THE MEASUREMENT OF THE THICKNESS OF ELECTROLYTIC CHROMIUM WITH THE RECORDING INTERFEROMETER

THESIS FOR THE DEGREE OF M. S.

Roger Clark Dawes

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[redacted]

THESIS

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THE MEASUREMENT OF THE THICKNESS OF ELECTROLYTIC CHROMIUM WITH THE RECORDING INTERFEROMETER.

A THESIS

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ROGER CLARK DAWES

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C O N S I D E R A T I O N S

The purpose of this problem was to find, by the use of a very accurate measuring device, the thickness of electrolytic chromium at various points on a block of flat plated steel.

The steel used in this investigation was made as nearly optically flat as possible, to aid in the measurement of the various points. A steel surface is not satisfactory to plate the chromium upon because of the labor involved in obtaining a smooth and highly polished surface. To overcome these objections, the block of steel was plated with alternate plates of copper and nickel. The nickel was made the outer plate. This nickel was very highly polished, as invisible scratches on the nickel show up markedly on the chromium plate. For the conditions of the problem the nickel plate was worked down optically flat. The block was then ready to be plated with the chromium, the thickness of which was measured with the recording interferometer designed by Doctor Chamberlain.

The plunger of the interferometer was let down at a point on the chromium plate. A series of readings were obtained and a mean taken of the number of bands present in the field of view. Then the plunger was raised until it

was possible, by protecting the plunger with a glass plate, to take off the chromium plate with a wad of cotton wetted with hydrochloric acid. After cleaning off the acid thoroughly, the plunger was let down at exactly the same point, and the number of bands in the field of view were observed. The difference represented, when multiplied by the correct factor, the thickness of the chromium plate at the point.

The temperature effect was taken into account, as with such small measurements, this would be large in amount.

The specimen, with the optically flat surface upwards, was placed on the platform # of the interferometer with a firm twisting motion. This was done to exclude as much air as possible between the specimen and the platform. According to the work of Doctor Chamberlain (Phys. Rev. 31, 170 (1910).) the air film would have a constant thickness.

The bath in which the plating was done had parallel sides so as to give a uniform cross-section of the plating bath all the way from the anode to the cathode. Also the specimen was lacquered at all points except where the plate was desired, so as to give no stray eddy currents.

The word platform is used throughout this thesis, to designate the part of the interferometer on which the block was placed to be measured.

I N T R O D U C T I O N

In 1901 W. Pfanhauser, Jr., (Z. Electrochem. 7, 895 (1901).) stated a relation between conductivity, cathode potentials and current distribution. He was the first to make any statement regarding the fundamentals of throwing power. In 1922 the following statements were made in the work of Kurt Arndt and Oskar Clemens (Chem. Ztg. 46, 925 (1922).). It was the first published work on the factors affecting the throwing power of solutions.

"There are two resistances opposing the flow of current, one, the ohmic of the bath and the other, an electrode surface resistance. When the plating begins the tendency is toward more deposition on the parts nearest the anode, but this decreases the ion concentration near those parts and gives rise to a concentration polarization that diminishes the current there. Relatively more current can then flow to those parts farther away from the anode. This viewpoint leads to the conclusion that the throwing power will increase the fewer metal ions there are in solution to begin with and the better the bath conducts; for with increasing conduction the differences in the resistance of the different paths becomes less." Also the throwing power is influenced by the temperature as well as by the agitation of the plating bath. That is to say the higher the temper-

ature or the greater the agitation the less is the throwing power of the given bath.

Horsch and Fuwa (Trans. Am. Electrochem. Soc. 41, 363 (1922).) made a study of the throwing power of four different zinc plating baths, which resulted in the development of a plating bath of high throwing power. Their statements were to the effect, that in order to have a bath of high throwing power, it was necessary to have in solution a large number of conducting ions and to have a relatively small number of free metal ions plated out. To accomplish this, salts which are slightly ionized or form complex ions with the metal ions present are used. In this type of a plating solution, polarization will take place very readily.

In their work the following statement regarding their calculations may be found: "---, simple calculations give, (1) the current efficiency of the three cathode plates as a whole, and (2) the throwing power, expressed in terms of the percentage of the total theoretical weight of zinc deposited on the three plates, which was deposited upon each of the three plates at varying distances from the anode.----."

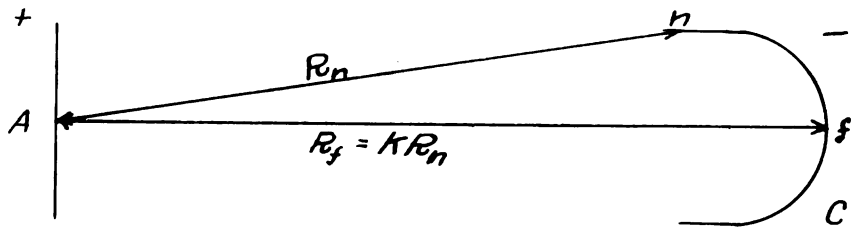


ILLUSTRATION OF THROWING POWER #

A --- Anode C --- Cathode

n --- unit area of the cathode nearest the anode.

f --- unit area of the cathode farthest from the anode.

R_n -- effective resistance through the solution from the anode to n.

R_f -- KR_n -- effective resistance through the solution from the anode to f; where K is any definite numerical factor, such as 2, 5, etc.

I_n -- current density at n.

I_f -- current density at f.

e_n -- cathode single potential at n.

e_f -- cathode single potential at f.

E_n -- potential drop through solution only, from anode to n.

E_f -- potential drop through solution only, from anode to f.

Current Distribution and Throwing Power -Haring and Blum. Trans. Am. Electrochem. Soc. 44, 317 (1923).

The anode and cathode are both good conductors as compared to the bath and we can assume that all points of the anode and cathode are at the same potential.

It is possible to measure directly during the electrolysis the following:

(1) The potential of the anode against the solution, which is conventionally expressed as having the same sign as the potential that must be applied to cause the anode to go into solution. This, of course, includes the static potential and the potential due to polarization.

(2) The potential drop through the solution which is expressed with the sign indicating the flow of a positive current.

(3) The potential of the cathode against the solution, which is equal to the static potential, minus the potential due to polarization.

From the same article as mentioned in the footnote on the preceding page, the following equations were obtained:

During electrolysis the total potential drops between the anode and the two points on the cathode are equal to each other, that is,

$$-e_n + e_a - E_n = e_a - E_f - e_f \qquad (1)$$

If the anode potential e_a is uniform, it may be eliminated and therefore,

$$E_n - e_n = E_f - e_f \qquad (2)$$

but $$E_n = I_n R_n \qquad (3)$$

and $$E_f = I_f R_f = I_f K R_n \qquad (4)$$

$$I_n R_n - e_n = I_f K R_n - e_f \qquad (5)$$

$$\frac{I_n}{I_f} = K - \frac{e_f - e_n}{I_f R_n} \qquad (6)$$

$$\frac{I_n}{I_f} = \frac{K - e_f - e_n}{E_f / K} \qquad (7)$$

$$\frac{I_n}{I_f} = K \left(1 - \frac{e_f - e_n}{E_f}\right) \qquad (8)$$

The metal ratio $$\frac{M_n}{M_f} = \frac{I_n D_n}{I_f D_f} \qquad (9)$$

I_n / I_f is the ratio of the current densities at "n" and "f", and is therefore a measure of the current distribution. As above defined, K is a measure of the primary current distribution.

