Methods for the grinding and polishing of sphere samples

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Three preparation methods for the production of sphere samples 0.5–5 mm in diameter have been refined and improved. The methods are: (1) a rotating horizontal surface technique in which the sample bounces randomly on a rotating surface, (2) a two-pipe lapidary method in which the sample is held between two pipes during grinding, and (3) a cage-held sample polishing procedure in which the sample is contained in a plastic cage while two oppositely rotating horizontal surfaces make contact with the exposed sample surface. The basic methods are described and the current improvements presented.

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INTRODUCTION

In the past, a number of methods have been used for the preparation of spherical samples.[1–18] These have generally been in four categories: (1) those involving a rotating horizontal surface,[1,5,8,10] (2) those involving the circular motion of samples driven by an air jet,[1–4,9,11–13,15] (3) those involving a two-pipe lapidary arrangement,[3,6,7,14,17] and (4) those involving two oppositely rotating horizontal surfaces.[18] Several other approaches utilize spark cutting for roughing out[14,16] and electropolishing.[14]

The important techniques and modifications are summarized in Table I. In general, the circular track/air jet method (2), the rotating horizontal surface method (1), and the two oppositely rotating horizontal surface method (4) are in common use for ferrite materials and some metals. The lapidary method (3) is quite suitable for metals, but is tedious and requires painstaking attention to obtain very good sphericity.

Three specific methods are currently in use in the magnetics laboratory of Colorado State University, a rotating horizontal surface method and a two-pipe lapidary method for sphere grinding, and a cage-held polishing method for narrow linewidth ferrite sphere production. The purpose of this paper is to describe these methods and recent refinements.

I. ROTATING HORIZONTAL SURFACE METHOD

The rotating disk apparatus is used for the rough rounding of alloy spheres for raw cubes and also for the preparation of ferrite spheres. It follows the approach of Carter *et al.*[5] The sample is placed inside a tube which is secured vertically above the surface of a rotating abrasive disk. Grinding occurs as the sample bounces up and down.

The apparatus in use at Colorado State University, shown in the schematic cross-section view of Fig. 1, utilizes small brass tubes secured vertically just above the surface of the rotating disk. The disks are cut from plastic and are faced with abrasive papers of different grits. These disks are secured to one of several motor-driven aluminum turntables and become the grinding surfaces. Each of the turntables is enclosed by a plexiglas safety cage with an opening at the top to receive up to four brass sample tubes. In practical operation, such small samples often "escape" during the final stages of grinding, especially when below about 1 mm diam. The safety cage scheme provides a margin of safety against the loss of such samples. The sample tubes are supported on a hinged plate for easy removal or adjustment.

This system has been used to make ferrite samples, spherical to better than 1%, down to 0.5 mm in diameter. It also can be used for the rough rounding of metal cubes, which are then ground to a spherical shape by the two-pipe lapidary method of the next section. When using the rotating horizontal surface method for metals, the process can be hurried by placing a small lucite rod somewhat smaller than the inner diameter of the tube, in the grinding tube. This increases the bounce rate and hence the grinding rate.

II. TWO-PIPE LAPIDARY METHOD

The two-pipe lapidary apparatus is built around a small hobby lathe mainframe, as shown in Fig. 2. It consists of two pipes, one rotated by the lathe head and the other held stationary by the tail stock. Two rubber rimmed wheels periodically rotate the sample about a horizontal axis perpendicular to the lathe rotation axis in order to obtain a uniform grinding action. The lower wheel also provides a continuous supply of oil suspended grinding compound from a plastic boat. During its motion, the wheel alternately dips into the boat, picks up the grinding fluid, and feeds fluid to the grinding area. The basic design follows a system in use at the University of Tokyo for many years.[17]

The specific grinding actions are as follows: A rough rounded sample is held loosely between the pipes. As the wheels grasp the sample it rotates by some amount normal to the rotation axis of the lathe drive. Subsequent to this rotation, the wheels move away from the

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TABLE I. Summary of reports in the scientific literature on sphere grinding techniques.

