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TITLE LONG-BASE FREE ELECTRON LASER RESONANT CAVITY

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Long-base free electron laser resonant cavity

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Abstract

A 65-meter resonant cavity has been constructed in order to experimentally determine the characteristics of long resonant cavities as would be required for a free electron laser (FEL). A version using normal incidence mirrors is reported here, and another that includes a grazing incidence mirror² is forthcoming. Either version is designed to simulate a FEL operating at 0.5 micron wavelength and is near-concentric with a stability parameter of 0.98. Argon-ion plasma tubes simulate the laser gain that would be provided by a wiggler in an actual FEL. The cavity was constructed on a seismic slab and air turbulence effects were reduced by surrounding the beam with helium in 6" diameter tubes. Alignment sensitivities are reported and compared to geometrical and diffraction predictions^{3,4} with good agreement.

Introduction

The long-base resonator experiments are intended to provide valuable experience in support of development of a high-intensity FEL resonator cavity. The test cavity is roughly 65m long and made to lase by one or two argon-ion plasma tubes having dimensions comparable to a FEL wiggler. This design is stable but nearly concentric, resulting in exacting alignment requirements and a high susceptibility to air turbulence and mount instability. The design will include a grazing incidence mirror (grazer) within such a cavity, but the many anticipated and confirmed pitfalls have led to staging the experiments in two steps. The first of these was to establish and debug a test bed bearing appropriate dimensions but no grazer. This step has been completed using a substitute end mirror much smaller than will accompany the grazer and will be the principle subject of this paper. The major thrust of testing was twofold. First, it was necessary to confirm the full applicability of traditional formulas and their available computer codes, and to establish tolerances for manufacturers and determine whether they could be met. The data in this paper was gathered toward such ends. The principle problem encountered was the difficulty in determining the radii of curvature of the end mirrors, which were needed to calculate a resulting "stability parameter" (often about $G = g_1 g_2 = 0.98$) and to predict the beam profile. Second, it was necessary to establish procedure, controls, instrumentation and environment in which laser behavior matched these ends and could be tested. That proved to be a considerable challenge, and no small amount of equipment is required to stabilize the beam. Failure to stabilize the beam results in unpredictable aperturing effects and difficulty in knowing the instantaneous locations of the centers of curvature of the mirrors.

Beyond the data shown, the outcome of test-bed experiments was the conclusion that a computer controlled double closed loop mirror alignment system would have to be in place to handle the level of testing desired and the conditions that will result when the grazer goes in place for step two. The grazer is a powered element with an angular magnification of approximately 9. The effects of vibrations and automatic realignment will be exaggerated accordingly.

Testing Scheme Perspective

The end mirrors used have radii of curvature of roughly 13 meters. These radii usually overlapped by 1 to 2 meters. Differences in the overlap in the horizontal and vertical planes (astigmatism) were frequently encountered. To measure and control this overlap, a strategy of prediction, measurement and comparison was applied as outlined in fig. 1.

The first step begins with one of a number of estimates of the radii of curvature of the chosen end mirrors. Usually the manufacturer's version sets the beginning iteration, but other independent measurements were made, resulting in a measurement range (shown in Fig. 6 where radii calculations will be compared). A cavity length is then chosen using considerations of plasma tube bore size and other interesting features such as beam motions expected while approaching concentricity. With a given cavity length established, the anticipated output beam size and scan slope are derived. The scan slope, $m = \Delta F / \Delta \theta$,

is the translation of the beam as measured at an end mirror (Δs), divided by the angular rotation ($\Delta \alpha$) of an end mirror used to induce the translation. The beam size and scan slope are next measured at one or both end mirrors and compared to the anticipated values. If there is a disagreement, estimates of the radii of curvature required to generate the measurements are made, complete with error bars associated with the measurements. The new radii are compared to the original. Conclusions drawn at this point lead to a variety of alterations in the test, such as minor changes in cavity length to confirm the reproducibility of the new radii, or possibly the correction of experimental flaws that frequently become apparent at this point. Evidence that the beam has scraped the top or bottom of the plasma tube during a horizontal scan, contamination of the helium environment and mode hopping during the test are typical problems detected during some tests and are used to correct the procedure. For example, proper performance of the laser is so sensitive that minor tension error in a mirror mount has caused the laser to be stable in one dimension and not in the other. This results in the beam profile and the direction of the beam motion in one dimension failing to meet predictions.

