Tips & Technology

For Bosch business partners

Current topics for successful workshops No. 05

Trucks

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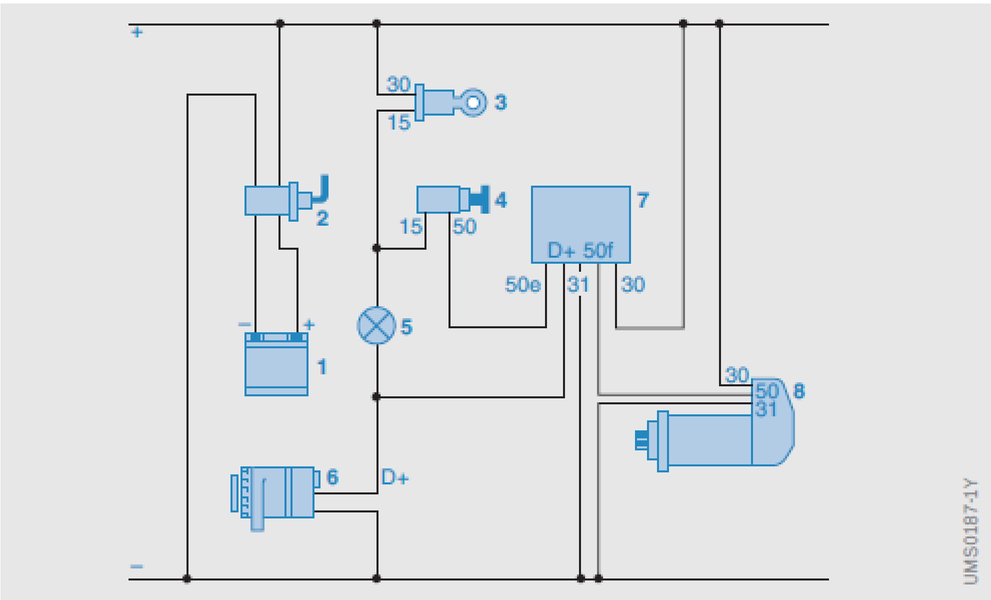
Starters and starter systems – Part 2

Moderately heavy commercial vehicles with diesel engines having a displacement of approx. 12 liters have starter systems that require a nominal voltage of 12 V or 24 V. In heavy commercial vehicles with diesel engines having a displacement up to approx. 24 liters, only 24-V starter systems are used; these are powered by two 12-V batteries connected in series. Sometimes, mixed 12/24-V systems with a 12-V vehicle electrical system and a 24-V starter voltage are encountered.

Starter systems with a start-blocking device

Starter system where the starting process cannot be perceived audibly clearly (e. g. in busses with a rear-mounted engine), required a more complex circuit, since they need effective protection for the starter and engine's ring gear.

Fig. 1: Starter system circuit with a start-blocking relay



1 Battery
2 Battery switch
3 Driving switch
4 Starting switch
5 Alternator indicator light
6 Alternator
7 Electronic start-blocking relay
8 Starter

A starter system with an electronic start-blocking relay (Fig. 1) protects the starter system in multiple ways:

- Disconnection after a successful start,
- Blocking when the engine is already running,
- Blocking when the engine is still coming to a stop,
- Blocking after an unsuccessful start attempt when the engine cannot continue running on its own.

In the latter two cases, another attempt to start cannot be made until a blocking time set in the relay has elapsed. This function is increasingly being integrated into the engine control module.

Starter system with 12/24-V battery switchover

Various commercial vehicles used a mixed 12/24-V system. In these systems, all electrical components – with the exception of the starter – and the alternator are designed for generating the nominal voltage of 12 V. The starter, on the other hand, is operated with a nominal voltage of 24 V. This provides the higher output needed to start larger engines. For this purpose, 12/24-V systems are equipped with a battery switchover relay. During normal driving or when the engine is not running, the two 12-V batteries of the vehicle's electrical system are connected in parallel, providing a voltage of 12 V to supply the consumers.

When the starting switch is actuated, the battery switchover relay automatically connects the batteries in series temporarily for the starting sequence so that a voltage of 24 V is applied to the starter terminals. All other electrical components continue to be supplied with 12 V. Once the starting switch is released, the starter is switched off and the batteries are connected in parallel again. While the internal combustion engine is running, the 12-V alternator (B+ terminal) charges the batteries.

