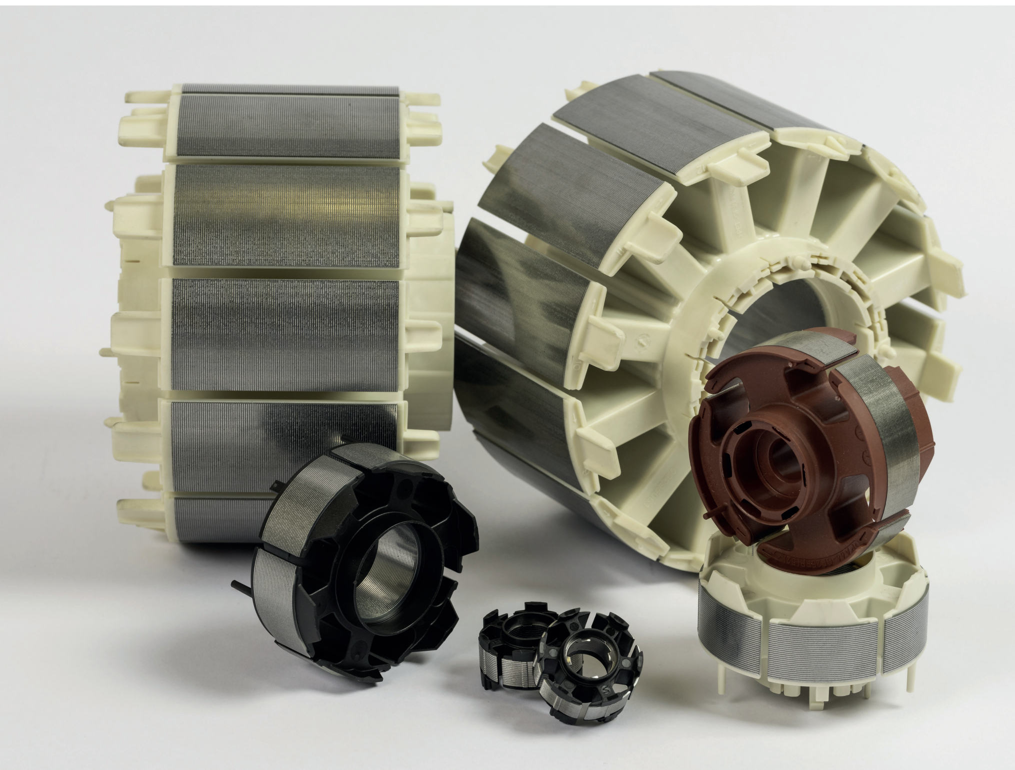
Injection Molds for Insulating Stators and Rotors

Overmolding as a Prerequisite for Cost-Efficient, High-Quality Electric Motors

Electrical components are made from conductive and nonconductive materials. Pressure of competition makes it necessary to reduce the number of components and work steps and to streamline assembly. The moldmaker Mühlbeyer uses a hybrid technology for manufacturing stators and rotors, in which the contact material and plastic are permanently bonded in one production step.



Various plastic-coated stators. During overmolding of the sheet components, not only insulation but also technical functions can be incorporated © Mühlbeyer

In our modern world, if something is caused to rotate or move at the push of a button, electrical drives are usually involved. Electric motors make manufacturing processes effective and efficient in many industries – e.g. machinery, apparatus, material processing, chemicals, plastics, paper, textile, foods, stone/earths. Electric motors are also indispensable in transport (rail, automotive, marine, air), household appliances, agriculture and consumer goods. In the mass production of electric drives, too, electric motors permit highly efficient manufacturing, enabling a very good price-performance ratio.

The key elements of a simple electric motor are:

- rotor (rotating electromagnet),
- stator,
- commutator (only for d.c. motors),
- brushes,
- coil, and
- shaft.

