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A SHAPE ALGORITHM FOR A RFQ VANE

Benito Juárez* and Elliott Treadwell

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I. Introduction

The Radio Frequency Quadrupole Linear Accelerator (RFQ) proposed by Kapchinskii and Teplyakov,[1] has become an accepted structure in the accelerator community. The first working model was developed at Los Alamos[2,3] for the 440 MHz cavity, and since then 200 MHz models have appeared at BNL, CERN, LBL, and KEK. The RFQ is very useful for bunching low-energy ion beams and accelerating them to sufficient energies for injection into a linear accelerator.

A Fermilab model of the RFQ would be a 200 MHz structure capable of accelerating H^- ions from 30 keV to 750 keV in 1.36 meters. The ion current of 50 mA would be pulsed at 15 Hz. Table I shows some revelant parameters for the 201.25 MHz cavity.[4] The RFQ vane-tip parameters, m(z) and a(z) are determined along the vanes according to an algorithm developed by K. Crandall et al.[3] Results of this calculation are stored on paper tape and input into numerically controlled milling machines for vane cutting. We have used the algorithm to calculate a vane shape for the 200 MHz RFQ and have plotted the results using the Device Independent Graphics System.

II. Generalized Potential Function for Axisymmetric Cavities

The electric fields are derived from the generalized, lowest-order function (in cylindrical coordinates):

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*Permanent address: Instituto de Fisica, Universidad Nacional Autónoma de México

$$U = U(r,\psi,z)\ F\ (t)$$
$$= \frac{V}{2}\left[X \left(\frac{r}{A}\right)^2 \cos\ (2\psi) + AI_0(r)\ \cos kz\right]\ \sin(\omega t + \phi). \qquad (1)$$

V is the intervane voltage, a is the intervane gap, I_0 is a Bessel function, λ and ω are the rf vane length and frequency respectively. ϕ is the synchronous phase, $k = \pi/L$ where $L = \beta\lambda/2$ (the length of one cell of the RFQ), and βc is the ion speed. The first term of Eq. (1) represents transverse electric focusing and the second term provides acceleration in the beam direction.

Figure 1 shows a unit cell in the r-z plane and illustrates the positions of a, radius parameter, and m, the modulation parameter. Let $z = z_j$ at the beginnning of the cell and $z = z_j + L$ at the end of the cell; then the time-independent part of Eq. (1) satisfies the following boundary condition

$$U(a,\ o,\ z_j) = U(ma,\ o,\ z_j + L) = \frac{V}{2}\ . \qquad (2)$$

From this boundary condition it is possible to deduce the expressions for A and X.[5]

$$A = \frac{(m^2 - 1)}{m^2 I_0(ka) + I_0(mka)}\ , \quad X = 1 - A\ I_0(ka). \qquad (3)$$

The dependence of a, m, and L on positions along the beam axis will be discussed in the following section.

III. The Algorithm

The first 1.88 in. of the vane, the region of radial matching, corresponds to a constant modulation m = 1, and decreasing a (z), the distance from the beam center line to the vane

$$a(z) = a_0[7(0.1 + 6.9z/z_0)]^{1/2}. \qquad (4)$$

(See Table I.)

The remainder of the vane is composed of cells and each cell has a sinusoidal dependence described by the parameter a(z)

$$a(z) = a_0\left[1 \pm \frac{(m - 1)}{(m + 1)} \sin\left(\frac{\pi z^i_{cell}}{L^i}\right)\right]. \qquad (5)$$

$z^i_{cell} = z - z^i_{0cell}$, where z^i_{0cell} is the beginning point of the ith cell, and i ranges from 9 to 126. One can deduce from Eq. (5) that the cell length varies from cell to cell, and the polarity of the sinusoidal term alternates.

IV. Results

We plotted Eq. (5) by dividing each cell into eight equidistant points, therefore $z^i_{cell} = nL^i/8$, and the correspondent coordinate is $z = z^i_{0cell} + nL^i/8$, n = 0,8. The data were stored in a program VANE1 and input into the Device Independent Graphics File (DIGF). Figure 2 shows the shape of the vane in the "Radial Matching" section; Figures 3(a) to (g) show the vane shape from the end of the "Radial Matching" section to the end of the "acceleration" section and the vertical scale is 5 in. of plot/0.1 in. of vane.

V. Acknowledgments

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Table I. RFQ Parameters.[2]

Frequency	201.25MHz
Length	53.6 in.
Intervane Voltage	60 KV
Average Radius (a_0)	0.178 in.
Minimum Radius	0.188 in.
Final Modulation	2.00
Initial Energy	30 keV
Final Energy	750 keV
Focusing Parameter (B)	7.0
End of "Radial Matching" (z_0)	1.88 in.

