ADVANCED MANUFACTURING PROCESSES FOR LOW COST GREENER LI-ION BATTERIES

Electrodes Laser Cutting

Comparison between Electrodes Mechanical Notching and Laser Cutting

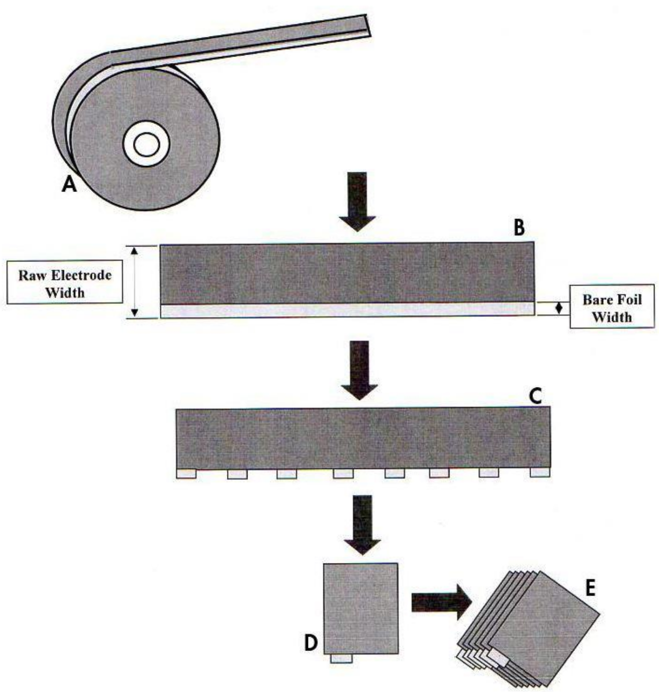
One of the GREENLION goals was to assess which laser technology to implement in electrodes laser cutting

In this chapter we will make a comparison between the mainstream mechanical electrode notching and the laser cutting technology resulting from the GREENLION investigation . We will put in evidence the key factors to be considered in order to understand when and why it is possible to choose one or another technology.

Introduction

Electrode cutting is required when the shape of the final cell is not directly achievable using the raw electrode rolls .

This is the case of prismatic cells that are composed stacking several elementary cells : a cut is required to separate the electrode from the roll and another to get the current collector from the uncoated edge.



The electrode foil is inserted into the machine starting from a reel which is made to unroll (A); · The alignment of the foil is continuously monitored by a sensor (B); · The foil is made to proceed until under the first notching of the tab only one electrode at a time (C); · The sheets via a supply system reaches a second shearing which proceeds to the cut of the individual electrodes, thus separating one from each other, which are then inserted in a transmission system (D); The electrodes are finally collected to storage box that is managed manually by an operator (E).

Mechanical Notching

The shearing is a process of cold plastic deformation that consists in cutting metal foils through the action of shear forces between two form tools: the punch and the matrix, which may take various forms on the basis of' application. This is an operation with very high productivity (0.1 to 5 rounds per second), therefore suitable for mass productions. The sheet of electrode comes from a coil and is placed on the sharp edge of the matrix, while the punch, moving from high downwards, notches the material with its sharp edge. Between punch and matrix is a well-defined gap, generally between 2.5% and 10% of the thickness of the sheet to be cut, that will be obtained by reducing in a suitable way the dimensions of the punch. This gap will have to be constant along all the entire contour of the cutting edge to ensure good processing conditions, and to provide uniformity in the distribution of pressures resulting in uniform wear of the molds. The quality of the cut, defined by the technical specifications of the electrodes, usually accepts burrs, processing defects, with the maximum size of 15 to 20 µm and absence of delamination of the material.

