PROGRESS WITH THE DESIGN OF THE UK'S NEW LIGHT SOURCE FACILITY

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Abstract

Recent progress with the design of the UK's proposed New Light Source facility is presented, together with an update on the current status.

INTRODUCTION AND CURRENT STATUS OF THE PROJECT

The New Light Source (NLS) project [1,2] was launched in April 2008 by the UK Science and Technology Facilities Council (STFC) to consider the scientific case and develop a conceptual design for a possible next generation light source based on a combination of advanced conventional laser and free-electron laser sources.

The NLS project has been from its inception "science driven" i.e. the first step was to define the long-term key science drivers, the second step was to define the technical solution. A series of workshops and meetings were held in 2008 to define the main scientific themes that required a new light source capability in the UK and led to the publication of a Science Case in September 2008 which was subsequently approved by the relevant STFC peer reviews, giving the go-ahead to proceed to a conceptual design of the facility.

Further scientific consultation and design work then led to an updated Science Case and Outline Facility Design which was published in July 2009 [3]. The NLS project was then reviewed in detail as part of STFC's overall science prioritization exercise, involving extensive external peer review and international panel experts. The review concluded that "*The NLS project would have very high impact. It would have a major lead in both a national and international context. It would be a unique, world leading facility in the area of biological imaging and would open up exciting new research areas and develop new communities.*" Unfortunately however, given the budget available, STFC's Science Board recommended "*no further funding for NLS development at this time*" and that "*STFC re-assess the NLS project in 3-5 years time in order to ensure that STFC considers future user needs.*"

With the imminent completion of the Conceptual Design Report (CDR) the NLS project is now drawing to a close. In this report we summarise the recent progress which has been made with the design of the NLS facility which forms the basis of the CDR.

DESIGN PROGRESS

Figure 1 shows the updated schematic layout of the NLS facility based on a single-pass 2.25 GeV CW superconducting linac.

Injector

Table 1: Performance of the 1st stage injector.

	Single spike SASE		SASE FEL	Seeded FEL
Charge	2 pC	5 pC	50 pC	200 pC
Projected emittance (mm mrad)	0.081	0.087	0.160	0.300
Central slice emittance (mm mrad)	0.073	0.075	0.134	0.285
Length FWHM (ps)	2.4	4.2	12	14
Central slice $\Delta E/E$	$3.6\ 10^{-7}$	$3.6\ 10^{-7}$	$1.1\ 10^{-6}$	$3.8\ 10^{-6}$
Mean E (MeV)	130.7	130.7	130.8	130.8

Baseline performance is met by the 1st stage electron gun, which is a modified version of the successful DESY FLASH/XFEL normal conducting L-band gun, optimised for 1 kHz operation [4]. Further optimisation, including the introduction of a degree of velocity bunching by running the 1st cavity of the following accelerating module off-crest, has resulted in some further improvement in beam properties. Table 1 shows the beam properties after the first accelerating module for various operating modes and bunch charges. Detailed sensitivity studies have been carried out which give confidence that the design parameters can be achieved, within a few tens of percent emittance increase, assuming state-of-the-art control of the jitter sources, careful alignment and careful cathode preparation. A study of dark current has also been made, which shows that most of it will be removed by a 3 mm diameter collimator located at 2.8 m from the cathode; the remainder can be removed by means of a collimator in the injection merger at a position where the

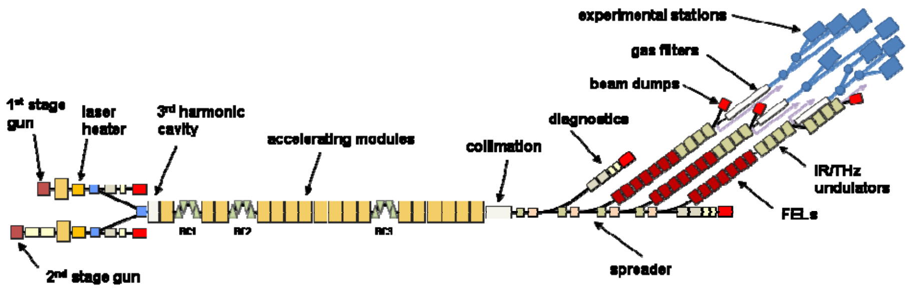

Fig. 1: Schematic layout of the NLS facility

dispersion function has a maximum.