From equation (8), if the cathode efficiences at "n" and "f" are equal and T is the throwing power,

$$T = 100 \frac{(e_f - e_n)}{E_f} \qquad (10)$$

If however the cathode efficiences at "n" and "f" are not equal, it may be shown that,

$$T = 100 \left(1 - \frac{D_n}{D_f} \left(1 - \frac{e_f - e_n}{E_f}\right)\right) \qquad (11)$$

where D_n / D_f is the ratio of the cathode efficiences at "n" and "f".

Haring (Trans. Am. Electrochem. Soc. 46, 107 (1924) found that the chief factor in throwing power in nickel plating is the cathode efficiency. This is for the most part determined by the ratio of the effective nickel and hydrogen ion concentrations in the cathode film. All conditions which increase this ratio improve the throwing power according to his experiments.

The other works read were more or less of a repitition of the above ideas. Work on throwing power of chromium was carried out at Washington University,- Stout and Carol (Ind. Eng. Chem. 22, 1324 (1930). The results were meaningless as far as this work is concerned.

APPARATUS AND MATERIALS

A steel block obtained from the Reo Motor Car Company was used in this investigation. The block was one-half ($\frac{1}{2}$) inch thick, two (2) inches long and one and one-half ($1\frac{1}{2}$) inches wide. The block was smooth to within one-thousandth (0.001) of an inch, which was not flat enough for this work. The side which was not to be plated was made as smooth as possible, using 240 grinding compound on a metallographic polishing wheel. The side to be measured was polished in the same manner. In addition it was made optically flat by hand polishing. The material used for polishing was levigated alundinum. The block was plated with thirty (30) minutes of nickel and polished very accurately again. Then plated with three (3) minutes of chromium.

In order to measure this very thin coat of chromium it was necessary to have an instrument which was capable of measuring very small variations in thickness. The Chamberlain Recording Interferometer was the only instrument known and available which would meet the requirements of this problem. It was capable, by the setting of the masks in the field of view, to the helium red and blue lines, of measurements to four millionths (0.000004) of an inch. For an

illustration of this instrument refer to Plate 2 of this thesis.

The copper and nickel plates were obtained from plating baths made up, in liter beakers. The eight centimeter measurements were carried out using a plating bath of chromium, made up in a liter beaker and heated over an electric hot plate. However the fourteen and twenty-eight centimeter measurements were carried out in a chromium bath of the same composition, only made up in the glass aquaria as shown in Plate 1. This apparatus was built in the following manner:

A glass aquaria 18" x 11" x 6", (the six inch dimension being the width), was fitted with three plates of glass cut from plate glass found around the laboratory. Two of these glass plates ($16\frac{1}{4}$ x 9) inches were used as sides, and the other ($16\frac{1}{4}$ x $1\frac{3}{4}$) inches was used to form a bottom to the box. The above was done to make a glass box conforming more closely to the block, and not let any eddy current get around the edge of the block.

A lead anode was cut to fit into the end of the box formed by these plates, and was fixed solidly at this point by bending over the end of the aquaria. The block to be plated was wound with one turn of copper wire. This was soldered securely to the block at all points. The block

was suspended from a movable cathode rod, also of copper, which could be moved along the top of the glass box formed by the glass plates mentioned on the preceding page.

A coil of pyrex glass was used to pass steam into the chromium plating bath to heat it to the desired temperature, (between forty and fifty degrees centigrade), The lower temperature being the most satisfactory. The coil was made from five feet of pyrex tubing. The time required to heat the bath from twenty degrees to forty-six degrees centigrade, was about three quarters of an hour.

The capacity of the aquaria, when filled to within about two inches of the top, was about twelve liters.

EXPERIMENTAL PROCEDURE

A block of steel two (2) inches by one and one-half ($1\frac{1}{2}$) inches by one-half ($\frac{1}{2}$) inches was used for most of the experiments. The steps of preparing it for plating and measuring were as follows:

The block of steel was ground flat on the side of a fine emery wheel. Then the piece was polished on a regular metallographic polishing table, using three different grinding compounds, namely; 240, 360 and levigated alundinum. This polishing operation was performed with a great deal of care, to keep the surface flat. Of course with such a large surface to be worked down, the time required to complete the polishing operation was very long.

After obtaining this smooth and flat surface, the block was plated, as will be described a little farther on. A pad of pitch was used in the first few attempts of polishing these plates. The pad was made by taking a pitch of a consistency slightly less rigid than sealing wax and melting it in a sand bath dish. Upon cooling, the pitch was cut into squares having about a centimeter to the edge. The cuts were made deep enough so as to form little pads of pitch which would give slightly upon the block passing over them. This pitch pad made an excellent buffing material, but it required nearly twenty-four hours of polishing move-

ments over the surface in order to give even a fair polish to the plated surface of the block.

Finally a piece of plate glass, flat to within five ten-thousandths (0.0005) of an inch was substituted for the pitch pad,and levigated alundinum was used as the abrasive material. The possibilities are that the work was not as well finished as in the case of the pitch pad, but the time that was saved was very great. The results which were obtained from plates prepared in this manner were entirely satisfactory.

It must be noted here that in all of the polishing operations, the only force acting down upon the piece was the attraction of gravity for the block of steel.

The block was now ready for the first plate. In the early runs the block was cleaned well in a sodium hydroxide (100 grams per liter) electrolytic cleaning bath; washed well in running water, and then immersed in the copper cyanide plating bath where it remained for two minutes, at two amperes per square decimeter and forty-five degrees centigrade. However in the later experiments with this same block, nickel was plated directly on the steel. The cyanide copper was buffed, the plate cleaned once more and about twenty to thirty minutes of acid copper, at one ampere per square decimeter and twenty-one degrees centi-

grade, was put on. The acid copper was buffed to a very highly polished surface, much more easily than the original steel block. After the acid copper plate was all buffed and optically flat, the surface was again cleaned electrolytically and the block immersed in a nickel plating bath. The nickel was plated from a bath running at one-half an ampere per square decimeter and at a temperature of about thirty-five degrees centigrade. Several different nickel baths were used for plating. They were all used at the same current density and temperatures as mentioned above, with fairly consistent results. After the nickel bath was used for some time, trouble was had with pitting. A cubic centimeter or two of hydrogen peroxide was added to each liter of nickel bath, to take care of the excessive gassing at the cathode.

For the composition of the various plating baths used in this work refer to pages 43 to 45 inclusive.

