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Author

Jackson, A.

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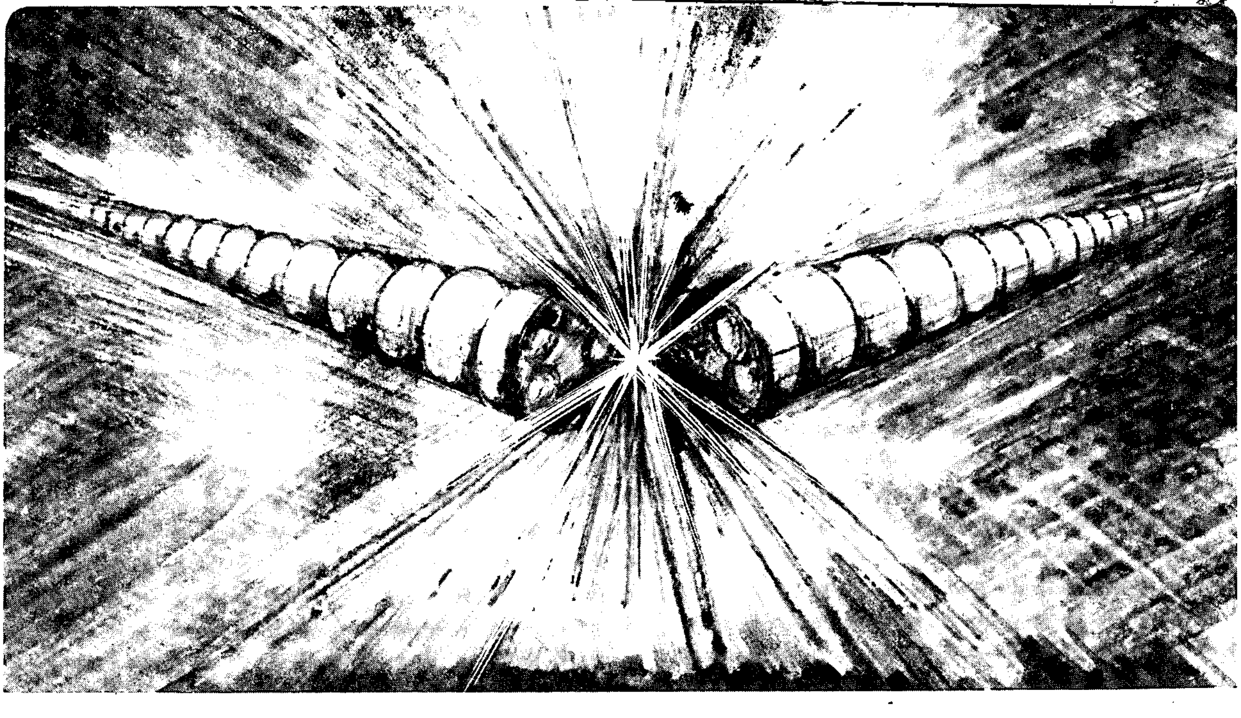

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Alan Jackson

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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Alan Jackson
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

I. INTRODUCTION

The Aladdin Upgrade Study is a multi-laboratory effort whose purpose is to "guarantee satisfactory performance (of Aladdin) with the new (800 MeV) injector".

This report describes work carried out as part of the study on the dynamic behavior of the Aladdin lattice after chromatic correction via the two available sextupole families.

The investigation was repeated for alternative lattices provided as part of the study by colleagues from the Argonne National Laboratory.

Effects of multipole fields (random and systematic) and orbit misalignments on the dynamic behavior of Aladdin are currently under investigation. A brief summary of the effects observed so far is included in this report for completeness.

II. METHODOLOGY

The next two sections deal with the dynamic behavior of perfect machines, i.e., without misalignment errors or magnet imperfections. For each machine a momentum scan and a plot of the stability limit are presented.

The momentum scan, an example of which is given in Fig. 2., shows the variation of tune, $\Delta\nu_{x,y}$, with the momentum deviation, δ (= $\Delta p/p$), computed using the code SYNCH. If the chromatic behavior of the machine has been correctly predicted, then the slope of the curve at $\delta = 0$ must be zero. The curvature at $\delta \neq 0$ arises from the correcting sextupoles themselves and can be a strong function of exactly where the sextupoles are located. Tune variations greater than 0.1, in the momentum range of interest, indicate that trouble may be expected in the dynamic behavior of the machine. But what constitutes the "momentum range of interest"?

A rough estimate of the quantum lifetime of an electron beam gives[1]

$$\tau_q \approx \tau_\varepsilon \frac{e^{n^2/2}}{n^2}$$

where n is the energy aperture of the machine measured in units of the energy spread in the beam, σ_ε.

This is a very rapidly increasing function of n, which for $n \geq 7$ gives essentially infinite lifetime. However, in order to allow for effects of beam growth, n is commonly taken as 10 or even 20 at the design stage. For Aladdin at 800 MeV $\frac{\sigma_\varepsilon}{E} \approx 5 \times 10^{-4}$

$$\therefore \quad 20 \frac{\sigma_\varepsilon}{E} = 10^{-2} = 1\% \ .$$

Thus the "momentum range of interest" is taken as ± 1%.

For all the cases discussed here, it will be seen that $\Delta\nu_{x,y} < 0.1$ within this momentum range.

The stability limit or dynamic aperture has been found by tracking test particles through the lattice with the computer code MARYLIE, which permits tracking in 6 dimensional phase space. A test particle is launched with a momentum deviation δ, at the synchronous phase and with an initial betatron amplitude. This starting amplitude (in either or both transverse

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[1] SLAC-121, M. Sands, "The Physics of Electron Storage Rings," 1970.

planes) is then increased until the motion is seen to become unstable. The maximum stable amplitudes define the stability limit for particles with momentum deviation δ.

In order to avoid problems with the injection process, which uses stacking in betatron phase space, it is necessary to choose a physical aperture which is smaller than the dynamic aperture in the plane of injection. After injection, the stability limit could be reduced below the physical aperture, as a result of changing the tune point for example, in which case such calculations as Touscheck and gas scattering lifetime should utilize the dynamic rather than the physical aperture.

The results of this method applied to four lattices are presented in the next two sections.

III. THE ALADDIN REFERENCE LATTICE - ALADDIN 1

The reference lattice is the "best fit" to the linear lattice parameters as measured on Aladdin at 800 MeV. Fig. 1 shows the structure and the lattice functions η, β_x and β_y, and Table 1 gives a short-list of parameters. The momentum scan is shown in Fig. 2 and indicates that there is no problematical behavior in the momentum range of interest.

For the tracking studies, a "thin" cavity was set up at the new cavity position between the downstream triplet and doublet in a long straight section. The cavity voltage was set to 65 kV at 50.5 MHz corresponding to an energy acceptance $\Delta E/E$ of 1%.

The stability limit shown in Fig. 3 corresponds to a particle with a momentum deviation of $\delta = 0.8\%$, approx. 17 σ_ε. Even at this large value of δ it can be seen that the stability limit in the radial plane falls well outside the physical aperture. In the vertical plane, however, a particle would become unstable before reaching the physical limit...but only just! For most calculations then, the physical aperture can be used without introducing any significant error.

IV. ALTERNATIVE OPTICS

Three alternative lattices have been produced by colleagues at ANL. The first, Aladdin 1A, is the same as Aladdin 1, but matched to a slightly different tune point. It has a somewhat higher dispersion around the arcs of the machine, but lower values at the current and projected RF cavity positions and at the injection point. Aladdin 2 employs the same geometric layout as lattice 1, but uses 9 families of quadrupoles, rather than 5, to impose a greater degree of symmetry, with zero dispersion in the long straight sections. Aladdin 3 reverts to 5 quadrupole families and imposes symmetry by moving the positions of the quadrupoles. The resulting structure is very similar to the BESSY/METRO structure and has the advantage of a smaller natural emittance.

a) Aladdin 1A

The structure of Aladdin 1A, together with the lattice functions and parameters, are shown in Fig. 4 and Table 2. Comparison with Fig. 1 and Table 1 demonstrates the similarity between these structures. Fig. 5 shows an acceptable momentum scan. The stability limit, Fig. 6, is seen to be larger than Aladdin 1, particularly in the vertical plane, probably due to the weaker sextupole requirement for chromatic correction. (cf. Tables 1 and 2.)

b) Aladdin 2

The structure of Aladdin 2 produces smaller β and dispersion functions as shown in Fig. 7, with a momentum compaction factor which is only one-half that of Aladdin 1. A short-list of parameters is given in Table 3. Chromatic behavior is acceptable, Fig. 8, and the stability limit is shown in Fig. 9 to lie entirely outside the physical aperture.