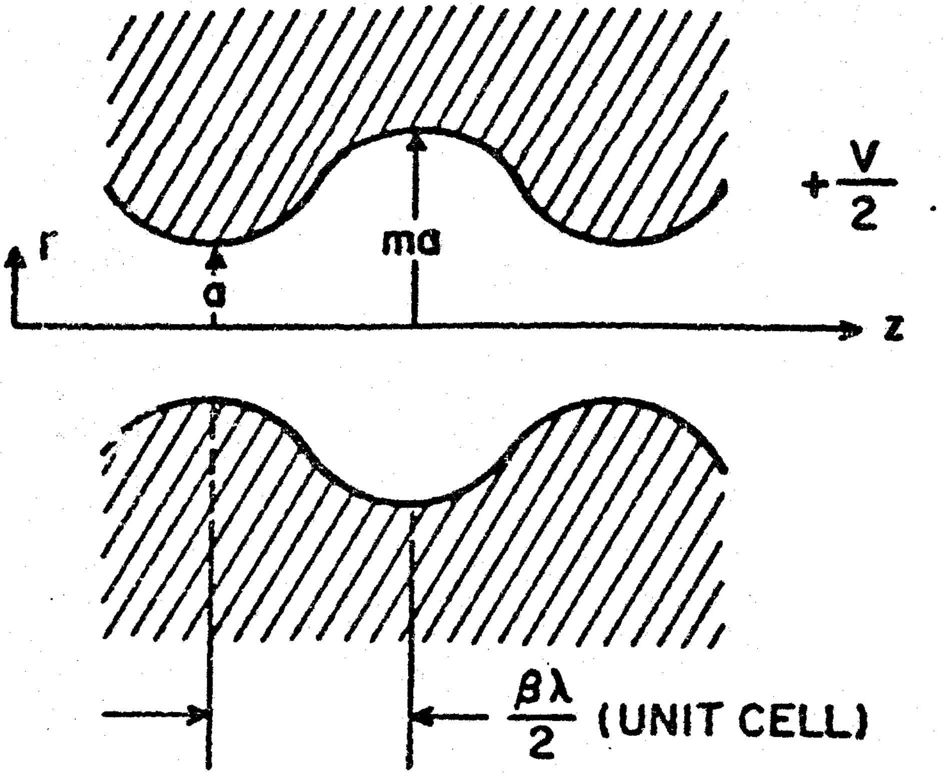


Fig. 1. RFQ Pole-Tip Geometry

Fig. 2. Radial Matching Section

