ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-86/64

M. Ambrosio, G.C. Barbarino, M. Castellano, N. Cavallo, F. Cevenini, M.R. Masullo, P. Patteri, M. Preger and A. Cutolo:
PROGRESS REPORT ON THE LELA EXPERIMENT

Estratto da:
Nucl. Instr. & Meth. Phys. Res. A250, 239 (1986)

Servizio Documentazione
dei Laboratori Nazionali di Frascati
Cas. Postale 13 - Frascati (Roma)

Nuclear Instruments and Methods in Physics Research A250 (1986) 239–243
North-Holland, Amsterdam

PROGRESS REPORT ON THE LELA EXPERIMENT

M. AMBROSIO, G.C. BARBARINO, M. CASTELLANO, N. CAVALLO, F. CEVENINI
and M.R. MASULLO

INFN, Sezione di Napoli, Dipartimento di FNSMFA, Università di Napoli, Pad. 20, Mostra d'Oltremare, 80125 Napoli, Italy

P. PATTERI and M. PREGER

INFN, Laboratori Nazionali di Frascati, Frascati (Roma), Italy

A. CUTOLO

INFN, Sezione di Napoli, Dipartimento di Elettronica, Università di Napoli, Italy

After the installation of the optical cavity of the LELA experiment, a series of tests of the cavity alignment relative to the electron beam direction has been performed, showing the problems due to the peculiarity of this cavity. The use of piezoelectric translators in ultrahigh vacuum has permitted a smooth and precise control of the cavity optical axis. Preliminary results on mirror damage due to UV radiation have also been obtained.

1. Introduction

Since the first operation of a free electron laser in 1977 at Stanford [1], a great number of experiments have been undertaken all around the world [2].

A couple of years ago the first FEL using a storage ring as electron source succeeded in reaching the oscillation threshold at Orsay [3], thus proving the feasibility of devices exhibiting a gain as low as 6×10^{-4}. The LELA experiment, in progress on the Adone storage ring in Frascati, differs from the experiment at Orsay by nature of the larger electron machine and the higher energy of the beam at Frascati. Both factors imply the use of a long optical cavity (17.5 m), the use of remote control of the system, and the acquisition of data via a remotely located computer. While these characteristics encumber the Frascati FEL with a heavier load of technical requirements, they will make it possible to extend the analysis of the mechanisms determining the evolution of the optical field inside the resonator.

Table 1
Main characteristics of the LELA experiment

Machine	
Energy	$E = 550$–625 MeV
Circumference	$L = 104.86$ m
Bunch to bunch distance	$t = 117$ ns
Fractional energy spread	$\sigma_p = 2.3 \times 10^{-4}$
Bunch length	$\sigma_t = 350$–1000 ps
rf frequency	$f_R = 51$ MHz
Number of bunches	3
Radial beam envelope	$\sigma_x = 2.5$ mm
Vertical beam envelope	$\sigma_y = 0.25$ mm
Undulator	
Period length	$\lambda_w = 11.6$ cm
Number of periods	$N = 20$
Length (with clamps)	$L_w = 2.412$ m
Maximum magnetic field on axis	$B_0 = 4.95$ kG
Operating field parameter	$K = 4.825$

The main characteristics of the experiment have already been presented at previous FEL Conferences [4,5], and are briefly summarized in table 1.

No further attempts have been made to increase the measured peak gain of 3×10^{-4}, but an effort is now in progress to improve the performance of the accelerator and we look forward to having, during the next year, a greater peak current and all the beam diagnostics required to put in operation a new magnetic structure which has a vanishing dispersion function in the straight section of the undulator. Under these conditions we could get an increase of the actual gain by a factor of 3–4, thus passing the 10^{-3} threshold which should make lasing action possible.

Meanwhile, after the installation of the vacuum optical cavity (17.51 m long), we have undertaken a series of tests on the possibility of aligning the optical axis of the cavity to the electron beam direction. We also obtained preliminary results on the mirror reflectivity degradation due to the high flux of UV radiation emitted on axis by our high K undulator.

