



Material and Energy Efficient Busbar Systems in Zinc and Copper plants

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Abstract

Industry plants with high electric direct currents in the range of several 100 kA, like graphitization plants and electrolysis for production of chlorine, aluminium, copper, zinc, etc. use busbar systems to connect rectifiers to process. Busbar systems provide sufficiently large cross sections to keep the transfer power losses in reasonable limits and are at the same time inherently stable to master the resulting static and dynamic forces. Often older industry plants are used as an example for design, material and dimensions without considering the possibilities of the new 21st century: current densities are used to determine cross sections, questions about the right material are not asked and side conditions like magnetic field evaluation are not respected.

Examples of installed busbar systems in copper and zinc plants will show how it is possible to improve operation data – which means higher energy efficiency – and at the same time increase efficiency on material usage. E.g. the tender specification of a busbar system for a new copper electrolysis required more than 700 t of copper. Against all expectations this was realized with approx. 500 t of copper plus 50 t of aluminium. Optimal usage of the busbar material led to this enormous material efficiency with improved operational data at the same time. This was only possible by a total new design taking into consideration all influencing parameters.

The new material and energy efficient design will be illustrated using drawings, graphs and pictures.



Introduction and Definitions

The term "Material Efficiency" in production units is defined as ratio between raw material and finished goods. On capital investment "Material Efficiency" describes the ratio between investment costs and operating costs. A third definition of "Material Efficiency" is given by the ratio of investment costs to process costs which is directly also connected with "Energy Efficiency". "Energy Efficiency" is very often connected to the usage or saving of energy in any kind of process to avoid useless energy consumption.

Material and energy efficiency of busbar systems are very often conflicting requirements, e.g. if you reduce the cross section of a busbar system for saving material (increased material efficiency) you increase the resistance and with the resistance the power losses (reduced energy efficiency). Busbar systems are used in all electrolytic process of basic industries producing aluminium, copper, zinc, graphite, chlorine and fluorine, just to mention some. Busbar systems connect rectifiers as the source of large DC currents with the process and also single process groups. In the following the reader will see some examples which show that there are possible solutions to increase both, material and energy efficiency, simultaneously.

In most applications material and energy efficiency can be defined from different perspectives meeting different requirements as:

- low voltage drop or power losses over the total length of the connection
- low installed costs or low operation costs over a period of time
- low installed cross section or mass
- low magnetic field
- low installation time or minimum space/volume requirements

The most important requirement is given by the specific industry plant and is different case by case. Nevertheless the other requirements should be respected as much as possible. In most applications there is room for improvements which are easy to realize during engineering and design phase but are difficult and costly afterwards. Therefore it is necessary to have a basic understanding about the working mechanisms of busbar systems. The design of busbar systems is not just the calculation of a current density with the nominal current. This in most cases is giving a working busbar system but one which is not optimized. Let us have a look to the basics.



Basic Equation of a busbar system

The purpose of a busbar system is to conduct electrical current from point A to point B. In almost all cases copper and aluminium and their alloys are used as conductors because both metals have reasonable high conductivity against material costs. E.g. silver is a better conductor but is by factor 50 more expensive than copper.

In the following we are talking about DC busbar systems with a value of between 20 and 500 kA nominal current. The conductor has an electrical resistance R and is heated up while the current is running as long as the balance is reached between heat dissipation and power loss. The following graph is illustrating this relationship.

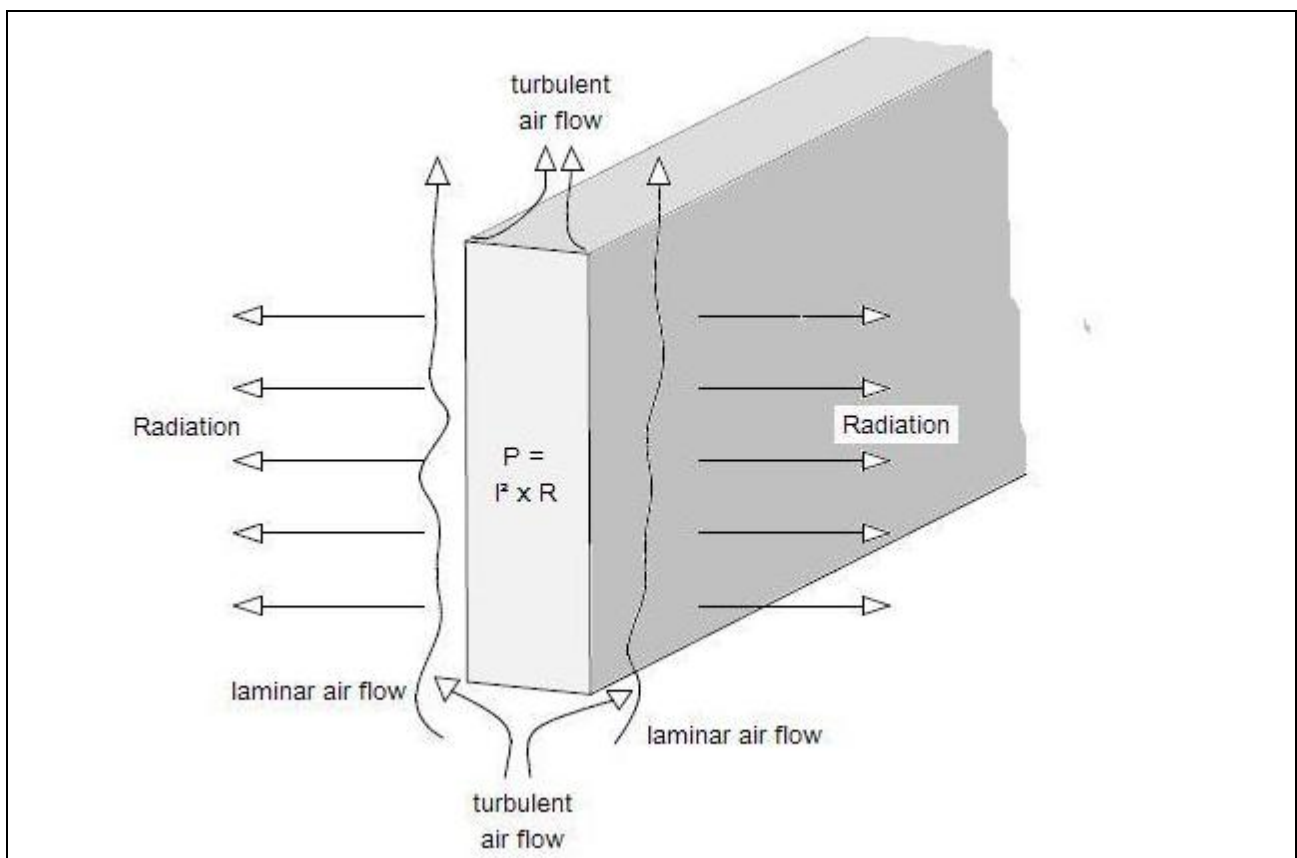


Figure 1: Heat Equation of Busbars

Power losses P in the busbar are created according to $P = I^2 \times R$. The resistance R itself alters with temperature T and is a function of the cross section A .



