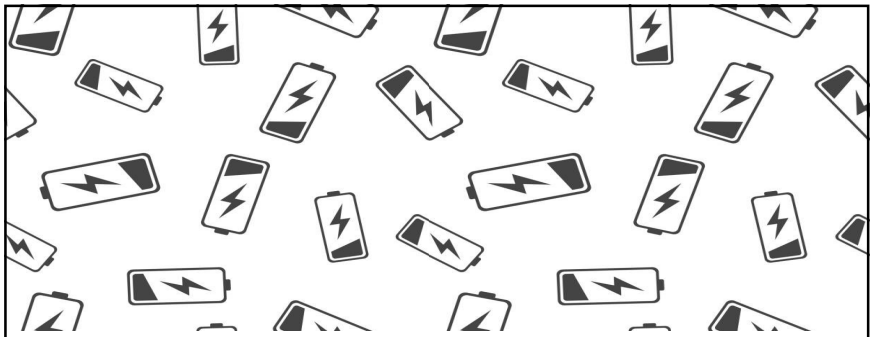
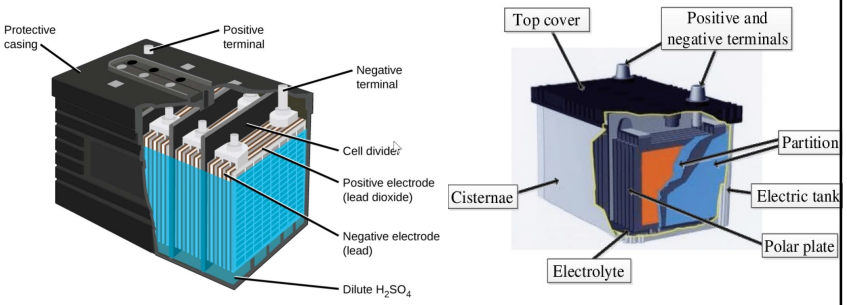


LEAD-ACID BATTERY

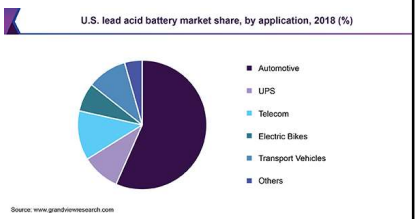
Dr. Vahid Esfahanian
An Introduction to Battery Technologies
Lecture #5

LEAD ACID BATTERY COMPONENTS



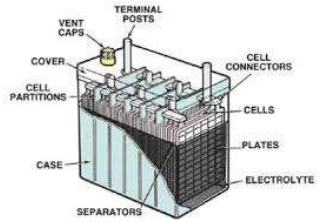
INTRO

- Lead acid battery is the safest battery in the world.
- A lead acid battery typically has a specific power of around 180 W/kg and a specific energy density of 35-40 Wh/kg, meaning it can deliver a relatively high power output for its weight but has a lower energy storage capacity compared to other battery types like lithium-ion batteries.
- In 2022, the flooded lead acid battery segment had the largest market share at over 65%. However, this segment is expected to lose market share due to high maintenance costs.



OVERVIEW AND CHARACTERISTICS

- Oldest type of battery for consumer use.
- lead-dioxide as cathode , sponge metallic lead as anode , sulfuric acid as electrolyte
- SLI batteries are common application
- 2.0 V and more that 70% eff.
- inexpensive and simple to manufacture
- low self-discharge
- good high rate performance

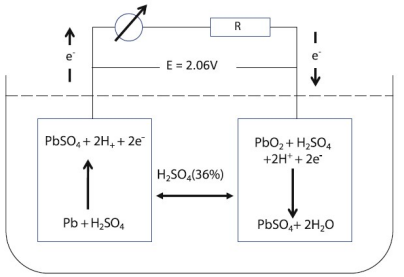


SOME DISADVANTAGES

- ✓ Low specific energy (up to 30 Wh/Kg)
- ✓ Low cycle life (50-500 full discharge)
- ✓ Unfavorable performance in non-optimum temperatures
- ✓ Prone to sulfation of the electrode plates
- ✓ lead toxicity and corrosivity of electrolyte (environmentally unfriendly)
- ✓ Risk on spillage in transportation
- ✓ With sealed lead–acid batteries , involving gas evolution and temperature rise during charging arises