Special starter systems for commercial vehicles

Special starter systems are used, for instance, in large commercial vehicles (large tour buses with a rear-mounted engine, special vehicles with an underfloor engine etc.), diesel railcars, ships and stationary generator sets. The different operating conditions frequently require more complex starter systems with specially configured protection and monitoring relays combined with one another in different ways. These relays control the starting sequence and also make it possible to use two starters in parallel simultaneously for starting. A battery master switch is specified in many larger electrical systems of commercial vehicles. It can be used to isolate the vehicle's electrical system from the battery when the engine is not running. Two important systems are presented in the following from the variety of special starter systems for various applications.

<u>Starter system with start-repeat device</u>

In starter systems with remote control or indirect starter actuation (e.g. in stationary systems, in diesel railcars and, in individual cases, also in commercial vehicles with a rear-mounted engine), a start-repeat relay is used - especially when it is not possible to determine directly whether an start attempt was successful. The start-repeat relay does not operate
when the starter pinion meshes successfully. In the event of a problem (blocked meshing), however, it interrupts the unsuccessful start attempt to prevent thermal overloading of the starter. It repeats the starting sequence automatically until the starter pinion meshes with the

ring gear and the contact for the starter current is made. The start blocking relay that is also incorporated into the starting circuit protects the starter against an unintentional start attempt when the engine is already or still running. This circuit is used exclusively for sliding-gear starters with electrical two-stage operation.

Starter system (12 V or 24 V) with a double-starting relay for parallel operation

To start very large internal combustion engines, a very large single starter would be required. For space reasons, it is preferable to use two (or more) smaller starters instead of one large starter. For the engine to reach the required cranking speed, both starters must drive the ring gear simultaneously in parallel. With an adequate supply of power, about twice the starter output of a single starter is obtained from a parallel arrangement of two starters. In low-voltage parallel starter systems (12 V or 24 V), the starter system incorporates a double-starting relay in addition to the start-blocking relay and the start-repeat relay. The double-starting relay ensures that full starter current is supplied only after full engagement of both starters. In this way, the two starters generate their full torque simultaneously and are subjected to equal loads. Accordingly, starters for parallel operation have an additional terminal.

Parallel starter systems from the HEP109 series

For internal combustion engines that need a cranking power of approx. 12 - 42 kW, a parallel starter system for 24-V vehicle electrical systems has been developed. These high cranking powers are needed, for instance, in construction machinery, large tractors, marine and railway applications and for stationary engines. Depending on the ambient temperature when cold-starting and the size of additional hydraulic loads when starting the engine, the system may already be required for engines having a displacement of 9 liters or more. In the standard application at a cold-start temperature of – 20 °C, it is designed for diesel engines with a displacement of up to 168 liters and gasoline engines with a displacement or more than 200 liters. The system is based on two or three coupled reduction-gear starters from the HEP109 series whose freely disengaging construction ensures resistance to environmental factors. With starters from the HEP109 series, blocked engagement is eliminated by the design. This makes the additional expense of a start-repeat relay unnecessary. The functionality of the double-starting relay is integrated into the arrangement of the individual parallel starters. Moreover, in a double- or triple-starter system, only identical HEP109 starter types are used, since the appropriate coding can be achieved with the aid of a 5-pin system connector as an option. With optimal distribution of the mechanical and electrical loads, about twice the service life is obtained compared to that for a single direct starter.

Starter design

The most important limiting conditions that must be taken into account when designing the starter are:

- The minimum starting temperature, i.e. the lowest temperature of the engine and the battery at which starting must still be possible,
- The cranking resistance of the engine, i.e. the torque required at the crankshaft, including that for all additional loads,
- The required minimum speed of the engine at the minimum starting temperature,
- The gear ratio between the starter and crankshaft,
- The nominal voltage of the starter system,
- The characteristics of the starter battery,
- The resistance of the cables between the battery and starter as well as the contact resistances at terminals and switching elements (isolation switch etc.),
- The speed/torque characteristic of the starter,

- The maximum permissible voltage drop in the vehicle's electrical system (functionality of the engine's electronics must be assured).

The starter cannot be viewed in isolation. As a component of the overall system consisting of engine and its ancillary equipment, the vehicle's electrical system with battery and wiring, and the starter itself, the latter must be matched to the other components.