The heat dissipation can be subdivided into the two major parts, convection and radiation cooling which are both functions of the conductor surface area. Radiation in this context means the net radiation which is the difference between the emission and immission taking also into account radiation sources in the near environment of the busbar system.

Radiation is a function of Temperature T and the surface condition of the conductor mainly represented by emission coefficient ϵ which has a value between 0 and 1. A value of 1 is characterizing a black radiation emitter. Convection cooling consists of laminar and turbulent flow. So the basic energy equation of a busbar is

$$\text{Power Losses} = \text{Radiation} + \text{Laminar Flow} + \text{Turbulent Flow}$$

which can be solved in a multi-step iterative process reaching a balance between both sides and a constant temperature giving the operating temperature of the busbar system. In most cases the operation temperature is an important value because it is limited by the surrounding and insulating parts of the busbar system which are in most cases plastic parts. Additionally other side conditions like ambient temperature, altitude, moving air, surface roughness, etc. need to be respected in the equation, too.

The solution of this simple equation leads to a very astonishing result: At a given temperature level of the busbar system we can reduce the cross section of the conductor by up to 40% without increasing the temperature of the conductor. In other words: It is possible to save 40% of the material and not increasing the temperature of the conductor. This is possible by choosing the right format which offers an optimum ratio between cross section (power losses) and conductor surface (heat dissipation). The following figure gives an illustration about the saving ratio. Both conductors have equal width and height.

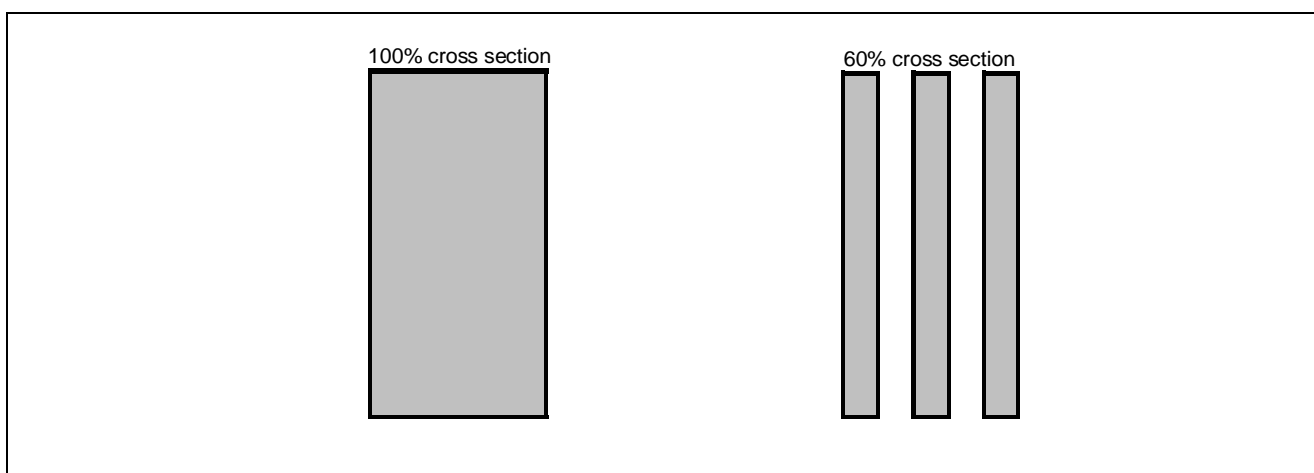


Figure 2: Conductors with different cross section but equal current carrying capacity



Differences between both concepts are in power losses, voltage drops and rigidity which have influence on static and dynamic loads in case of e.g. short circuit.

Copper or Aluminium

The material choice is the most critical decision in the design of the busbar. Copper or aluminium, grade and format, air or water cooled, enclosed or not enclosed, painted or unpainted, welded or bolted connections and many more different questions have to be answered. Silver is the best metal conductor but very expensive. The conductivity of copper is close to silver but the cost of copper was factor 100, today factor 50, lower than the cost of silver. So copper was the first choice for conducting current. Copper also provides very good surface contact characteristics which allow reliable and easy bolting of conductor elements.

During the decades another metal became very attractive: aluminium. Aluminium has only 60% of the conductivity of copper but offers also advantages against copper. The density is 30% of copper (2,7 against 8,9 kg/dm³). For the same conductor resistance you need only 50% of the mass of aluminium for the substitution of copper.

The price per kg or ton of aluminium was equal with the price of copper in the first years of the new millennium. In the meantime this relation changed dramatically: Copper today is sold per mass unit between factor 3 and 4 higher than aluminium. Taking the price difference into consideration aluminium has a today cost advantage of factor 6 to 8 on the pure metal price. The development of copper and aluminium prices are shown below

