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FOUR-POINT MOUNTING CONFIGURATION FOR RESONATORS SUBJECTED TO S--ETC(U)

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Research and Development Technical Report

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FOUR-POINT MOUNTING CONFIGURATION FOR RESONATORS SUBJECTED TO SEVERE ENVIRONMENTS

Arthur Ballato
Electronics Technology & Devices Laboratory

November 1977

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AT-cut quartz plate resonators are usually edge mounted. For precision applications, and especially where ruggedness is required, a four-point mount is necessary. This report investigates those mounts consisting of two pairs of diametric attachments. For this class of mount a locus is found for the angles of attachment of the circular plate with respect to the crystallographic axes such that radially directed edge forces are compensated. One point on the locus is found to be particularly frequency insensitive to mounting errors, and defines the optimum setting for the four-point mount.

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INTRODUCTION

On-going development of crystal resonators for high precision frequency control has led to specific conclusions regarding identification and management of various error budget entries. The constraints imposed by stringent performance requirements for digital communication, position location, and sensor systems provided, e.g., the impetus that produced a new ceramic resonator package.[1,2]* This enclosure is a high-alumina flat-pack that uses special sealing techniques. It is adaptable for various roles, such as (1) high g-force and fast warm-up and (2) maximum frequency precision with minimum long-term aging.

Given the design of the ceramic flat-pack and the necessity of mounting the AT-cut quartz resonators on four supports for high-shock applications, a significant contribution to the frequency error arises from forces transmitted from the alumina package to the quartz. The subject of frequency perturbations in quartz vibrators produced by external forces has received both experimental[3-19]* and theoretical[20-27]* attention. It is known that the frequency changes are due to both the static deformation of the crystal lattice and a nonlinear elastic constant effect.[21-25] In this report certain results involving the force-frequency effect are applied to the question of mounting an AT-cut circular resonator on four points in a manner adaptable to use in the ceramic flat-pack. It is found that an optimum orientation of the mounting supports exists with respect to the crystal axes, and also that misalignments about the optimum produce minimal frequency shifts.

THE FORCE-FREQUENCY EFFECT

Figure 1 defines the geometry under consideration. The crystallographic X axis is the datum from which angle ψ is measured; force F_1 acts along the crystal plate diameter with azimuth ψ, while the diametric force F_2 is applied at azimuth $\psi + \gamma$. The points of application of F_1 and F_2 represent the positions of the mounting supports. The problem is to find the proper values of angles ψ and γ to ensure a minimum sensitivity of frequency to applied force.

Although it is not necessary for the mounts to be diametrically paired as shown in Figure 1, virtually all of the experimental data exist in this form as well as most theoretical results. In addition to this, it turns out that the force-frequency effect due to opposing forces acting across the crystal diameter is superposable.[13] This means that the separate contributions to the frequency shift under loads F_1 and F_2, each acting alone, add linearly to produce the overall frequency excursion seen when F_1 and F_2 act together. This fact leads to a simple solution to what is otherwise a very difficult problem.

The force-frequency effect produced in circular crystal plates acted upon by a diametric pair of forces F at angle ψ is characterized by Ratajski[14]

* See list of references beginning on 12.

