FABRICATION AND MEASURING METHODS FOR DISK-LOADED WAVEGUIDES

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I. Introduction

During the past ten years, extensive studies on electron linacs have been carried out in Japan. About ten machines, which were constructed by the universities or by Japanese manufacturers, are working well for various purposes. The author wishes to report on the new methods developed recently in that country to fabricate disk-loaded guides and to measure their performance precisely. This work was carried out by the group of the University of Tokyo and by the staffs of the Mitsubishi Heavy Industries, Inc. and the Toshiba Electric Company.

II. New Methods for Fabricating Guides with High Accuracies

Disk-loaded guides used in electron linacs are usually made either by a brazing or an electroforming method. These two methods were also tried in Japan and led to fairly good results in obtaining accurate guides.[1] However, in the former method, one needs to tune each cell after its fabrication unless one is extremely careful during the brazing process, while the usual electroforming method is expensive because of time consuming and troublesome procedures during fabrication. A new method has now been developed which is a combination of the strong points of these two and which eliminates those difficulties.[2]

In order to achieve and to maintain high accuracy throughout the fabrication process, copper disks and cylinders are machined separately and assembled by jigs. The outer surface of the assembled body is then electroplated to form a complete structure (Fig. 1). This method is considerably simpler than the brazing or electroforming technique previously used and eliminates a number of undesirable effects such as: 1) high temperature due to brazing, which results in dimensional distortion, and 2) use of aluminum spacers and the necessity for removing them by etching. Typical values of machining errors obtained are shown in Fig. 2. It should be stated that the resonant frequency of each cell is strongly dependent on the shaping of the cross section of the disk holes since the field strength should be strongest at that point. A rough