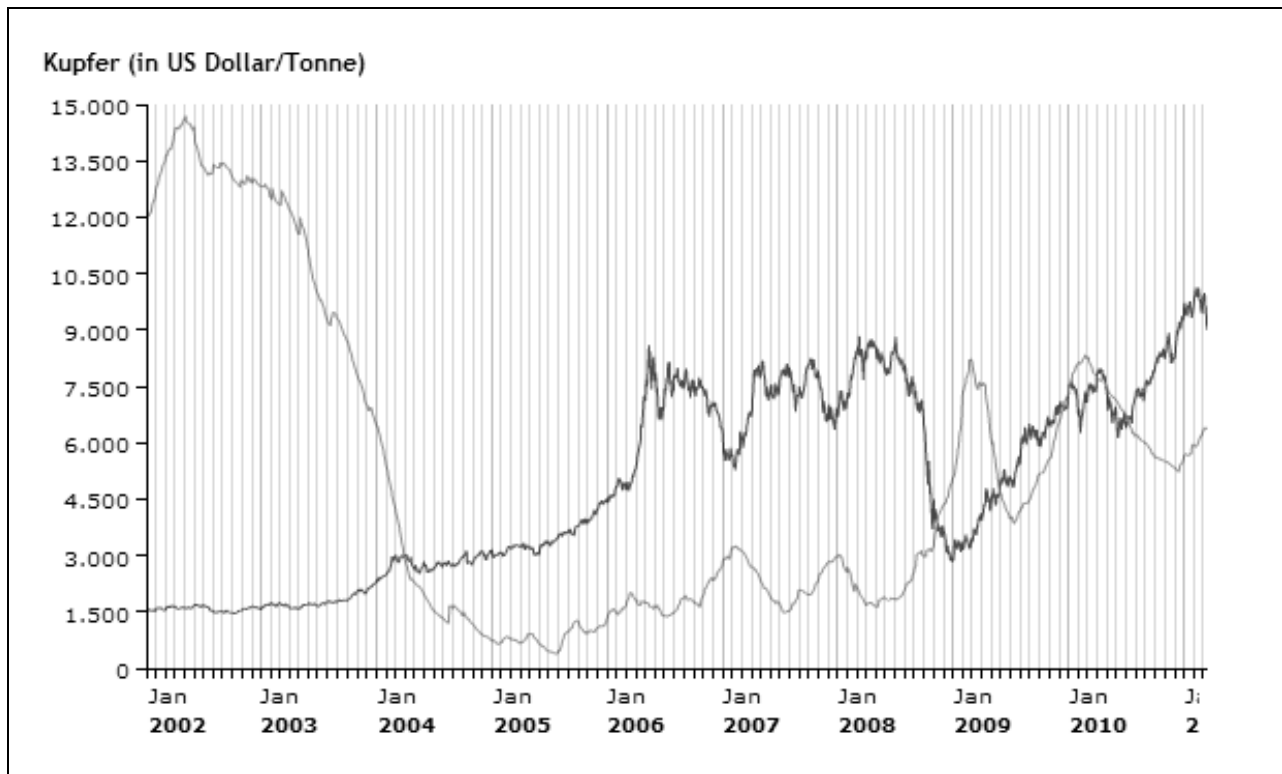


Figure 3: The thin line represents the stock quantity of copper in tons whereas the thicker line is giving the price fluctuation over the last years

Still, despite of the large cost advantage of aluminium there are good reasons for using copper: available space, easy connection method on site, corrosion resistance, etc. Especially corrosion resistance is an argument often used but not valid in all cases. E.g. in chlorine plants in some companies it is forbidden to use aluminium below electrolyser because aluminium is washed away by caustic running out of the piping system of the electrolyser. Additional protection is solving that problem and today you find aluminium busbars below new chlorine electrolyser.

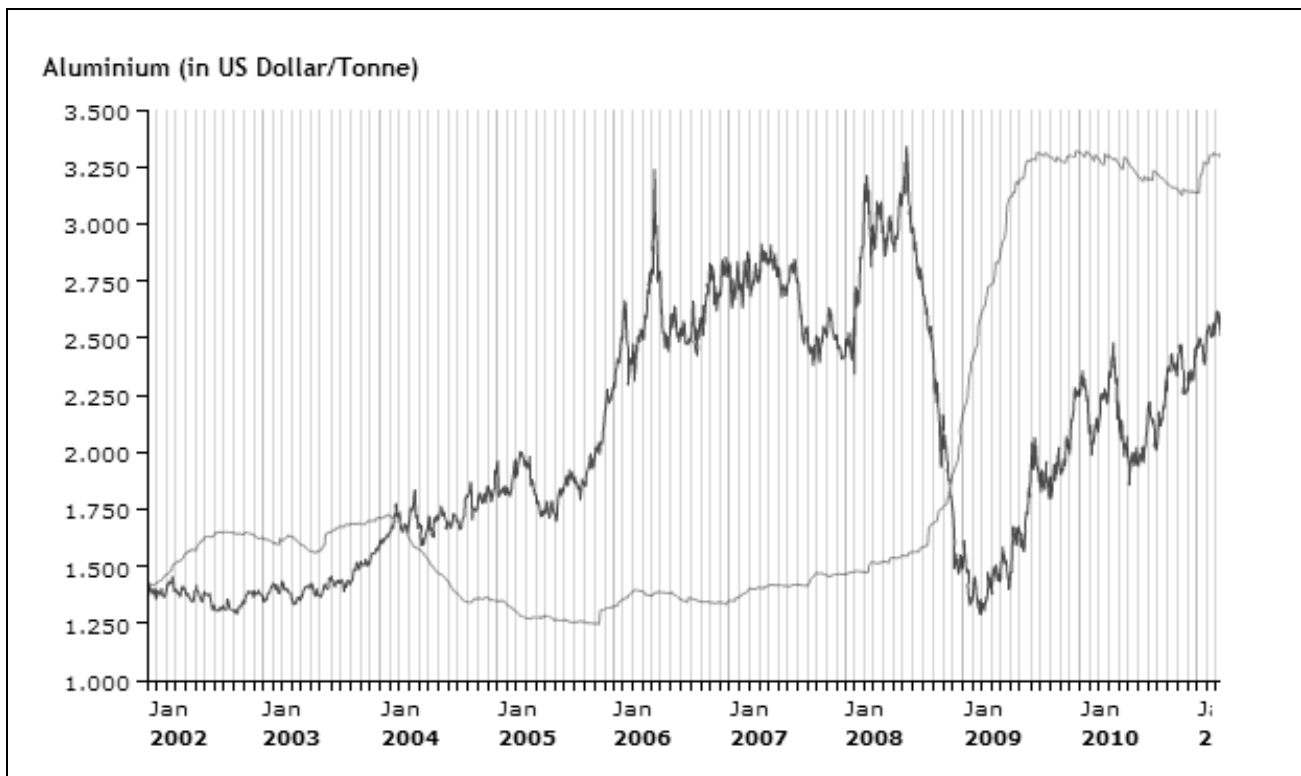


Figure 4: The thin line represents the stock quantity of aluminium in tons whereas the thicker line is giving the price fluctuation over the last years

The final answer to the question of choice is to use copper and aluminium whenever there is an advantage for one of the metals. E.g. the requirement for a connection over a long distance is low voltage drop without increase over the years combined with low material costs.

The only possibility for keeping the voltage drop constant over years is to weld the single busbar elements together. Both, aluminium and copper can be welded on site. Aluminium is offering lower material costs than copper. Then the choice might be using an oversized aluminium bar to keep the voltage drop very low. The connections to the end devices

Copper-Aluminium Connections

The following example is used to explain the decision process on the following requirements:

1. Long outdoor distance (< 120 m) between rectifier and cell house
2. Extremely low voltage drop because rectifier transformer is on his maximum voltage
3. No additional voltage drop over the design lifetime of 30 years



4. Low material and installation cost

5. Connections to the devices in the cell room with copper

Both, copper and aluminium can be used for long distances and low voltage drops, calculating the right cross section (requirements 1 & 2). Bolts and nuts connections will always result in additional voltage drop over years due to corrosion between the contact surfaces of busbar elements. The only way to fulfil requirement 3 is welding. Both, copper and aluminium can be welded on site but aluminium welding is much easier: Therefore in most cases copper is bolted and aluminium is welded on site.

