Technology Introduction

Making Plating Thickness Constant by Simulation

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1 Introduction

Recent years have seen the promotion of digital technologies including artificial intelligence (AI) and Internet of Things (IoT) in virtually all fields. Even techniques that have long been conveyed as craftmanship are becoming subject to standardization with digital technologies.

KYB Corporation frequently applies hard chrome plating to sliding parts of shock absorber piston rods and other components. This plating requires masking jigs (hereinafter "jigs") [Note 1)] because of its characteristics. Conventional jig design relies on work learned only through actual experience (so-called knack or intuition) of operators. It is difficult to achieve constant deposition of plating (hereinafter "film thickness"). Since jig fabrication and plating prototyping are needed for each try, many man-hours are spent to discuss and determine the form of jigs [Note 2)] (Fig. 1). With this background, KYB has developed a jig design methodology requiring no knack or intuition by utilizing simulation software. This paper introduces a case study of our efforts to achieve constant plating thickness of industrial hydraulic equipment products by means of simulation.

Note 1) Masking jigs used to prevent plating or limit the film thickness

Note 2) Three to four tries were needed before completion: 2 weeks/try

(according to interviews with operators)

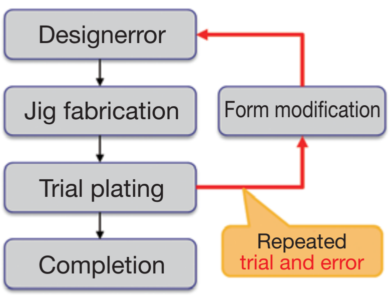

Fig. 1 Conventional jig design flow

2 Characteristics of Electroplating

This chapter describes the major characteristics of electroplating including hard chrome plating. For electroplating, the film thickness is generally proportional to the quantity of electricity (current × time) (Faraday's 1st law).

When applying plating to workpieces, the current is likely to concentrate at the edges of them, resulting in thicker films (Fig. 2). This phenomenon can be prevented by the use of shorter electrodes. In facilities where workpieces of different lengths are plated, however, just changing the length of the electrode would not be enough. Then, jigs can be installed at the edges of a workpiece to suppress the concentration of the current at the edges, curbing the increase in plating thickness.

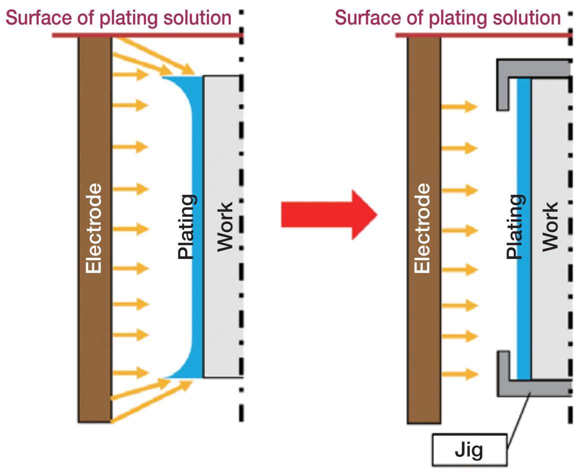

Fig. 2 Illustration of effects of jigs

3 Preliminary Test on Stepped Work

Before redesigning the jig through simulation, a preliminary test was conducted using a stepped workpiece. Fig. 3 shows the front view of the preliminary test equipment. The workpiece and electrodes are vertically inserted into the plating bath. In total four electrodes are installed around the workpiece. This stepped workpiece consists of thick and narrow sections: the former has a diameter of ø22 and the latter ø10. All of these sections, regardless of the diameter, are 100 mm long. The test conditions are shown in Table 1. As mentioned in the previous chapter, the edges or corners of the workpiece are likely to have higher current density which builds thicker films. The test was carried out to verify whether this phenomenon can be reproduced in simulation.