One detracting feature of this structure is the "wealth" of systematic resonance lines close to the chosen working point, (in fact, in the unit integer square, see Fig. 10), though the lattice does look flexible enough to tune into a different square.*

c) <u>Aladdin 3</u>

Aladdin 3 is an attempt to rearrange the lattice structure to produce a machine with a smaller emittance. The dipole magnets are left undisturbed and fewer quadrupoles, placed symmetrically about the center of the long straight, are utilized. A secondary result is that the straight section length available for insertion devices increases slightly.

The structure and optical functions for this lattice are shown in Fig. 11 and a short-list of parameters is given in Table 4. Again, the chromatic behavior is seen to be reasonable, see Fig. 12, and the stability limit is very large when compared with the physical aperture, as shown in Fig. 13. (The reason for the poorly defined stability limit is due to the long synchrotron oscillation period, ~ 900 turns, requiring more lengthy tracking computations to achieve more definitive results.)

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* We have been informed that this lattice has indeed been tuned and optimised in a different region of tune space; however, we have not had time to analyse the new structure.

V. CONCLUSIONS - IDEAL LATTICE

In terms of the dynamic behavior of the ideal lattice, there is no strong case to suggest any change to the geometric layout of Aladdin. The sensitivity of emittance and dispersion to tune (cf. Aladdin 1 and 1A) may be undesirable but does not point to any pathological behavior of the lattice.

With the addition of 4 quadrupole power supplies, the optics can be converted to Aladdin 2 which has the attraction of zero dispersion in the long straight sections and a higher degree of symmetry. This will permit optimum matching of insertion devices, reduction of possible synchro-betatron resonances and insensitivity during injection to momentum/phase spread of the injected beam.

There is no justification from the work described here to consider changing to Aladdin 3 unless lower emittance becomes a crucial issue.

VI. TRACKING WITH ERRORS

This section summarizes the effects of multipole fields and orbit errors on Aladdin 1 which have been studied to date. The investigation is continuing.

At present, the only data on multipole fields in the Aladdin magnets comes from rotating coil measurements of a single quadrupole magnet.[*]

Orbit displacements after correction are typically 2 mm rms in both planes.[+]

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[*] W • Trzeciak - Private communication - gives for higher multipole fields in the quadrupoles:

$$\frac{\Delta B}{G} = 0.977\ x^{3} + 1.2 \times 10^{4}\ x^{5} + 9.2 \times 10^{6}\ x^{8} + 1.44 \times 10^{9}\ x^{9}$$

[+] Typical 800 MeV orbit data measured at Aladdin.

These data have been used in the code PATRICIA to track on momentum particles through a model lattice with no RF.

The study took the following course:

a) Tracking in the Radial Plane Only

(i) Including systematic multipole fields as measured in the quadrupole magnets.

(ii) As (i), but including a 2 mm rms radial closed orbit displacement.*

(iii) As (ii), but including a random multipole component assumed to have an rms spread of 1/4 times the systematic components.*

(iv) As (iii), but including a 2 mm rms vertical closed orbit displacement to give coupling from the radial into the vertical plane.*

b) Tracking in the Vertical Plane Only

(i) As in a(iii), but with initial trajectories started in the vertical plane.*

c) Tracking in Both Planes

(i) As in a(iii), but with initial trajectories started in both planes.+

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* In each case which involved random generation of data for either closed orbit and/or random multipole components, five "different lattices" were analysed.

\+ Only two of the five "different lattices" have been fully tracked as described in c(i).

VII. RESULTS AND DISCUSSION

a(i) Switching on the systematic multipole components in the quadrupoles reduces the maximum stable amplitude in the radial plane from ~ 50 mm to ~ 26 mm. Note that the physical aperture limit at this position in the lattice is ~ 22 mm.

a(ii) Including a radial closed orbit deviation of 2 mm rms reduces the stable betatron amplitudes by ~ 2.5 mm over and above that aperture which is lost to the closed orbit deviation itself.

a(iii) When random multipole fields are imposed, the dynamic aperture is further reduced by ~ 1.5 mm.

It is interesting to note in all cases described above that the stability limit is reached when the tune shift is such that the test particle engages the 1/5th integer systematic resonance $5\nu_x = 36$.

a(iv) There was no change in the radial dynamic aperture when a vertical closed orbit deviation of 2 mm rms was introduced.

b(i) In the vertical plane, the stability limit was reached at a betatron amplitude of 11 mm, almost equal to the physical aperture. It is not yet clear what resonance drives the particle unstable at this amplitude.

c(i) Two of the five "different lattices" were tracked to determine the full dynamic aperture. The results are shown in Fig. 14.

It can be seen that in these two cases the stability limit matches almost exactly the physical limit.

The result must be considered to be worrisome since no account has been taken of the effects of errors in the main dipole magnets and no momentum effects have been included.

At present, the author is attempting to model all these effects using the code DIMAT. The findings of this study will be presented at a later date.

TABLE 1. Short List of Parameters for Aladdin 1.

Parameter	Value		Unit
Natural emittance:	$\varepsilon_x = 7.7 \times 10^{-8}$		m
Betatron tunes:	$\nu_x = 7.161$	$\nu_y = 7.116$	
Uncorrected chromaticity:	$\xi_x = -12.7$	$\xi_y = -18.3$	
Correction sextupoles ($k\ell$):	$K_F\ell = 4.99$	$K_D\ell = -8.76$	m^{-2}
Momentum compaction:	$\alpha = 0.036$		
Natural Bunch length:	$\sigma_\ell = 0.093$		m
Natural Momentum spread:	$\sigma_{p/p} = 4.8 \times 10^{-4}$		
Transverse damping times:	$\tau_x = 26.7$	$\tau y = 27.3$	ms
Longitudinal damping time:	$\tau_\varepsilon = 13.8$		ms

TABLE 2. Short List of Parameters for Aladdin 1A

Parameter	Value		Unit
Natural emittance:	$\varepsilon_x = 10.3 \times 10^{-8}$		m
Betatron tunes:	$\nu_x = 7.135$	$\nu_y = 7.095$	
Uncorrected chromaticity:	$\xi_x = -11.5$	$\xi_y = -18.9$	
Correction sextupoles:	$K_F\ell = 2.86$	$K_D\ell = -6.05$	m^{-2}
Momentum compaction:	$\alpha = 0.033$		
Natural Bunch length:	$\sigma_\ell = 0.089$		m
Natural Momentum spread:	$\sigma_{p/p} = 4.8 \times 10^{-4}$		
Transverse damping times:	$\tau_x = 26.7$	$\tau y = 27.3$	ms
Longitudinal damping time:	$\tau_\varepsilon = 13.8$		ms

TABLE 3. Short List of Parameters for Aladdin 2

Parameter	Value		Unit
Natural emittance:	$\epsilon_x = 7.3 \times 10^{-8}$		m
Betatron tunes:	$\nu_x = 5.236$	$\nu_y = 6.281$	
Uncorrected chromaticity:	$\xi_x = -7.5$	$\xi_y = -10\ 4$	
Correction sextupoles:	$K_F\ell = 2.33$	$K_D\ell = -6.08$	m^{-2}
Momentum compaction:	$\alpha = 0.018$		
Natural Bunch length:	$\sigma_\ell = 0.067$		m
Natural Momentum spread:	$\sigma_{p/p} = 4.8 \times 10^{-4}$		
Transverse damping times:	$\tau_x = 26.7$	$\tau y = 27.3$	ms
Longitudinal damping time:	$\tau_\epsilon = 13.8$		ms

TABLE 4. Short List of Parameters for Aladdin 3

Parameter	Value		Unit
Natural emittance:	$\epsilon_x = 1.8 \times 10^{-8}$		m
Betatron tunes:	$\nu_x = 5.838$	$\nu_y = 3.774$	
Uncorrected chromaticity:	$\xi_x = -16.5$	$\xi_y = -10\ 5$	
Correction sextupoles:	$K_F\ell = 8.29$	$K_D\ell = -7.16$	m^{-2}
Momentum compaction:	$\alpha = 0.0066$		
Natural Bunch length:	$\sigma_\ell = 0.040$		m
Natural Momentum spread:	$\sigma_{p/p} = 4.8 \times 10^{-4}$		
Transverse damping times:	$\tau_x = 26.7$	$\tau y = 27.3$	ms
Longitudinal damping time:	$\tau_\epsilon = 13.8$		ms