Further work has also been carried out on possible second stage higher repetition rate guns. The favoured options to provide the required beam properties are a normal conducting VHF gun and a superconducting L-band gun. Recent work has included simulations of the VHF gun with and without a booster cavity [5] and of a simpler 1½-cell superconducting gun based on TESLA-shaped cavities [6]. The latter produces the best results with slice emittance similar to that of the normal-conducting low repetition rate design.

To permit the 2nd stage gun to be developed and tested without disturbing operations, the injector building will contain two separate shielded enclosures. Furthermore, the injector layout now includes a dogleg section in order to offset the injector axis by 2.8 m from the main linac axis (see Fig. 1). In this way it will be possible to switch operations easily between the two guns, to permit full commissioning at higher repetition rate, and later-on to provide redundancy and/or further gun development.

Linac

The superconducting linac is based on TESLA/XFEL technology, modified for CW operation. Since the linac represents a significant fraction of the total cost of the facility, a detailed cost optimisation was carried out, taking into account capital and 10-year operating costs of all relevant components including the cryoplant and RF power, as well as infrastructure [7]. This produced a shallow minimum centred around 19 MV/m at today's electricity costs, 17.5 MV/m if costs were to double. The final choice was made taking into account also technical risks and operating margins, and resulted in a lower value of 15 MV/m which is within 5% of the minimum total cost at today's electricity prices, 2% if these double.

Recent design work has also included a detailed assessment of the engineering changes to the TESLA/XFEL modules to make them suitable for CW operation with significantly higher cryogenic load [8] and also an industrial study to determine the optimum solution for the cryogenic plant [9].

Accelerator Optimization

The accelerator has been re-optimized (location and strength of bunch compressors, accelerating module and 3rd harmonic cavity settings) taking into account the introduction of the injection merger, and the increased number of cryomodules [10]. In order that chromatic effects in the merger do not disturb the beam dynamics it proved necessary to remove the energy chirp from the 1st accelerating module, and instead introduce this in the second module, after the merger. The 1st bunch compressor (BC1) is therefore now located after the 2nd accelerating module at 205 MeV, rather than after the 1st module as previously. The 2nd bunch compression takes place at 460 MeV, similar to previously, however the 3rd compressor has been increased in energy to 1.5 GeV to limit space charge effects.

The resulting optimised electron bunch with 0.2 nC charge has very similar properties to the previous one, including a 100 fs region in which the estimated FEL gain length is constant to within 10%, a requirement for compatibility with seeded FEL operation.

Beam Collimations and Dumps

The linac is followed by dedicated transverse and energy collimation sections. Detailed tracking has now been carried out [11] to show that the beam halo is removed and does not enter the undulators, which otherwise could result in radiation damage.

Separate beam dumps are located after each of the three FELs, as well as after the dedicated diagnostics line, and straight-ahead diagnostics section. These dumps are rated for the baseline operation at 1 kHz (450 W beam power). Consideration has also been given to the later stage of operation at up to 1 MHz (450 kW beam power) and the option of a solid dump with graphite core has been studied [12]. Because of the size of such a dump, the possibility of transporting all waste beams to a common dump is being considered.

FEL Sources

The baseline performance will be met by three FELs with overlapping photon energy ranges - FEL-1: 50-300 eV, FEL-2: 250-850 eV, FEL-3: 430-1000eV - selected to match the range of scientific applications. Harmonics will extend the output to 5 keV. Each FEL will be seeded with laser pulses obtained from High Harmonic Generation (HHG) in gases to provide the required longitudinally coherent output radiation, with pulses of reproducible shape tightly synchronised to other laser sources.

The seed sources will be tuneable between 50 and 100 eV, the required FEL output up to 1 keV being obtained by a one- or two-stage harmonic generation scheme. A further optimization of the scheme has taken place, resulting in a change to the lengths of the modulator sections, which has increased the output power, reduced the saturation length and improved the contrast ratio of power in the seeded portion to the SASE background [13]. Figure 2 shows the new arrangement.