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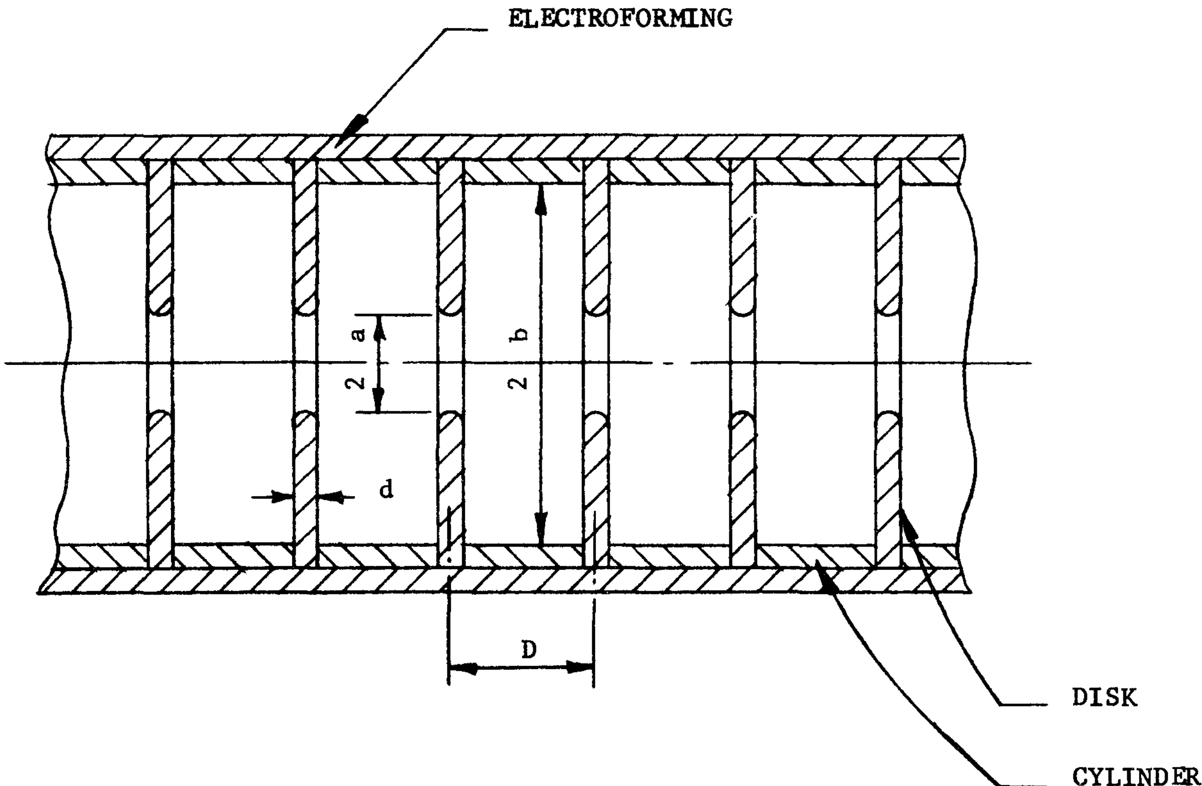
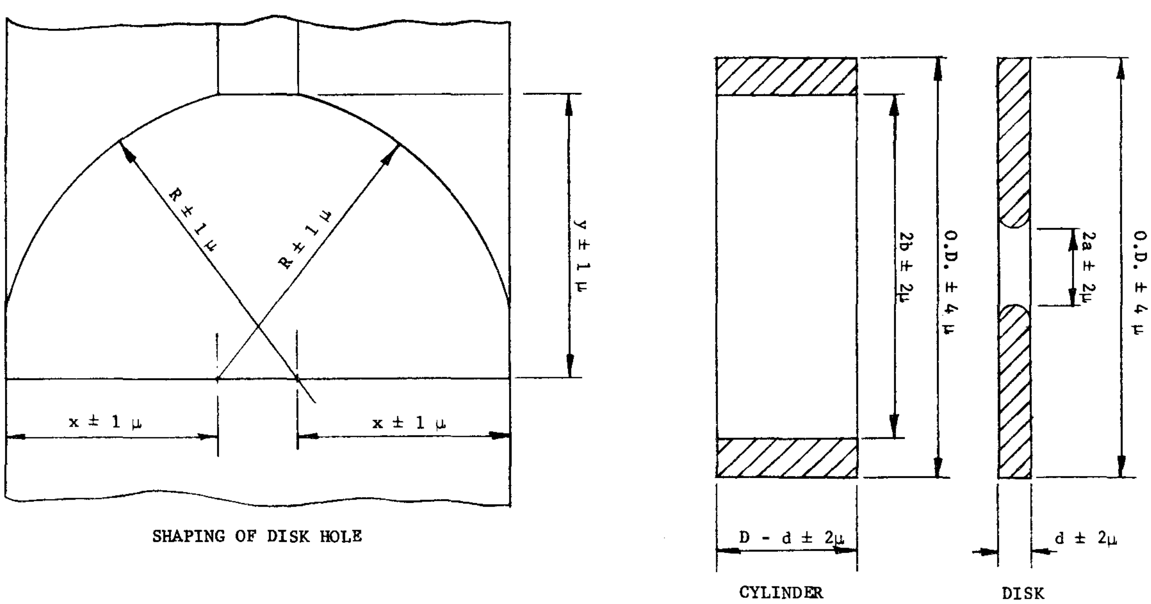


