Tips & Technology
For Bosch business partners

Current topics for successful workshops No. 05

Trucks

Invented for life

Starters and starter systems – Part 1

Requirements and functions

Internal combustion engines must be cranked at a certain minimum speed by a starter before they can generate enough energy from the combustion cycles to meet the torque requirement for the compression and charge exchange cycles. At this point, the bearings in the engine are not yet lubricated adequately so that significant friction must be overcome when cranking the engine.

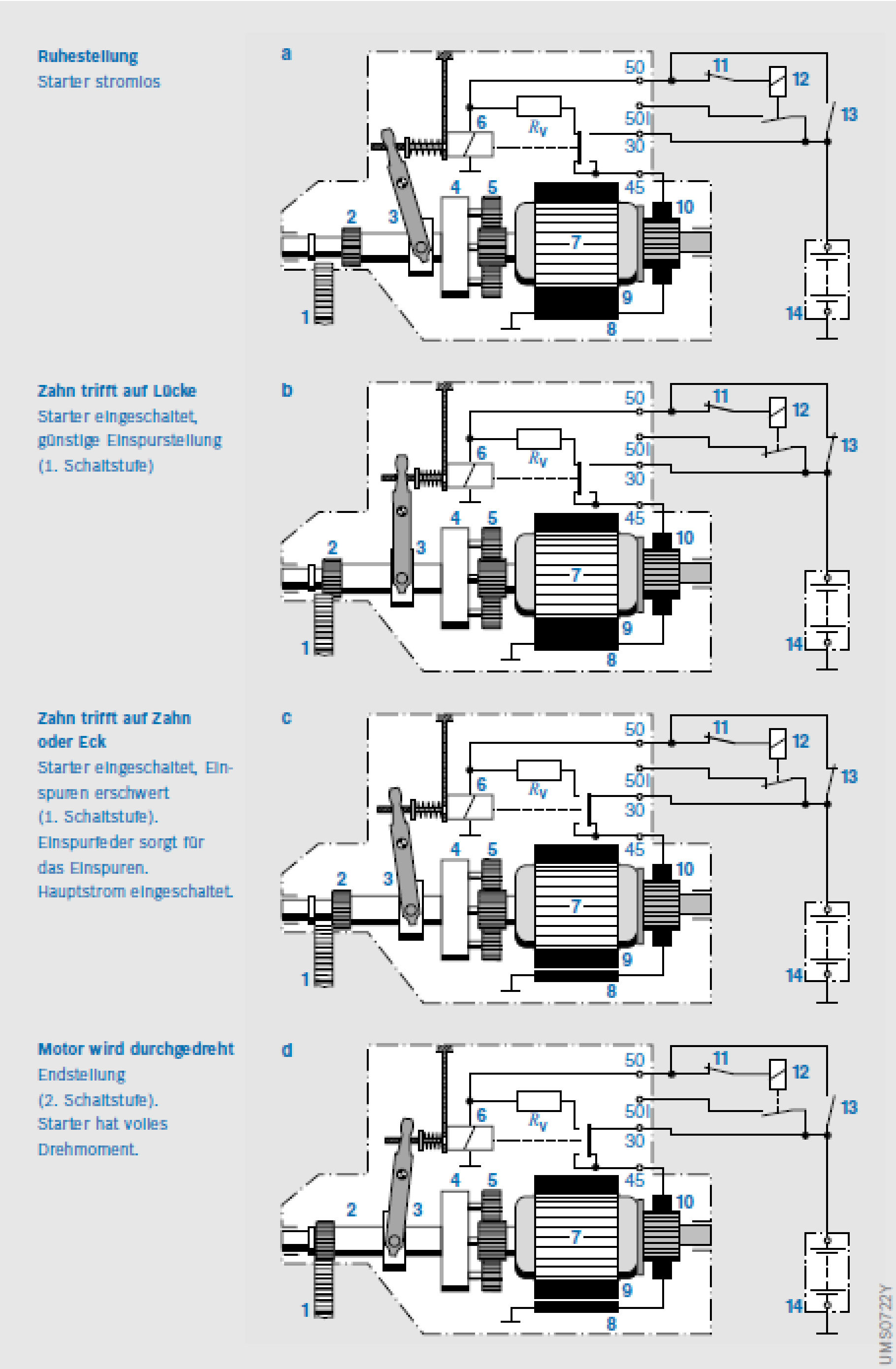
To start internal combustion engines, electric motors (DC, AC and three-phase motors) as well as hydraulic and pneumatic motors are used. The electric DC series-wound motor is especially well-suited for use as a starter motor, since it develops the required high starting torque needed to overcome the cranking resistance and accelerate the engine masses. As a rule, the energy needed for the starting process is drawn from the battery, which also supplies the other electrical components of the vehicle's electrical system. The torque generated by the starter is usually transmitted to the engine via a pinion and ring gear, but to some extent also by V-belts, toothed belts, chains or directly to the crankshaft.

