# EC Contract ERBFMGECT980102

## "Development of a Combined Synchrotron Radiation and VUV Free-Electron Laser Facility"

Minutes of the 7th Project Meeting, held at Sincrotrone Trieste, Italy
on the 10th March 2000.

Participants -

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| Sincrotrone Trieste: | M. Marsi (MM), R. Roux (RR), M. Trovò (MT),<br>R.P. Walker (RPW) + B. Diviacco, F. Iazzourene (part time) |
| CEA: | D. Garzella (DG), E. Renault |
| CLRC Daresbury: | N. Bliss (NB), M.W. Poole (MWP) |
| Univ. Dortmund: | D. Nölle (DN) |
| ENEA Frascati: | L. Giannessi (LG) |

Guest from SRFEL Network -
Tech. Univ. Eindhoven C.A. Thomas

1. PROJECT MANAGEMENT

The second draft of the minutes of the 6th Project Meeting (Hamburg, August ’99) were approved with a minor correction.

RPW confirmed that the 1st Annual Report had been accepted, and that the maximum intermediate payment had been received, bringing the total to 90 %. The final payment of 10 % will not be obtained until after the acceptance of the final report. He also confirmed that in accordance with EC rules the appropriate payments had been made straight away to all partners. He reminded all of the partners that the money was strictly an advance, and so all costs still had to be justified, and also that if allowable costs do not reach the required limit it may be necessary to repay some of the money. RPW distributed copies of the EC “Releve de Compte” for each partner, and summarised the financial situation for each partner (see the table below):

| **Partner** | **A) EC contribution requested (kEUR)** | **B) EC contribution received so far (kEUR)** | **C) Accepted payment so far (kEUR)** | **Percentage of total contribution accepted so far (C/A)x100** |
|---|---|---|---|---|
| Sincrotrone Trieste | 423 | 380.7 | 305.6 | 72.2 |
| CEA | 200 | 180 | 110.6 | 55.3 |
| CLRC Daresbury | 195 | 175.5 | 184.4 | 94.6 |
| Univ. Dortmund | 110 | 99 | 21.2 | 19.3 |
| ENEA Frascati | 50 | 45 | 25.8 | 51.6 |
| MAX-lab | 22 | 19.8 | 13.0 | 59.1 |
| *TOTAL* | *1,000* | *900* | *660.65* | *66.1* |

RPW summarised the present financial situation for Sincrotrone Trieste. A total of 1,146 kEUR has been committed on equipment, giving an allowable cost (after taking into account percentage use etc.) of 431 kEUR. The manpower recorded (underestimated) since 1/5/99 is 45 man-months, including the full-time contribution of M. Trovò. The estimated EC contribution that could be requested at the end of the second year is 264.4 kEUR, giving a total over two years of 570 kEUR, i.e. well in excess of the available 423 kEUR.

DG presented data for CEA which showed that 5 man-months had been dedicated to the project (M.E. Couprie, D. Nutarelli and D. Garzella) in the second year up to the end of February '00, which together with the work of post-Doc E. Renault, makes a total allowable cost of 127 kEUR. Other expenses included 34.4 kEUR for consumables (RSA and Delfour substrates, and coating), which together with travel brings the total allowable cost to about 164 kEUR. The total accepted contribution at the end of year 2 should therefore be close to the maximum 200 kEUR.

MWP reported that the original CLRC manpower estimate for the project was 507 days (300 for mirror chamber construction, the rest for commissioning etc.), but that this had been greatly exceeded, reaching 500 days in September '99, and 1000 days by January '00, mainly because of the extra amount of time required for vacuum processing. The total equipment cost of £ 257k had been much closer to the budget (once the specification was clear). Despite the large overspend MWP said that he still hoped to spend significant effort on the remaining part of the project, mainly in the scientific rather than engineering domain.

DN reported that PhD student H. Quick had left at the end of February and that a new student (Marc Grewe) had started in August '99 on FEL related work. However, since the priority at Dortmund is shifting away from FELs the topic of his PhD has recently been altered. RPW said that payments under this contract have to be related to the FEL activity and requested a separate discussion to resolve the question.

LG was unable to report on the ENEA financial situation, and agreed to ask the coordinator to forward this information.

