U. S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

RESEARCH PAPER RP866

Part of Journal of Research of the National Bureau of Standards, Volume 16, February 1936

MESLE'S CHORD METHOD FOR MEASURING THE THICKNESS OF METAL COATINGS

By William Blum and Abner Brenner

ABSTRACT

This study was made to improve methods for measuring the thickness of an electroplated coating at any specified part of the surface. The "chord" method depends upon just cutting through the coating on a plane surface, with a grinding wheel of known radius, or on a curved surface, with a fine file. In either case the thickness T can be computed from C, the width of the cut, that is, the chord, and R, the radius of the wheel or curved surface, by the equation

$$T=\frac{C^2}{8R}.$$

Tests on coatings of known thickness showed that the results are accurate within about 10 percent for coatings at least 0.0002 in. (0.005 mm) thick. This accuracy compares favorably with the results obtained by measuring metallographic cross sections, a method that is more laborious and time-consuming than the chord method.

CONTENTS

I. INTRODUCTION

Specifications for electroplated coatings that were recently adopted by the American Society for Testing Materials and the American Electroplaters' Society include requirements for the minimum, rather than the average, thickness of the deposits. The successful application of such specifications demands simple, reliable methods for measuring the thickness of the coating at any given part of the article. Recently published dropping tests[1] are valuable for zinc and cadmium coatings. For deposits of nickel, copper, silver, and chromium, microscopic measurements of cross sections are usually employed. These require considerable time of skilled operators.

In a recent article by F. C. Mesle[2] entitled Standard Quality for Plated Tableware, there was described an ingenious method for

[1] R. O. Hull and P. W. C. Strausser, Monthly Rev. Am. Electroplaters' Soc. 22 (March 1935).
[2] Metal Ind. (N. Y.) 33, 283 (1935).

measuring the thickness of deposits. He urged "further study and refinement for greater convenience and accuracy." The purpose of this paper is to explain more fully the principles and calculations involved, and to describe typical procedures for applying this method to miscellaneous articles and coatings. As the results obtained indicate that under favorable conditions an accuracy of about 10 percent is usually obtainable, the method warrants thorough trial to determine whether it should be incorporated into formal specifications.

II. PRINCIPLES AND CALCULATIONS

The principle of the method is illustrated in figure 1. If a grinding wheel of radius *R* just cuts through a plated coating of thickness *T*

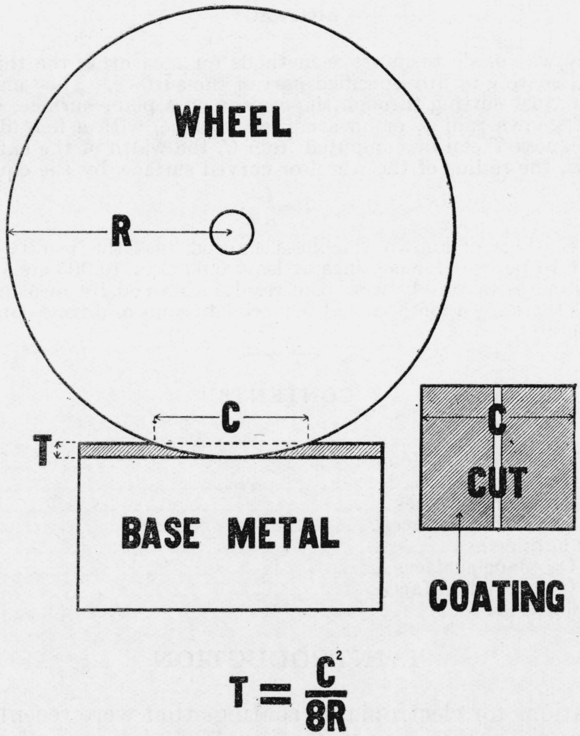

FIGURE 1.—*Testing a coating on a plane surface with a grinding wheel.*

on a flat surface, the width *C* of the cut is determined by the thickness, which can therefore be computed from *R* and *C*. Exactly the same relations exist if, as in figure 2, the coating on a curved surface of radius *R* is just cut through with a flat file. In either case the only dimensions required to calculate the thickness *T* (which is equal to the "sagitta" of the arc) are *R*, the radius of the wheel or plated surface, and *C*, the "chord", that is, the width of the cut.