REFERENCES

1. M. Sands, "The Physics of Electron Storage Rings," SLAC-121, 1970.

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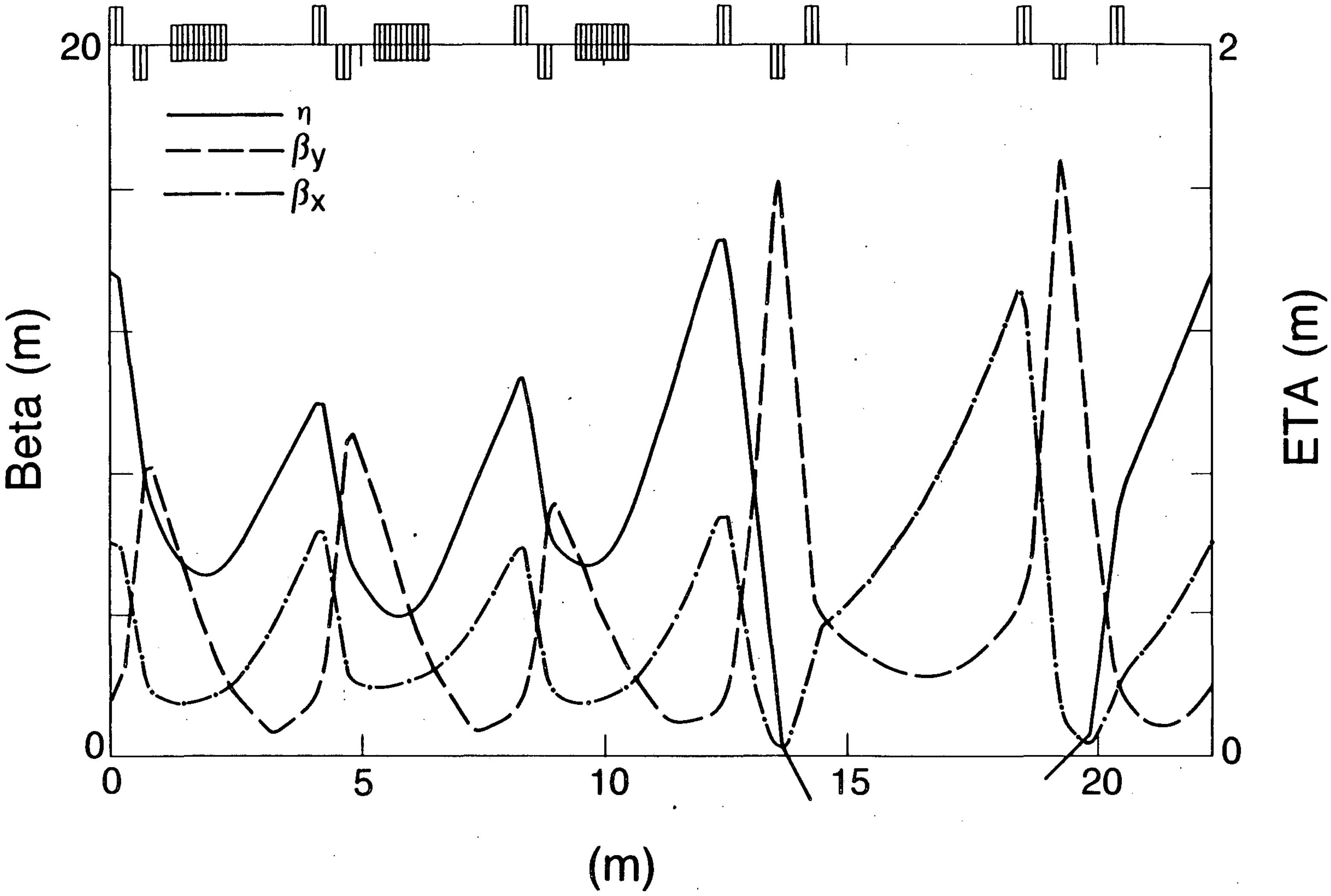

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FIG. 1. ALADDIN 1 STRUCTURE AND LATTICE FUNCTIONS

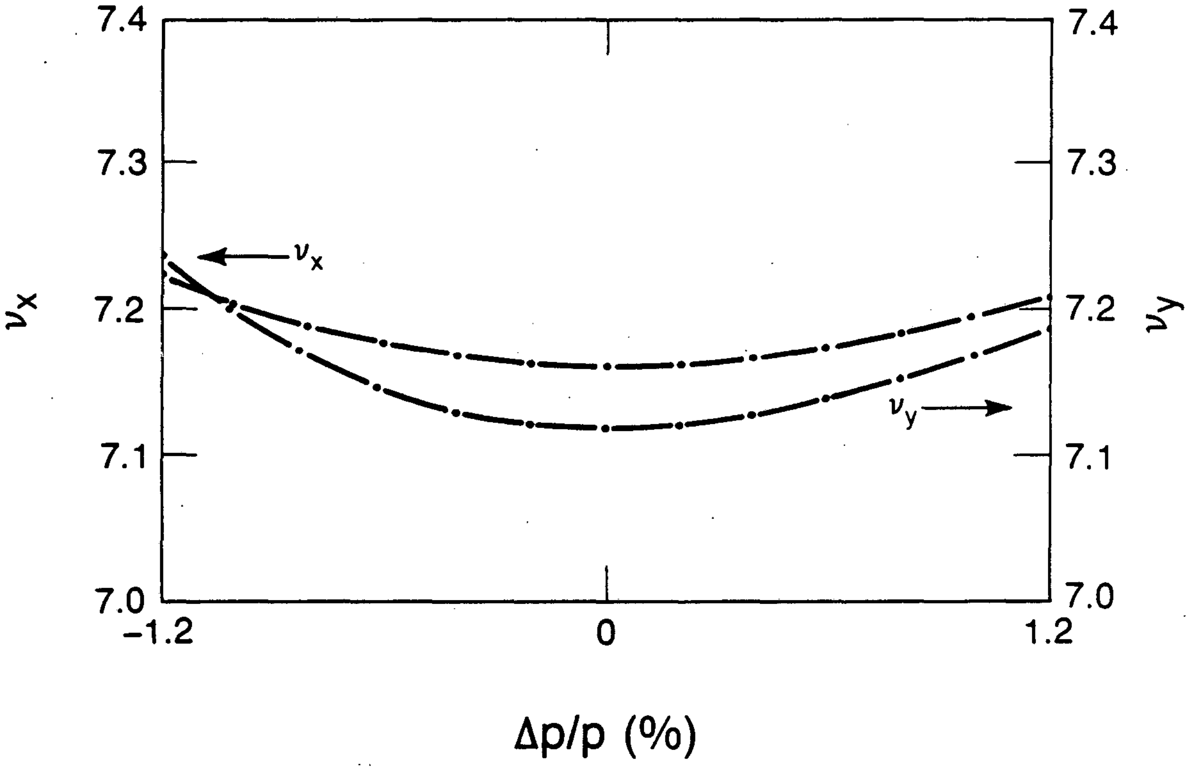

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FIG. 2. ALADDIN 1 MOMENTUM SCAN

