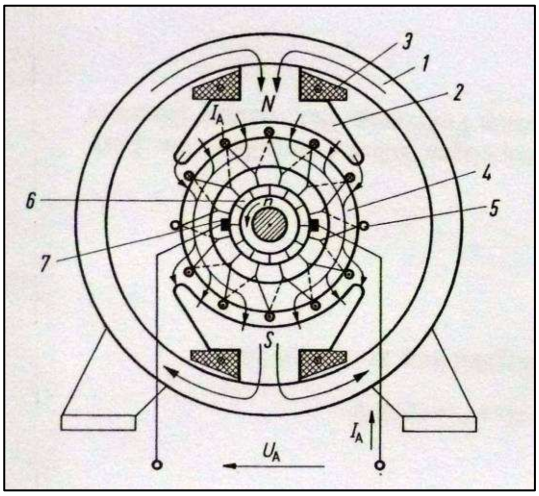
Electric Motors: Introduction and Maintenance

Works of art with electric motors possess as one artistic means, unlike many other genres, a mechanical function. This function is characterized by the conversion of energy into movement with the help of a machine. It is characteristic of such machines that movement causes them to wear out and fail. When searching for a solution for dealing with electric motors that is defensible from the perspective of conservation, as a rule it will be necessary to work with specialized electromechanical workshops. The following treatise should help you to develop with such a partner the best strategy from the perspective of conservation ethics. It should be stated at the outset that nearly all motors can be repaired in a way that is invisible from the outside at no great expense.
There are a number of very different electric motors, which is why few details of their construction are documented here.

Construction Types and Components

Direct Current Motors



1. Yoke ring
2. Main pole
3. Excitation winding
4. Armature core
5. Armature winding
6. Commutator
7. Carbon brushes

Direct current motors are constructed in essence like universal motors. The photographs in the section "Universal Motors" can thus be compared as illustrations for the following text. On the construction of direct current motors, Fischer 2004 writes: "The fixed stator of solid or coated iron supports an electromagnet [in smaller motors permanent magnets are also found—*Author's note*], whose excitation winding provides the linkage necessary to create the field. The ends of the magnet, the main poles, are extended inward with so-called pole shoes, to accommodate the largest possible number of conductors. The external magnetic return is ensured by the yoke ring.

The shaft of the machine supports an iron body coated with magnetic sheet steel, which in the illustration is depicted as a ring. The magnetic circuit is thus, apart from the required ventilation duct, . . . composed entirely of iron. All of the conductor bars, together with the connections, form the armature winding, which in the illustration . . . is shown as a ring winding. The entire rotating part of a direct current motor is called the armature.

In order to enable the conductors, filled with current in the stator field, to produce a continuous torque, the direction of current in the armature conductor has to be reversed when the pole area changes during rotation. This is done by means of a commutator, also known as a collector, which is made up of segments of copper or laminae and are attached with the armature stampings on the shaft. The ends of individual coils of the armature winding are attached sequentially to the segments. The current is transferred to the armature winding by carbon brushes that produce a sliding contact with the rotating commutator and feed the winding between the main poles."[1]

"Depending on whether the armature and field winding are connected parallel or in series, a direct current motor is said to be 'series-wound' or 'shunt-wound.'"[2] "Small series-wound motors with output up to approx. 500 watts are built as universal motors that work with either direct or alternating current."[3]

Universal Motors

Universal motors are electric motors that can be operated either with direct current or with single-phase alternating current. Seyfert mentions accordingly: "Universal motors are as a rule intended for the usual alternating current supply grid and are thus sometimes referred to in the literature as 'single-phase alternating current motors.' Their primary identifying feature is a brush commutator system. As a rule, carbon brushes are used for alternating current, since their sliding also serves to clean the surface of the commutator. Frequently the number of lamella on the commutator is twice the number of slots on the rotor to improve operation. . . .

The stator of a universal motor always has two distinct, symmetrically arranged main poles. As a rule, the windings are impregnated.

The rotation speed can be altered by controlling the voltage and resistance. On smaller universal motors this is usually done by controlling the phases, using diodes, for example.

The iron cores of the windings in the stator and rotor are always covered with insulated plates 0.5 to 0.7 mm thick. This prevents the loss of energy and the heating that would be caused by eddy currents. The use of alternating current makes this necessary because of the alternating fields in both parts of the machine.

[1] Fischer 2004, pp. 33–34.
[2] *Brockaus der Naturwissenschaft un der Technik* 1957, p. 145
[3] *Brockhaus* 2006, p. 710

Universal motors typically rotate more than 3,000 and up to about 25,000 times per minute. The rotation speed is dependent on the number of windings in the coil. The fewer the windings, the faster the rotation speed—or the lower the voltage required for operation.

The decisive technical advantage of universal motors is their small size for their relatively high output, which makes them so attractive for use in portable or handheld devices. Their disadvantage is their relatively high . . . maintenance requirements and their relatively loud noise when operating. Typical inputs range from just a few watts to about 2,000 watts."[4]

[4] Seyfert 2001, pp. 152–55.