After plating several times with copper and nickel, alternately, the block was ready to have the final chromium plated upon it for measuring. Before the block was placed in any plating bath, a trial was made with another piece of steel, nickel plated, of the same size and shape to be sure that the plating bath was in the best of working order. Previous to these trials, however, many runs were made to determine the best conditions and the

best compositions of plating baths for the various plating operations. It was very essential that all of the factors influencing the plating of chromium be carefully recorded at the time of each plating attempt. From a study of chromium plating the following factors were listed as influencing the plating of chromium; composition of the bath, this factor was more or less constant, as the same bath was used for all trials; the current density used; the distance from the anode to the cathode; length of time of plating and the temperature of the bath. From this data the conclusion could be drawn as to just what the relative order of importance of these factors would be.

After the block was plated with chromium it was placed in a bath of clean, running water for several minutes and then the block was dried with a towel. The specimen was then placed in a dessicator and remained there for at least a half hour or perhaps over night.

As mentioned under the introduction, the instrument used to make these accurate measurements was the "Chamberlain Recording Interferometer". An illustration of this instrument is found on Plate 2. The platform was cleaned free of dust particles, as well as the block and tip of the plunger. The dust was removed with a camel's hair brush. After this removing of dust particles, the block was placed with a twisting motion and using considerable force, upon

the platform. Then the interferometer was slipped down the supporting post until the tip of the plunger just touched the surface of the block. This could be observed by the reflection in the highly polished surface of the block.

When the instrument was in this position and a source pf white light was placed in front of the colimating lens, (the telescopic looking projection at the lower right hand end), a spectra characteristic of white light could be seen by looking through the eye-piece of the telescope at the upper left hand corner of the instrument. At the same time streaks could be noticed running vertically in the field of view. These streaks were caused by dust particles in the slit of the colimating telescope, so we will call them dust lines. The dust lines make possible a very good means of adjusting the interferometer. When the interferometer was in proper adjustment, these dust lines were straight, but when it was out of adjustment, the lines were bent. If the lines were bent, the upper adjusting screw was turned until the lines were straight, which took only a very slight movement of the adjusting screw, sometimes just touching it would change the lines from bent to straight. At this point the interference bands appeared very faintly in the field of view. By turning the other adjusting screw with the same degree of care it was possible to bring the bands out into sharp contrast with the light

back ground.

Upon obtaining these sharp dark bands, the interferometer was prepared for the next adjustment.

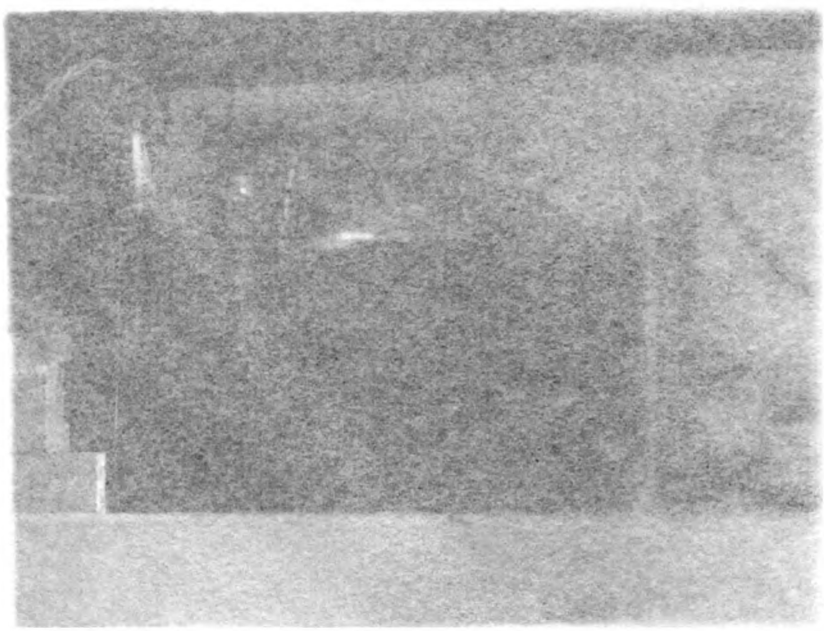
The next adjustment consisted in setting the two masks so as to make the instrument read in even decimals of an inch. With these masks set in this manner the appearance of each new band signified a certain even decimal of an inch change. This also applied if a band vanished from the field of view. For these measurements, the masks were set on the red and blue lines of helium. This was accomplished in the following manner; the helium tube was placed in front of the slit of the collimator. The current for the helium tube was furnished by a transformer connected on one side to the lighting circuit, of one hundred and ten volts, and the other side connecting with a Ford spark coil. Looking into the eye-piece, the spectra of helium was observed, a red line at the top and two blue lines at the bottom were the only lines that were of interest for this adjustment. The upper mask was slipped down until it just began to eclipse the red line. Then the lower mask was slipped up until it just began to eclipse the upper blue line or the brightest blue line. The instrument was then in adjustment for reading to even decimals of an inch.

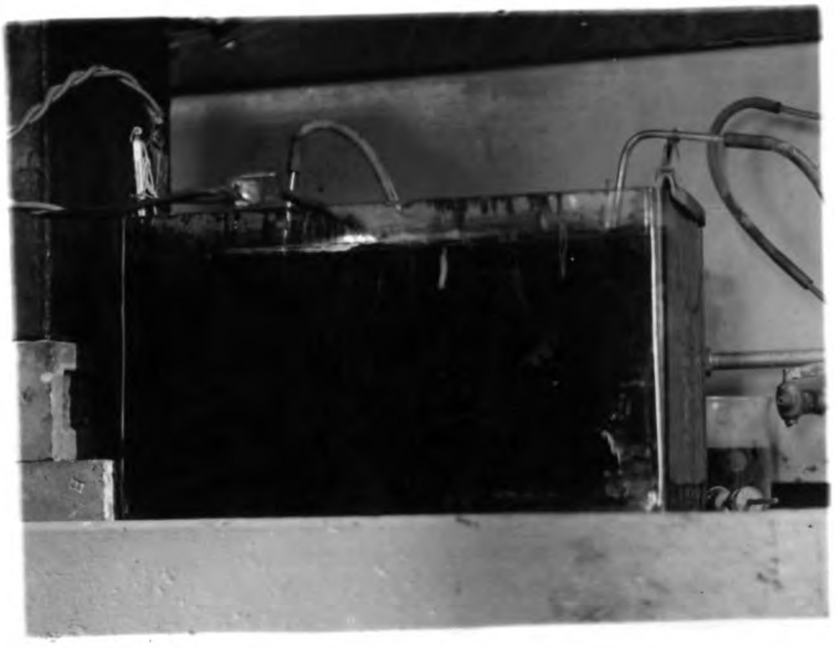
The source of white light was placed again in front of the collimator. Then the plated block was placed under

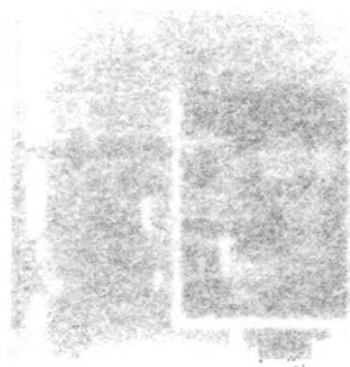
the plunger. The block was placed on the platform in the manner that has been described, so as to make the air film below it as nearly uniform as possible and also to make the block firm, so that constant measurements of the same point could be made. The plunger was let down with a force of sufficient amount, so that a distinct click could be heard. This same force was duplicated in each case that the plunger was let down. Four readings of the number of bands present in the field of view were taken and averaged. Fractions of bands were read to within one tenth of a band.

