HIGH-PERFORMANCE ACCELERATORS FOR FREE-ELECTRON LASER (FEL) AND SECURITY APPLICATIONS*

A. Todd#, H. Bluem, V. Christina, M. Cole, D. Dowell†, K. Jordan†, J. Park, J. Rathke, T. Schultheiss and L. Young†, Advanced Energy Systems, Medford, NY, USA.

Abstract

We describe the status of two accelerators that Advanced Energy Systems (AES) has designed and built, and is presently installing prior to commissioning. One system will drive the THz Free-Electron Laser (FEL) at the Fritz Haber Institute (FHI) of the Max Planck Society in Berlin, while the other will produce radiation for CBRNE (chemical, biological, radiological, nuclear, and explosive) detection applications. A key aspect of the required FEL accelerator performance is low longitudinal emittance, < 50 keV-psec at 200 pC bunch charge, from a thermionic electron source. The other system is compact, robust and efficient since it must be transportable.

INTRODUCTION

AES has recently designed and built high-performance accelerator structures for FEL applications and CBRNE detection. These standing-wave (SW), on-axis-coupled structures are tailored to their applications. Both utilize gridded thermionic guns to achieve their respective performance, which is quite dissimilar. The top-level performance requirements of the FHI FEL [1] are given in Table 1. The most stressing parameter is the 50 keV-psec longitudinal emittance from a thermionic gun. This required designing in special features that are described below. A rather unusual requirement for the CBRNE system [2] is that it must be transportable, which in turn leads to special design-driving considerations of robustness, compactness, efficiency and weight.

Table 1: FHI FEL Top-level Design Specifications

Parameter	Unit	Specification	Target
Electron Energy	MeV	20 - 50	15 - 50
Energy Spread	keV	50	< 50
Energy Drift per Hour	%	0.1	< 0.1
Charge per Pulse	pC	200	> 200
Micropulse Length	psec	1 - 5	1 - 10
Micropulse Repetition Rate	GHz	1	1 & 3
Micropulse Jitter	psec	0.5	0.1
Macropulse Length	μsec	1 - 8	1 - 15
Macropulse Repitition Rate	Hz	10	20
Normalized rms Transverse Emittance	π mm-mrad	20	20

In order to meet the requirements of these systems, we determined to use a gridded thermionic gun. Such a gun is sufficiently rugged for the CBRNE system and capable of optimization to meet the taxing transverse and longitudinal phase space requirements of the THz FEL. We have selected a CPI IOT gun as the source for these devices [3]. We report the testing performed to date with such a gun. This is followed by brief discussions of the designs and progress towards commissioning of both the CBRNE and THz FEL systems.

GRIDDED ELECTRON GUN TESTING

Figure 1 shows a 1 GHz gridded gun in test at AES. The upper right corner beam spots are the idle current beam (left) and the RF-tailored spot (right) that is of interest. The different energy beam spots are separated by a steering magnet. Our high-voltage gun power supply uses a fast switch to suppress this idle current between macropulses. The lower left beam spot is the pinhole image from our emittance measuring system.

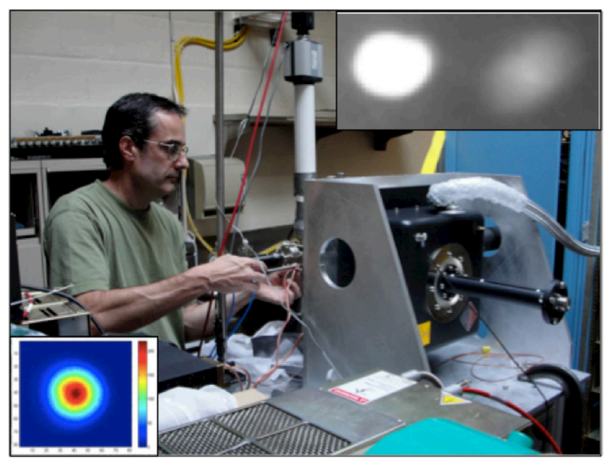

Figure 1: Gridded gun testing in progress at AES.

We have performed emittance measurements, for which pinhole data is shown in Figure 2, at voltage levels up to 32.5kV. Our nominal system operating voltage will be 45 kV. After processing, these indicate the beam transverse rms emittance is 8-10 mm-mrad at 20kV. These results are consistent with our previously reported gun simulations [4].