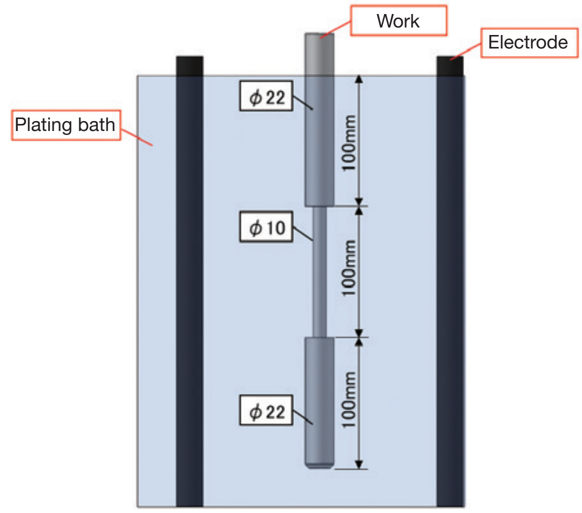

Fig. 3 Sketch of preliminary test equipment

Table 1 Plating conditions for preliminary test

Item	Settings
Plating bath	Sargent bath
Plating solution temperature	50°C
Plating area	1.7 dm^2
Current density	40 A/dm^2
Current setting	70 A
Plating time	30 min.

The simulation software used for this research is intended to be used for analysis of current density (A/dm^2). Since analysis results cannot be directly compared with film thickness measurements, the analysis results (A/dm^2) have been converted into the film thickness (μm) using Equation (hereinafter "Eq.") (1):

$$\text{Film thickness } \mu m = \text{Deposition speed } \mu m/min \cdot A \cdot dm^{-2} \times \text{Current density } A/dm^2 \times \text{Plating time min} \times \text{Current efficiency} \quad (1)$$

A contour diagram of the analysis results is shown in Fig. 4. For convenience, the top section of ø22 is called A, the middle section of ø10 called B, and the bottom section of ø22 called C. The edges of sections A and C as well as the central part of section B have a higher current density, while the edges of section B have a lower current density.

Comparison between the analysis results and the measurements are shown in Figs. 5 to 7. For the purpose of this paper, the "film thickness" (vertical axis) in the Figures indicates individual measurements that have been divided by the mean value of the film thickness of the flat parts (A: 10 mm to 60 mm, B: 130 mm to 170 mm, C: 230 mm to 270 mm) of the workpiece and then made dimensionless.

The trends of film thickness distribution of sections A, B and C obtained through simulation almost match those obtained through actual measurement. Therefore, the use

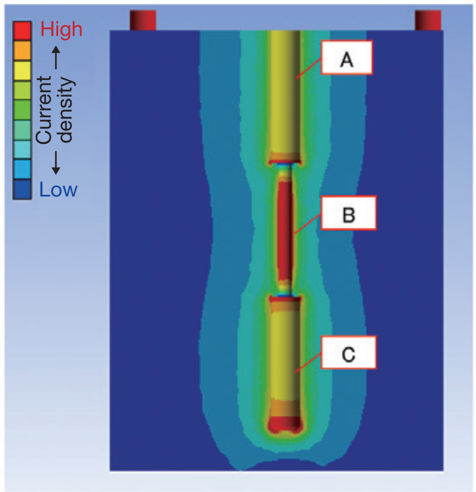

Fig. 4 Analysis results (current density distribution)

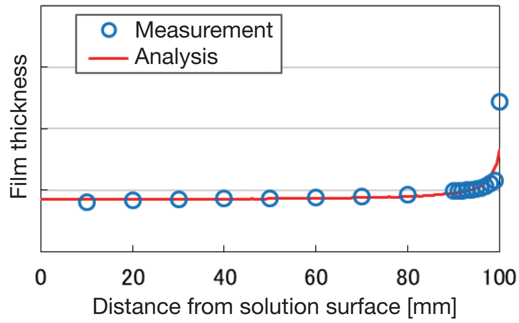

Fig. 5 Comparison in section A

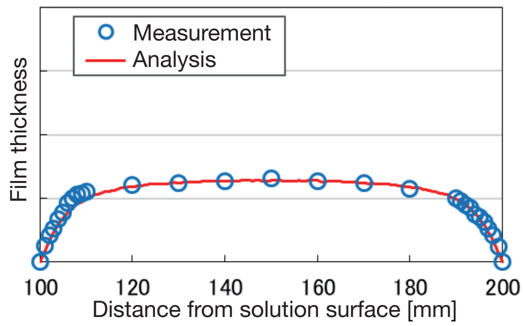

Fig. 6 Comparison in section B

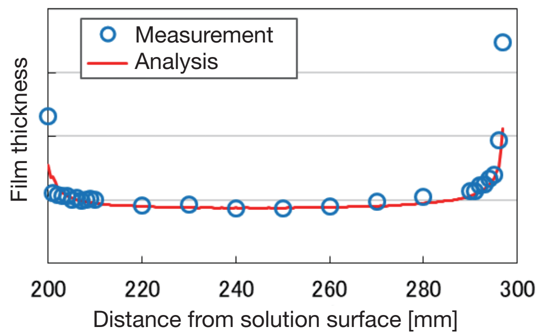

Fig. 7 Comparison in section C

of the simulation model and conditions developed for the research can be used to obtain a film thickness distribution similar to the actual phenomenon.