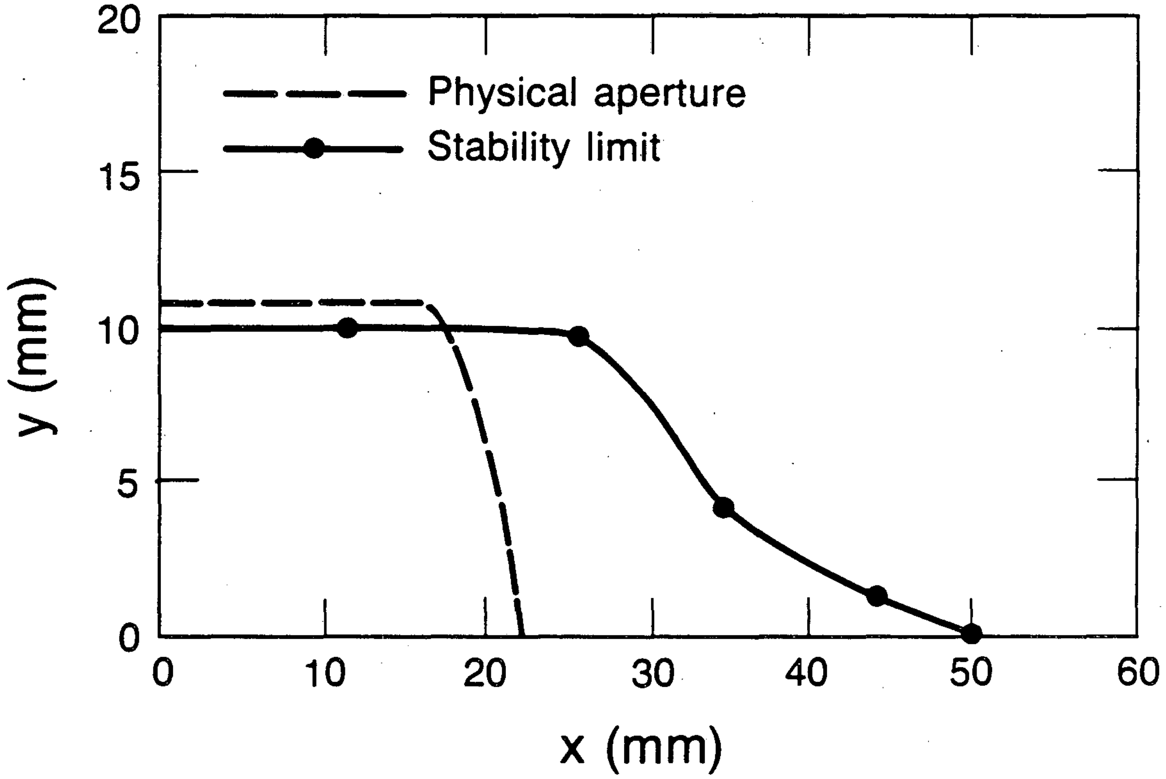

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FIG. 3. ALADDIN 1 STABILITY LIMIT

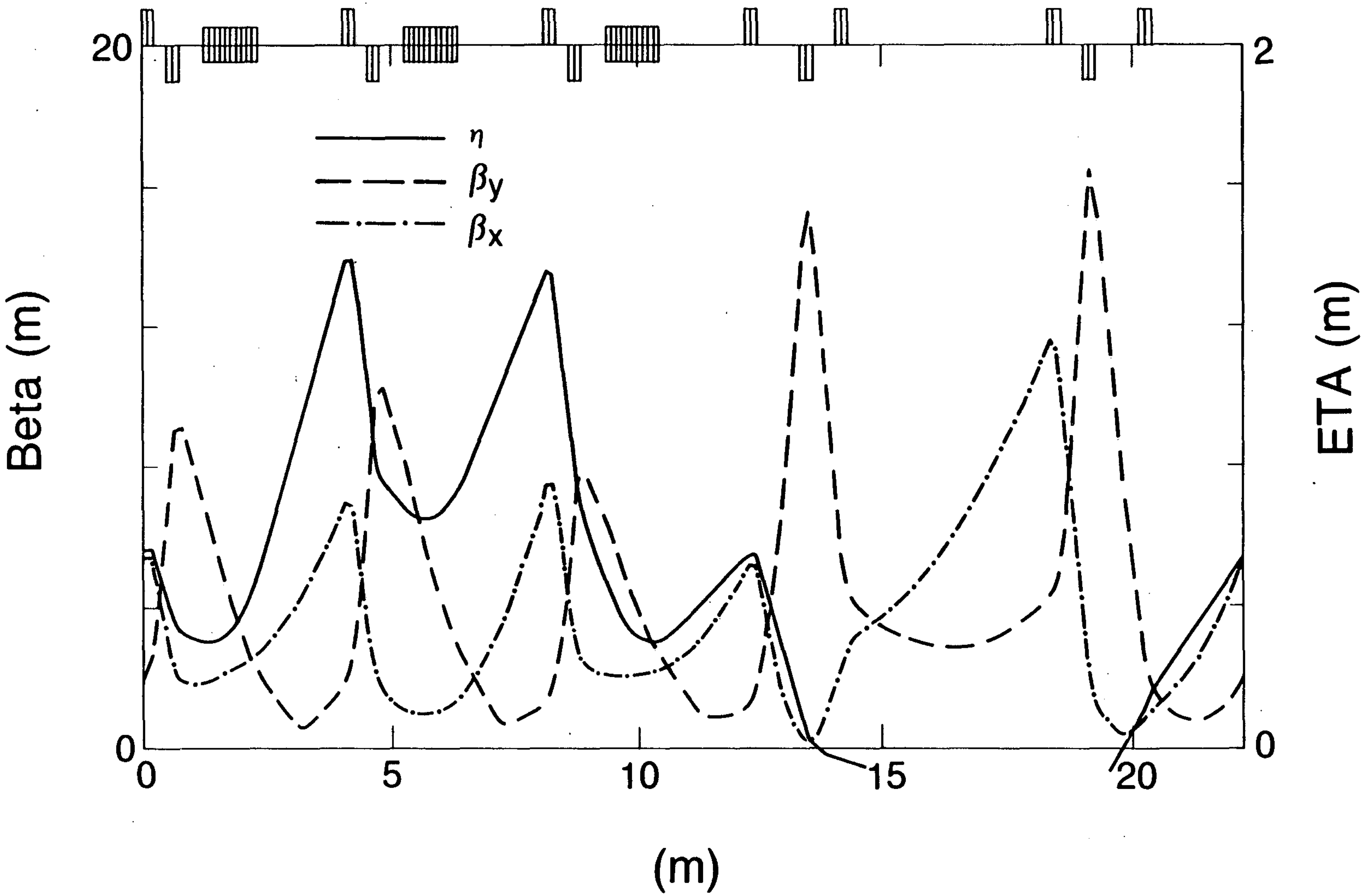

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FIG. 4. ALADDIN 1A STRUCTURE AND LATTICE FUNCTIONS

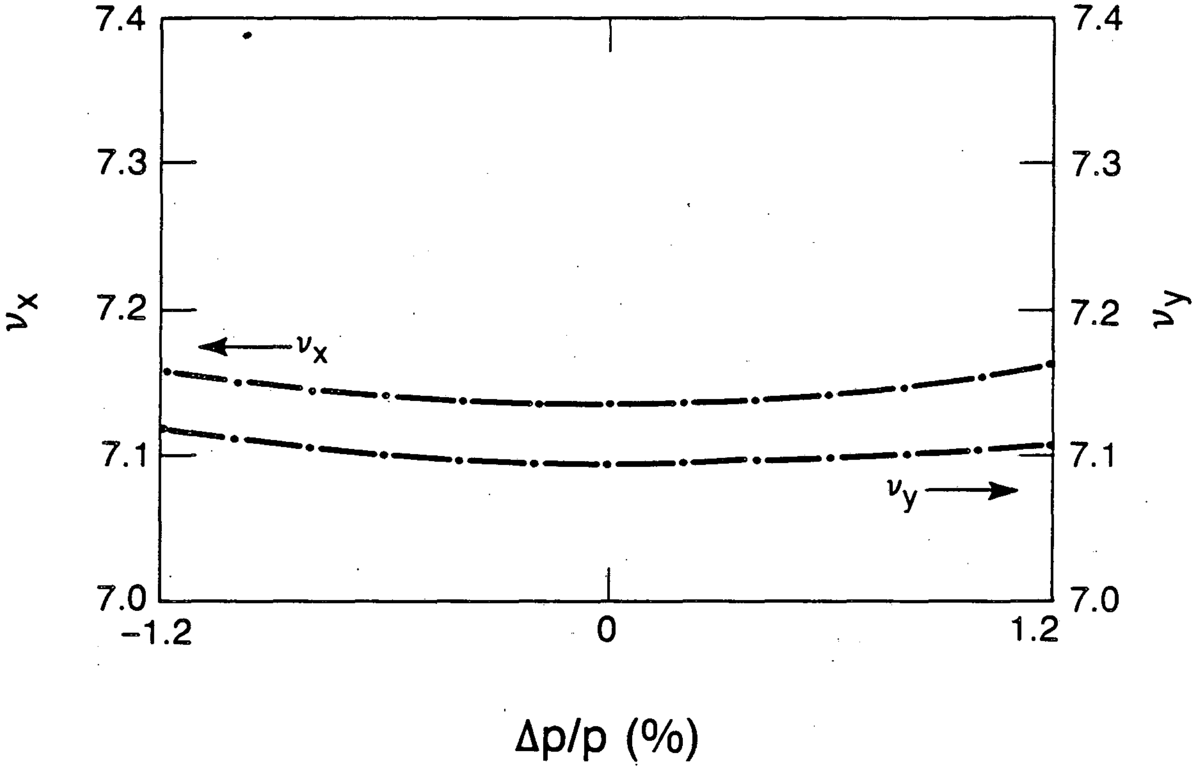

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FIG. 5. ALADDIN 1A MOMENTUM SCAN