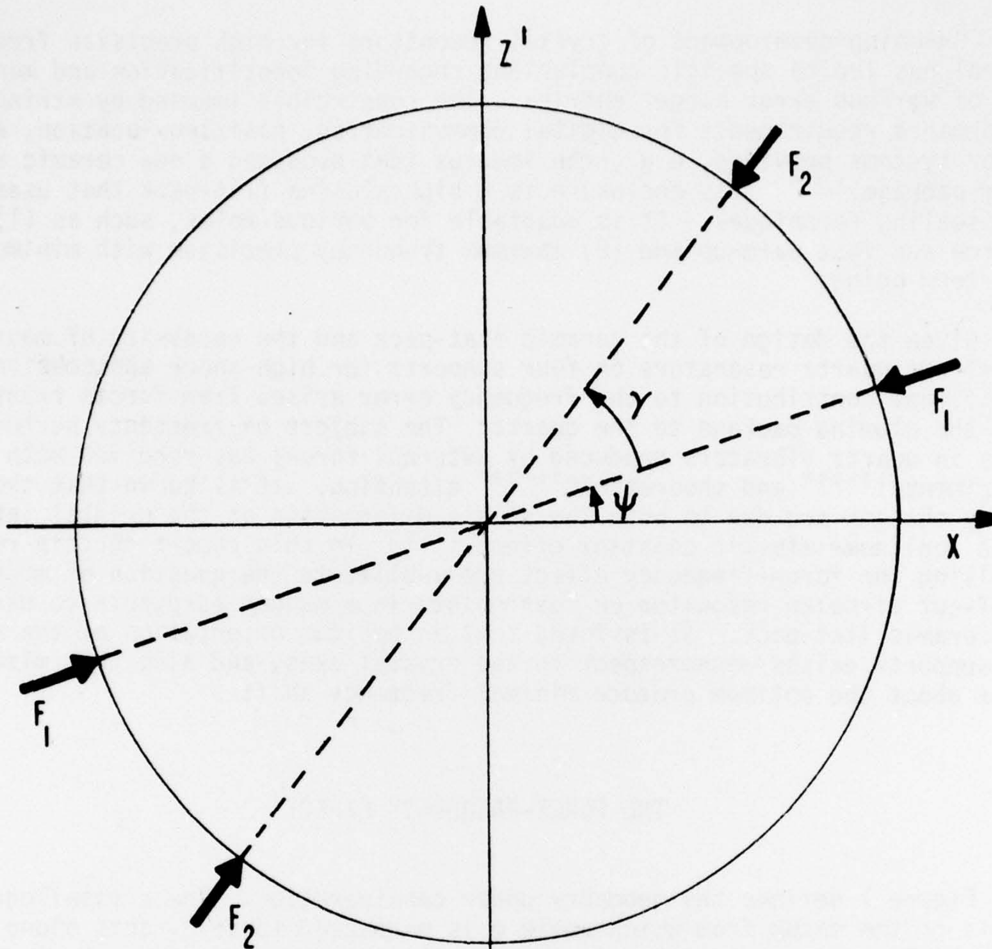

FIGURE 1. DEFINITION OF MOUNTING ANGLES WITH RESPECT TO CRYSTAL AXES.

by means of a force-frequency coefficient $K_f(\psi)$. For a plate of diameter D, thickness 2h, nominal frequency f_o, and frequency constant N, $K_f(\psi)$ is defined as

$$K_f(\psi) = \frac{\Delta f}{f_o} \cdot \frac{2h \cdot D}{F} \cdot \frac{1}{N} \quad . \tag{1}$$

In Equation (1), Δf is the frequency change brought about by application of compressional force F. For the AT-cut of quartz,

$$N = 2h \cdot f_o = 1.660 \text{ MHz-mm}. \tag{2}$$

$K_f(\psi)$ in Equation (1) can be interpreted as being a proportionality factor relating the fractional frequency change $\Delta f/f_o$ to the average stress acting across the crystal diameter $F/(2h \cdot D)$. For overtone operation of resonators, it is found that Δf and f_o are each multiplied by the harmonic number so that $K_f(\psi)$ is invariant, for a given value of the azimuth. The azimuthal dependence arises from the anisotropic nature of the crystal lattice.

To determine a compensated mounting configuration, the variation of $K_f(\psi)$ with ψ must first be accurately determined. With time, the theoretical curves have become increasingly better fits to the experimental data. However, at present, it is felt that the greatest accuracy in characterizing $K_f(\psi)$ versus ψ is to be had by using the experimental results.