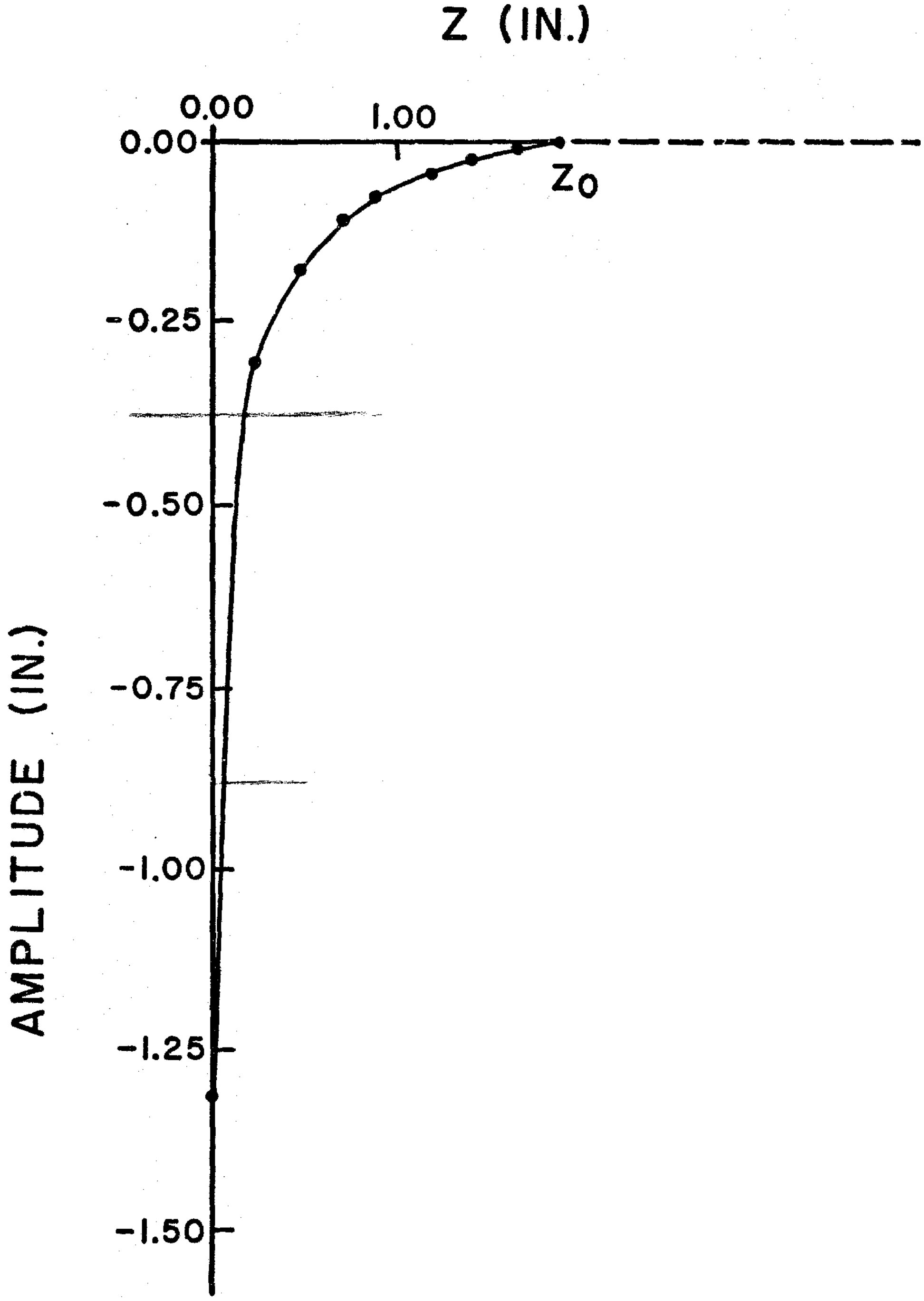
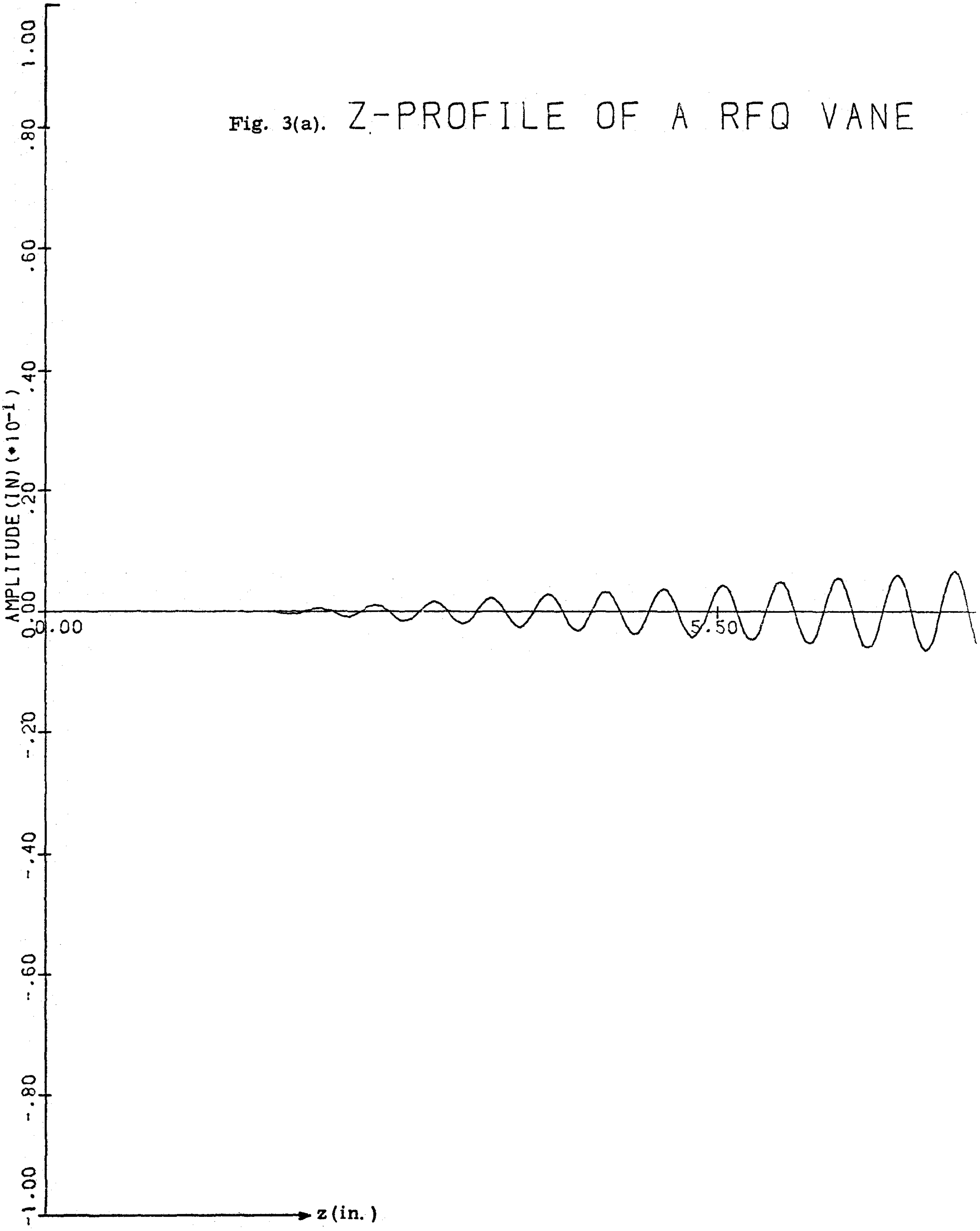


Fig. 3(a).