The present paper will describe the main problems

Table 2
Main characteristics of the LELA optical cavity

Pressure inside the whole cavity	10^{-9} Torr
Cavity length	$L = 17.51$ m
Upstream mirror curvature radius	$R_1 = 7$ m
Downstream mirror curvature radius	$R_2 = 12$ m
Diffraction losses per pass	$\alpha < 10^{-4}$
Fundamental cavity mode waist at $\lambda = 6328$ Å	$w_0 = 0.68$ mm
Rayleigh length	$Z_r = 2.4$ m
Alignment of the optical Axis on the electron beam trajectory	≤ 10 µrad
Longitudinal tuning of the cavity	≤ 10 µm

encountered during these tests. In section 2, after briefly describing the optical cavity [7], we report the results of the performance, under high vacuum conditions, of the piezoelectric translators used for remote control of the mirrors. In section 3 we discuss the main problems encountered in obtaining good alignment of this long optical cavity, and finally, in section 4, we discuss some preliminary results of the radiation induced degradation of the mirrors.

2. The optical cavity

The free electron laser under construction on the Adone storage ring requires an optical cavity with a length of 17.5 m and losses less than 10^{-4}. These characteristics, very unusual for typical laser cavities,

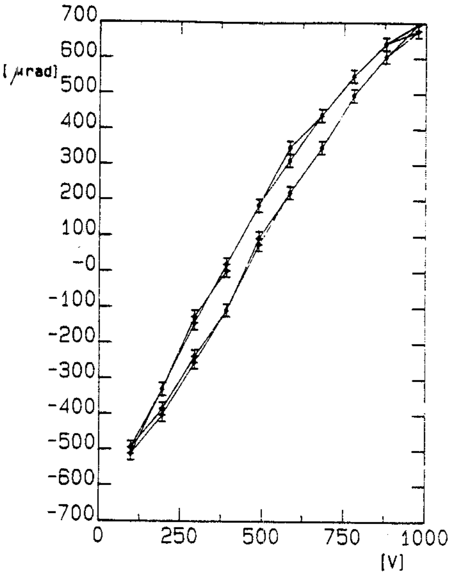

Fig. 2. Piezoelectric translator hysteresis loop measured inside the cavity at 10^{-9} Torr.

are imposed by the requirements of synchronizing the radiation pulses with the recirculated electron bunches and by the very small gain. The optical and mechanical details of the cavity have been already presented [6] and its main parameters are listed in table 2.

To keep the losses below the required value, no separating windows are allowed, and the complete cavity is directly connected to the accelerator pipe under ultrahigh vacuum (10^{-9} Torr). Due to the radiation

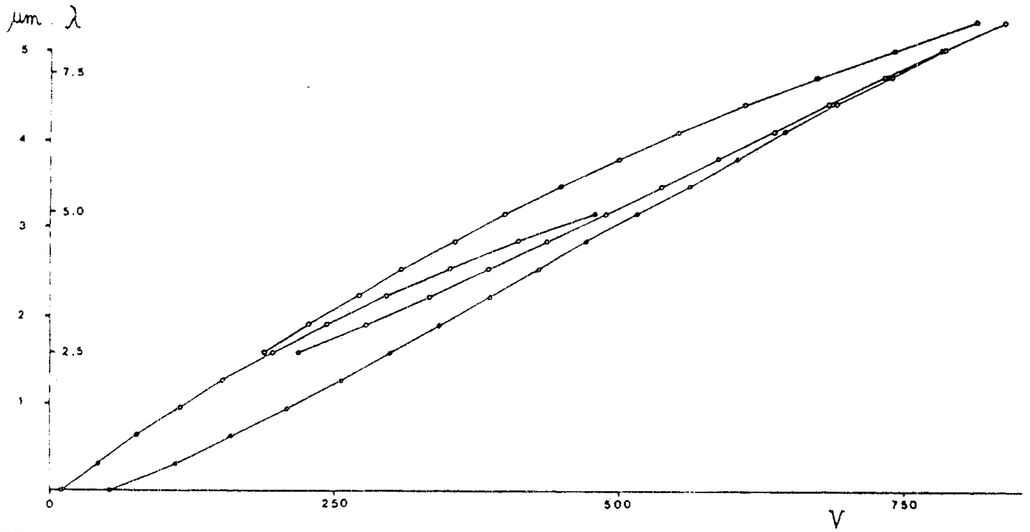

Fig. 1. An example of a piezoelectric translator hysteresis loop measured in the laboratory at atmospheric pressure.