To this end, the data for the AT-cut given by Ratajski,[14] representing a compilation from a number of sources, were subjected to a least-squares fit. From symmetry considerations the function $K_f(\psi)$ must satisfy the relations:

$$K_f(-\psi) = K_f(+\psi), \tag{3}$$

and

$$K_f(\pi/2 - \psi) = K_f(\pi/2 + \psi). \tag{4}$$

With due regard for these symmetries the functional form adopted for $K_f(\psi)$ is

$$K_f(\psi) = \sum_{n=0}^{N} A_n \cos^{2n} \psi. \tag{5}$$

A five-term least-squares fit gives the following coefficients:

- $A_0 = -9.21$ (6)
- $A_1 = +31.82$ (7)
- $A_2 = +64.51$ (8)
- $A_3 = -95.15$ (9)
- $A_4 = +32.27,$ (10)

all in units of 10^{-15} m.s/N. The resulting curve is shown in Figure 2. It will be seen that the curvature at $\psi = 0^o$ is quite small; the second

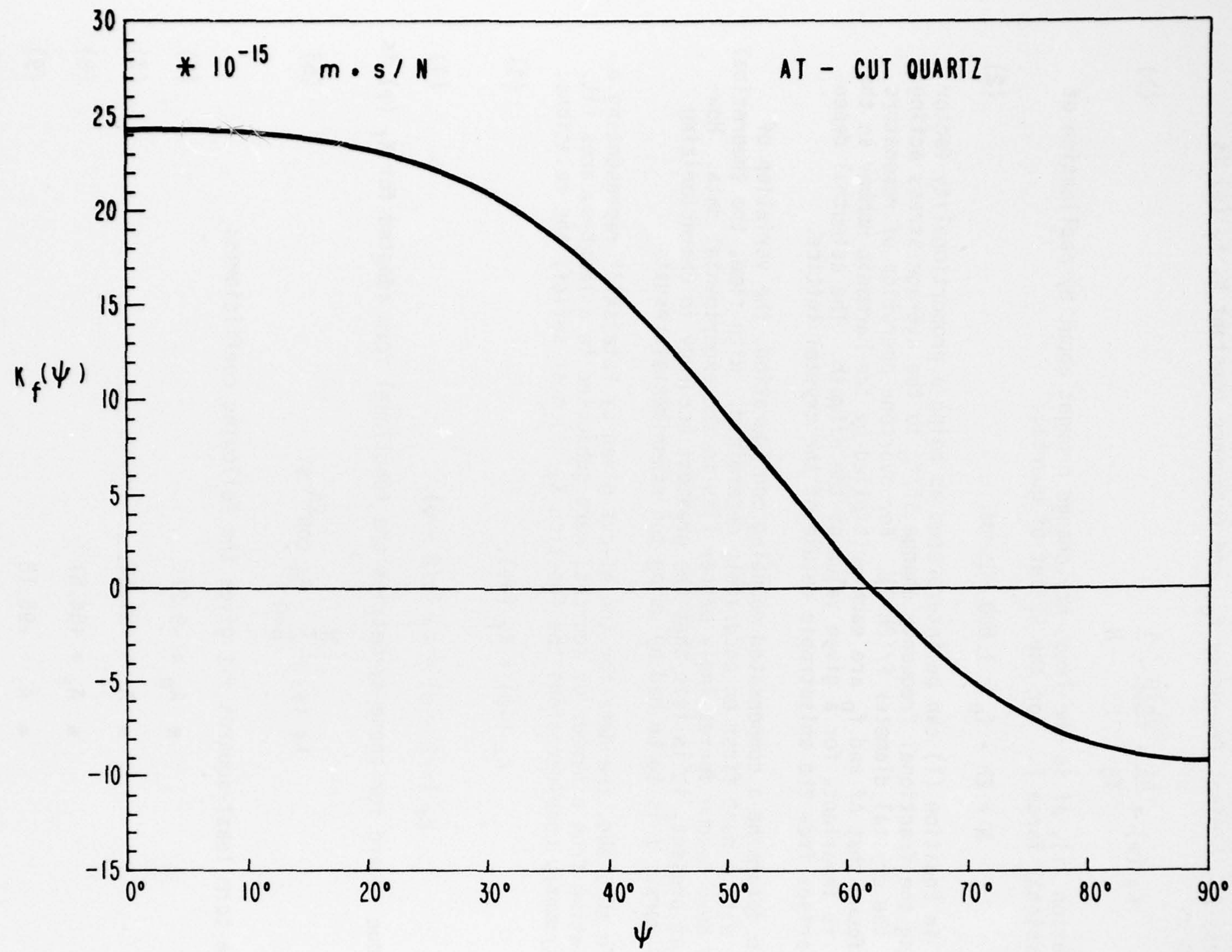

FIGURE 2. K_f VERSUS AZIMUTH ANGLE psi FOR AT-CUT QUARTZ.