Z-PROFILE OF A RFQ VANE
AMPLITUDE (IN) (*10^{-1})
1.00
.80
.60
.40
.20
0.00
-.20
-.40
-.60
-.80
-1.00
0.00
5.50
z (in.)

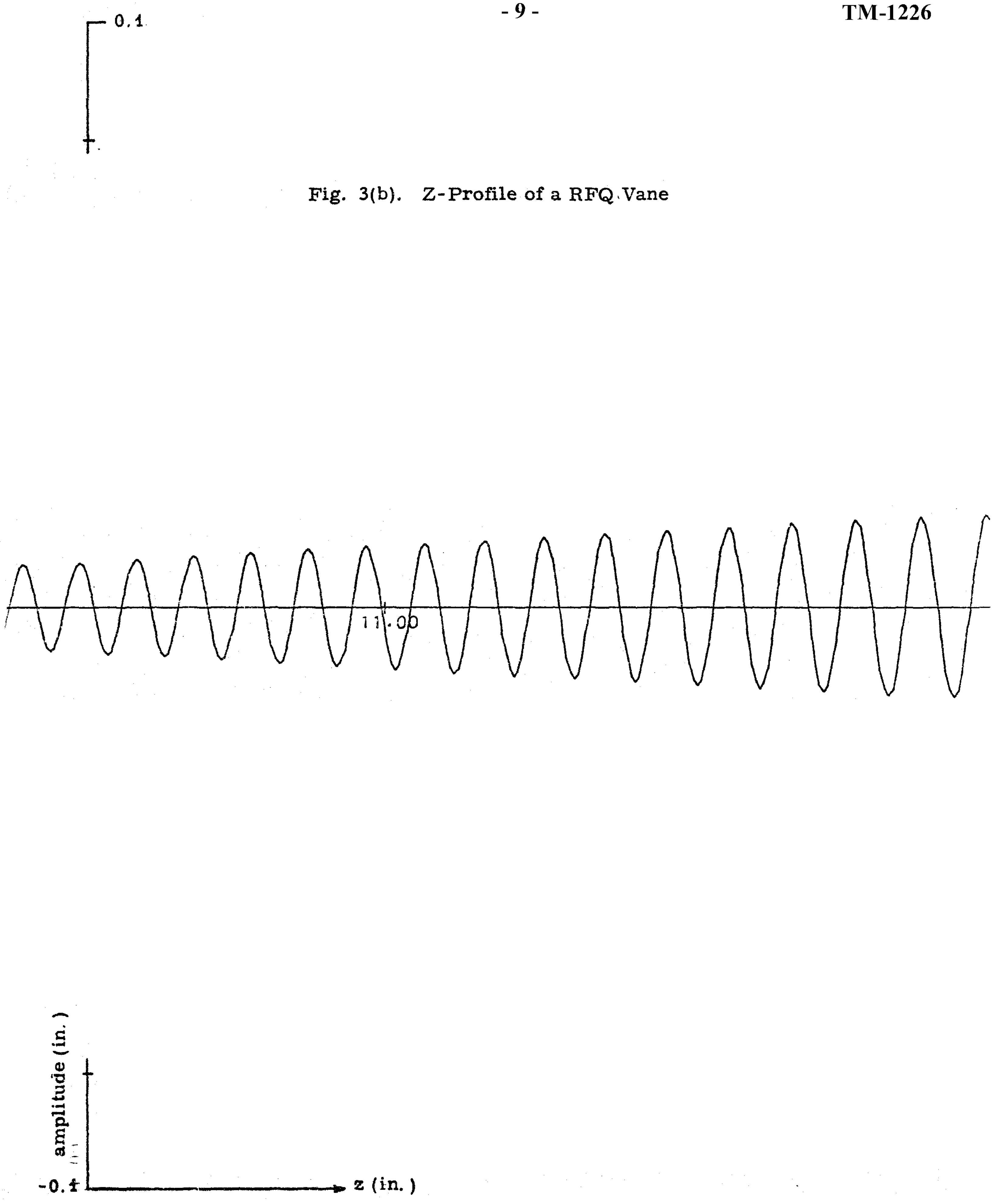


Fig. 3(b). Z-Profile of a RFQ Vane

Fig. 3(c). Z-Profile of a RFQ Vane