Date	Author(s)	Ref.	Technique
			Method
1951	Bond	1	1: Motor-driven disk below an abrasive line stationary hollow cylinder.
			2: Air-driven sample in circular track lined with abrasive.
1953	Senio and Tucker	2	2-1: Air-driven sample in circular track made from abrasive wheel.
1954	Bond	3	2-2: Air-driven sample in abrasive coated cylinder.
			3: Two-pipe lapidary method, manual manipulation, and application of abrasive.
1955	Reggia and Stadler	4	2-3: Air-driven sample in circular track made from silicon carbide wheels.
1959	Carter *et al.*	5	1-1: Motor-driven disk below a vertical stationary tube.
1959	Durand	6	3-1: Two-pipe lapidary, using sequentially smaller hollow pipes.
1961	Cross	7	3-2: Two-pipe lapidary, both pipes rotate. Sample rotated also by rubber wheel.
1962	Heintzelman *et al.*	8	1-2: Motor-driven phenolic anvil rotating inside a weighted cup.
1964	Belson	9	2-4: Air-driven sample in circular tunnel track made from an abrasive epoxy.
1965	Lam	10	1-3: Motor-driven tufnol anvil a rod-in-sleeve top plate.
1965	Schuyff and Hulscher	11	2-5: Air-driven sample, circular tunnel track.
1967	Brown *et al.*	12	2-6: Air-driven sample, circular track, removable abrasive ring/plate inserts.
1967	Laughon and Anthony	13	2-7: Air-driven sample, abrasive plastic resin circular track.
1969	Gray and Spedding	14	3-3: Two-pipe lapidary method for final rounding.
			4: Spark cutting for rough cutting.
			5: Electropolishing for final stain removal.
1970	Crandal	15	2-8: Air-driven sample in tunnel track with viewing window.
1971	Kaul	16	4-1: Modified spark-cutting method.
1977	S. Chikazumi	17	3-4: Two-pipe lapidary method.
1979	W. Tolksdorf	18	6: Cage-held polishing method.

sample, the lower wheel dips into the plastic boat, and grinding fluid is picked up for transfer to the grinding region. The tail stock is adjusted so that the sample has a small amount of play between the two pipes. If the

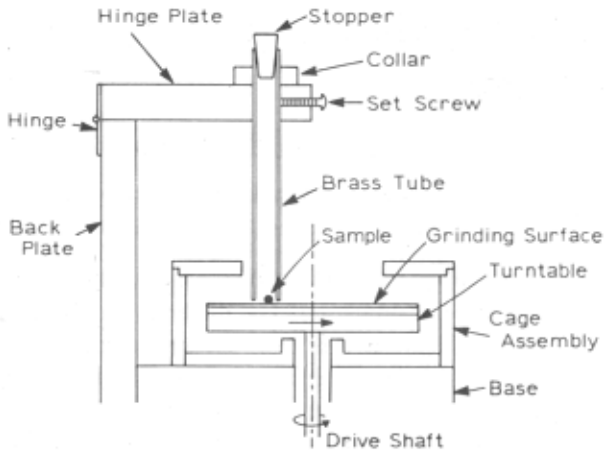

FIG. 1. Diagram of rotating horizontal surface sphere grinding system at Colorado State University.

adjustment is too tight, the metal sphere can be scored by the pipes. If it is too loose, no grinding will occur and the sample will fall into the boat (or elsewhere!). From experience, the pipe diameter should be about the same as the sphere size desired and the pipes should be drilled out about half that size. Soft metals such as copper are suitable pipe materials.

The cam drive arrangement for the wheels is shown in Fig. 3. It consists of a gear box which is used to drive the rubber rimmed wheels at some speed, while driving the cam at a lower speed. The cam serves to push the wheels away from the sample during part of the cycle, which is facilitated by the U-joints on the wheel drive rods. Small sleeves are placed on the drive rods over the cam contact area to facilitate replacement after wear becomes excessive. A mechanical variable gear reducer is fitted between the lathe motor and the cam/wheel drive box so that relative rotation speeds can be easily adjusted for optimum grinding. In actual practice, metal spheres can be produced with high sphericity (better than 0.1%) and good surface polish with a minimum of effort. Typical grinding times range from two to four hours after the initial rounding. Operator attention is required every 15–30 minutes to readjust the tail stock position or change to a finer grinding compound.

