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How bad formation connections cost you

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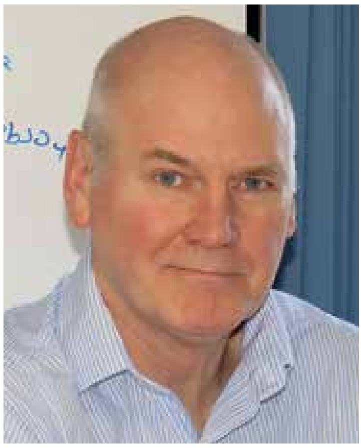
Bad connections make your losses grow



The humble formation connector may not look like much but it's the biggest thief in your battery formation business, silently stealing hundreds of thousands a year electricity costs, given up as heat. ESPL's technical consultant Michael McDonagh and Mark Rigby of UK Powertech, have made the measurements and done the costing. Dr McDonagh shows how a new design and changed working practices can save you a small fortune.

The financial pressure to cuts costs is a now a given, year-on-year on all aspects of manufacture. In our business, formation is no longer the log-jam it used to be.

Formation times used to take anything from 24 to 72 hours, depending on the battery's size and the cooling methods used to prevent excessive temperature rise.

Now the process can be complete in as little as six hours for automotive batteries and 24 hours for traction cells, thanks to recirculating electrolyte, better water bath cooling and current pulsing rectifiers.

The downside of this is that the currents used in this process have greatly increased. You still have to put into the battery the required number of ampere hours, typically four or five times the battery capacity, and if the time is reduced, then the current has to increase to compensate.

Average currents used in an automotive formation programme over the last 10 years have gone from 30 to 80 amps. This number is far greater for heavy duty and industrial batteries.

Whilst the acid cooling and charging equipment have been improved to allow shorter times and higher currents, the connectors to do the job have not.

High resistance joints due to bad connection deficiencies have always been a problem, responsible for lost energy, product scrap and warranty returns.

> **"Our conservative estimates and verifiable measurements show that energy losses alone can cost a medium-sized lead-acid battery factory upwards of €0.5m per year!"**

That problem is now magnified by a measurable 100-fold increase in resistance. Add in the connector arcing and the increased heat from the simple I^2R effect and you can alter the properties of the active material, and you can safely add a lot more to the cost of your operation.

Our conservative estimates and verifiable measurements show that energy losses alone can cost a medium-sized lead-acid battery factory upwards of €0.5m per year! Add to this the internal scrap and rejection rates due to damaged batteries, plus the increased warranties due to active material damage, then the true cost can be in six figures.

This is like building a racing car to beat the land speed world record with tyres from a used run around car.

It doesn't make sense, yet that is exactly what is happening in every formation department of every single lead-acid battery factory across the globe. It's a largely hidden scandal that managers miss, because they've never done the arduous job themselves and shop floor workers don't give a damn about, because nobody tells them there's a real problem. So read on if you want to make a huge saving for your business.

The typical formation connector

A formation connector has to have several properties:

- Corrosion resistance
- Shape integrity at higher temperatures
- Low resistance, particularly at joints
- Good contact area with the battery post

Fig 1 is a schematic view of a typical formation connector showing the materials of construction and fabrication methods. The lead terminal is connected to the insulated copper wire when it is cast in a mould. The end of the bared cable is usually dipped in a flux and lead tin solder to ensure the wettability of the cable when the molten lead alloy is poured into the mould. Lead is the normal choice for the terminal as it is both electrically conductive and resistant to sulfuric acid.

There are potential areas for corrosion with this design due to either acid ingress at poor joints or spillage onto the terminal from the connection and formation process. Other types of contamination are also possible due to oil in the battery electrolyte or charred plastic from burnt lids. A poorly conductive surface from any possible source will increase the resistance of the joint between the connector and the battery terminal post. The resistance is caused by a non- or partially-conducting layer over the interior surface of the connector terminal. ***Fig 2*** shows how the build-up of this layer will affect the connector/post interface to increase the resistance.