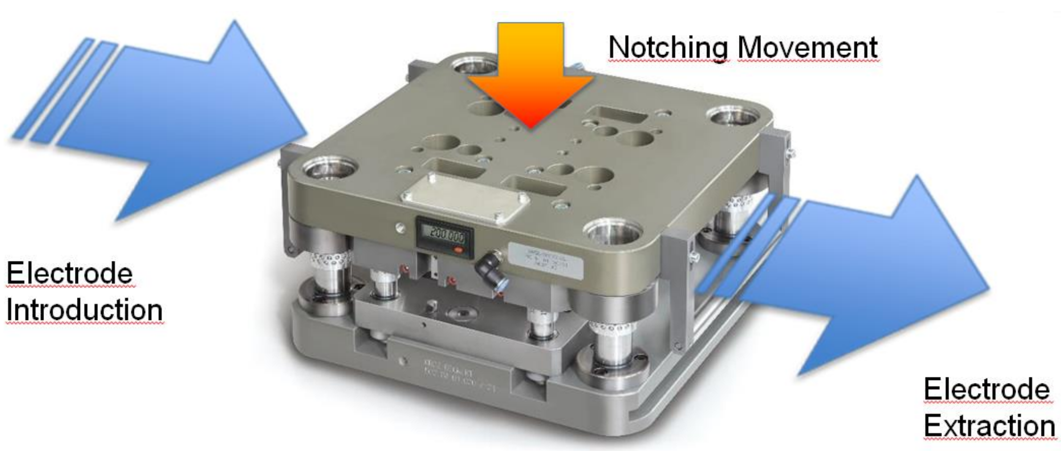


Figure 1: Mechanical Notching tool . (Reproduced with permission from [1])

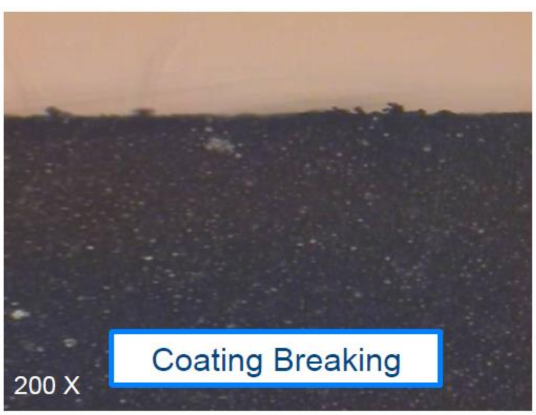
Notching Parts : Punch and Matrix
Clearance between Punch and Matrix 2.5% to 10% of electrode Thickness e.g. 2.5 µm for a 100 µm electrode
Clearance must be uniform along all cutting area to guarantee cutting quality
Up to 5 punches per second depending on tool mass
Notching tool mass : 45 kg

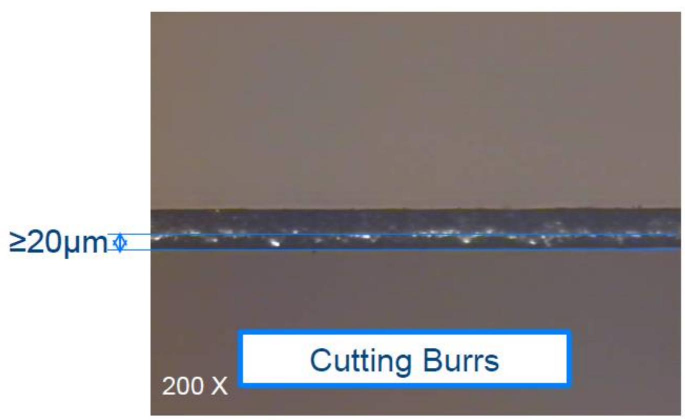
Cost Extrapolation from Typical Mechanical Notching Workflow

To process the raw electrode roll and typically get a second roll with the right carved profile, an automatic machine is built around the notching tool. The heavy rolls have to be wound and unwound, the foils need to be tensioned and aligned and moved with the right speed profile to match the tool.

Since, basically, most of this hardware is required even if we change the cutting technology we will focus in our comparison only on the parts that change.

It is considered for simplicity of analysis that the machining operations on the anode and on the cathode are identical. The mechanical notching tool can be purchased in Asia at a cost of € 25,000 or in Europe or in the US at a cost that is between € 28,000 and € 30,000. Mechanical cutting performed on the electrode causes burrs in the microstructure of the sheet, the dimensions of which vary according to the wear of the edge of the cutting blades. To keep the quality of the electrode within the required technical specifications, ie burrs maximum size of 20 microns, is necessary to maintain the components of the equipment.





It is was verified that after approximately one million cycles of the machine it is necessary to re-sharpen the blade. The cost of this operation varies according to the chosen supplier; in Asia the rate is about 400 €, while in Europe and the United States is around € 600. The time required for regrinding falls within the working day, while the total time for this operation varies according to the logistic policies adopted for the transport. It is reasonable to assume that the total time, including the performance of the activities and logistics, both of 3 days. A tool edge can be reground up to 25 times, after which you need to recondition replacing the die and punch. The cost for this operation is 60 ÷ 65% of the cost of the complete notching tool and the time required varies with the same considerations of regrinding and is supposed to be three days. It is not possible to recondition more than 3 or 4 times depending on the machine used, since the extended use can generate serious problems of wear that would compromise the quality of the cut. The initial investment cost on the notching machine, for the acquirer, will therefore depend on its daily production of electrodes. Assuming a high rate production, in 3 days presumably reaches the maximum limit of cycles beyond which it is necessary regrinding then it is appropriate to do an initial investment that includes three cutters, two of which available in stock for replacement. A medium production rate requires only two cutters in order to avoid production stops during the three days required for re-sharpening while an experimental production will need only one.

The blanking process involves the use of a suction system that recovers the coarse dust generated and the excess material but this is typically always present in a plant of this type, therefore, the analysis will not considered that cost. The notching tool also requires installation of a mechanical handling with an estimated the cost of € 14,000, including the cost of the motor that moves the cam of the punch, the cost of the linear motor and that of the cutting motor.

Issue	Number	Unit Cost
Mechanical Setup for machine interface	1	14.000 €
Multiple Notching Tools required to avoid machine downtime during maintenance	2	22.430 €
Limited notchings without maintenance	1 million	
Limited Resharpening Capability before reconditioning: Reconditioning time 3 days	25	400
Limited Reconditioning Capability before complete Tool replacement	4	14.580 €
Total tool life after reconditioning [notchings]	100 millions	

Table 2: Electrode Mechanical Notching Key Points

Issue	Number	Unit Cost
Mechanical Setup for machine interface	1	2.000 €
Laser Source Cost	1	130.000 €
Beam Transport and Focusing	1	20.000 €
Fumes Filtering System	1	10.000 €

Table 3: Electrode Laser Notching Key Points

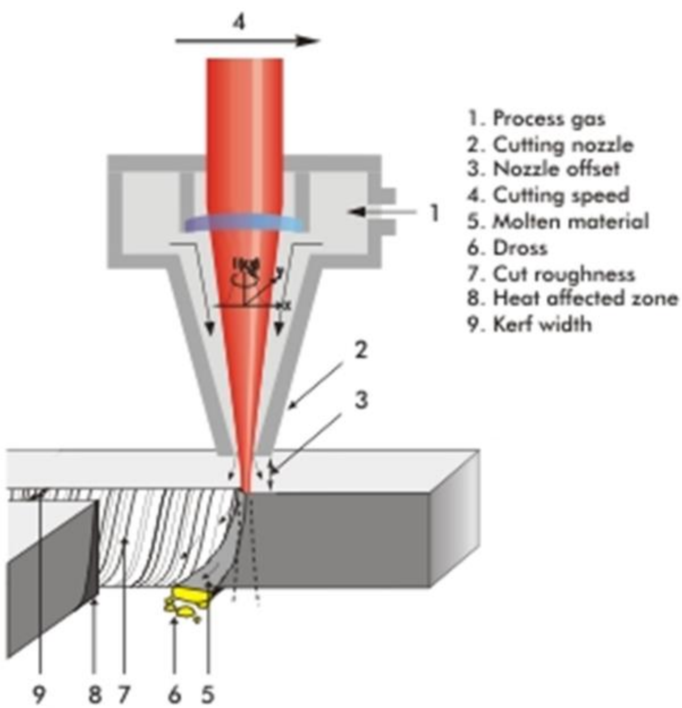
Laser Cut

There are three different cutting processes when looking at laser technology:

A) Fusion cutting
B) Flame cutting
C) Sublimation cutting

Basically, metal laser cutting is effected by locally heating the material at the focal point of the focused laser beam above its melting point. The resulting molten material is ejected either by a coaxial gas jet or the induced vapor pressure, thus forming the cut kerf.