The rotor (**Fig. 1**) is the moving part of the motor and moves between the two poles of the stator (**Fig. 2**). Depending on the type of electric drive and electrical winding, there are two types of electric motor, depending on how power is generated:

- The laminated core serves for guiding and locally concentrating the magnetic field lines.
- The electrical winding generates the magnetic field.

The laminated core of an electric motor consists of thin sheets of a soft magnetic material, with thicknesses from about 0.1 to 1.2 mm, depending on the type and size of the machine. The two dimensional form of the rotor or stator is punched out of these sheets with punching tools. The sheets are stacked in the axial direction and are insulated from one another to minimize the effect of eddy currents.

The winding of an electric motor consists of copper wire of various types: stranded, flat, profile, fine, drill, braided, baked varnish or standard wire, insulated and, in some cases, with a lubricant coating. Irrespective of the type of winding (distributed or concentrated), the wires are electrically insulated from one another and with respect to the laminated core.

The winding insulation is the electric motor's Achilles' heel as regards heat resistance. Thermal materials have service

Fig. 1. Examples of plastic-coated rotors © Mühlbeyer

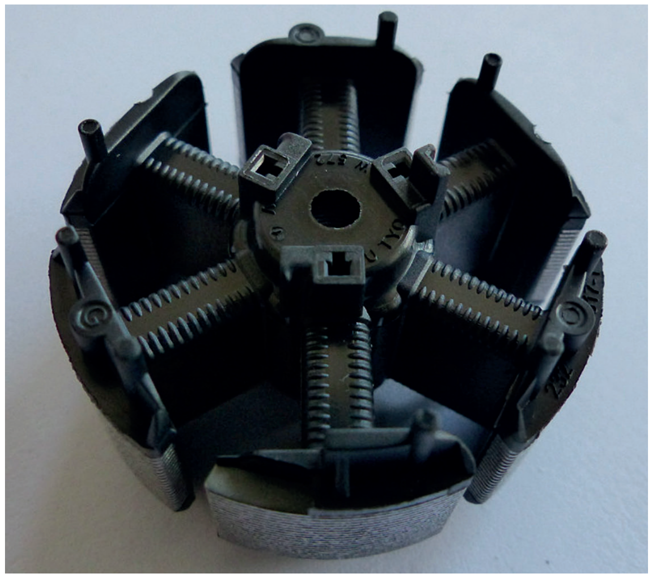


Fig. 2. Stator coated with a polyphenylene sulfide (PPS) © Mühlbeyer

temperatures up to 250 °C. At the same time, the copper conductors form the largest heat source by far due to current heat losses. That means that the power density is dependent on the thermal loading capacity of the insulation and on the possibility of dissipating the heat loss. For conducting the current, the insulating materials are just as important as the conductor materials.

The Insulating Materials Are as Important as the Conductor Materials

The large number of available insulating materials makes selection and a summary presentation very difficult. There are various requirements, such as high dielectric strength, high tracking resistance, good thermal conductivity, high thermal resistance, good chemical resistance, high mechanical strength and low costs. Since these goals are difficult to reconcile with one another, specially modified insulating materials are selected depending on the priority. The insulating materials used have a direct influence on the thermal conductivity, the voltage tolerance and in particular the geometrical design of the motor. The thicknesses of the insulating layer and creepage paths should thus be provided according to design criteria.

Here it should be considered how the insulating system of the electric motor can be designed according to the load. Among other things, the voltage distribution must be analyzed under different operating states and various insulation materials characterized. This function is generally performed by plastics.

During overmolding of the laminated core, plastic-coated stators/stator segments must include, in addition to the slot insulation and the base plate for fitting the laminated core, also technical functions such as track ribs for wire bonds, pole-pocket insulation, plug shafts for contact parts, deflection pins, passages for wire guides, pole-piece inner flanges, clearances for screw heads, inlet and outlet slots (**Fig. 3**).

At the beginning of the injection cycle, the laminated core is inserted into the mold manually or automatically by grippers, and positioned via a center core. As the mold closes, it is held in position by slides and subsequently overmolded with plastic, e.g. a PPS-GF40, to form the final part. Finally, a camera performs automatic optical quality inspection of the parts. Such molds are one of the specialties of Mühlbeyer Werkzeug- und Formenbau GmbH.

Mold Components Are More Expensive at High Mold Temperatures

The plastic selected for insulating the stator segments, the stator, rotor or fan impeller crucially influences the costs of the injection mold. Polyamide (PA), which requires a mold temperature of 80 to 100 °C, causes far lower costs than a plastic such as polyphenylene sulfide (PPS), which requires a mold temperature of approx. 150 °C, polyetherketone (PEK) or polyetheretherketone (PEEK), which require a mold temperature as high as 240 °C or more. »

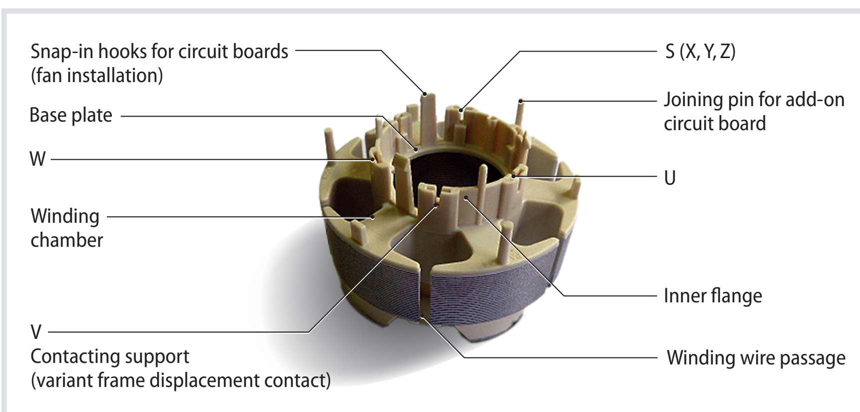
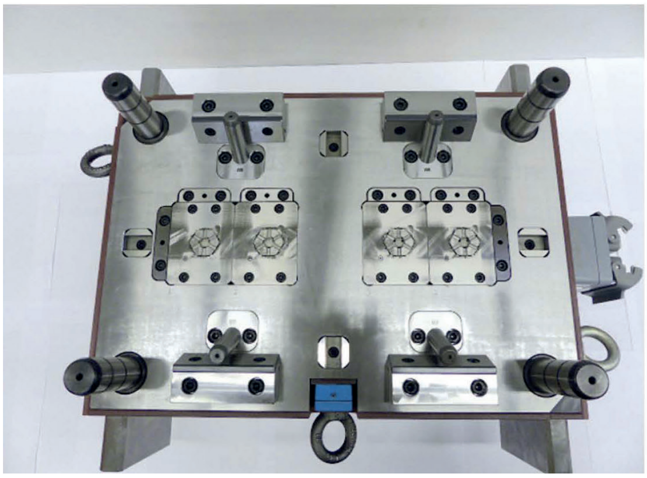


Fig. 3. Plastic-coated stator with additional technical functions. U/V/W refers to the electrical connection (motor star connection, S = star point) © Mühlbeyer



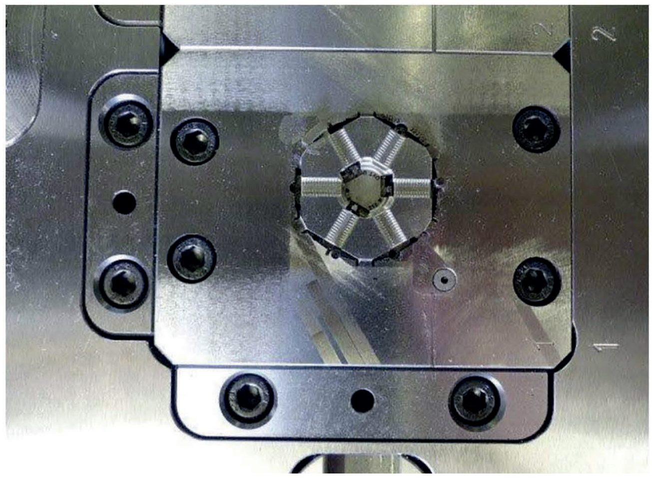


Fig. 4. Fixed half of a 4-cavity injection mold for plastic-coated stators. Along side the main application of mold in close-up view © Mühlbeyer

