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Intelligent disassembly of components from printed circuit boards to enable re-use and more efficient recovery of critical metals

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Abstract

Based on previous experiences in intelligent disassembly of components from printed circuit boards our goal was to develop an economic solution for reducing the amount of material for the later hydrometallurgical recovery process and to recognize reusable parts on printed circuit boards. Usually the hydrometallurgical recovery process is very time consuming and therefore the recovery rate still relatively low. Therefore, it is beneficial to enrich the content of critical metals in the input fraction by extracting only those components from printed circuit boards that are rich in the target metals (e.g. tantalum, rare earth, platinum group metals).

In addition, there are reusable parts on printed circuit boards which have a high enough resell value on the market. These components must be dismantled, but in a more careful way in order not to destroy the function of the component by thermal or mechanical influences.

One advanced possibility for solving both problems is the adaptation of our semi-automated, flexible disassembly cell for printed circuit boards. This modular cell was developed some years ago for removing re-useable electronic components from old as well as new printed circuit boards. Main modules are a transportation system, a vision system and heating-unsoldering stations.

In this contribution, this new approach will be described from the technological as well as from the economic point of view.

1. Introduction

Electr(on)ic products consist of a high amount of diverse metals. According to a survey of Sullivan, D.E. (2006) e.g. mobile phones have a metal content of 25 % (accumulator and recharger not included), mainly copper (Cu), iron (Fe), nickel (Ni), silver (Ag) and zinc (Zn). Though the absolute amounts of each device regarding the most valuable elements are low (16 g Cu, 0.35 g Ag, 0.0034 g Au, 0.015 g Pd, and 0.00034 g Pt) this adds up to e.g. 0.7 t of platinum based on estimated 2 billion of cell phones in 2015.

Regardless of their low amount in specific electronic components there are some metals which are highly preferred or are even essential for the present technology. The most famous example is tantalum and niobium.

2. Materials and methods

We performed experimental tests on a sample of printed circuit boards (PCBs) that have been manually dismantled from End-of-Life computers. These PCBs were first visually inspected and the mounted components analysed. In a literature search we identified potentially interesting components based on their re-use value as well as on their material composition (percentage of critical metals). These results we used to modify our semi-automated dismantling line – initially developed to disassemble only re-usable and hazardous (for depollution) components to extract components rich in critical metals, but as quick and cheap as possible. We ground the extracted components to a powder with a particle size of less than 2 mm as input to our hydrometallurgical HydroWEEE process.

3. Results and discussion

3.1 State of the art

Currently disassembling for recycling, if it is done anyway, is mainly a manual process. But with the enormous increasing amount of products to be recycled and therefore also to be disassembled, such as computers, printers, telephones and other electronic devices and all sort of household-equipment, it is necessary to automate this aim to increase efficiency. High flexibility and low-cost of disassembly processes will be necessary. The automation potential will be one of the most important productivity factors for this new production process and becomes a new challenge for engineering. The two main goals are:

- Reduce the costs of disassembling for optimizing the recycling processes and;

- Create a humane working environment in disassembly factories.

Due to the particular characteristic and requirements of disassembling tasks, disassembling needs structures and methods for a semi-automated disassembling with both, use of manual and automated (e.g. robotised) workplaces to meet the requirements of a new life cycle strategy.

With an intelligent form of disassembly, it will be possible and economically feasible to extract the re-usable components in a larger amount.

Until now a very high standard in the field of automation and robotics have been reached, but focused mostly on assembly. Few parts of electronic scrap are recycled after disassembling; however, the degree of automation is still very low - only some pilot or demonstration projects are realised mainly in research institutes.

Disassembling, as the first and most important operation in the recycling process, will be a part of the industry with a high rate of expansion. Not only with the increasing trend of de-manufacturing and re-manufacturing there will be a high growth potential.

(Semi-)Automated disassembly

Existing concepts are very inflexible and only developed for a special task or product. “Stiff” automated disassembly in single purpose cells – only for one product (e.g. one type of PC) – cannot be economically feasible today. The number of devices or parts to be collected and concentrated on the place of the disassembly cell is usually too low for a two-shift operation of the cell.