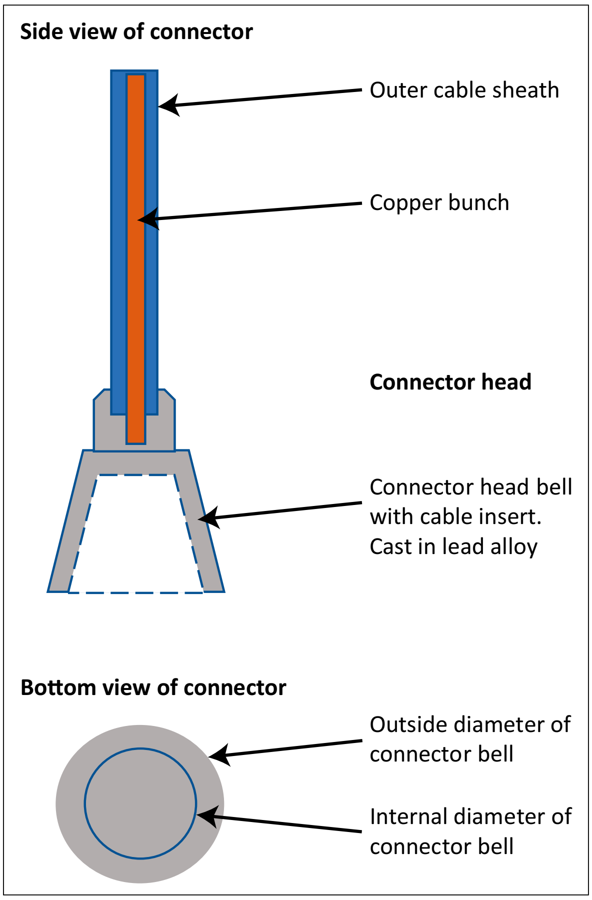


Fig 1: Schematic of standard connector

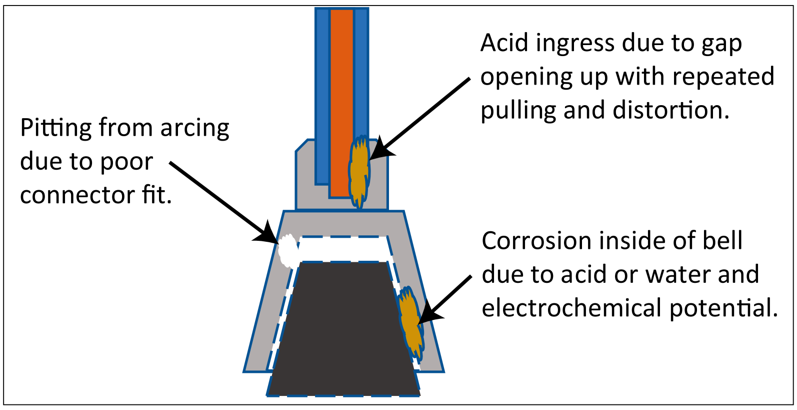


Fig 2: Standard design connector fitting over a battery terminal post. Corrosion and damage zones

Another source of connector high resistance, apart from corrosion, is the physical damage to the terminal, either by distortion or gouging of the interior to produce bumps or deep rivulets into the surface, providing sites for electrical arcing. This problem can cause serious damage to the battery terminal and lid as well as to the connector, leading to either scrapping or reworking of the battery. The poor condition that connectors can reach in service is shown in ***Figs 3a*** and ***3b***, which show both pitting and internal corrosion.

In the majority of lead-acid battery formation departments, there is limited time to fix the intercell connectors to the battery posts. The majority of monobloc processes have moving conveyors feeding batteries into the formation baths; many of these are not single line but may have three or four parallel rows of batteries. The operator has to reach all of the rows from a fixed position, normally leaning across the water bath, which may be more than a metre wide. ***(Fig. 4)***

To be able to properly place several hundred connectors in a few minutes and also ensuring that they are properly secured with no loose or badly placed terminals is a very arduous and tiring task. The possibility of operator mistakes is extremely high and the additional encumbrance of a high resistance layer or coating on the internal connector lug surface virtually guarantees either electrical arcing or high resistance at the joints. The

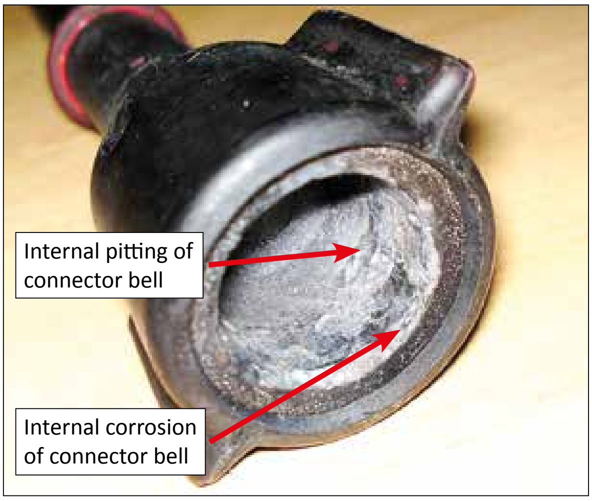


Fig 3: Used connectors in service
3a (above): Typical connector condition with several months use
3b (below): Connectors with heat damaged outer casings

