EnerSys®

Power/Full Solutions

STORE, MONITOR, SWITCH

the three pillars of battery power management in armoured land vehicles

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ABSTRACT

Reliable availability of battery power in an armoured land vehicle is essential to its mission success and to the safety of its crew. Both are threatened by a combination of growing power demand from onboard systems, inaccurate information on remaining power reserves, and inefficient management of that power. In this technical guide, based on an interview with Thomas Spinks, Land Product Manager, and Bert Schenk, Sales Director Defence Land-Systems from EnerSys®, we highlight the problems and explain how they can be solved. The answer lies in proven power management technology with optimised storage, monitoring and switching.

INTRODUCTION

Lack of battery charge can jeopardise an armoured land vehicle's mission or even cost the lives of its crew. Alarmingly, the likelihood of such a situation is increasing as the array of electrically powered systems fitted to such vehicles rapidly expands. Most are struggling to cope with the growth in power requirements illustrated in Fig. 1.

The array of electrically powered systems fitted to military vehicles has expanded far beyond the level anticipated a few years ago. Most vehicles were not designed to cope with the additional power need.

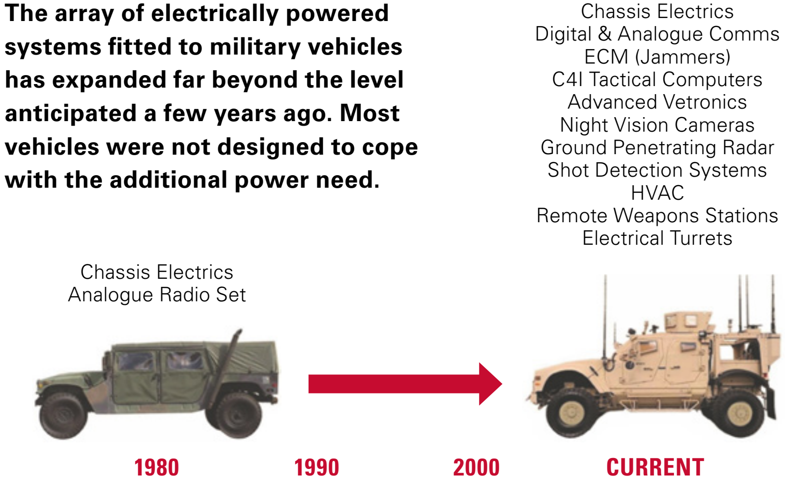

Fig. 1: Representation of rapidly increasing demand on batteries

Consider, in particular, the power needs of a vehicle on silent watch. At the very least, low battery charge levels will limit the mission's potential duration. At the worst extreme, there may be insufficient battery power left to start the engine and escape from an imminent threat, or activate weapons and defence systems, or even call for help.

The problem is not just that there are limits to the capabilities and capacities of batteries and battery systems fitted to the vehicle. It is that vehicle commanders are working without accurate information on how much power remains available to them for use in achieving their mission. As well as putting personnel in danger, unexpected loss of power is contrary to the purpose of the investment made in tactical systems and architectures.

A related concern is the potential necessity for last-mile logistics convoys during conflicts. If battery lifespan is shortened by inefficient use, extra batteries may have to be delivered to the battle zone. Meanwhile, battery failures may have an impact on the readiness of essential vehicles.

Given that the funding available for a military operation is not unlimited, the expense of delivering those additional batteries to a forwarding base near the battle theatre is an issue. Another source of cost, relating to uncertainty over charge levels, is the practice of idling large diesel engines to keep batteries charged, often unnecessarily. Problems of excessive diesel consumption and the high expense – and danger – involved in moving fuel around battle zones are further compounded by increased engine wear and associated maintenance costs.

The answer, as this guide will show, is to choose the right batteries and to manage their power efficiently. We will start with a summary of the main battery types, highlighting the advantages and disadvantages most relevant to armoured vehicles. We will go on to introduce the concept of successful battery power management through storage, monitoring and switching. Each of these three elements will be explored in turn to give an understanding of how battery power management works.

Finally, we will explain the functionality and features of the field-proven EnerSys® DataCell II® battery monitoring system and EnerSys® VBMS™ (Vehicle Battery Management System). These solutions, whose technology is already deployed on more than 1,500 armoured land vehicles worldwide, put the 'store, monitor, switch' principle into practice with optimum results.

