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Final Report for AF Contract F49620-84-C-0012

Period of Performance: 15 December, 1983 to June 15, 1989

Principal Investigator: John M. J. Madey
Professor (Research)
Electrical Engineering
Stanford University

Abstract: This report reviews the objectives, issues, progress and present status of the research funded by the AF-12 contract. Details of the research funded by this contract are reviewed in the attached technical and scientific reprints.

1. Summary of Objectives:

The principal objective of the research funded by AF Contract F-49620-84-C-0012 was the development of a high brightness storage ring and linac injector for use in advanced XUV FEL and synchrotron radiation research and as a source of high brightness electron beams for the development of other advanced short wavelength radiation sources.

2. Summary of Issues:

The AF-12 contract was the fourth in a sequence of contracts funded by the Air Force to evaluate or develop a high brightness storage ring as a source of electrons for advanced short wavelength FEL research. Research on the physics of high brightness storage ring FELs was begun in 1983 with the support of AF Contract F49620-83-K-0030. This research led to the development of specifications and a design for the ring and to the completion of our research on the dynamic stability of storage ring FELs. Work on the linac injector was also begun at this time with the support of AF Contract F49620-82K-0022 to evaluate the condition and utility of the then-surplus accelerator sections from the old MkIII linac which had been made available to the project. At the conclusion of this study, the Air Force made available funds through AF Grant AFOSR-83-0303 to begin to acquire the components required to assemble the linac.

With the basic specifications and design in hand for the ring and its linac injector, the principal technical issues for the AF-12 research program concerned the development of the components and subsystems required for operation of these systems. Although the design principles for the ring and linac had been proven either in our prior research or in the course of work in other laboratories, the actual construction of these systems required the development of the precision electronic, magnetic, vacuum, and mechanical components required for operation. Fabrication of these components and subsystems required an extensive research effort to insure compliance with the specifications for the ring and manufacturing feasibility. Additionally, work was required to develop the electrical, cooling water, and shielding systems required by the ring and linac.

As it turned out, the AF-12 research program also encountered an unanticipated administrative issue. As submitted by Stanford, the proposal and budget for the AF-12 contract called for the use of third-party labor-hour subcontractors in the design, fabrication, assembly, and installation of the major components and subsystems for the ring and linac. The estimated costs of these subcontracts were capitalized as part of the capital cost of the ring and linac. As capital costs, these labor-hour subcontracts were classified by Stanford as exempt from overhead.

Subsequent to the negotiation and award of the AF-12 contract, Stanford revised its indirect cost policy and reclassified all labor-hour subcontracts as non-capital expenses fully subject to overhead. This change in policy substantially increased the estimated cost to complete the ring and linac, and also increased the projected future cost to develop the magnetic and optical components required to bring the ring into operation as an FEL source. As a result of the adoption of the new overhead guidelines by Stanford, it became impossible to complete the ring and linac at Stanford.

3. Summary of Accomplishments:

Most of the critical components and subsystems of the ring and linac were successfully designed, fabricated and tested prior to the termination of the work supported by the AF-12 contract. The list of components developed with AF-12 support include:

1. a high brightness microwave gun for the linac injector
2. a long pulse high power modulator for the linac injector
3. a short pulse high power modulator for the linac
4. the control chassis for the long and short pulse modulators
5. a high power pressurized waveguide feed system for the SLAC-type S-Band accelerator sections
6. quadrupole lenses for the linac

7. mechanical supports and alignment fixtures for the linac's accelerator sections,
8. the dipole, quadrupole, and sextupole magnets for the ring;
9. the water-cooled vacuum chambers for the arcs of the ring; and
10. the beam position monitors for the arcs of the ring.
11. the low-level timing electronics for the ring
12. the control racks for the ring, including trim magnet power supplies and CAMAC controllers
13. the electronics and power supplies for the high power RF system for the ring
14. the mechanical supports and alignment fixtures for the arcs of the ring
15. the deionized water cooling system for the linac and ring
16. a heavy steel deck to support the short and long pulse modulators for the linac
17. a shielded cave for the linac
18. a shielded cave for the east straight section of the ring

With the exception of the dipole and sextupole magnets in item 9 above, the performance of these components was established by operation or through prototype tests to satisfy the operating specifications which had been established for the ring and linac. In particular, the linac injector was successfully operated in 1987 and 1988 for several thousand hours as the driver for the Mk III FEL research program.

In the case of the dipole and sextupole magnets, it was found that saturation and proximity effects resulted in an unacceptable loss of field quality in these magnets at the field levels required for operation at 1.3 GeV. As a consequence of this finding, a research effort was begun to determine the cause of the observed distortion and the means available to improve the quality of these magnets. If this problem can not be resolved, the level of distortion observed in the dipole and sextupole magnets will limit the maximum energy at which the ring could be operated to the order of 1 GeV.

In addition to the immediate work required to develop these components and subsystems, a comprehensive effort was made to fully document the design specifications and detailed mechanical and electrical drawings for this hardware.

With respect to the administrative issues, a decision was made to move the FEL project to Duke University following a Government review in December 1987, of the technical and financial status of the program and the facilities available at Duke. After this review and decision the effort funded by the AF-12 contract at Stanford was directed towards the completion of the work in progress and preparations to move the equipment and records of the project to Duke.