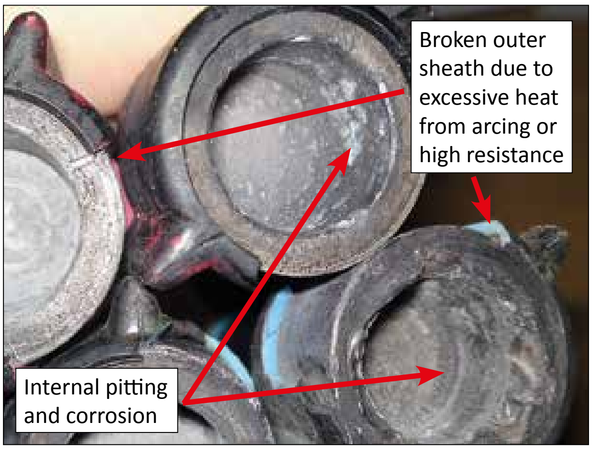


Figure 4: Typical water bath and formation circuit for monobloc batteries

chances of having all series and parallel circuits connected perfectly are very remote.

The connectors are poorly treated after formation. Instead of washing in dilute caustic soda to neutralise a residual acid, they are unceremoniously dropped into a container near the formation area. They thus spend the majority of their working lives being ravaged by the corrosive battery acid.

The consequence of corrosion is high resistance caused by the two corrosion products of lead oxide and lead sulfate.

To understand the type of compounds formed we can look at the results obtained from connector/battery terminal resistance tests and the typical environmental conditions experienced by formation connectors. Reference to the Pourbaix diagram for lead in sulfuric acid ***(Fig 5)*** shows clearly the potential and pH regions where lead forms lead sulfate. It is evident that at pH levels between 0 and 6 and potential levels of -0.2 to + 1.3 thst lead is oxidised to $Pb^{2+}$and will form lead sulfate according to the reaction:

$$Pb + H_2SO_4 = Pb^{2+} + SO4^{2-} + 2H^+$$

$$Pb^{2+} + SO4^{2-} + 2H^+ + O^- = PbSO4 + H_2O$$

The conditions at the interface between the connector head and the battery terminal post will determine the nature of the reactions on the surface of the lead post and connector as described above. The two parameters are pH or acid concentration and the potential difference.

The pH will be dependant on the acid concentration on the lead surface; the potential depends on the resistance at the post/ connector interface and the current being passed

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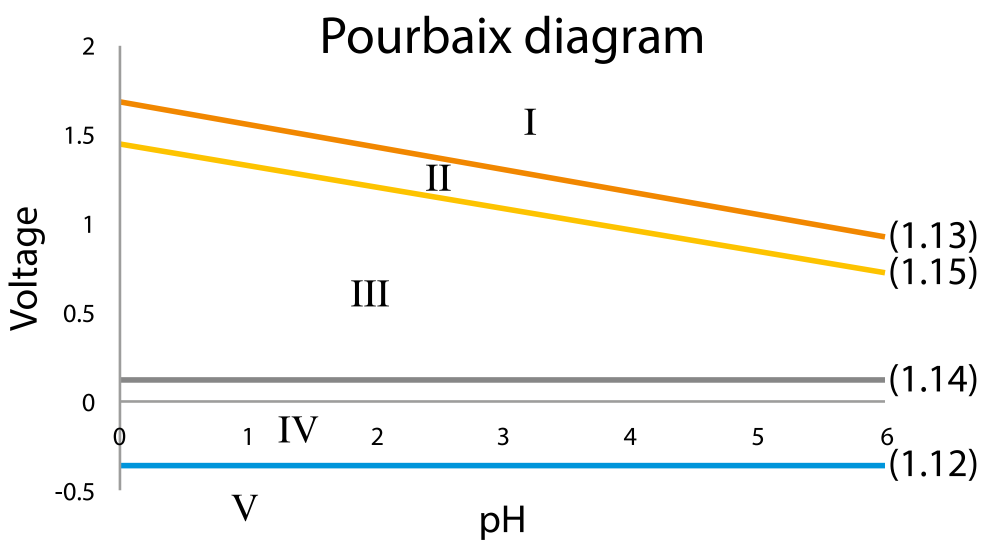