CHOOSE THE RIGHT BATTERY

The first choice is between lead-acid and lithium-ion (Li-ion) battery technologies. Li-ion technology has advantages in many applications, and whilst EnerSys® continues to investigate specific application solutions, there are two main reasons why we believe it is currently unsuitable for armoured vehicles.

The first is its potential for thermal runaway. This is a situation in which rising temperature in a battery accelerates uncontrollably. Thermal runaway is also the reason why charged Li-ion vehicle batteries cannot be carried by aircraft, which makes rapid logistics difficult.

The internal battery management system is primarily in place to prevent such situations from occurring and will respond by shutting the battery down, which could result in power loss at a critical moment, such as in the heat of battle. Lead-acid batteries – especially those recommended for armoured vehicles – are unlikely to behave in this way.

The second issue is a lithium-ion battery's vulnerability to damage in the battlefield if the vehicle comes under attack. Exposure of the lithium material to air – and the water that air contains – can create a fire that burns extremely hot. By contrast, a sealed lead-acid battery can be damaged or even punctured and will continue to work. There is no leakage of electrolyte, and if the puncturing object remains within the battery a kind of healing process occurs. The initial intrusion causes a short circuit, which generates localised heat that melts away the surrounding lead, so the foreign object becomes effectively isolated. In addition, the positioning of a potentially flammable Li-ion battery within a vehicle needs to be very carefully considered. Locating it close to the crew is undesirable, but in more distant locations it may have less protection from damage.

Conventional flooded lead-acid batteries, containing lead plate electrodes suspended in a sulphuric acid electrolyte, have several major disadvantages compared to sealed packs. In particular, they require more maintenance, in the form of regular water top-ups. With their free-moving liquid content, which poses an acid leakage risk, they must always be mounted upright. They can be transported by air, but only if safely packed in suitable containers. Their emission of explosive gases during charging is another key issue. They also score poorly on functional versatility, lifespan, charging speed and deep discharge recovery.

Demand on battery	Demand on battery			
	Flooded	Gel	AGM	TPPL AGM
High current for SLI (starting, lights, ignition) automotive functions	Y	Y	Y	Y
Deep-cycle, longer, low-power discharge for silent watch	Y	Y	Y	Y
Dual purpose (automotive and silent watch)	N	Y	Y	Y
Fast recharge	N	N	Y	Y
Maintenance-free	N	Y	Y	Y
Recoverable from deep discharge	N	N	Y	Y
Long life	N	N	N	Y
Mountable in any direction	N	Y	Y	Y

Fig. 2: What the military needs from its batteries

Valve-regulated lead-acid (VRLA) batteries remove the need for maintenance and the risks related to gases and free acid. Although sometimes referred to as 'sealed', they contain valves that allow gases to escape when internal pressure exceeds a certain level. Their electrolyte is securely contained as a gel, in gel batteries, or within a very fine glass-fibre mat, in absorbent glass mat (AGM) batteries. Gel batteries fall short on charge acceptance, deep discharge recovery, lifespan and air transport-ability. In addition, their gel electrolyte can break down in high-vibration applications and their deep cycling (ability to be deeply discharged) is limited to about 50% of their nominal capacity.

Standard AGM batteries tick every box on the list of military application requirements – see Fig. 2 – apart from long life. This requirement is satisfied by TPPL (Thin Plate Pure Lead) AGM, an evolution of AGM that offers all of AGM's benefits plus longer life. AGM batteries can be safely transported by air, deep-cycled down to 20% of their nominal capacity, without damage, and recovered in the event of deep discharge.

EnerSys® AGM batteries with TPPL technology use high-purity lead in thinner plates to create a greater surface area for the necessary chemical activity. This increases the available energy and lowers internal resistance, so more power can flow. Use of 99.99% of pure lead also extends the battery's cycle life – the total number of charge and discharge cycles it can deliver – and hence its longevity. In addition, TPPL batteries can be topped up with short opportunity charges, without any ill effect, and can be stored for long periods with minimal self-discharge.

EnerSys® has designed these TPPL AGM advantages into its Hawker® ArmaSafe® Plus batteries. More than two million of them have been installed on a wide variety of combat and tactical vehicles worldwide. Their additional military-related features and benefits include integrated flame arresters, high shock resistance, superior cold-cranking performance and an ability to operate within a temperature range from -40°C to +80°C.