Simple geometric calculations show that for both cases (figs. 1 and 2) the following equation must be used to calculate the thickness very accurately:

$$T = R - \tfrac{1}{2}\sqrt{4R^2 - C^2}. \tag{1}$$

Suppose the radius of a plated tube is 2 in., and the width of the cut produced with a file is 0.2 in., that is, $R=2$ and $C=0.2$. Then

$$T = 2 - \tfrac{1}{2}\sqrt{4\times 2^2 - (0.2)^2} = 0.002\ 501\ 6 \text{ in.}$$

Calculations by eq 1 are very laborious, since seven-place logarithms must be used to obtain fair accuracy in the fourth decimal place. Fortunately the calculation can be much simplified for those cases in

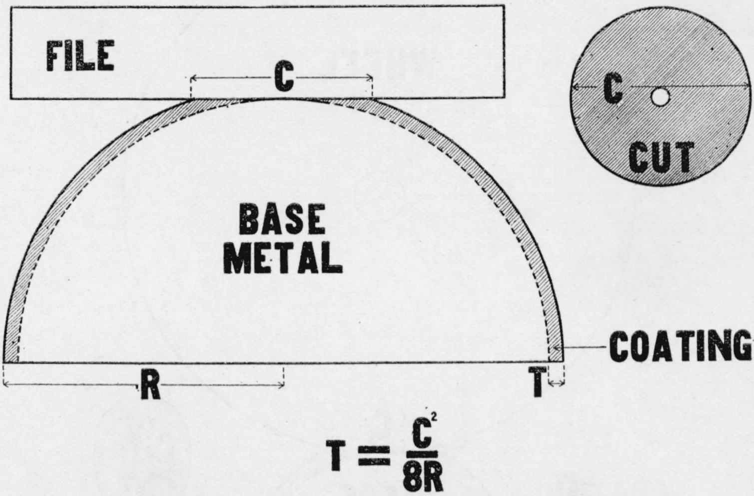

FIGURE 2.—*Testing a coating on a spherical surface with a file.*

which the thickness is small compared to the radius, which cases include almost all plated coatings (except on wires). The above exact equation can be expanded into a series, of which only the first term is necessary for moderate accuracy under the conditions specified. The simplified equation is

$$T = \frac{C^2}{8R}. \tag{2}$$

If the above problem is solved by this equation, we have

$$T = \frac{(0.2)^2}{8\times 2} = 0.0025 \text{ in.,}$$

which differs by less than one part in 1,000 from the exact value. For the number of significant figures usually justified, this result is identical with the value computed from the more exact equation.

It is evident that this is a mechanical method of magnifying the thickness, in contrast to the optical methods, which employ a microscope. In the example cited, the effective magnification is

$$\frac{0.2}{0.0025}=80.$$

From eq 2 it may be shown that the degree of magnification, that is, $\frac{C}{T}$, is equal to $\sqrt{\frac{8R}{T}}$. Therefore, the magnification for a given thickness is

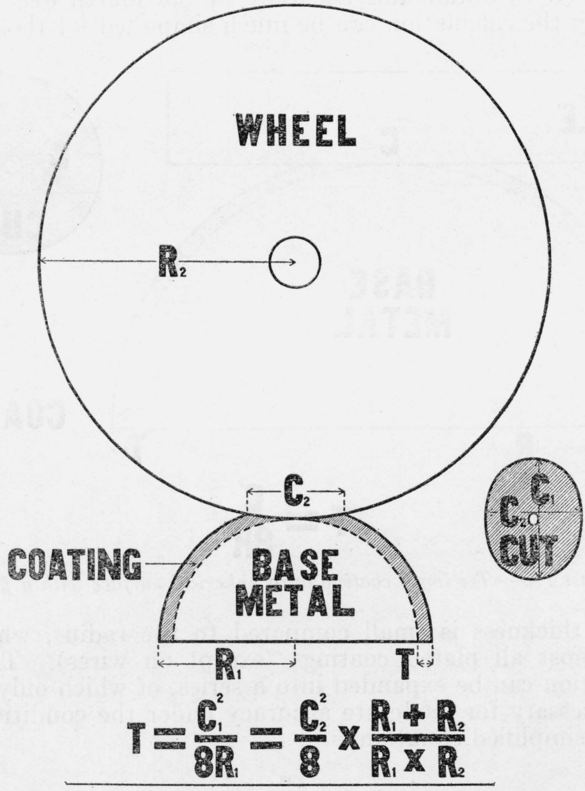

FIGURE 3.—*Testing a coating on a sphere with a wheel.*

increased (but not proportionally) by enlarging the diameter of the wheel; and for a given size of wheel the magnification increases as the thickness of coating decreases. In testing flat surfaces, the grinding wheel should therefore be the largest that will run very true on the machine used. On curved surfaces the effective magnification for a given thickness is fixed by the radius of curvature.

Equation 2 indicates the precision in the thickness measurement that will result from a given precision in measuring C and R. As the thickness varies as C^2, any error in measuring C will produce about twice that relative error in the calculated thickness. For practical measurements, where an accuracy of $\pm$ 10 percent is usually desired, the width should therefore be measured with a precision of at least 5 percent. With the average pocket lens and scale, it is possible to measure a width as small as 0.08 in. (2.0 mm) with this precision on the average plated surface. This width of cut is produced by a wheel with a radius of 4 in. on a coating 0.0002 in. thick. The method is therefore not accurate with much thinner coatings, on which, moreover, the definition of the narrower cuts is less distinct.

