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Lead-acid batteries in micro-hybrid vehicles☆

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ABSTRACT

More and more vehicles hit the European automotive market, which comprise some type of micro-hybrid functionality to improve fuel efficiency and reduce emissions. Most carmakers already offer at least one of their vehicles with an optional engine start/stop system, while some other models are sold with micro-hybrid functions implemented by default.

But these car concepts show a wide variety in detail—the term “micro-hybrid” may mean a completely different functionality in one vehicle model compared to another. Accordingly, also the battery technologies are not the same. There is a wide variety of batteries from standard flooded and enhanced flooded to AGM which all are claimed to be “best choice” for micro-hybrid applications.

A technical comparison of micro-hybrid cars available on the European market has been performed. Different classes of cars with different characteristics have been identified. Depending on the scope and characteristics of micro-hybrid functions, as well as on operational strategies implemented by the vehicle makers, the battery operating duties differ significantly between these classes of vehicles.

Additional laboratory investigations have been carried out to develop an understanding of effects observed in batteries operated in micro-hybrid vehicles pursuing different strategies, to identify limitations for applications of different battery technologies.

1. Introduction

For reasons of fuel saving and reduction of carbon dioxide emissions, most car manufacturers developed different types of hybrid cars recently. Within the wide range of possible concepts, currently the most important seem to be full-hybrid and micro-hybrid vehicles. While full-hybrid vehicles are based on a high-voltage electrical system and exhibit the ability to drive a certain distance pure electrically, micro-hybrid vehicles are technically orientated at the common 14 V electric system of today's cars.

Currently, especially in Europe a strong focus on micro-hybrid vehicles is observed, and around 2.8 million micro-hybrid cars are on the road already. Car manufacturers are committed by law to lower their fleet fuel consumption. In the European Union there is a target of 130 g CO_2 emissions per km to be reached in 2015, for example. For 2015 it is expected that 70% of all new cars will comprise micro-hybrid features. In other regions similar legal requirements have to be met, and the widespread usage of micro-hybrid vehicles is one way to get closer to this goal.

For different micro-hybrid applications, the battery industry offers different types of lead-acid batteries. The range of batteries implemented in current micro-hybrid vehicles varies from standard lead-acid starter batteries to enhanced flooded to AGM batteries. Which battery fits best to which application, is dependent on operating strategies, technical requirements and life time expectations.

1.1. Micro-hybrid functions

Starting in 2006, we have investigated many micro-hybrid vehicles available in Europe. All of these cars offer an engine start/stop function, some of these combined with additional functions like regeneration of braking energy, charge voltage control and passive boost functions. Not all of these functions are combined in one car, but we have found different combinations of these functions.

An overview of the micro-hybrid functions is shown in Fig. 1.

The engine start/stop function switches off the combustion engine while the car stopped (e.g. at traffic lights or in traffic congestions) and restarts the engine afterwards. In some cars the engine is stopped when the speed is below a certain limit, of 6 km h^{-1}, for example. It is most important to ensure full power supply of the vehicle electric system in the stop phases as well as to ensure the engine re-crank. For the lead-acid battery this means higher performance requirements: the battery undergoes more and deeper cycling due to stop phases and has to exhibit a high charge accep-

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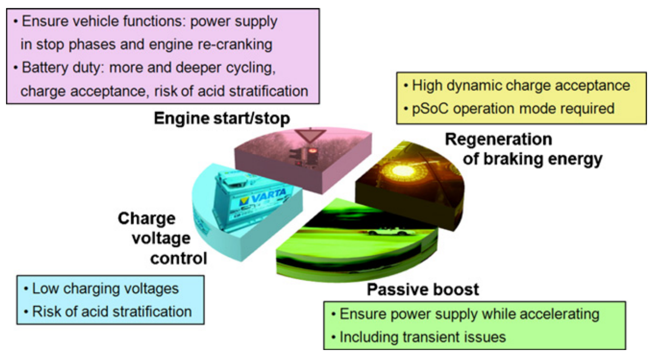

Fig. 1. Overview of micro-hybrid functions found in vehicles.

tance capability for being recharged quickly after the end of each stop phase. For flooded batteries this operation mode may imply a severe risk of acid stratification and subsequent deterioration.

The regeneration of braking energy (recuperation) means to recover a part of the kinetic energy of the car by recharging the lead-acid battery predominantly while braking. To achieve a higher energy balance, the recharge voltage is increased during braking or rolling phases of the car. For the battery this means the necessity of a high charge acceptance capability. As charge acceptance is low for fully charged batteries, they are intentionally operated at a partial state of charge (pSoC), with a target SoC significantly below 100%. This pSoC operation mode implies a risk of sulfation of the battery's active masses. In consequence, this means that it is recommended to fully recharge the battery regularly to avoid sulfation. The effectiveness of battery refresh was investigated by Schaeck et al. [1].

