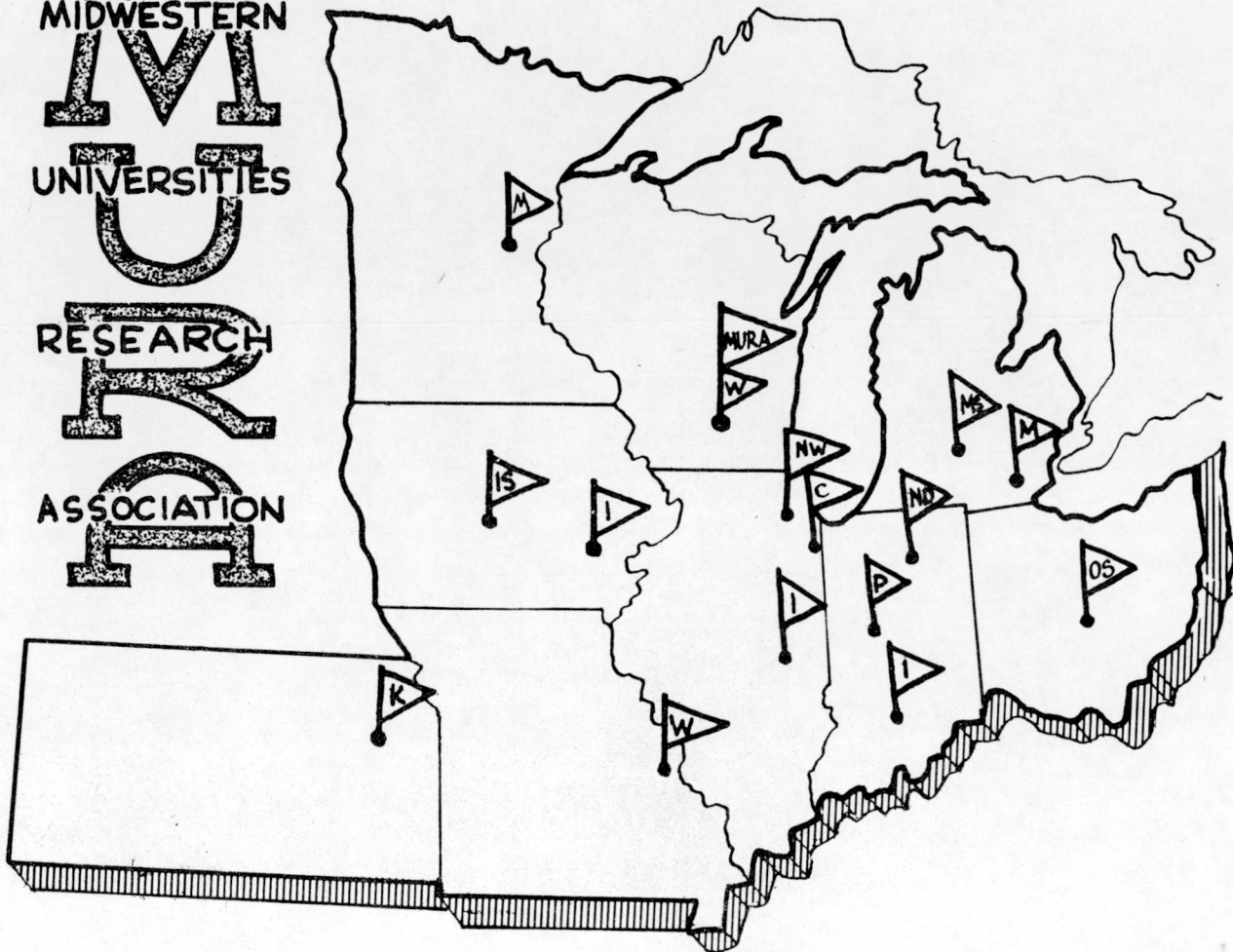


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FREQUENCY MEASUREMENTS AND RESONANCE SURVEY IN THE  
ELECTRON MODEL SPIRAL SECTOR FFAG ACCELERATOR

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REPORT

NUMBER 361

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## MIDWESTERN UNIVERSITIES RESEARCH ASSOCIATION\*

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FREQUENCY MEASUREMENTS AND RESONANCE SURVEY IN THE  
ELECTRON MODEL SPIRAL SECTOR FFAG ACCELERATOR