Equation 2 shows that an error in measuring the radius of the wheel or plated surface produces about the same percentage error in the calculated thickness. The small changes in the radius of the wheel that occur during its moderate use are therefore not significant, but the wheel should be measured often enough to know its radius within about 2 percent.

When a curved surface has a radius of more than 1 in., a grinding wheel produces a more sharply defined cut than a file. Figure 3 shows an arrangement for applying a wheel to a coating on a convex spherical surface.[3] The object is moved back and forth under the wheel in a direction parallel to the wheel axis, while the wheel is lowered with the micrometer-feed in increments of about 0.0002 in. The cut thus produced is shown in figure 3. If the width of cut C_1 is measured parallel to the wheel axis, the result is the same as if a file had been used, and eq 2 is employed. If, however, the width of the cut C_2 is measured perpendicular to the wheel axis, the radii of both the wheel R_2 and of the curved surface R_1 enter into the calculation, in accordance with eq 3, as follows:

$$T=\frac{C_2^2}{8}\left(\frac{R_1+R_2}{R_1\times R_2}\right). \tag{3}$$

If, for example, the width of cut was 0.10 in., when a surface with a radius R_1, of 1 in. was tested with a wheel having a radius R_2, of 4 in., then

$$T=\frac{(0.10)^2}{8}\left(\frac{1+4}{1\times 4}\right)=0.0016 \text{ in.}$$

For testing a cylinder, the arrangement shown in figure 4 may be used, with the axis of the wheel perpendicular to the axis of the cylinder. The cut is made in the way described for figure 3, and has the section shown in figure 4. If the width is measured in direction C_1, the result is the same as with a file, and eq 2 is used, with R_1, that is, the radius of the cylinder. If the cut is measured in direction C_2, the result is the same as if the wheel had cut a plane surface. Equation 2 is again used, but with R_2, that is, the radius of the grinding wheel.

One objection that might be raised to the chord method is that it is necessary to expose an appreciable area of the base metal to detect it with certainty. This difficulty is entirely eliminated if, as is recommended, the width is measured at the point where the base metal is just exposed. Practically, however, the error made by disregarding a

[3] It is possible to apply the chord method to a coating on a *concave* surface by cutting into it with a grinding wheel with a radius *smaller* than that of the curved surface. The equation then becomes

$$T=\frac{C^2}{8}\left(\frac{R_1-R_2}{R_1\times R_2}\right).$$

As this method is difficult to apply in practice, and as the thickness on concave surfaces is not usually important no actual measurements were made to test this method.

very small width of exposed base metal is usually negligible. Suppose, for example, that in making a flat circular cut on a sphere (fig. 2) the width C_2 of the exposed base metal is 10 percent of the width C_1 of the entire cut. The true thickness may then be computed from eq 4, as follows:

$$T=\frac{C_1^2}{8R}-\frac{C_2^2}{8R}. \tag{4}$$

If C_2 is only 10 percent of C_1, C_2^2 is only 1 percent of C_1^2; that is, an error of only 1 percent is made by disregarding an exposed width of 10 per-

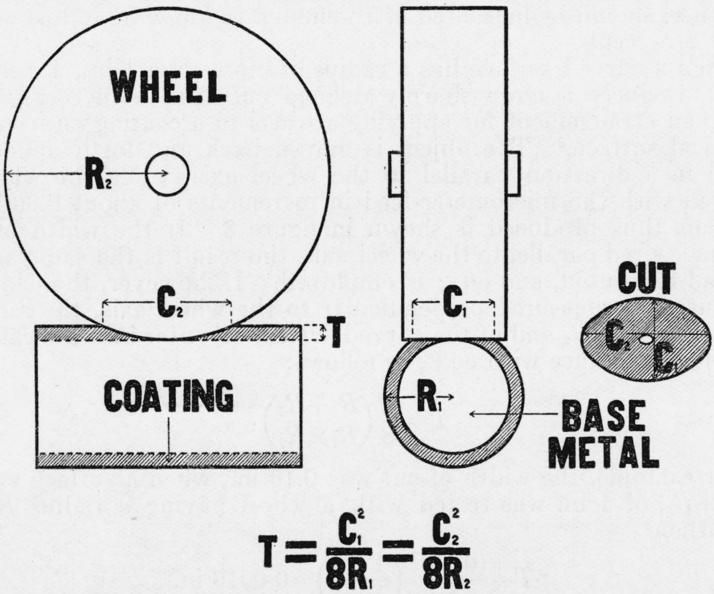

FIGURE 4.—*Testing a coating on a cylinder with a wheel.*

cent. It should be noted that it is not permissible merely to subtract C_2 from C_1, which would be equivalent to using the following *incorrect* eq 5:

$$T=\frac{(C_1-C_2)^2}{8R}, \tag{5}$$

which, in the above example, would produce an error of about 20 percent.

