

# Maximising decorative electroplating productivity by optimizing the rack design for a family of ten different door handles

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Costs are designed into products. Choices made on the design, the materials and indeed the manufacturing processes employed have a profound impact on the final product cost.

There is a growing view, that with the availability and improvement of computer aided engineering tools (CAE), electroplating should be considered as a science rather than an art. The chemistry and physics are known and just as computing tools are regularly used for thermal, stress and fluid flow analysis in product and process development, they can also be used in optimizing racking and tooling design for plating processes. Plating thickness distribution can be predicted on a component or rack of components of any complexity.

This paper describes how such a software tool was used to effectively deliver a virtual *plating plant* with the goal to assess the impact of manufacturing process decisions. In order to minimize operator costs and error a starting premise was that a range of 10 different door handle designs could be plated on a single rack design. For such a wide variation of designs from small to large, sharp-edge to smooth and curvy, arriving at a single optimized rack design was quite a challenge. A trial and error approach of building and testing racks for all 10 different handle designs and a range of different decorative surface finishing options (e.g. satin nickel, bright chrome, antique brass) would be inconceivable as it would be far too consuming in terms of lead time, hardware prototype racks and manpower efforts, incurring large cost and time penalties. For such a wide range of part designs and surface finishing options, Computer Aided Engineering is definitely the answer to maximize productivity.

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## **1 Introduction**

Decisions made in manufacturing, aimed at addressing product quality, productivity and cost control have a direct impact on the final product cost. In the past, key drivers included continuous reduction in costs and time to market, now an additional challenge for suppliers is to consider the environmental impact of their decisions, not only during product life but during manufacturing. Manufacturing choices directly affect material and energy used and indeed the effluents emitted – particularly in electroplating.

Over the past 25 years Computer Aided Engineering (CAE) and Computer Aided Design (CAD) tools have been developed addressing initially fundamental physics, such as stress, fluid flow and heat transfer. CAE tool development then integrated these physics in order to assess more complex processes such as mould flow in plastics manufacturing up to electroplating of all types of components.

With the availability and improvement of computer aided engineering tools (CAE), electroplating should be considered as more of a science rather than an art. Elsyca have developed new technology and capability which enables the accurate prediction of the electrodeposited metal thickness distribution about any complex geometry. On a project basis, Elsyca exploits this unique capability to design and optimize electroplating processes, tooling and racking. Elsyca's simulation platform essentially allows the import of CAD data and delivers an analysis which clearly illustrates and addresses manufacturing issues related to electroplating.

The following case describes how this technology has been challenged by delivering an optimized racking solution for a family of 10 different door handles, with the goal to maximize productivity during the decorative electroplating cycle. The case clearly illustrates how time, money and energy can be saved using electroplating simulation technology.

## **2 Rack design challenge**

The starting premise for the project is that a complete range of the 10 different door handle designs could be plated on one single rack design. This will enable limiting rack investments to only 1 type of rack instead of 10 different rack types and also minimizing operator costs and error.

As can be seen in Figure 1, there is a wide variation of door handle designs from small to large, sharp-edge to smooth and curvy. Arriving at one single optimized rack design for all door handles types is quite a challenge while trying to simultaneously account for the following requirements:

- scrap rates should be minimized, thus reducing waste and costs;
- production capacity should be maximized, independently from the door handle design.



**Figure 1: simplified CAD configuration of 10 door handle designs**

A trial and error approach of building and testing racks for all 10 different handle designs and a range of different decorative surface finishing options (e.g. satin nickel, bright chrome, antique brass) would be inconceivable as it would be far too consuming in terms of lead time, hardware prototype racks and manpower efforts, incurring large cost and time penalties. For such a wide range of part designs and surface finishing options, Computer Aided Engineering is definitely the answer to maximize productivity, enabling to create a virtual plating plant to try out the effect of manufacturing decisions “off-line”.

### **3 Plating process and specifications**

The plating process under consideration, involves the following electrochemical **process steps**:

- Cyanide Copper Strike;
- Cyanide Copper Plate;
- Semi – Bright Nickel;
- Bright Nickel;
- Satin Nickel;
- Hexavalent Chromium.

In table 1, the **thickness targets** for the various metal layers are summarized. A type surfaces are exposed frontal view surfaces. B type surfaces have only exposure by side view (hence the back side of the door handles) and C type surfaces are not visible when mounted (bore diameter). Figure 2 provides a rough classification of the surfaces for the design F door handle, with A type surfaces in yellow, B type surfaces red and C type surfaces in dark grey.