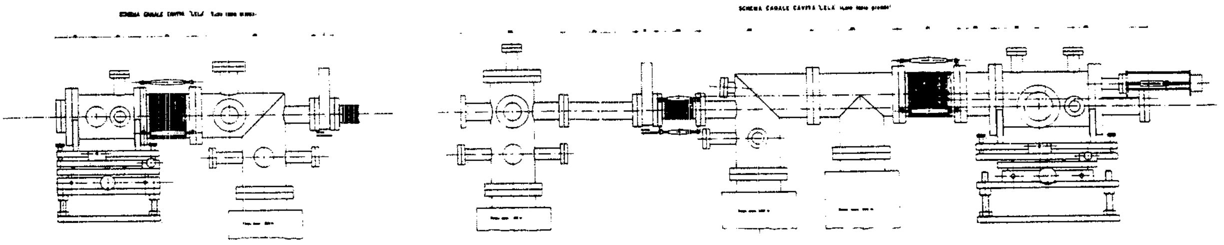

Fig. 3. Actual layout of the optical cavity vacuum vessel.

exposure hazard, both mirrors must be remotely controlled.

This control under vacuum is obtained by means of piezoelectric translators. The performance of the translators has been guaranteed by the manufacturer up to 10^{-6} Torr vacuum and their main characteristic is a well-pronounced hysteresis loop. We have extensively measured the performance of these translators in our laboratory using interferometric methods, and in fig. 1 one result of these measurements is shown. We found that the best reproducibility can be obtained by following the hysteresis loop in the decreasing voltage direction.

After the installation of the translators in the vacuum cavity, we tested their performance by looking at a reflected laser beam at a distance of 20 m from the remotely controlled mirror. The position of the reflected spot has been measured by means of a TV camera controlled by a digital circuit, obtaining a resolution of 300 μm. The result of such a measurement is shown in fig. 2, in which two complete loops are presented.

These results completely agree with those obtained in laboratory tests at atmospheric pressure. No degradation of the vacuum has been observed during the action of the piezoelectric translators, whose position reproducibility has proven to be better than 0.2 μm.

The results on mirror reflectivity degradation, discussed in section 4, induced us to modify the vacuum vessel in order to improve the vacuum pressure obtainable in the mirror holder heads. To achieve this goal, we doubled the pumping power and decreased the impedance between pumps and mirror containers. The present layout of the vacuum cavity is shown in fig. 3.

3. Alignment of the optical cavity

It is well known that the alignment of an optical cavity requires the use of an external laser beam. Although in general this operation is not very difficult, in our case the problems are strongly increased by the length of the cavity which is completely closed in an evacuated vessel. In particular, a critical factor is represented by the fact that the ratio between the cavity length and the Rayleigh number of the cavity's fundamental mode is about 10. This fact poses strong requirements on the quality of the external laser beam and of its matching with the cavity.

In this section we present some preliminary experimental results on the alignment of the LELA optical cavity. In this set of measurements we have used SiO_2–TiO_2 multilayer dielectric mirrors whose reflectivity has been measured to be 99.8% at 6328 Å.

The alignment of the cavity to the electron beam direction is obtained by means of a two-step procedure. First, the external argon laser is aligned on the spontaneous radiation and the cavity is aligned on the laser beam. Then, using the remotely controlled piezoelectric translators, the final alignment is obtained by maximizing the coupling of the spontaneous radiation to the fundamental mode of the optical cavity.