RPW reminded the partners that the second year of the project ends on the 30$^{th}$ April, and that the second Annual Report has to be submitted to Brussels by the end of May. As last year, a first draft of the report will be produced by RPW and then distributed for comments and additions. On the topic of publications, he reminded the partners that he had received an invited oral presentation at EPAC 2000 for the project. He also distributed copies of an abstract that he had recently submitted to SRI 2000, requesting an oral presentation; all present were in agreement. MWP added that the optical cavity paper presented at FEL '99 had been accepted for a full-length reviewed article.

## 2. TASK C: UNDULATOR etc.

B. Diviacco summarised the final magnetic performance of the two elliptical undulators and the electromagnetic phase modulator. The undulator field strength is within specification, allowing a maximum 455 nm wavelength at minimum gap (1 GeV). The field quality is also very good: after correction an rms phase error of less than 3$^{o}$ was achieved at any gap and phase. Residual field integral errors are less than 2.5 Gm at any gap and phase, easily correctable using the installed correction coils – although the calibration has yet to be performed. The undulators produce significant tune shifts at 1 GeV, due to the poor transverse field homogeneity inevitably present in this type of structure. The electromagnetic modulator provides an effective Nd of 84.8 at 250 A, compared to the specified 80. Field integrals are less than 1 G m (horizontal) and 2.5 G m (vertical) up to 250 A.

F. Iazzourene described the effects of the undulators on the electron beam. To avoid beam loss a simple procedure has been developed for pre-compensation of the tunes before closing the undulator sections one at a time. As well as producing significant tune shifts, the undulators also cause a reduction in beam lifetime. Experience has shown that a compensation of the tunes using local quadrupole pairs in the dispersion-free straights gives a better lifetime than a global compensation. Calculations show that local tune compensation gives reduced variation of horizontal beta function (but larger in the vertical plane); on the other hand global compensation gives smaller vertical beta variation but larger variation in the horizontal plane. Dynamic aperture calculations however are not consistent with the significantly better beam lifetime in the local compensation case. Alphamatching (which eliminates beta function variation in both planes) together with global tune compensation shows better dynamic aperture, but has not so far been tested on the machine. Further work is therefore required on applications software to test this kind of matching, as well as for a faster automation of the correction procedure. Other topics still to be investigated are the optimisation of the working point and harmonic sextupoles to try to improve the beam lifetime.

## 3. TASK A: OPTICAL CAVITY

MWP reviewed activities on the mirror chambers since August '99. At that time all components were available at Daresbury and delivery was planned for the end of October. In September however a long series of problems started with both stepper motors and piezo units:

- stepper motors contaminated the vacuum processing rigs and one motor became demagnetized for no apparent reason
- various piezo units also failed vacuum conditioning due to a failure of the coating on the ceramic, resulting in a M=36 Chlorohydrocarbon contaminant, believed to be due to a processing fault at the Queensgate factory. A final piezo failed on the 9th January, at the end of testing. Queensgate must still repair this piezo and also explain the reasons for the faults, which they so far do not accept responsibility for.
- the piezos were also supplied with an incorrect feedthrough connector.

The mirror chambers were finally delivered to Trieste on the 17th January, by dedicated road/tunnel transport. Installation, together with a spare piezo unit and new connectors, was complete by February 17th.

NB reviewed in more detail the mirror chamber testing and installation. Testing of the complete system at Daresbury included tests of the mirror change mechanism, load lock and transfer arm, measurements of repeatability of mirror position, water flow and pressure tests, vacuum bake and leak tests etc. The accuracy and repeatability of all motions is close to specification. The Y2 (mirror change) motion has a worse accuracy (32 µm) than specified (5 µm) but is within the specified reproducibility (5 µm). After bakeout a pressure in the $10^{-10}$ mbar range was achieved, without NEG activation, and with water flow on. At Trieste, installation of the front unit (assembly B) went smoothly; more time was required on the back unit (assembly A) to change the failed piezo unit which required removal of the mechanism and some time was lost due to leaks on the beam exit window and well as the top lid. A water cooling leak on the back end unit after installation meant that the device has had to be operated without water cooling since then; an intervention is proposed by DL staff during the week commencing 27th March. NB also mentioned that at the same time the fast entry doors will be replaced with a more robust version.