The second area well worth setting into perspective is turbulence and vibration. For a cavity such as ours, laser beam displacements at the end mirrors in a normal room take on centimeter proportions within a few passes. This is beyond one spot size (usually less than 1 centimeter) and would be unworkable. Tubes about the beam to still the air bring the deflection down to a few millimeters. Lasing can occur but with considerable beam wander. This problem is resolved using a plastic liner placed within the tubular baffles and filled with helium after evacuation of the air. The lower index of refraction and improved thermal behavior of helium reduce the turbulence effects to the point that the beam motion is caused largely by mirror motions.

In our installation, seismic tests suggest a relationship between beam motion and seismic sources, though translational seismic motion is too small to make significant contributions through corresponding mirror translation. Angular motions in the floor or table are apparently occurring. This is minimized by mounting the end mirrors on the same table and using an odd number of turning mirrors to fold the laser within the room. This cancels much of the beam motion. Vibrations shown in the beam tend to have a few dominant resonances between 20-35 Hz with a magnitude in the millimeter realm and, therefore, small compared to spot size. Slow drifts of several millimeters are often experienced over many minutes, and are presumed to be correctable since beam power restores when the mirrors are manually returned to their original locations. They may originate in part from the drift of the piezoelectric pushers that control the mirrors, but similar drifts have been found in purely mechanical mounts. Mirror tilt of a microradian yields a beam displacement of roughly 1 mm at the end mirror, or a beam rotation about 30 times the mirror tilt. Such a tilt would require a pusher motion or mechanical deformation at the mirror support edge of about 0.05 μ m. The slow and fast motions just mentioned are the major contributors to the error bars shown in beam location related data.

Layout and equipment

The layout of the cavity is shown in Fig. 2. Both end mirrors are mounted on the same NRC table, which has kinematic legs setting directly on the isolation slab. Turning mirrors are on sand-filled pedestals on the same slab. The mirror mounts are adjusted by computer-controlled piezos. Mirror tilt is measured with Hewlett-Packard interferometers, with the exception of the vertical output mirror motion for which there is insufficient equipment to monitor. Motions of 0.1 microradian can be read but only at a rate of a few samples per second. These readings are not available to the computer, but records of drift during measurements are kept. The beam location is measured using quadrant detectors (QDs). For scan measurements, a QD is attached to an oscilloscope in the x-y mode and used as a null detector. The QD has a range far less than the scan and is translated by remote control to minimize disturbance of the table. The perpetual motion of the beam forms blur spots on the scope screens. Data taken is, therefore, averaged with simultaneity of measurements at the two ends of the cavity destroyed. Power measurements are recorded with each scan step.

The beam profile is made available by photographing individual lines sliced with a video analyzer from a TV image of the beam.

Beam profiles

A digitized version of the beam profile plot was fitted to a gaussian by a computer routine with results shown in Fig. 3. The good agreement lends credence to the use of the beam width in calculating apparent end mirror radii. Such calculated radii will appear with the label "spot size data" in Fig. 6 for comparison to other radii derivations.

Scan slopes

Scans are made by incremental voltage changes upon one piezo with the motion confirmed by the HP interferometer and converted to end mirror tilt. The measured motion of the beam is then plotted against the tilt to form scan curves as shown by Fig. 4. A slope $m = \Delta b / \Delta \alpha$ is plotted on the scan curve about the coordinates of peak power. The region included in these curves is roughly the range across which lasing action is still producing a reliably measurable signal (>0.1 beam max). The zone in which the slope is unaffected by aperturing with the plasma tube is small, about 10 microradians. The asymmetry arises from being unable to perfectly position the stationary end mirror radial point with the computer removed in the null detection mode.