Fig. 1



MATERIAL OFHC 99.99%

SURFACE ROUGHNESS 0.3 μ OR LESS

Fig. 2

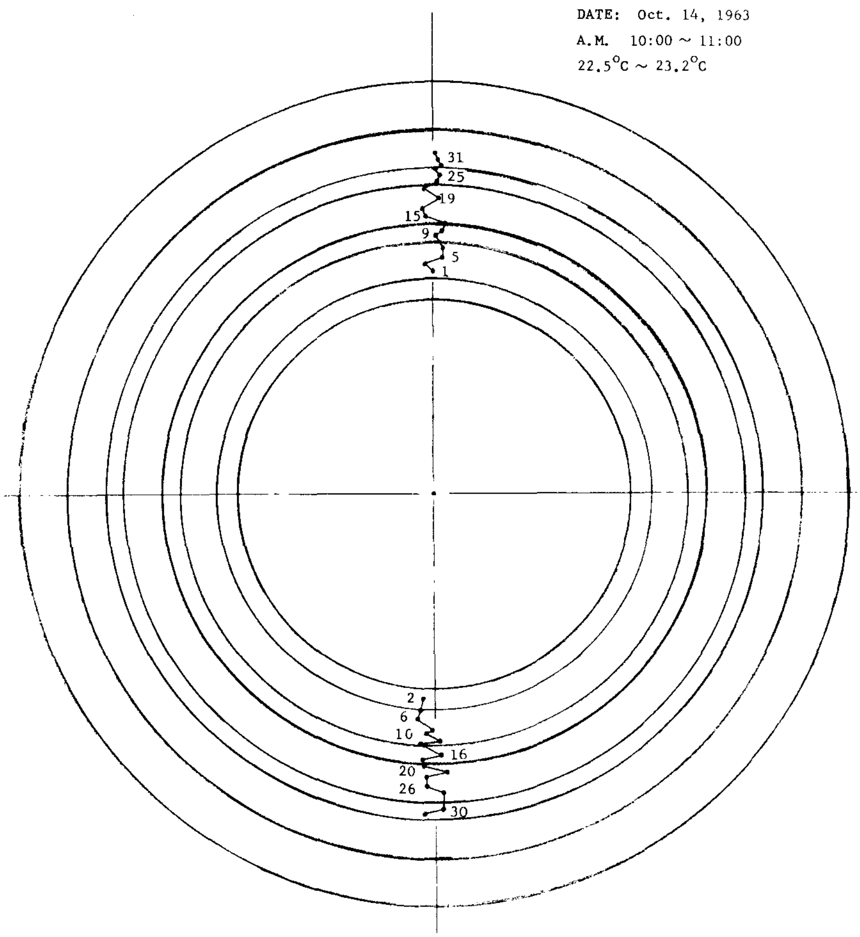

DATE: Oct. 14, 1963
A.M. 10:00 ~ 11:00
22.5°C ~ 23.2°C
31
25
19
15
9
5
1
2
6
10
16
20
26
30

Fig. 3

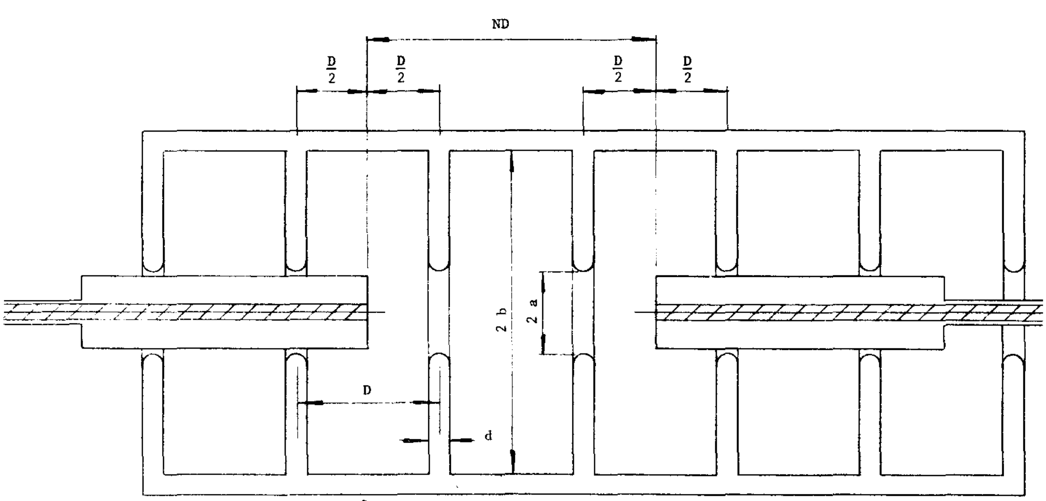

ND
D/2
D/2
D/2
D/2
2 b
2 a
D
d

Fig. 4

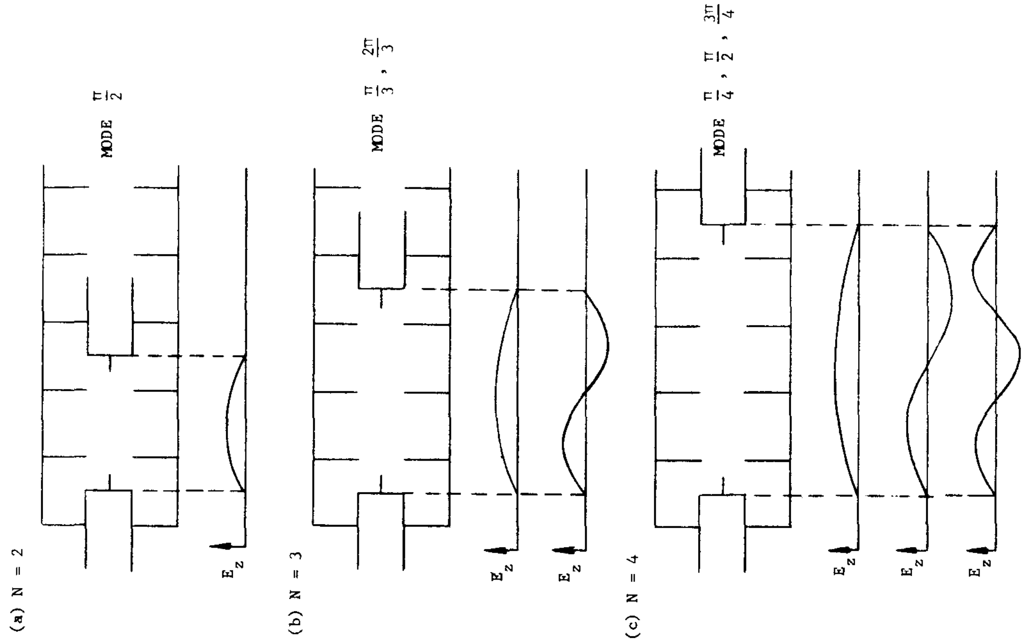

(a) N = 2
MODE $\frac{\pi}{2}$
E_z
(b) N = 3