STORE

The previous section explains issues to be considered when deciding which type of battery to choose for an armoured vehicle. We will now focus on factors affecting the amount and availability of stored power supplied by the chosen battery. This is the first element of the 'store, monitor, switch' approach to getting the most out of an armoured vehicle's batteries. The next is monitoring the state of health, charge level and related battery parameters to enable informed decision-making. The third is switching the current inflow or outflow between two or more battery banks to achieve optimum effectiveness. If all three are in place, the vehicle's power can be managed successfully.

To understand the challenges involved in optimising a battery's capacity and capabilities, it is useful to compare a charged battery with a tank of fuel. One immediate difference is that a fuel tank can always be refilled to the same maximum level. A battery, on the other hand, loses capacity with age and use. The rate of decline depends on its construction quality and design, the harshness of its use (magnitude of current draw and depth of discharge) and the temperature at which it operates. A battery is normally considered to have reached its end of life (EOL) when its actual capacity falls to 80% of its original nominal capacity.

Temperature is a key environmental factor affecting the performance and longevity of batteries, and overheating is one of the main causes of damage and premature failure. While higher temperatures increase charging rates and power availability, they shorten the battery's lifespan. For maximum life, an operating temperature of 25°C is recommended – although that is difficult to control in the field. It is worth mentioning, also, that cooler temperatures are best for battery storage as they minimise self-discharge rates.

PRIMARY POWER SYSTEMS
Batteries vs. Fuel tanks

FUEL TANK
100 L capacity

BATTERY
100 Ah capacity

Slow rate use	High rate use (Double slow rate)
5L/h for 20h	10L/h for 10h
Capacity independent of load	
5A for 20h	10A for 9h
Capacity has reduced to 90Ah, Capacity varies with load	

Fig. 3: Battery capacity reduction with current (load)

The next big difference between fuel tanks and batteries is that a battery's capacity is reduced if the rate of drawing charge from it is increased. By contrast, consumption rate has no effect on a fuel tank's capacity. Fig. 3 presents some figures to illustrate this. If a vehicle is driven faster, and therefore burns up fuel at a higher rate, the tank is emptied sooner but its capacity remains the same. If a vehicle draws a higher current, the battery's capacity is reduced by an amount calculable using Peukert's Law. It should be noted that this capacity loss varies between battery types. TPPL AGM loses least capacity, followed in order of superiority by AGM, gel and then flooded. One of the aims of efficient battery power management is to reduce the size of current drawn from each battery bank, so its capacity is maintained and its runtime is extended.

Another important difference is that all of the fuel in a tank is usable, while a battery's state of charge should not be allowed to fall below a certain level. If a battery becomes too 'empty', it will be difficult to recharge and its life may be shortened. A more immediate issue for armoured vehicles is that an SLI (starting, lights, ignition) battery must always retain enough charge to start the engine. Conventional flooded or gel lead-acid batteries need to remain about 70% charged for this. An ArmaSafe® Plus battery can start an engine with just 30% of its charge remaining.

MONITOR

The key parameters for monitoring are voltage, current (net charge or discharge) and temperature, from which readings of state of charge (SoC), state of health (SoH) and time remaining are produced. SoC tells the user how much charge is left in the batteries. SoH, which is of more interest to the maintenance team, indicates what percentage of the battery's original capacity when manufactured remains.

Accurate measurement of SoC is vital to the user's decision-making and to any automated battery management system. There are three widely used methods: Amp-hour counting, mathematical modelling and ohmic systems. Amp-hour counting gives excellent accuracy, although it can lose precision if not periodically reset and recalibrated. Mathematical modelling is slightly less accurate when used on its own, but when applied 'in sync' with Amp-hour counting it reinforces accuracy. Both of these techniques have the advantage of low power consumption.

Ohmic systems can be good for one-off measurements but they consume large amounts of power, which is counterproductive when the aim is efficient power management. In addition, their accuracy can be compromised by corrosion, grease or any other obstruction to contact with the battery.

Many battery monitoring system manufacturers use only one SoC method or include ohmic measurement. EnerSys® uses an effective combination of Amp hour counting and mathematical modelling in its DataCell II® battery monitoring system.