Using the scan slopes, the apparent radii of curvature of the mirrors can be calculated, as shown in Fig. 6 with the title "scan slope data." From these apparent radii, an anticipated beam size can be calculated, and this has been compared to the measured beam profile in Fig. 5 with good agreement.

Compared radii estimates

A wide variety of measurements were used to establish the correct radii of curvature of the mirrors. This included three types of measurements of the mirrors themselves done at this and other laboratories. The results from these studies were quite varied and not highly reproducible. They established a set of upper and lower boundaries shown in Fig. 6 where the apparent radii calculated from scan slopes and spot profiles are also shown. Data has been gathered at several cavity lengths, the shortest of which results in a waist size larger than the 2.5-mm diameter plasma tube bore and, therefore, a modification in the laser's performance.

Aperturing Effects

Observed alignment sensitivity may be expected to deviate from that predicted by geometric analysis whenever there are restricting apertures comparable to or smaller than the $1/e$ beam diameter. A controlled study of this behavior was performed by placing a variable aperture just inside one cavity end and tilting one mirror through the same scan procedure used before. The measured beam displacement was compared with that predicted theoretically by a Los Alamos diffraction propagation code, LOTS2B.

Initial comparison between code and experiment showed discrepancies significantly larger than the experimental error. This was ultimately traced to the way in which mirror tilts were handled in LOTS2B. After minor software modifications, the code correctly predicted the observed behavior as demonstrated in fig. 7.

Conclusion

The long-base resonator experiment has been shown to be a useful tool supporting the development of a high intensity FEL device. Results of operation in the geometric and physical optics regimes show agreement between the theory and experiment.

Future plans

Mirrors that simulate a high-intensity grazing incidence mirror cavity configuration are being procured and will be evaluated in the setup in the near future. Interferometry monitoring the mirrors and attached to the computer will be in place to stabilize the mirror motions at all times including scan tests. Subsequent experiments planned include ring resonator evaluation, unstable configuration evaluation, active cavity length control and real time alignment systems.

References

1. C. A. Brau, "Progress in free-electron lasers." Abstr. in Bull. Amer. Phys. Soc., vol. 28, p. 1028, 1983.
2. P. R. Akkapeddi, P. Glenn, and A. Fuschetto, "Grazing Incidence Beam Expander", This publication.
3. H. Kogelnik and T. Li, "Laser Beams and Resonators," Applied Optics 5, No. 10, November 10, 1966.
4. A. E. Siegman, An Introduction to Laser and Masers, McGraw-Hill, 1971.

Figure 1 The multiple comparison strategy used to assess radii of curvature of the end mirrors. Any demonstration that laser performance matches the geometric and physical models depends upon these values

Figure 2 A schematic of the folded laser cavity used for tests discussed here

Figure 3 Measured beam profile (measurement points) compared to best fit gaussian (solid line)

Figure 4 Beam motion at the end mirrors due to tilt of one end mirror, with slope lines m_1 and m_2 for peak power (initial alignment).

Figure 5 The measured gaussian compared to the gaussian predicted from the slope data.

Figure 6 Apparent mirror radius as calculated from various performance measurements using several cavity lengths

Figure 7 Scan slopes with a variable aperture just inside the output end mirror

SELF-CONSISTENT GAUSSIAN BEHAVIOR CAN BE CHECKED WITH MULTIPLE APPROACHES

• DIFFICULTY IN OBTAINING PRECISE MEASUREMENTS OF THE MIRROR CURVATURES CREATES UNCERTAINTY IN EXPECTED RESULTS

$$\frac{d(\Delta B/a)}{dR} \approx 0.584 \text{ mm}/\mu\text{rad} \quad \frac{dw}{dR} \approx 1.4 \text{ mm}$$

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