derivative of $K_f(\psi)$ is only -8.94/radian^2, in units of A_η. A comparison between the fit to the experimental data using Equations (5)-(10) and the latest theoretical results is given in Table 1. The agreement is satisfactory.

THERMAL EXPANSION

In the sequel it will be necessary to have an expression for the thermoelastic coefficient $\alpha''_{11}(\psi)$, usually called the thermal expansion constant. Applying the transformation law for second-rank tensors to coordinate axes rotated first about the X axis by θ, and then about the Y' axis by angle ψ, we obtain for quartz:

$$\alpha''_{11}(\psi) = \alpha_{11}(\cos^2\psi + \sin^2\psi \sin^2\theta) + \alpha_{33}(\sin^2\psi \cos^2\theta). \tag{11}$$

This result is independent of rotations about the initial Z axis. Using the numerical values for α-quartz,

$$\bullet \quad \alpha_{11} = 13.72, \tag{12}$$

and

$$\bullet \quad \alpha_{33} = 7.48, \tag{13}$$

in units of 10^{-6}/K, gives the results shown in Figure 3 for θ values of 0° (Y-cut), $+35.25^{\circ}$ (AT-cut), and -49.2° (BT-cut).

THE FOUR-POINT MOUNT

The anisotropy of quartz with respect to thermal expansion, shown by Equations (11)-(13), will in general produce unequal forces on the mounting supports because the ceramic flat-pack holder is isotropic, and differential strains will be azimuth-dependent. Since, by Equation (1), the Δf produced by a force is proportional to both the force and to the value of $K_f(\psi)$ at the azimuth of the force, and it is desired that the algebraic sum of both frequency shifts equal zero, we have

$$K_f(\psi) + \rho(\psi,\gamma)^* K_f(\psi + \gamma) = 0. \tag{14}$$

In Equation (14), the geometry of Figure 1 is used, and

$$\rho(\psi,\gamma) = F_2/F_1 \tag{15}$$

is the force ratio. Because the forces depend on the differential expansion coefficients for a fixed temperature change, the force ratio is given by

$$\rho(\psi,\gamma) = (\alpha''_{11}(\psi + \gamma) - \alpha_o)/(\alpha''_{11}(\psi) - \alpha_o), \tag{16}$$

where

$$\bullet \quad \alpha_o = 6.5 \times 10^{-6}/\mathrm{K} \tag{17}$$

is the thermal expansion coefficient of alumina (99.9%).