MODE $\frac{\pi}{3}$, $\frac{2\pi}{3}$
E_z
E_z
(c) N = 4
MODE $\frac{\pi}{4}$, $\frac{\pi}{2}$, $\frac{3\pi}{4}$
E_z
E_z
E_z

Fig. 6

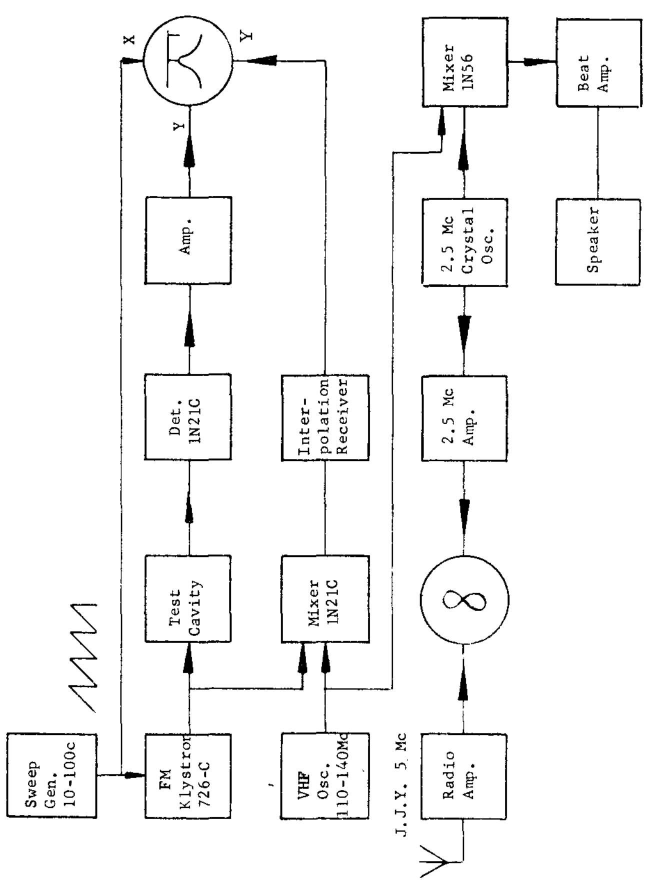

Sweep Gen. 10-100c
FM Klystron 726-C
Test Cavity
Det. 1N21C
Amp.
X
Y
Y
VHF Osc. 110-140Mc
Mixer 1N21C
Inter-polation Receiver
J.J.Y. 5 Mc
Radio Amp.
2.5 Mc Amp.
2.5 Mc Crystal Osc.
Mixer 1N56
Beat Amp.
Speaker

Fig. 5

estimate, using a perturbation calculation, shows that an accuracy of about one micron is necessary in order to keep the frequency error to less than 10^{-5}. Also the surface roughness of the finished disks is held to 0.3 microns to get high Q values.* Good rf contact between disks and cylinders is assured by a knife-edge contact with appropriate pressures leading to Q values as high as 13,000 for the S-band $2\pi/3$ mode guide.** The vacuum seal of the guide is obtained by electroforming ; the gases escaping from a fabricated guide were measured to be about 2×10^{-8} $\ell\mu$/sec/cm^2. Figure 3 shows the results of a nodal-shift phase measurement for a one-meter section, giving an error of less than 2.5 degrees when plotted on a Smith chart, which is certainly the order of the experimental error in such a measuring method.

III. New Method for Measuring Performance of Guides

A simple new method for measuring the resonant frequency and the Q value of each cell has been developed.[3] A metallic plunger with an antenna probe is inserted from each end of the guide. Their positions are adjusted to be set at the center of a cell or at the center of a disk hole so as to make the distance between the two ND (D is the cell length and N is an integer) (Fig. 4). Such a position can easily be found by a slight shift from the correct position, as shown in Fig. 7, and the following description. The radio-frequency power is fed into one of the antennas and detected by the other. The radio-frequency power is frequency modulated by a sawtooth wave, and the resonance behavior is measured by comparison with a wavemeter. A block diagram of the typical electronic device used is shown in Fig. 5.

In the usual nodal-shift method with a metal plunger and a standing-wave detector, the axial electric field can take a maximum at the plunger surface. In the present method such a mode is detuned by the antenna probes, and only the mode having a zero field at the plunger surface should be excited, as shown in Fig. 6. If one moves the plunger position, the detected amplitude and the frequency of the resonance vary as shown in Fig. 7, giving the correct position of the plunger with a minimum detected power. In the nodal-shift method, the error in the measurements is caused by mismatching at the input coupler of the guide. Such an error

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*Precise optical and matching techniques to measure and control the disk-hole shaping and the surface roughness are described also in Reference 1.

**Combined with the field measurement, the corresponding shunt impedance obtained is 59 MΩ/m.

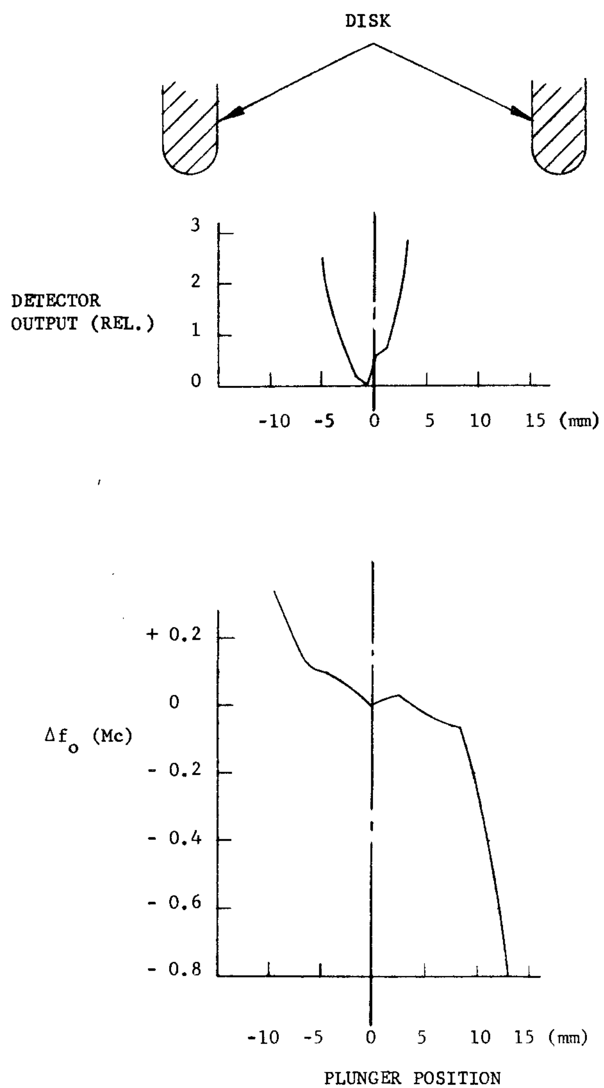
DISK
DETECTOR
OUTPUT (REL.)
3
2
1
0
-10
-5
0
5
10
15
(mm)
+ 0.2
0
- 0.2
- 0.4
- 0.6
- 0.8
Δf o (Mc)
-10
-5
0
5
10
15
(mm)
PLUNGER POSITION