MT summarised experience with the mirror chamber units and their interfacing. In addition to the water leak, the flowmeter was damaged during installation and will be substituted by Sincrotrone Trieste. The ion pump connector also failed and because of a lack of spare parts for this kind of pump, the pump was replaced with another type. Regarding the vacuum performance, after 10 days bake-out and NEG activation the front unit reached 5 $10^{-10}$ mbar. Only 4 days were available for baking the back unit which reached 4 $10^{-9}$ mbar. During the time that the chambers were being installed it was found that the Nupro let-up valves mounted on both the mirror chamber and the transfer chamber leaked at a pressure of $10^{-9}$ mbar; it was decided therefore to remove these valves on the main chamber but leave them on the transfer chambers.

During use of the mirror chambers it was observed that the Y2 motor heats up significantly, and on one occasion reached the 120 $^{o}$C alarm value; to avoid this problem it is necessary to limit the motion to small steps (1-2 cm) which therefore requires about half-an-hour to move between extreme mirror positions. The motion also causes an increase in pressure to the 5 $10^{-8}$ level; for this reason the valve between the ring and the mirror chamber is closed during mirror change. Small movements of pitch and yaw have no effect on temperature or pressure. On one occasion the limit switch of the pitch motor remained activated, the fault disappearing after a few days. NB explained that the switches are not a commercial unit and the reliability is therefore unknown; he recommended setting software limits to avoid driving onto the switches. MT also summarised the programs that had been written to control motor and piezo units, including panels allowing correlated motions of the optical axis position and angle. There remains to be implemented a vacuum interlock for the piezo units as well as an interlock on water flow; MWP emphasised the need for this interlock.

NB presented a list of recommended spare parts, with a total cost of £17k, £7k of which have already been ordered by Daresbury.

## 4. TASK B: MIRRORS

DG summarised the status of 30 substrates ordered by CEA, all with nominal radius of curvature of 17.5 m :

- the 10 RSA sapphire substrates all have very good roughness (mean 1.1 Å, rms 0.13 Å) and accuracy of radius of curvature (mean 17.58 m, rms 0.07 m)
- the 10 Maris Delfour sapphire substrates have bad roughness (mean 13.4 Å, rms 3.9 Å) and wide variation of radius of curvature (mean 18.95 m, rms 0.32 m)
- the 10 Maris Delfour silica substrates overall have high roughness (mean 4.1 Å, rms 2.1 Å) but the best 6 have acceptable roughness (mean 2.5 Å, rms 0.2 Å) and radius (mean 17.61 m, rms 0.12 m)

The six best silica and two best sapphire substrates from Maris Delfour were subsequently coated by Mackowski. As expected the sapphire showed much higher absorption losses (0.015-0.03 %) compared to the silica (0.003 %) because of the higher roughness. The remaining 4 silica substrates were sent back to Maris Delfour for polishing, and will be tested before deciding on how to proceed with the sapphire ones.

MM reported on the development of alternative silicon mirrors being pursued by Sincrotrone Trieste. Ten substrates were supplied by SESO (January 2000) with Al coating and ten without, in each case five with 19 m radius of curvature and five with 16 m. Each group of five has various hole diameters: 0, 0.8, 1.4, 2.2 and 2.8 mm. The Aluminium coating has measured 92 % reflectivity at 350 nm, decreasing to about 90 % at roughly 200 nm. At shorter wavelength the reflectivity is not known, but is estimated to be > 85 % at 180 nm. The uncoated substrates were subsequently coated by LZH, a subcontractor of IOF-Jena, with a new dual-band dielectric coating prepared by IBS, with high reflectivity at 350-400 nm ($HfO_2/SiO_2$) and 220-230 nm ($Al_2O_3/SiO_2$). The reflectivity is however less than expected, reaching 95 % at 350 nm and 94.1 % at 220 nm, possibly because of absorption of the 350 nm radiation by the top ($Al_2O_3/SiO_2$) layers.

## 5. TASK F: FEL COMMISIONING

RR firstly summarised the various bunch length measurements that had been made since the installation of the new aluminium vacuum chambers in August/September. Apart from occasions when anomalously high values were obtained, the bunch lengths are all consistent, showing that no effect has been introduced by the new chambers. Although in October ’99 it had been possible to inject up to 25 mA in a single bunch, there had generally been some difficulty in accumulating high currents in 4-bunch mode. Not much time however was directed specifically on this topic, partly because injection at that time was at 0.9 GeV. Later in December, when injecting again at 1 GeV, up to 16 mA/bunch was obtained in 4-bunches.