After the readings were taken at a point on the plate, with the chromium plate still on, the plunger was lifted out of the way by the means of a thin glass plate and the plate was left there to protect the plunger from any acid fumes or spray. Then a thin glass rod, with a small swab of cotton soaked in hydrochloric acid twisted onto it, was inserted between the glass plate and the block thus removing the chromium plate at that point. The block was washed well with water, using a cotton swab and seeing that the block was not disturbed the least bit. Finally the water was dried off with a piece of cotton. Then waiting for at least fifteen minutes, to be sure that the temperature of the block was back to that of the room temperature, the plunger was let down at the exact spot where it had rested before the plate had been removed. The plate

being off, the number of bands in the field of view this time were different. The difference between the average reading before removing the plate and after removing the plate gave, of course, the number of bands representing the thickness of the chromium plate at that point. The difference multiplied by 0.00004, (the number of inches represented by a change of one band in the field of view), gave the thickness of the chromium plate in inches at the point measured. This procedure was followed for the remainder of the points on the block and for each trial.







DATA

Trial	Plate	Amps./dm^2	Time	Temp.	Results
1 - 60	Cu-Ni	.5	30 min.	40^o	Good.
61	Cr-l	16	5 "	49^o	"
62	" "	10	3 "	49.5	"
63	" "	8	3 "	49.5	No good.
64	" "	10	3 "	51	" "
65	" "	9	3 "	50	" "
66	" "	7	3 "	50	" "
67	" "	8	3 "	49.5	" "
68	" "	12	3 "	49.5	Good.
69	" "	12	3 "	49.5	"
70	" "	12	3 "	49.55	"
71	" "	8	3 "	41.0	No good.
72	" "	8	3 "	49.5	" "
73	" "	12	3 "	49.5	" "
74	" "	4	3 "	49.5	" "
75	" "	8	3 "	49.8	" "
76	" "	12	3 "	50.0	" "
77	" "	8	3 "	50.0	Fair.
78	" "	9	3 "	50.0	"
79	" "	8	3 "	51.0	Good.
80	" "	8	3 "	51.0	"
81	" "	10	3 "	51.0	Poor.
82	" "	5	3 "	51.0	No good.

DATA 2

Trial	Plate	Amps./dm^2	Time	Temp.	Results
83	Cr-1	8	3 min.	45.9	Good
84	" "	8	3 "	48.0	"
85	Cu-1	1	25 "	21.0	"
86	Ni-6	.5	30 "	41.0	"
87	Cr-1	16	3 "	46.0	"
88	" "	10	3 "	47.0	No good
89	" "	8	3 "	45.5	" "
90	" "	8	3 "	46.0	" "
91	" "	12	3 "	46.0	" "
92	" "	15	3 "	46.0	" "
93	" "	10	3 "	46.0	" "
94	" "	9	3 "	46.0	" "
95	" "	12	3 "	46.0	" "
96	" "	14	3 "	47.0	" "
97	" "	15	3 "	46.6	Fair
98	" "	15	3 "	46.0	"
99	" "	14	3 "	47.5	"
100	" "	8	3 "	48.8	Good
101	" "	16	3 "	48.6	"

DATA 3 8 cm.

Plating Trial 61. Measurement No. 1.

Before removing plate.

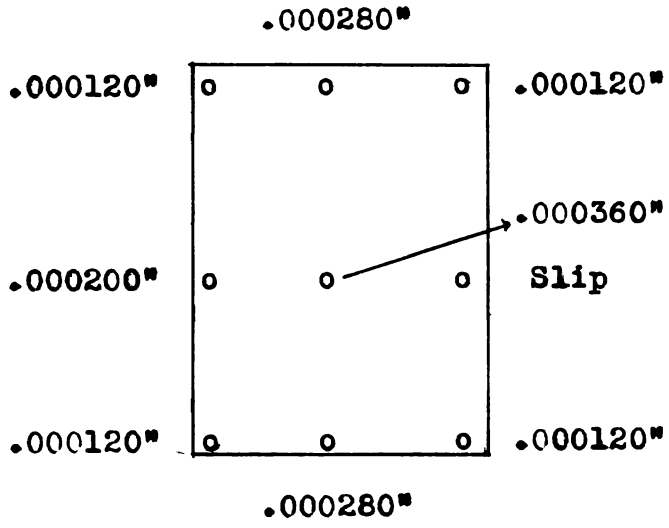
Trial	1	2	3	4	Mean.
Point	Number of bands in view.				
1	43	41	41	41	41
2	36	37	38	37	37
3	36	36	36	36	36
4	59	58	57	58	58
5	49	47	48	48	48
6	-16	-16	-16	-16	-16
7	-7	-7	-7	-7	-7
8	11	10	11	12	11
9	53	53	53	53	53

After removing plate.

Trial	1	2	3	4	Mean	Before Mean	Diff.	Thickness.
Point	Number of bands in view.							
1	38	38	37	38	38	41	3	0.000120"
2	29	31	30	30	30	37	7	0.000280"
3	33	33	33	33	33	36	3	0.000120"
4	Due to slip no data here.							
5	46	44	45	45	45	48	3	0.000120"
6	-23	-23	-23	-23	-23	-16	7	0.000280"
7	-10	-10	-12	-10	-10	-7	3	0.000120"
8	6	5	6	7	6	11	5	0.000200"
9	43	45	44	44	44	53	9	0.000360"

Measurement No. 1

8 cm.



DATA 4 8 cm.

Plating Trial 69. Measurement No. 2.