Fig. 7

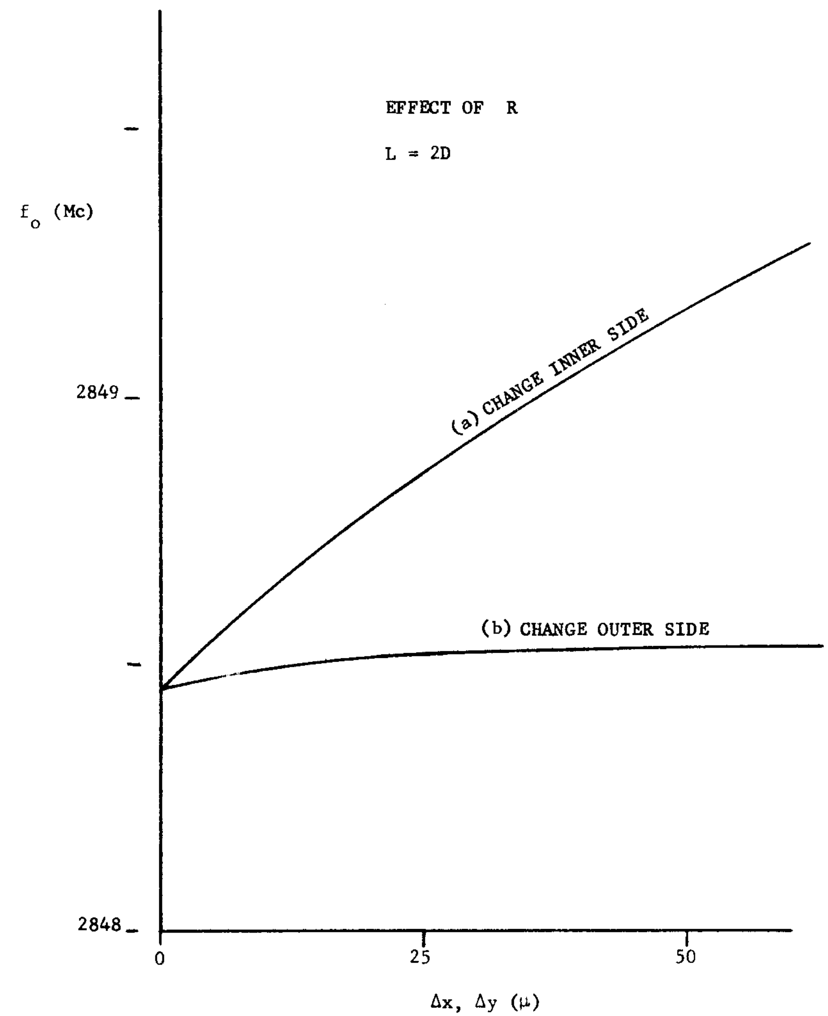
EFFECT OF R
L = 2D
f o (Mc)
2849
2848
(a) CHANGE INNER SIDE
(b) CHANGE OUTER SIDE
0
25
50
Δx, Δy (μ)

Fig. 8

is eliminated in the present method, where the length of the antenna loops affects the frequency measurements. By an extrapolation of the results obtained for various antenna lengths, this measuring error can also be corrected.