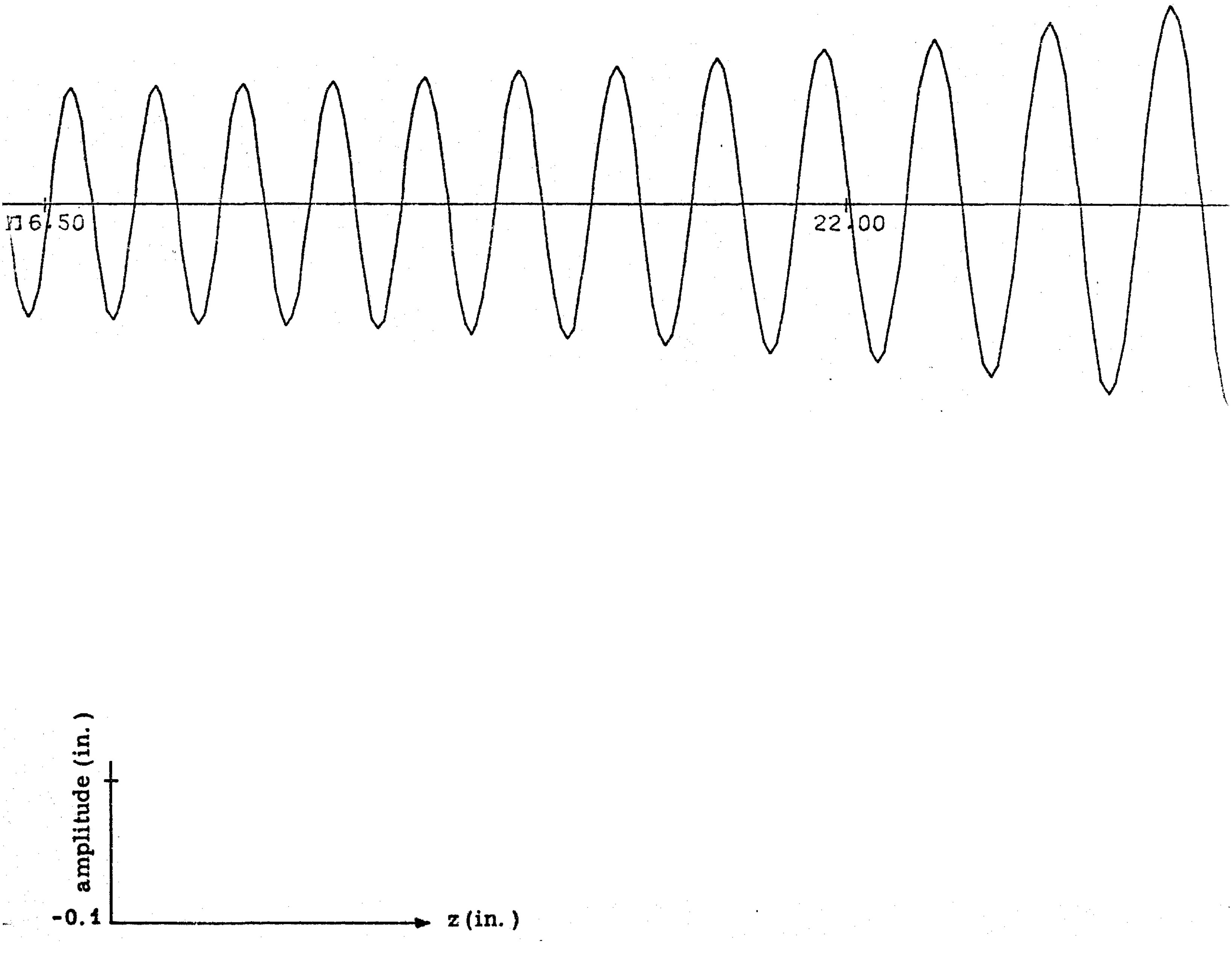


Fig. 3(d). Z-Profile of a RFQ Vane

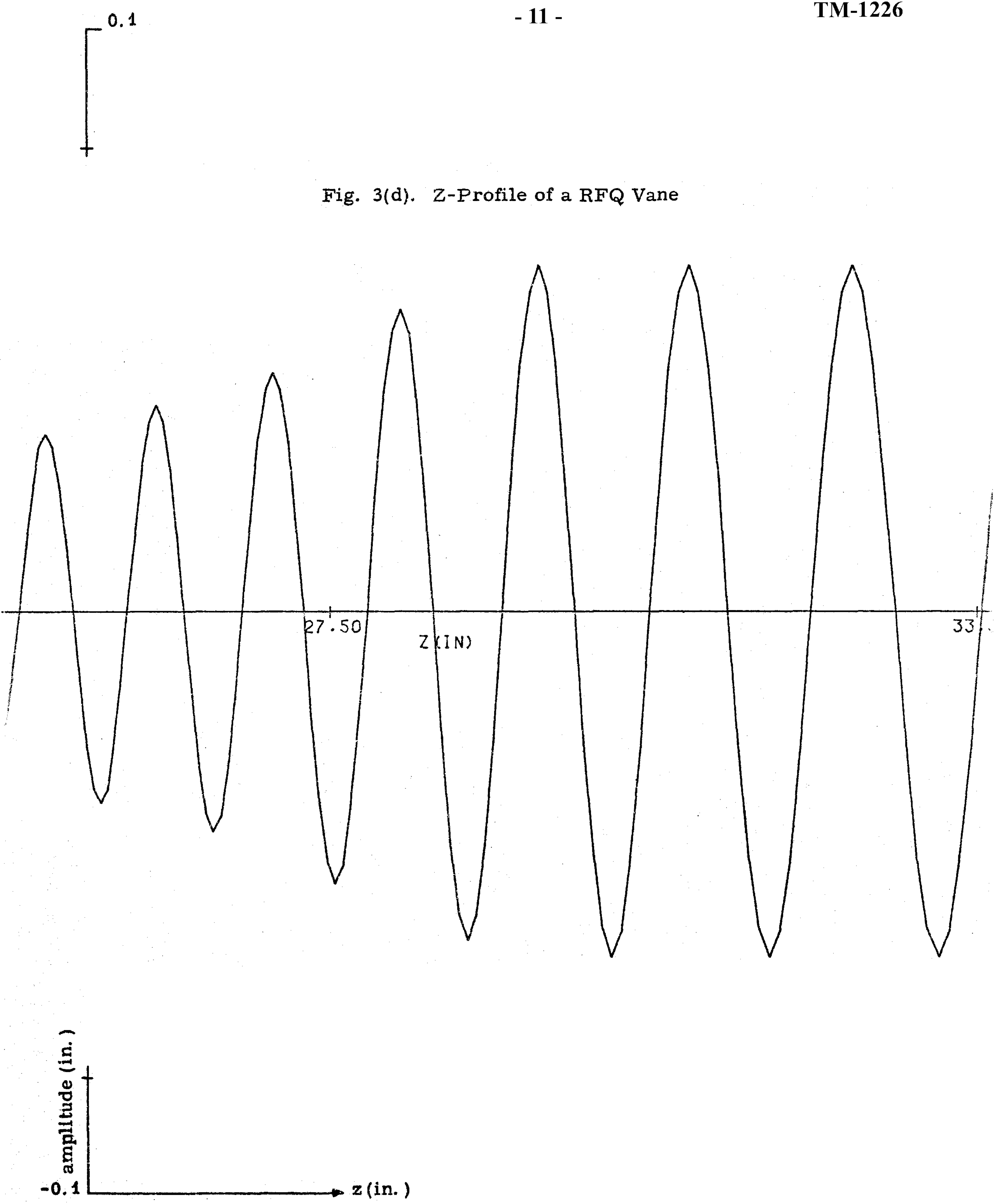