RR then summarised the FEL commissioning work, including analysis of the undulator and optical klystron spectra and the alignment method, culminating in first lasing at 05:35 on the morning of the 29th February, with a total beam current of 17 mA. The initial lasing wavelength was 352 nm, but this shifted later to 357 nm after various cavity length adjustments. Since only one hour of time was available few results have so far been obtained. The cavity losses were measured from the decay profile of the trapped spontaneous radiation to be 2.4 %, in good agreement with the expected value from the mirror measurements of 2.6 %. The mirrors were silica in the front, and sapphire in the back. The gain was estimated from the bunch lengthening of the electron beam, and assuming losses of 2.6 %, to be 8.2 % at 9 mA total current, in reasonable agreement with expectations. After optimising the cavity length a minimum spectral width (FWHM) of 0.21 nm and temporal width (FWHM) of 20 ps were measured. An interesting observation was also the significant increase in beam lifetime (1 hour to 3 hour) when the laser was on.

## 6. TASK E: THEORY

LG gave an update of his calculations of hole coupling, expanding the field in a series of Laguerre modes. The hole causes diffraction which widens the beam, transferring power into the higher order modes. A practical difficulty is that with large mirrors many modes are required in the calculation of the empty cavity in order to achieve convergence. Including a variable aperture in the calculation also changes the mode distribution; closing the slits forces more power to be outcoupled, until a limit when the slits start to strongly diffract. The situation changes further with the FEL operation since the higher order modes have smaller gain; in fact within the width of the gain curve the number of modes reduces to the order of $2\pi$. The modes however are coupled i.e. the field of one mode can cause gain on another one. For one practical case of interest, at 220 nm with approximately 10 mA/bunch, a FEL gain of 12 %, 4 % reflection losses, a net gain of 3 % is calculated with 1 mm hole radius.

## 7. TASK G: FEL EXPERIMENTS

MM proposed that in keeping with the project timescales the aim should be to carry out “one photon” experiments by the end of this year. The most convenient way to do this is to use the SPE-LEEM microscope that will be installed in August/September this year on the Nanospectroscopy beamline, the branch line of the FEL beamline, in order to perform spectromicroscopy experiments in the UV. In order to perform interesting experiments the goal in the short/medium term should be to cover the range 300-200 nm, or at least 280-220 nm, using a range of “conventional” dielectric oxide multilayer coatings. Since only limited machine beamtime will be available, experiments must be chosen for their relative simplicity, and good chance of success. High power is of less importance compared to tunability; change of polarization could however offer interesting possibilities.

In parallel with the preparation and carrying out of first experiments, work should proceed in parallel to lower the wavelength to below 200 nm, as well as to improve source stability etc. More complex pump-probe (SR+FEL) experiments should be planned not before the final phase of the project, next year.

## 8. DISCUSSION

Following MM's proposed wavelength range for first experiments (280-220 nm), taking into account the wider tunability at longer wavelength, DG suggested that this could possibly be achieved with 3 mirror types, covering roughly the ranges 250-280 nm, 230-250 nm and 220-230 nm. The first two types could conveniently be characterized using the CEA/LURE equipment at 264 nm, and 238/244 nm. The possibility of using a double-band coating to allow the mirrors to be easily aligned prior to switching to short wavelength could also be considered. DG agreed that the CEA sapphire substrates could be used at least for the first two ranges (e.g. 4 for the first range, 6 for the second) but that CEA could not support the costs of the coating. RPW agreed that Sincrotrone Trieste would try to cover these costs and also announced that an order had already been placed with SESO at the end of December '99 for 10 further sapphire substrates (17 kEUR) which could be used for the third wavelength range.

To reach shorter wavelengths, the possibilities appear to be either the existing Al mirrors (if the gain is sufficiently high), or fluoride multilayers on either transparent $CaF_2$ or silicon with hole output coupling. Experience of hole coupling will soon be gained during the forthcoming shifts in March, in order to judge if this is a viable strategy.

## 9. CONCLUSION

It was agreed that ideally the next Project meeting should be held before the May 13/14$^{th}$ shifts, possibly in conjunction with the proposed TMR SRFEL Network meeting in Dortmund.

## SUMMARY OF MAIN ACTIONS:

- tune/optics compensation and lifetime optimisation with undulator operation (ST)
- order mirror chamber spares (CLRC/ST)
- repair of back mirror chamber water leak (CLRC/ST)
- interlock on vacuum level and water flow (ST)
- further studies of hole coupling (ENEA)
- place orders for mirror coating (ST)

R.P. Walker
Trieste, 7th December, 2000