3.2 Semi-automatic disassembly of printed circuit boards

The process can be divided into several steps which are performed successively.

At the beginning, PCBs (printed circuit boards) are dismantled from collected electrical and electronic equipment manually. In this stage, the flexibility of manual operators is used which allows the disassembly of equipment from various sources.

After this manual disassembling procedure, the PCBs with a maximum size of 300x220 mm are fixed on frames with special holding devices and enter the disassembly cell on a conveyor belt. The disassembly cell itself consists of the following stations:

- Vision system
- LASER de-soldering system
- Robot removal station
- Infrared heating removal station
- Stock for de-soldered components

A recognition system with image processing - “Vision System” - identifies re-usable parts and toxic components

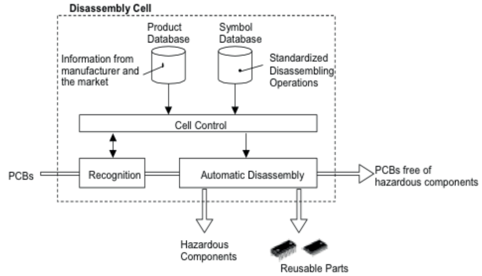

Figure 1. Schematic of the semi-automated disassembly cell for PCBs.

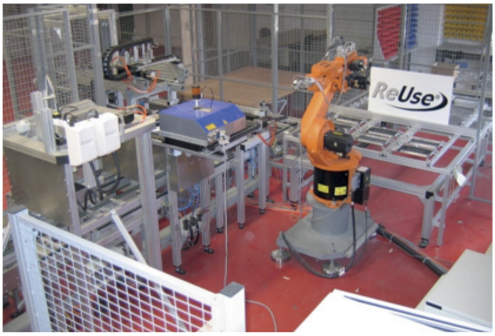

Figure 2. Industrial realization of the disassembly cell.

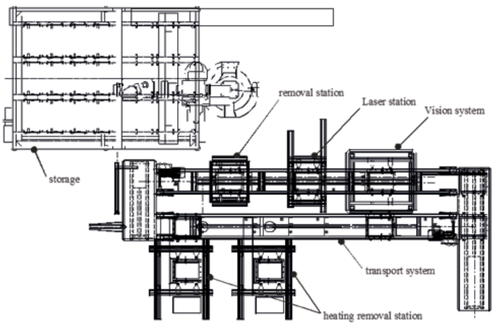

Figure 3. Layout.

on the PCB. This is done by comparing the shape and labels of the parts with a database containing information from manufacturers and information from the re-use market. Beside this the system has to determine the position, size, and the centre of area of the considered component and provide this data as input for the next stations.

To acquire the data, required for a selective disassembly, a high-quality image processing system is necessary. To localise and identify the reusable components on the PCB the vision systems must be able to reach a position in accuracy of 0.1 mm (coordinates, etc.) and recognize the characters on the part by means of Optical Character Recognition (OCR).

Components which are recognised as valuable or potentially hazardous are de-soldered either by Laser or infrared heating and removed using special robotic grippers in the next process step. The combination of a special laser de-soldering technology and special robot

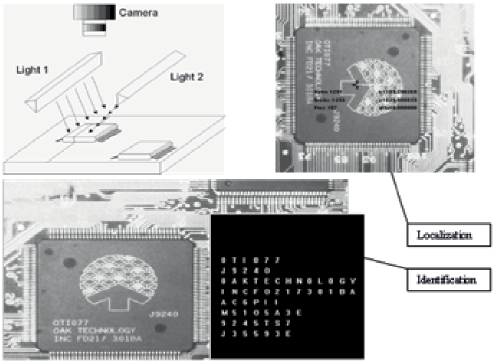

Figure 4. Vision System.

grippers allows us to remove a wide variety of electronic components from the processed PCB. The application of a laser de-soldering process has several advantages compared to conventional techniques (e.g. hot air):

- The temperature of the de-soldering process can be controlled precisely.
- The laser is flexible in view of shape and position of the different components.
- The necessary time for the de-soldering process is very short due to the direct heat transfer.
- The laser beam can be focused on the pins without heating the body of the components.