Before removing plate

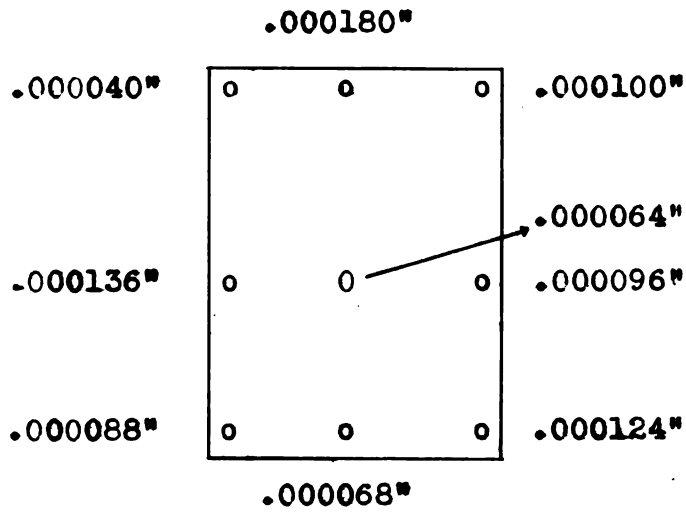
Trial	1	2	3	4	Mean.
Point	Number of bands in view.				
1	70	71	70	70	70
2	-22	-22.5	-22.3	-22.3	-22.3
3	-10.3	-10.3	-10.2	-10.4	-10.3
4	-15.3	-15.6	-15.4	-15.4	-15.4
5	-12.4	-12.4	-12.5	-12.4	-12.4
6	39.2	39.3	39.1	39.2	39.2
7	-15.1	-15.1	-15.2	-15.1	-15.1
8	6.9	7.0	7.1	7.0	7.0
9	-38.5	-38.4	-38.5	-38.5	-38.5

After removing plate

Trial	1	2	3	4	Mean	Before Mean	Diff.	Thickness
Point	Number of bands in view.							
1	69	69	69	69	69	70	1	0.000040"
2	-26.8	-26.7	-26.8	-26.8	-26.8	-22.3	4.5	0.000180"
3	-12.8	-12.7	-12.9	-12.8	-12.8	-10.3	2.5	0.000100"
4	-17.8	-17.8	-17.7	-17.8	-17.8	-15.4	2.4	0.000096"
5	-15.4	-15.4	-15.4	-15.5	-15.5	-12.4	3.1	0.000124"
6	37.5	37.5	37.5	37.4	37.5	39.2	1.7	0.000068"
7	-17.3	-17.3	-17.3	-17.2	-17.3	-15.1	2.2	0.000088"
8	3.6	3.6	3.6	3.5	3.6	7.0	3.4	0.000136"
9	-40.0	-40.1	-40.1	-40.1	-40.1	-38.5	1.6	0.000064"

Measurement No. 2

8 cm.



DATA 5 8 cm.

Plating Trial 70. Measurement No. 3.

Before removing plate

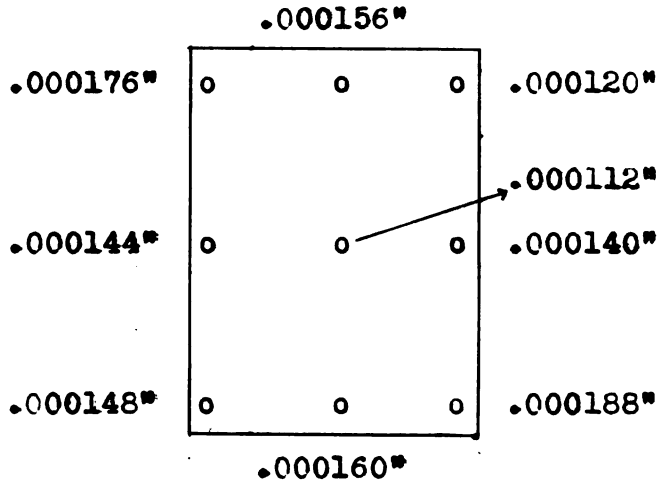
Trial	1	2	3	4	Mean
Point	Number of bands in view.				
1	32.0	32.2	32.1	32.1	32.1
2	-24.4	-24.5	-24.3	-24.4	-24.4
3	21.4	21.3	21.3	21.2	21.3
4	15.9	16.1	16.0	16.0	16.0
5	14.9	14.8	14.9	14.9	14.9
6	-31.3	-31.3	-31.2	-31.3	-31.3
7	31.5	31.5	31.6	31.5	31.5
8	36.3	36.4	36.3	36.2	36.3
9	6.5	6.5	6.5	6.5	6.5

After removing plate

Trial	1	2	3	4	Mean	Before Mean	Diff.	Thickness.
Point	Number of bands in view.							
1	27.7	27.6	27.7	27.7	27.7	32.1	4.4	0.000176"
2	-28.3	-28.3	-28.4	-28.3	-28.3	-24.4	3.9	0.000156"
3	18.3	18.2	18.3	18.3	18.3	21.3	3.0	0.000120"
4	12.5	12.4	12.5	12.5	12.5	16.0	3.5	0.000140"
5	10.2	10.3	10.1	10.2	10.2	14.9	4.7	0.000188"
6	-35.3	-35.4	-35.3	-35.3	-35.3	-31.3	4.0	0.000160"
7	27.8	27.8	27.8	27.8	27.8	31.5	3.7	0.000148"
8	32.7	32.6	32.8	32.7	32.7	36.3	3.6	0.000144"
9	9.3	9.3	9.3	9.2	9.3	6.5	2.8	0.000112"

Measurement No. 3

8 cm.



DATA 6 8 cm.

Plating Trial 78 Measurement No. 4.

Before removing plate

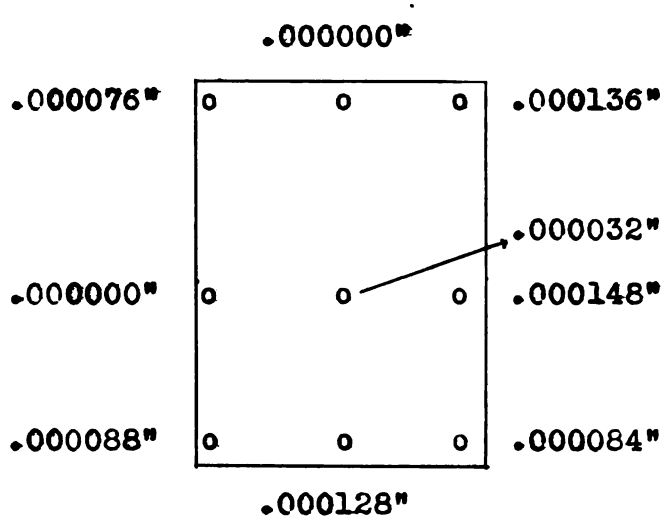
Trial	1	2	3	4	Mean
Point	Number of bands in view.				
1	11.5	11.4	11.5	11.5	11.5
2	No plate at this point.				
3	13.9	14.0	14.1	14.0	14.0
4	9.0	9.1	9.0	9.0	9.0
5	5.3	5.2	5.3	5.4	5.3
6	10.2	10.3	10.2	10.2	10.2
7	3.8	3.9	3.7	3.8	3.8
8	6.7	6.7	6.6	6.7	6.7
9	8.0	8.0	8.1	8.0	8.0

After removing plate

Trial	1	2	3	4	Mean	Before Mean	Diff.	Thickness
Point	Number of bands in view.							
1	9.5	9.7	9.6	9.6	9.6	11.5	1.9	0.000076"
2	No plate at this point							
3	10.6	10.6	10.6	10.5	10.6	14.0	3.4	0.000136"
4	5.3	5.4	5.3	5.3	5.3	9.0	3.7	0.000148"
5	3.2	3.1	3.2	3.2	3.2	5.3	2.1	0.000084"
6	7.0	7.0	6.9	7.0	7.0	10.2	3.2	0.000128"
7	1.6	1.5	1.6	1.6	1.6	3.8	2.2	0.000088"
8	6.7	6.6	6.7	6.8	6.7	6.7	0.0	0.000000"
9	7.2	7.2	7.2	7.2	7.2	8.0	0.8	0.000032"

Measurement No. 4

8 cm.