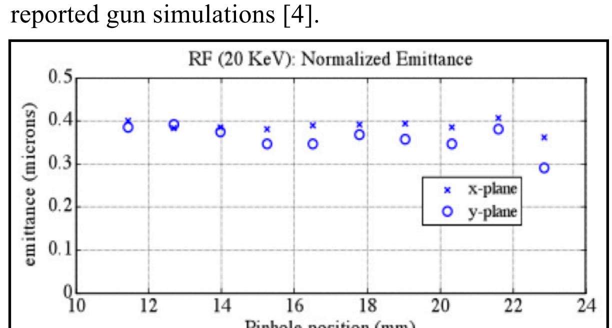

Figure 2: Electron gun pinhole emittance data.

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# alan_todd@mail.aesys.net
† Indicates Consultant

We have also studied the dependence of the extracted current as a function of RF power applied to the gun at 18kV. After the initial transient phase, near linear behavior is observed in Figure 3. The maximum values achieved were 214mA at 32.5kV and ~ 100W input RF power, and 806mA at 23.2kV and ~ 200W input RF power.

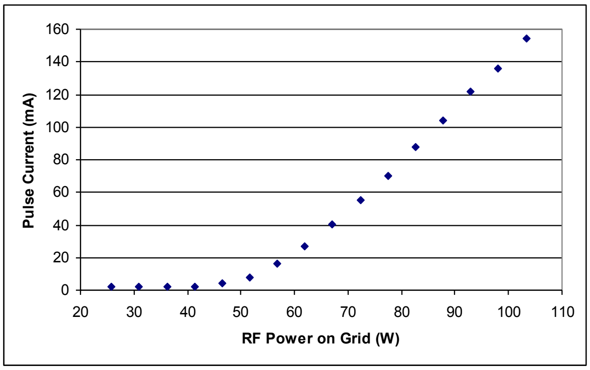

Figure 3: Pulse current as a function of grid RF power.

CBRNE SYSTEM

The accelerator-based CBRNE system is a transportable successor to the Reference [2] material of Figure 4. A conceptual accelerator driver for this device is illustrated in Figure 5. It is being developed for Raytheon Integrated Defense Systems [5].

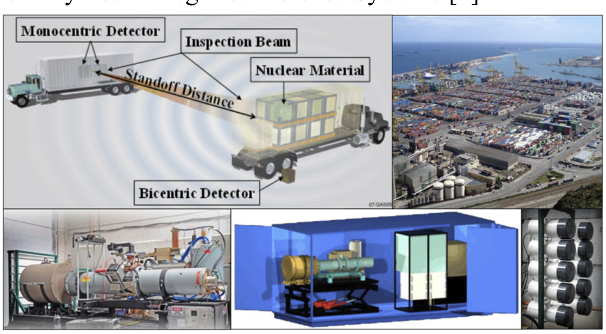

Figure 4: CBRNE detection scheme.

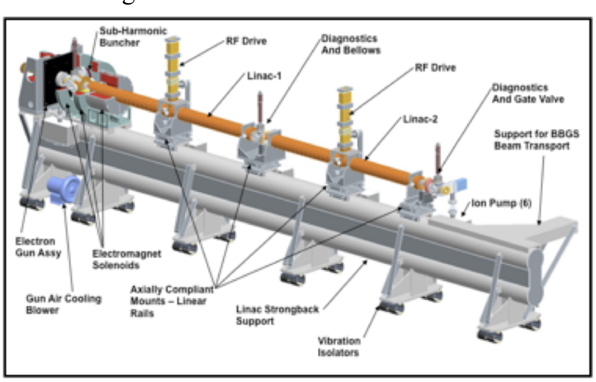

Figure 5: CBRNE conceptual accelerator segment.

FHI THZ FEL

The Fritz Haber Institute (FHI) and the Max Planck Society will celebrate their Centennials in October 2011. Coincident with this event, the FHI Department of Molecular Physics will christen a THz FEL that will operate from 3 to 300 microns. The FEL linac, with the gridded thermionic gun described above, will operate from 20 to 50 MeV at 200 pC, while delivering a transverse rms emittance of 20 mm-mrad in a 1 psec rms, 50 keV rms energy spread bunch at the wigglers. Mid-IR and Far-IR wigglers enable this electron beam to deliver the required radiation spectrum. In addition to the longitudinal emittance, a key design requirement is the minimization of the micropulse and macropulse jitter to ensure radiation wavelength stability and timing consistency for pump probe experiments. The top-level parameters for this system and their "stretch" values were given in Table 1. Design considerations were previously covered in Reference [4].