Minimum starting temperature

The frictional resistance that needs to be overcome is highly dependent on the lubricant viscosity and thus the engine temperature. At low temperatures, the frictional resistance can be two to three times higher than at the engine's operating temperature. In addition, as the temperature decreases, the minimum cranking speed needed to obtain satisfactory mixture formation in a gasoline engine or compression ignition in a diesel engine increases. Consequently, the starter must generate considerably more power for cold starts than when the engine is warm. At the same time, the vehicle's battery can provide only a reduced voltage or less current under cold conditions, since the internal resistance of the lead-acid batteries usually used increases significantly with decreasing temperature. As a result, the power of the starter system drops at lower temperatures. The increasing frictional resistances of the engine, on the one hand, and the decreasing power of the starter system, on the other, mean that the speed achievable decreases as the temperature drops and under certain circumstances may not be enough to start the engine at low temperatures. For this reason, the engine can be started only above a certain temperature, the minimum starting temperature.

In Europe, starter systems are generally designed for the minimum starting temperatures listed in Table 1, with the values reflecting the different climate conditions encountered in the individual countries.

Table 1: Minimum starting temperatures

Engines for	Minimum starting temperature
Cars	- 18 °C…- 28 °C
Trucks, buses	- 15 °C…- 32 °C
Tractors	- 12 °C…- 15 °C
Drive and auxiliary engines on ships	- 5 °C
Diesel locomotives	+ 5 °C

Cranking resistance

The cranking resistance, i.e. the torque required to turn the engine over, depends primarily on the engine's displacement and the viscosity of the engine oil (and thus on the engine temperature). The design of the engine, the number of cylinders, the ratio of stroke to bore, the compression ratio, the mass of the moving engine components and the nature of their bearings, as well as the additional drag from the clutch, transmission, and auxiliary equipment also have an effect. In general, the mean cranking resistance increases with increasing speed in the case gasoline engines. In diesel engines, on the other hand, the resistance may decrease after peaking at an engine speed of 80...100 rpm because of the energy recovered from the relatively high compression work.

Minimum cranking speed

The minimum cranking speed varies with engine type; start-assist measures also have an effect in diesel engines. Table 2 shows some empirical values.

Table 2: Empirical values for minimum cranking speed at - 20 °C

Engine	Speed
Gasoline engine	60 rpm ...100 rpm
Direct-injection diesel engine without start assist	80 rpm ...200 rpm
Direct-injection diesel engine with start assist	60 rpm ...120 rpm

The combination of required torque at minimum starting temperature and the minimum cranking speed yields the required starter output as the first criterion for selecting a starter type.

Rated power

The rated power of the starter is a characteristic determined on a test stand and depends on the prevailing conditions when starting. The data provided by Bosch are based on a cold start using the largest permissible battery at a charge state of "20% discharged" at a temperature of – 20 °C. The resistance of the main starter cable is 1 m Ω. The p
engines ring gear.

Rated power data based on considerably different prevailing conditions are also common. Other measurement specifications and standards sometimes call for measuring at + 20 °C and application of torque at the center of the pinion so that the losses at the engine's ring gear do not need to be considered. Lastly, the specified battery characteristic curves also differ. Because of this, the power output data listed for starters today is quite inconsistent overall.

Actual power output

The actual power output of a starter system depends primarily on the battery cable resistance and battery's internal resistance. The lower the internal resistance of the battery, the higher is its output and hence also the output of the starter. The battery must be sized to provide the required current at the minimum starting temperature and this for a sufficiently long period of time even under unfavorable operating conditions. The battery and starter must be matched to one another. Starters are designed for a maximum and
a minimum battery size. When operated with a smaller battery, the actual output of the starter system is less than the rated output. As long as the cold-start requirements and functional reliability of starting-relevant assemblies (control modules, relays) are satisfied, this is technically permissible. When operated with a larger battery, the output is greater than the rated value. This can result in overloading of mechanical parts, increased wear and thermal overloads. In permanent magnet-excited starters, partial demagnetization of the permanent magnets may occur and thus irreversible torque loss. Accordingly, the battery size intended must not be exceeded.

Transmission ratio

Selection of the correct starter output (based on a combination of torque and speed) is not sufficient to design the starter. Instead, the starter must be matched to the needs of the engine in terms of speed and torque. This requires that the transmission ratio from the starter pinion to the engine's crankshaft be considered as an additional design variable. This can be accomplished within limits by selecting different numbers of teeth on the starter pinion.

