THE FRITZ HABER INSTITUTE THZ FEL STATUS

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Abstract

The Fritz Haber Institute (FHI) of the Max Planck Society in Berlin, Germany [1], will celebrate its Centennial in 2011. Coincident with this event, the Department of Molecular Physics will christen a THz Free Electron Laser (FEL) that will operate from 3 to 300 microns. A linac, with a gridded thermionic gun, is required to 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. We present the completed conceptual and engineering design that delivers the required performance for this device and summarize the status of fabrication. Shipment is scheduled for early in the new year with first light targeted for October 2011.

INTRODUCTION

The FHI THz FEL, shown in Figure 1, consists of a 50 MeV accelerator driven by a gridded thermionic gun with a beam transport system that feeds two wigglers and a diagnostic beamline. Advanced Energy Systems (AES) is designing and delivering the accelerator and electron beam transport system. STI Optronics is contracted to deliver the Mid-IR wiggler and BESTEC GmbH the oscillator mirror optical equipment. FHI is responsible for the facility, optical transport and user laboratories.

The electron gun is followed by a subharmonic buncher, both of which operate at one third of the fundamental 2.9985 GHz RF frequency. Two individually-powered S-band, on-axis-coupled standing-wave accelerating structures are separated by a chicane with focusing and diagnostics. Solenoids are used on the front-end of the beamline for focusing. The diagnostic beamline, that permits measurement of transverse emittance, bunch length and energy spread, is inline with the accelerator axis and incorporates a 60 degree spectrometer dipole leading to an instrumented beam dump. The Mid-IR single-plane-focusing wiggler is designed to deliver 3-30 micron

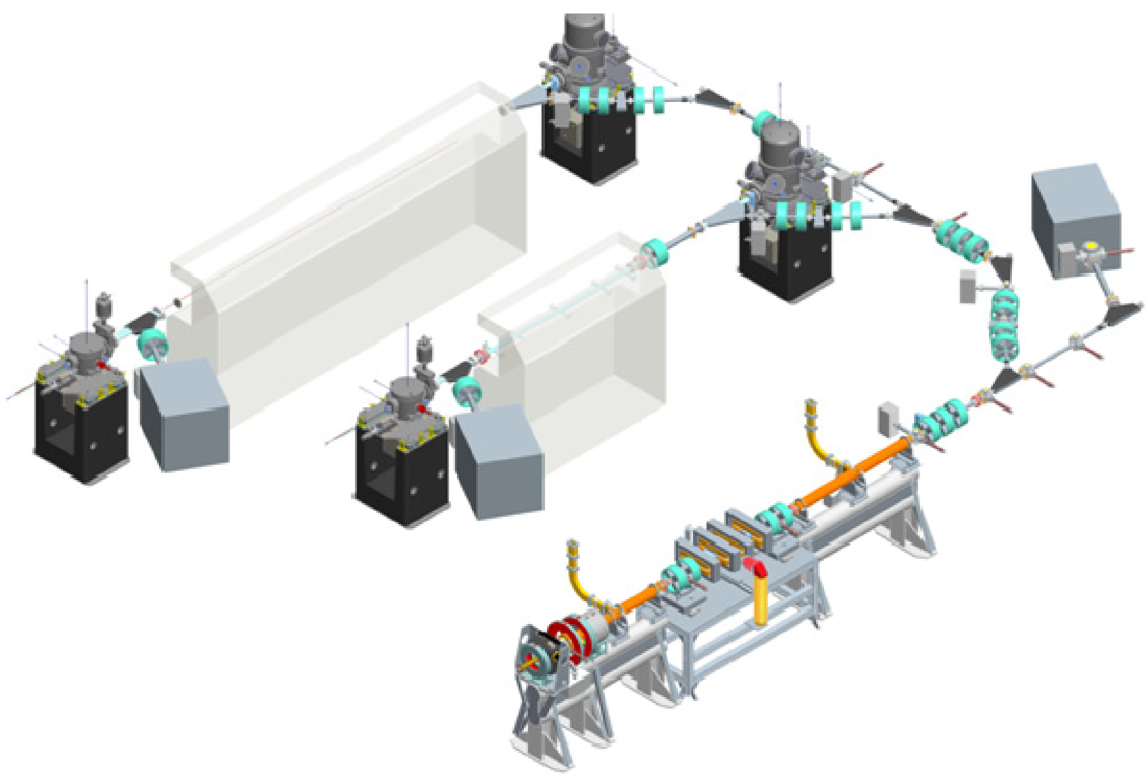

Figure 1: Schematic diagram of Fritz Haber Institute free electron laser.