IV. Some Typical Results of Performance Measurements

The resonant frequency of each cell fabricated by the new method is found by the above measuring method to be within $\pm$ 25 kc of the desired frequency (S-band, $2\pi/3$ mode). The corresponding phase error for a one-meter section should be 0.1° or 2×10^{-3} rad.* Some other interesting results follow:

1. The effect of hole shaping

A disk having an unsymmetrically shaped hole was used to examine the effect of hole shaping. It had a correct dimension on one half-side of the cross section and an incorrect dimension on the other side. The resonant frequency of a $\pi/2$ mode cell was measured with this disk. The disk was turned over, and measurements were done for both cases: (i) the incorrect side is inwards to the measuring cell (Fig. 8, curve a), and (ii) it is outwards (Fig. 8, curve b). The result indicates a frequency shift in case (i) but not in case (ii). Since, with the present measuring method, microwave energies are stored mainly in the inner cell and not in the half outer cells, the result obtained is quite understandable and means that we can inspect the performance of each cell separately by successive measurements. This assures also that one can make Q measurements without effects of end walls.

2. Tuning of each cell

If we had observed a big frequency error in one of the cells, we could easily make a correction by a tuning operation, observing the frequency of that cell. Some typical examples of tuning are shown in Fig. 9 where a small portion of the wall is pushed down in the usual manner, and the resonant frequency is corrected by a trial-and-error method. Also the aging effect of the deformed wall was examined over several days as shown in the right-hand side of Fig. 9.

3. Measurement of field distribution

One can also obtain the field distribution of a cavity by measuring the resonant frequency when the boundary is perturbed. An example of

*At the present stage, a guide having the total length of 3 m can be made with a similar performance.

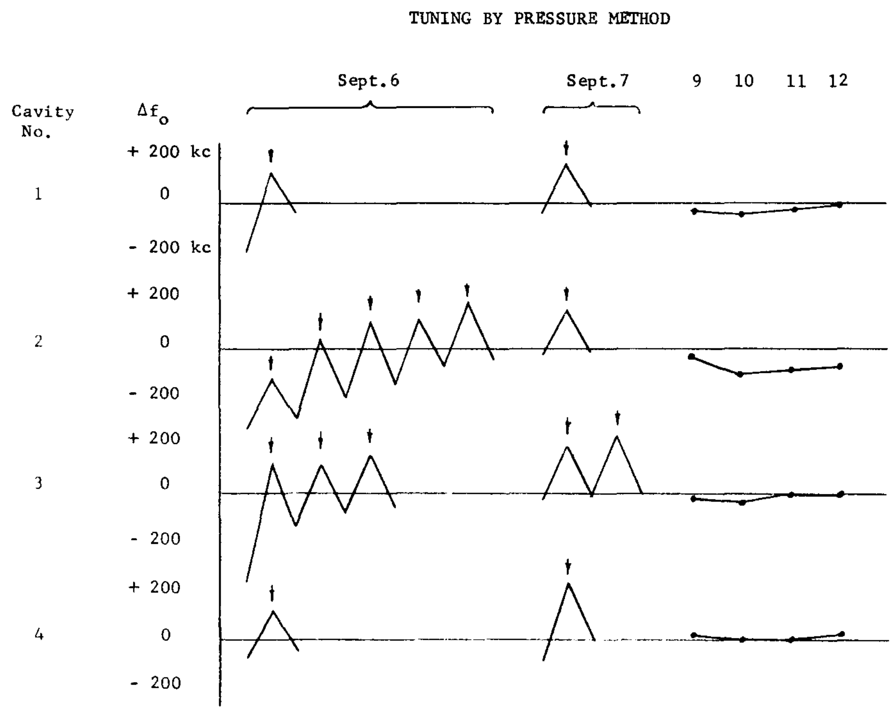
TUNING BY PRESSURE METHOD
Sept.6
Sept.7
9
10
11
12
Cavity No.
Δf_o
+ 200 kc
0
- 200 kc
+ 200
- 200
1
2
3
4