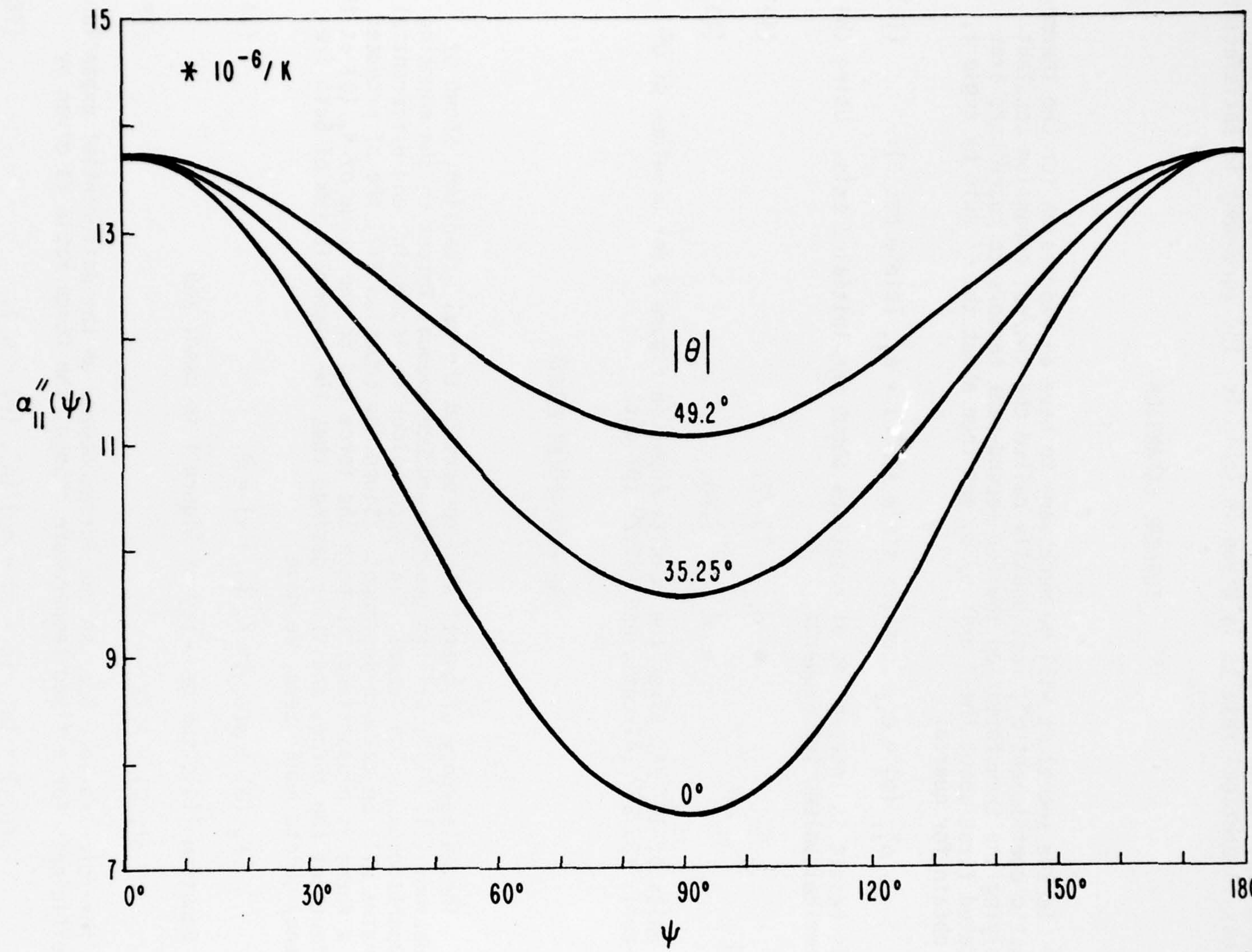

FIGURE 3. THERMOELASTIC COEFFICIENT VERSUS AZIMUTH FOR THREE VALUES OF ANGLE theta.

Insertion of Equation (11) into Equation (16) and the result into Equation (14) yields the desired relation between ψ and γ for which the total frequency change is zero. The result of solving Equation (14) is shown in Figure 4. The locations where the curve crosses the $\gamma = 0^{o}$ axis represents the case where the four-point mount degenerates into a two-point mount. About those locations the mounting points are close together, and the sensitivity to mounting misalignment is large. At the points marked "A" and "B," the individual contributions to Δf are each zero, and the mounting locations are symmetrically disposed about the X and Z' axes. Furthermore, the sensitivity to errors in mounting is minimized. This defines the optimum mounting configuration for this problem. Angles ψ and γ are related by

$$2\psi + \gamma = \pi \tag{18}$$

for the optimum configuration. The variation of $K_f(\psi)$ in the vicinity of point "A" with the angle constraint of Equation (18) is given in Table 2. Table 3 is a compilation of solutions to Equation (14) as function of ψ and γ, in the vicinity of point "A." From Table 3 it is seen that for

$$\bullet \quad \gamma = 56^{o}, \tag{19}$$

substantial errors in ψ, the crystallographic orientation with respect to the mounting points, the frequency change is quite small.