SWITCH

Figs. 4 to 7 will help to explain the principle of switching, as used by the EnerSys® VBMS™ battery management system. Fig. 4 shows a traditional set-up with two unconnected battery banks (groups of batteries): one for the engine and one for auxiliary functions like communications. In this scenario, the minimum battery charge level needed to start the engine is set at 40%. If the charge level falls below 20%, special charging techniques may be needed to recover the battery.

A current of 10A is being drawn from the auxiliary bank (but none from the engine bank) to power communications and other equipment. When its charge level falls below 20%, discharge continues as there is no battery protection system to stop it. Eventually the battery is fully discharged and the mission must end. The engine battery bank still has more charge than it needs, so there is no problem in starting and returning the vehicle to base.

In Fig. 5, the two battery banks are joined and two VBMS™ battery management system-'gateways' have been introduced to allow sharing and switching of charge as necessary. Starting with two fully charged banks, power for auxiliary functions is initially drawn equally from both. By sharing the load, each need only supply 5A. As discussed earlier, a lower load means higher battery capacity – so this is the first performance gain.

When charge levels drop to 40%, the VBMS™ battery management system steps in to separate the battery banks and ensure the engine batteries retain enough charge for their primary function of starting the engine. By then, however, they have contributed substantially to powering the mission by supplying charge, which in the traditional system would have remained unused – the second performance gain.

The auxiliary batteries can continue to supply power, now at 10A. When their charge level drops to 20%, the VBMS™ battery management system will halt discharge to protect them. The commander can then make a fully informed decision on whether to override the system, and continue the mission, or prioritise battery health.

SWITCHING – BATTERY DISCHARGE
(Traditional System)

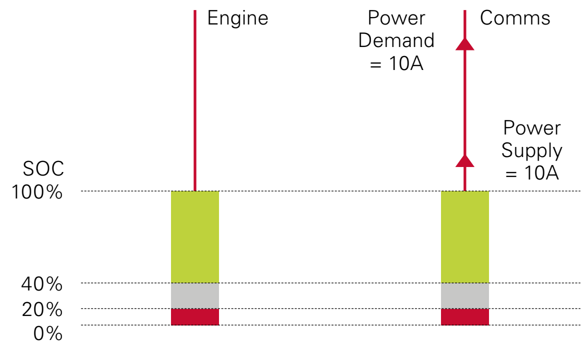

Fig. 4: Battery discharge in traditional system

SWITCHING – BATTERY DISCHARGE
(VBMS System)

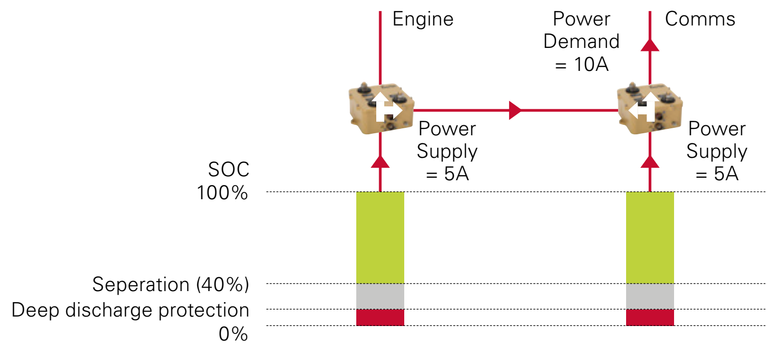

Fig. 5: Switching battery discharge in VBMSTM battery management system

Fig. 6 shows the use of switching to optimise recharging of the batteries by an alternator. The VBMS™ battery management system has been programmed here to prioritise charging of the engine battery bank. It first charges the engine batteries to about 80%. This phase is known as bulk charging. They then enter their absorption phase, in which the final 20% is delivered. The charge current typically tails off during this phase, so additional energy becomes available for the auxiliary bank's bulk phase to be delivered simultaneously.

Bulk and absorption phases usually take about the same time to complete – so by the time the engine batteries reach 100% charge, the auxiliary bank has received its bulk charge and is ready for its absorption phase. Assuming equal duration for each bulk charging and absorption phase, charging in this order takes three-quarters of the time that would be needed to charge the engine bank fully before moving to the auxiliary bank. In this case, engine battery recharge has been prioritised, but prioritisation of another critical function can also be considered.

