# EXPERIMENTAL TESTING OF THE TTF RF PHOTOINJECTOR

E. Colby, M. Conde, J. Rosenzweig, University of California, Los Angeles
P. Colestock, H. Edwards, K. Koepke, F. Nezrick, Fermi National Accelerator Laboratory*

*Abstract*

Results from the experimental testing of the prototype TESLA Test Facility (TTF) RF photoinjector are summarized. Preliminary measurements of the performance of the injector indicate that, with refinement, the design values for the transverse emittances ($20 \times 20\pi$ mm-mr) are not unrealistic, with uncompressed transverse emittances of $40\pi$ mm-mr having been obtained under somewhat less ideal circumstances than those simulated. Preliminary pulse length measurements with and without the pulse compressor suggest pulse compression, but further study is required.

## 1 INTRODUCTION

The TTF linac is a 0.5 GeV super-conducting L-band accelerator designed to test engineering issues associated with constructing and maintaining a super-conducting linear collider. Two injectors have been designed and built for beam tests of the linac[1], the first a low bunch charge (37 pC) thermionic injector producing 8 mA average current to test the RF feedback, beam line and control systems, the second a high bunch charge (8 nC) RF photoinjector also producing 8 mA, but in 1 kA peak current bunches to probe wakefield losses at cryogenic temperatures.

A prototype injector was built, similar in all respects to the planned TTF Injector except duty cycle, to test the single-bunch beam dynamics issues associated with producing reasonable quality high charge bunches with short pulse lengths (1 mm)[2]. Testing of the prototype injector occurred in two phases. The 1.625 cell RF gun was tested initially alone, with a short beamline with charge, profile, emittance and energy diagnostics. Studies of the gun under variations of the launch phase, bunch charge, and solenoid field were made to test the PARMELA model used to design the injector.

Once tests of the gun alone were completed, the 9-cell booster linac and pulse compressor were added. Charge, profile, emittance, energy and bunch length diagnostics were installed along the beamline to permit testing of critical issues such as “freezing” of the transverse emittance at the space charge correlation corrected value, emittance preservation, and pulse compression.

## 2 RF TESTS OF GUN AND LINAC

Cold-test measurements of the gun have been presented elsewhere[3]. RF conditioning proceeded with the the $4\mu$s long RF pulses from the AWA RF system, with sample traces shown in figure 1 below. It is clear from the loop signals that the gun cavity is still filling when the RF pulse ends, with the result that the $\emptyset$-mode of the cavity may well still be weakly excited when beam is launched, giving a field imbalance.

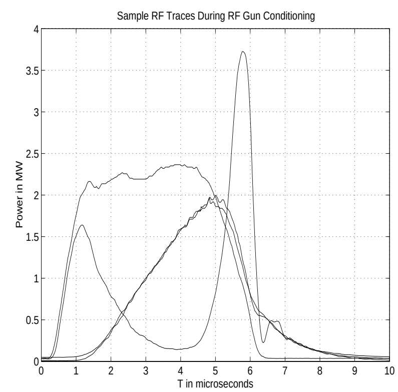


Figure 1: RF Forward, reverse and loop traces from gun during conditioning.

The booster linac was fabricated from a cold test model of the TTF super-conducting 9-cell cavity, made from copper rather than niobium. Cooling tubes were bonded to the cavities with thermally conductive epoxy, a high power input coupler was designed and mounted to the central ($5^th$) cell, as opposed to the beam-tube coupling used in the super-conducting case. A clamping assembly was added to tune subgroups of the cells to achieve field balance. The opening in the central cell for power coupling drastically changed the field balance qualities of the structure, requiring significant retuning. The final field profile, coupler mounted and properly coupled, is shown in figure 2 below.

The linac was conditioned to 10 MW (giving an estimated field of 15 MV/m) with $4\mu$s pulses, again only very incompletely filling before the end of the RF pulse. The field imbalance present during the fill (and hence during beam) may well be the reason the beam energy was lower than expected (17 MeV measured, versus 19 MeV computed).