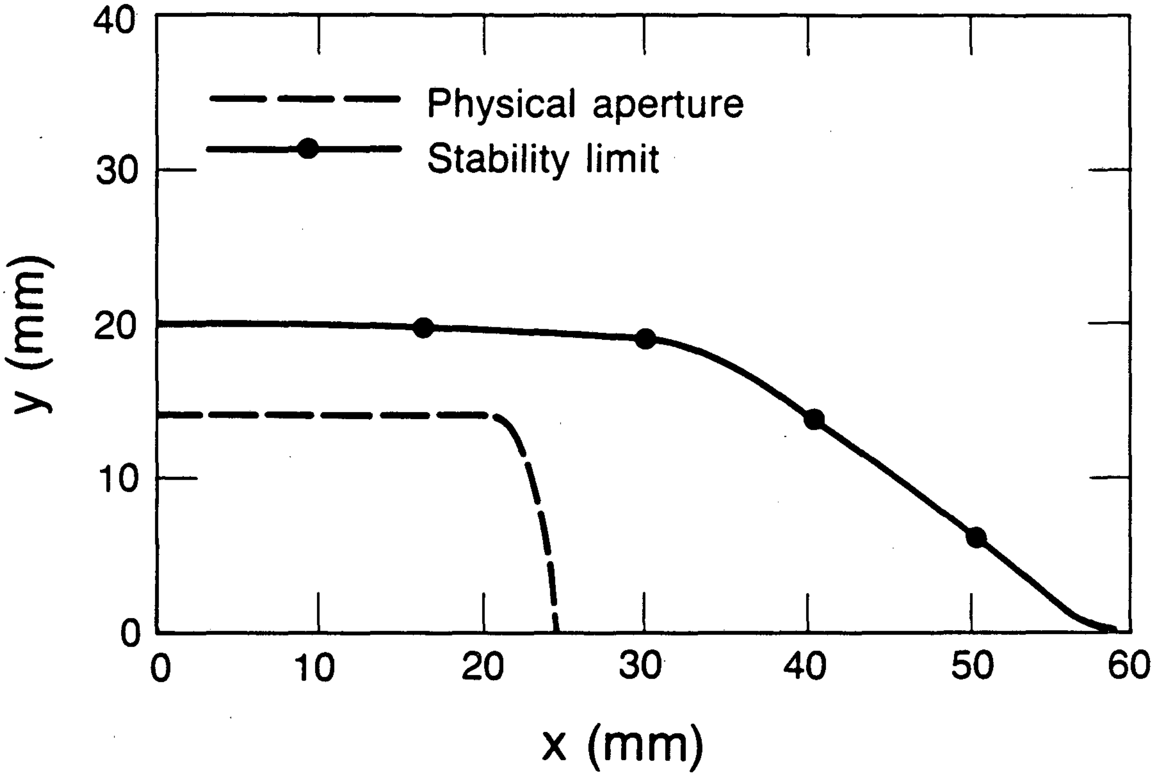

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FIG. 6. ALADDIN 1A STABILITY LIMIT