4. Summary of Conclusions:

The research funded by AF-12 has established in considerable detail the feasibility of the storage ring and linac required to support FEL operation in the ultraviolet and extreme ultraviolet. The development work funded by this contract has, further, resulted in the fabrication of most of the critical components required for the operation of these systems, although some further development work is required on the dipole and sextupole magnets for the ring.

In events subsequent to the termination of the AF-12 contract, most of the research equipment funded by the contract was transported by the Air Force from Stanford University to Duke to support the continuation of the FEL research program at Duke. The principal items of equipment left at Stanford include the shielding for the linac and ring and the klystron gallery for the linac. A new dedicated laboratory has been begun at Duke to accommodate the continuation and expansion of the program.

Given the successful transfer of the FEL program to Duke University, the construction of a dedicated new laboratory for the program at Duke, and the continuation of research support for the ultraviolet and extreme ultraviolet research program, it appears possible to bring the ring and linac into operation as originally planned with a minimum of further delay.

5. List of Attached Publications:

The following publications and reports are attached to provide a detailed description of the results of the research funded by this contract:

1. John M.J. Madey. "Conceptual System Design of XUV FELs" AIP Conference Proceedings No. 188. Free Electron Generation of Extreme Ultraviolet Coherent Radiation, Brookhaven/OSA, 1983, Page 12.

2. Stephen Benson and John M.J. Madey. "Quantum Fluctuations in the XUV Free Electron Lasers" AIP Conference Proceedings No. 188. Free Electron Generation of Extreme Ultraviolet Coherent Radiation, Brookhaven/OSA, 1983, Page 173.

3. G. Stolovy, W. Wadensweiler, J.M.J. Madey, S. Benson, and Michel Velghe. "High Quality Hybrid Wiggler for Infrared FEL and Coherent Harmonic Generation" SPIE Vol. 582 International Conference on Insertion Devices for Synchrotron Sources (1985).

4. J.E. LaSala, D.A.G. Deacon, and J.M.J. Madey. "Options for the Development of FEL Oscillators from 200 to 1000 Angstroms" SPIE Vol. 582 International Conference on Insertion Devices for Synchrotron Sources (1985).

5. J.E. LaSala, D.A.G. Deacon and E.T. Scharlemann. "Optical Guiding Simulations for High Gain - Short Wavelenth FELs" Proceedings of the 7th International FEL Conference (Tahoe City, CA Sept. 8-13, 1985).

6. Stephen Vincent Benson. "Diffractive Effects and Noise in Short Pulse Free-Electron Lasers" Ph.D. Dissertation, Stanford University (1985).

7. J.E. LaSala, J.M.J. Madey and D.A.G. Deacon. "Options and Issues for XUV Free Electron Laser Oscillators" American Institute of Physics Conference Proceedings No. 147. Short Wavelength Coherent Radiation: Generation and Applications, Monterey, CA 1986, Page 1.

8. J.E. LaSala, D.A.G. Deacon, and J.M.J. Madey. "Performance of an XUV FEL Oscillator on the Stanford Storage Ring" Nucl. Instr. Methods A250 (1986) 262.

9. H. Wiedemann. "Future Development for Synchrotron Radiation Sources at Stanford" Proceedings of the IEEE 1987 Particle Accelerator Conference, Page 395.

10. L. Emery, C. Chavis, C. Cork, N. Hower, T. Martin, R. Melen, F.T. Ning, W. Ortiz, G. Swift, J. Voss, P. Wang, W. Wadensweiler, and H. Wiedemann. "The 1.2 GeV High Brightness Photon Source at the Stanford Photon Research Laboratory. Proceedings of the IEEE 1987 Particle Accelerator Conference, Page 1496.

11. David A.G. Deacon and John M.J. Madey. "Development of Short Wavelength Storage Ring Free Electron Laser Sources" Presented at International Symposium on Short Wavelength Lasers and Their Applications, November 11-13, 1987, Osaka University, Japan. To be published in Springer-Verlag.

11. Antonello Cutolo and John M.J. Madey. "Achromatic Storage Ring for Free-electron Lasers" J. Appl. Phys. 62 (1987) 3550.

12. J.E. LaSala, D.A.G. Deacon, and J.M.J. Madey. "Optical Guiding in a Free-Electron-Laser Oscillator" Phys. Rev. Lett. 59 (1987) 2047.

13. John Edward LaSala. "Transverse Mode Evolution in a Free Electron Laser Oscillator" Ph.D. Dissertation, Stanford University (1987).

14. Ming Xie. "Theory of Optical Guiding in Free Electron Lasers" Ph.D. Dissertation, Stanford University (1988).

15. Ming Xie, David A.G. Deacon, and John M.J. Madey. "Eigenmode Analysis of Optical Guiding in Free Electron Lasers" Submitted to Physical Review A.

16. Ming Xie, David A.G. Deacon, and John M.J. Madey. "The Guided Mode Expansion in Free Electron Lasers" To be Published in the Proceedings of the 9th International Free Electron Laser Conference.