The first step of this procedure is affected by two different sources of errors, which prevent us from reaching an alignment better than 300–400 μrad. First, the argon laser beam is injected into the cavity through the upstream mirror. Then, both the laser and the spontaneous radiation are extracted from the cavity by means of a 45° movable mirror, while the laser is aligned on the spontaneous radiation along their path in air. The cavity mirror intersected by the laser beam has a 7 m radius of curvature and therefore acts as a lens. Due to the distance involved, about 30 m, this lens effect cannot be neglected. The laser trajectory after the mirror depends on the point where the mirror is intersected. As a result this operation has to be iteratively repeated until the laser is aligned on the spontaneous radiation and the upstream mirror of the cavity is centered on the laser. In this way we can obtain an alignment which is restricted to be no better than 0.2 mrad.

The second source of error comes from the alignment of the cavity. This alignment is made, as usual, by looking at the several reflections generated on the cavity mirrors by the laser beam traveling back and forth through the cavity. The cavity can be considered aligned when only one spot appears on each mirror. As is extensively discussed in ref. [8], the use of this method for such a long cavity requires perfect control of the laser mode; even a little mismatch gives rise to a significant alignment error. In our case, taking into account only the errors due to the tolerances of the lenses forming the matching telescope, we obtain a misalignment of the order of 0.3 mrad.

It is thus clear that, using only this technique, we are very far from our goal of obtaining an alignment within 10 μrad given by the necessity of not significantly reducing the gain. This has led to the necessity for the piezoelectric translators, which become the most fundamental instruments of our experiment.

After the completion of this laborious alignment procedure, we found that the electron trajectory was shifted from the center of the undulator by more than half a centimeter. In these conditions the spontaneous radiation reflected by the downstream mirror was intercepted by an inner part of the vacuum pipe, and the upstream mirror remained only partially illuminated. Of course, our next step will be the correction of the electron orbit to shift it to the center of the undulator. This operation is made more difficult by the lack of efficient orbit diagnostics, a new version of which will be implemented in the near future.

To test the position sensitivity of our automatic control of the optical axis, we have made some runs with the cavity misaligned. In these runs we injected into the storage ring only one electron bunch. As the cavity length is determined by the necessity of synchronizing the successive light pulses of three electron bunches, it was possible to see, after the passage of the bunch, two successive reflections of the light pulse in the cavity.

The radiation was injected in the cavity with an angle of about 1 mrad with respect to the optical axis, so it was easily lost in the successive reflections, but also under this condition we were able to demonstrate the stability of the optical axis direction within 5 μrad in a few hours of run, and the piezoelectric translators have proven to be an excellent instrument, giving a smooth and precise control of the mirrors.

As a conclusion of this section, we want to stress that, due to the large uniform field volume of our undulator, the electron orbit shift has no consequences at all on the spectrum of the spontaneous radiation, as the measurements already reported [9] show very clearly.

4. Mirror damage

After the ACO results it has been evident that one of the major problems for a low gain FEL experiment is the degradation of dielectric mirrors' reflectivity induced by UV radiation.

The high K value of our undulator, and thus the large flux in higher harmonics of the spontaneous radiation spectrum, leads us to predict that this will be the most crucial point of our experiment. For this reason, during the preliminary tests of the alignment of the optical cavity, we analyzed the reflectivity of the mirrors exposed to the spontaneous radiation, although during these tests we used commercial laser grade mirrors. We measured their reflectivity before the introduction into the cavity by means of the cavity phase shift method [10] and a HeNe laser, finding a reflectivity of 99.8% at 6328 Å. After the exposure, a large decrease of reflectivity has been measured.

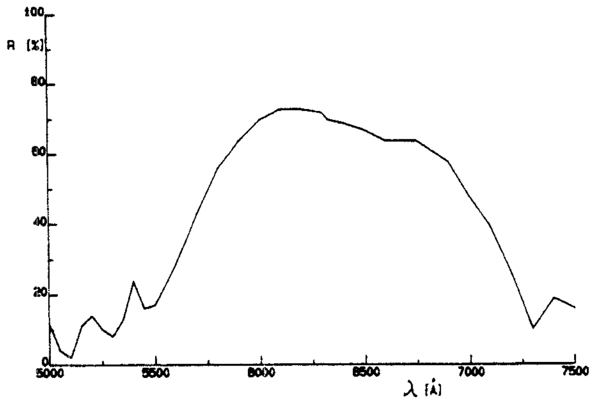

Fig. 4. Reflectivity curve of a dielectric mirror after exposure to the undulator radiation for an integrated current of 800 mA h.

