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Technique for Polishing Single Crystal Yttrium-Iron-Garnet Spheres*

A simple method of polishing yttrium-iron-garnet spheres which produces samples of fractional oersted linewidths has been employed at the Air Force Cambridge Research Center. The technique consists of "hand-polishing" the crystal spheres in diamond pastes and aluminum oxide powders of diminishing grit sizes. This method significantly increases, both by greater pressure and efficiency of abrasive contact, the rate of removing material from the surface of the sample, which is fundamental in the polishing process. Results attest to a substantial reduction in fine-polishing time to a matter of hours. At present, fine-polishing using the more or less conventional technique of tumbling the sample in an air-cyclone chamber requires a period of days.

Rough samples are shaped into spheres and the coarse-polishing phase completed by either the previously mentioned air-cyclone chamber or metallurgical grinder[1] methods. Fine-polishing is initiated by rolling the spheres in a figure eight pattern under light finger pressure in 6 μ-grit diamond paste that has been dabbed on a metallurgical polishing cloth. Since a very small amount of material is removed by hand polishing, reasonable care insures uniform polish over the entire crystal surface and maintains sample sphericity. After approximately one hour of such polishing, the process is repeated with successively finer grits, *viz.*, 3 μ-, 1 μ-, and 0.5 μ-diamond pastes, followed by dry aluminum oxide powders of grit size 0.3 μ and 0.1 μ. Toward the conclusion of the process, the aluminum oxide powder was mixed with acetone into a slurry, yielding an extremely high degree of polish.

At regular intervals within each polishing phase, a visual inspection under a 90X microscope was made and the linewidth of the sample was measured to compare the effectiveness of each grit size in narrowing the linewidth. Table I lists the measured linewidths of three YIG spheres for various grit sizes and polishing times.

Samples A and B were grown in the same batch in the laboratory, while sample C was purchased. Sample B, though adequately polished, appears to have solvent inclusions which probably account for its relatively large linewidth.

Each value listed in the preceding table is the average linewidth taken over many sample orientations, thereby eliminating any dependency of linewidth on crystal orientation. These values were obtained using both the cavity perturbation technique,[2] where appropriate, and a new method[3] designed especially for use with narrow linewidth samples.

TABLE I
LINEWIDTH IN OERSTEDS

Grit Size	Hours	Sample A	Sample B	Sample C
At completion of coarse-polishing phase		4.47	2.5	~3.0
6 μ-Diamond Paste	½	—	—	1.89
	1	—	1.28	—
3 μ-Diamond Paste	½	2.72	—	1.39
	1	1.35	1.30	1.13
1 μ-Diamond Paste	½	1.27	—	1.16
	1	1.00	1.25	0.84
0.5 μ-Diamond Paste	½	1.05	—	—
	1	1.00	1.24	—
0.3 μ-Alumitum Oxide Powder	½	0.86	—	0.73
	1	0.95	1.25	—
	2	—	1.04	—
	3	—	1.03	—
0.1 μ-Aluminum Oxide Powder	½	0.80	—	—
	1	0.65	—	—
	2	—	1.07	—
	3	—	1.12	—
Final Diameters		0.015 inch	0.021 inch	0.014 inch

It is felt that further experience will reveal not only that one or more steps can be eliminated in the polishing procedure, but also that an optimum polishing time per stage can be determined.

To mechanize the process, a simple polishing machine consisting essentially of two reciprocating polishing plates is being developed.

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Tunable Two-Mode Cavity with Capacitative Loading*

A cavity with two independently tunable modes in the 4- to 9-kMc frequency range was needed for experiments in paramagnetic relaxation. It had to be small enough to fit inside a liquid helium dewar and had to possess a region of approximately uniform RF magnetic field common to both modes over part of its volume.

To meet these requirements a box shaped copper cavity of inside dimensions 0.670 inch×0.670 inch×0.866 inch was built, and its natural resonant frequencies were lowered into the required range by means of copper blocks mounted in the central region. If the cavity is regarded as the limiting case of an LC resonant circuit, the effect of such loading is to increase the capacity. The fundamental unloaded frequencies were 11.18 kMc in the two modes which were used and 12.48 kMc in the third mode. The 11.18-kMc modes were shifted to frequencies in the range from 4 to 9 kMc by an appropriate choice of loading block. The third mode was damped out by the joint in the cavity wall and by the brass rod used to support the center block. The cavity was tuned by moving dielectric plungers in and out of the region of the strong electric field. In most of the geometries tested, these regions were distinct for each mode so that changes in the tuning of one had comparatively little effect on the other.