The cut geometry, cycle time, system technology and, above all, the material composition are the crucial factors for the decision which laser source to choose.



A) Laser Fusion Cutting

In the case of higher alloyed steels and aluminum, an inert gas (nitrogen, argon) is typically used as a cutting gas. This process is solely depending on the energy of the laser beam. The required laser power is therefore higher than that for laser flame cutting. Laser fusion cutting affords oxygen-free cut edges, which is particularly important when welding is the next process step after cutting. Today, laser fusion cutting is used industrially for material thicknesses of up to 15 mm.

In principle, both high power CO_2 and solid-state lasers are suited for this kind of applications. Providing higher average power, CO_2 lasers are an excellent option for the separation of thicker cross sections.

B) Laser Flame Cutting

For low-alloyed steels in particular, oxygen is typically used as a cutting gas. This process, known as laser flame cutting, receives additional energy from the exothermic reaction of the material, which is heated above the ignition temperature. The required laser power is therefore lower than for laser fusion cutting. Today, laser flame cutting is used in industry for material thicknesses of up to 25 mm.

Here, too, both high power CO_2 and solid-state lasers are applied. Providing higher average power, CO_2 lasers are an excellent option for the separation of thicker cross sections.

C) Laser Sublimation Cutting

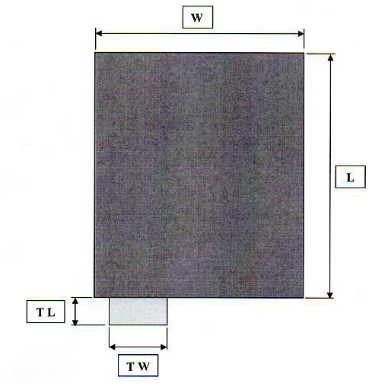
In sublimation cutting the material is molten by the absorbed laser energy until it partially evaporates. since the resulting steam is pressurized, material removal is effected by ejection from the open cut against the beam impact direction. This requires significantly higher power densities is simultaneously associated with much slower speeds than the two cutting processes mentioned above.

Since the cutting depth in a single-pass is typically in the range of some 10 microns, thicker materials are separated by the so-called multi-pass process. Commonly, material thicknesses that can be cut economically do not exceed 1 mm.

Here, mostly solid-state lasers are employed for metals, ceramics, or diamond and CO_2 lasers are applied for ceramics and plastics. Pure sublimation cutting processes, that means the direct transition from solid to gas state, are applied for cutting of wood and PMMA.

Determination of maximum cutting speed

To make a performance comparison between the cutting systems we will start assuming a reference electrode shape and a notching frequency, hence we will derive the requirements for laser beam cutting speed.



Technological limits of the reference machine:

Maximum Linear speed of the electrode sheet : 320 mm/sec and 130 Cycles per minute

The reference electrodes:

Electrode size : W_{max} = 100 mm L_{max} = 152 mm TL = Ltab $_{max}$ = 18 mm

consider the linear velocity fixed, and thus verify if the cycles per minute needed to produce an electrode of maximum size is less than the technical limit of the machine:

(100 mm/s) / (152 mm/cycle) = 2.16 cycles/s = 129.72 cycles/min

Since the value found less than 130 cycles per minute, the limit of the machine to produce such electrode is the linear velocity of 320 mm/s which defines accordingly the maximum number of cycles per minute.

