COST FACTORS OF THE CLEANING PROCESS—
PART 1

IMPROVED EFFICIENCY USING ROOT CAUSE
FAILURE ANALYSIS • FUTURE INDUSTRY
DIRECTIONS • A REVIEW OF HALOGEN/HALIDE-
FREE TEST METHODS • BGA OPTICAL JOINT
INSPECTION CRITERIA • DIS-INTEGRATED CIRCUITS
Cost factors of the cleaning process—part 1

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Companies are constantly striving to reduce costs incurred during electronics production in order to increase cost effectiveness. Generally rising costs or the need to preserve competitiveness relative to low-wage countries further reinforce this development. Being part of the value chain and production, cleaning processes for electronic assemblies are also subject of cost analyses. The following article, the first in a three-part series, presents a detailed summary of all cost factors relevant to the acquisition and operation of cleaning processes. A detailed analysis for optimizing individual cost factors in batch spray systems and inline processes will be conducted in two additional studies.

The cost of a cleaning process depends on different factors. These can vary significantly depending on the application or the cleaning equipment. Therefore, total costs have to be calculated relative to the throughput or to the number of cleaned parts in order to determine a cleaning process’s true costs. So, the general rule is:

\[
\text{cost per cleaned part} = \frac{\text{costs of a cleaning process}}{\text{number of cleaned parts}}
\]

The result of this calculation shows the cost incurred for each cleaned assembly depending on production output. Naturally, every company’s objective is to keep these costs at a minimum.

However, to establish the cost per cleaned part and to reduce it by implementing appropriate process improvements, the factors influencing a cleaning process’s investment and operating costs must first be determined.

Therefore, over the past few months, extensive studies on the subject of “cost factors of the cleaning process” have been conducted at Zestron’s worldwide Technical Centers using different machine types (Figure 1).

The study’s objectives were:
1. to identify all major cost drivers in cleaning processes,
2. to determine factors influencing the cost drivers, and
3. to identify approaches for realizing cost reductions.

Step one, identifying the major cost drivers, can be illustrated quite quickly. As already mentioned above, a distinction is made between the investment and the depreciation of a new process and the operating costs of an existing cleaning application.

With a new investment, users must consider the following factors as they have a major impact on the cleaning process’s type as well as size and therefore on later investment costs:
- Expected production throughput
- Necessary degree of automation
- Equipment size and/or available floor space
- Type of cleaning medium

Subsequently, operating costs occur during electronics production due to:
- the consumption by equipment peripherals such as exhaust systems, etc.,
- the operating staff and maintenance costs, and
- the consumption of cleaning media and energy

Figure 2 illustrates and compares all relevant cost factors of a cleaning process.

After identification of the major cost drivers, a more detailed analysis will determine the other influencing factors and possible options for cost optimization.

1. Cost factor: cleaning equipment
When the cost factor “cleaning equipment” is discussed, the initial investment in the cleaning machine is often considered first and is naturally the greatest cost factor.
when installing a new cleaning process.

The selection of the equipment should be based on the expected throughput and the user should first decide for one of the three basic machine types: ultrasonic benchtop, batch machine (i.e. one-chamber spray-in-air equipment), or inline machine. Table 1 illustrates the different application areas and serves as a basic guide.

Apart from the expected throughput, there are further requirements that the user should evaluate before selecting the equipment. The approved investment budget should not be exceeded and the machine's size must be suitable for the available footprint. Furthermore, the cleaning machine's level of automation must be considered for the purchase decision since it influences subsequent operational costs of the process. The user must turn to the operational costs of the cleaning process once the equipment has been purchased.

Looking at the operating process, costs are incurred at various points depending on machine types construction. On the other hand, these can also provide options for savings.

Using the smallest process, the benchtop, cleaning and rinsing takes place in separate process tanks. Savings are thus realized primarily through the optimal positioning of the parts to be cleaned and the drip-off mechanism.

For batch machines, such as one-chamber spray-in-air machines, existing pipes, spray bars and pumps are often used for cleaning and rinsing. The drag out of the cleaning medium due to dead volumes in the machine thus influences the process costs. However, drag out does not just occur due to the machine's construction, but also due to the configuration of the parts to be cleaned. Since the assembly geometry cannot be changed, the main option for optimization is the drip-off time.

Apart from the exhaust system, the most important cost-driving factor of inline machines is the drag out of cleaning medium into the rinse stages. A suitable configuration of the air knives thus represents a prerequisite for potential savings.

