EC Contract ERBFMGECT980102

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

Minutes of the 2nd Project Meeting, held at LURE, Paris
on the 22nd-23rd July 1998.

Participants -

Sincrotrone Trieste:	B. Diviacco (BD), M. Marsi (MM), R.P. Walker (RPW)
CEA:	M.E. Couprie (MEC), L. Nahon, D. Nutarelli (DN), E. Renault, R. Roux
CLRC Daresbury:	N. Bliss (NB), A. Chesworth, J.A. Clarke, M.W. Poole (MWP)
Univ. Dortmund:	H. Quick (HQ)
ENEA Frascati:	G. Dattoli (GD)

1. INTRODUCTION

The minutes of the previous meeting and the agenda for the present meeting were approved.

2. PROJECT MANAGEMENT

RPW discussed several topics related to the management of the project:

i/ the need for partners on a Full Cost basis (ST, CEA, CLRC, ENEA) to keep proper time records was emphasized. CEA, CLRC and ST showed examples of the recording systems that are being used to fulfil the obligations of the contract.

ii/ the first 40 % payment is about to be received from the EC; all partners who had not already done so were asked to provide their bank details to the coordinator to enable the payments to be made.

iii/ a copy was shown of the report on the project that had been sent for the TMR review.

iv/ the abstract submitted to the International FEL Conference has been accepted for oral presentation; RPW requested assistance for the preparation of the article, a draft of which will be distributed for approval.

v/ the setting up a web site has still to be activated.

On the topic of recruitment, MEC said that E. Renault has a 1 year contract with CEA from 1st July, working 100% on the project on mirror measurements. HQ said that at Dortmund no candidates for the PhD studentship have been found and that he will work on the project for 3 months from the 1st October. RPW said that Sincrotrone Trieste is also looking for people. RPW stressed the fact that people hired by the present project must actually work on the project.

3. LAYOUT AND MAIN PARAMETERS

Optical cavity length. RPW showed the layout of optical cavities of various lengths in the ELETTRA straight section that had been dedicated to the FEL, straight 1. The 21.6 m cavity had been rejected at the previous meeting since the back mirror would be inside the tunnel, and was anyway incompatible with the present size of the mirror chamber. Both 32.4 and 43.2 m cavities allowed the back mirror to be brought outside the tunnel. In the case of the 32.4 m cavity the front mirror would be in front of the SR beamline deflection mirror and in the case of the 43.2 m cavity would be after it. However, in either case the front mirror must be within the shielding hutch and so will only be accessible with the beamline shutter closed. CLRC pointed out that inserting new mirrors will be done via a load-lock system so that no vacuum let-up is required of the mirror chamber. Apart from the unlikely event of a failure of the mirror chamber therefore, the impact on beamline operation is therefore the same in either case.

Arguments put forward in favour of a 32.4 m cavity rather than 43.2 m were as follows:

- easier alignment
- allows smaller mirror sizes, or more margin with the same mirror sizes
- smaller mode size in the undulator, and hence higher gain, for cavities with acceptable stability parameter
- higher average laser power
- higher total storage ring current, giving better compatibility with SR users.

MEC and RPW stressed that compatibility with SR users was not only an important requirement for this project, but also an important issue in general for future SRFELs.

The main objection to the 32.4 m cavity was that less space is available around the mirror chambers. In addition, since it appears that the front mirror chamber must replace the final chamber of the standard beamline front-end, the functions of residual gas analysis and fast pressure sensor would have to be integrated into the mirror chamber. It was agreed however that that the advantages of the 32.4 m cavity were sufficiently important that this should be the goal.

NB pointed out that if for space reasons the transfer arms of the cavity units have to point away from the shielding wall at both ends, then the two units would no longer be identical and so require additional drawing effort. It was therefore agreed to try to accommodate identical mirror chambers if at all possible. The question of the addition of an intra cavity Brewster plate (for extraction of coherent harmonics) or etalon (for linewidth reduction) was discussed. The latter, which can be mounted near the back mirror, was considered more relevant to the project and so it was agreed that about 0.5 m should be made available for a separate vacuum chamber for an etalon if at all possible.