Fig. 3(e). Z-Profile of a RFQ Vane

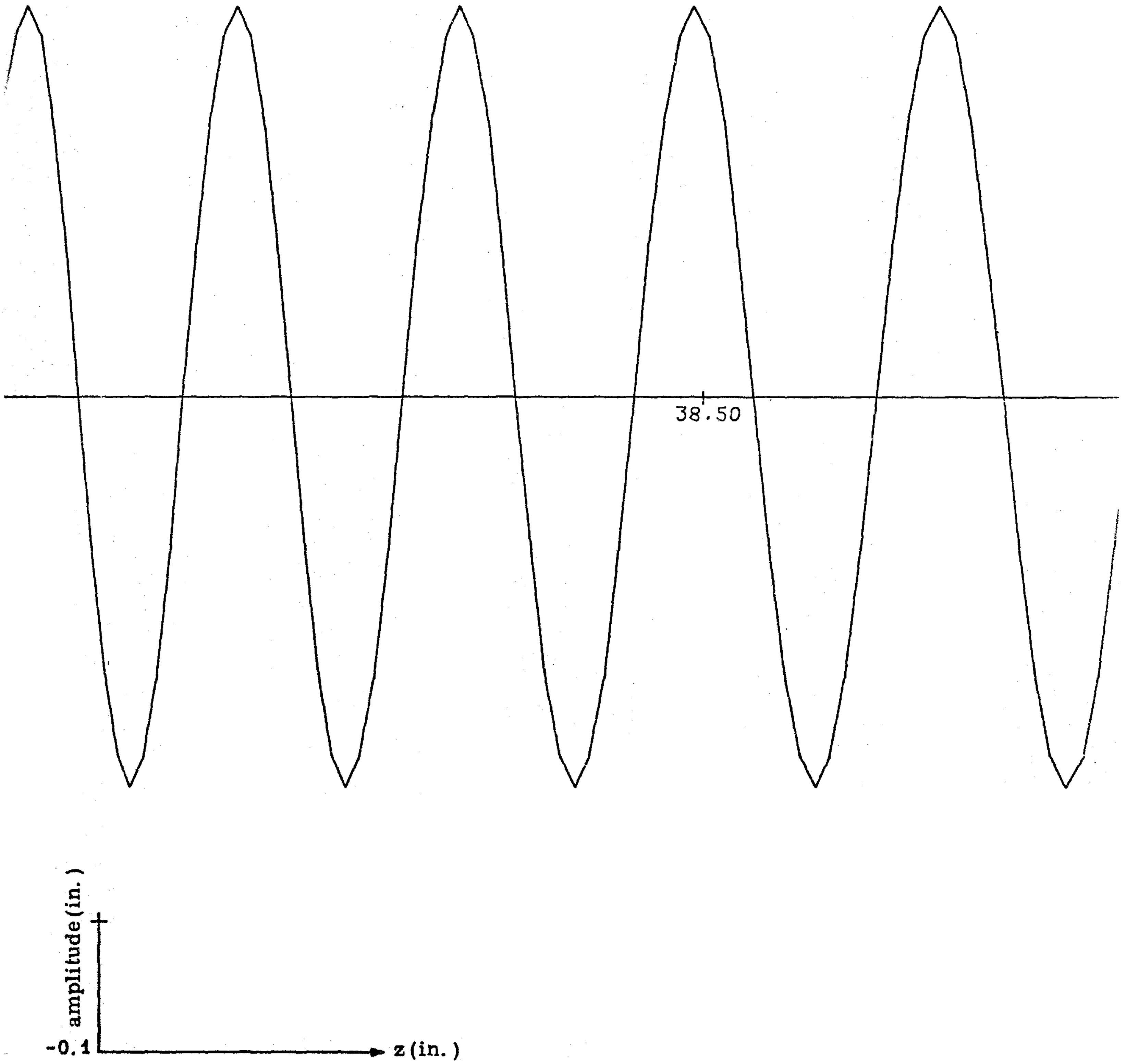
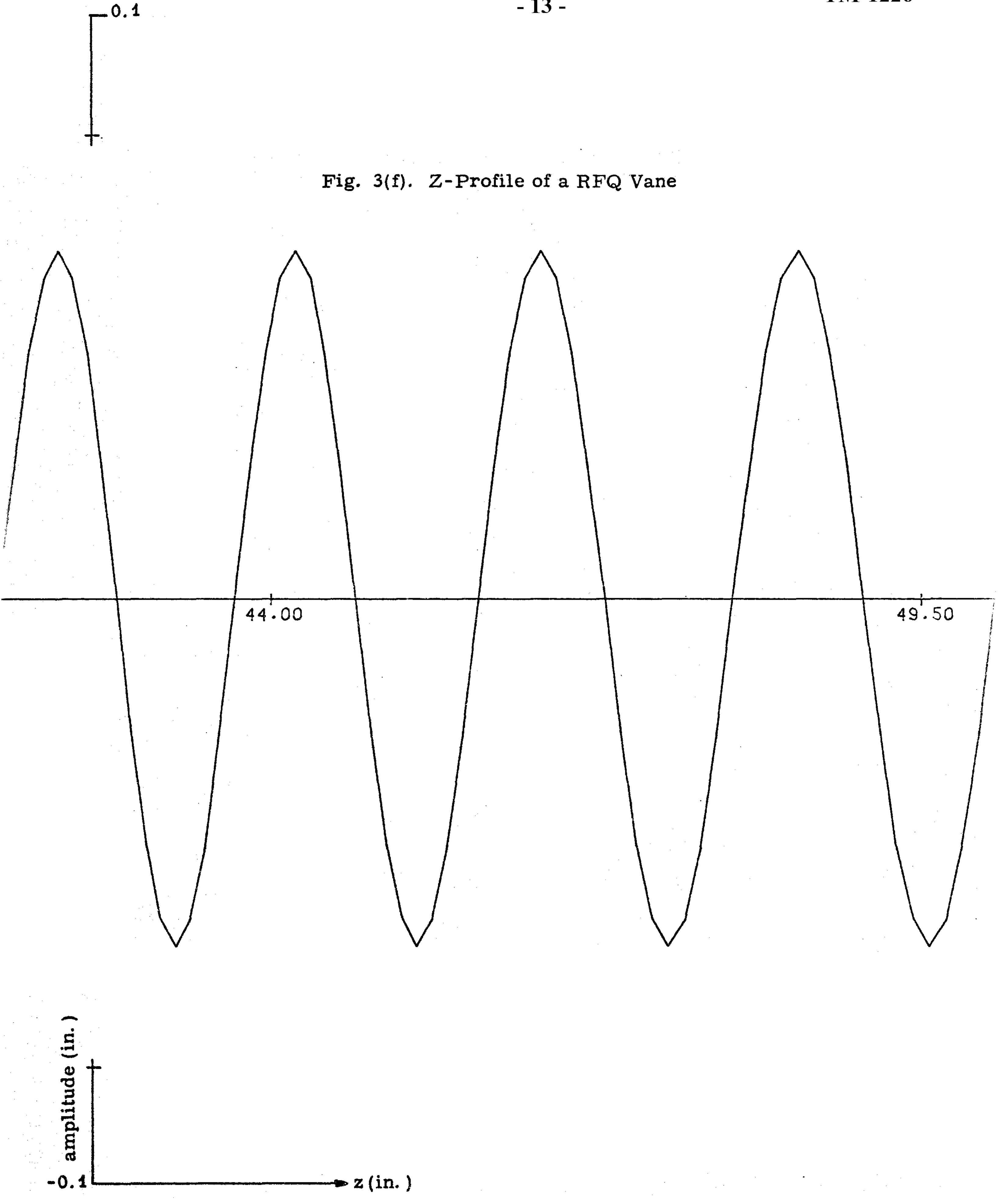