III. METHODS OF APPLICATION

1. TO PLANE SURFACES

For testing the coatings on nearly flat surfaces, a precision surface grinder with a magnetic chuck is convenient. A 6- or 8-inch grinding wheel, (R=3 or 4 in.), with a face 0.15 to 0.5 in. wide, is usually satisfactory. The wheel radius should be measured within about 2 percent. The wheel must revolve rapidly, about 3,000 rpm, which for an 8-inch wheel, corresponds to a peripheral speed of about 6,000 ft/min. The surface of the wheel should be dressed at intervals with a diamond to keep it cylindrical. Precise feed of the wheel is necessary to make sharp cuts. It is essential that the specimen be held very rigidly. Steel pieces can usually be held directly on the magnetic chuck. Nonferrous metals may sometimes be held on this chuck with steel strips, otherwise mechanical clamps must be used.

If the wheel is brought down so that it just cuts the plane surface, and the latter is moved parallel to the wheel axis, a cut with parallel edges (fig. 5 (A)) will be produced.[4] If this cut does not expose the base metal, the wheel is lowered slightly, for example 0.0002 in., and a deeper cut is made, and so on until the base metal is just exposed (fig. 5 (B)). The width *C* of the last cut is then measured.

There are two practical difficulties in applying this procedure. It involves making repeated cuts, and it is difficult to just expose the base metal. Moreover, most commercially flat surfaces are not

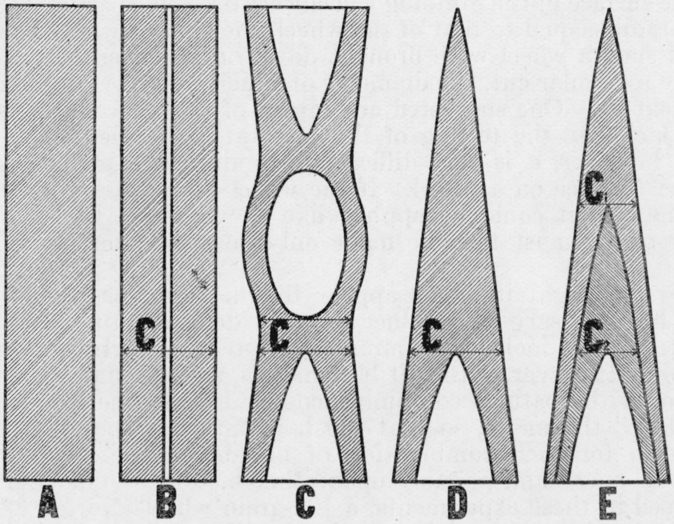

FIGURE 5.—*Appearance of typical cuts with a wheel on a flat surface.*

A. Parallel cut that has not exposed the base metal.
B. Parallel cut with slight exposure of base metal.
C. Cut produced on a surface that is not quite plane, exposing base metal at invervals. The thickness *T* can be computed from the chord with C, wherever the base is just exposed.
D. Tapered cut produced by slightly inclining the plate.
E. Tapered cut on plate with a composite coating. The thickness of each coating may be computed from the chord width where the next lower layer is just exposed.

exactly plane, and in practice the cut is likely to resemble figure 5 (C), on which the base metal is exposed for only part of the length. This behavior suggested a simple modification that is useful on more nearly flat surfaces. The surface is tilted slightly, for example, by putting a sheet of paper under one edge of the magnetic chuck. The cut (fig. 5 (D)) then tapers, and it is easy to note where the base metal is just exposed, and to measure the width *C* at that point. The thickness is then calculated by eq 2. With multiple coatings (fig. 5 (E) and 6) the thickness of each layer is computed from the

[4] By careful use of the micrometer-feed on the surface grinder, the thickness of the coating can be measured directly, but usually with a precision of not greater than 0.0002 in. As this represents an error of 20 percent in coatings 0.001 in. thick, the method is not reliable for any thinner coatings. To make such a direct measurement, the gage on the micrometer-feed is read when the wheel touches the surface of the coating and again when the coating is just cut through. The difference is the thickness of the coating.

41375—36——7

width of cut (C_1 or C_2), where the next lower layer is just exposed. If the surface, for example, on cast plates, is wavy and a cut like figure 5 (C) is produced, it is unnecessary to tilt the plate, as the width C can be measured wherever the base metal is just exposed.

If a perfectly flat plate be slightly tilted so as to produce a cut like figure (D) it is possible to calculate the thickness from the *length* of the cut up to the point where the base metal is just exposed, provided that the angle of tilt is known exactly. This method can be used to yield a very high magnification, and has been occasionally employed in the examination of coatings. Actually, however, the surface is never exactly plane, and it is practically impossible to measure with even moderate accuracy a very small angle, such as one with a tangent of 0.001.