The cavity was made in two parts joined along a central plane as shown in Fig. 1.

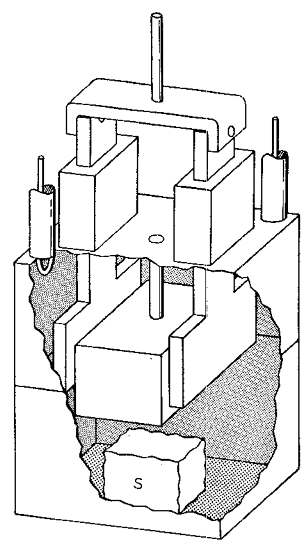

Fig. 1—Cutaway view of loaded cavity. In magnetic resonance experiments the sample (*S*) may be placed in the space below the loading block. For clarity, only one pair of dielectric tuning plungers are shown.

Dielectric plungers, loading blocks, and coupling loops were mounted in the upper part, the lower part being left for accommodation of the specimen. The plungers were made of SC24 ceramic (relative dielectric constant 9) and connected in pairs by brass brackets outside the cavity so that each

* Received by the PGMTT, June 1, 1960.

pair moved as a unit. The loading blocks were mounted in the center space by a 0.050-inch brass supporting tube clamped in the top of the cavity. Four blocks were tested (Fig. 2): one with a square cross section to give nearly equal frequencies, one with rectangular cross section to give moderate separation of frequencies, one *I* shaped block to give extreme separations, and the block shown in Fig. 2(d). The large horizontal dimensions of this last block make the space between block and cavity walls small, thereby providing high capacitative loading. The holes in the corners help conserve the effective inductance by allowing the magnetic field a near normal path. Each block had a vertical dimension of 0.280 inch (*i.e.*, about one third of the depth of the cavity). The other dimensions are shown in Fig. 2.

Power was introduced by two magnetic coupling loops which could be rotated or retracted. The two loops could be used to feed each mode independently, or one loop could be oriented to feed both and the other loop left as a tuning monitor.

Measured Q values corrected for coupling losses were 2000 to 3000. Tuning curves for the cavity when loaded with the rectangular block are shown in Fig. 3. Results for this and other blocks are summarized in Table I.

Ceramic plungers with a thickness of 0.120 inch (*i.e.*, two times the original thickness) were fitted and tested with the square cross section block [Fig. 2(a)]. This resulted in a tuning range from 5655 Mc to 7450 Mc for each mode. A block of quartz (relative dielectric constant 4) with a volume of 0.034 cubic inch was placed in the bottom of the cavity to estimate the amount of detuning likely to be caused by the presence of a paramagnetic or other sample in the cavity. The quartz occupied about one fourth of the total volume available for the sample and lowered the cavity frequency by less than one per cent.

Capacitative loading by centrally mounted copper blocks is free from lossy joints between conducting elements and does not lead to an excessive deterioration in Q. In magnetic resonance experiments, there may be an over-all gain in sensitivity due to the reduction in cavity volume and the increase in sample filling factor. For a given size cavity the operating frequencies may be chosen anywhere in a wide range and may be altered merely by substituting new loading blocks. Because of the effect of the block in concentrating the electric field between itself and the cavity wall, it is possible to obtain a fair degree of independence in the tuning of the two modes and to cover a range up to twenty per cent without using large amounts of dielectric. The lower third of the cavity volume is left free for the mounting of samples and contains the region of strong magnetic field common to both modes.