Electrode Perimeter = 2* (148 mm + 215 mm + 18 mm) = 0.762 m

LaserSpeed = 2.16 cycles/s * 0.762 m/cycle = **1.65 m/s**

Considering another case where the maximum number of cycles per minute is 260 we get:

Electrode Perimeter = 2* (100 mm + 152 mm + 18 mm) = 0.54 m

LaserSpeed = 1.65 cycles/s * 0.54 m/cycle = **2.40 m/s**

Selection of Laser Source

On the basis of the speed that the laser will have to support and other parameters, with the help of technologists of Bologna University it was possible to identify the industrial laser source which is proposed as an alternative to mechanical cutting. It must also take into account in the selection, that the materials of the current collectors of the cathode and anode, that is, respectively, aluminum and copper, are reflective materials (Al absorbs 50% Cu and absorbs 10%), therefore a more powerful source is required. It is considered, therefore, a fiber laser with the following specifications:

Wavelength = 1064 nm	Power = 500W
Pulse Repetition Rate = 2 MHz	Beam Quality Factor M^2 = 1.5

This means that the beam diameter is 40 μm, the width of the cut of the layers of the active electrode, however, is approximately 100 μm (greater than the diameter of the beam due to thermal conduction) and the cutting speed can go from 0.5 m s to 2.5 m/s to 3 m/s.

The laser is considered to be usable both for cutting cathode and anode.

Dust and Fumes produced by Laser Cut

During cut the ablated materials composing the electrode diffuse in the cut area.

Fumes

Rather fine dust particles

Irritating or toxic impurities

To reduce the risk of electrode contamination and for machine operators safety a specialized suction and filtering unit must be provided

An estimation of the ablated materials is done as follows:

AblatedRate = BeamWidth * ElectrodeThickness * LaserSpeed

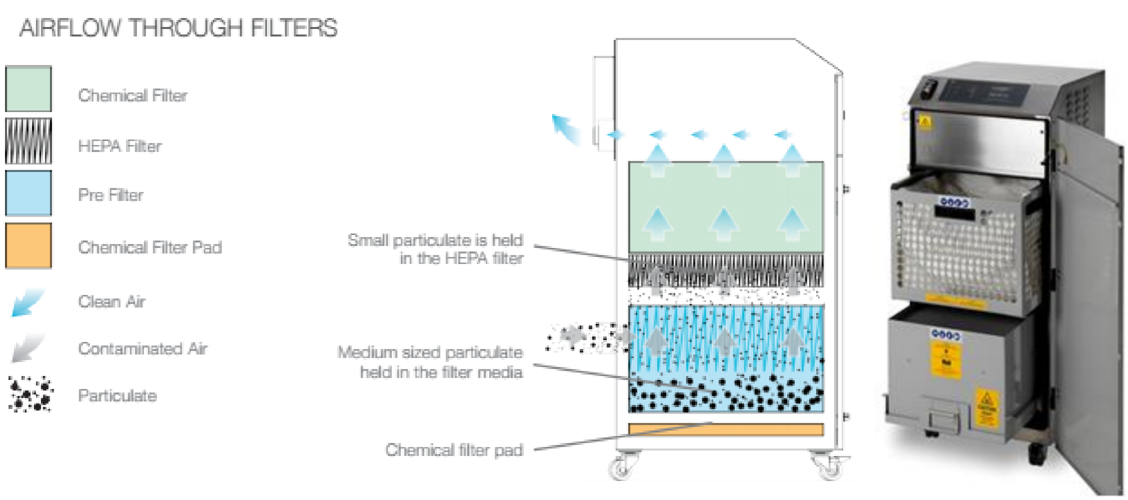
With typical values we get :

AblatedRate = 0.1 * 0.25 * 3000 = 75 [mm^3/s]

Fumes Filtering

Having calculated the data on the amount of dust produced, and according to the knowledge of the materials that makes up the electrodes, the filtration system type AD PVC iQ was proposed by supplier of filter plants Bofa International Ldt.