If the surface of the grinding wheel were dressed so as to be convex, with a radius equal to that of the wheel, the surface would be spherical. If such a wheel were brought down on a flat surface, it would produce a circular cut, the diameter of which would serve to measure the thickness. One suggested advantage of this procedure is that it would facilitate the testing of thickness at a specified spot. Practically, however, it is very difficult to produce and maintain a true spherical surface on a wheel. If the wheel were dressed convex but not spherical, it could be applied like a cylindrical wheel, but the measurements must then be made only perpendicular to the wheel axis.

At first thought it might appear that a very fine-grained wheel would be necessary to produce sharply defined cuts. With hard metals, such as nickel, chromium, and steel, a fairly fine grain is desirable. However, with soft base metals, such as zinc, copper, and brass, or with coatings containing copper layers, fine wheels fill up and "drag" the metal, so that the boundaries are not sharp. The best grain for each combination of metals will depend upon the peripheral speed and possibly upon other factors. Under the conditions used in these experiments, a 120-grain wheel (Norton 38120 J) was found to be most satisfactory for the hard metals, and a 90-grain (Norton 3890 H) for soft base metals.

No high magnification is required or warranted for measuring the widths of the cuts, as, with high enlargement, the edges are very irregular. A pocket lens with a magnification of about 12 diameters, and a thin steel scale graduated to 0.01 in., are usually adequate for a precision of 5 percent. The combination of lens and metric scale (fig. 7) that is commonly used for measuring Brinell hardness indentations is very convenient.

2. TO CURVED SURFACES

In the method described and used by Mesle for testing the thickness of silver on a spoon, the latter was rubbed on a fine, flat file until the base metal was just exposed. The curvature of the surface at the point tested was determined with a multiple template, and the width of cut was measured with a transparent scale, after which the thickness was calculated as above.

Tests made at this Bureau on spheres and cylinders have shown that the cuts made with a fine file (for example no. 6) are very satisfactory if certain precautions are observed. It is essential that the

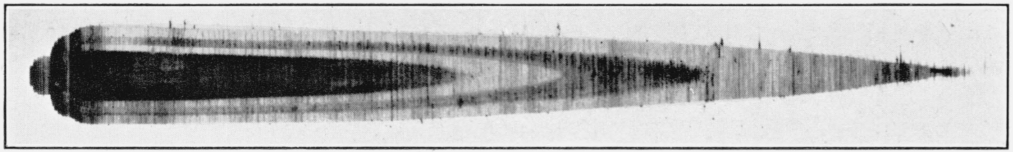

FIGURE 6.—*Cut produced on composite coating of nickel, copper, nickel on steel* (× 2).

Total thickness 0.002 inch. The dark center portion is the exposed steel that has been treated with copper sulphate to produce contrast. The next dark area is the copper layer between two nickel layers.

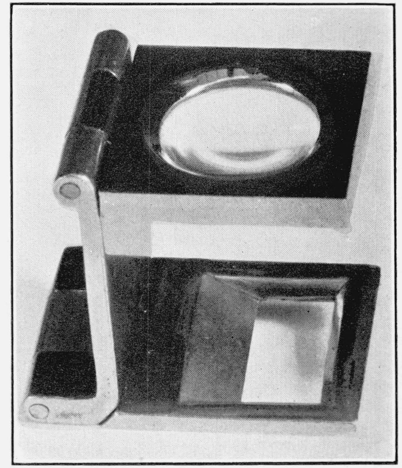

FIGURE 7.—*Pocket lens and scale (usually metric).*

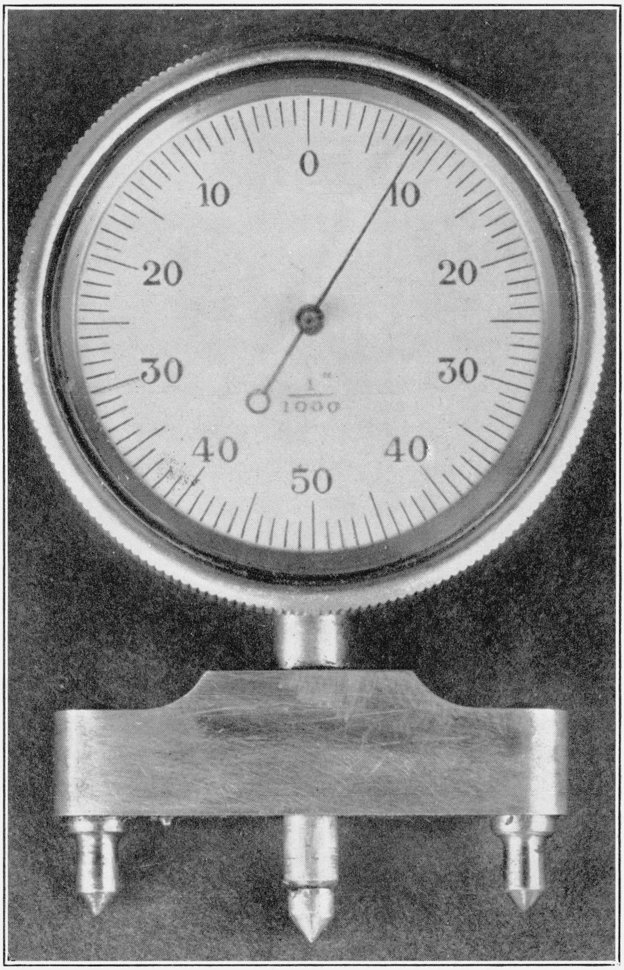

FIGURE 8.—*Typical spherometer for measuring curvatures of surfaces.*

file travel in a plane, that is, it must not "rock" longitudinally, and if measurements are to be made in two directions, it must not rock transversely. Rocking can be prevented by attaching, to the vise which holds the specimen, a steel support that is level with the surface to be tested and is a few inches away. The file rests on this support and the article and is thus kept in a plane. For routine testing of similar articles, a filing machine could probably be adapted to making the cuts.

The curvatures of spherical, cylindrical, or conical surfaces of small radii, for example up to 1.0 in., can be measured with fair accuracy with suitable templates, such as the sets of radius gages that are used in machine shops. Surfaces with larger radii can usually be measured with a "spherometer" [5] (fig. 8), the principle of which is similar to that involved in the chord method. Certain types of spherometer are regularly used for measuring curvatures of optical surfaces, such as spectacle lenses. It is possible to calibrate a spherometer to give a direct reading of the curvature. Otherwise, the radius can be computed from eq 6:

$$R=\frac{C^2}{8T}+\frac{T}{2}, \tag{6}$$

where R is the radius, C the chord, and T the sagitta of the arc measured.

At best it is very difficult to measure a curvature that is not constant over the length of arc covered by the spherometer or gage. In such cases the curvature may be approximated by assigning limits to it.

IV. RESULTS OBTAINED

1. ON PLANE SURFACES

The accuracy of the chord method was determined by comparing its results with the average thicknesses estimated from the total weights of deposit on pieces that were plated with precautions to insure nearly uniform distribution. These included some of the steel specimens prepared for the exposure tests that were conducted jointly by the American Electroplaters' Society, American Society for Testing Materials, and National Bureau of Standards,[6] and of the nonferrous metals now being prepared for new exposure tests. In fact, this method has recently been used as a regular means of testing the thickness and distribution of coatings on the nonferrous specimens. In a few cases the results were also checked by microscopic measurements on cross sections taken adjacent to the points where the chord method was applied.

In the accompanying tables, the term "Set" refers to the corresponding specimens in the exposure tests. Each result for the chord method represents the average of from 10 to 20 measurements on that

[5] It has been suggested that a spherometer or similar dial gage might be used to measure directly the thickness of the coating by noting the difference in reading before and after the coating is filed or ground through. The principle of this method is sound, but its precision is usually less than that of the chord method. This may be illustrated by a typical example. If the curvature of a sphere with a 1-in. radius is measured with a spherometer having the points 1 in. apart, the length of the sagitta (from which the radius is computed) is about 0.135 in., which can readily be measured to ± 2 percent. If the coating is 0.001 in. thick, the corresponding chord is 0.09 in., which can be measured with a lens and scale to ± 5 percent, corresponding to ± 10 percent in the computed thickness. If the latter is measured directly with a spherometer an appreciable error might arise from the difficulty of exactly replacing the points after the cut is made; and an error of 20 percent would be produced by an error of 0.0002 in. in reading the dial.

[6] W. Blum, P. W. C. Strausser, and A. Brenner, J. Research NBS **13**, 331 (1934) RP712.

specimen. The "errors" reported in the tables are the deviations from the values based on the weights of the coatings. As the deposits were never absolutely uniform in thickness, errors of less than 5 percent are probably not significant.

When there was a difference in the color of the coating and the base metal, the line of demarcation was usually distinct. Even with zinc and cadmium on steel, exposure of the steel was easily detected. With nickel on steel it was found most satisfactory to treat the cut surface with a neutral, saturated solution of copper sulphate, which caused deposition of copper on the steel but not on the nickel. With deposits of nickel or chromium on brass or nickel-brass, better contrast was obtained by treating the surface with a solution containing chromic acid and sulphuric acid, or with a solution of ammonium persulphate, both of which etch the base metal.

Measurements by different observers showed that the precision of individual readings of width was usually about 0.004 in. (0.1 mm), that is, from 2 to 4 percent of the usual chord lengths of 0.10 to 0.20 in. (2.5 to 5 mm). This represents an error of 4 to 8 percent in the computed thickness. The average reading error of a number of measurements was considerably less.