The ceramic flat-pack enclosure incorporating mounting pads spaced according to Equation (19) will not be subject to large manufacturing errors. By reasonable attention to keep

$$\bullet \quad \psi \approx 62^{o}, \tag{20}$$

the force-frequency effect contribution to the resonator frequency error may be readily minimized. The angular spread between the four mounts should be sufficient to permit this design to be used in high shock applications.

Figure 5 shows a polar plot of $K_f(\psi)$ against ψ. Diameters are drawn through the locations $K_f(\psi) = 0$, defining the positions of the optimal mounting configuration. Black circles simulate the positions of fixation of the quartz plate. Considerations similar to those given in this report apply to the design of mounting supports for SC-cut[17-19] crystals. In the case of doubly rotated cuts in general, the $K_f(\psi)$ versus ψ curve does not exhibit symmetry, and the resulting sensitivities to errors in ψ and γ are increased.

CONCLUSIONS

The four-point mounting problem for circular AT-cut quartz resonator plates subjected to thermally induced mounting forces has been solved. A locus of acceptable configurations has been determined, and from this locus the position of minimum sensitivity to mounting errors has been found.

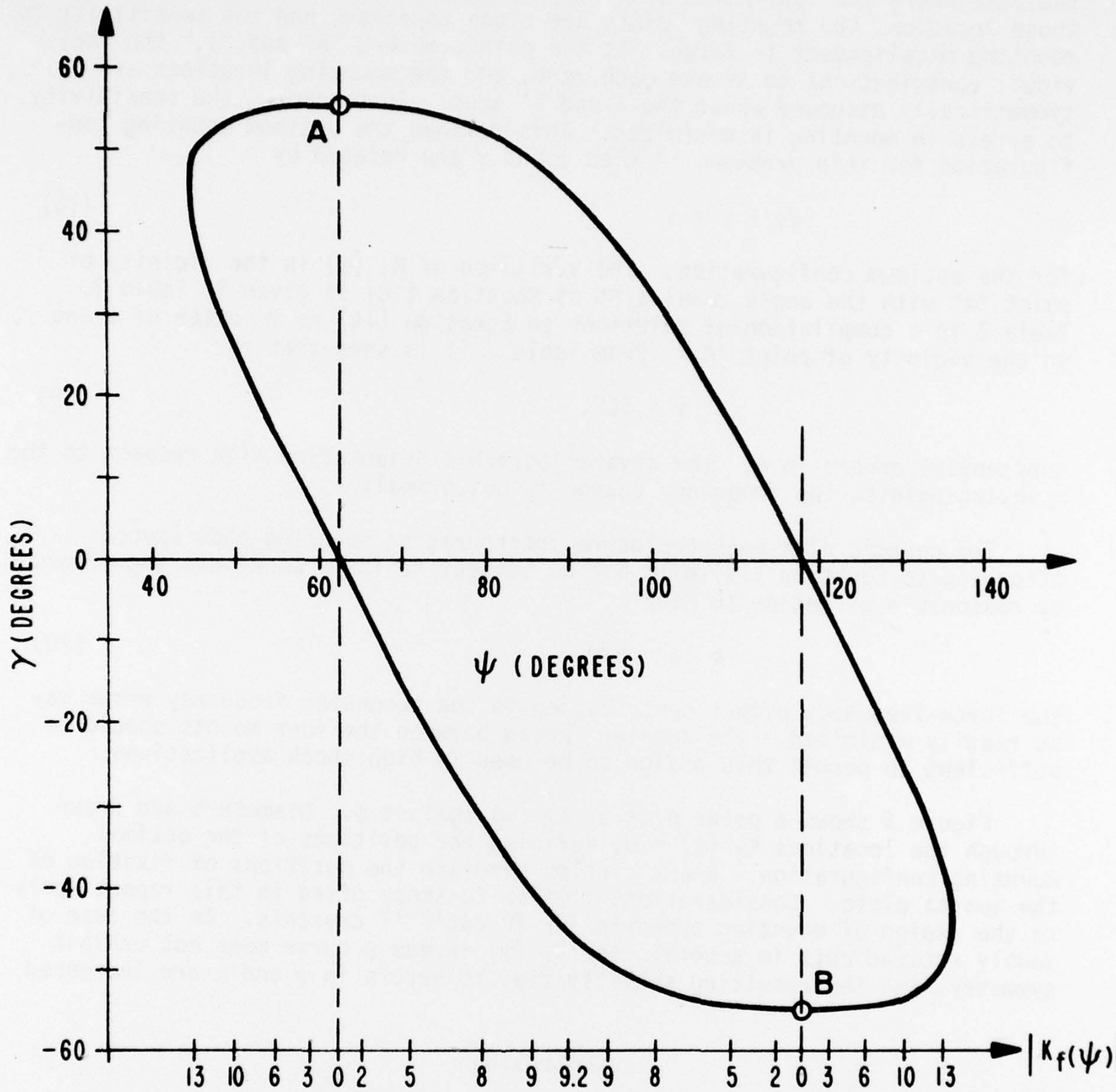

FIGURE 4. ANGLE psi VERSUS ANGLE gamma ON LOCUS OF ZERO FREQUENCY SHIFT.