DATA 7 14 cm.

Plating Trial 79 Measurement No. 5

Before removing plate

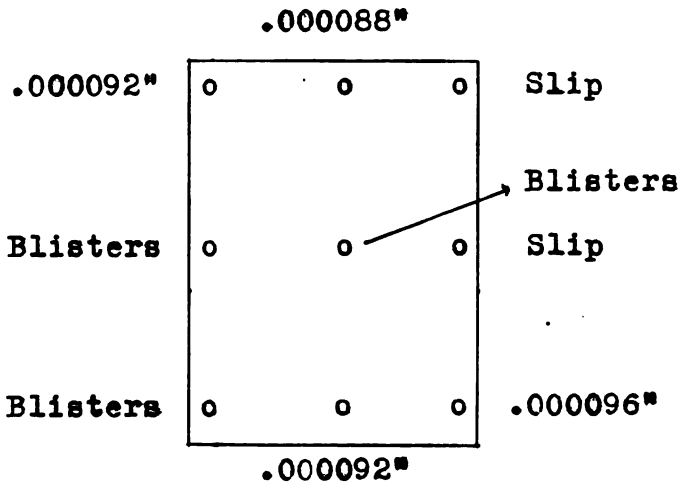
Trial	1	2	3	4	Mean
Point	Number of bands in view.				
1	6.4	6.5	6.5	6.6	6.5
2	-17.5	-17.5	-17.5	-17.5	-17.5
3	5.6	5.4	5.4	5.4	5.4
4	5.0	5.0	5.0	5.0	5.0
5	8.0	7.8	7.9	8.0	7.9
6	12.1	12.1	12.2	12.0	12.1
7	Blisters.				
8	Blisters.				
9	Blisters.				

After removing plate

Trial	1	2	3	4	Mean	Before Mean	Diff.	Thickness
Point	Number of bands in view.							
1	4.0	4.2	4.2	4.3	4.2	6.5	2.3	0.000092"
2	-19.7	-19.8	-19.7	-19.7	-19.7	-17.5	2.2	0.000088"
3	This not obtained due to slip of interferometer.							
4	This not obtained due to slip of interferometer.							
5	5.4	5.5	5.5	5.5	5.5	7.9	2.4	0.000096"
6	9.9	9.8	9.8	9.8	9.8	12.1	2.3	0.000092"
7	Blisters.							
8	Blisters.							
9	Blisters.							

Measurement No. 5

14 cm.



DATA 8 14 cm.

Plating Trial 83 Measurement No. 6

Before removing plate

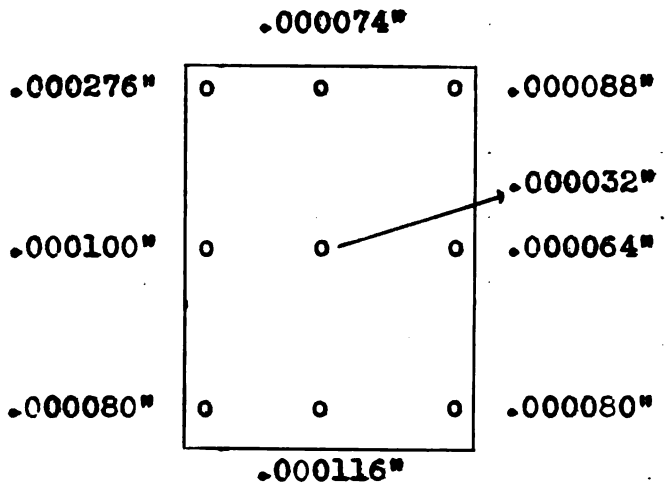
Trial	1	2	3	4	Mean.
Point	Number of bands in view.				
1	13.8	14.0	13.9	14.0	13.9
2	10.0	9.8	9.7	9.9	9.85
3	7.5	7.2	7.4	7.0	7.3
4	7.8	7.9	8.0	7.9	7.9
5	4.0	3.9	4.1	4.0	4.0
6	7.0	6.9	6.8	6.8	6.9
7	7.0	7.0	7.0	7.0	7.0
8	7.0	6.9	7.1	7.0	7.0
9	6.9	7.1	7.1	7.0	7.0

After removing plate

Trial	1	2	3	4	Mean	Before Mean	Diff.	Thickness
Point	Number of bands in view.							
1	6.5	7.5	7.0	7.0	7.0	13.9	6.9	0.000276"
2	8.0	8.0	8.0	7.9	8.0	9.85	1.85	0.000074"
3	5.2	5.0	5.2	5.1	5.1	7.3	2.2	0.000088"
4	6.3	6.2	6.4	6.3	6.3	7.9	1.6	0.000064"
5	1.9	2.0	2.0	2.1	2.0	4.0	2.0	0.000080"
6	4.0	4.1	3.9	4.0	4.0	6.9	2.9	0.000116"
7	5.0	5.0	5.0	5.0	5.0	7.0	2.0	0.000080"
8	4.3	4.6	4.5	4.8	4.5	7.0	2.5	0.000100"
9	6.2	6.1	6.3	6.2	6.2	7.0	0.8	0.000032"

Measurement No. 6

14 cm.



DATA 9 14cm.

Plating Trial 84 Measurement No. 7

Before removing plate

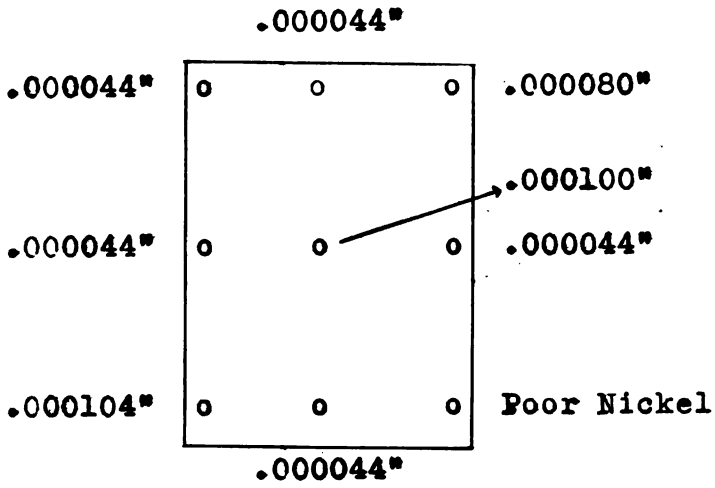
Trial	1	2	3	4	Mean
Point	Number of bands in view.				
1	11.5	11.6	11.2	11.2	11.4
2	10.0	10.0	10.2	10.1	10.1
3	6.6	6.5	6.5	6.5	6.5
4	8.0	8.0	8.0	8.0	8.0
5	7.2	7.1	7.0	7.0	7.1
6	8.0	8.0	8.0	8.1	8.0
7	8.9	9.0	8.8	8.9	8.9
8	8.0	8.3	8.5	8.3	8.3
9	8.5	9.0	9.0	8.5	8.8