4 Making Film Thickness Constant

Since the simulation model was validated through the preliminary test, its utilization in mass production equipment was tried.

4.1 Target Product

The piston rods for forklift cylinders were selected as the target product (Fig. 8).

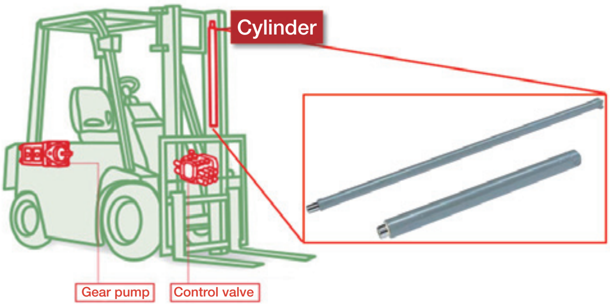

Fig. 8 Target product

4.2 Conventional Jig

Fig. 9 shows measurements of plating thickness obtained with the conventional jig (Photo 1). An electromagnetic plating thickness gauge was used to measure the film thickness of workpieces longitudinally along a straight line. The Figure includes a sketch of the workpiece installed with the jig.

The jig design was based on operators' knack and intuition, resulting in uneven film thicknesses. In particular, the masked portion had a substantially lower film thickness. To compensate for the film thickness in this portion, thicker plating was made overall. This led to longer plating time and consumed extra electricity and chemicals.

While the central part of the rod has a constant film thickness, the edges of the rod have uneven film thicknesses due to the concentrated current and the shielding effect of the jig. Through comparison with the simulation results, it was verified that the tendency of the film thickness distribution was successfully reproduced.

4.3 Redesigning the Jig

To make the current density distribution indicated by the analysis results more uniform, we tried to find an optimal form of the jig by repeatedly changing and analyzing the aspect ratio, hole diameter and the number of holes of the jig model (Fig. 10). This redesigning was carefully conducted because the current density distribution greatly varies with the jig form (Fig. 11). The authors

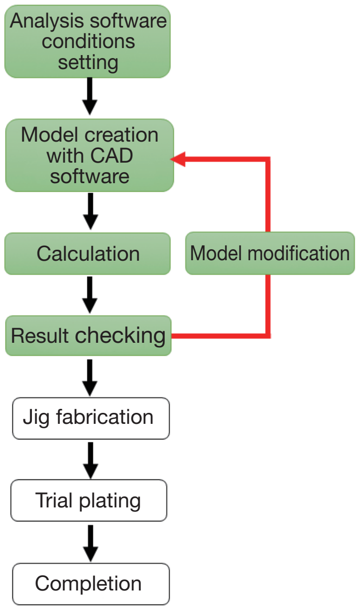

Fig. 10 Jig design flow using simulation software

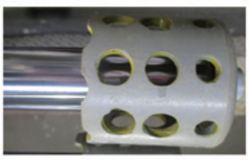

Photo 1 Conventional jig

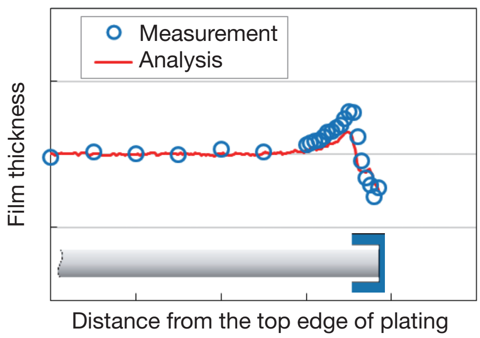

Fig. 9 Comparison between measurement and simulation (conventional jig)