Example of a Universal Motor

Known data:

- Lilliput universal motor, model U-24G2.
- *ac*: Alternating current: the data below apply to AC current.
- *CONTINU*: designed for continuous operation.
- *CV 1/35*: Gear reduction: 1/35.
- *V 48*: Required voltage: 48 Volt.
- *t/m 3600*: Rotor shaft turns at 3,600 revolutions per minute.
- ~ –: suitable for direct or alternating current.

Fig. 2. Lilliput universal motor, circa 1950s

Fig. 3. Front view of the motor.

Fig. 4. Screw cap to secure carbon brushes

Fig. 5. Disassembled carbon brush with pressure spring

Fig. 6. Disassembled carbon brushes

Fig. 7. Disassembled motor housing with exposed armature shaft

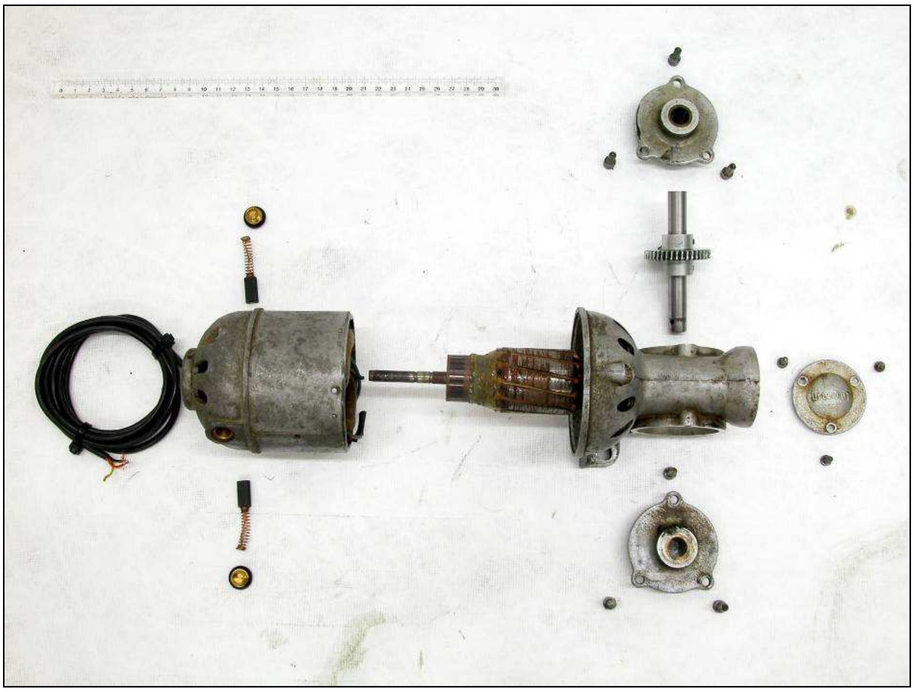


Fig. 8. Disassembled gearbox

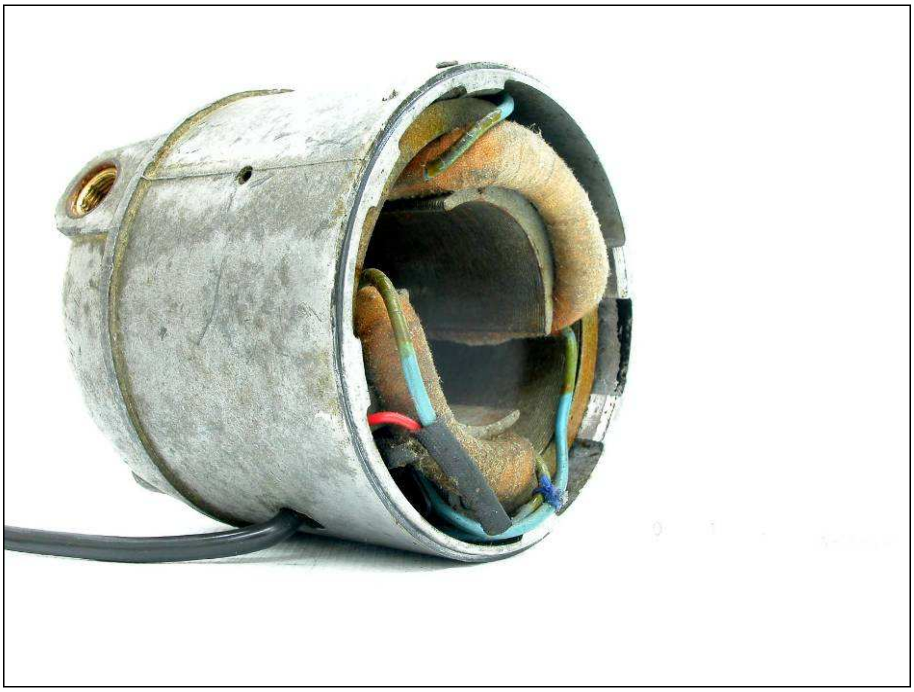


Fig. 9. