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REDUCTION OF GOLD-PLATING THICKNESS VARIATION

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Introduction

A company is engaged in manufacturing various models of Gents and Ladies Watches for the past three decades. For a watch, apart from precision and durability, the aesthetic part also is critical with the ever-changing fashion in modern society. Thus, the watch must look elegant. Nearly 50% of the watch bezels manufactured are plated with gold. Although gold is an expensive metal, a thin layer of gold deposit over the bezels will improve the appearance and makes the watch a piece of jewelry.

Background

In all applications of "gold plating," a major aim is to achieve uniformity of thickness. This is important from an economic viewpoint because gold is a major cost driver. Furthermore, from the technical viewpoint, it is also important because the variations in thickness may affect other critical characteristics of the coating such as porosity, stress, wear, and corrosion resistance. Because gold is an expensive metal, its efficient distribution on components is essential, otherwise the marginal excess of gold deposited becomes unreasonable and, therefore, represents a loss.

Data on thickness measurements of gold deposits on watch bezels indicated that there was always considerable variation in gold-plating thickness of bezels (3.2 ± 2.41 μ). Considerable savings can be realized if the plating is carried out by maintaining the minimum thickness required at any point on the bezel with least variation. Hence, an in-depth study was initiated with the following objective: To arrive at a suitable combination of process parameters so as to reduce the variation in thickness of bezels in the gold-plating process. The specification is 3.5 ± 0.7 μ after acid gold plating.

Study of the Process

Electroplating is the production of adherent deposits of metal on a conductive surface by the passage of DC electric current through a conductive metal in a solution called an electrolyte. The rate of plating depends on current and time. The plating occurs at the cathode (i.e., the negative electrode). The deposit thickness is determined by the following:

1. Time during which the current is passed
2. Current supplied to the surface being plated
3. The metallic concentration of the bath

Most of the plating solutions require proprietary additives that are organic or metallic. An increase in concentration, temperature, and agitation will enable faster plating rates and higher cathode efficiencies, but will decrease the throwing power and bath stability. To produce uniform deposits on the job (cathode), a uniform current distribution over the surface of the cathode must be maintained. In this regard, adequate electrical contact of rack to part, current flow through the rack, and its distribution on the watch bezels are of paramount importance. Uniform plating requires uniform current density at both the anode and the cathode. Gold electroplating allows a small amount of metal to be thinly and evenly distributed over a relatively very large area so that it may simulate bulk gold and, as such, be used to decorate a variety of less expensive consumer items. The acid 3N Gold Plating process is carried out in two stages:

1. Gold strike (flash plating) which will build up to 0.5 μ
2. Acid gold plating during which a deposit of nearly 3 μ will be achieved

The process flow diagram is as follows:

Wiping→Racking→Electro Degreasing→Rinsing→HCl Dip→Rinsing→DI Water Dip
↓
← DI Water Dip← Rinsing←Gold Strike←DI Water Dip←Rinsing←Ni Plating←
↓
3N Heavy Gold Plating→Rinsing→DI Hot Water Dip→Drying→Visual Inspection

The various parameters and their operating levels maintained are presented in Table 1. Table 2 presents the process parameters for two methods.

To identify and examine the nature and sources of overall plating thickness variation, data were collected in a planned manner. Two baths were involved in data collection because the heavy gold plating can be carried out in any one of the two acid gold baths. One carrier at a time full of watch bezels can be plated with gold. Each carrier has six racks (top to bottom). Their relative positions are fixed. For the purpose of the study, two randomly chosen carriers were used. From each rack of a carrier, three bezels were chosen, and in each bezel, both top and bottom sides were considered for recording plating thickness, and two observations are made for each side. Thus, racks and sides are cofactors. After collecting the data as per the plan, the data were sub-

Table 1. Operating Levels of Parameters

OPERATION	SOLUTION COMPOSITION	SPEC.
Gold strike	Metallic gold concentration	2 g/L
	pH	3.8–4.0
	Specific gravity	1.1
3N heavy gold plating	Metallic gold concentration	3–5 g/L
	pH	3.8–4.0
	Specific gravity	1.1

Table 2. Collection of Data and Problem Quantification

PROCESS PARAMETER	GOLD STRIKE	3N HEAVY GOLD PLATING
Current (A)	15	15
Count (A min)	7.5	250
Temperature (°C)	50–55	28
Agitation	Mechanical	Mechanical
Filtration	Continuous	Continuous
Anode	Platinized titanium	Graphite
Anode/cathode ratio	10:1	Anode covers cathode circularly
Purity (karat)	23.5	22.5–23

Table 3. ANOVA

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F-RATIO
Between baths	1	3.36	3.36	18.26[a]
Between carriers (within baths)	2	0.595	0.297	1.615
Between racks	5	56.13	11.226	61.01[a]
Between bezels (within racks)	48	5.74	0.12 (0.184)	0.604
Between sides	1	82.72	82.72	417.78[a]
Residual	230	45.54	0.198	
Total	287	194.09		

[a]Significant at the 1% level of significance.

jected to an analysis of variance (ANOVA), as shown in Table 3.