The next requirement is making the difference: copper is much more expensive than aluminium. But the last requirement asks for copper. Therefore copper-aluminium transition pieces like presswelded, MIG-welded, explosion bonded or other methods are necessary to provide a good copper to aluminium connection. The following pictures will show several examples.

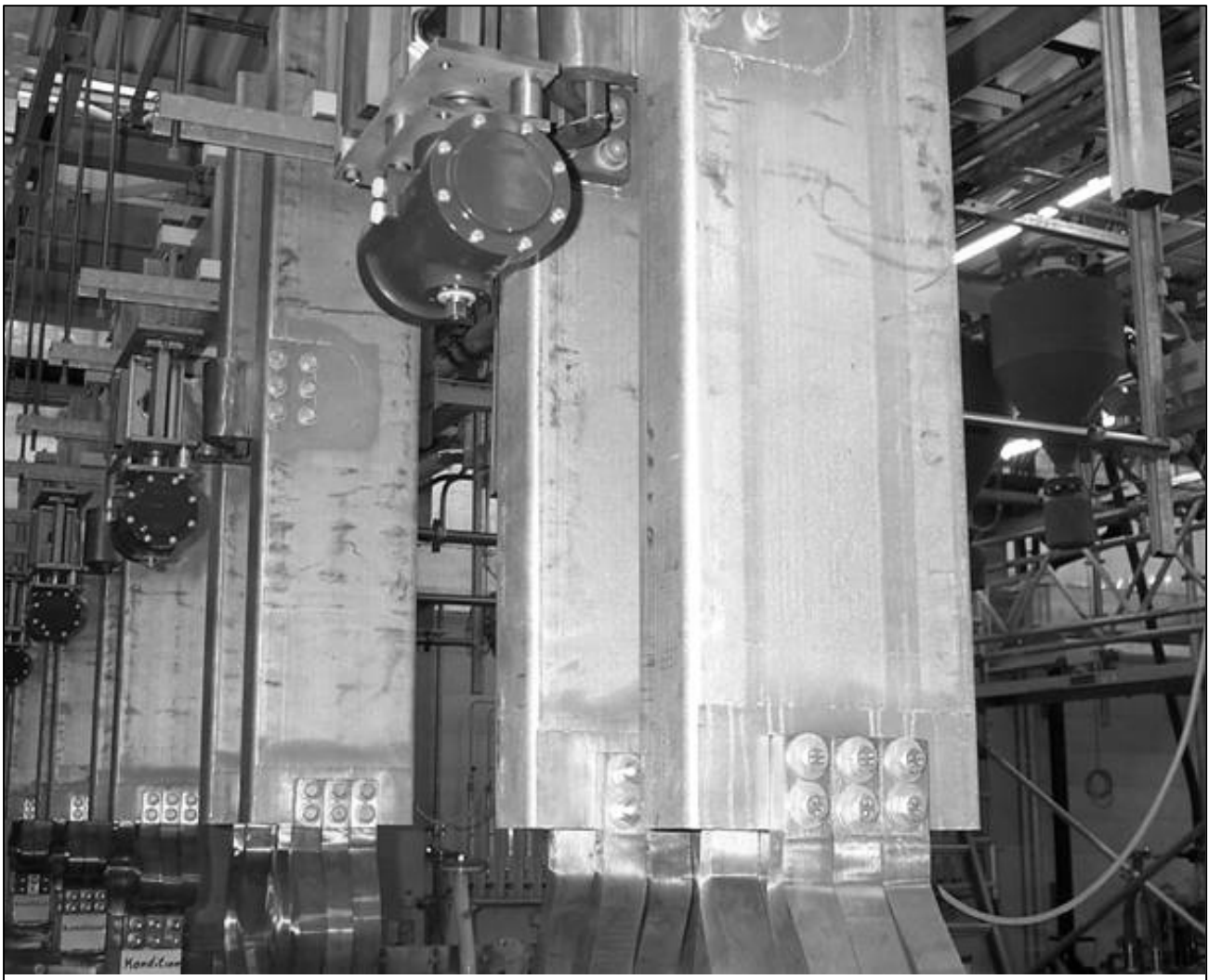


Figure 5: Large aluminium bars with presswelded copper flexibles, directly connected