PRINCIPLE OF OPERATION

- ✓ Sulfuric acid participates in the reaction and it is consumed during discharge, effectively lowering its concentration.
- ✓ Protons(H^+) go in the solution and electrons exit the electrode
- ✓ Sulfuric acid is consumed during discharge, lowering its concentration



PRINCIPLE OF OPERATION

Negative electrode oxidation : $\mathbf{Pb} \leftrightarrow Pb^{2+} + 2e^-$

Pb^{2+} ions immediately react with sulfate ions from solution to form lead sulfate, $PbSO_4$, which then precipitates as crystal on the electrode : $Pb^{2+} + SO_4^{2-} \leftrightarrow \mathbf{PbSO_4}$

Positive electrode reduction : $PbO_2 + 4H^+ + 2e^- \leftrightarrow Pb^{2+} + 2H_2O$

Subsequently, Pb^{2+} ions react with SO_4^{2-} ions to form lead sulfate $\mathbf{PbSO_4}$: $Pb^{2+} + SO_4^{2-} \leftrightarrow \mathbf{PbSO_4}$

PRINCIPLE OF OPERATION

Negative electrode half reaction : $Pb + HSO_4^- \leftrightarrow PbSO_4 + H^+ + 2e^-$ $\quad E°_{ox} = -0.355\ V$

Positive electrode half reaction : $PbO_2 + HSO_4^- + 3H^+ + 2e^- \leftrightarrow PbSO_4 + 2H_2O$ $\quad E°_{red} = +1.686\ V$

Overall : $Pb + PbO_2 + 2H_2SO_4 \leftrightarrow 2PbSO_4 + 2H_2O$ $\quad E°_{cell} = 2.041\ V$

$$E = E° + \frac{RT}{nF} \ln \frac{[H_2O]^2}{[H_2SO_4]^2}$$

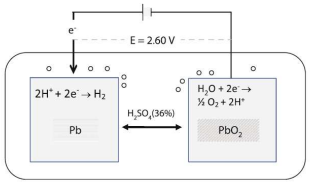
PRINCIPLE OF OPERATION

Overcharging :

All $PbSO_4$ from both electrodes is converted to lead on the negative electrode and PbO2 on the positive electrode

Since there is no more $PbSO_4$, the only reactions that can happen are the H_2 reduction or H_2 evolution on the negative electrode and O_2 evolution on the positive electrode.

Therefore, the overcharge reaction is the electrolysis of water



- ✓ Gas generation (battery requires vent caps for flooded type batteries)
- ✓ gas generation creates physical damage to electrodes by disrupting their structural consistency and causing particle detachment.
- ✓ the volume and level of electrolyte decrease
- ✓ lead to loss of the active surface area and would result in lower current.
- ✓ Sealed lead–acid batteries are constructed differently and have hydrogen and oxygen gases recombined inside a cell.

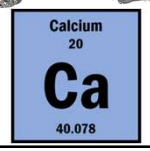
TYPES OF LEAD–ACID BATTERIES

How we classify lead-acid batteries ?

- ✓ Electrode additives
- ✓ Thickness of plates
- ✓ Variations to electrolyte
- ✓ Change from open to sealed batteries.

Electrode additives (Ca addition)

- ✓ The addition of 3–6% calcium makes battery plates more resistant to corrosion, overcharging, gassing, water usage, and self-discharge.
- ✓ Provide for higher currents or **Cold Cranking Amps**.
- ✓ These batteries require little or no maintenance.
- ✓ Disadvantage is poor high-temperature performance.