Dimensions (HxWxD)	1090 x 570 x 640mm
Airfow / Pressure	300m^3/hr (176cfm) / 96mbar
Weight	95kg



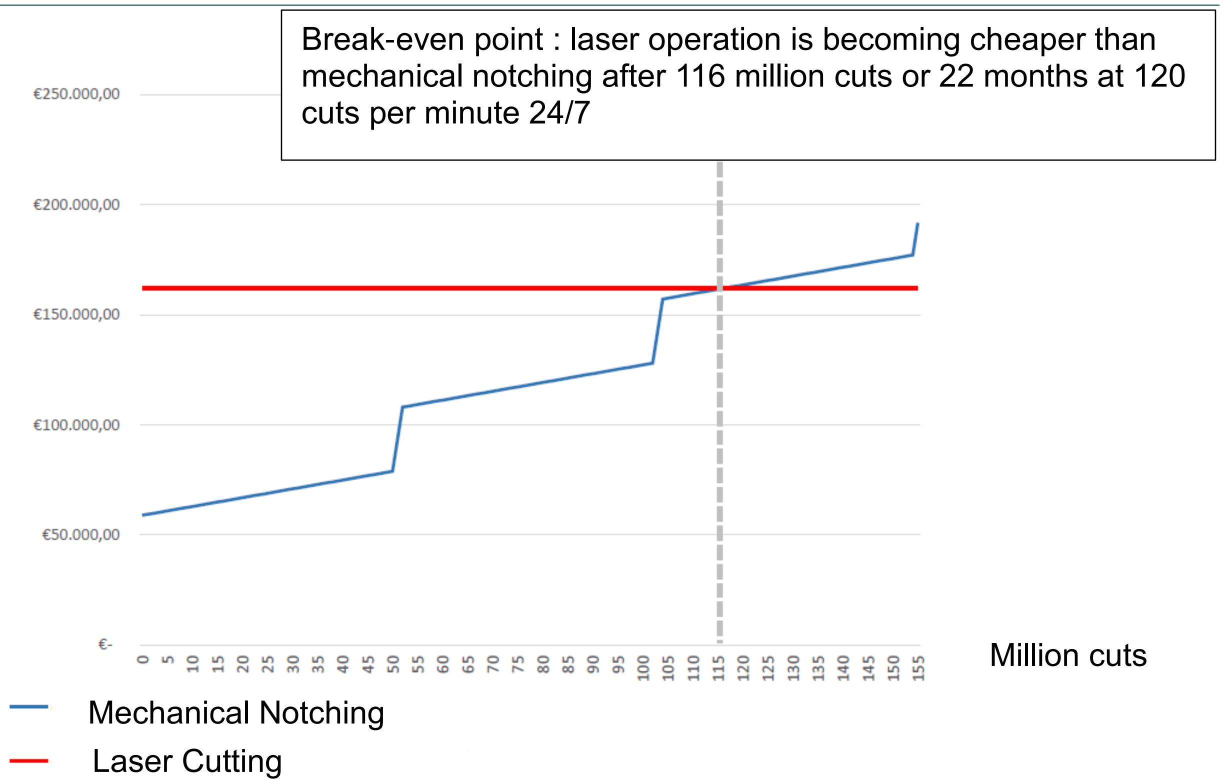
Foil Guidance System

The laser cutting requires a mechanical system so that it maintains the vertical tolerance of +/- 0.5 mm of the film during cutting. Go out of focus would mean for the car a power decrease of ¼ of the total power. To achieve a good alignment two rollers should be placed under the film electrode, one just before the laser field of operation and one just after. The distance between the two rollers can be adjusted and depends on the speed of sliding of the film, because by increasing the distance between the rollers increase considerably the vibrations to which might incur the film electrode which undergoes cutting. It was estimated for this system a cost of 2000 €.

Costs related to Lase Laser Cut

The source of the laser considered, provided by the company IPG Photonics has a cost of € 130,000, this must be added the cost of the transport system and the focus that can reasonably be supposed a total of € 20,000. A further cost to be added concerns the filtration system of dust and fumes that are developed following the cutting with a cost of € 10,000. Finally there is the cost of the mechanical system to maintain the film electrode in the vertical tolerance required, the approximate cost of 2000 €. For a total cost of € 162 000 system. The laser does not require maintenance, therefore must not be considered further additional, variable costs depending on the productivity of 'buying company, unlike what happens with a mechanical cutting.