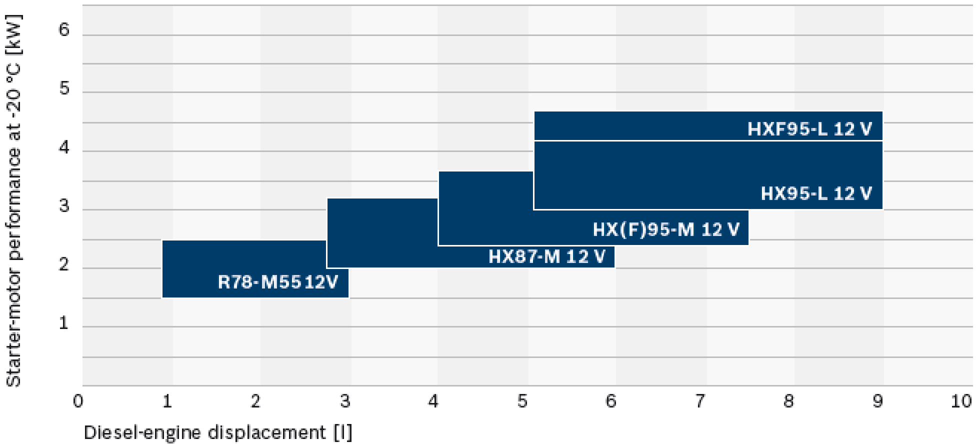
Considerably more flexibility is offered, however, through use of an internal reduction gear in the starter, which permits a wider range of characteristic curves.

Rated voltage

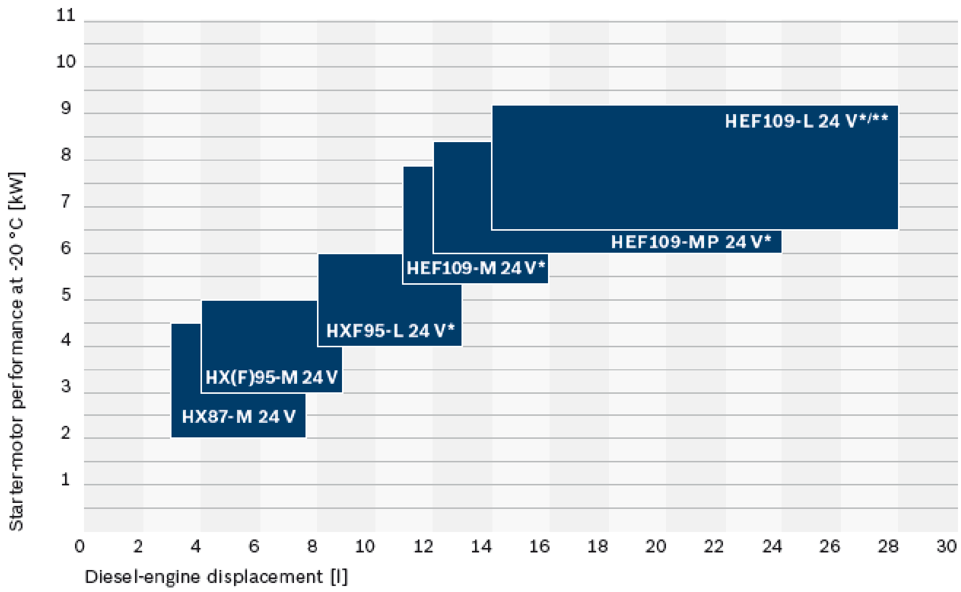
As a rule, the rated voltage of starter systems is specified. This is currently 12 V throughout the industry for passenger cars and 24 V in Europe for large commercial vehicles. In the USA, even commercial vehicles use 12-volt electrical systems for the most part. On vans, construction and ground preparation vehicles as well as small generator set engines and ship engines, both 12 V and 24 V are common. Stationary installations, locomotives and special vehicles are sometimes also equipped with special systems that use 36...110 V.

Starter types

Starter types for commercial vehicles (12 V)