Passive boost means to de-energize the alternator while the car is accelerated. From a car driver's point of view, in this phase a larger portion of the combustion engine's power is available for traction; a reduced portion is needed to generate electrical energy. The lead-acid battery has to supply the electrical system's load requirements in this phase. Due to this additional discharge and subsequent recharge, the cycle load of the battery increases. Again, a higher cycling ability of the battery has to be ensured. This operation mode includes transient issues—a highly dynamic alternation between high-rate charging and discharging, which is not the usual operating mode of SLI batteries up to now.

The charge voltage control function is implemented to minimize the energy needed for recharging the battery. By decreasing the recharge voltage to a minimum value, the battery is sufficiently charged, but not overcharged at any time. The battery is not charged when the efficiency of the combustion engine is low (e.g. during idling phases). For flooded batteries this means an increased risk of acid stratification again—recharge with low voltages may be an issue for flooded batteries, especially when combined with a pSoC operating mode.

1.2. Battery technologies

There are several lead-acid battery technologies on the market with significantly different performance levels.

(a) The standard flooded starter battery is the most common of these products. It is used for engine starting, lighting and ignition (SLI). For many of the conventional vehicle applications it is the best choice in terms of cost–performance-ratio. For micro-hybrid applications the standard flooded battery is not recommended, because micro-hybrid operations require a higher cycling ability and higher robustness against acid stratification.
(b) Recently enhanced flooded batteries (EFBs) were developed, specially designed to fulfill higher cycling requirements and to withstand some impacts from acid stratification significantly better than standard flooded batteries. EFB design includes more robust active masses and a protection against mass shedding. The enhanced flooded battery is most often used for micro-hybrid cars with engine start/stop functions on a high SoC target level.
(c) The AGM battery (adsorbent glass mat technology) exhibits the highest cycling ability of all these lead-acid technologies and does not show any acid stratification [2]. The sulfuric acid is bound in a glass mat separator, and by battery design, the AGM type battery is robust against mass shedding and acid stratification. The limited amount of acid may be regarded as critical for high-heat applications, but simulations as well as real-life tests show, that the performance of AGM batteries under high-heat operating conditions in a taxi fleet test may be even higher than the performance of flooded batteries [3].

2. Batteries in micro-hybrid applications

Standard lead-acid batteries are designed for the use in vehicles with a conventional electrical system. Their main tasks are to crank the engine, to buffer the electrical system while driving, and to ensure power supply during parking.

Batteries installed in micro-hybrid applications have to fulfill many more requirements. Deeper discharges due to stop phases and passive boost, a lower target SoC for regeneration of braking energy or charge voltage control mean some additional stress to the battery which was not a design goal in former days. Nevertheless, the lead-acid batteries used in micro-hybrid vehicles in the last years up to now, which mainly are enhanced flooded or AGM batteries, seem to withstand these additional requirements.

In parallel to the investigation of micro-hybrid vehicles, we developed a laboratory battery test to simulate a micro-hybrid battery load profile reproducibly under controlled conditions.

2.1. Investigation of micro-hybrid vehicles

Micro-hybrid vehicles available on the European market from 2006 to 2010 were investigated, with a strong focus on battery load patterns and battery performance requirements. The scope of micro-hybrid functions (engine start/stop, regeneration of braking energy, charge voltage control and passive boost) was examined, as well as the type of battery installed (flooded/AGM). The battery operation SoC range was of special interest. Within the regular operation range there is a lowest SoC limit and a highest DoD limit, in such a way that all the micro-hybrid functions are activated within these limits. Outside these limits the cars normally work like conventional cars, but without any micro-hybrid functions activated.

In total, 15 vehicles were investigated, whereof 10 vehicles were of European brands, 5 of Asian brands. The European brands' vehicles predominantly are equipped with AGM batteries of EN container size, the Asian brands' vehicles predominantly with JIS-type flooded batteries. There are only a few exceptions from this general rule.

All 15 vehicles comprise an engine start/stop function. Six of the investigated cars do not offer any further functions in addition to start/stop. The remaining 9 cars can be divided into two groups: besides engine start/stop, they offer either a combination of regenerative braking and passive boost functions (4 vehicles), or a charge voltage control function (5 vehicles). No car was found with an implementation of all four functions in combination. Roughly, European brands' cars tend to use regenerative braking and passive