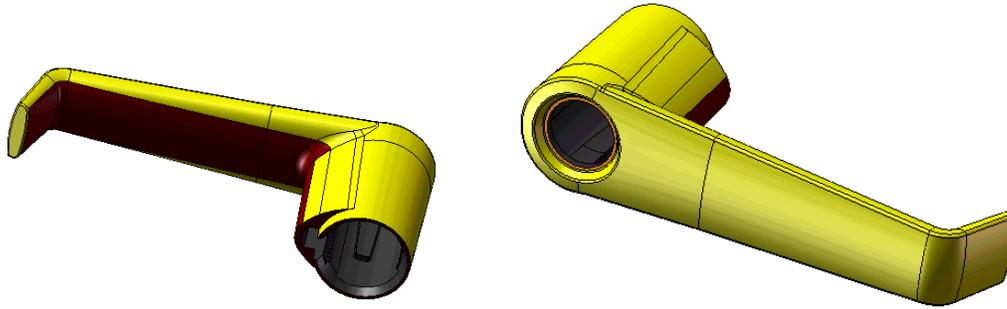


Figure 2: definition of A, B and C type surfaces for door handle design F

Basically, there are no specifications for the B type surfaces, unless that Cr coverage is required. From experience, full Cr coverage is only obtained when a layer of 0.05 micron is present, otherwise only Cr nuclei will form on the Ni, not being merged together. This will typically give the yellowish color, known as 'Ni show'.

Table 1: layer thickness targets (from The Electroplating Handbook) (micron)

	Cu strike	acid Cu	Semi-br Ni	Bright Ni	Cr
A type	0.1 / 2.5	0.3 / 7.5	0.5 / 13.0	0.3 / 7.5	0.01 / 0.25
B type	-	-	-	-	0.002 / 0.05
C type	-	-	-	-	-

On the other hand, the **quality of the deposits** should be maintained at any position of the door handle. If locally too high current density values are encountered, flaws will occur.

- For the copper baths, this concerns the formation of rough deposits
- For the Ni baths, a nodular (cauliflower like) deposit will form
- For the Cr baths, burning will occur.

Sample **process parameters** for each plating step are listed in table 2.

Table 2: intended average current density values and process times as provided by the plating chemical supplier.

	Cu strike	Cu plate	Semi-br Ni	Bright Ni	Cr VI
Plating time	353 s	988 s	988 s	449 s	198 s
Current density	15 - 30 ASF	15 - 30 ASF	40 - 50 ASF	40 - 50 ASF	150 ASF
□V nominal	9 V	9 V	9 V	9 V	12 V

The plating line is cycle style and for that reason each plating step is voltage controlled. The process time for each plating step is fixed, and depends on the number of tank stations per plating step.

For the computer simulations of the cycle line plating steps (Cu and Ni) it is important to know the overall effect of the contact and bus bar resistances, because part of the imposed voltage will be consumed as ohmic drop in the electrical network outside of the tank, and the voltage range of the rectifiers is limited. The Cr plating is performed in a separate hoist line.

Simulation of the electroplating process focuses on the semi-bright Ni and the Cr layer:

- The semi-bright Ni layer is typically the thickest Ni metal layer with more relative variation in thickness than occurs for the copper plating steps. In case of too high current density, cauliflower growth might occur.

- The Cr layer is crucial since this is the thinnest layer. If current density is too high, Cr burning might occur. Also issues of Ni show should be avoided, appearing as spots with no Cr coverage.

#### 4 Evaluation of the existing situation

Figure 3 depicts the rack configuration as initially proposed. The rack contains in total, 96 parts in 8 columns and 6 rows. The enclosing electrolyte volume and anodes (red) are also shown.