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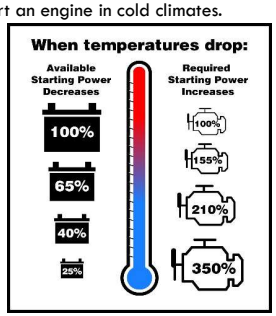
WHAT IS COLD CRANKING AMPS

Cold Cranking Amps (CCA) measure a battery's ability to start an engine in cold climates.

The rating refers to the number of amps a 12-volt battery can deliver at 0°F for 30 seconds while maintaining a voltage of at least 7.2 volts.



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TYPES OF LEAD–ACID BATTERIES

Electrode additives (antimony addition)

- ✓ improves the mechanical strength of electrodes
- ✓ reduced internal heat and water loss due to gassing.
- ✓ Compared to Ca addition, service life of batteries with Sb addition is greater
- ✓ recharge and battery recovery from a fully discharged state are easier
- ✓ these batteries are also less expensive than the Ca version.
- ✓ addition of Sb leads to higher self-discharge (2–10% per week), compared to 1–5% per month for the calcium version

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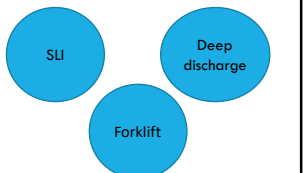
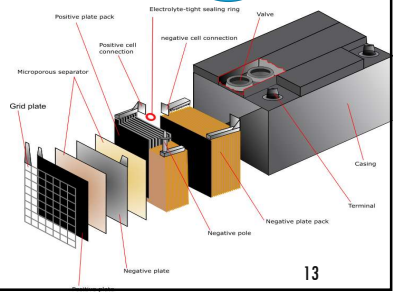
TYPES OF LEAD–ACID BATTERIES



Thickness of plates (SLI) :

- ✓ is designed to provide short bursts of high current, roughly 500 A, to start a car. This causes a battery to lose up to 5% of its charge.
- ✓ The battery has thin plates or electrodes with larger surface area for high current capability.
- ✓ is designed to have high power density, but it has low total energy content and is not designed to deliver energy for long periods of time.
- ✓ It can also not handle deep discharge. (DoD of only 20%).
- ✓ The cycle life of a car battery is around 500.



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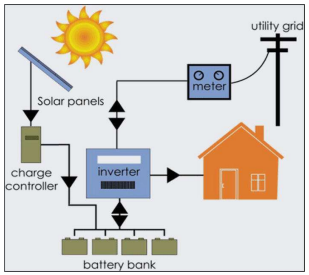
TYPES OF LEAD–ACID BATTERIES

Thickness of plates (deep discharge) :

- ✓ have thicker electrodes and store more energy
- ✓ The plates in these batteries are more robust and contain additives such as Ca or Sb.
- ✓ not capable of delivering high current
- ✓ in photovoltaic systems, where a battery needs to deliver steady power for several hours



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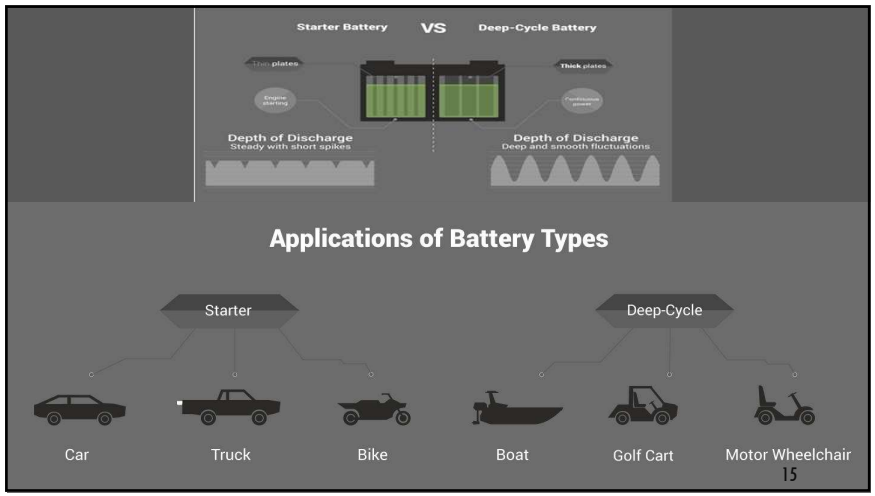