The components of variance were estimated as follows:

Estimated total variance = $\hat{\sigma}^2$

$$= \hat{\sigma}^2 \text{ residual} + \hat{\sigma}^2 \text{ between sides} + \hat{\sigma}^2 \text{ between racks} + \hat{\sigma}^2 \text{ between baths}$$

$$= 0.198 + 0.573 + 0.230 + 0.022$$

$$= 1.023.$$

Hence,

$$\hat{\sigma} = 1.011 \ \mu.$$

From the analysis of variance, it can be concluded that the variation between baths and between racks (within a carrier, within a bath) is significant at the 1% level of significance. Similarly, the variation within a bezel (between upper and lower sides with respect to the case pipe) is also significant at the 1% level of significance. Although the variation between baths have been found to be significant, it does not significantly contribute toward the total variation.

Brainstorming and Cause-and-Effect Analysis

The preliminary analysis results were reviewed with all concerned personnel in the gold plating area. It was strongly agreed that the variation between racks within a carrier and that within a bezel (i.e., between sides) must be reduced because these two sources contributed to a larger extent to the overall variation. A brainstorming session was held to list down the various factors that influence the plating thickness variation and this was presented in a systematic way using a cause-and-effect diagram (Fig. 1).

Need for Planned Experimental Approach

Because the existing variation of plating thickness on the bezels in a carrier was found to be considerably high even after controlling the parameters at specified levels, it was felt that a breakthrough must be made in reducing variability. Various factors can affect this variability: the shape of the rack, the pH value, current, and so forth. Thus, a systematic and scientific experimental approach was adopted in order to get a comprehensive picture of the factors affecting the variability and, thus, to arrive at a suitable combination of them so as to achieve a reduction in the variation of plating thickness.

Plan of Experimentation

Selection of Factors and Levels

After reviewing the cause-and-effect analysis and the subsequent literature survey, it was planned to experiment with the factors presented below. (See Table 4.)

Current

The advantage of maintaining the current at a particular level, regardless of voltage changes, solution temperature variations, or anode polarization changes, is that uniform plating is expected from one load to the other. Hence, current was studied at three levels to arrive at the best level which minimizes variation.

pH Value of Bath

The pH value, a measure of the acidity of a solution, was maintained in the range 3.8–4.0. It was varied in a controlled