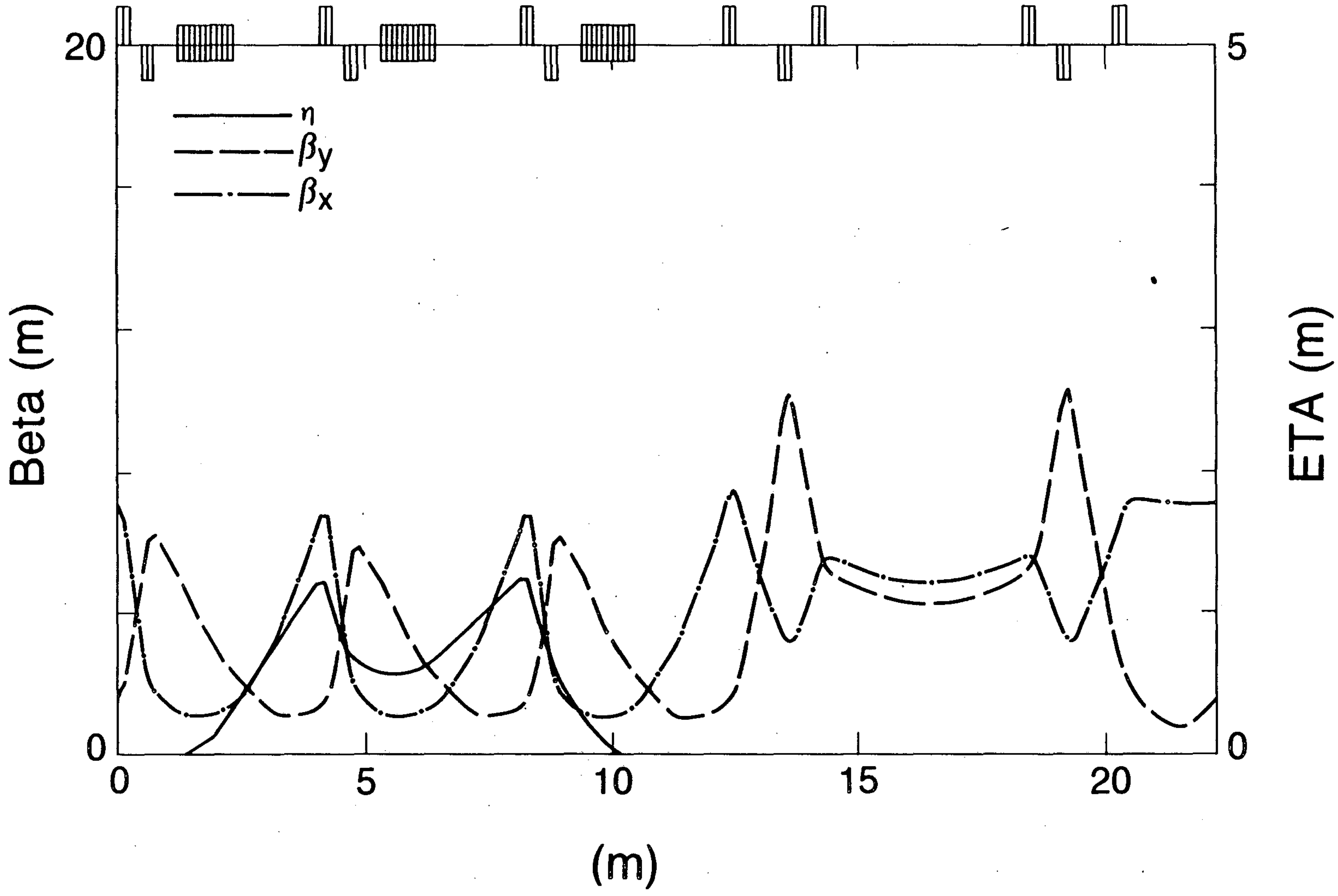

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FIG. 7. ALADDIN 2 STRUCTURE AND LATTICE FUNCTIONS

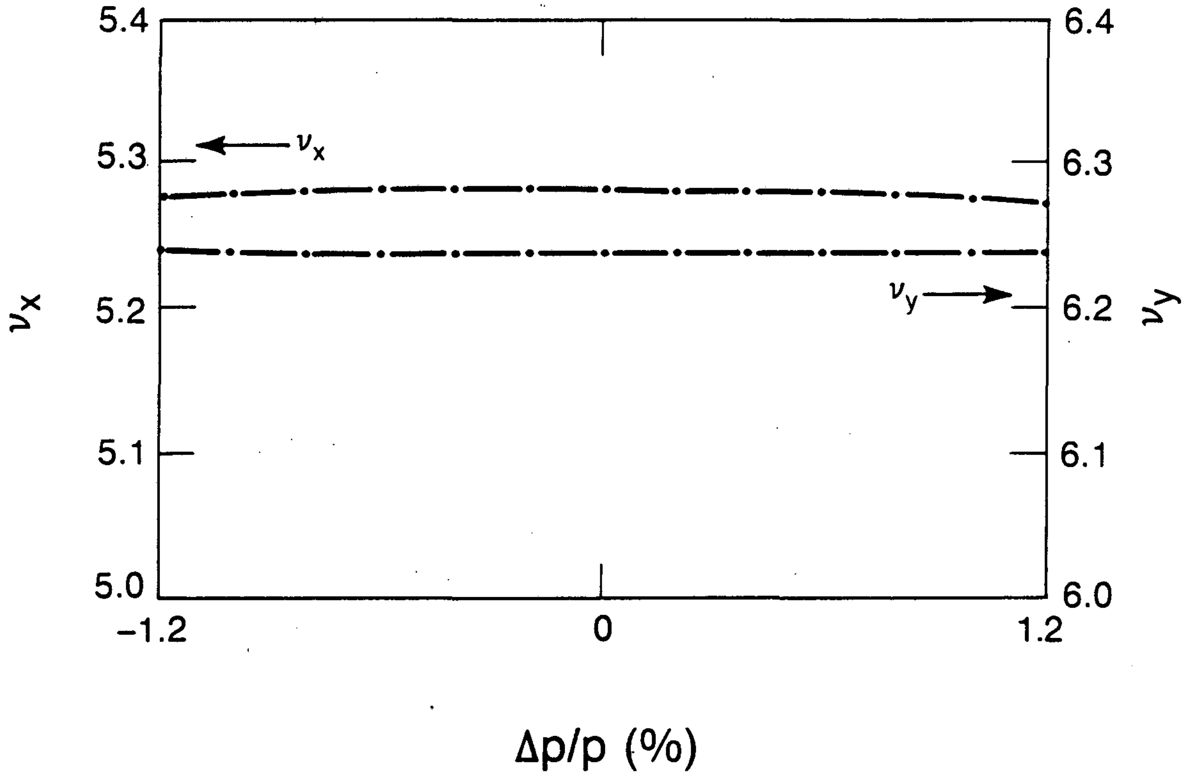

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FIG. 8. ALADDIN 2 MOMENTUM SCAN

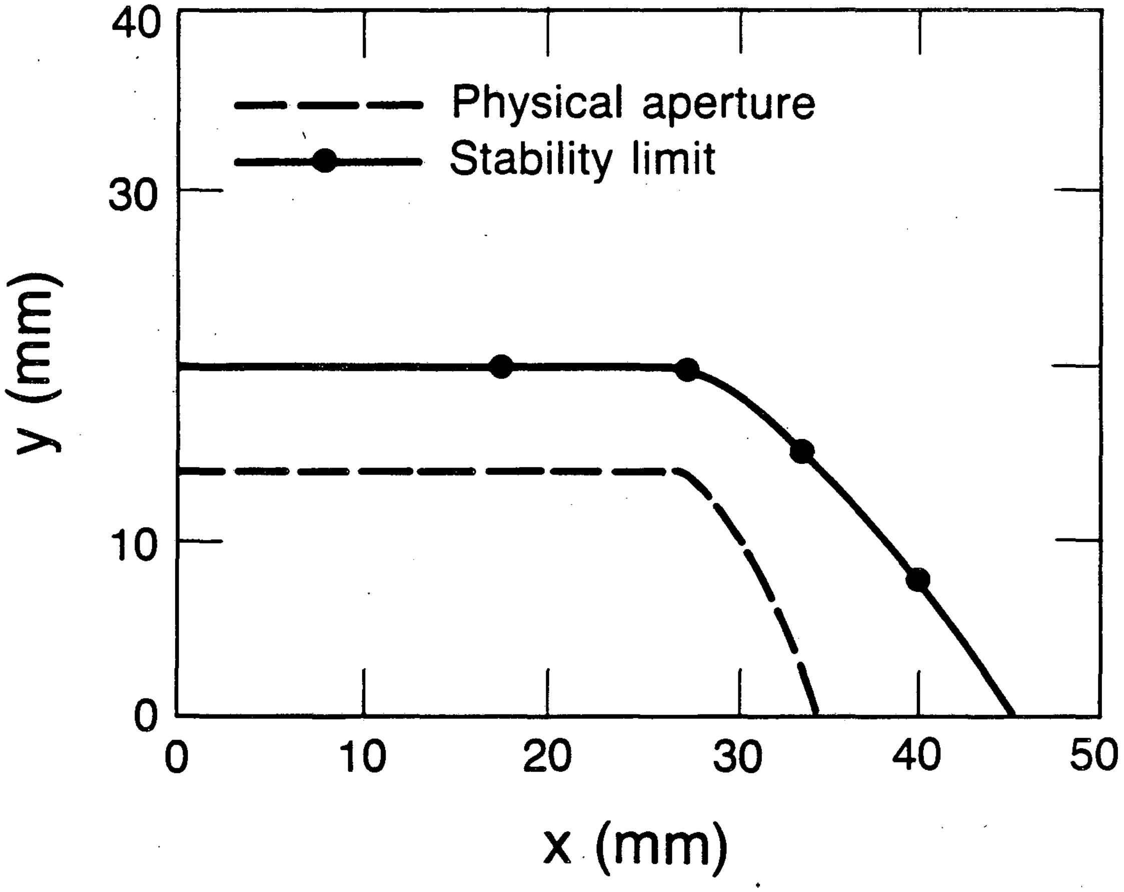

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FIG. 9. ALADDIN 2 STABILITY LIMIT