Summarizing the applied laser technique causes minimal thermal stress for the components, which results in an extended life-time for the re-usable components.

Additionally, the infrared heating appliance unsoldering technology is used to extract components which are not suitable or valuable enough for the laser unsoldering station. By means of the infrared heating station through hole mounted components can be de-soldered (e.g. electrolyte capacitors).

Finally, the disassembly process results in PCBs which are less environmentally relevant and electronic components suitable for re-use.

This system has been operated successfully in industry since 2003.

3.3 The HydroWEEE project

The aim of the research project called HydroWEEE (Innovative Hydrometallurgical Process to recover Metals from WEEE including lamps and batteries) was the recovery of base, precious and critical metals from WEEE residues. Within the HydroWEEE project, different processes for the exploitation of WEEE residues were developed to extract high-purity metals.

In the first research project, a mobile pilot plant with a reactor size of 1 m^3 has been developed that has been and still can be used for process development and optimization. However, in order to really demonstrate the stability, financial credibility and resource-efficiency of our innovative processes an industrial stationary plant as well as a full-scale mobile plant (2-3m^3 reactor) has been necessary. Finally, the previously developed processes of extracting yttrium, indium, lithium, cobalt, zinc, copper, gold, silver, nickel, lead, tin still can be improved even more and new processes to recover additional metals which are still in these fractions (e.g. cerium, platinum, palladium, europium, lanthanum, terbium, …) from WEEE or other sectors (e.g. automotive, …) as well as innovative solutions for the integrated treatment of waste water as well as solid wastes must be developed. The objective of the just finished follow-up project HydroWEEE Demo (2012-2017) has been to build 2 industrial scale, real-life demonstration plants (one stationary and one mobile) in order to test the performance and prove the viability of the processes from an integrated point of view.

These used the WEEE residues for the recovery of Y from fluorescent lamps; Y and Zn from CRTs; Li and Co from Li-ion accumulators; and Cu, Ag, and Au from PCBs. The advantages and novelty of this portable plant include its cost-effectiveness and the use of innovative processes that can be applied anywhere where the plant is based. This last arises from the portable nature of this plant, which allows small enterprises without their own recycling plant, along with the many collection facilities that can now be found in most countries, to take advantage of its transportability.

Especially with printed circuit boards we found that the critical metals are in a too low concentration to make the extraction using hydrometallurgical processes economical.

That was the starting point for us to develop a new cheap technology to extract the components that are rich in critical metals and only use these components - and not the complete, populated printed circuit board - as input material to our HydroWEEE process. With this new idea – combining semi-automated disassembly with the chemical recycling process - we could enrich the content of target metals in our input flow dramatically.

Figure 5. Mobile HydroWEEE Demo plant.

3.4 *The RECLAIM project*

Based on our previous experience with semi-automatic disassembly lines as well as with hydrometallurgical processing of critical metals our goal in the RECLAIM project has therefore been to develop a new, low-cost dismantling system that selectively disconnects components containing critical metals.

In order to do so, we carried out a literature and internet search on which components contain which materials. Then we started to develop a concept for a much cheaper RECLAIM solution. The main differences between the re-use and RECLAIM lines are:

- Focus shifts from careful removal of components for re-use to a quick and low-cost removal for RECLAIM.
- Only vision system, selective infrared heating, removal and storage for different components (according to material content for further processing) necessary.
- Afterwards no sorting must be necessary .

In order to estimate the necessary investment, we configured a special infrared heating and removal system. Compared to the previous re-use system the recovery system does not contain the laser de-soldering station as well as the disassembly robot.

First discussions with suppliers of such an equipment led to approximate investment costs of 40 -50.000 € net.

After that we had to estimate the disassembly cost per component. The cycle time per boards consists of a time period that the PCB fixture needs to enter and leave the infrared heating and removal station (10 seconds), a period to heat the board before the extraction of components can be started (25 seconds) and finally the time for picking a component from the board and placing it in the right container (5 seconds) which means that we have a fixed time for loading/unloading and heating as well as a variable (depending on the number of components per board). Because of that we analysed 131 printed circuit boards collected locally in Austria and found the following distribution of components per board, see figure 6.

On average 46.85 components were on this sample on one board. But as not all components can be economically extracted, we investigated also the number of extractable components per board, see figure 7.

On average 6.34 components per board are extractable and contain interesting amounts of critical metals.

Concerning the time necessary for heating the infrared module (1000W, 64kWm-2, 900°C, 2-10 μm), you can see in the graphs below that the first heating takes about 2-3 minutes, but as the time between for exchanging the boards is rather short, we assumed that we leave the heating on and only the time necessary for the radiation and convection has to be taken into account.

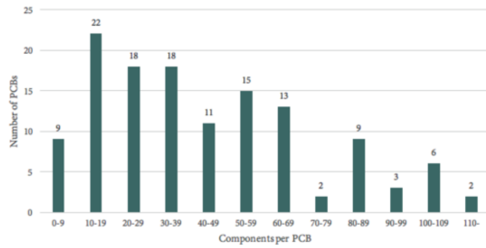

Figure 6. Number of components per PCB.

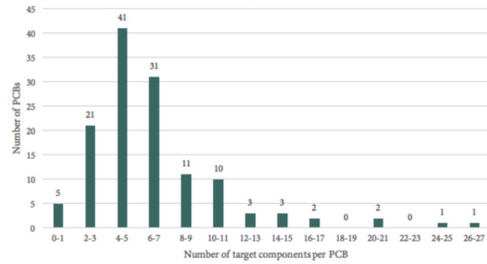

Figure 7. Number of target components per PCB.

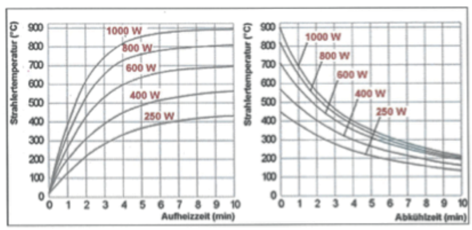

Figure 8. Step responses for heating and cooling of the de-soldering station.

All these results we used as input for the calculation of 2 principle set-ups of RECLAIM disassembly systems:

- Version I: consisting of 1 vision system and 1 infrared heating and removal station with approx. total investment costs of 150.000 € net.
- Version II: consisting of 1 vision system and 2 infrared heating and removal stations with approx. total investment costs of 220.000 € net.

From previous investigations we used as typical costs (including all overheads and indirect costs like maintenance, electricity, …) in recycling companies in Western Europe for 1 hour in a workshop of approximately 60 €.

As a result, we can expect average costs of 0.20 € per component and an annual capacity of 1.1 million targeted components for a Version I system and 0.11 € per component and a capacity of 2.1 million components for a Version II system.

When the focus is put on re-use of components we can expect typical costs of 0.70 € per component for carefully removed components (integrated circuits, memory chips, …) and similar costs as in the RECLAIM lines for the hazardous components.

The optimal economic feasibility will be achieved by combining both lines into one and extracting re-usable, hazardous and components rich in target materials as the fixed time for mounting, transport, clamping, detection, … can be distributed over a larger number of components. And this leads automatically to decreasing costs per disassembled component.

4. Conclusions

The main goal of this paper is to describe a cost oriented way for extracting rare materials and reusable components from electronic scrap.

Based on previous works it consists of a combination of a hydrometallurgical process with semi-automated disassembly lines.

Because the hydrometallurgical process is very time consuming the amount of the input material is dramatically reduced by means of semi-automated disassembly of the interesting components for extracting rare materials as well as reuse.

This allows also a very accurate temperature control for unsoldering of reusable components important for overheating and the remaining life time of the components.

The economy of this method is illustrated by means of tests on several PCBs.

Further work will concentrate to decrease the costs of the lines e.g. by means of advanced control algorithms for reducing the heating time.

In addition, the costs for intelligent disassembly will be benchmarked with manual dismantling in low-income countries.

Finally, the costs for dedicated dismantling will be compared with the revenues from critical metals extracted with the HydroWEEE process in order to check the profitability of this additional step in the recycling chain.

Because of the relatively high additional (functional compared to only material) value of the re-use components we are convinced that a combined re-use and recovery line will be profitable anyway.

5. Acknowledgement

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