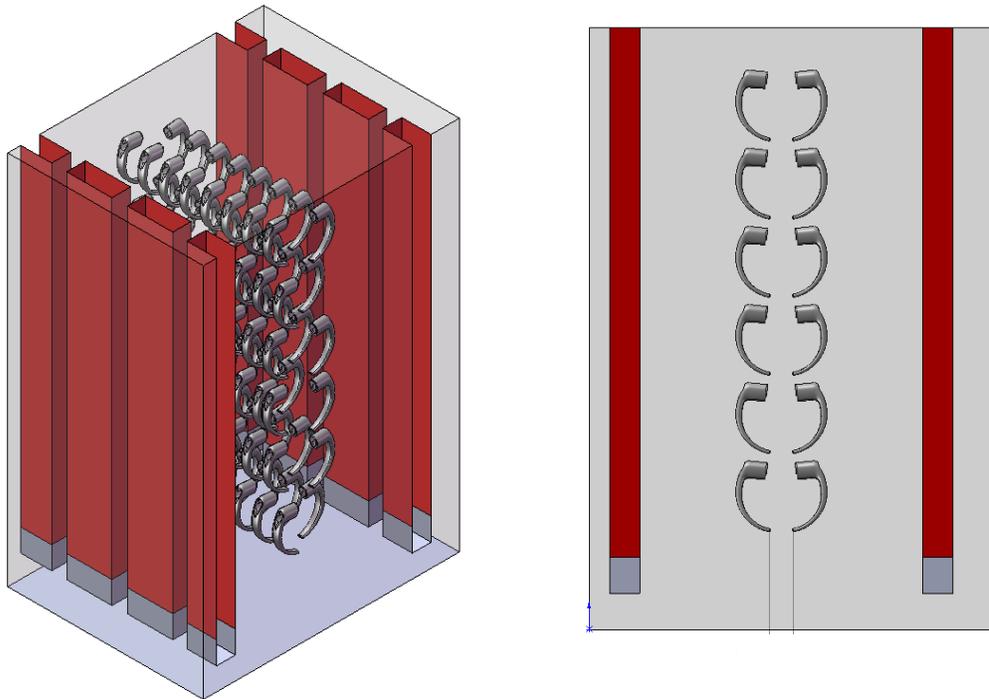


Figure 3: CAD of a Ni plating station with 96 parts load

##### 4.1 Semi bright Ni plating step

Figure 4 shows the simulations for the semi-bright Ni step. At the left the current density distribution is shown. In the red areas current densities are higher than the threshold value for nodular Ni deposits, meaning the so-called cauliflower growth could appear.

In the right picture, the edge effect over the rack is obvious: the outer door handles receive higher currents and thus higher layer thickness deposits. The red areas receive as much as 40 microns of Ni compared to a specification of 13 micron. There is clearly a large variation in Ni layer thickness and thus a potentially large overconsumption of metal.

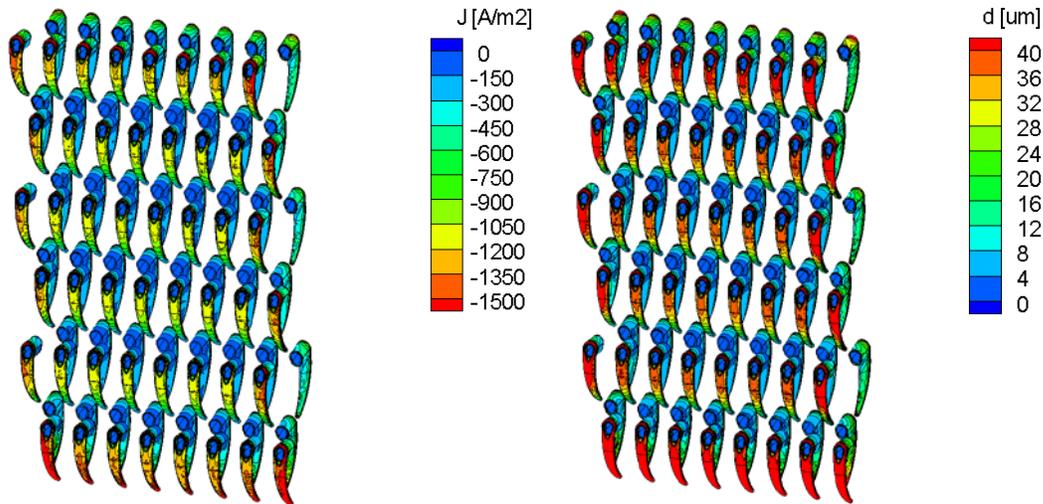


Figure 4: Left: semi-bright Ni current density distribution;  
Right: semi-bright Ni layer thickness distribution

#### 4.2 Hexavalent Chromium plating step

Figure 5 shows the simulation plots for the Cr plating step. The red areas on the left plot indicate again too high current densities leading to Cr burning. On the right plot the dark blue spots receive not enough Cr leading to Ni show, even on B type surfaces.