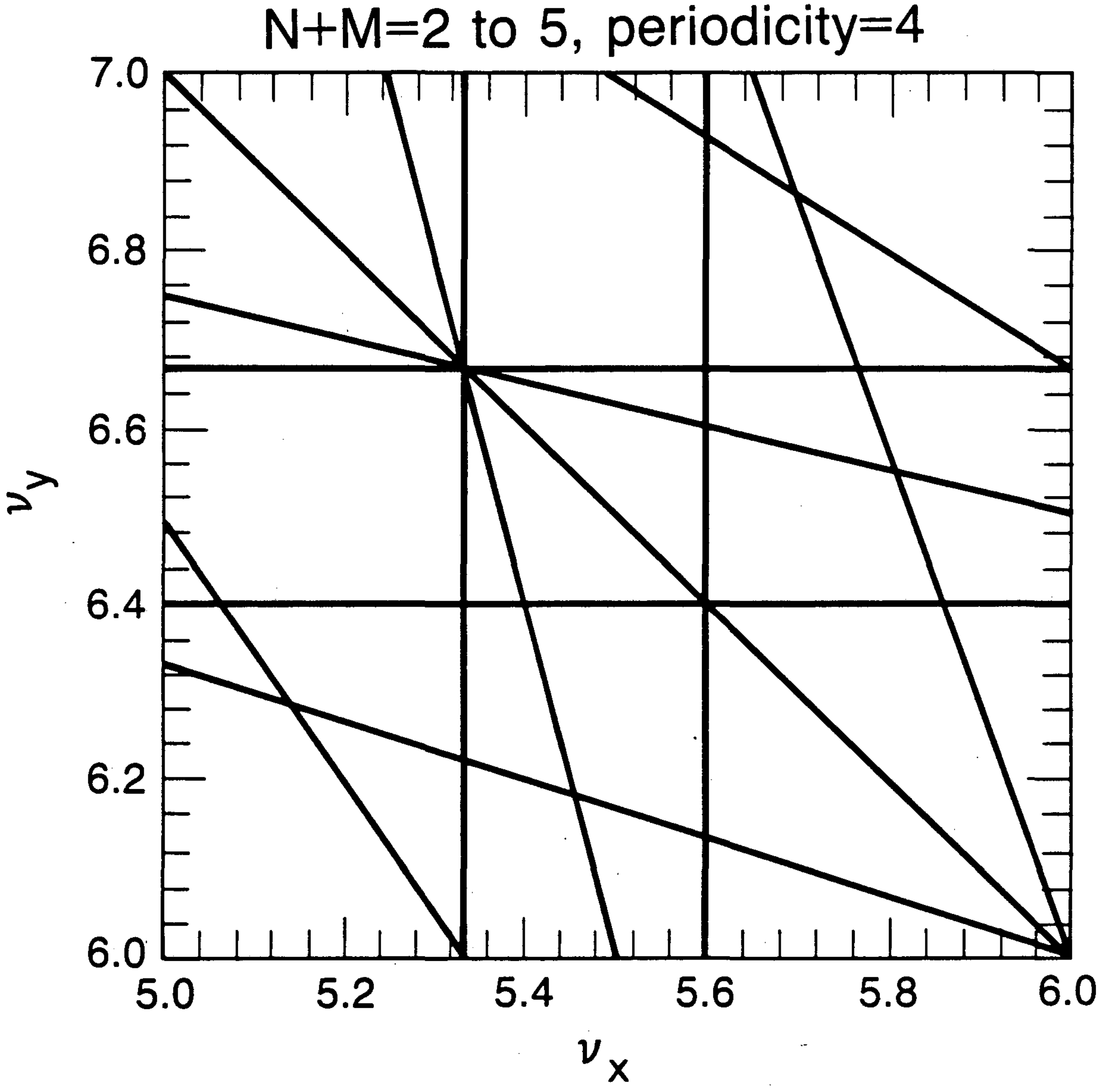

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FIG. 10. ALADDIN 2 INTEGER TUNE SQUARE - SHOWING THE SYSTEMATIC SUM RESONANCES UP TO ORDER 5.

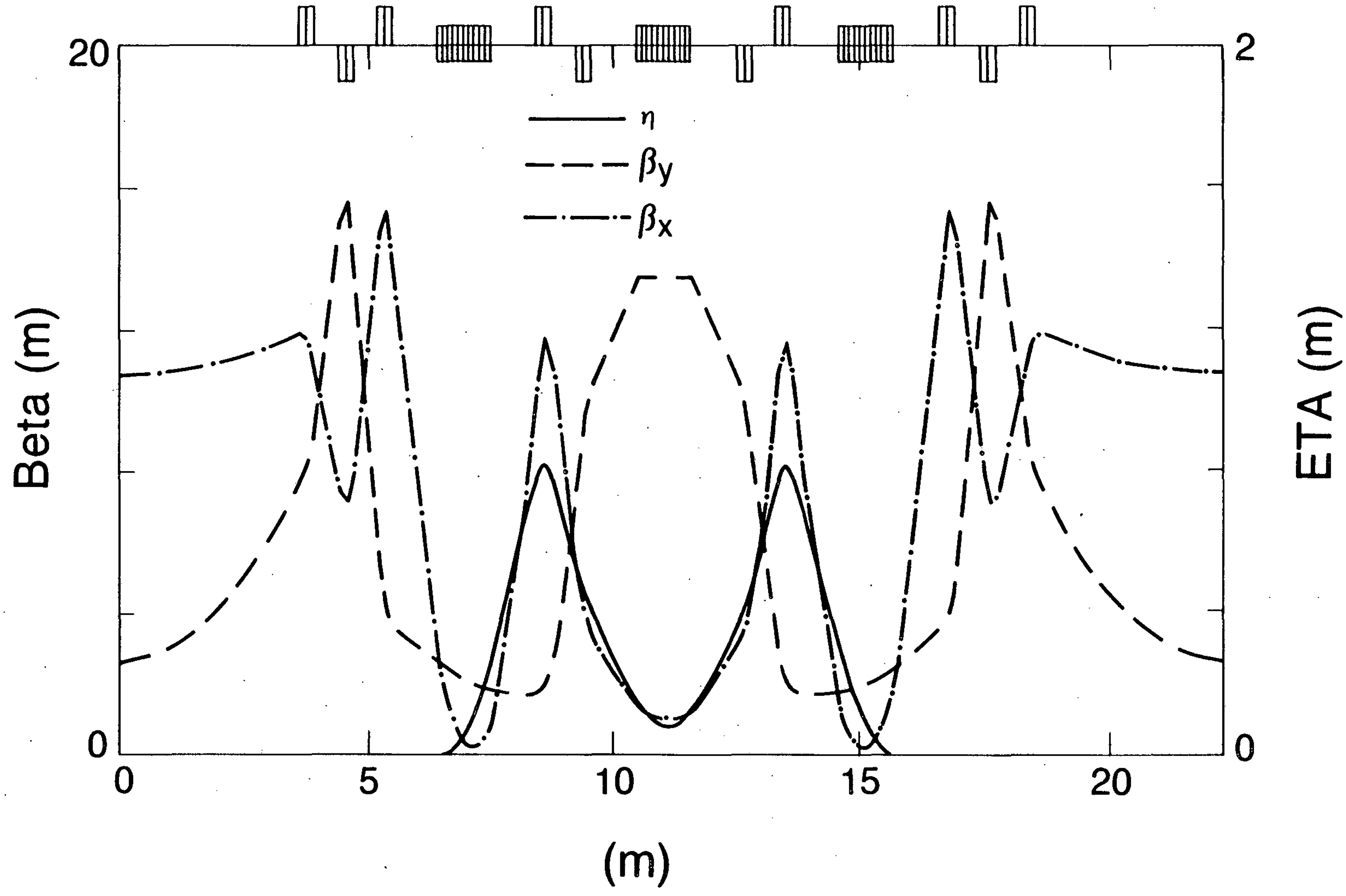

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FIG. 11. ALADDIN 3 STRUCTURE AND LATTICE FUNCTIONS

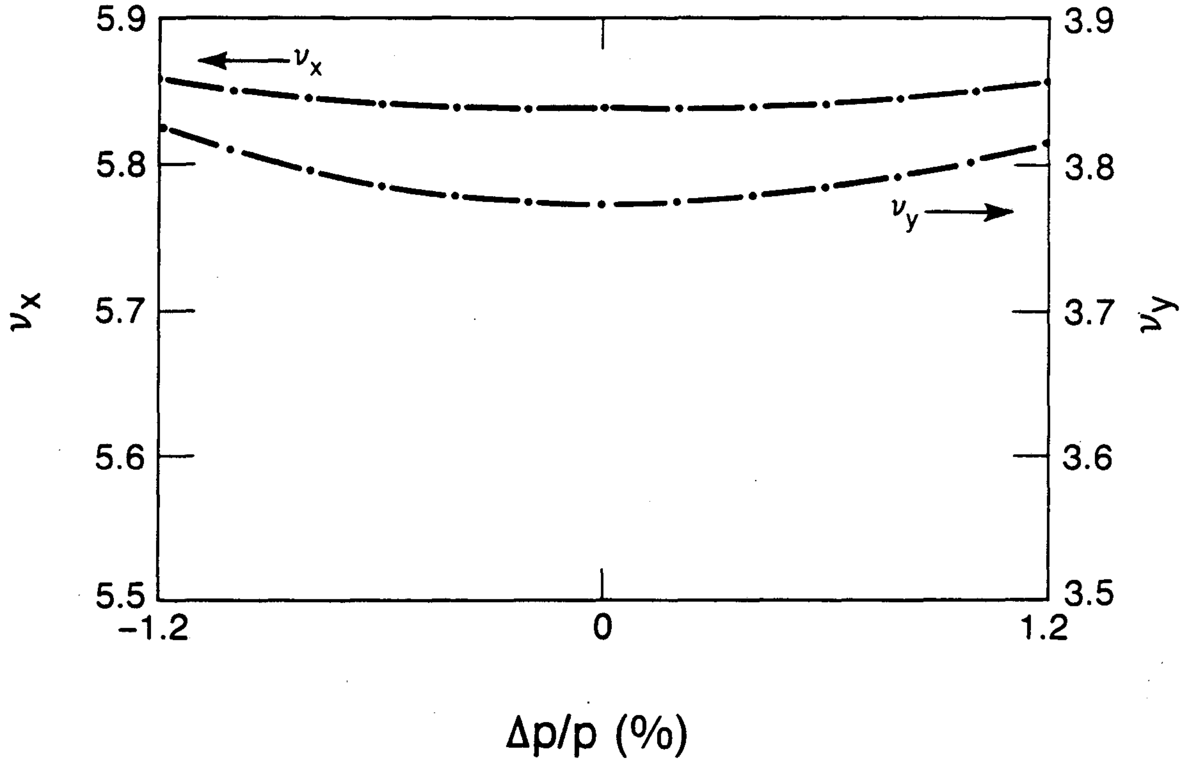

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FIG. 12. ALADDIN 3 MOMENTUM SCAN