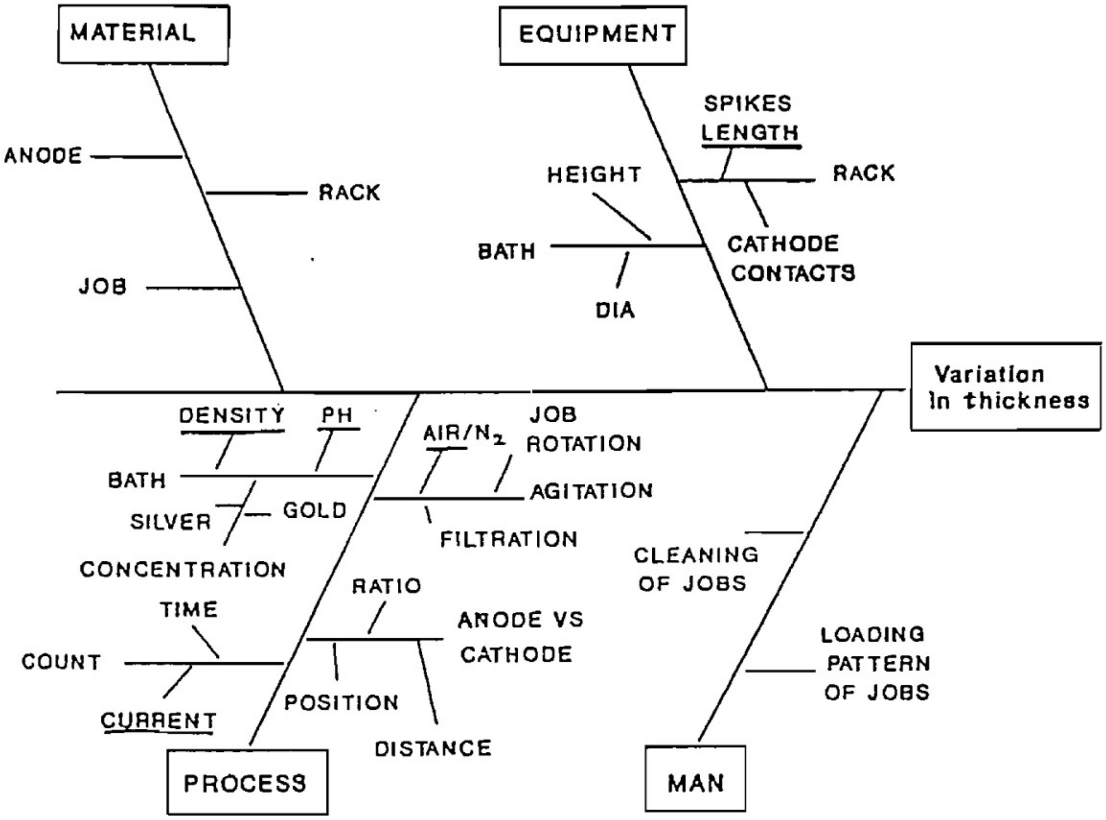

Figure 1. Cause-and-effect diagram.

manner within the same permissible range to study its effect on the variation in plating thickness.

Specific Gravity

The specific gravity of a solution indicates the total salts content in the bath. The specific gravity may vary with temperature. The correct level of specific gravity is necessary to obtain the required uniform plating. A change of specific gravity was made deliberately to obtain its best level. Thus, it was considered as a factor.

Carrier Design

It was found in the relevant literature that to improve the metal distribution throughout any plating rack, the low-den-

Table 4. Factors and Levels Selected for Experimentation

FACTOR	CODE	LEVEL 1	LEVEL 2	LEVEL 3
Current (A)	A	11	12	15
pH	B	3.80 ± 0.02	3.90 ± 0.02	4.00 ± 0.02
Specific gravity	C	1.09	1.105	1.12
Carrier design	D	Existing (Fig. 2a)	Modified (Fig. 2b)	—
Air agitation	E	Without	With	—

Note: The interactions suspected were A × B and A × C. In the case of factors D and E, level 1 is repeated for level 3.

Table 5. Experimental Layout with Data

EXP. NO.	CURRENT A(1)	pH B(2)	SPECIFIC GRAVITY C(5)	CARRIER DESIGN D(8)	AIR AGITATION E(11)	AVERAGE ($\bar{x}$)	S.D. (s)
	FACTORS (COLUMNS)						
1	11	3.8 ± 0.02	1.09	Existing	Without	1.766	0.1746
2	11	3.8 ± 0.02	1.105	Modified	With	2.223	0.2546
3	11	3.8 ± 0.02	1.12	Existing	Without	2.988	0.2527
4	11	3.9 ± 0.02	1.09	Modified	Without	1.968	0.4043
5	11	3.9 ± 0.02	1.105	Existing	Without	1.858	0.3162
6	11	3.9 ± 0.02	1.12	Existing	With	3.226	0.7025
7	11	4.0 ± 0.02	1.09	Existing	With	2.888	0.7314
8	11	4.0 ± 0.02	1.105	Existing	Without	2.226	0.4838
9	11	4.0 ± 0.02	1.12	Modified	Without	1.970	0.4577
10	13	3.8 ± 0.02	1.09	Existing	Without	2.063	0.3172
11	13	3.8 ± 0.02	1.105	Modified	With	1.565	0.1442
12	13	3.8 ± 0.02	1.12	Existing	Without	3.003	0.4095
13	13	3.9 ± 0.02	1.09	Modified	Without	1.880	0.2247
14	13	3.9 ± 0.02	1.105	Existing	Without	1.900	0.5190
15	13	3.9 ± 0.02	1.12	Existing	With	2.710	0.5351
16	13	4.0 ± 0.02	1.09	Existing	With	2.937	0.6694
17	13	4.0 ± 0.02	1.105	Existing	Without	2.279	0.2976
18	13	4.0 ± 0.02	1.12	Modified	Without	2.404	0.3186
19	15	3.8 ± 0.02	1.09	Existing	Without	1.502	0.2038
20	15	3.8 ± 0.02	1.105	Modified	With	1.290	0.1464
21	15	3.8 ± 0.02	1.12	Existing	Without	2.603	0.5472
22	15	3.9 ± 0.02	1.09	Modified	Without	1.741	0.1900
23	15	3.9 ± 0.02	1.105	Existing	Without	1.973	0.2595
24	15	3.9 ± 0.02	1.12	Existing	With	2.574	0.8659
25	15	4.0 ± 0.02	1.09	Existing	With	2.877	0.7091
26	15	4.0 ± 0.02	1.105	Existing	Without	1.695	0.2340
27	15	4.0 ± 0.02	1.12	Modified	Without	2.894	0.5835