## 3 GUN BEAM TESTS

Gun beam tests were devoted to understanding the various technical issues associated with commissioning an injector. Specifically, the alignment of the solenoids and the transverse effects of launch phase, gradient and solenoid focussing field. Measurements of the horizontal emittance as a function of solenoid strength are shown in figure 3 be-

* Operated by the Universities Research Association, Inc., under contract for the U. S. Department of Energy

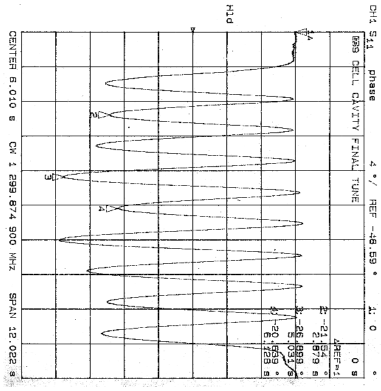

Figure 2: Final field balance condition of 9-cell booster linac cavity.

low. Poor laser spatial characteristics and wide laser amplitude variations made measurements prone to substantial fluctuation. Attempts to gate data to a limited charge range around the target value of 8 (or 10) nC using charge data from a gun-mounted integrating current transformer helped, but could not eliminate the spatial profile problems.

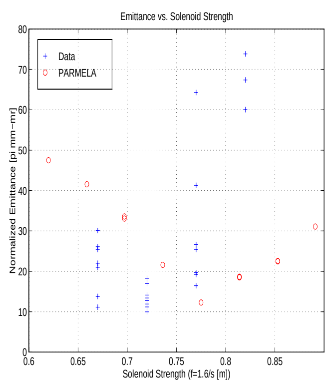


Figure 3: Measured and calculated transverse emittances measured at 3.5 MeV

It is suspected that the narrow acceptance of the $10\mu$m wide slits used in this emittance measurement scraped off the most divergent particles, resulting in potentially large underestimates of the emittance. Emittance slits were widened to $35\mu$m on these grounds.

Gun shunt impedance is estimated from beam energy measurements to be 19 M$\Omega$/m, as compared with the Superfish calculated value of 24.6 M$\Omega$/m, a discrepancy arising from two factors: first, the calculated shunt impedance assumes $\beta = 1$ throughout, whereas the electrons slip nearly $\lambda/8$ against the RF wave as they accelerate, and second, imperfections in the cavity itself.

## 4 INJECTOR BEAM TESTS

The bunch energy spectrum was measured for a variety of gun and linac phasing conditions to establish correct phases for optimal energy operation and the correct offset phase for pulse compression to occur. Measured energy profile for the beam is shown in figure 4 for the case of maximum energy (beam uncompressed). Comparison of the calculated (1.5%) and measured (1.5%) energy spreads shows good agreement.

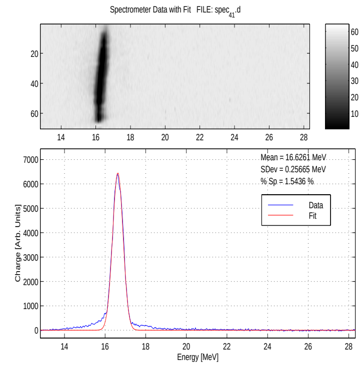


Figure 4: Energy spectrum of uncompressed 8 nC bunch at end of injector.

Transverse emittance was measured after the booster linac (before the pulse compressor) for several launch phases and several solenoid settings, with the results shown in figures 5 and 6. Again, wide fluctuations in initial beam parameters induced by laser fluctuations contributes to the substantial error bars on the measurement.

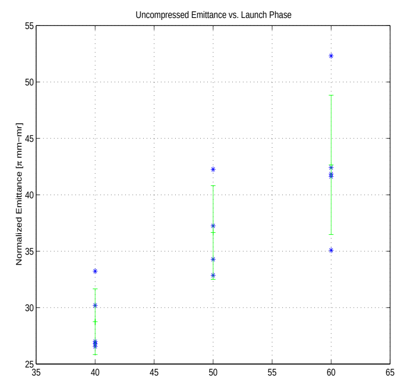


Figure 5: Emittance measured for several launch phases.

The spatial uniformity of charge emission from the cathode was measured and discovered to be rather sharply peaked toward the center of the cathode. Rough patches were observed on the cathode surface suggesting arc damage, and occurring in a concentration close to center of the cathode, which prompted a careful polishing of the surface with $0.3\mu$m alumina to obtain a smooth but optically poorly reflective surface for emission. Re-measure of the quantum efficiency after the polishing showed improved uniformity, and absence of the central peak.