<u>Mirror size.</u> MEC stressed that larger mirror would be a definite advantage for an easy alignment and start-up of the laser and that this did not compromise the mirror quality that could be obtained, or increase significantly the cost. NB on the other hand pointed out that smaller mirrors would be preferred from an engineering point of view to increase the stability of the mirror holder mechanism, however the present design which includes 40 mm diameter mirrors seemed acceptable. It was agreed therefore to use 40 mm diameter mirrors.

It was pointed out that larger mirrors accept more spontaneous radiation power, which increases off-axis in the helical geometry, however it was agreed that this was no argument in favour of smaller mirrors since the slits could be closed if needed to reduce the power after alignment.

<u>Cavity parameters.</u> A small Rayleigh length reduces the mode size in the undulator and hence increases the gain, and also reduces the power density on the mirrors, but the cavity becomes increasingly unstable. MEC said that for the SuperACO 18 m cavity a stability parameter (g1g2) of 0.85 is considered a safe limit. Since a longer cavity requires a smaller value for equivalent angular alignment tolerance, a Rayleigh length of 4 m was considered a reasonable lower limit for which $g_1 g_2 = 0.78$. GD confirmed that his optimization shows that the best position of the waist is at the undulator centre. In this case the mirror radii become 19.27 m and 15.14 m which can be rounded to 19.0 and 15.0 m. The largest mode size (w)

at the mirrors is then 3.1 mm. The 40 mm diameter mirrors therefore provide a better ratio to the mode size (12.9) than the 25 mm mirrors at SuperACO (10.9), confirming the acceptability of this value.

Slot height and front-end aperture limits. MEC described the results of an experiment to close the slits at the SuperACO FEL, located 6.8 m from the undulator centre. The results suggest that an aperture of at least 11 times the mode size (w, where $w/2$ is the rms, $e^{-1/2}$, of the power distribution) is required for FEL start-up. MEC however recommended a value of $20w$ to allow an adequate safety margin. MEC explained that the argument is therefore not simply diffraction loss of the Gaussian mode (for which an aperture of $\pi\omega$ is adequate) but rather losses of the trapped spontaneous emission during start-up, including the effects of alignment errors. For the 32.4 m cavity with Rayleigh length of 4 m, the mode size is 1.23 mm at the slot. According to the above, an absolute minimum aperture of 15 mm is therefore required, preferably 25 mm for safety. RPW agreed therefore to try to increase the slot to 25 mm, or if not possible the largest feasible value.

RPW raised the question of using existing front-end components with internal diameters of 39 mm. At the limiting point, 11.5 m from the undulator centre the mode size is 2.03 mm, which is therefore close to the MEC $20w$ criterion. It was agreed therefore that a 39 mm aperture was sufficient up to this point.

Operating energy and undulator parameters. Concern had been expressed at the last meeting about the large K value of the undulator. BD pointed out that for reasonable values of period length the K value would inevitably be large; for example, 5.1 for 100 mm period and 4.5 for 125 mm period for 350 nm at 1 GeV. GD also thought that a large K value was of no particular importance.

As regards the operating wavelength, it was confirmed that 350 nm would be the longest value and the starting point. MEC pointed out the need for some increase over this value since mirrors centred on 350 nm would have a tuning range of about 20 nm. It was also confirmed that initial operation would be at 1 GeV, both for 350 nm and lower wavelengths.

MEC stressed the importance of operating in the future at higher than 1 GeV in order to increase the laser power and provide better compatibility with normal SR operation. To go in this direction implies either a longer period and/or maximizing the K value for any given period length. MM however stressed the need to maintain a small period length for the users of the SR beamline. The general conclusion was therefore that 100 mm already represented a good compromise between SR and FEL operation. ST must now make the final definition of permanent magnet block dimensions (width and height) in order to achieve the maximum K value within reasonable cost limits. The future possibility of reducing the undulator vacuum chamber gap was also mentioned as another way of reaching higher energy operation.

Layout. In terms of the overall layout, it was mentioned that although the back mirror would be more accessible for diagnostics, nevertheless a monochromator would be needed on the front mirror in order to analyse also the spontaneous radiation. To satisfy laser safety regulations the diagnostics will also have to be carried out in a closed hutch. It was concluded therefore that it is quite important to plan the layout of the diagnostic hutches at an early stage to make sure that there is enough space.

4. TASK A: OPTICAL CAVITY

MWP presented a program for the delivery of the mirror chambers to Trieste by the end of July 1999. He added that the timescales are very critical and depend on finishing design work and placing orders by the end of October.

NB presented the updated design of the mirror chamber which now allows 3 x 40 mm diameter mirrors plus a straight through direction of diameter 35 mm. It was agreed however that this latter would be increased to 40 mm. The vacuum chamber is now larger and rectangular to allow extra space for the future addition of cooling tubes. Fiducial marks on the outside will allow an accurate survey of the units into their correct position.

MM asked about the effect of the force that is exerted during mirror transfer and NB agreed to consider this.

MWP requested a specification of the partial pressures for the various gas species likely to be present. Since no precise specification can be given it was agreed that the best procedures of standard UHV monochromator technology should be the guideline. NB added that all components should be compatible with a 120 ^{o}C bakeout temperature. It was agreed that CLRC would supply controllers for the vacuum equipment and that ST would look after the interface to the control system. To simplify this task RPW provided a list of standard vacuum equipment used at ST.

NB presented a specification of the range and precision for each motorised axis and asked for comments on this as soon as possible. There was some discussion on the 20 mrad range for coarse pitch and yaw adjustment and it was agreed that NB should check the implications on the hinges of doubling this quantity and also to consider what angular variations could result from the insertion of new mirrors.

MEC pointed out that at SuperACO the fine adjustment of cavity length requires adjustment of the r.f. frequency to a setting resolution of 1 part in 10^8 (1 Hz at 100 MHz) equivalent to 200 nm in cavity length.

5. TASK B: MIRRORS

MEC reported that CEA was looking for new suppliers since their previous collaborator (Fourrier) cannot supply mirrors below 350 nm. Mackowski (Institute of Nuclear Physics, Lyon) had supplied Ta_2O_5 mirrors on sapphire substrates for 361 nm with very low initial losses (0.05 %). After 65 mA h exposure the losses had increased to 0.7 % which also recovered to 0.1 % after plasma cleaning and annealing. The 300 nm mirrors that had been fabricated using the same material were not however not so good. Attempts will be made with HfO_2 also.

HQ reported that Dortmund had ordered 3 sets of 4 mirrors for 250, 225 and 200 nm for the DELTA FEL program from the Fraunhoffer Institute (IOF), Jena. The mirrors will be produced using electron beam sputtering on sapphire and silica substrates. He said that the choice between fluorides and oxides had not yet been made and that the first results are expected in October. He showed data that suggested that the previous mirrors made using IBS for 470 nm showed no degradation with SR dose. MEC however suggested that the measurement technique may not be precise enough and that the shift of the fringes in the transmission curve probably indicated that there had been degradation; she added that cavity ring-down is a better technique for measurement of total losses.

MEC said that the new Argon laser purchased under this contract had been delivered but was not yet operational. Lines will be available at 265, 257, 248, 244 and 238 nm, the strongest being 257 and 244 nm. She said however that some time will be needed to set-up the measurement system and optimize it for the new wavelengths and that manpower was limited. It was agreed that the present campaign of measurements at 350 and 300 nm should be given priority at the moment and that the system should be optimized for 257 nm in the January/February shutdown when more time will be available. To make use of this possibility HQ agreed that the longest wavelength mirrors being purchased for Dortmund will be changed to 257 nm. For shorter wavelengths MEC said an excimer laser could possibly be obtained from Saclay and she agreed to find out what wavelengths could be available and when. DN pointed out that the effect of the pulsed operation will also have to be carefully considered.

The question of the power loading on the mirrors due to both the spontaneous and laser radiation was discussed, since this determines the type of substrate (sapphire for high power, silica for lower power) that can be used. MEC said that at SuperACO the main effect is due to the spontaneous radiation on the front mirror. A value of 20 W at 100 mA beam current is considered acceptable for sapphire mirrors, however this is still sufficient to increase the temperature to 100 °C. The actual value is variable depending on the thermal contact between mirror and holder. In the ELETTRA case the spontaneous emission may be less because of the helical geometry, however the laser power is larger. The spontaneous power must therefore be calculated, including the effects of a misaligned beam, unequal K values, higher energy operation and actual field distribution. The effect of the higher power and power density of the laser mode also needs to be considered.