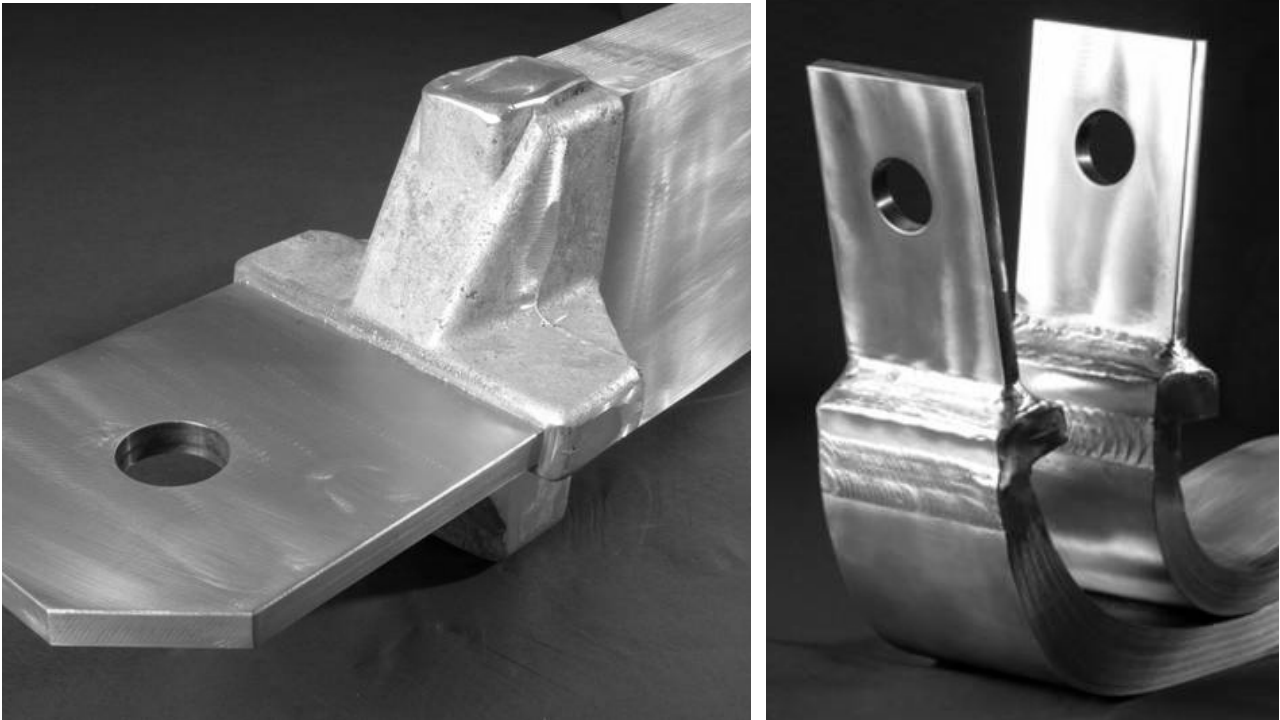


Figure 6: Examples of copper terminals welded to aluminium flexibles

Copper/Aluminium transition joints

Another application for copper-aluminium connection is found in zinc electrolysis: the cathode contact which is aluminium welded to the cathode header bar and the copper contact which is making the transition to end and intermediate cell bars. In many cases the copper-aluminium bond is realized by explosion bonding or similar methods. Nevertheless corrosion takes place due to the presence of strong electrolyte vapours coming out of the cell.

Improved efficiency in this case is understood as increased life time of the copper-aluminium interface. By just using little more of copper, the remaining interface area is much better protected and therefore the whole piece has much longer lifetime. The following figure shows the difference.

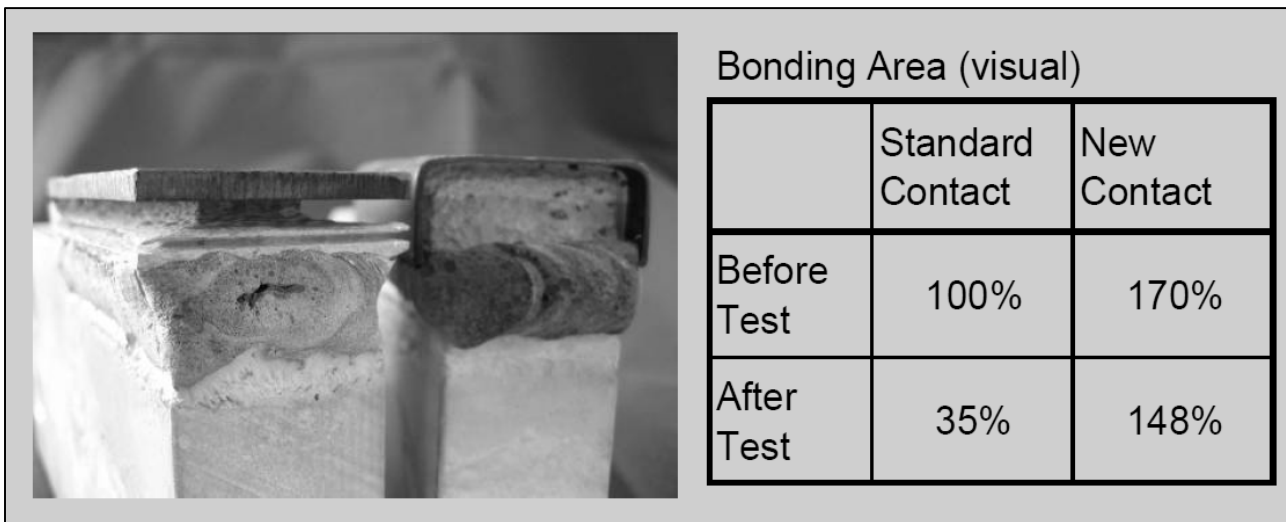


Figure 7: Improved material efficiency under heavy corrosive environment

Watercooled Bus Bars

In some cases space problems do not allow to use large aluminium or copper conductor profiles which are normally aircooled. Reduction of cross section is only possible by a higher cooling effect which keeps the conductor temperature on a permissible level. The technical solution in industry is forced water cooling providing a conductor which is hollow or has an integrated piping system.

With watercooled bus bar systems the conductor cross section can be reduced by factor 5 – 10, depending on the application. Disadvantages are stray currents (mainly through the water pipe connection), increased power losses and voltage drops. Additional equipment like cooling water circuit with necessary pumps, heat exchangers, valves and instrumentation has to be integrated. In general water cooled systems are not as robust as air cooled systems and need higher maintenance attention. The following pictures show different types of watercooled busbar systems.