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TYPES OF LEAD–ACID BATTERIES

Thickness of plates (forklift) :

- ✓ Bigger and more robust plates than the car battery
- ✓ They use antimony alloys to affect mechanical stability of the electrodes
- ✓ low cost and can last for up to 20 calendar years

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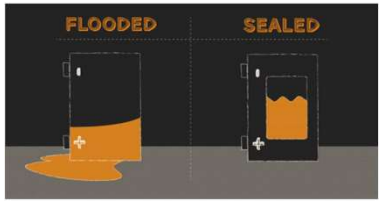
TYPES OF LEAD–ACID BATTERIES

Different design feature (Sealed battery) :

- ✓ The design prevents loss of electrolyte through evaporation, spillage, or gassing in the overcharge phase.
- ✓ Longer battery life
- ✓ improved safety because there is no free electrolyte
- ✓ Maintenance free operation, and the ability to operate in any position

AGM SLA VRLA



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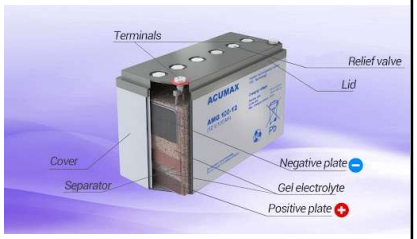
TYPES OF LEAD–ACID BATTERIES

SLA(Small sealed lead acid battery)

- ✓ are known as gel cells
- ✓ most commonly used in UPS or uninterruptable power supply
- ✓ electrolyte in gelled form through addition of silicon dioxide
- ✓ Gas production must be controlled to not fill the container too quickly
- ✓ not very tolerant to overcharge
- ✓ must be charged using low current, usually C/20.



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TYPES OF LEAD–ACID BATTERIES

VRLA(valve-regulated lead–acid)

- ✓ Full charge is never reached in these batteries
- ✓ VRLAs have pressure valves ,they open under very high pressure.
- ✓ hydrogen and oxygen produced in the overcharge phase recombine into water

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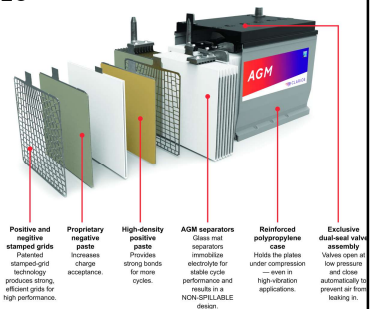
TYPES OF LEAD–ACID BATTERIES

AGM(absorbed glass mat):

- ✓ uses boron silicate fiberglass mat.
- ✓ glass mat is positioned between the two electrodes(preventing shorts)
- ✓ capable of withstanding shock and vibration
- ✓ no electrolyte leakage can occur even if the case is cracked
- ✓ nearly all hydrogen and oxygen are recombined
- ✓ very low self-discharge, 1–3% per month
- ✓ Expensive



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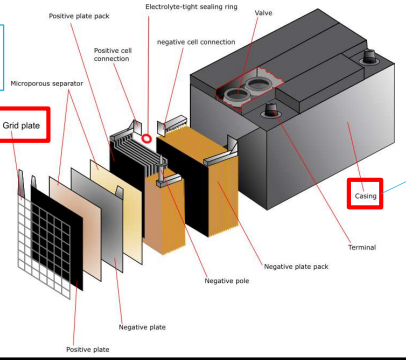
CELL COMPONENTS

The Pb grids are used as support for electrode active masses and as current collectors.



-Resistant to sulfuric acid
-Free of impurities no effect on sulfuric acid

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