At high mold temperatures, standards such as sensors, actuators, magnets for inserts, complete all-round insulation of the injection mold, the hot runner system, or more complex slides (flash formation), become significantly more expensive. The dimensional tolerances of the mold components are smaller and may require a machining accuracy of 2 µm. Furthermore, the corrections for the high-performance plastics PPS, PEEK and PEK are much more complex, since the viscosity (flash formation on the spotting surfaces) is higher than for PA. In high-voltage insulating bodies, the flash formation can lead to partial discharges or even damage wires or winding errors.

There is a negative influence on the flow behavior of plastic compounds containing glass fiber reinforcement or mica. Therefore, an injection molding simulation (mold flow analysis) should be performed if possible to avoid a faulty design due to wrong assumptions. Possible error patterns of the injection molded part could be: incomplete injection, weld line defects, etc. In the simulation, additional flow aids, multiple gates, etc. can be introduced and simulated if necessary – or else an overflow cavity in which the excess plastic is automatically separated off as the mold is opened.

Flow Guides Assist Filling in Thin-Walled Regions

Flow aids are additionally installed at places that do not affect the function of the electric motor. This may be, e.g., at the slot insulation surface, toward the inner-central region of the yoke ring, which is not in contact with the winding. Flow guides can also be implemented by means of holes through the laminated core of the rotor or stator with diameters of a few millimeters. These flow guides support the material flow of thermoplastics and promote complete filling of thin-walled sections.

Such injection molds must always incorporate compensation of the laminated core tolerances (up to 0.8 mm) to ensure a stable process. Because of the winding technique, extremely small geometries (e.g. 0.1 mm radius) are necessary for placing the winding wire. For inclined winding in grooves, a certain surface roughness is necessary to prevent slipping of the winding. Of course this presupposes that the polymer insulating material can also perform this.

There Are Consequences to How Precisely the Inserts Are Positioned

Inserts such as permanent magnets, laminated core or others must be precisely positioned in the injection mold; their position must be clearly defined during injection molding. This is possible with various Mühlbeyer clamping systems in the injection mold. The greater the positioning accuracy of the inserts, the lower is the motor imbalance. That means that the asymmetric distribution of the rotor mass is advantageously reduced. A lower imbalance in turn has a positive effect on the

Fig. 5. 4-cavity mold (moving half) for a stator, which runs on a round-table machine. It contains a CVe monitor for electronic mold monitoring, which displays number of shots, cycle time and percentage utilization on the display © Mühlbeyer

efficiency of the electrical drive and at the same time reduces the noise and component wear. Furthermore, due to precise positioning of the laminated core or basic body in the injection mold, the tolerance chain is improved in the radial, circumferential and longitudinal directions.

For design of the injection mold, a functional flow charge should be specified for the injection mold. This establishes the function and position of the inserts. The wire guidance must likewise be ensured. The different heights of the stators and rotors due to the different laminated cores must be taken into account by means of mechanical height adjustment in the injection mold (**Figs. 4 and 5**). The gating point or points must also be specified to ensure complete filling and low-warpage of the plastic insulation.

Complete filling is essential to eliminate any possibility of dielectric failure during operation. Another challenge for the design of the injection mold is the brightness of the outside and inside of the yoke ring, which is often required. This, too, requires design measures. It can be done, for example, with various sealing technologies with respect to the punched part.