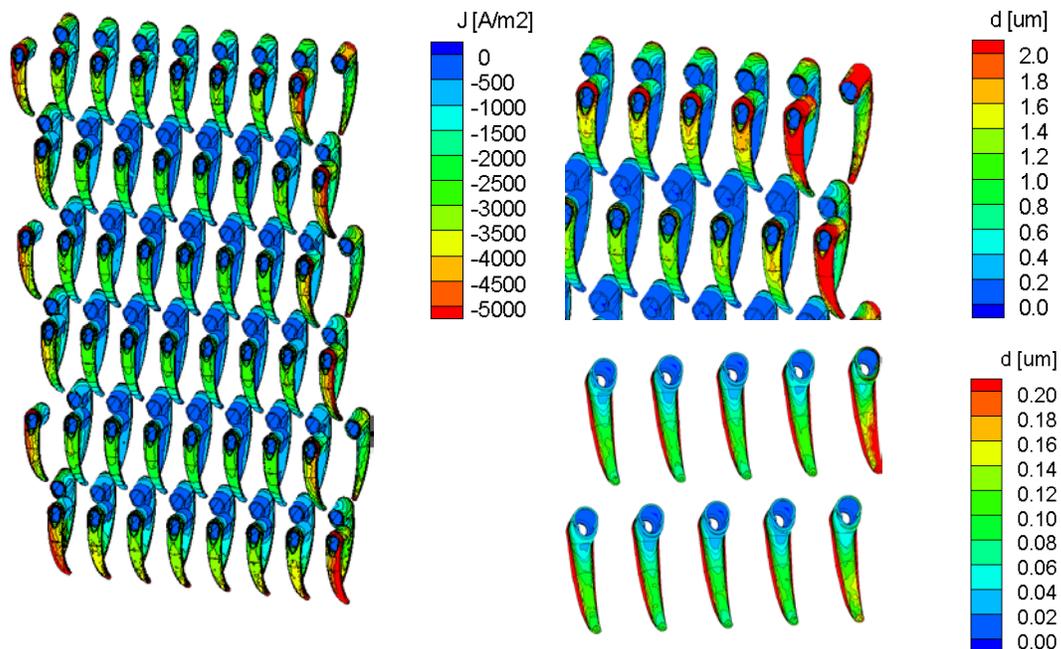


Figure 5: Left: Cr current density distribution;  
Right: Cr layer thickness distribution

#### 4.3 Evaluation for all door handle designs

Simulations are performed for the semi bright Ni and Cr steps for the 10 door handle designs.

The results are summarized in table 3, showing the probability of defects for the different designs with respect to Cr burn, Ni show, Ni nodular growth, and the rectifier being out of range.

The several defects are caused by:

- Too low Cr deposition: Ni show
- Too high current density: Cr burn & nodular Ni growth
- Too high rack load: rectifier out of range

Note however, that the table, in case of a high defect probability, eg Cr burn in design E, does not mention how many parts of the total load will be affected. Judging from the plots in Figure 5, this will however easily be 50%, namely all affected parts at the outer edges.

**Table 3: Overview of defect categories as observed for each part program for the existing rack configuration**

Part	Probability of Defect			
	Cr Burn	Ni Show	Nodular Ni Growth	Rectifier $\Delta V$ out of range
Design A	High	High	High	High
Design B	High	High	High	High
Design C	High	High	High	High
Design D	High	Medium	High	Medium
Design E	High	Medium	High	Medium
Design F	Medium	Medium	High	Medium
Design G	Medium	Low	Medium	Medium
Design H	Medium	Low	Medium	Low
Design I	Medium	Medium	Medium	Low
Design J	Medium	Low	Medium	Medium

#### 4.4 Conclusion for existing configuration

The proposed rack configuration is not acceptable viewing the number of parts that should be scrapped because of quality defects. Should this design go ahead, the predicted scrap rate of 42%, would result in a significant cost.

Obviously, alternative rack configurations should be considered. Table 4 gives 9 alternative rack configurations (based on general rack plating experience) and describes how these configurations are different from the initial one.

Simulation enables to quickly evaluate if there is any improvement versus the initial rack configuration. For these simulations, the most challenging door handle design is selected (design C), and the Ni show defect on the backside of the door handle is selected as the criterion to judge if there was any improvement.