To start the engine, the pinion on the starter meshes with the ring gear on the engine. The ring gear, which typically has approx. 130 teeth (103...144 on cars, 110...160 on commercial vehicles), is located on the engine's flywheel in vehicles with a manual transmission or on the torque converter housing in vehicles with an automatic transmission. The starter pinion, which typically has 10 teeth (8...10 on cars, 9...13 on commercial vehicles), is initially a few millimeters away from the ring gear. When the driver turns the ignition key to the starting position, a mechanical connection is established between the starter and the ring gear (meshing) to transmit the torque from the now-turning starter to the engine. As a result of the high gear ratio between the starter pinion and ring gear, the starter can be designed for a high speed at a low torque. This allows the size of the starter to be kept small and the weight low.

Starters for commercial vehicles with an electrical two-stage pinion-engaging system

A variety of starters in the higher performance range for commercial vehicles with large internal combustion engines (Bosch types HX(F)95-L, HEF109-M to -L) are equipped with an electrical two-stage pinion-engaging system (see Fig. 1) that permits safe and smooth meshing with the ring gear. The first switching stage merely assists meshing of the starter pinion at a slow starter motor speed; the starter is not yet cranking the internal combustion engine. The main circuit is completed only in the second stage. The two-stage pinion-engaging process is achieved through use of a pilot relay and an engaging relay. The meshing spring is incorporated into the engaging relay.

Fig. 1: Electrical two-stage pinion-engaging system



1 Ring gear
2 Pinion
3 Engagement lever
4 Roller-type overrunning clutch
5 Planetary gearset
6 Engaging relay
7 Armature
8 Exciter winding
9 Pole shoe
10 Commutator
11 Thermal switch
12 Pilot relay IMR
13 Starting switch
14 Battery

RV Series resistor

1. Switching stage (preliminary stage)

The voltage signal from the ignition lock or a control unit initially energizes the pilot relay, which can switch the required high current of approx. 180...200 A (for 24-V starters). The current flows through a series resistor or a pull-in and hold-in winding. This causes the engagement lever to move the overrunning clutch with pinion shaft in the axial direction, while the electric motor turns gently. In this way, complete meshing of the pinion with the ring gear is usually achieved before full current is supplied to the motor through closure of the main circuit.

2. Switching stage (main stage)

Once the pinion has meshed successfully with the ring gear, the relay armature disconnects the current through the series resistor or pull-in winding by means of its NC contact shortly before the end point is reached. A few milliseconds later, the primary current is connected and the starter begins to generate full torque. In some cases, meshing may not occur because of unfavorable positioning of the pinion with respect to the ring gear (edge on edge). In this case, the meshing spring in the relay armature ensures connection of the primary current before full engagement of the pinion in the ring gear occurs. Single-stage meshing is then the consequence.

Attempts were made to protect the pinion and ring gear even before the electrical two-stage pinion-engaging system was invented. For instance, electrical pinion rotation (types KB, QB, QF, TB, TF;) and mechanical pinion rotation (types JE, KE) were used.

Sliding-gear starters for commercial vehicles with electrical pinion rotation

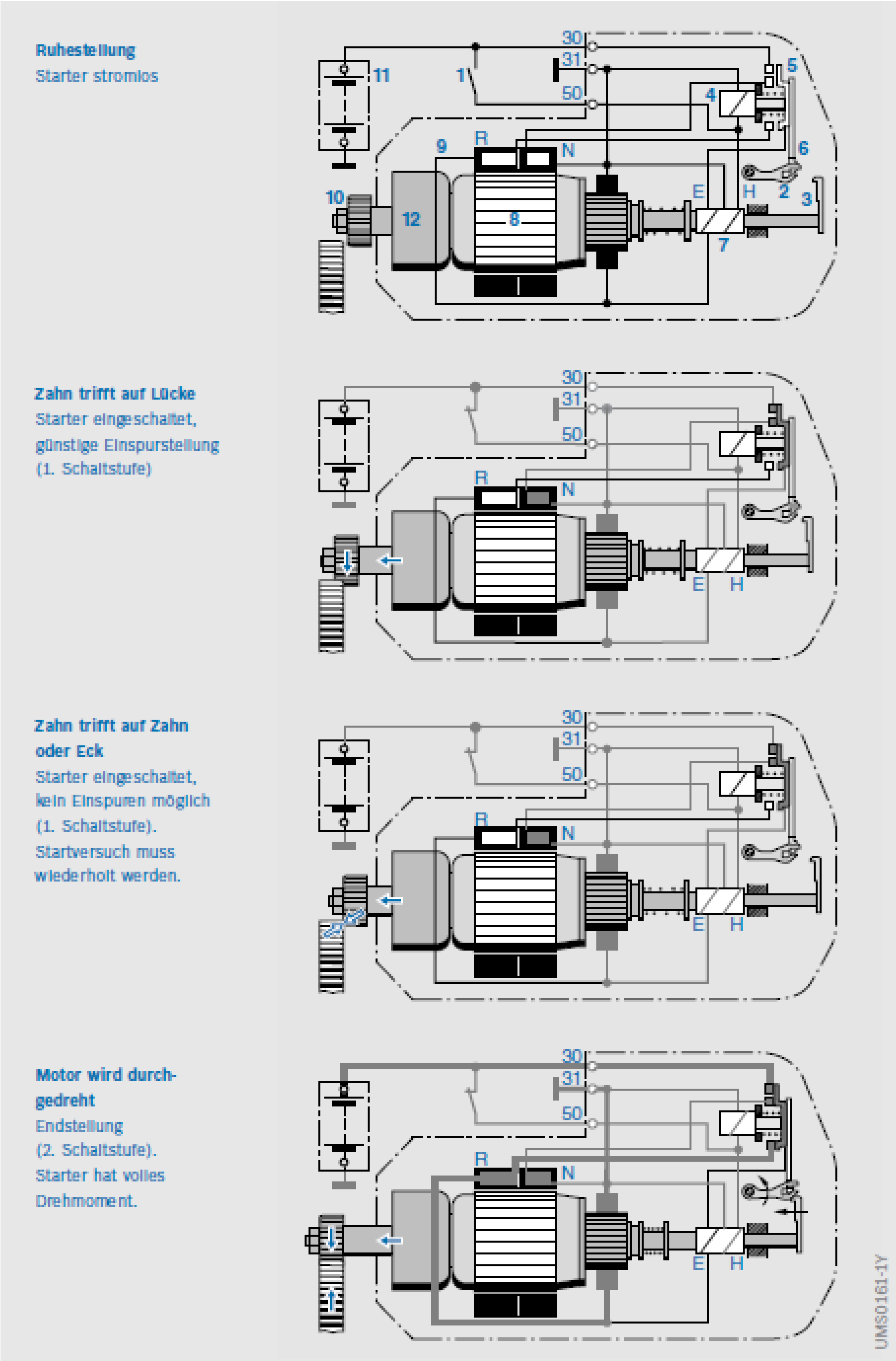
1. Switching stage (preliminary stage)