The table below summarises the favoured species in each of the regions (I-IV)

Region	In the presence of SO_4^{2-} in H_2O	In the presence only H_2O
I	PbO_2	PbO_2
II	$PbSO_2$	PbO_2
III	$PBSO_4$	Pb^{2+}
IV	$PBSO_4$	Pb
V	Pb	Pb

MIT Spring 2014 Electrochemical Energy systems

Fig 5: Derived Pourbaix diagram showing fields of corrosion and stability for lead in sulfuric acid and water. MIT Spring 2014 Electrochemical Energy systems

during formation. ***Table 1*** shows the results obtained from new and used connectors subjected to normal automotive formation currents some as low as 8A. The resistance values obtained clearly show that a potential difference of over 500mV would be obtained under charging currents of around 100A. This puts the connector in the corrosion zone for pH values of 0 – 6. This pH/V condition would be obtainable between the connector head and battery post under most formation conditions.

Fresh acid on the surface of a connector from a spillage or seepage or spray from the top of a battery lid just once would provide sufficient acid at pH values of less than one to start the reaction. As the acid is consumed over many formation cycles, the pH at the surface would be modified as lead sulfate builds up. The pH value would then gradually climb to higher levels as acid is consumed and lead salts created. During this time the sulfate corrosion reaction would still be occurring until the pH reaches a value of around nine.

Even washing the connectors in limited volumes of water, e.g. dipping in a container of water, would not completely remove the acid and in fact simply shift the pH value to a higher level still within the corrosion zone. The container with wash water would also become acidic with pH values below seven until it was washed out and the water changed. Washing connectors in running water will be an improvement but they need to be dried before use, as any moisture will create a cell, which will drive an electrochemical reaction.

Costs of poor connections

So far, the consequences of high resistance joints or damaged and corroded connectors have been described but not quantified. This can be done in two parts: energy losses and product losses.

Energy losses due to high resistance joints or corroded cables.

Table 1 gives the financial implications for the energy losses from increased connector/battery post interface resistance.

The energy losses are calculated by measuring the voltage difference between the connector head and the terminal post using current values between 8A and 80A; which are very common values used in automotive formation schedules. The voltage difference and applied current readings were used to calculate the resistance for the connector/battery post interface. The additional heat generation from this resistance is calculated using the applied currents.

The values of energy loss for a battery formation department have been calculated on an average formation current of

Connector type used for battery connection	Connection resistance Milli-ohms	Formation Current Amps	ΔV-Potential difference -connector to battery post milli-volts	Energy lost per 100 ah battery Wh	Cost/Million 100ah batteries (Whx1000x0.18) Euros
New Connectors– Gravity cast lead terminals	0.08	100	8.0	4.8	864
New connectors– Die cast terminal	0.05	100	5.0	3.0	540
New Connectors– Die Cast Terminal– Loose Touch fit	0.13	100	13.0		1,404
Used connector direct from customer 4-8 months old Gravity Cast	6.52	100	652.0	391.2	70,416
Used Connectors– Fitted loosely as in most factories– Highest value	10.9	100	1090	654	117,720
Used Connectors– Fitted loosely as in most factories– Average value	6.83	100	683	409.8	73,764

Table 1: Resistance values and lost energy costs for battery connector cables used in lead-acid battery formation departments.

100A based on a 100Ah battery capacity with a six to ten hour formation time, i.e. three or two turnarounds per circuit per day. It is a value per battery, and is simply the additional watts generated by the connection resistance and the ampere hours used in formation, i.e. **current x time x voltage difference due to connector/post resistance.**

Table 1 clearly shows the energy losses from normally corroded battery connectors in service is around €75,000 per one million batteries, based on €0.18 per KWh of energy. For a factory producing 5 million SLI batteries per year this would be around €375,000 on average and possibly more depending on the real state of the connectors and the working practices of the employees.