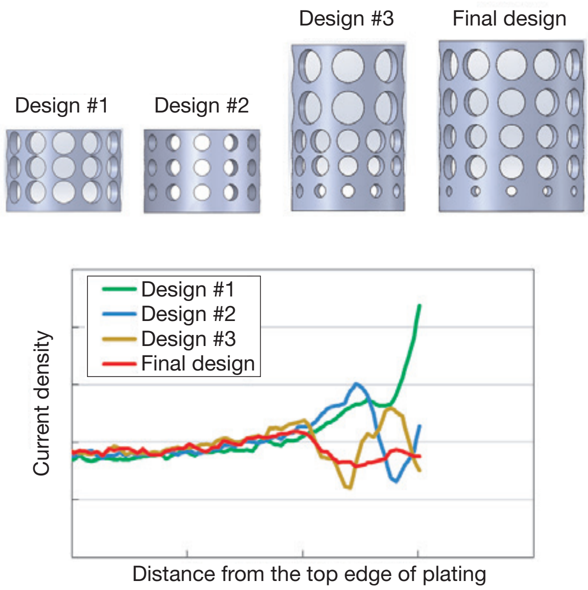

Fig. 11 Analysis results of various jig model versions

had no previous experience of jig form design. After about two weeks of redesigning work, the "final design" included in Fig. 11 was obtained through repetitive modification of the jig model.

As indicated by the workflow in Fig. 10, the simulation cycle was effectively used to successfully fabricate the jig and verify the plating with a single try.

4.4 Verifying the Effect

The jig prototype obtained through the jig fabrication and trial plating processes was compared with the conventional jig. For the purpose of this paper, the prototype is called the "improved jig" (Photo 2). Fig. 12 shows film thickness measurements with the conventional and improved jigs. The film thickness variation {(Maximum film thickness - Minimum film thickness) / Mean film thickness} of the conventional jig was 57% of the mean film thickness. In contrast, the film thickness distribution of the improved jig was as low as 11% of the mean value.

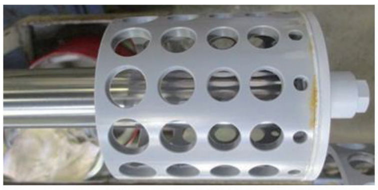

Photo 2 Improved jig

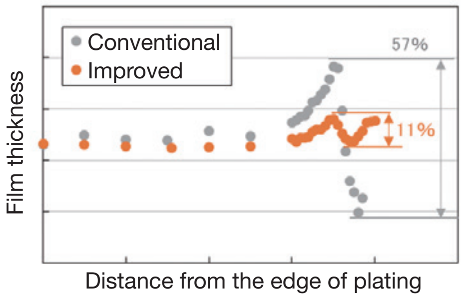

Fig. 12 Comparison of film thickness measurements

5 Further Efforts for Even Higher Efficiency

The company's traditional jig improvement relied on operators' knack and intuition and the redesigning required about six weeks. For the authors' jig improvement through simulation, the redesigning time was reduced to two weeks. However, the model improvement through simulation involved repetitive trial and error and could not completely exclude the dependence on operators' knack and intuition. The reduction of improvement time remains a big challenge even after the introduction of simulation.

Then, we tried to reduce the redesigning time and eliminate the dependence on knack and intuition by introducing an optimization software product[Note 3)] to allow the model modification and calculation processes to be done automatically (Fig. 13).

Note 3) Software used: Simcenter HEEDS®

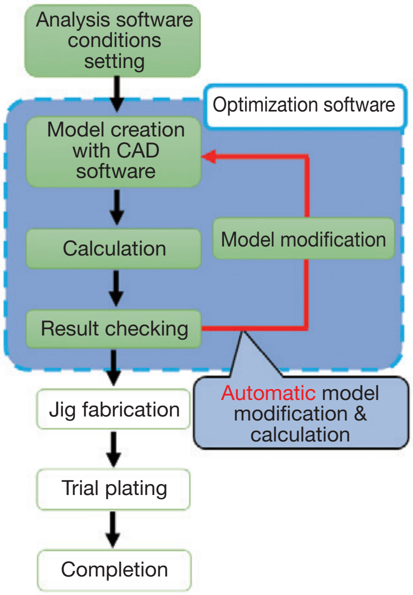

Fig. 13 Jig design flow using optimization software

5.1 Conditions Setting

For the purpose of redesigning the jig, the five parameters listed in Table 2 were selected for conditions setting in the optimization software. 100 combinations of parameter settings were subjected to calculation by the software to determine the jig form with the smallest variation in film thickness. Fig. 14 shows what the parameters indicate in the actual jig.

Table 2 Parameter settings for optimization software

Parameter settings	
Outside diameter	ø47-85 mm
Height	5-130 mm
Hole diameter	ø1-30 mm
Number of longitudinally aligned holes	2-10
Number of circumferentially aligned holes	4-20

100 combinations of parameter settings were analyzed.