Fig. 3(f). Z-Profile of a RFQ Vane



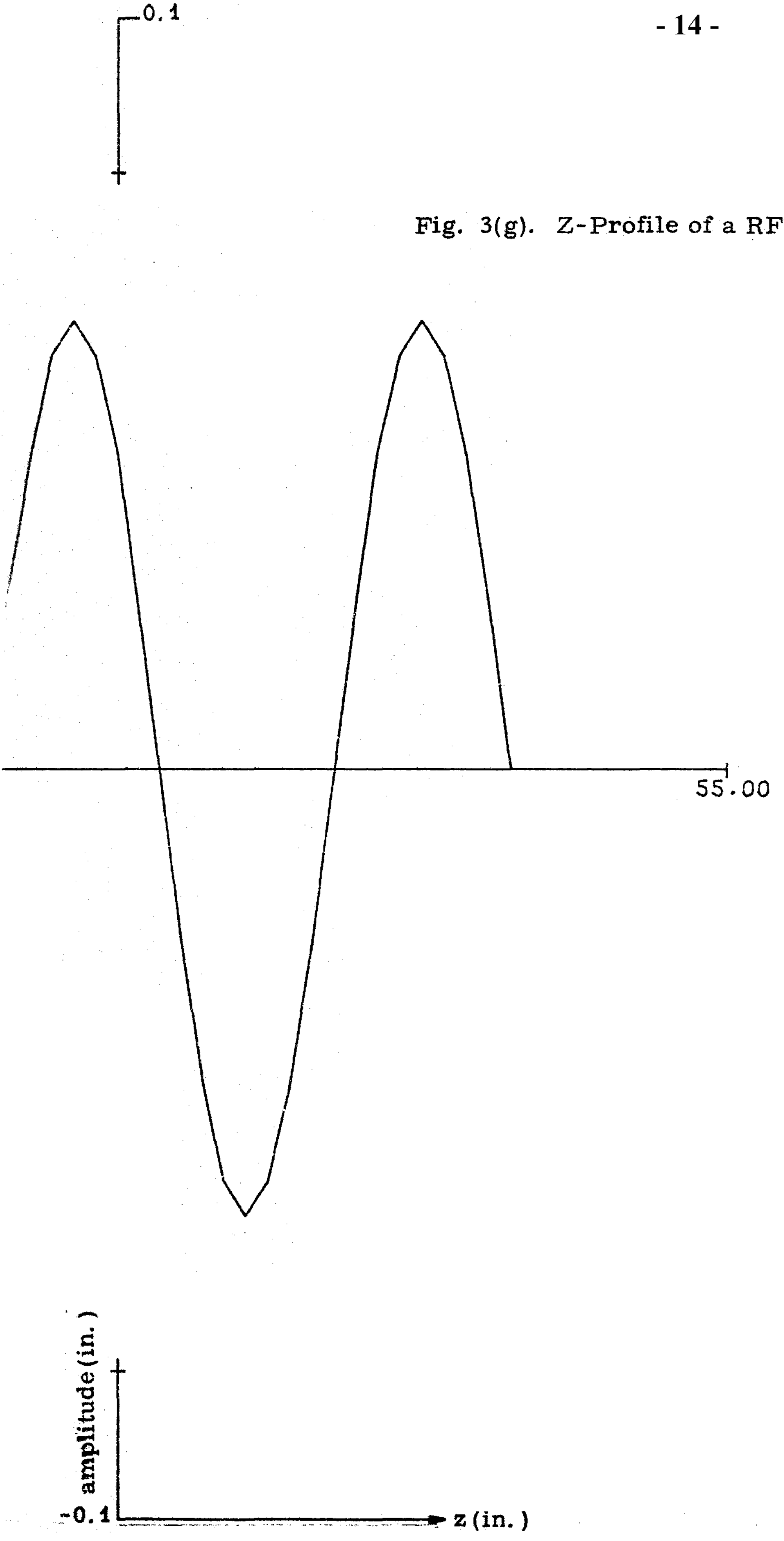


Fig. 3(g). Z-Profile of a RFQ Vane