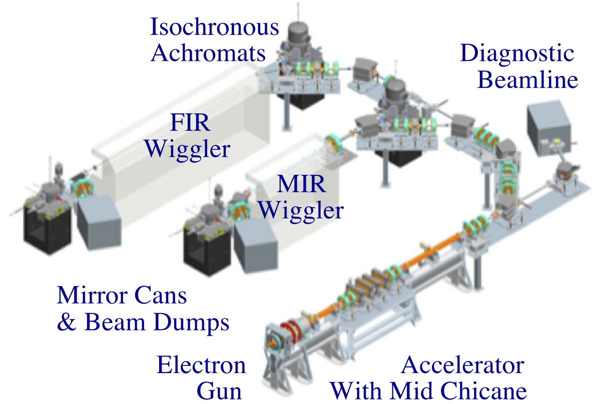

Figure 6: Isometric view of the FHI THz FEL.

An isometric view of the FEL is shown in Figure 6. As Figure 5 shows more clearly, a gridded electron gun feeds a sub-harmonic buncher prior to two accelerating structures. The first structure has solenoid focusing and is run primarily at a fixed accelerating field. The second structure field is adjusted to vary the delivered energy, which can include running the two structures in an accelerating-decelerating mode. The short bunch length of the FHI device is primarily achieved by the use of an up to 30 degree chicane between the two structures. A straight-ahead diagnostic beamline, the central Mid-IR FEL beamline, and the upper Far-IR FEL beamline are all identified in Figure 6. The 90 degree bends are isochronous achromats with 48 degree and reverse 6 degree dipoles, while the diagnostic beamline and dump dipoles are 60 degree magnets. For scaling purposes, the FIR wiggler is 4.4m long.

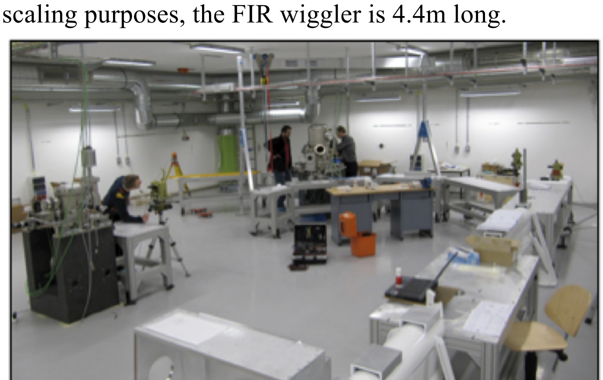

Figure 7: Installation at FHI as of March 2011.

The electron gun has been operating at AES for some time, as indicated above, and installation in the FHI vault in Berlin is already well underway, as shown in Figure 7. Here the Mid-IR mirror chambers, designed and fabricated by Bestec GmbH [6], and the AES beamline support stands, taken from more or less the same perspective as Figure 6, can be identified. The Mid-IR wiggler for this beamline will be delivered by STI Optronics [7] in April 2011. Meanwhile, the accelerator fabrication is proceeding largely to plan. Figure 8 shows the two structures undergoing RF measurement at AES. The final stack brazes and tuning will be completed shortly with delivery to Berlin scheduled for April 2011.