After removing plate

Trial	1	2	3	4	Mean	Before Mean	Diff.	Thickness
Point	Number of bands in view.							
1	10.2	10.5	10.4	10.2	10.3	11.4	1.1	0.000044"
2	9.0	9.1	9.0	8.9	9.0	10.1	1.1	0.000044"
3	4.5	4.4	4.6	4.5	4.5	6.5	2.0	0.000080"
4	7.0	6.9	6.7	7.0	6.9	8.0	1.1	0.000044"
5	Poor nickel at this point, no measurement.							
6	6.9	6.9	6.9	6.9	6.9	8.0	1.1	0.000044"
7	6.2	6.3	6.2	6.5	6.3	8.9	2.6	0.000104"
8	7.1	7.3	7.3	7.0	7.2	8.3	1.1	0.000044"
9	6.2	6.3	6.5	6.4	6.3	8.8	2.5	0.000100"

Measurement No. 7

14 cm.



DATA 10 14 cm.

Plating Trial 87 Measurement No. 8

Before removing plate

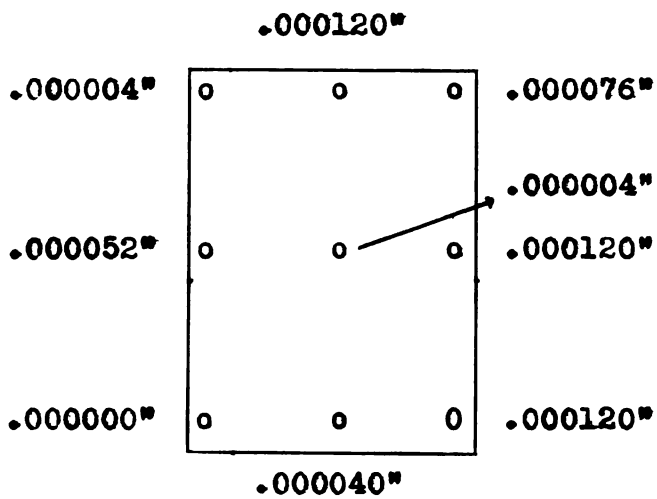
Trial	1	2	3	4	Mean
Point	Number of bands in view.				
1	6.0	6.1	5.9	6.0	6.0
2	8.9	9.0	9.0	8.9	9.0
3	5.6	6.0	6.0	5.8	5.9
4	5.8	6.0	6.0	6.0	6.0
5	7.0	7.0	6.9	7.0	7.0
6	7.9	8.0	8.0	8.0	8.0
7	8.0	8.0	8.0	8.0	8.0
8	9.8	10.0	9.8	10.0	9.9
9	6.2	6.3	6.2	6.1	6.2

After removing plate

Trial	1	2	3	4	Mean	Before Mean	Diff.	Thickness
Point	Number of bands in view.							
1	5.9	6.1	6.1	5.8	5.9	6.0	0.1	0.000004"
2	6.0	6.0	6.0	6.0	6.0	9.0	3.0	0.000120"
3	4.0	4.0	4.1	4.0	4.0	5.9	1.9	0.000076"
4	3.0	3.0	3.1	3.0	3.0	6.0	3.0	0.000120"
5	4.0	4.0	4.0	4.0	4.0	7.0	3.0	0.000120"
6	7.0	7.0	7.0	7.1	7.0	8.0	1.0	0.000040"
7	8.0	8.0	8.0	8.0	8.0	8.0	0.0	0.000000"
8	8.5	8.5	8.9	8.5	8.6	9.9	1.3	0.000052"
9	6.0	6.0	6.1	6.2	6.1	6.2	0.1	0.000004"

Measurement No. 8

14 cm.



DATA 11 28 cm.

Plating Trial 100 Measurement No. 9

Before removing plate

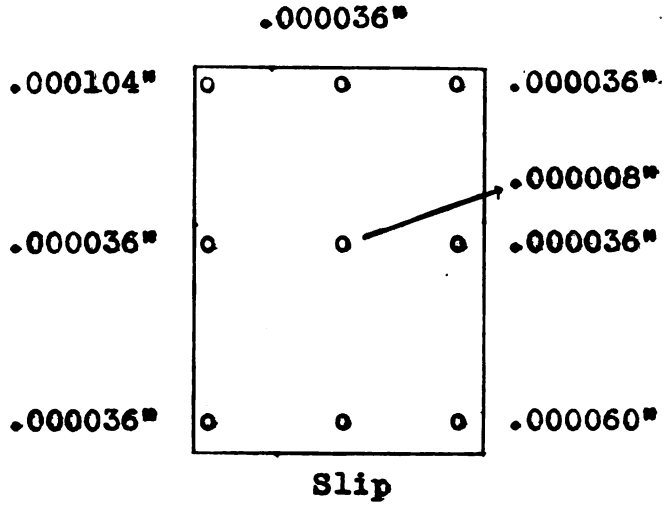
Trial	1	2	3	4	Mean
Point	Number of bands in view				
1	6.0	6.2	6.1	6.0	6.1
2	8.9	9.0	9.0	9.1	9.0
3	10.0	10.0	10.0	10.0	10.0
4	6.3	6.2	6.3	6.3	6.3
5	6.0	6.0	6.0	6.0	6.0
6	9.0	9.0	9.0	9.0	9.0
7	8.0	8.0	8.0	8.0	8.0
8	6.0	6.0	6.0	6.0	6.0
9	5.1	5.2	5.0	5.2	5.2

After removing plate

Trial	1	2	3	4	Mean	Before Mean	Diff.	Thickness
Point	Number of bands in view.							
1	3.5	3.6	3.5	3.5	3.5	6.1	2.6	0.000104"
2	8.2	8.0	8.0	8.1	8.1	9.0	0.9	0.000036"
3	9.1	9.2	9.0	9.1	9.1	10.0	0.9	0.000036"
4	5.5	5.3	5.4	5.4	5.4	6.3	0.9	0.000036"
5	4.5	4.3	4.5	4.5	4.5	6.0	1.5	0.000060"
6	Specimen was moved at this point, no reading.							
7	7.1	7.1	7.1	7.1	7.1	8.0	0.9	0.000036"
8	5.1	5.1	5.2	5.0	5.1	6.0	0.9	0.000036"
9	4.9	5.1	5.0	5.0	5.0	5.2	0.2	0.000008"

Measurement No. 9

28 cm.



DATA 12 28 cm.