In particular cases, if the application is running on a system with a round table, the lower part of the mold is duplicated (**Fig. 6**). In the automatic manufacturing system, the laminated cores and possibly additional inserts must be inserted with pinpoint accuracy into the mold cavity. The round table allows the loading gripper enough time to dock and carefully insert the laminated core and other inserts at the correct position. This is performed by a robot. For this purpose, the gripper automatically orients itself above the four-cavity mold to an accuracy of a few hundredths of a millimeter. The exact positioning of the inserts, whose completeness is checked by means of a camera subsequently takes place in the mold. After the overmolding, the robot picks up the overmolded parts. The circular table rotates through 180° into the correct position for the injection molding. The overmolded part is subsequently placed by the robot in boxes, which are stacked one on top of the other and are transported out of the system on a conveyor belt. Simultaneously, the cavities of the second lower half of the mold is filled again at the other side of the round table. A complete injection cycle takes 26 s. This means very high productivity for the customers.

The machining of the individual components for the stator or rotor injection molds may also require special measures. For example, in a short mold, which serves for production of rotors and stators of electric motors, apart from the laminated cores, magnets are also inserted. This makes it necessary to use a material for the cavities that is not magnetic itself. Mühlbeyer therefore opted for the non-magnetizable material ferrotitanium for this mold.

In the first trials to mill this material, which at 48 to 53 HRC is not particularly hard but because of its titanium carbide and austenitic structure, is very wear resistant, the milled-off chips fused in the mill cutters. Special milling cutters therefore had to be used for the ferrotitanium. In addition, additional clamping devices had to be constructed since the magnetic chucking technology is unusable for this titanium-iron alloy.

Summary

The mold technology described here for plastic-coated laminated cores and inserts is an added value for customers who manufacture and assemble stators and rotors for electric motors (current-excited or permanent magnet). The overmolding technology used, which Mühlbeyer also uses to serve users from the automotive, rail, wind power, electrical, control, air conditioning, plant and automation technology, is characterized by high process and cost efficiency, since, besides the insulation, technical functions are also incorporated into the part. ■

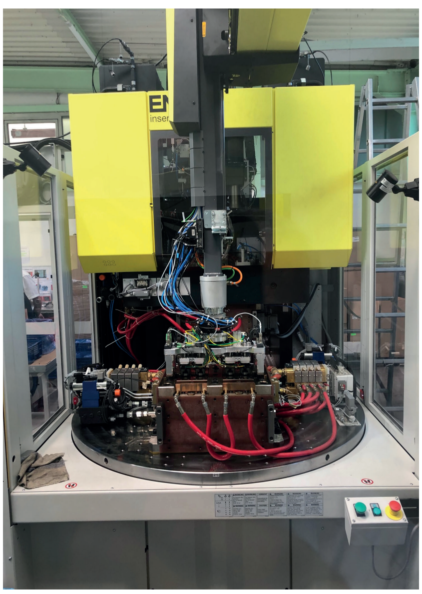


Fig. 6. Fully automated manufacturing line: the 4-cavity mold for stators – consisting of a mold upper part and two mold lower parts mounted on the round table – including handling, was designed and constructed by Mühlbeyer

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Company Profile

One of the focuses of **Mühlbeyer Werkzeug- und Formenbau GmbH** is the construction of injection molds overmolding laminated cores and other inserts with an insulating material for the manufacture of plastic-coated stators and rotors for electric motors. The advantages of overmolding technology compared to conventional paper insulation include:

- only one injection mold is required for the entire insulation (slot insulation and face insulation, end plates with numerous additional functions),
- improved thermal conductivity,
- easier motor winding,
- high cost efficiency

Mühlbeyer offers injection molds for twisted and non-twisted external rotors for stators and rotors, overmolded with plastic insulation (laminated core height up to approx. 90 mm, thin-walled insulation 0.5 mm), single or double overmolded stator segments or stators with overmolded ball bearings or sintered bearings, or with dial and cover cap for perfect coordination of the individual components to ensure optimum and automated assembly.

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