In the 1st stage, the starter pinion moves in the axial direction and simultaneously slowly rotates in order to allow smooth meshing. When the starting switch is operated, the control relay and the hold-in winding of the engagement solenoid are energized. The control relay then immediately completes the circuit for the pull-in winding. The engaging armature then pushes the pinion against the engine's ring gear by means of the engagement rod and drive spindle. At the same time, the shunt winding, which initially is connected in series with the starter armature, is energized. It acts in conjunction with the pull-in winding of the engagement solenoid as a series resistor for the starter armature winding. This circuit limits the armature current so that the starter armature can produce only a small amount of torque and turns only slowly. If the pinion and ring gear are positioned tooth-on-tooth, the pinion rotates to the next gap in the ring gear teeth. In the case of edge-on-edge positioning ("blocked engagement": pinion can neither slide into engagement with the ring gear nor rotate in front of the ring gear), the starting process must be stopped and repeated.

2. Switching stage (main stage)

Immediately before the pinion reaches the end of its engagement travel, a release lever lifts up a tripping lever and release the control relay's contact bridge. A pre-tensioned spring can then abruptly press the contact bridge against the contacts. The starter motor now receives full current and, with its full torque, cranks the internal combustion engine by means of the multi-place overrunning clutch.

Fig. 2: Electrical pinion rotation



1 Ignition switch or driving switch
2 Tripping level
3 Release lever
4 Control relay
5 Contact bridge
6 Stop
7 Engagement solenoid
8 Armature
9 Exciter winding
10 Pinion
11 Battery
12 Multi-plate overrunning clutch

E Pull-in winding
H Hold-in winding
N Shunt winding
R Series winding

Sliding-gear starters for commercial vehicles with mechanical pinion rotation

1. Meshing stage

When the starting switch is operated, the engagement relay initially moves the engagement lever against the return spring. The engagement lever slides the spur-gear overrunning clutch in a straight line over the straight tooth gearing until it meets the ring gear. If the pinion happens to slip into a gap between the teeth of the ring gear, it will continue moving the full extent of its travel.

2. Meshing stage

If the pinion encounters a tooth of the ring gear as it advances, the remaining components of the spur-gear overrunning clutch continue to move in a straight line toward the ring gear. The helical spline of the spur-toothed clutch component causes the pinion to rotate in the working direction while simultaneously tensioning the meshing spring of the overrunning clutch. The tooth on the pinion gear slides past the tooth on the ring gear to the next gap in which the pinion can mesh under the pressure of the tensioned spring. In the case of edge-on-edge positioning ("blocked engagement": pinion gear tooth can neither slide into engagement with the ring gear nor rotate in front of the ring gear), the starting process must be stopped and repeated. In this case, the helical spline forces the starter armature to rotate opposite the normal direction of rotation (armature reversal) when the spur-gear overrunning clutch is being moved by the engagement lever. The next time starting is attempted, the pinion is in a better position relative to the ring gear and can mesh. The spur-gear overrunning clutch and relay are matched to one another in such a way that the relay contact (primary current contact) cannot close until engagement is complete. Only then can the starter transmit its full torque to the ring gear.