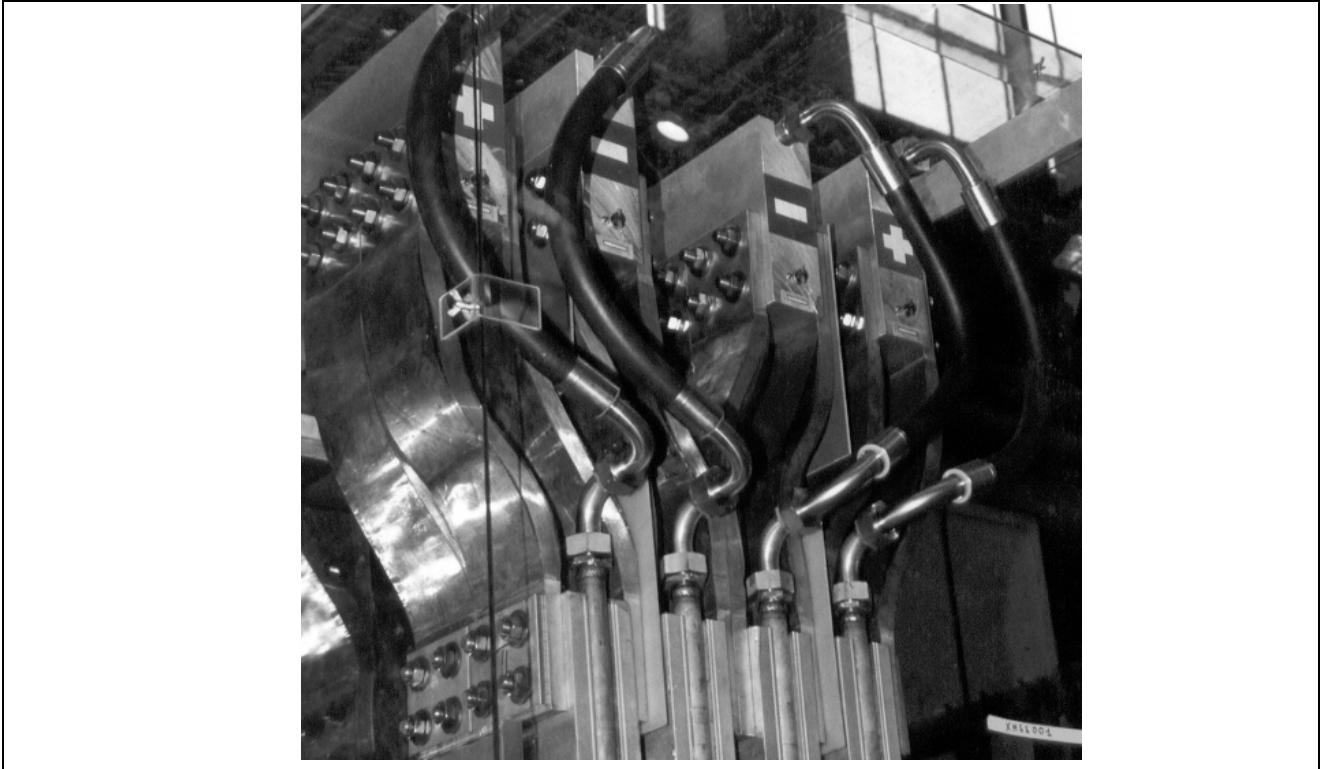


Figure 8: Watercooled aluminium busbar with stainless steel water pipe

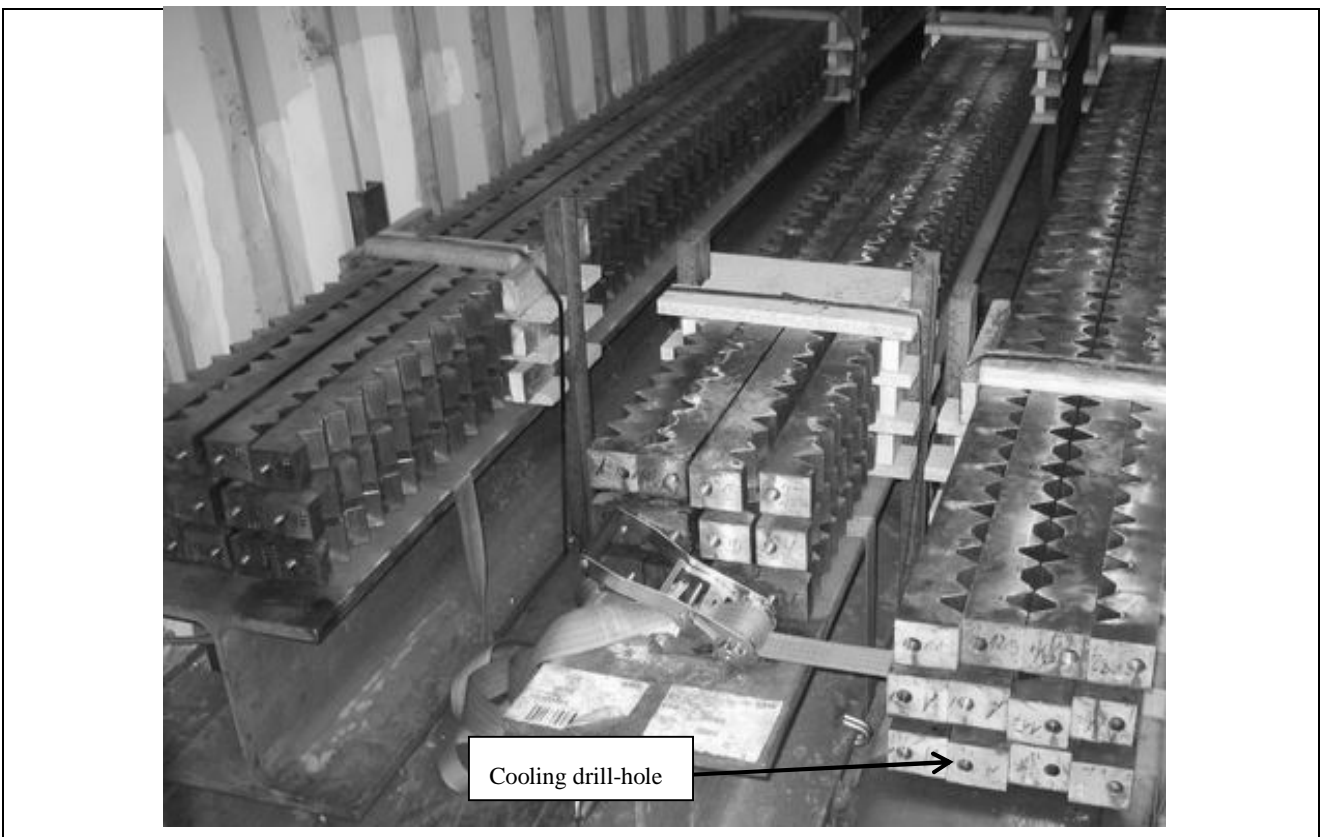


Figure 9: Watercooled copper profile with integrated cooling hole



Aluminium in Copper Electrolysis

Many copper electrolysis do not want to use aluminium busbars in the cell room. This arises from some experience in electrorefining not electrowinning:

An electrorefining electrolyte contains a wide range of metallic cations coming from the dissolution of the impure copper anode. Among these are arsenic and antimony. If the acidic electrolyte contacts aluminium busbars hydrogen is evolved which can combine with the arsenic and antimony to form arsine and stibine respectively. Both of these are toxic gases. This situation gives rise to the knee jerk reaction of "no aluminium busbars in copper plants".

However in copper refineries such bars can be quite safely used if the aluminium is confined to the trunk bars away from the electrolyte and even for front and back bars if properly shielded from electrolyte drips by plastic sheeting.

For almost all electrowinning plants, especially those associated with solvent extraction plants, there is no arsenic or antimony present in the electrolyte and aluminium can be used for busbars with impunity. Shielding and drip sheets may be provided where electrolyte dripping occurs simply to protect the bars from acid attack but there are no safety concerns.



Current Distribution at End Cells

Transferring the operation current from rectifier to cell room is in most cases not a challenge. The correct and efficient distribution of the current to the first cells is in many cases not done in the most efficient way.