R. Stump\*\* and B. Waldman\*\*\*

August 30, 1957

ABSTRACT

Beam intensities, vertical and radial betatron oscillation frequencies, and stop bands in the tuning range of the spiral sector FFAG accelerator were measured. The machine is tunable from  $\nu_z = 0.46$  to  $1.76$  and  $\nu_x = 1.12$  to  $1.71$ . In this tuning region the resonances  $\nu_z = 1$ ,  $\nu_z = 0.5$ ,  $\nu_z = 1.5$ ,  $\nu_x = 1.5$ ,  $\nu_x + \nu_z = 2$  and  $2\nu_x + 2\nu_z = 6$  are observed to destroy the beam. Of these only  $\nu_z = 1$ ,  $\nu_z = 0.5$  and  $2\nu_x + 2\nu_z = 6$  cause complete loss of beam at all points in the available tuning range. The Walkinshaw resonance ( $2\nu_z - \nu_x = 0$ ) appears as a minimum of beam intensity.

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## Introduction

This report describes a series of measurements which were made on the electron model spiral sector FFAG accelerator, to determine the tuning characteristics of this machine. Beam intensities, vertical and radial betatron oscillation frequencies, and stop bands in the tuning range available were found.

## Experimental Arrangement

### 1) Detector

A cylindrical plastic scintillator of 1 cm diameter and 1 cm length was mounted at the end of a light pipe inside the vacuum donut. A thin layer of aluminum was evaporated over the scintillation to make it light tight and still allow the electrons to enter. The photomultiplier was outside of the magnetic field. The presence of an electron beam was detected by observing a pulse on an oscilloscope at the proper time after injection.

### 2) RF Probe

Betatron frequencies were determined by the rf. knock-out method described by Cole et al (RSI, 28, 403 (1957) ). The probe consisted of two parallel plates inserted approximately at the beam position in the donut. One plate was grounded, the other had an rf. voltage of approximately 50 volts. Resonance with the radial betatron frequency was identified by the shift of the time of arrival of the beam. Vertical betatron frequency was identified by a decrease of intensity. Resonances identified were usually of the form:



$$f_{rf}/f_0 = |av-n|$$

where  $f_0$  is the frequency of revolution of the electron,  $f_{rf}$  is the applied rf. frequency,  $a$  is 1 or 2, and  $n$  is zero or any integer.

Radio frequencies were measured with a grid dip meter and could be reproduced to about 1%.

### 3) Tuning Parameters

The current through the flutter ( $\Delta F$ ) coils could be varied from zero to  $\pm 1.5$  amperes. Likewise the current in the  $\Delta k$  coils could be varied from zero to  $\pm 1.33$  amperes.

### Results

The betatron frequencies,  $\nu_x$  and  $\nu_z$ , were measured at the radius of 42.5 cm, over the complete range of tuning. The results are plotted in Fig. 1 and Fig. 2.

The tuning regions where a beam was not obtained were identified in terms of the parameters  $\Delta F$  and  $\Delta k$ . Fig. 3 illustrates these data. Beam intensity varied with inflector and injector voltage. These were adjusted to give maximum beam when determining regions of beam extinction. All magnetic fields were recycled in these regions to eliminate hysteresis effects.

With the data of Fig. 1 and Fig. 2 a cross plot of Fig. 3 was made. This is shown in Fig. 4. Certain resonances are entered on this plot.

Intensities were estimated by the amplitude of the pulse from the photo-multiplier. Where no beam is indicated the intensity was less than  $10^{-3}$  times the intensity found in neighboring regions. Where minima are indicated (Fig. 4), the intensity dropped to  $10^{-1}$  to  $10^{-2}$  times the normal beam intensity.