From the above it became clear that the thermal contact between the edge of the mirror and the holder is very important. MM suggested that the mirror should be in good thermal contact but not rigidly fixed so as not to induce stresses. A possibility would be to use Indium-Gallium “glue” (often used in UHV monochromators) to attach the mirror to the holder, together with a light clamp for security, however the temperature would then have to be limited to less than 80 °C. It was concluded that because of the importance of the issue further discussion of the mirror attachment needs to take place.

6. TASK C: UNDULATOR AND FRONT-END

BD reported that the order for the mechanical support structures was about to be placed. Budgetary offers for the permanent magnets had also been received, and some discussions are presently going on with the favoured supplier in order to explore the variation of cost with magnet dimensions.

RPW said that following the decision that the aperture of existing front-end components was adequate (see 2) the front-end would be constructed in-house.

7. TASK D: ELECTRON-BEAM TESTS

RPW presented results from 3 ½ shifts dedicated to the FEL that had been carried out since the previous meeting. Three and four bunch operation had been tried for the first time. Up to 100 mA in 4 bunches and 90 mA in 3 bunches had been achieved at 1 GeV, limited by caution in not inducing parasitic mode loss heating. Examination of stripline spectra showed that stable longitudinal conditions could be reached in both cases with about 0.5° rms phase motion (where 1° at 500 MHz is equivalent to 5.6 ps) by a careful tuning of the r.f. cavity temperatures in order to obtain a cancellation of two higher order modes. A measurement of lifetime as a function of betatron coupling had however not given useful results. First measurements of bunch length in 4-bunch mode and another attempt to measure the effect of betatron coupling are planned for July 31st. Further FEL related measurements will then be carried out with the new Streak Camera later in the year; the period Nov. 19th-20th, was put forward as a likely possibility for partners’ participation.

8. TASK E: THEORY

GD presented calculations which showed that the optimum phase advance in the modulator for maximum small signal gain was approximately equal to the number of periods in each undulator, given the nominal energy spread of 0.19 % for 20 mA/bunch. A lower value of phase advance however was required to optimise output power. For the design of the modulator therefore the condition for maximum gain can be taken, with some appropriate smaller value of energy spread. GD said that his calculations indicated a maximum output power of about 1 W (80 mA in 4 bunches) with 10% output coupling and zero losses. DN however reported a larger value of 16 W for the same current and for 3 % losses and optimized 5 % output coupling. GD observed that his calculation, unlike those of DN, includes the increase in bunch length and energy spread due to the laser as predicted by theory, but does not include the suppression of the microwave instability that has also been observed. A subsequent calculation gave a power of 6 W if the bunch length is kept constant. Further work must be carried out to understand the difference of the two approaches.

GD also presented some considerations about the length of the photon pulse. The simple model in which the minimum length is given by the geometrical mean of the total slippage and the electron bunch length, gives in this case a value of 1 ps.

9. CONCLUSION

It was agreed that the next meeting should be held in about 3 month's time, toward the end of October.

SUMMARY OF MAIN DECISIONS:

- 32.4 m cavity
- 40 mm diameter mirrors
- optical cavity parameters: Rayleigh length ~ 4m, radii R1 = 19 m, R2 = 15 m.
- increased slot size is needed; goal is 25 mm
- leave ~ 0.5 m space for separate etalon and Brewster plate chambers if possible
- accept 39 mm diameter front-end elements
- no water cooling of the mirror chamber in the initial phase; provision for retrofit
- long wavelength limit and first operation at 350 nm
- initial operation at 1 GeV; higher energy for higher power operation later on
- confirmed 100 mm undulator period

SUMMARY OF MAIN ACTIONS:

- detailed layout of 32.4 m cavity (ST)
- examine implications of slot height increase (ST)
- outline of diagnostic hutches (ST)
- define final undulator parameters (ST)
- calculate spontaneous power on the mirror (ST)
- investigate availability and suitability of excimer lasers for mirror measurement (CEA)
- consider effect of laser power on the mirrors (CEA)
- consider forces during mirror transfer (CLRC)
- assess required angular range for coarse pitch and yaw (CLRC)
- assess other movement ranges and tolerances (ALL)
- consider mirror attachment to optimise thermal contact (CLRC, CEA, ST)
- consider survey requirements for mirror chambers (CLRC, ST)
- investigate discrepancies between power calculations (ENEA, CEA)

R.P. Walker
Trieste, 11th August, 1998