the second pulse to sample a small range of times before the second driver reaches the test object. If a kicker could be developed to remove the second driver from the high energy line it would enable the wakefields to be measured for essentially any time of interest.

How useful measurements of the type discussed in this note can be may be fully apparent only after some trials. There has been no intention to suggest that it is trivial to integrate a device into a foreign vacuum system, measure small electrical signals in the vicinity of a high current pulsed accelerator, and determine wakefields from digitized beam images from the spectrometer. By appropriate test cases we can expect to uncover difficulties; there is also the prospect of demonstrating benefits from an independent line of attack on important problems of long standing.

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DRIVER		
Energy	21.	MeV
Charge	(2.) 5.	nC
Bunch width	(9.) 5.	ps
ε_L	$\sim$ 6.	keV ps
ε_T	10.	π mm mrad
r_{rms}	1.6	mm
Δz_{rms}	1.1	mm
$\beta^*_{x,y}$	0.3	m
WITNESS		
Energy	15.	MeV
Charge	$\sim$ 1.	pC
Time delay	-0.2–1.8	ns
$\beta^*_{x,y}$	1.	m
SPECTROMETER		
Momentum acceptance	$\sim$ 100 .	%
Momentum resolution	0.1	%
Deflection sensitivity	$\sim$ 0.5	mrad
LINAC		
RF	1.3	GHz
Cycle (max.)	800.	Hz

Table Principal Parameters of the Argonne Advanced Acceleration Test Facility (Figures in () refer to current performance.)

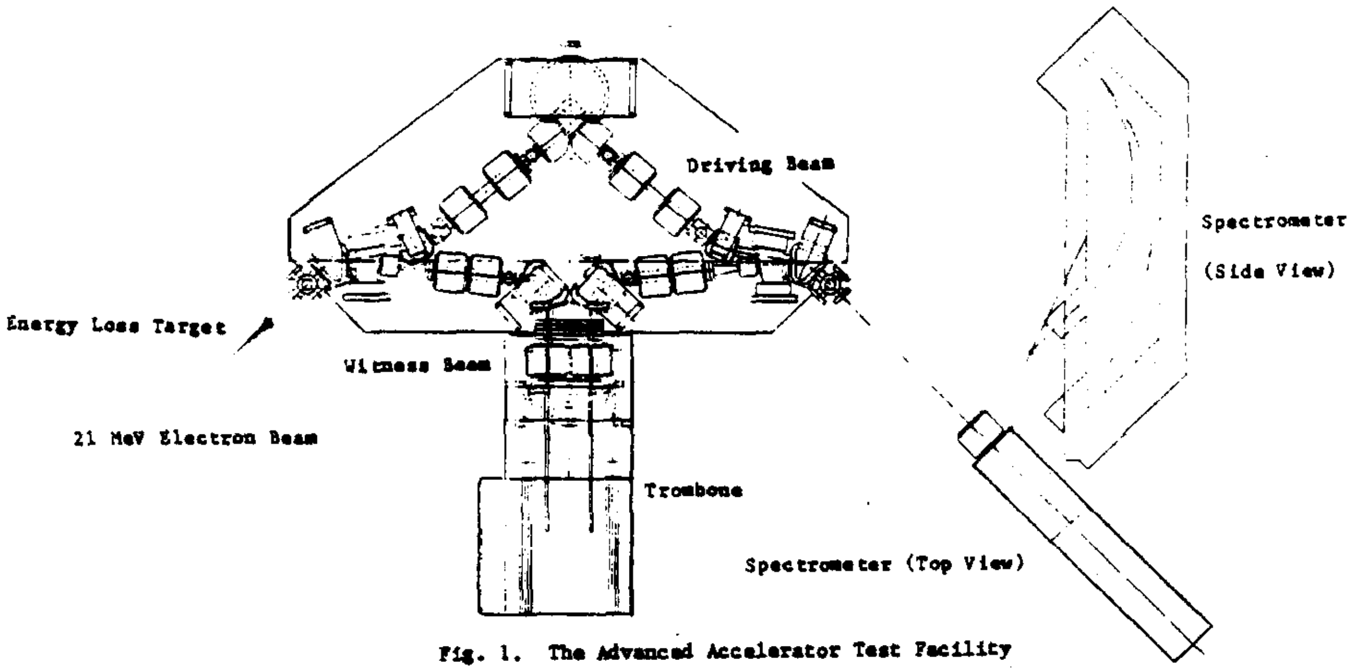

Fig. 1. The Advanced Accelerator Test Facility

Figure Layout of Argonne Advanced Acceleration Test Facility (from 1986 Linac Conference Proceedings)