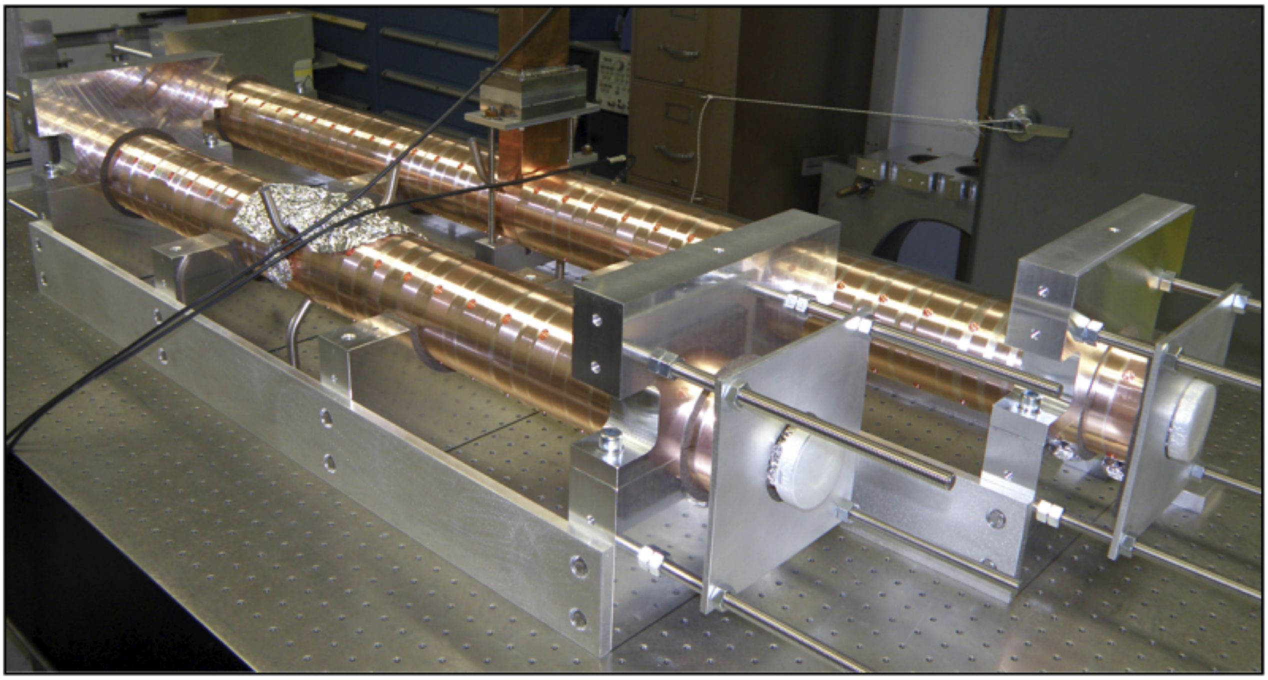

Figure 8: RF measurement in progress on the two FHI accelerators.

Other components of the system are already in place in Berlin or scheduled for imminent delivery. The klystrons and modulators are already installed and control system development is ongoing. One of the klystrons is shown in Figure 9 (left) during installation in a modulator. The center picture is actually a different CBRNE system modulator at AES, but the FHI modulators are already located in the equipment room and powered. The solenoid magnet family consisting of 4 different types, two of one type being shown in the right of Figure 9, the two Scanditronix quadrupole families (large and small bore) and the four Stangenes dipole families (30 degree chicane, 60, 48 and 6 degree) will be delivered in April and May. Current plans call for installation and conditioning to continue through May with commissioning starting in June. First light is targeted for October 2011.

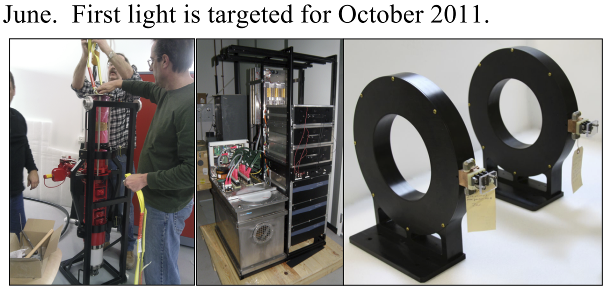

Figure 9: Thales klystron during installation at FHI (left), ScandiNova modulator at AES (center) and Stangenes accelerator solenoid magnets (right).

SUMMARY

The accelerator design and system procurements for a THz FEL at the Fritz Haber Institute in Berlin and a CBRNE system are complete with fabrication and tuning in the final stages for each. Installation of the FHI FEL has begun and the CBRNE detection device assembly will begin shortly. Electron gun transverse rms emittance < 10 mm-mrad at 100 mA has been measured. Near-linear current scaling with RF power is observed. Commissioning will begin in June with first FHI results anticipated to be reported at IPAC 2011. First light in Berlin remains targeted for October 2011.

REFERENCES

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