The table also mentions the load (number of parts on the rack) and the performance. Results will be illustrated in the next section for case 1 (96 parts, poor performance), case 2 (96 parts, very good performance), and the finally selected case 9 (84 parts, very good performance).

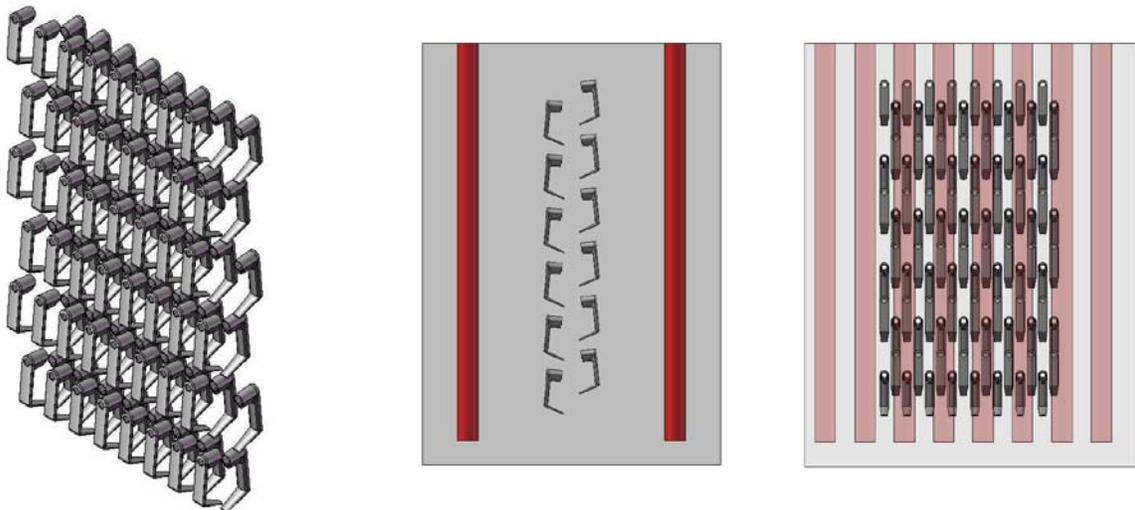
**Table 4: Overview of different rack configurations**

	Description	# parts/rack	Performance
Case 1	Parts at back side of rack shifted over small vertical distance $\Delta y$	96	Poor
Case 2	6 columns, 8 rows	96	very good
Case 3	7 columns, 6 rows	84	Good
Case 4	7 columns, 5 rows	70	Good
Case 5	Parts at back side of rack mirrored from front side, no horizontal shift $\Delta x$ between different rows	96	Reasonable
Case 6	Alternating 8 parts per row and 7 parts per row	90	Reasonable
Case 7	7 rows, alternating 7 and 6 parts per row	92	Good
Case 8	8 rows, alternating 6 and 5 parts per row	88	Good
Case 9	6 columns, 7 rows	84	very good

## 5 Global rack optimization

### 5.1 Case 1

Case 1 is a configuration whereby the parts at the back side are shifted over a small vertical distance (see Figure 6). In this way, the rack load still equals 96 parts to be plated per rack.



**Figures 6: CAD of Ni and Cr tank load, Case 1**



Figure 7: Cr layer thickness distribution over lower parts on rack, Case 1

However, as is shown in Figure 7, there is still a poor throwing power to the back of the door handles. The dark blue regions indicate areas where the Cr deposit will not be high enough and will result in the yellowish Ni show.

## 5.2 Case 2

Case 2 is a configuration with 6 columns and 8 rows (Figure 8). In this way, the load again equals 96 parts, but unfortunately the vertical dimension is exceeded (the parts exceed the boundaries of the blue box representing the maximum package as set by the customer).