With grinding wheels having radii of 3 to 4 in., it was impossible to make clearly marked cuts less than about 0.04 in. (1 mm) wide. This corresponds to a thickness of about 0.000 05 in. (0.001 25 mm), which is therefore the least thickness measurable under these conditions. Practically, the method possesses very little accuracy for coatings less than 0.0002 in. (0.005 mm). It therefore is not applicable to the very thin coatings of chromium (about 0.000 02 in. or 0.0005 mm) that are regularly used for decorative purposes. For such coatings a very small grinding wheel or stone might be used to produce a narrow but well-defined cut, the width of which could be measured with a microscope.

TABLE 1.—*Nickel and composite coatings on steel plates*

[Average thickness]

Experiment	Set	Coating measured	Weight thickness	Microscopic		Chord	
				Thickness	Error	Thickness	Error
			Inch	*Inch*	*Percent*	*Inch*	*Percent*
1	52	Ni	0.000 27			0.000 27	0
2	5	Ni	.000 52	0.000 50	−4	.000 53	+2
3	5	Ni	.000 50			.000 52	+4
4	101	Ni	.001 04			.001 05	+1
5	101	Ni	.001 04			.001 09	+5
6	6	Ni	.001 99			.001 99	0
7	111	Cu+Ni	.001 07			.001 07	0
		Cu	.000 54			.000 51	−6
		Ni	.000 53			.000 54	+2
8	17	Ni+Cu+Ni	.001 04			.001 01	−3
		Ni	.000 19			.000 16	−16
		Cu	.000 30			.000 25	−17
		Ni	.000 55			.000 59	+7
9	16	Ni+Cu+Ni	.001 96	.001 88	−4	.001 91	−3
		Ni	.000 39	.000 38	−3	.000 37	−5
		Cu	.000 58	.000 56	−4	.000 54	−7
		Ni	.000 99	.000 94	−5	.000 99	0
		Average error			−4		±5

Another factor in the accuracy is the smoothness of the coating and of the base metal. Almost all satisfactory commercial plating that has been buffed is sufficiently smooth to yield well-defined cuts. If, however, the base metal is rough, for example from excessive pickling or sandblasting before plating, the definition is poor and the results are unreliable.

The data in table 1 show that the average accuracy for nickel or composite coatings on steel is about ±5 percent, which compares favorably with the accepted metallographic methods. The only errors greater than 10 percent were for the relatively thin layers in composite coatings.

From the contrast between the colors of nickel and of copper or brass, it might be expected that the method would be especially adaptable to nickel coatings on these metals. Actually, however, as shown in table 2, the accuracy was not as high as on other base

TABLE 2.—*Nickel coatings on copper and brass plates*

[Average thickness]

Experiment	Set	Base metal	Weight thickness	Chord	
				Thickness	Error
			Inch	*Inch*	*Percent*
1	C 1	Copper	0.000 19	0.000 22	+16
2	C 1	do	.000 20	.000 19	−5
3	C 2	do	.000 49	.000 54	+10
4	C 2	do	.000 50	.000 50	0
5	B 32	Brass	.000 11	.000 15	+36
6	B 21	do	.000 26	.000 28	+8
7	B 38	do	.000 19	.000 22	+16
8	B 34	do	.000 49	.000 49	0
9	B 34	do	.000 58	.000 56	−4
10	N 5	Ni-brass	.000 21	.000 18	−14
				Average error	±11

metals. The cuts for the experiments in table 2 were made with a 90-grain wheel (Norton 3890H), and the exposed base metals were etched with a mixture of chromic and sulphuric acids. When a 120-grain wheel was used, the results were about 20 percent low. In spite of the fact that zinc-base die castings are softer than brass, the

TABLE 3.—*Nickel coatings on zinc-base die-cast plates*

[Average thickness]

Experiment	Weight thickness	Chord	
		Thickness	Error
	Inch	*Inch*	*Percent*
1	0.000 28	0.000 30	+7
2	.000 47	.000 49	+4
3	.000 89	.000 90	+1
		Average error	±4

results in table 3 for nickel coatings on such alloys were very satisfactory.

The results in tables 4 and 5 show that the method is applicable to coatings of soft metals such as zinc and cadmium on steel. The

TABLE 4.—*Zinc coatings on steel plates*

[Average thickness]

Experiment	Set	Weight thickness	Chord	
			Thickness	Error
		Inch	*Inch*	*Percent*
1	207	0.000 23	0.000 26	+13
2	208	.000 54	.000 56	+4
3	209	.001 07	.001 09	+2
4	215	.001 04	.001 12	+8
5	219	.000 87	.000 89	+2
			Average error	±6

TABLE 5.—*Cadmium coatings on steel plates*

[Average thickness]

Experiment	Set	Weight thickness	Chord	
			Thickness	Error
		Inch	*Inch*	*Percent*
1	310	0.000 19	0.000 20	+5
2	302	.000 55	.000 58	+5
3	312	.001 00	.001 03	+3
			Average error	±4

TABLE 6.—*Chromium coatings*

[Average thickness]

Experiment	Set	Base metal	Weight thickness	Chord	
				Thickness	Error
			Inch	*Inch*	*Percent*
1	128	Ni on steel	0.000 06	0.000 06	0
2	154	do	.000 11	.000 08	−27
3	B 24	Brass	.000 23	.000 21	−9
4	N 1	Nickel-brass	.000 22	.000 17	−23
				Average error	±15

accuracy shown in table 6 with a very hard metal (chromium), is fair, even though the coatings were relatively thin. For such thin coatings, microscopic examination is preferable.