2. Cost factor: equipment peripherals

In reference to the cleaning equipment's periphery, the study's results reveal that costs during the process operation essentially arise through processing, drag out and exhaust. The equipment periphery is structured differently depending on the machine type. Table 2 shows the peripheral systems that were investigated.

In summary, this means the following:
1. The cost aspect 'equipment periphery' is virtually non-existent with ultrasonic benchtops, since typically neither the cleaner nor the water are treated
2. The biggest cost driver in the batch process investigation, such as one-chamber spray-in-air machines, proved to be the processing or production of deionized water for rinsing. Using either an ion exchanger or reverse osmosis are reasonable depending on the amount of deionized water consumed. Costs also arise for processing the cleaning agent in closed loop, e.g. through filter changes.
3. In inline processes for high-volume production, peripheral equipment costs have the largest impact

<table>
<thead>
<tr>
<th>Cleaning equipment</th>
<th>Ultrasonic benchtop</th>
<th>Batch process, e.g. one-chamber spray-in-air equipment</th>
<th>Inline process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput per shift</td>
<td>approx. 50–100</td>
<td>approx. 500–1,500</td>
<td>&gt; 3,500</td>
</tr>
<tr>
<td>Investment volume</td>
<td>1,000–5,000€</td>
<td>20,000–80,000€</td>
<td>&gt; 100,000€</td>
</tr>
<tr>
<td>Foot print</td>
<td>&lt;1 m²</td>
<td>1 m² to 3 m²</td>
<td>&gt;10 m²</td>
</tr>
<tr>
<td>Degree of process automation</td>
<td>none (manual)</td>
<td>medium (manual loading/unloading of cleaning goods)</td>
<td>high (fully automated, completely integrated into the production process)</td>
</tr>
</tbody>
</table>

Table 1. List of common cleaning systems. (These data are merely a guide).

<table>
<thead>
<tr>
<th>Ultrasonic benchtop</th>
<th>Batch process, e.g. one-chamber spray-in-air equipment</th>
<th>Inline process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not available</td>
<td>• Deionized water treatment (e.g. activated carbon, mixed bed resin)</td>
<td>• Machine exhaust</td>
</tr>
<tr>
<td></td>
<td>• Processing of the cleaning medium (filtration)</td>
<td>• Deionized water treatment (e.g. activated carbon, mixed bed resin)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Processing of the cleaning medium (filtration)</td>
</tr>
</tbody>
</table>

Table 2. Cost-relevant periphery by cleaning equipment.
on the total process cost. This is mainly due to the vapor losses through the machine's exhaust system. As the investigation shows, the exhaust gas temperature and the spray nozzles’ atomization of the cleaning medium are the decisive factors. Furthermore, the results show that cost savings are possible by optimizing the treatment cycle of the cleaning agent and the rinse water.

The energy consumption and maintenance costs of the above mentioned cleaning processes were also investigated in the study. In addition to the operating costs incurred by machine peripherals during cleaning, the results for energy consumption and equipment maintenance are listed below.

### 3. Cost factor: energy consumption and equipment maintenance

Depending on the cleaning process, the amount of operational costs varies considerably. Figure 3 illustrates this.

Ultrasonic benchtop processes suitable for the lowest throughput exhibit the lowest total operating cost in this context since relatively little power is needed to heat the bath and additional costs for compressed air and for drying are not necessary. On the other hand, staff costs comprise the largest share of the operating costs since all process steps such as cleaning, rinsing and drying must be conducted manually. In addition, due to the low bath volume, this type of process does not have an integrated filtration system so that frequent bath changes are required and can lead to further maintenance costs.

In batch cleaners, the cleaning agent, and, if necessary, the rinse water must be reheated after each cleaning step. Due to this and the drying of the entire cleaning chamber, considerably higher energy costs arise in batch systems compared to benchtops. In addition, discharging the water after each rinse causes further operational costs. As this type of process is mainly automated, staff costs usually only occur for loading, unloading and maintaining the machine. Furthermore, the integration of a treatment process for the cleaning agent, such as filtration, maximizes the bath life, so that expensive bath changes are required considerably less often than with benchtop systems.