Plating Trial 101 Measurement No. 10

Before removing plate

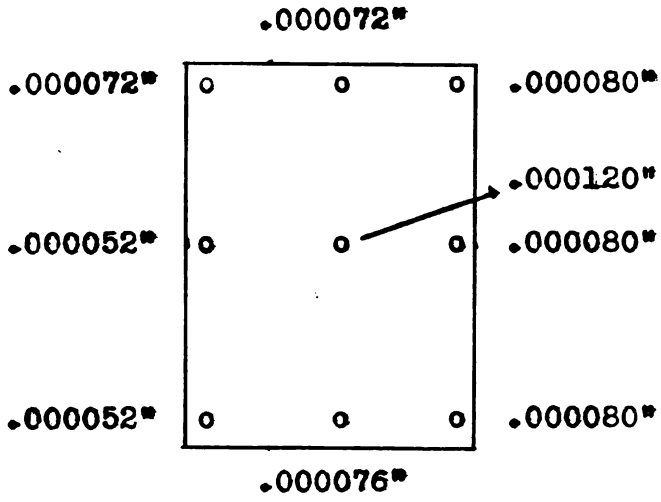
Trial	1	2	3	4	Mean
Point	Number of bands in view				
1	7.0	7.2	7.1	7.1	7.1
2	7.9	8.0	8.0	7.9	8.0
3	8.5	8.6	8.3	8.5	8.5
4	6.0	5.9	5.9	6.1	6.0
5	12.0	12.0	12.0	12.0	12.0
6	5.9	5.8	6.0	6.0	5.9
7	6.2	6.3	6.1	6.1	6.2
8	13.5	13.1	13.2	13.3	13.3
9	8.0	7.9	8.1	8.0	8.0

After removing plate

Trial	1	2	3	4	Mean	Before Mean	Diff.	Thickness
1	5.3	5.2	5.3	5.3	5.3	7.1	1.8	0.000072"
2	6.1	6.2	6.2	6.1	6.2	8.0	1.8	0.000072"
3	6.5	6.6	6.4	6.5	6.5	8.5	2.0	0.000080"
4	4.0	4.1	4.0	3.9	4.0	6.0	2.0	0.000080"
5	10.0	10.1	10.0	10.0	10.0	12.0	2.0	0.000080"
6	4.0	4.0	4.0	3.9	4.0	5.9	1.9	0.000076"
7	4.8	5.0	5.0	4.9	4.9	6.2	1.3	0.000052"
8	12.0	11.9	12.0	12.0	12.0	13.3	1.3	0.000052"
9	5.0	5.0	5.0	5.0	5.0	8.0	3.0	0.000120"

Measurement No. 10

28 cm.



DATA 13

Sulphate Test Using Kocour Sulphate Test Set.

Trial	Ppt. Tube 1	Ppt. Tube 2	Difference	Grams per Liter
1	5.5	0	5.5	4.125
2	5.2	0	5.2	3.900
3	5.3	0	5.3	3.975
4	5.6	0	5.6	4.200
5	5.7	0	5.7	4.275
			Mean -	4.095

Reading on Baume Scale.

30° at 21° C.

Composition of Chromium Bath.

Chromic Acid	240 grams per liter
Sulphuric Acid	1.2 grams per liter

Composition of Acid Copper Bath.

Copper Sulphate	200 grams per liter
Sulphuric Acid	50 grams per liter

COMPOSITION OF NICKEL BATHS.

NICKEL NO. 1

Boric Acid	15.46	g/L.
Nickel Sulphate	140.	g/L.
Ammonium Chloride	13.	g/L.

NICKEL NO. 2

Boric Acid	15.46	g/L.
Nickel Sulphate	70.	g/L.
Ammonium Chloride	13.	g/L.

NICKEL NO. 3

Boric Acid	15.46	g/L.
Nickel Sulphate	270.	g/L.
Ammonium Chloride	13.	g/L.

NICKEL NO. 4

Boric Acid	15.46	g/L.
Nickel Sulphate	140.	g/L.
Sodium Chloride	15.	g/L.

NICKEL NO. 5

Boric Acid	15.46	g/L.
Nickel Sulphate	100.	g/L.
Nickel Chloride	30.	g/L.

COMPOSITION OF NICKEL BATHS.

NICKEL NO. 1

Boric Acid	15.46	g/L.
Nickel Sulphate	140.	g/L.
Ammonium Chloride	13.	g/L.

NICKEL NO. 2

Boric Acid	15.46	g/L.
Nickel Sulphate	70.	g/L.
Ammonium Chloride	13.	g/L.

NICKEL NO. 3

Boric Acid	15.46	g/L.
Nickel Sulphate	270.	g/L.
Ammonium Chloride	13.	g/L.

NICKEL NO. 4

Boric Acid	15.46	g/L.
Nickel Sulphate	140.	g/L.
Sodium Chloride	15.	g/L.

NICKEL NO. 5

Boric Acid	15.46	g/L.
Nickel Sulphate	100.	g/L.
Nickel Chloride	30.	g/L.

NICKEL NO. 6

Boric Acid	15.46	g/L.
Nickel Sulphate	140.	g/L.
Magnesium Chloride	25.	g/L.

NICKEL NO. 7

Boric Acid	15.46	g/L.
Nickel Sulphate	140	g/L.
Ammonium Sulphate	17.	g/L.

NICKEL NO. 8

Boric Acid	15.46	g/L.
Nickel Sulphate	140.	g/L.
Sodium Fluoride	11.	g/L.

NICKEL NO. 9

Boric Acid	15.46	g/L.
Nickel Chloride	119.	g/L.

NICKEL NO. 10

Boric Acid	15.46	g/L.
Nickel Chloride	119.	g/L.
Ammonium Chloride	13.	g/L.

C O N C L U S I O N S

After working with the apparatus and using the same point on the block, it was found unnecessary to have the surface of the block optically flat. In the measurements recorded in the data, the block was placed on the platform and not moved during the time that a certain point was being measured. Therefore any irregularities in the block would not affect the measurements as long as the block was smooth enough to rest firmly upon the platform.

The later data shows the number of bands in the field of view as being considerably less than in the early measurements. The reason for this is two-fold:- First, the fewer the number of bands the more rapidly the readings can be made. Second, the fewer and the wider the bands the more accurately they record the thickness of the chromium plate. That is because even a fraction of a band change in the larger and broader bands can be readily observed.

By a series of experiments it was found that with the wiping off of the block with water after the acid had reacted, the block was cooled sufficiently to allow it to come back to the room temperature in a period of less than five minutes. In these trials the length of time taken was fifteen minutes, so as to be absolutely certain that no error due to the expansion of the block, by the heat of re-

action, would be present.

From a study of the graphic representation of the data, the following conclusions can be drawn:

(1) The thickness of the plate varies directly with the current density used.

(2) The higher the temperature of the bath, the higher the current density must be in order to give the same thickness to the plate.

(3) The metal distribution over the block is better at the greater distances from the anode.

(4) The throwing power is very poor. For at the greater distances the plate becomes thin as compared with the plates received closer to the anode.

(5) One cause for the extremely poor throwing power of this bath is the high sulphate content, which has been verified by other workers in the field.

(6) The difference in thickness of the plates at various distances from the anode, was used to determine the throwing power.

(7) The throwing power of this bath measured by the thickness of plates is -31.4% .

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