2. ON CURVED SURFACES

The data in tables 7 and 8 show that the accuracy on curved articles is fully equal to that on plane surfaces. There was no consistent difference in the results obtained with a file and a wheel, although it was observed that on articles with a radius of 1 in. or more, the definition of the cut was sharper with a wheel than with a file.

The results of measurements in the two directions were very concordant, even though with cylinders the chord measured perpendicular to the wheel axis was much longer than the chord that was parallel to the wheel axis (fig. 4).

TABLE 7.—*Nickel coatings on brass cylinders*

[Average thickness]

Wheel axis perpendicular to cylinder axis:
⊥ indicates cut measured perpendicular to wheel axis.
= indicates cut measured parallel to wheel axis.

Experiment	Radius of cylinder	Method: Device	Method: Measure	Weight thickness	Chord: Thickness	Chord: Error
	Inches			*Inch*	*Inch*	*Percent*
1	2.00	Wheel	⊥	0.000 62	0.000 69	+11
		do	=	.000 62	.000 66	+6
		File		.000 62	.000 72	+16
2	1.00	Wheel	⊥	.000 66	.000 68	−3
		do	=	.000 66	.000 68	−3
		File		.000 66	.000 68	−3
3	0.5	Wheel	⊥	.000 65	.000 58	−11
		do	=	.000 65	.000 56	−14
		File		.000 65	.000 58	−11
4	0.25	Wheel	⊥	.000 64	.000 68	+6
		do	=	.000 64	.000 64	0
		File		.000 64	.000 62	−3
					Average error	±8

TABLE 8.—*Zinc coatings on steel spheres*

[Average thickness]

⊥ indicates cut measured perpendicular to wheel axis.
= indicates cut measured parallel to wheel axis.

Experiment	Radius of sphere	Method: Device	Method: Measure	Weight thickness	Chord: Thickness	Chord: Error
	Inch			*Inch*	*Inch*	*Percent*
1	1	Wheel	⊥	0.001 23	0.001 30	+6
		do	=	.001 23	.001 25	+2
		File		.001 23	.001 35	+9
2	0.5	Wheel	⊥	.001 53	.001 54	+1
		do	=	.001 53	.001 62	+6
		File		.001 53	.001 52	−1
3	0.25	Wheel	⊥	.001 94	.001 64	−15
		do	=	.001 94	.001 68	−13
		File		.001 94	.001 64	−15
4	0.25	File		.002 09	.002 20	+5
					Average error	±7

TABLE 9.—*Silver on the outside of teaspoons*

[Average thickness]

Experiment	Portion tested	Average radius of curvature	Micrometer thickness	Chord	
				Thickness	Error
		Inch	*Inch*	*Inch*	*Percent*
1	Not overlaid	0.70	0.000 95	0.000 78	−18
2	{Overlay	.74	.003 6	.003 6	0
	{Rest of bowl	.63	.001 34	.001 34	0
3	{Overlay	.74	.003 8	.003 5	−8
	{Rest of bowl	.67	.001 21	.001 23	+2
				Average error	±6

The results in table 9 were obtained on nickel-brass teaspoons that had been plated by F. C. Mesle with a separable silver deposit, so that the thickness of the coating adjacent to the file cut could be measured with a micrometer after removing the coating. The average accuracy of ±6 percent is just about equal to that reported by Mesle for similar measurements. One difficulty with spoons is that the radius of curvature varies over the length of the bowl, and it is hard to measure this radius accurately at any given point.

V. CONCLUSIONS

1. The chord method can be applied by cutting through a coating on a plane surface with a grinding wheel of known radius, or on a curved surface with a file or grinding wheel.

2. The thickness of the coating can be computed from the equation

$$T=\frac{C^2}{8R},$$

where T is the thickness, C is the chord, that is, the width of the cut where the base metal is just exposed, and R is the radius of the grinding wheel, or of the curvature of the surface tested.

3. The method is simple and quick, and the results usually agree within about 10 percent with microscopic measurements and with the average thickness computed from the weight of coating. For coatings less than 0.0002 in. (0.005 mm) the method is not very accurate, and the microscopic method is preferable.

4. Although the coating is necessarily damaged in the test, the base metal is penetrated so little that the tested articles can usually be salvaged by stripping, polishing, and replating.

The authors desire to express their appreciation to F. C. Mesle, of the Oneida Community, and to P. W. C. Strausser and C. Kasper, of this Bureau, for assistance and suggestions during this investigation.

WASHINGTON, January 6, 1936.