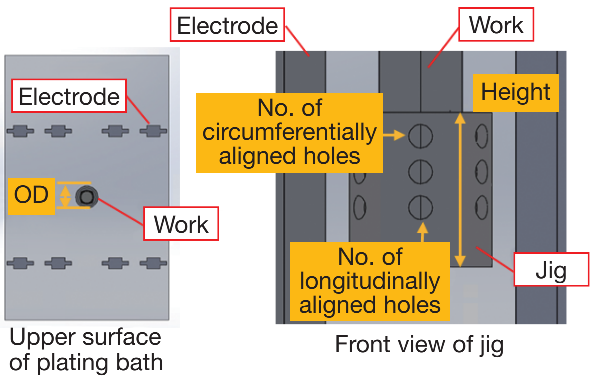

Fig. 14 Locations of parameters

5.2 Film Thickness Measurements

The model obtained through calculation using the optimization software was used to fabricate a jig (Photo 3). This jig was trial plated and then subjected to measurement of film thickness.

As shown in Fig. 15, the film thickness variations were reduced to about 1/3 (19%) of those of the conventional jig, although this result was inferior to that of the improved model (11%) obtained only through the simulation software. Furthermore, the redesigning time was reduced to as little as eight hours, which is about 1/10 of the time spent for the improved jig (i.e., two weeks: equivalent to 80 working hours). Thus, "anyone" can now "easily" design a jig in a "short time" just by entering the five parameters.

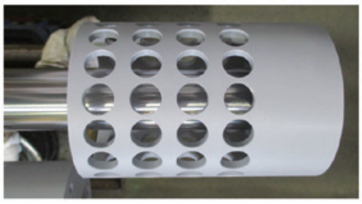

Photo 3 Improved jig Ver.2

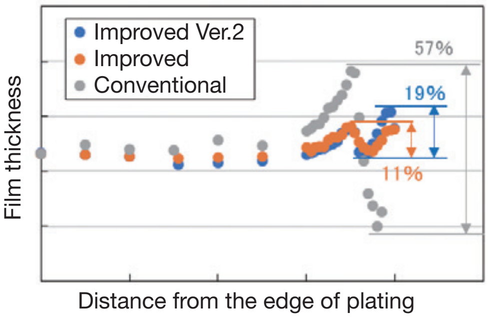

Fig. 15 Comparison of film thickness measurements #2

6 Future Prospects

Additional expected benefits from this effort include lower processing costs (for electricity and chemicals) and lower CO_2 emissions due to shorter plating time.

Plating should be applied to applicable products to ensure that the thinnest part of the plating film meets the film thickness requirements. However, conventional plating has been applied based on the film thickness at the edges, which is lower as shown in Fig. 16. Plating in this way will provide an excessive film thickness on the flat part that is away from the edges of the plated work. Then, the improved jig can be used to ensure work has a higher film thickness at the edges than on the flat part, thereby enabling the excess in film thickness to be eliminated (see the shaded zone in Fig. 16). The plating time can also be reduced by an amount corresponding to the film thickness reduction, leading to lower processing cost and lower CO_2 emissions.

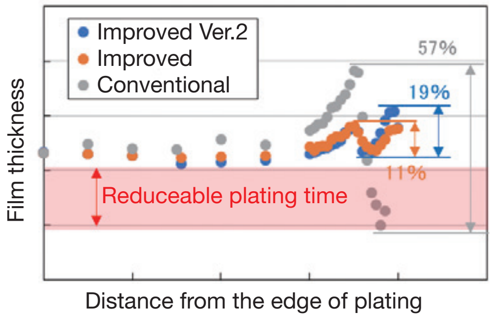

Fig. 16 Expected benefits

7 In Closing

It was verified that the simulation is very effective for achieving constant plating films and higher productivity. In addition, the utilization of the optimization software was shown to enable jig redesigning that does not depend on knack and intuition and a substantial reduction in redesigning time.

The simulation can also be expected to be utilized to find causes of inappropriate film thickness or even for discussion of the specifications for new plating lines (such as throughput). KYB operates a variety of working processes including heat treatment and cutting as well as plating. It is desirable to effectively apply the simulation methodology not only to plating but also to various other working processes.

Finally, we would like to take this opportunity to sincerely thank all those concerned inside and outside KYB who have extended cooperation to this development.

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