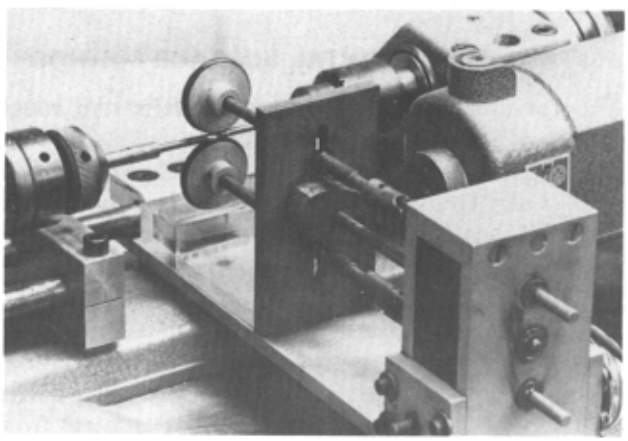

FIG. 2. Close up of drive wheel and cam gearing arrangement for the lapidary grinder.

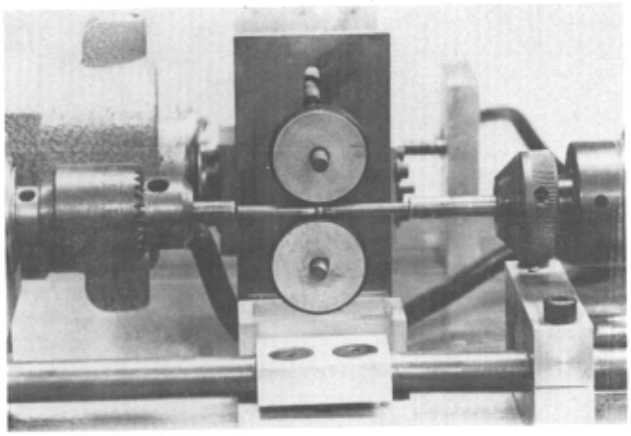

FIG. 3. Close up of the pipe, drive wheel, and boat arrangement for the lapidary grinder.

III. CAGE-HELD POLISHING METHOD

Following the sphere grinding operation for ferrites a polishing operation is sometimes needed. Various polishing procedures are described in the literature. One of the best for the production of ferrite spheres on a small scale appears to be the "cage-held" method in use at Philips Research Laboratories, Hamburg. A similar setup has been put into operation at Colorado State University. The apparatus is used to produce polished spheres for microwave resonance studies.

The basic cage-held polishing method is indicated in Fig. 4. The "cage" consists of a thin ribbon of PVC or teflon which is sandwiched between two rotating disks as shown. The spherical sample is placed in a hole drilled in the ribbon and polishing action occurs as this "cage-held" sample is massaged by the polishing surfaces of the rotating disks.

A cross-sectional detail of the sample, cage, and polishing surface configuration is shown in Fig. 5. The ribbon thickness is generally selected to be about 20% smaller than the sample diameter. The cage diameter is made about 20% larger. The lower surface of the upper disk and the upper surface of the lower disk are faced with thin sheets of nonwoven material[19] as used for lens polishing. A water paste of 0.3 μm aluminum oxide powder, when applied sparingly to these surfaces, serves as the polishing agent.

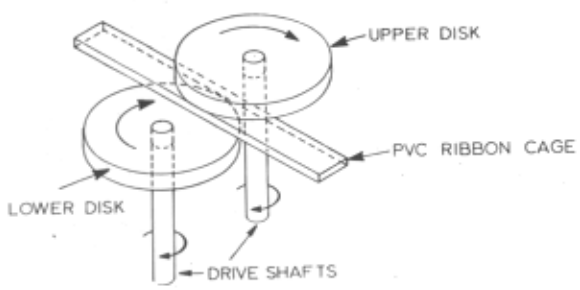

FIG. 4. Diagram of cage-held polisher.

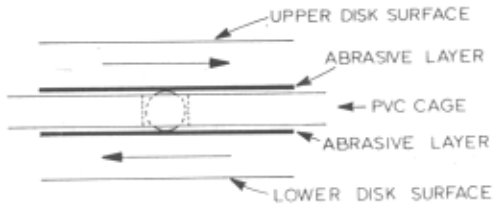

FIG. 5. Diagram of PVC cage and sample during the polishing operation.

The actual mechanical design provides for the secure positioning of the PVC ribbon between the disks. The upper disk is free to move up and down on its drive shaft, so that the pressure on the sample is simply due to the weight of the upper disk. The optimum rotation speed for the 10 cm diam disks is about 5–10 rpm.

The polishing operation takes about eight hours. No quantitative surface roughness measurements have been made, but ferromagnetic resonance linewidth values below 0.5 Oe for single crystal YIG (yttrium iron garnet) spheres at 10 GHz are suggestive of the surface roughness in the tenth-micron range.

ACKNOWLEDGMENTS

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