A detailed analysis of these results will be presented separately [11]; here we will limit ourselves to show the reflectivity curve of a mirror exposed to 800 mA h of radiation (fig. 4), in which a value as low as 70% is reached.

The result of our analysis seems to indicate the presence of two different sources of damage: a surface absorption of carbon atoms, which affects more strongly the downstream mirror, and a bulk damage not directly related to the spontaneous radiation intensity which affects both the mirrors.

In the near future, besides studying more accurately the sources of damage, we will try to reduce the damage by improving the vacuum in the mirror containers and by testing some protective coating on the mirrors themselves.

Acknowledgements

We are grateful to the people of the Accelerators Division of LNF for their contribution in the first stage of the experiment.

We are greatly indebted to Prof. S. Solimeno for his continuous help and fruitful discussions.

References

[1] D.A.G. Deacon, L.R. Elias, J.M.J. Madey, G.J. Ramian, H.A. Schwettman and T.I. Smith, Phys. Rev. Lett. 38 (1977) 892.

[2] Proc. of the Bendor FEL Conf., J. Phys. (Paris) Coll. Cl. Tome 44; Free Electron Generators of Coherent Radiation. SPIE 453 (1984).

[3] M. Billardon, P. Elleaume, J.M. Ortega, C. Bazin, M. Bergher, M. Velghe, Y. Petroff, D.A.G. Deacon, K.E. Robinson and J.M.J. Madey, Phys. Rev. Lett. 51 (1983) 1652.

[4] R. Barbini, G. Vignola, S. Trillo, R. Boni, S. de Simone, S. Faini, S. Guiducci, M. Preger, M. Serio, B. Spataro, S. Tazzari, F. Tazzioli, M. Vescovi, A. Cattoni, C. Sanelli, M. Castellano, N. Cavallo, F. Cevenini, M.R. Masullo, P. Patteri, R. Rinzivillo, A. Cutolo and S. Solimeno, J. Phys. (Paris) Cl 44 (1983) p. 1.

[5] M. Biagini, R. Boni, S. de Simone, S. Guiducci, M. Preger, M. Serio, S. Tazzari, F. Tazzioli, S. Trillo, M. Vescovi, M. Ambrosio, G.C. Barbarino, M. Castellano, N. Cavallo, F. Cevenini, M.R. Masullo, P. Patteri, R. Rinzivillo and S. Solimeno, SPIE 453 (1984) 275.

[6] M. Biagini, R. Boni, S. de Simone, S. Guiducci, M. Preger, M. Serio, S. Tazzari, F. Tazzioli, M. Vescovi, M. Ambrosio, G.C. Barbarino, M. Castellano, N. Cavallo, F. Cevenini, M.R. Masullo, P. Patteri, R. Rinzivillo, S. Solimeno and A. Cutolo, Nucl. Instr. and Meth. A237 (1985) 273.

[7] M. Ambrosio, G.C. Barbarino, M. Castellano, N. Cavallo, F. Cevenini, A. Cutolo, M.R. Masullo, P. Patteri, R. Rinzivillo and S. Solimeno, Frascati Rep. INFN/TC-84/9 (1984).

[8] A. Cutolo and S. Solimeno, these proceedings (7th Int. FEL Conf.) Nucl. Instr. and Meth. A250 (1986) 293.

[9] M. Castellano, N. Cavallo, F. Cevenini, M.R. Masullo, P. Patteri, R. Rinzivillo, S. Solimeno and A. Cutolo, Nuovo Cimento 81B (1984) 67.

[10] J.M. Herbelin, J.A. McKay, M.A. Kwoh, R.H. Veunten, D.S. Urevig, D.J. Spencer and D.J. Bernard, Appl. Opt. 19 (1980) 144.

[11] M. Ambrosio, G.C. Barbarino, M. Castellano, N. Cavallo, F. Cevenini, M.R. Masullo and P. Patteri, these Proceedings (7th Int. FEL Conf.) Nucl. Instr. and Meth. A250 (1986) 289.