Fig. 9

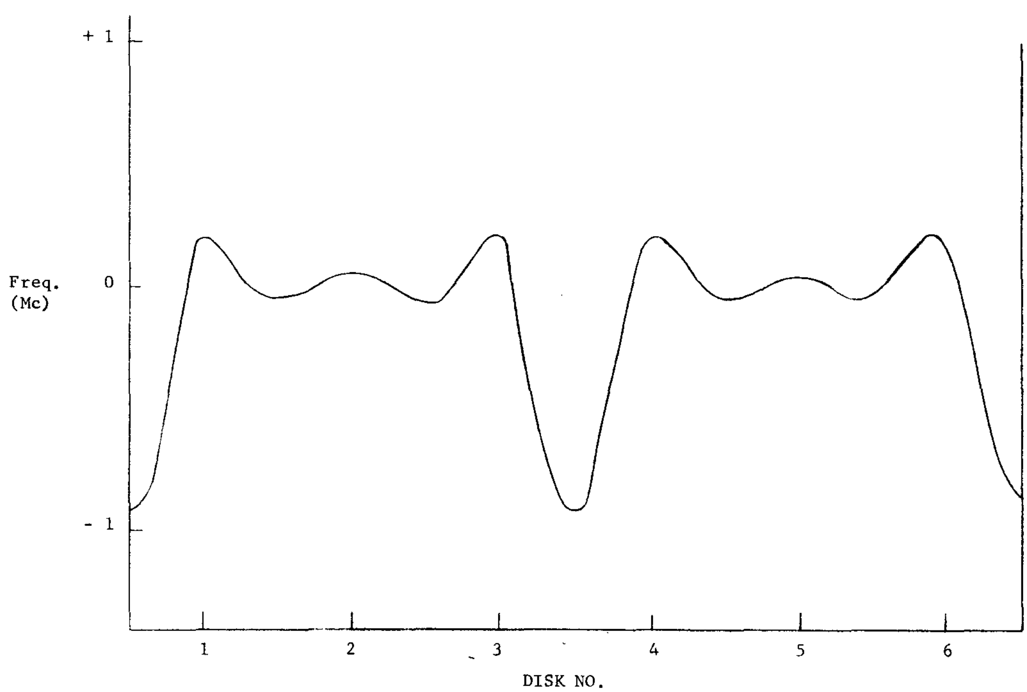
+ 1
0
- 1
Freq. (Mc)
1
2
3
4
5
6
DISK NO.

Fig. 10

the $\pi/2$ mode, in which a small teflon bead is slid down along the axis, is shown in Fig. 10.

LOEW: Do you plan to use this method and tune afterwards also, or do you plan to use only one method?

NISHIKAWA: We usually do not use the tuning, but if we have made an error, we can adjust it easily.

LOEW: Was the number 10^{-2}, for the total phase shift per cavity, expressed in radians?

NISHIKAWA: Yes, radians.

REFERENCES

1. J. Tanaka, "The Construction and Test Operation of INS Linear Electron Accelerator", J. Phys. Soc. Japan 16, 2081 (1961); J. Tanaka, T. Nishikawa, A. Miyahara et al., "On Electroforming of Disk-Loaded Waveguide for Linear Accelerators", Appl. Phys. in Japan 31, 146 (1962); J. Tanaka, T. Nishikawa, A. Miyahara, and K. Kobayashi, "Microwave Measurements on Disk-Loaded Waveguide for Electron Linear Accelerators", Internal Report of the Institute for Nuclear Study, University of Tokyo (March 1961, in Japanese).

2. "Mitsubishi Linear Accelerator Tube Manufactured by Electroforming Method with Copper Spacer", (July, 1964), issued by Mitsubishi Heavy Industries, Ltd., Nagoya, Japan.

3. T. Okada, N. Shigemura and K. Takeuchi, "A Measuring Method of Frequencies of Accelerator Guides", Report on the Meeting of the Physical Society of Japan (April 1964).