Examination of Fig. 4 shows that the integral resonance  $\nu_z = 1$ , the half-integral resonances  $\nu_z = 0.5$ ,  $\nu_z = 1.5$ ,  $\nu_x = 1.5$  and the linear sum resonances  $\nu_x + \nu_z = 2$  and  $2\nu_x + 2\nu_z = 6$  (which is also a cubic resonance  $2\sigma_x + 2\sigma_z = 2\pi$ ) all destroy the beam completely at some tuning. Of these only  $\nu_z = 1$ ,  $\nu_z = 0.5$  and  $2\nu_x + 2\nu_z = 6$  cause complete loss of the beam at all points in the tuning region. Beam was found in some regions of half-integral resonance. In these regions there was however a marked decrease of intensity. These regions were carefully examined to determine both that the beam existed and that the frequencies actually crossed the resonances. The Walkinshaw resonance ( $\nu_x - 2\nu_z = 0$ ) appeared as a minimum, but did not destroy the beam completely. The  $2\nu_x + 2\nu_z = 6$  resonance appears to have the wrong slope. This is possibly due to the lack of scaling in the machine, together with the possibility that this resonance is serious only near injection.

#### APPENDIX

##### Parameters of the Electron Model Spiral Sector FFAG Accelerator

$N = 6$	$R_O = 55 \text{ cm. (Outer radius)}$
$\frac{I}{w} = 6.25$	$E_{inj} = 25 \text{ kev (Injection Energy)}$
$k = 0.7$	Design Flutter = 1.08
$R_i = 30.5 \text{ cm. (Inner radius)}$	Measured Flutter = 1.02