Table 6. ANOVA

CODE	SOURCES OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F-VALUE
A	Current	2	0.0304	0.0152	
B	pH	2	1.4713	0.7356	9.13[a]
C	Specific gravity	2	1.1606	0.5803	7.20[a]
D	Carrier design	1	0.7774	0.7774	9.64[a]
E	Agitation	1	0.4334	0.4334	5.38[b]
A × B		4	0.1765	0.0441	
A × C		4	0.5896	0.1474	
	Error (pooled)	(20)	(1.6079)	0.0806	
	TOTAL	26	5.4506		

[a]Significant at the 1% level of significance.
[b]Significant at the 5% level of significance.

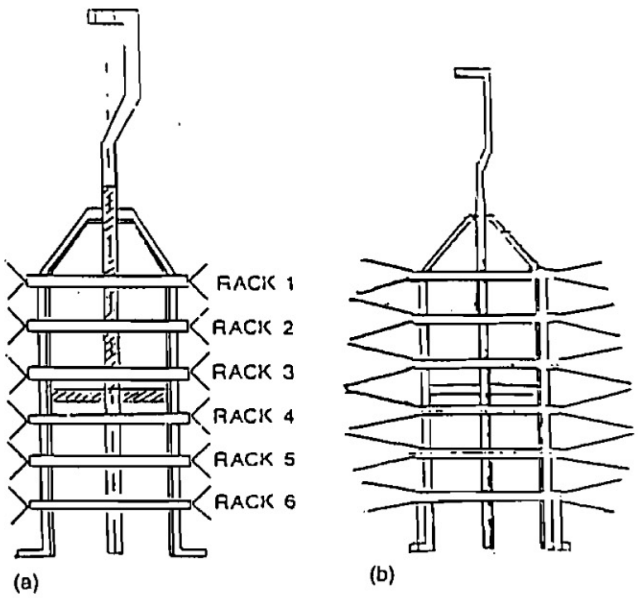

Figure 2. (a) Existing design (outer diameter uniform through top to bottom); (b) modified design (outer diameter is greater near the middle zone of the carrier and progressively decreases at the top and bottom positions).

sity areas must be closer to the anode than the high-current density areas.

Experimentation

The L_{27} orthogonal array design was used to arrive at the physical layout of the experiments; the experiments were carried out in random order. For each experiment, one carrier was considered. From this carrier, a total of six bezels were collected—one bezel from each rack. The plating thickness was measured and recorded for this sample of six bezels. The thickness was measured at four different positions, with two on the upper side of the case pipe and two on the lower side of the case pipe.

The heavy gold plating can be done in one of the two acid gold baths. One carrier at a time full of watch bezels can be plated with gold. Each carrier has six racks from top to bottom. It is designed in such a way that it will accommodate 12 bezels in each rack, for a total of 72 bezels per carrier.

Analysis

The analysis of the experimental data was carried out using the analysis of variance technique taking $\log_{10}s^2$ as the experimental response; this is shown in Table 6. The average response table is presented in Table 7.

Conclusions

From the analysis of variance table (Table 6), it was seen that all the factors, except current, were significant at the 5% significance level. The interactions A × B and A × C were found to be insignificant. From Table 7, the best level for each factor was noted. The best combination that gives the minimum thickness variation was given in Table 8.

Confirmatory Trial

A carrier was run with the best combination obtained as above. The standard deviation of the plating thickness was found to be 0.278 μ. The variation was found to be in the range of 3.05 ± 0.83 μ. However, the average plating thick-

Table 7. Average Response Table

		LEVEL		
CODE	FACTOR	1	2	3
A	Current	–0.8408	–0.9111	–0.9279
B	pH	–1.2146	–0.7981	–0.6671
C	Specific gravity	–0.9266	–1.1288	–0.6243
D	Carrier design	–0.7733	–1.1332	—
E	Agitation	–0.9828	–0.7141	—

Table 8. Best Combination

CODE	FACTOR	LEVEL
A	Current	3 (15 A)
B	pH	2 (3.80 ± 0.02)
C	Specific gravity	2 (1.05)
D	Carrier design	2 (Modified)
E	Air agitation	1 (Without)

ness can easily be brought to the center value (3.5 μ) by increasing the current or time appropriately.

Implementation

Management was informed about the results of the experiment regarding the reduction in the plating thickness variation. The suggested best combination was adopted for the watch cases, including the modification of the change in the carrier design.

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