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radiation and is located in the centre of the vault. The beam transport line to this wiggler consists of two isochronous 90 degree achromats in order to minimize the effect of beam jitter on planned pump probe experiments. The Far-IR two-plane-focusing waveguide wiggler is designed to produce from 30 to 300 microns. An identical 90 degree isochronous achromat delivers the beam to this wiggler. 60 degree dipole magnets transport the beam to the two beam dumps.

The anticipated performance of the FEL accelerator at the wigglers is listed in Table 1. The specified values constitute the contractual deliverables. The target values are those that the design endeavours to accommodate. We anticipate being able to operate down to 15 MeV and up to about 300 pC, though all target values will not be achievable simultaneously.

Table 1: FHI FEL electron beam parameters.

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

Achieving the target transverse emittance requires scraping of the beam at the subharmonic buncher in the front end of the system, where adequate cooling must be provided. The longitudinal beam properties are also quite demanding and are achieved by the use of the mid-accelerator chicane.

In operation, we will fix the setup of the first accelerator to deliver the nominal 20 MeV with all energy variation achieved by adjusting the accelerating gradient in the second linac. For energies less than 20 MeV, the second structure is operated as a decelerator.

BEAMLINE DESIGN

The electron beam after the second linac, with the chicane set for 30 degrees, is shown in Figure 2. We use TSTEP [2], the evolving version of PARMELA [3], for these simulations. Here 3% of the current in the low energy tail that will subsequently be lost in the beamline has been removed. The green curve shows achievement of the ~ 1 psec bunch specification while the red curve confirms the 50 keV energy spread projected from the longitudinal phase space plot center left. The transverse beam spot is shown upper right. The lower plots are the x and y transverse phase space plots.

We have also confirmed the performance of the beam transport system with successful matching into both wigglers over the entire range of the respective wiggler parameters, K, and from 15 to 50 MeV. The 10% energy spread that we are require to accept after the wigglers required that careful attention be paid to the design of the

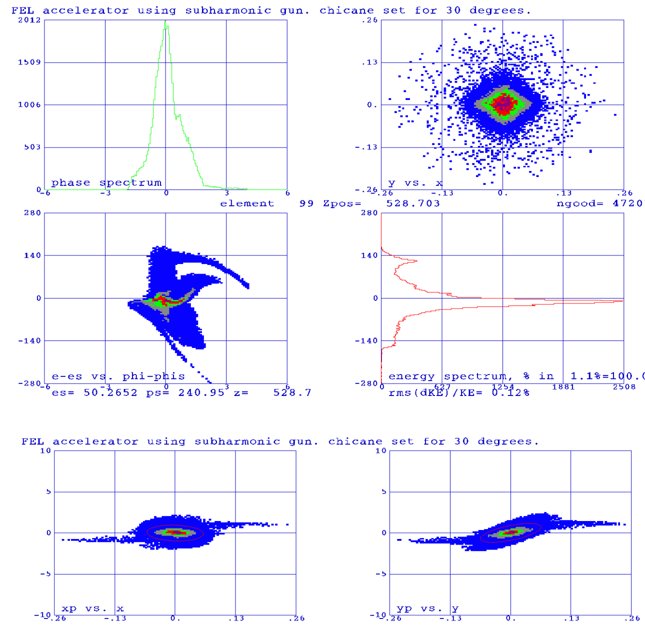

Figure 2: End of Linac 2 electron beam phase space.

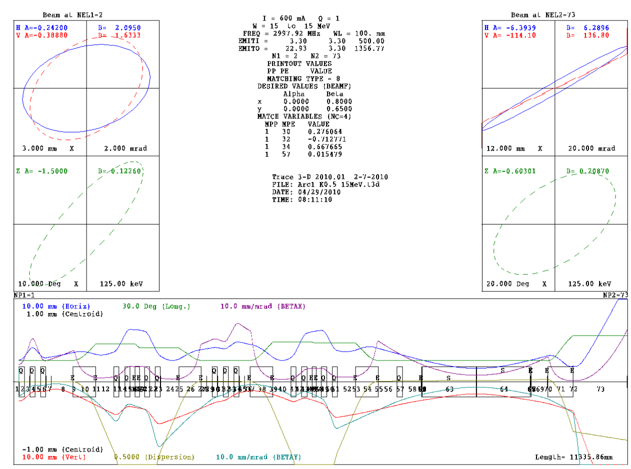

Figure 3: TRACE 3D [4] beam transport line envelopes for the Mid-IR wiggler with K = 0.5 at 15 MeV.