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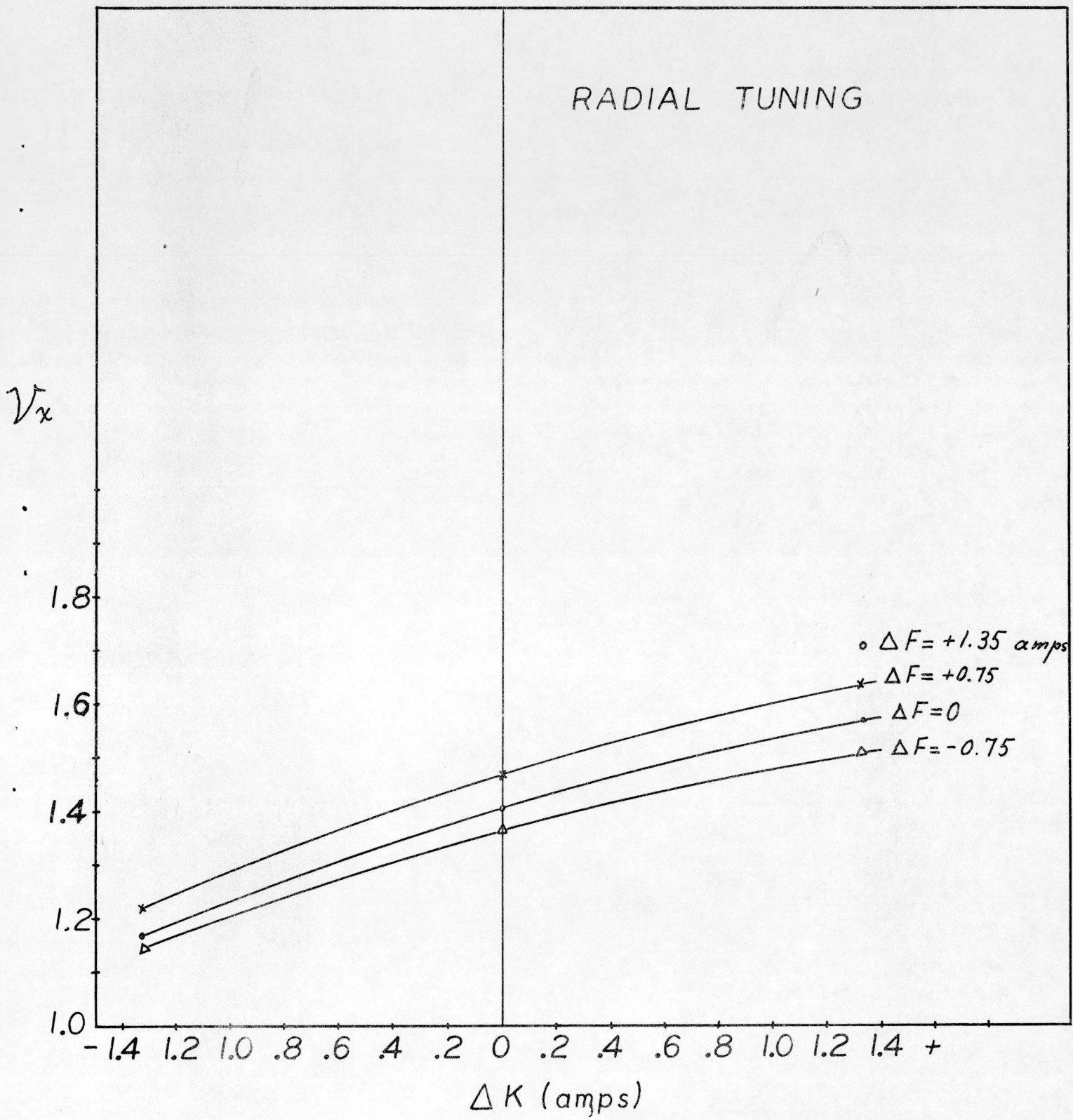
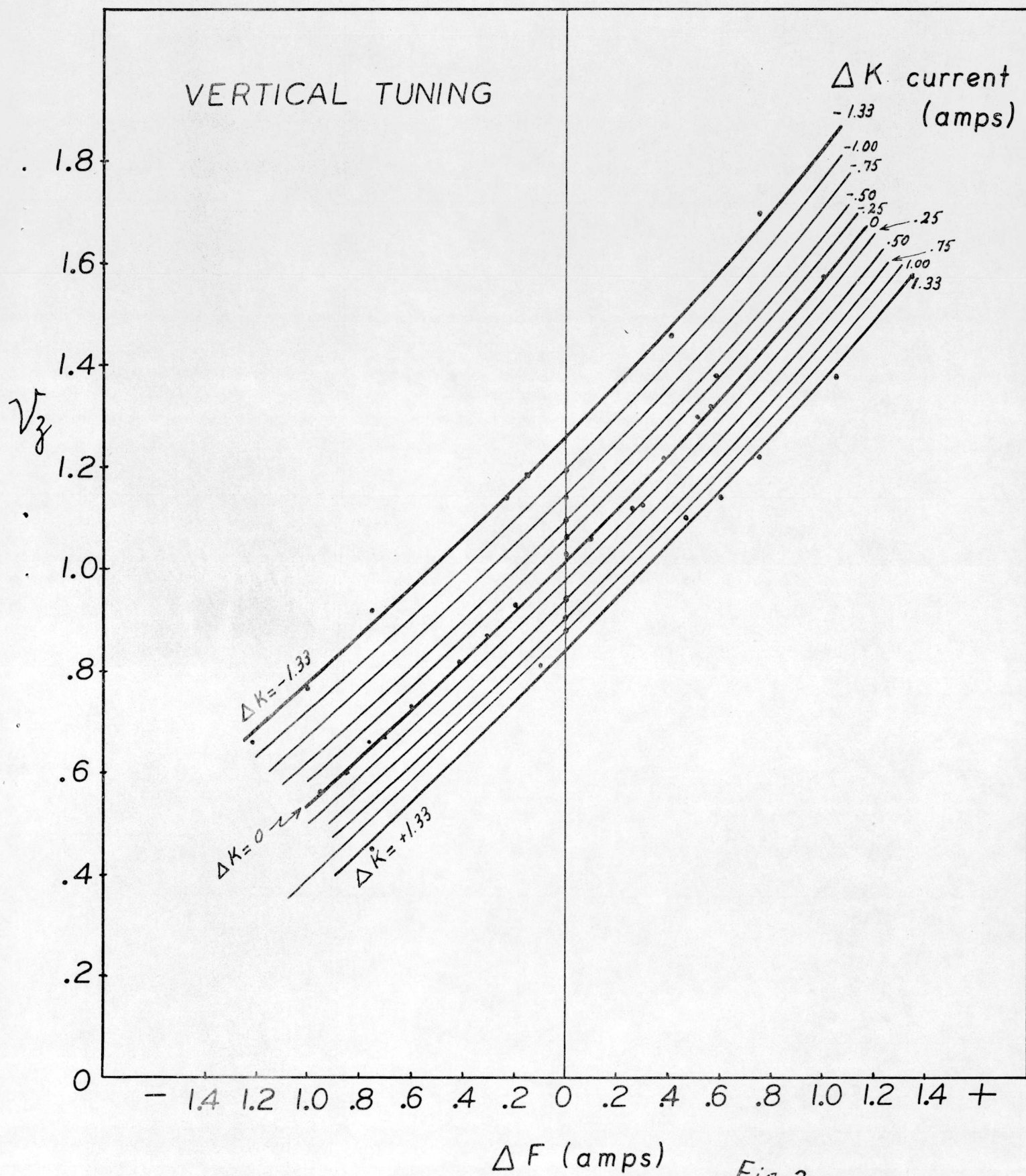