In the studies, the consumption of water, energy and compressed air by inline systems had the greatest effect on the overall process costs (as expected). In general, these are closed loop circulation systems and the processing cost for rinse water is relatively high. Furthermore, most inline systems must be operated continuously to ensure consistent process results and even during times when no parts have to be cleaned. Due to this, continuous energy expenditures arise and are generated by the cleaning bath's circulation and heating as well as by the exhaust system after the rinse stage and before drying. Additionally, costs are incurred when blowing off the cleaned parts, as air knives are integrated into the line multiple times. Due to the inline sys-

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**Figure 3. Relationship of operating costs for the different machines per part.**

<table>
<thead>
<tr>
<th>Solvents</th>
<th>Cost advantages</th>
<th>Cost disadvantages</th>
</tr>
</thead>
</table>
| • long bath life  
• short process times | • high evaporation losses  
• expensive exhaust treatment  
• explosion protected equipment required |

<table>
<thead>
<tr>
<th>Traditional surfactants</th>
<th>Cost advantages</th>
<th>Cost disadvantages</th>
</tr>
</thead>
</table>
| • low evaporation losses  
• low application concentrations | • short bath lives, thus expensive bath changes needed |

<table>
<thead>
<tr>
<th>Modern water-based cleaners (e.g. MPC® media)</th>
<th>Cost advantages</th>
<th>Cost disadvantages</th>
</tr>
</thead>
</table>
| • low application concentrations  
• long bath life  
• low evaporation losses | • filtration for enhanced bath life required, thus cost for filter changes, etc. |

**Table 3. Cost consideration of the operating process.**

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**Figure 4. Comparison of bath lives.**
tem’s permanent operation, comparatively high maintenance and repair costs occur as well. However, operator costs are relatively low due to the fact that inline machines are completely integrated into the production line and therefore easier to operate and monitor by a single person.

In summary, it can be stated that operating costs increase relative to the throughput and the equipment size. At the same time, the study confirms that personnel costs decrease as the cleaning process’s degree of automation increases. Furthermore, immersion systems and spray processes only incur costs during cleaning, whereas operating costs for inline systems arise even during idle phases.

After all costs associated with the cleaning equipment have been carefully considered, as a next step, a suitable cleaning agent must be selected. The relevant cost factors in this area will be shown in the following part of the study.

4. Cost factor: cleaning medium

In the industry, primarily three types of cleaning agents are used for the cleaning of electronic assemblies. These include alcohols, conventional surfactants and modern water-based cleaning media. When a new cleaning machine is purchased and the tank has to be filled with a cleaning agent for the first time, companies often focus on the cleaning medium’s price per liter. However, this is not the only fact that determines the ultimate costs of the cleaning agent.

For example, the bath life is crucial, i.e. how long the cleaning agent can be used before a bath change is required. Thus, a cleaning agent with a short bath life may be more expensive in the long run, despite its favorable price per liter, than a cleaning medium with a higher purchase price providing a longer bath life.

Based on their respective chemical properties, the three types of cleaning agents mentioned above have individual cost advantages and disadvantages during cleaning, as Table 3 shows.

Most solvents exhibit long bath lives and short process times due to their excellent drying properties (see Figure 4). However, there are cost disadvantages due to high evaporation losses, the necessary explosion protection for cleaning equipment, which typically has an impact on the initial investment or even an expensive filtration of the exhausted air.

Conventional surfactants do not have these problems. At the same time, they are sold at an appealing price per liter and are often used with low application concentrations. Nevertheless, their bath life is mostly quite short, which leads to frequent bath changes and increases the costs due to the higher cleaner consumption (Figure 4).

On the other hand, modern water-based cleaning media provide very long bath lives (Figure 4) and can also be operated at low application concentrations. Costly evaporation losses, as with solvents, are neglected. Also a long bath life can be achieved via a filtration cycle in the cleaning machine for additional costs.

At this point, to choose the right cleaning agent, users should seek advice from a cleaning expert, who can determine the most cost effective solution. Similarly, it is crucial to choose a cleaning agent that is suitable for removing the specific contamination and thus ensures the best possible cleaning results.

Summary

To determine the cost per cleaned part and to take appropriate measures to reduce costs, all cost drivers and their parameters must be identified. Therefore this article has provided a fundamental basis.

The results of the previously mentioned technical studies point out that the throughput during assembly cleaning essentially represents the basis for the equipment selection. At the same time, however, operating costs for energy consumption and maintenance are also largely determined by the equipment choice while specific measures for realizing significant savings cannot be taken.

Once the cleaning process is implemented, the cleaner, the equipment periphery and the process parameters prove to be the only cost factors that can be influenced and thus optimized. Therefore, these three factors will be specifically investigated in two subsequent studies focusing on batch and inline processes to even better understand them and to detail possible savings potentials. These types of cleaning processes involve the highest cost cases due to their technology’s complexity and thus have the most potential for savings.