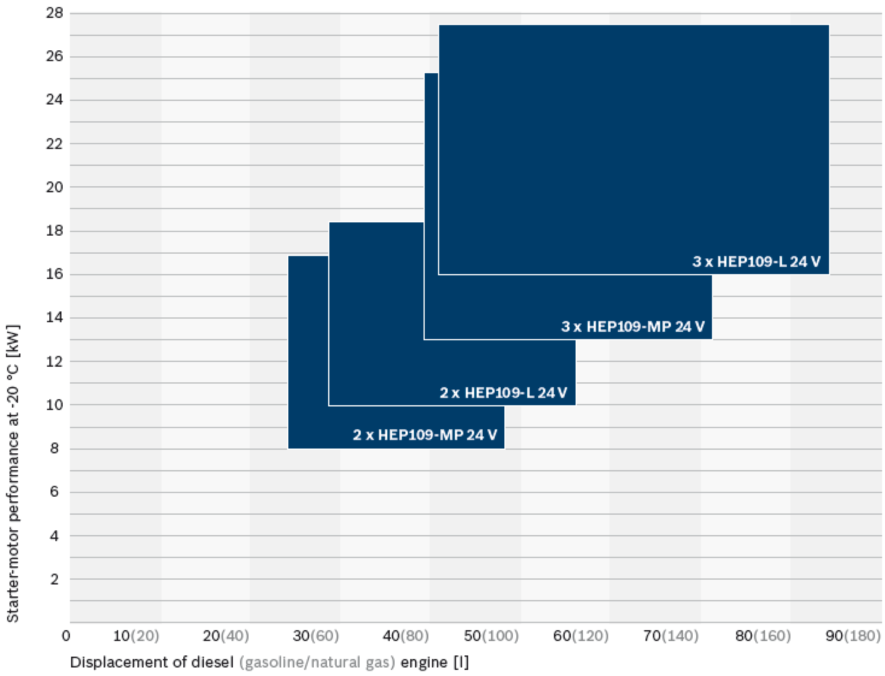
Starter types for commercial vehicles (24 V)



* electrically 2-stage

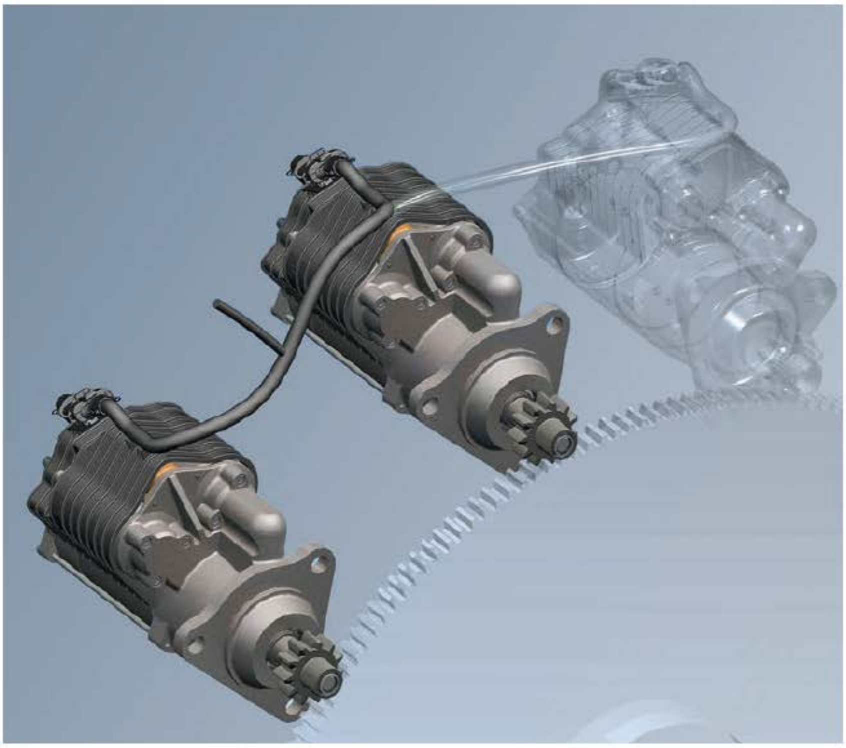
** with extended performance range for use with larger battery (DIN 360 Ah/1,200 A instead of 220 Ah/900 A)

Parallel-start systems:



Range of applications for HEP109 parallel starting system

System designations



HEP109-MP 24 V parallel starting system

The starter designation provides information on the series, the excitation system, the bearing type, the pole housing diameter and the armature core length. Starters from Bosch are identified using the system designations shown in the following figure.

HEF 109-MP 24V (R)

Series	Excitation system	Bearing type	Pole housing diameter	Armature core length	Option	Optional: voltage, direction of rotation	
R: reduction gear up to Ø86	**-:** permanent	**-:** mouth	86 / 88	**S:** shortest	**P:** boosted type	12 V	(R)
H: reduction gear from Ø86	**E:** electrical 6 pole	**F:** FAS	95	**M:** medium		24V	(L)
D: direct	**X:** electrical 4 pole	**P:** FAS parallel starter	109	**L:** long		36 V	
C: compact				**E:** longest			

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