SWITCHING – SPLIT CHARGING
(VBMS System)

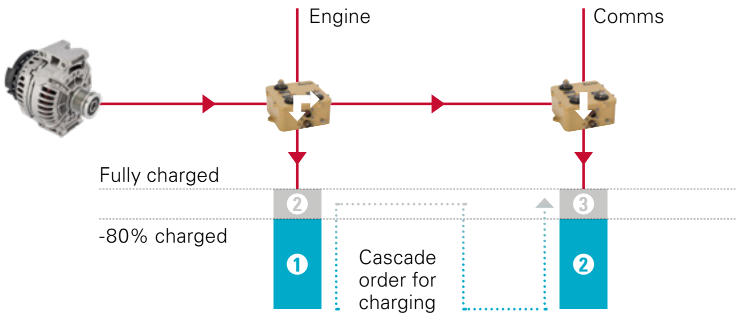

Fig. 6: Switching battery charge in VBMS™ battery management system

Fig. 7 summarises the power economy achieved by the VBMS™ battery management system and its switching, compared to a traditional system. Total runtime (discharge time) is extended from 9 to 14 hours. After this time, battery 1 (engine) is still able to start the vehicle but in the traditional system it contains a lot of unused charge. With VBMS™ battery management system, battery 2 (auxiliary) holds 20% charge and is rechargeable, while in the traditional set-up it is completely flat. Furthermore, charging time with VBMS™ battery management system has been reduced by a quarter.

	Traditional System	VBMS System
Discharge time	9 Hours	14 Hours
Battery 1	100% - Useable	40% - Useable
Battery 2	0% - Flat	20% - Rechargeable
Charge time	4 periods	3 periods

Fig. 7: Comparison of system performance between traditional and VBMSTM battery management system

ENERSYS® DATACELL II® BATTERY MONITORING SYSTEM

Both the DataCell II® battery monitoring system and the VBMS™ battery management system are easy to integrate with existing technologies and systems on any vehicle. Along with the functionality already described, they enable reporting and analysis with a view to improving user practices. They can be used with any type or brand of battery but will achieve maximum accuracy and advantage with Hawker® ArmaSafe® Plus batteries.

Most importantly, DataCell II® battery monitoring system gives commanders clear and accurate information on battery state of charge and indicates how long a silent watch or similar mission can continue. There are no unexpected brown outs and there is no need for guesswork in deciding when to use the engine or an auxiliary power unit (APU) to recharge. Failing batteries are easily identified and good batteries are not wastefully replaced due to misdiagnosed problems.

The system can monitor up to four battery banks simultaneously. It reports via its own LCD display, which is temperature-tolerant and compatible with use of night vision goggles, or via the vehicle's existing inbuilt display. Alternatively, or in addition, it can be connected to the vehicle CANbus - Controller Area Network. If installed without VBMS™ battery management system, its outputs through the CANbus network can be used for switching an external relay. This may serve to connect or disconnect remote weapons stations, for example, providing a way of automatically preventing such functions from flattening the battery.

Each DataCell II® battery monitoring system is pre-configured by EnerSys® for the vehicle and batteries with which it will be used. If a different battery type is fitted later, it will automatically adapt but will lose a little of its accuracy unless reconfigured. Software is provided free of charge, including options for customising displays.

ENERSYS® VBMS™ BATTERY MANAGEMENT SYSTEM

VBMS™ battery management system incorporates DataCell II® battery monitoring system, which serves all the functions described above. In addition, VBMS™ battery management system manages the vehicle's available power. The DataCell II® battery monitoring system display functions are built into the VBMS™ battery management system display unit or, alternatively, all information can be displayed through the vehicle's existing screens. One VBMS™ battery management system can support up to four battery banks, as well as multiple power sources including alternators, APUs and external chargers.

VBMS™ battery management system ensures that power is delivered to different battery banks in the right proportion and is then used in a way that maximises runtime, protects batteries, avoids unexpected flattening and preserves engine start-up ability. These functions are described in the 'Switch' section of this guide.