TABLE 1. COMPARISON OF $K_f(\psi)$ VALUES

Condition on $K_f(\psi)$	Ratajski[14]		EerNisse[27]	
	ψ	$K_f(\psi)$	ψ	$K_f(\psi)$
maximum	0	24.2	0	24.5
zero	62.0	0	64.7	0
minimum	90	-9.2	90	-11.5

(ψ in degrees; $K_f(\psi)$ in 10^{-15} m·s/N)

TABLE 2. psi AND gamma IN THE VICINITY OF $K_f = 0$.

ψ	γ	$K_f(\psi)$
61.98	56.04	-1.15
61.99	56.02	-0.46
62.00	56.00	0.24
62.01	55.98	0.93
62.02	55.96	1.62

(ψ and γ in degrees;
$K_f(\psi)$ in 10^{-17} m·s/N)

TABLE 3. $K_f(\psi) + \rho(\psi,\gamma)^* K_f(\psi + \gamma)$ VERSUS psi AND gamma.

ψ \ γ	51	52	53	54	55	56	57	58	59	60	61
57	2.46	1.96	1.43	0.87	0.29	-0.32	-0.95	-1.61	-2.28	-2.97	-3.67
58	2.69	2.16	1.61	1.03	0.42	-0.20	-0.85	-1.52	-2.21	-2.91	-3.62
59	2.88	2.33	1.76	1.15	0.53	-0.11	-0.78	-1.46	-2.15	-2.86	-3.58
60	3.04	2.47	1.87	1.25	0.61	-0.05	-0.72	-1.42	-2.12	-2.84	-3.56
61	3.17	2.57	1.96	1.32	0.66	-0.01	-0.70	-1.40	-2.11	-2.83	-3.56
62	3.26	2.64	2.01	1.36	0.69	0.00	-0.69	-1.40	-2.12	-2.84	-3.56
63	3.31	2.68	2.03	1.37	0.69	-0.01	-0.71	-1.42	-2.14	-2.86	-3.59
64	3.33	2.68	2.02	1.34	0.65	-0.05	-0.75	-1.47	-2.19	-2.90	-3.62
65	3.31	2.65	1.98	1.29	0.60	-0.11	-0.82	-1.53	-2.25	-2.96	-3.67
66	3.26	2.59	1.90	1.21	0.51	-0.20	-0.91	-1.62	-2.32	-3.03	-3.73
67	3.17	2.49	1.80	1.10	0.40	-0.30	-1.01	-1.72	-2.42	-3.11	-3.80

(ψ and γ in degrees; $K_f(\psi) + \rho(\psi,\gamma)^* K_f(\psi + \gamma)$ in 10^{-15} m•s/N)