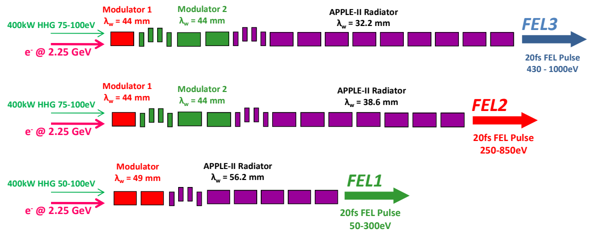

Fig. 2: Schematic of the revised harmonic cascade FEL scheme; blocks represent undulator module 2.5 m long.

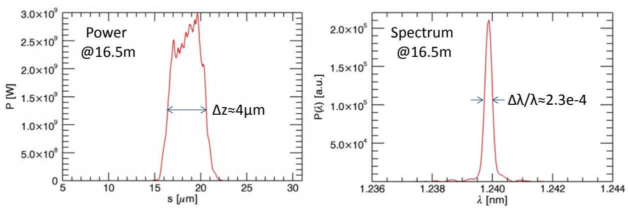

Fig. 3: FEL-3 pulse profile (left) and spectrum (right).

Figure 3 shows the output from FEL-3 at 1 keV resulting from start-to-end calculations in which electrons are tracked from the gun cathode through the injector (with ASTRA), linac (with elegant) and FEL (with Genesis). The time-bandwidth product is 0.77, close therefore to being Fourier transform limited ($\Delta\nu\Delta t = 0.44$ for Gaussian pulses). The ratio of the peak power to the average SASE background is better than 10^4.

Recent work has also included extensive jitter calculations to show that seeded operation is feasible with the achievable RF amplitude and phase stability [10]. Another area that has been further explored is that of producing sub-fs radiation pulses, including start-to-end simulations of two complementary techniques [14].

Facility Layout

Figure 4 presents an architect's view of the NLS facility. The preferred option for construction remains "cut-and-fill", with the linac and FEL hall below normal ground level in order to provide radiation shielding, however for stability reasons it is now proposed to locate the RF Services building to the side rather than on top of the linac tunnel, as shown in Figure 5. The total building length is approximately 700 m.

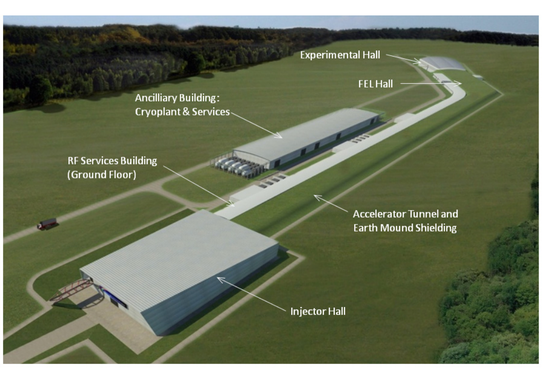

Fig. 4: Architects View of NLS

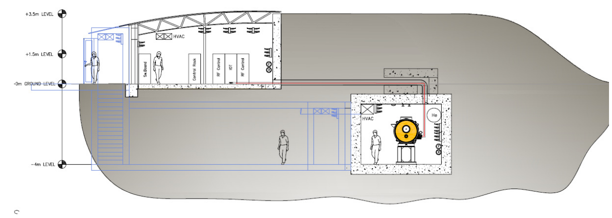

Fig. 5: Linac tunnel and RF services building

Recirculating Linac Option

Significant progress has also been made with an alternative accelerator design based on a recirculating linac [15]. After solving various complex beam dynamic issues, start-to-end simulations have now confirmed that such a scheme is feasible, at least for standard operation with 0.2 nC bunch charge. Further work is required however to explore other more demanding operational modes.

CONCLUSION

A conceptual design report has been produced for an advanced light source facility based on a combination of seeded free-electron lasers and other radiation sources. Both the science case that defines the need for such a facility and the proposed technical realization have been extensively reviewed and highly rated. The financial situation however dictates that work on NLS will now terminate. It is hoped that the CDR will serve as a good starting point for any future design work for an advanced light source in the UK, as well as be of benefit for the wider accelerator and FEL community.

The authors would like to thank the many people who have contributed to the design of NLS with advice and encouragement, in particular the members of the International Technical Advisory Committee chaired by Prof. J. Rossbach.

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