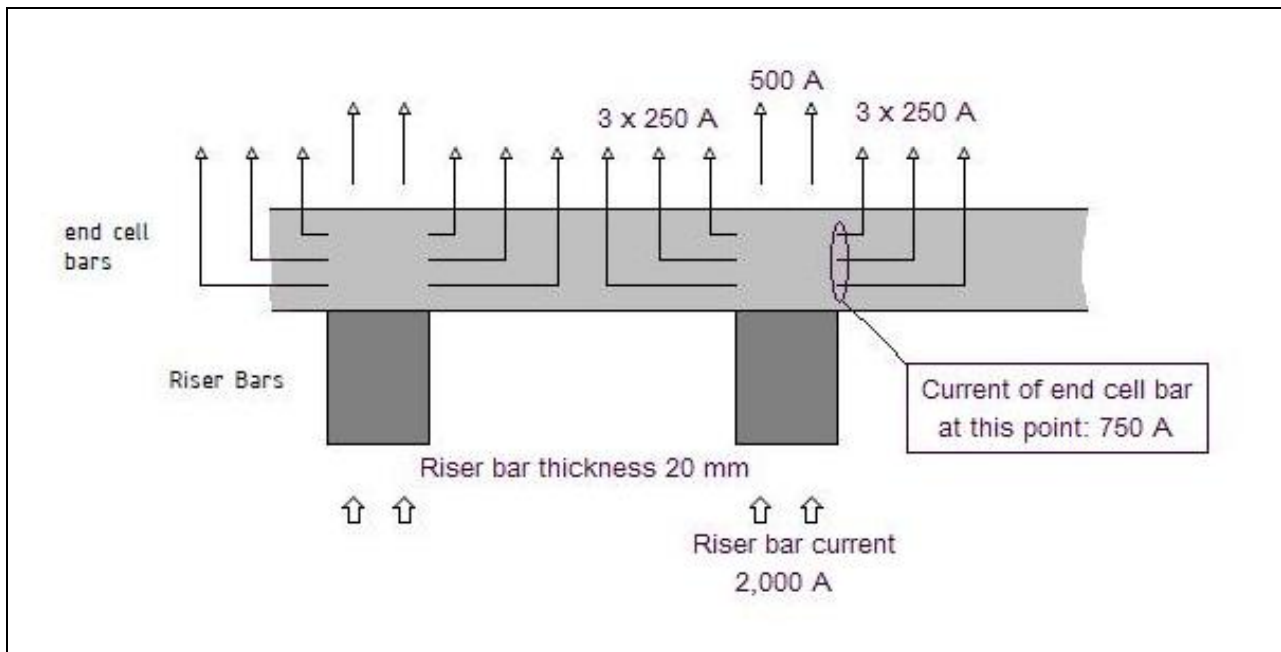


Figure 10: Example 1 – Current distribution from riser bar to cathodes/anodes with low number of riser bars

Example 1 with two riser bars between the main busbar system and the end cell is illustrating the situation. For better understanding rounded figures for currents are used. The thickness of the riser bars is assumed to be 20 mm which is then able to carry 2,000 A in this example. The distance between the riser bars is approx. three times the width of one riser bar. Two times 250 A is running straight to the cell across the end cell bar. The remaining 750 A on both sides are running thru the end cell bar sideways. Consequently the cross section of the whole end cell bar has to be designed to carry his current or at least 500 A as an average value. Normally the same format of the end cell bar and the intercell bar is used, even not necessary due to different current flow and current densities.

Example 2 is using double number of riserbars with only half the thickness of 10 mm. First of all this gives double surface at every bolted connection which means half of the contact power losses. Main advantage is the more equal current distribution and feeding of the end cell bar.

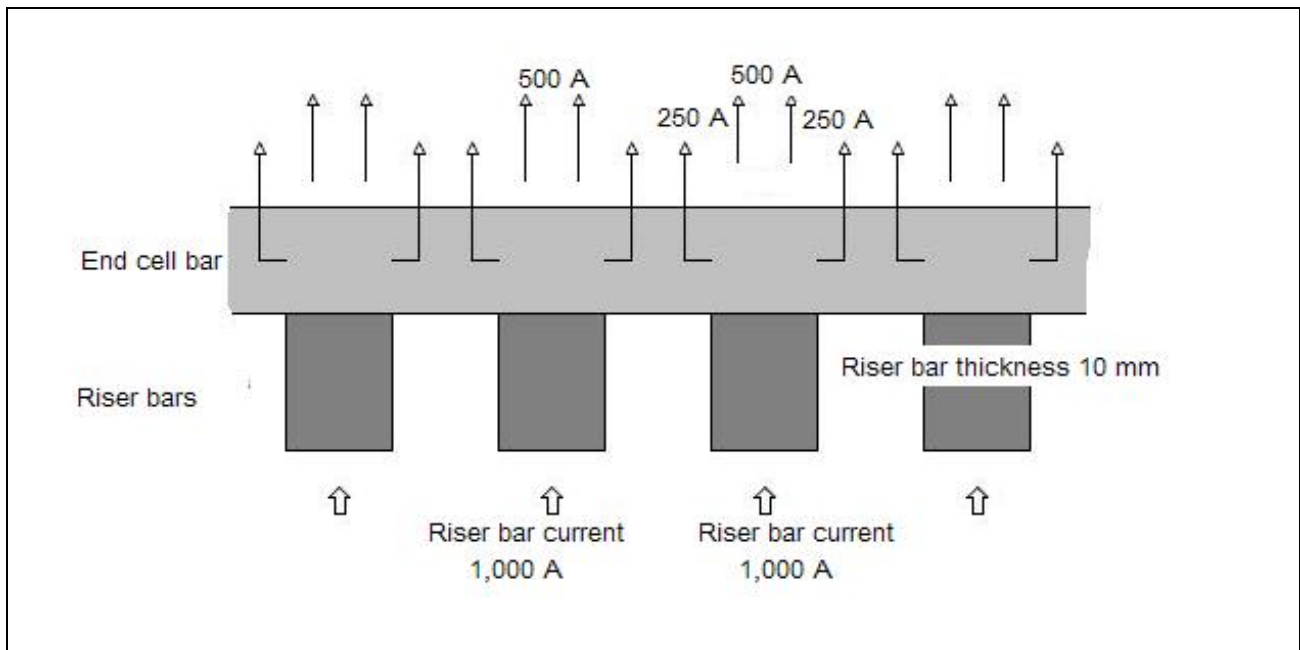


Figure 11: Example 2 – Current distribution from riser bar to cathodes/anodes with double number of riser bars

A current of 500 A from each riser bar is running across the end cell bar directly to the cell as in example 1. The remaining 500 A of the riser bar current is running lengthwise the end cell bar, rectangular to the riser bar, split into both sides giving just 250 A to each side. In example 2 one riser bar carries half the current than that in example 1. The current running alongside the end cell bar is only 250 A (one third) compared with the current of 750 A of example 1. Therefore the cross section of example 2 can be reduced and will still give better efficiency in terms of reduced power losses. Together with the end cell bars the cross section of all intercell busbars can be reduced giving a real saving of material without any negative aspect.