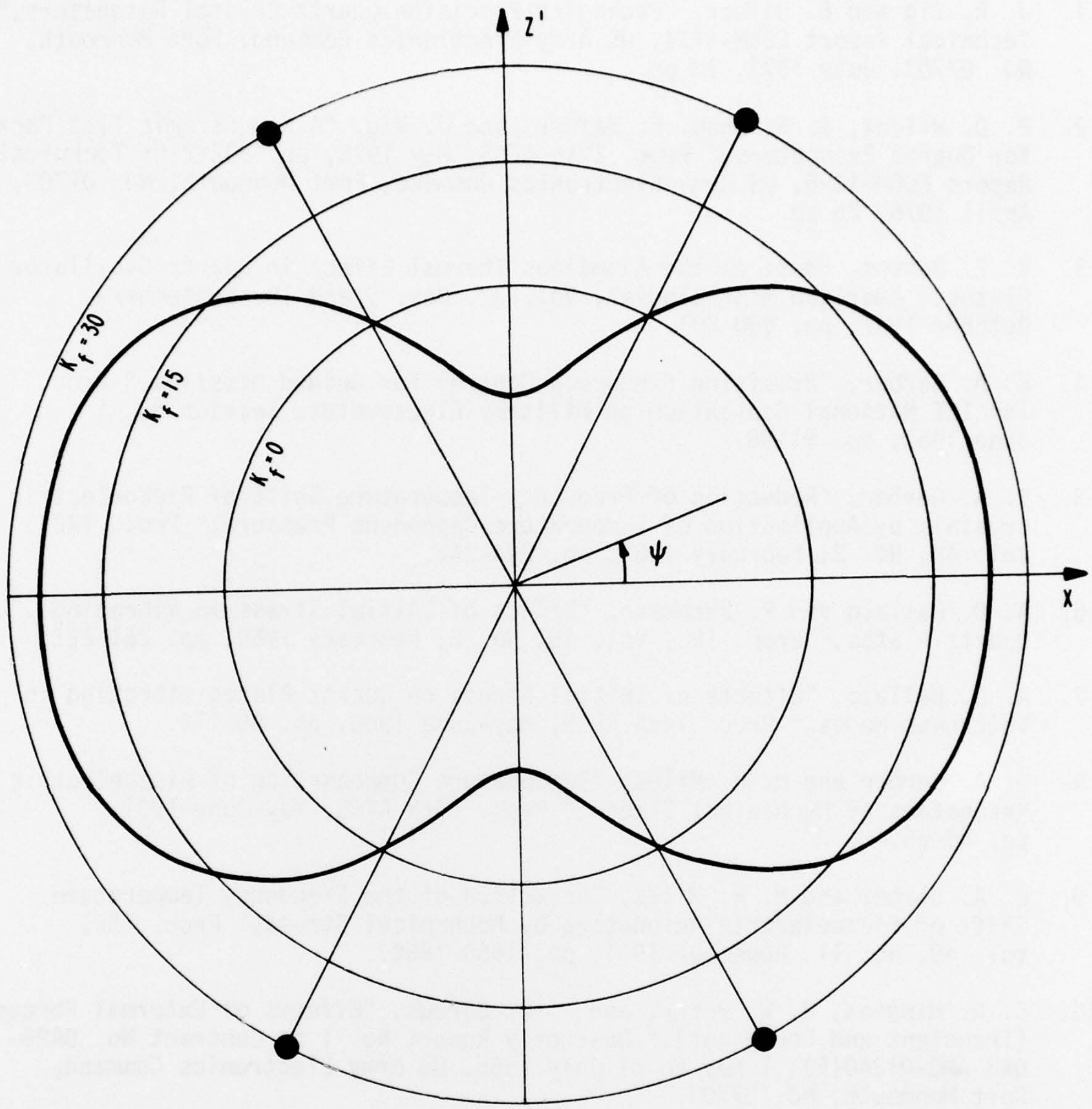

FIGURE 5. POLAR PLOT OF K_f VERSUS ANGLE psi. UNITS OF K_f ARE 10^{-15} m·s/N.

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