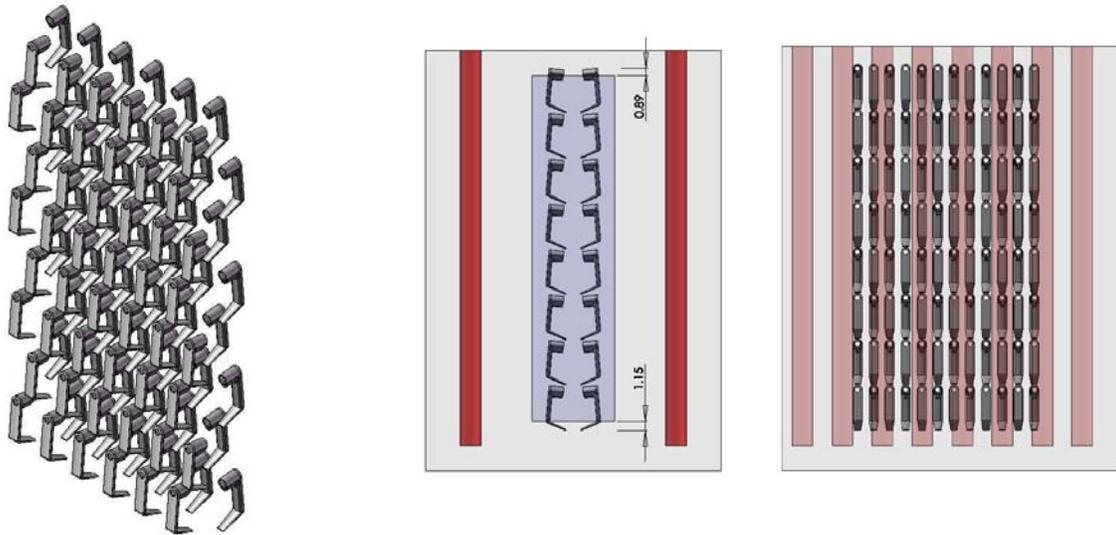


Figure 8: CAD of Ni and Cr tank load, Case 2

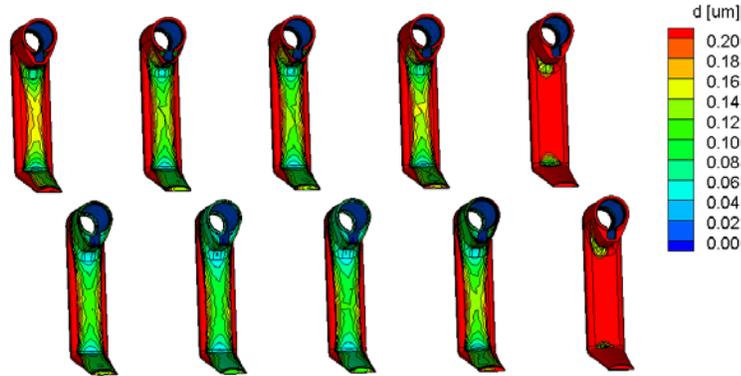


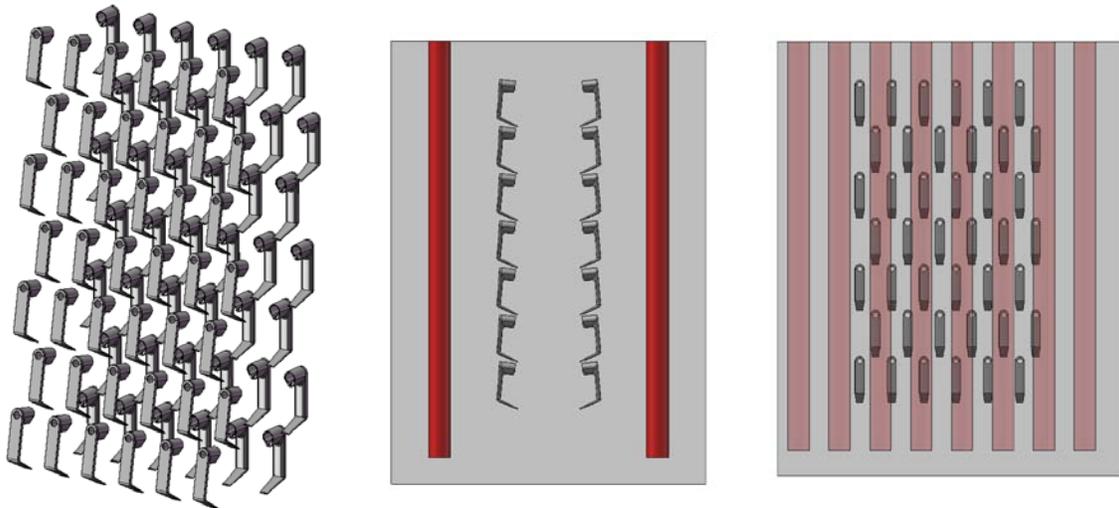
Figure 9: Cr layer thickness distribution over lower parts on rack, Case 2

Note the higher deposit thickness compared to the previous case as there are no dark blue regions in Figure 9.