Additional functionality includes options for emergency paralleling of batteries or overriding automatic discharge limitation if extending a mission is vital. Electronic battery isolation removes the need for a mechanical switch, which is often located in an inaccessible or vulnerable position. It can be placed close to crew access points for ease of use. Amongst its many user-friendly controls, VBMS™ battery management system offers a button-press night mode as well as remote triggering of blackout through centralised vehicle blackout switching. A dual-press procedure, involving a 'prime' button, avoids accidental activation of functions.

The VBMS™ battery management system hardware consists mainly of a microprocessor-controlled 'hub' with cable connections to a number of 'power gateways' which house high-current contactors. Military-grade contactors, capable of around a million cycles, ensure durability. In the event of an incident inflicting catastrophic damage on the VBMS™ battery management system, there are bypass procedures for manual switching.

For applications not requiring the full VBMS™ battery management system set-up, there are three single-box VBMS™ battery management system solutions available. PowerGuard PRO provides flat battery protection only, for single battery banks where charge sharing is not needed. SmartBank enables power sharing between two banks while protecting engine batteries from deep discharge. VBMS™ "Lite" offers a wider range of functions, including deep discharge protection for two battery banks, on vehicles with tight space limitations.

Integration of VBMS™ battery management system with the vehicle's power system is quick and easy. So, too, is addition of data to its CAN, RS232 or GVA network. Configuration to the vehicle-specific architecture is part of the engineering support that comes with each VBMS™ battery management system.

ENERSYS® DATACELL II® BATTERY MONITORING SYSTEM AND VBMS™ BATTERY MANAGEMENT SYSTEM IN ACTION

User cognitive burden is an essential consideration in system design. During a mission, a vehicle crew needs to focus on the task in hand and not have to worry about battery power. VBMS™ battery management system provides alerts when decisions are needed. For example, as a discharging battery approaches a critical charge level, a solid icon may be displayed. As it gets closer, a flashing icon may appear on multiple screens. Before automatic protection engages, an audible warning may sound. Delivery of information in ways like these can be flexibly programmed to meet the end users' needs.

By looking at 'time remaining' on the display, a commander sees how long the mission can continue without starting the engine or APU, withdrawing to a safer position or taking other appropriate action for their mission objectives. It is worrying to note that most armoured land vehicles today do not provide this certainty. Instead, commanders must rely largely on guesswork. In effect, the accuracy of electronic information they expect from a modern car is not available on the vehicle in which they go to war.

Integration of ArmaSafe® Plus batteries, DataCell II® battery monitoring system and VBMS™ battery management system in product design helps to meet the mobility, survivability and firepower trade-offs of the armoured vehicle 'Iron Triangle'. It gives confidence, especially, in the availability of power to start the vehicle and operate both defensive and weapons systems.

The technology and functionality used in today's DataCell II® battery monitoring system and VBMS™ battery management system have been successfully deployed in more than 1,500 armoured vehicles since 2007. Use in the harshest environments in which the technology has proved its worth include within the latest-generation main battle tanks, Infantry fighting vehicles, and troop transport and logistics vehicles. Recent applications include the BAE® CV90 tracked combat vehicle for Norway and the NIMR® Ajban transport vehicle for UAE.

Buyers can choose DataCell II® battery monitoring system and VBMS™ battery management system confidently, based on their track record to date and on the deep experience of EnerSys® as a complete power system provider. The ideal approach is for EnerSys® engineers to apply their knowledge and understanding to the vehicle platform while it is new or still under development. Working closely with the vehicle's design engineers, they will address all power problems and leave the developers free to focus on meeting their primary military objectives.

For further information, visit www.enersys.com.

About EnerSys®

EnerSys, the global leader in stored energy solutions for industrial applications, manufactures and distributes reserve power and motive power batteries, battery chargers, power equipment, battery accessories and outdoor equipment enclosure solutions to customers worldwide. Motive power batteries and chargers are utilized in electric forklift trucks and other commercial electric powered vehicles. Reserve power batteries are used in the telecommunication and utility industries, uninterruptible power supplies, and numerous applications requiring stored energy solutions including medical, aerospace and defense systems. With the recent Alpha acquisition, EnerSys provides highly integrated power solutions and services to broadband, telecom, renewable and industrial customers. Outdoor equipment enclosure products are utilized in the telecommunication, cable, utility, transportation industries and by government and defense customers. The company also provides aftermarket and customer support services to its customers in over 100 countries through its sales and manufacturing locations around the world.

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