Fig. 1







Cross-hatched regions  
are regions where no  
beam is obtained

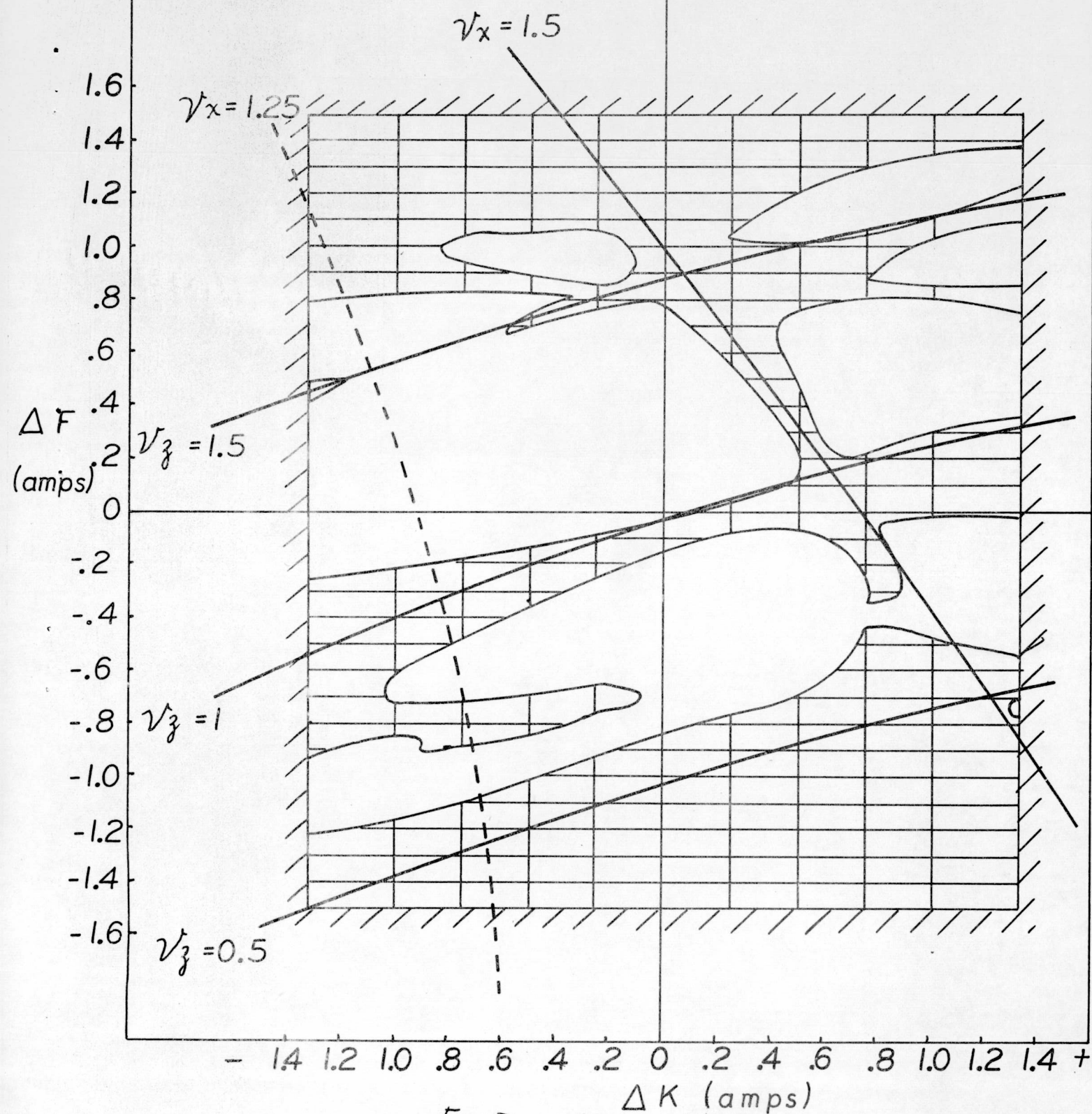


Fig. 3

$\nu_3$

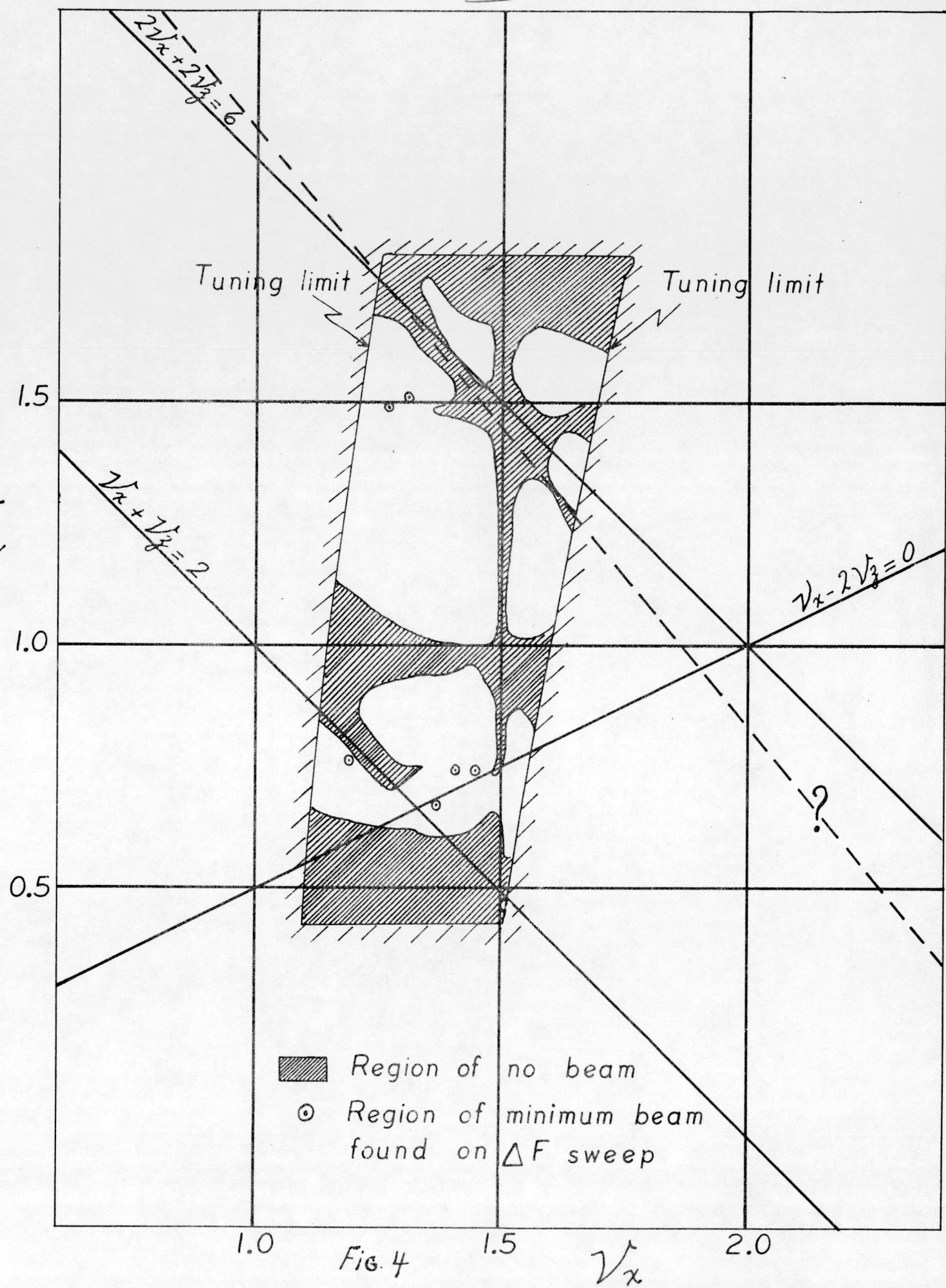


Fig. 4