The limitation for the reduction of the cross section is the mechanical integrity of the of the end cell bar. The end cell and intercell bars are loaded with the weight of anodes and cathodes. A tension analysis as shown in the next picture is helpful in finding the right thickness.

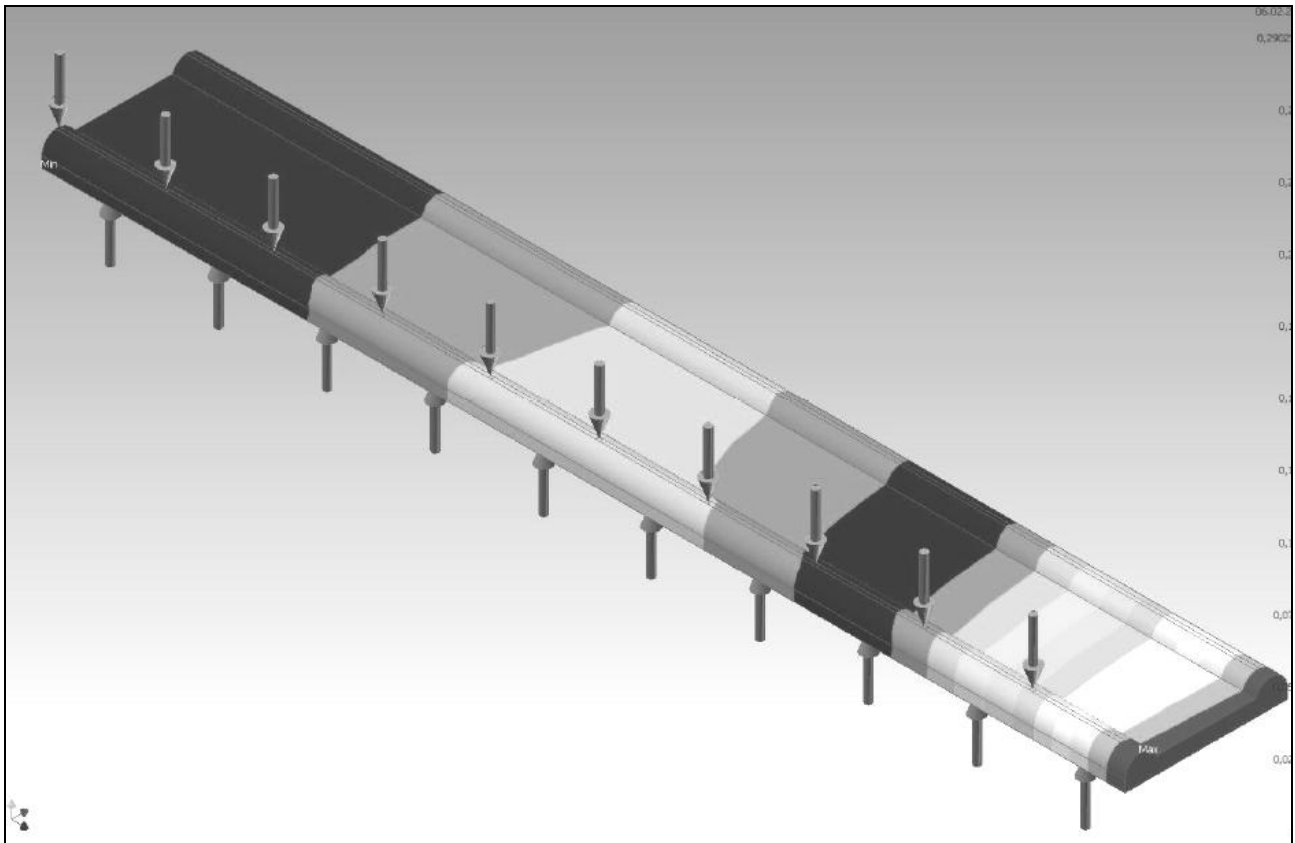


Figure 12; Result of the tension test analysis of endcell bar

Power losses $P_L = f(I^2)$ which means that at places with double current density you find four times the power losses. This makes Example 1 even worse because this explains local hot spots.

Unequal current distribution leads to unequal feeding of cathodes. This effect can be noticed in some zinc or copper plants where the outer plates of the first, second or sometimes third cell do not carry as much metal as the inner plates. Lost metal winning is the consequence. This shows that material efficiency means optimum usage of material in making the process more efficient and which does not need any additional material but just know-how to use it best. The picture below shows a situation with 12 riser busbars to get an optimized current distribution even in the first cells.

As a second improvement bolt connections between riser bars and the feed plates are outside of the corrosive area of the electrolyte. This is achieved by welding the feed plates to the end cell bars which gives a molecular bond of the same material in the acid vapour loaded area. The bolt and nut connection is not any more subject to heavy corrosion – the contact resistance will remain low for a long time.



Figure: 12 riser bars feeding the end cell with a current of approx. 200 kA which leads to a nominal current of 16,5 kA per riser bar.



Material Saving in an Electrolysis Plant

Using the different principals explained in the preceding pages, large material savings can be achieved with additional increased performance. The increased efficiency can be measured on

- total installation costs
- reduced operation costs, e.g. reduced voltage drop and power losses which means lower electricity consumption per ton of produced material
- improved process costs, e.g. higher amount of material produced per month or year.

The following material saving was achieved for the busbar system in an electrolysis plant after re-design:

- Main Busbar System incl. Block Bridges: originally 430 t of copper were reduced to 300 t of copper plus 55 t of aluminium
- Endcell, Intercell and Riser Busbars: 270 t of copper were reduced to 220 t of copper

In total 700 t of copper had been transferred into 55 t of aluminium plus 520 t of copper

Conclusion

Systematic design and engineering of high current bus bar systems for electrolysis, especially zinc and copper, but also for other plants like aluminium, graphite, chlorine, etc. is vital for the efficient use to materials, energy and process resources. While it is difficult, almost impossible, to redesign existing running plants there is a chance for a large improvement on new plants fulfilling the requirements of environmental sensitive, resource saving engineering and design. Bus bar systems are not always in the focus but can contribute a lot on total plant performance. Modern methods of today are necessary to install modern bus bar systems for the production of future materials.