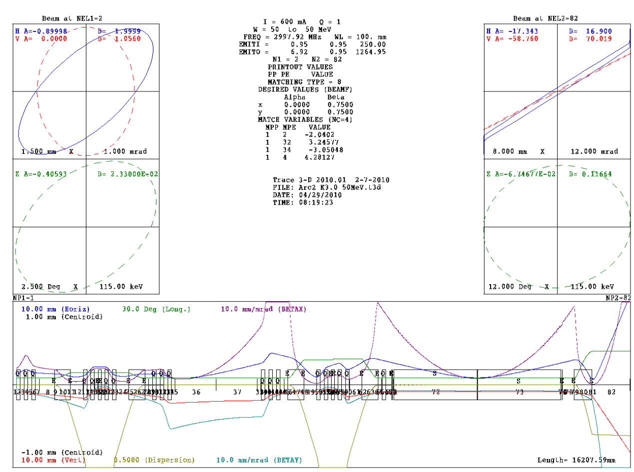

Figure 4: TRACE 3D beam transport line envelopes for the far-IR wiggler with K = 3.0 at 50 MeV.

beam dump transport. Figures 3 and 4 respectively show the matched beam envelopes into the Mid-IR wiggler for low energy and K (15 MeV and 0.5) and the Far-IR wiggler for high energy and K (50 MeV and 3.0).

The sensitivity of the electron bunch arrival time/phase at the wiggler, along with other important parameters, was determined by varying the simulation parameters with the results shown in Table 2. The beam phase is most sensitive to the field amplitude in first linac due to the action of the chicane. Use of the isochronous 90 degree bends substantially reduces the sensitivity to field variations in the second linac structure.

Table 2: Beam jitter static sensitivity.

parameter	Beam phase (degree)	Energy (MeV)	energy spread rms (keV)	Rms pulse length (deg) [pico-seconds]	Pulse charge pico-colomb	Longitudinal emittance Deg-keV	Transverse emittance mm-mrad
Sub-bunch-phase -1°	22.3524	50.177	45	1.5110 [1.05]	211.57	105.	15.8
Sub-bunch-phase +1°	22.5588	50.083	74	0.8529 [0.79]	213.83	79.4	15.5
Gun voltage -1%	22.3141	50.1389	43	1.336 [1.24]	209.76	106.9	15.3
Gun voltage +1%	22.2312	50.1028	52	0.8558 [0.79]	210.98	55.7	16.
Solenoid fields +1%	22.255	50.140	58	1.106 [1.028]	213.75	78.3	15.6
Sub-bunch amp +1%	22.206	50.145	45	1.1349 [1.05]	213.34	76	15.5
Sub-bunch amp -1%	22.317	50.132	48	1.093 [1.02]	212.49	84.3	15.5
Control	22.2462	50.139	47	1.105 [1.02]	212.9	77.6	15.5
Linac 1 phase +1°	21.2826	50.160	45	1.2619 [1.17]	212.56	91.9	15.5
Linac 1 Amp -1% #	29.59	49.68	69	1.554 [1.44]	203.74	42.1	15.0
Linac 2 Amp +1%	23.6917	50.429	44	1.1315 [1.05]	205.35	89.7	15.2
Linac 2 phase +1°	22.1944	50.1192	48	1.0487 [0.98]	212.67	72.6	15.4
Linac 1 Amp +1%#	16.53	50.2466	67	1.2970[1.21]	13.81	130.	15.7

COMPONENT TESTING

The first of the two gridded thermionic guns for the FEL is in test at AES. We have determined the emittance of the gun using a pinhole measurement system with a 1 mm pinhole, scanned horizontally, followed by a phosphor screen to measure the downstream spot size. An image from the phosphor screen is seen in Figure 5.