Case 2 is giving the best performance, but the part load does not remain within the vertical plating package and could therefore not be retained.

### 5.3 Case 9

Finally, case 9 was proposed as the optimal configuration. This rack configuration gives the best performance in terms of deposit thickness (see Figure 11) and product quality. The load however had to be restricted for this configuration to 84 parts divided as 2 times 6 columns times 7 rows (Figure 10).



Figures 10: CAD of Ni and Cr tank load, Case 9

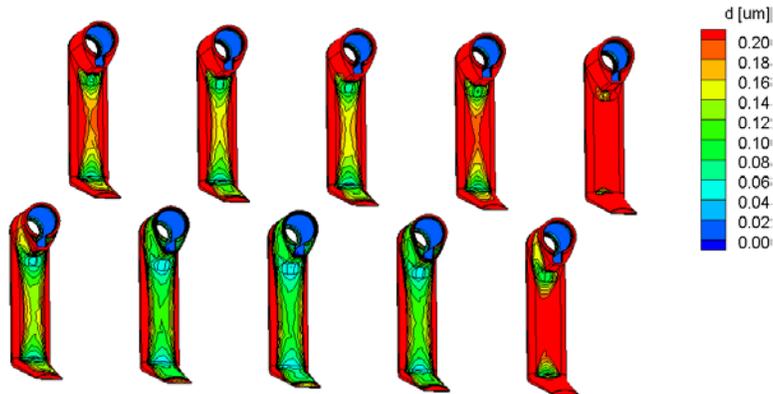


Figure 11: Cr layer thickness distribution over lower parts on rack, Case 9

#### 5.4 Conclusions for global rack configuration optimization

Table 5 indicates the resulting probability of defects for all door handle designs in the final selected configuration compared to the initial one.

To summarize, the initial configuration had:

- A load of 96 parts
- with very high probability of defects
- and 42% of the 96 parts affected with defects.

whereas the new rack configuration has

- a load of 84 parts,
- very low probability of defects
- and a maximum of 5% of the 84 parts affected with defects.

Table 5: Overview of different rack configurations, optimized situation

Part	Probability of Defect				
	Rough Cu	Cr Burn	Ni Show	Nodular Ni Growth	Rectifier $\Delta V$ out of range
Design A	Low	Medium	Low	Low	Low
Design B	Low	Medium	Low	Low	Low
Design C	Low	Medium	Low	Low	Low
Design D	Low	Medium	Low	Low	Low
Design E	Low	Low	Low	Low	Low
Design F	Low	Medium	Low	Low	Low
Design G	Low	Medium	Low	Low	Low
Design H	Low	Low	Low	Low	Low
Design I	Low	Medium	Low	Low	Low
Design J	Low	Low	Low	Low	Low

## 6 Further local optimization: intelligent rack shielding

As illustrated above, the way that parts are distributed over a rack has been optimized, ensuring a rack configuration whereby all door handle parts receive more or less similar current densities.

Nevertheless, further, local optimization to improve the layer thickness distribution over 1 single part is possible. For this purpose, “intelligent” tooling, being it current robbers, auxiliary anodes or shields, can be designed through software simulation,