Other production costs

Internal scrap, lost production and rework (repair) are tangible consequences of damage to batteries from faulty formation connections. In the worst cases, electrical arcing inside the connector hood will generate sufficient heat to melt battery terminals or cause a fire. The arcing will not be generated by a high resistance joint but by insufficient or loose contacts from either damaged or incorrectly fitted connectors. In most cases the damage is to the take-off posts or lid of the battery. This damage is repairable and most companies have a designated area with specialist tools to effect the repair; usually known as 'rework'. Simple post repairs can be completed in minutes but the battery has to put into a repair jig using the correct tooling, then examination using quality control procedures and removal form the jig with corrections or modifications to the paperwork and physical relocation to quality approved stock areas.

On the occasions when plates or inter-cell welds are damaged, then the battery is irreparable and will be classed as scrap. In this case we have the double whammy of the cost of the lost batteries and the lost production output.

The cost of the scrap batteries and the lost production is easily identified and generally well accounted for using standard costing procedures. However, rework costs are not so easy to verify.

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For this article, an estimate for the rework costs has been made based on personal experience and discussions with departmental managers and personnel. The assumptions made are that 0.5% of the batteries per shift are reworked and 0.1% are scrapped as a direct result of formation connector damage. The rework costs are based on 15 minutes labour time and €2 in energy and materials per battery. Labour is costed at €20/hour to include overheads and overtime rates.

Warranty returns
Low performance with failure to start engines particularly in cold weather is a major source of warranty claims for automotive batteries. Warranty rates for lead-acid batteries are generally quoted in numbers of batteries and as less than one percent of output. Looking at warranty returns of SLI batteries due to low cold crank as being three tenths of the warranty claims then we can expect a return rate of 3,000 batteries per million produced, which is directly attributable to high resistance connections during formation.

Total cost of high resistance or defective formation connections
The three sources of additional costs outlined above can be summarised as follows:

Energy losses, production losses (rework and scrap), and warranty claims.

The cost of **energy loss** has been given as €375,000

Production losses can be calculated as follows:

- Annual **rework** costs for 1,000,000 batteries:
- Labour time x hourly rate x % of production reworked = 0.25 hours x 20 x 0.005 x 1,000,000 = €62,500 /annum
- Materials for rework at €1 per battery = 0.005 x 1000000 = €5,000

Scrap batteries due to bad formation connection = 0.1% = No. of scrap batteries x (sale price of battery – scrap price of battery) = 1,000,000 x 0.001 = 1,000 x (25 – 8) = 17,000

> “For a factory producing five million batteries per year the losses could easily exceed €1million, simply and entirely attributable to poor battery connections in the formation process.”

Warranty claims due to bad formation connections at 0.1% = 1,000 batteries at €25 = €25,000.

Total cost of damage due to inadequate battery connection in formation = €109,500 per one million batteries.

For energy loss and battery damage, the grand total of 109,500 + 75,000 = €184,500 per one million batteries per annum as a conservative estimate.

For a factory producing five million batteries per year the losses could easily exceed €1million, simply and entirely attributable to poor battery connections in the formation process.

Preventive measures
The costs outlined above are incurred as a result of current standard formation practices and cost management measures in most lead-acid battery formation departments. There are working practices and purchase options which can drastically reduce these costs by providing either clean and/or a new design connector along with better working practices.

Ensuring that connectors are kept clean and dry by washing once a week in very dilute caustic is a useful precaution.

Buying an extra 20% of the connector stock (one day’s use) and using this as buffer to allow the washing and drying would help to achieve this. The cost for a normal company using around 2,500 connectors per annum per million batteries at €4 per connector would be just €2,000. This would not only provide substantial energy savings but would also extend the life of the connectors.

The standard design of connector has been described earlier and has several shortcomings.

- The cable to connector head joint is prone to acid ingress due to cracks opening up with repeated stress from the handling methods used by formation operators. The connector-cable end and lead end material are prone to corrosion from acid ingress. Both of these corrosion sites will significantly increase the connector resistance.

- The connector head lead alloy is susceptible to non-conducting compounds forming on the surface, which provides a high resistance layer on the inside of the connector head.

- The lead alloy used is often not hard enough to resist distortion or damage when pressed onto the battery terminal post or handled roughly.

- The casting methods used to manufacture the connector head often produce a shape which is inconsistent with the pillar they are designed to fit. This can lead to poor contact area and difficulty of fitting correctly.

UK Powertech, in partnership with its customers has developed an advanced connector using materials and manufacturing methods which address all of these problems, greatly reducing the incidence of damage and high resistance joints with considerable reductions in the energy losses and battery damage which is common in most formation departments.

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