A novel Čerenkov emitter was tried and found to produce excellent light output. A 3mm thick block of Aerojel,

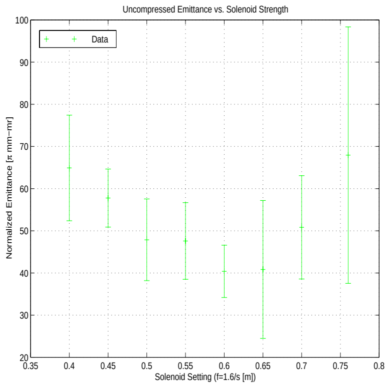


Figure 6: Emittance measured for several solenoid field focal lengths.

mounted in a special pressure cell to prevent damage from the vacuum, was installed after the pulse compressor to permit measurement of compressed and uncompressed bunch lengths. Light from the radiator was transported some 15 meters to a Hamamatsu streak camera with a nominal resolution of 1 ps. Preliminary analysis of the data indicate pulse lengths on the order of 2 mm at best, with some evidence of pulse compression observed, but detailed analysis of the data remains.

## 5 HIGH POWER TESTING AT FERMILAB

Following decommissioning at Argonne, the injector was partially reassembled at Fermilab to enable continued testing until the high duty cycle gun is fabricated. Ultrahigh vacuum tests and long-pulse tests have been completed, with the gun attaining a resting vacuum in the upper $10^{-10}$ Torr range, and a running vacuum in the mid $10^{-9}$ Torr range with $50\mu$s pulses of 3.5 MW at 5 Hz. Gun Conditioning to RF pulse lengths as long as $400\mu$s at full power has been completed. Dark current is estimated to be $\sim 4-6$ mA, with the specific source of the dark current still under investigation.

## 6 DESIGN IMPLICATIONS

Several design concerns have been addressed with the high power, extended RF pulse operation for the Argonne gun, namely, the proof that water-turbulence induced wall vibrations within the RF cavity produce no measurable cavity phase shifts, and that excellent running vacuum, of particular interest for operation with exotic photocathode materials such as $Cs_2Te$, is attainable without modification of the gun. The suspected large dark current, however, may point to the need to redesign the cathode electrical contact altogether, with a resonant RF trap replacing the choke spring currently in use.

Wakefield effects have recently been calculated using a modified version of PARMELA, with the results indicating that further advance of the phase of the linac is needed to overcome the short-range wakefield, which tends to cancel the phase-energy correlation needed for pulse compression, with the gun and linac irises contributing the largest wakefield kicks of all the beamline components. A collimator, planned in the initial design, has been found in simulations to effectively double the entire longitudinal wake in the injector, prompting its removal.

## 7 FUTURE EXPERIMENTS

Re-commissioning of the old injector for continued testing at Fermilab will continue until the high duty factor gun is complete. Laser facilities[4] will be completed early this summer. Testing of the full injector under both single pulse and full macropulse conditions will be top priority through early 1998, with the commissioning of the high duty cycle RF photoinjector DESY occurring shortly thereafter. A second, similar photoinjector, being fabricated in parallel with the first, will allow an advanced accelerator research and development program to continue after injector II ships to DESY. Thomson-scattering based picosecond x-ray source and plasma acceleration experiments will begin preparations for planned beam experiments to begin in earnest by late 1997 in the AØ building at Fermilab.

## 8 ACKNOWLEDGEMENTS

The authors wish to gratefully acknowledge the members of the Argonne Wakefield Accelerator group, and in particular Jim Simpson and Wei Gai, for their hosting of this prototype experiment at the AWA facility.

## 9 REFERENCES

[1] TESLA Test Facility Linac - Design Report, D. A. Edwards, Ed., TESLA-95-01, (1995).

[2] E. Colby, F. Ostiguy, and J. Rosenzweig, Fermilab TM-1900, (1994).

[3] E. Colby, *et al*, IEEE Part. Accel. Conf., 1995, p. 967-9.

[4] A. Fry, *et al*, in these proceedings.