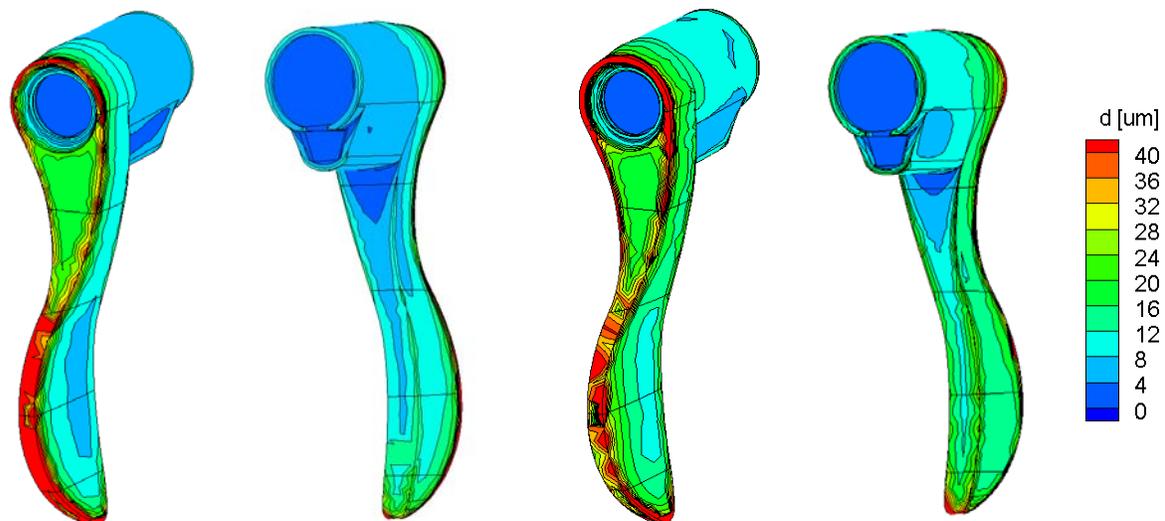
In this case, the focus is on intelligent shielding. The design of current robbers is not feasible due to the fact that the racks are multi-purpose (serving all 10 door handle types), while the use of auxiliary anodes is not accommodated for in the design of the concerned plating lines.

With dedicated shielding, the layer thickness values can be brought much closer to the specifications that are listed in table 1 for the different metal layers, on A and B type surfaces. Also, shields enable a drastic reduction of defects caused by peak current density values above the maximal allowable values.

Another advantage is the material savings that can be obtained. The shields enable a reduction the layer thickness on frontal A type surfaces, while maintaining the same or higher deposit at the other surface areas of the parts.

For the semi bright Ni plating step for the part configuration of case 9, figure 12 illustrates how intelligent shielding, designed with Elsyca’s simulation platform, can help to improve uniformity and avoid defects on a single part:

The minimal layer thickness criterion of 13 micron for semi-bright Ni is now met at the flanks of the part, in sharp contrast to the situation without dedicated shields. At the same time, the high current density area (in red on the left), is reduced to orange except for a small part near the flank. And also the dark blue spot on the backside is drastically reduced.



**Figure 12: semi-bright Nickel layer thickness distribution without (left) and with dedicated shielding (right)**

From an operational point of view, the shields could simply be hooked up to the rack after the door handle parts are loaded. Similarly the shields are removed before the rack is unloaded.

Shields could be considered later in a program as a way of further process improvement, or indeed, as a retro-fitting option for other part programs. Detailed analysis and description of the intelligent shielding design is out of scope of this paper.

## **7 Final conclusions**

The above rack design case clearly illustrates the power of CAE engineering.

The challenge to design a rack suited for decorative Cr plating of 10 different door handle designs, accounting for the objectives of minimal scrap and maximal productivity, was tackled by making use of Elsyca's advanced simulation technology.

It goes without saying that a trial-and-error approach as often used in actual daily practice is way too time and money consuming. A typical trial wet run comprises the following steps:

1. improve of the design of the rack (based on experience/feed back from previous test runs or from production);
2. refurbish an existing rack (or build a completely new rack);
3. series of production runs with the newly build/improved rack;
4. visual inspection and destructive testing on a number of sample parts.

Considering the time and expense required to fabricate and test a rack design in practice, such an approach can easily take 2-3 weeks, involving the consumption of energy, chemicals and actual component/parts to test and measure. CAE needs no pilot plant facility, requires only the part and rack CAD and takes only 1-2 days to evaluate a rack design.

Simulation of the initially proposed rack configuration enabled to indicate the probability of defects for the different door handle designs with respect to Cr burn, Ni show, Ni nodular growth, and the rectifier being out of range. The potential scrap rate for the proposed rack design was unacceptable and lead to a program of further design and optimization.

Alternative rack configurations were defined and simulated to judge the improvement versus the initial rack configuration. On the finally selected rack configuration the number of parts on one rack was lowered from the initial number of 96 to 84 parts, but the realized savings are significant due to an enormous scrap fraction reduction, leading to additional benefits of increased yield, shorter lead times, metal savings, and reduced costs for waste and water treatment.

Further local optimization is possible making use of intelligent shields on the rack. These shields again are designed with the same simulation platform.

The use of simulation technology upfront of production has proven to be a valuable decision-support tool to steer the production process and allows saving considerable time and money.