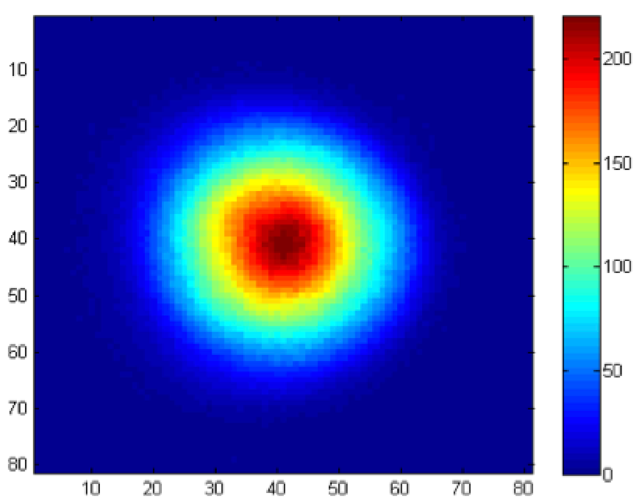

Figure 5: Image of the electron beam spot after pinhole.

A horizontal sweep of the pinhole yields a map of the emittance across the beam which is shown in Figure 6. For comparison, our estimate of the thermal emittance is roughly half the measured emittance. The emittance was measured in this manner at cathode voltages ranging from 7kV to 19kV showing essentially constant emittance with voltage.

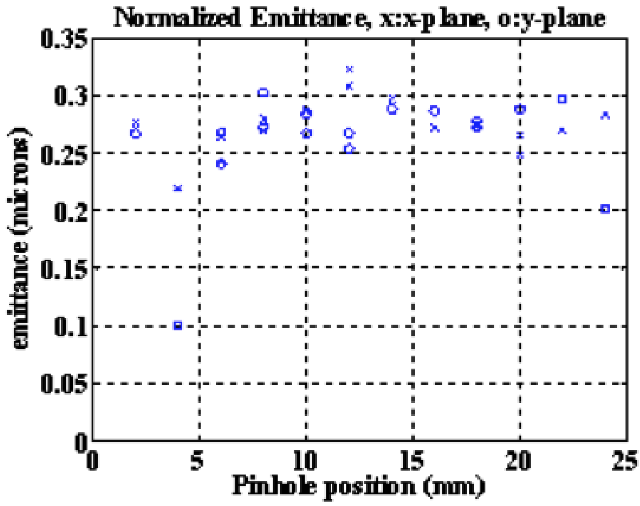

Figure 6: Normalized emittance across the electron beam.

SUMMARY

The physics and engineering design of the FHI THz FEL has been completed. The final low-power RF model work on the subharmonic buncher will be completed in August 2010.

The accelerator and beam transport components are in fabrication or being procured. The status of the facility vault in Berlin as of July 2010 is shown in Figure 7, where it can be seem that the project is progressing to schedule. Plans call for the shipment of all hardware to Berlin by the first weeks of January 2011, after which assembly and commissioning will begin. First light is targeted for October 2011.

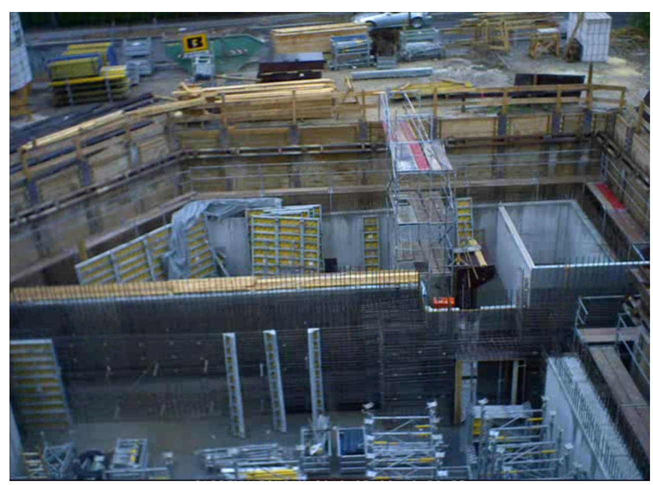

Figure 7: FHI THz FEL facility as of July 2010.

REFERENCES

[1] http://www.fhi-berlin.mpg.de/mp/
[2] L. M. Young, priv. comm.
[3] L. M. Young, Los Alamos National Laboratory Report No. LA-UR-96-1835, or http://laacg1.lanl.gov/laacg/services/serv_codes.phtml#parmela
[4] http://laacg1.lanl.gov/laacg/services/download_trace.phtml