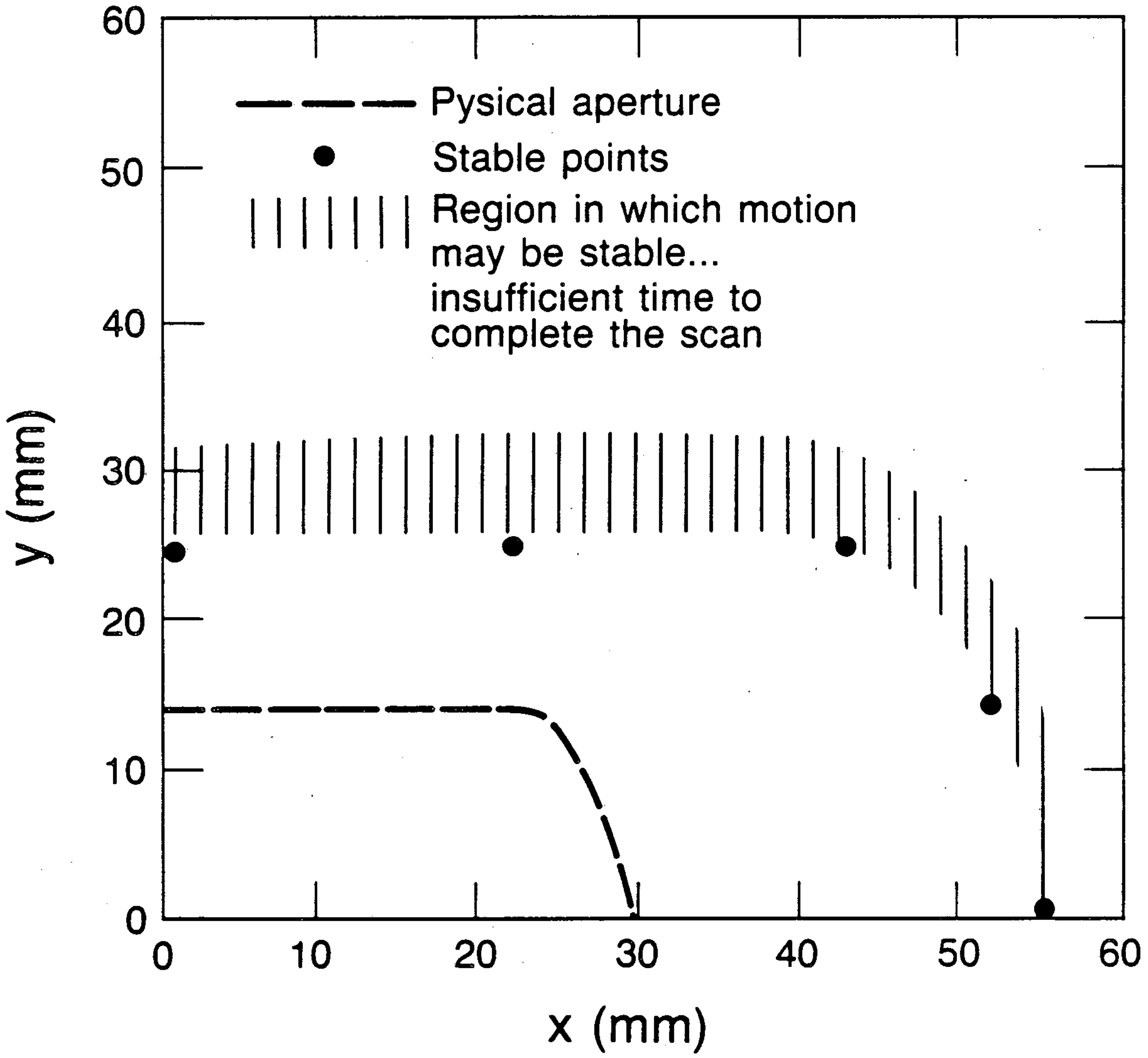

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FIG. 13. ALADDIN 3 STABILITY LIMIT

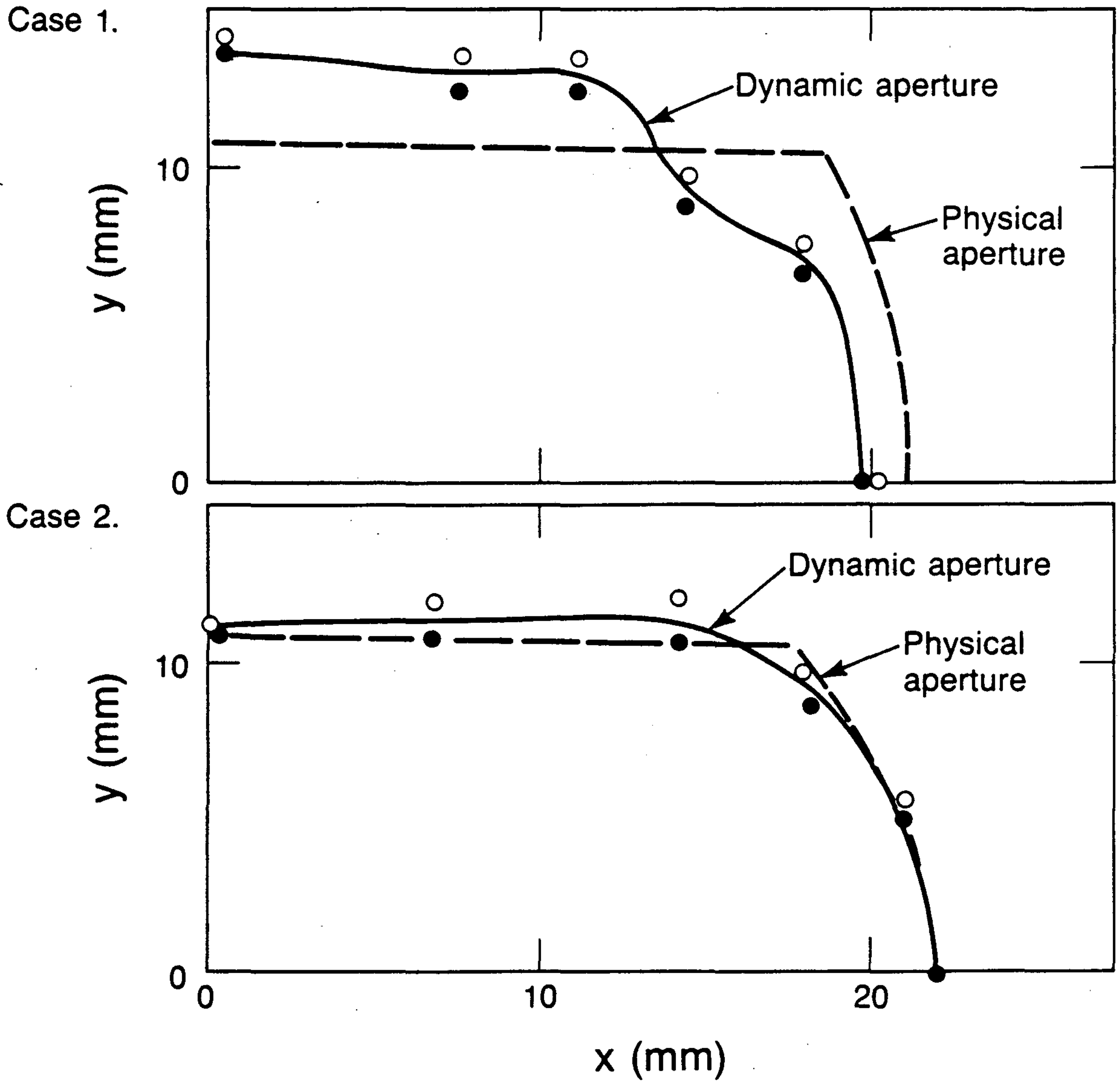

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FIG. 14. ALADDIN 3 DYNAMIC APERTURE IN THE PRESENCE OF MULTIPOLE FIELDS (RANDOM AND SYSTEMATIC) AND RADIAL CLOSED ORBIT DISTORTIONS.

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UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720