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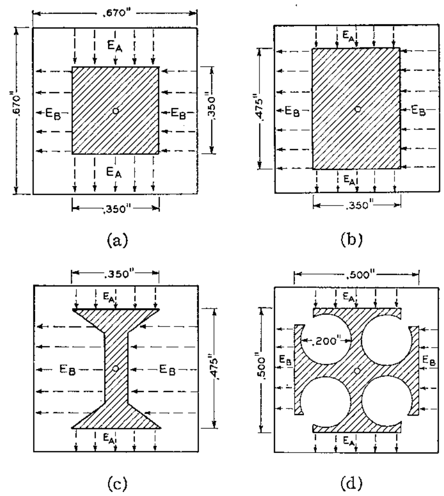
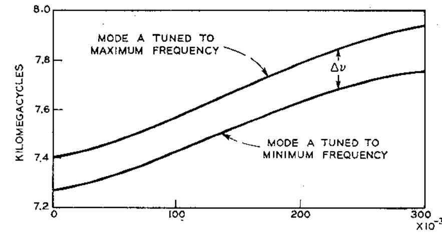
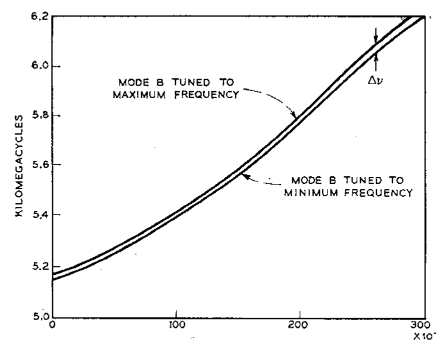


Fig. 2—Plan views of cavity with each loading block in place. E_A and E_B indicate the direction of electric field for modes A and B. Third dimension of all blocks in 0.280 inch.



(a) Displacement of mode B tuning plungers in inches.



(b) Displacement of mode A tuning plungers in inches.

Fig. 3—Tuning curves for each cavity mode when loaded with rectangular block [Fig. 2(b)]. Tuning plunger displacements are measured from the central position (*i.e.*, the position in which the plunger occupies the space between the loading block and the side wall). The two curves shown in each case correspond to the two extreme tuning settings in the remaining mode. Δv is a measure of the independence of tuning.

TABLE I*

Type	High End	Δv	Low End	Δv	Tuning Range
Square Block Modes A and B	7700 Mc	50 Mc	7075 Mc	40 Mc	625 Mc
Rectangular Block Mode A Mode B	 6220 Mc 7940 Mc	 25 Mc 190 Mc	 5150 Mc 7265 Mc	 20 Mc 135 Mc	 1070 Mc 675 Mc
I Block Mode A Mode B	 5280 Mc 9150 Mc	 25 Mc 305 Mc	 4400 Mc 8500 Mc	 2 Mc 255 Mc	 880 Mc 650 Mc
Block of Fig. 2(d) Modes A and B	4950 Mc	30 Mc	3850 Mc	50 Mc	1100 Mc

* Δv is a measure of independence of tuning. It is the change in frequency of one mode when the tuning control for the other mode is taken from one extreme end to the other. See Fig. 3.

Unloaded Q of Single Crystal Yttrium-Iron-Garnet Resonator as a Function of Frequency*

The practical feasibility of constructing magnetically tunable broad-tuning range microwave filters using single crystal yttrium-iron-garnet resonators was demonstrated in a recent paper.[1] Experimental results were presented on one- and two-resonator filters which can be tuned by varying a dc magnetic field bias over a full waveguide bandwidth and greater, at the same time maintaining an insertion loss performance which is comparable to mechanically-tuned cavity filters. The crucial parameter of the resonant elements in a bandpass filter is the unloaded Q, Q_u. With a spherical single crystal of yttrium-iron-garnet the Q_u decreases with frequency below X-band frequencies reaching very low values at frequencies around 2000 Mc.

Analytical formulas for Q_u ($=2\pi\times$frequency$\times$total energy stored/power absorbed at resonance) have been developed.[2] First, formulas given by Lax[3] were used for the effective susceptibility, which relates the RF components of magnetization inside a ferrite to the *external* RF fields. Lax uses the original Landau-Lifshitz formulation of the equations of motion and makes the substitution $\alpha=1/\omega\tau$ for the original damping parameter α, where $\tau=a$ relaxation time, and $\omega=2\pi\times$frequency. By using his susceptibility formula the following expression for Q_u of a sphere was obtained:

$$Q_u = \omega_0\tau/2 \text{ (Lax)}. \quad (1)$$

Recently an analytical formula for the effective susceptibility was developed[4] using the modified form of the Bloch equations of motion of magnetization which were given by Bloembergen.[5] Using this result a new re-

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[5] N. Bloenbergen, "Magnetic resonance in ferrites," Proc. IRE, vol. 44, pp. 1259–1269; October, 1956. Eq. (5) (Bloch-Bloenbergen equations of motion) contains an error. The term $-M_0/\tau$ should be deleted.