Cost Comparison and Final Remarks



The analysis carried out within the company has allowed us to highlight some peculiarities of the process of mechanical cutting is currently in use. - First of all, the need to obtain a cut as precise, then with possible presence of burrs of maximum 20 microns and absence of delamination of electrode, has led to consider a first important negative aspect of mechanical cutting, the 'wearing of equipment. The repeated cutting of 'electrode, causes with time consumption of the blade, which in turn causes a loss of precision in the cut executed. From this arises the need to perform maintenance repeated with cadence which depends on the productivity of the machine, reflected in the variable costs of materiality is not negligible (400 € for regrinding and 14579.5 € the re-sharpening). The laser technology instead with very good approximation requires no maintenance and is assumed infinite useful life, with the exception of the 'onset of obsolescence, for which a plant is still perfectly working undergoes aging statement since exceeded by the' advance of progress technological. - The production cycle currently in use does not provide for 'use of cutters to cut that the entire shape of electrode, but the cut is divided into two successive stages, the first notch of the tab and the second separation of the electrodes' s one from another. This involves the 'use of two cutters in succession which increase the cost of investment and the processing time. The costs related to the second shearing are minor compared to those considered for the first shearing in 'analysis carried out; It was chosen, however, in agreement with the 'company and representatives of'

For these costs are worth the comments made in the previous chapters.

universities to make the comparison for simplicity only between the 'carving tab (first stage in the current system) and the cutting of the' entire perimeter made by the laser. Since the laser cuts 's entire shape of' electrode, it requires following the cutting of a mechanism that taps the cut piece and the positions in a warehouse or buffer accumulation. The 'previous approximation was created by' having assumed with good reason d 'be that the cost of such a mechanism is comparable with the cost of the second phase of cutting current is not considered in' analysis. You have chosen to consider the cut of 'entire perimeter as it is the most suitable operational solution for the' use of the laser. - Were not considered energy costs since the same for both types of cut, and the environmental characteristics in which they work are for both 20 ° C and RH = 20%.

6.2- The advantages of laser technology for laser cutting machine cannot even seem to blow d 'eye convenient because of' high initial investment cost, considerably higher than that of actual mechanical cutting mechanism, it appears to be a series of reasons it emerged throughout the 'analysis. First, the laser does not undergo wear and related costs instead present in the mechanical cutting, in fact, the cutting takes place without contact of the tools with the 'electrode and quality thus proves to be higher. The 'analysis was wanting to compare the speed of laser cutting (of' entire shape) with the speed of carving a cutting (only two sides); Whereas this comparison there is a net increase in the speed of processing for the 'whole process of production of lithium batteries, as it eliminates the second cutting step; Furthermore the speed of cutting laser could be higher than that considered the shearing if there was a need. A further very important advantage of laser cutting regards flexibility. Especially in very turbulent markets, it may rise to the sudden necessity of having to change the shape of the electrodes making up the lithium batteries produced. With l 'current application that requires the' purchase of molds of the required shape, then new costs and additional set up time. Quest 'activities with the laser is practicable in the absence of additional cost since it requires only reprogramming via CAD cutting path of the laser beam, and this activity appears to be economic, easy and fast realization, also the laser can be used for more complex geometries. Finally it shows that the mechanism of laser cutting allows the 'company to be competitive all' inside of the target market, through an investment in a relatively short time is fully repaid; therefore lower costs, increased performance of the machine and the quality of the cut, minor maintenance issues, resulting in more profit for companies and customers resulting in increased loyalty in respect of 'manufacturer Kemet.

References

[1] E. Impellizzeri, L. Tomesani, A. Fortunato, A. H. A. Lutey, (2014): Passaggio dal taglio meccanico al taglio laser: Implicazioni economico-produttive. Degree Thesis , Engineering Department, School of Engineering and Architecture, ALMA MATER STUDIORUM - UNIVERSITÀ DI BOLOGNA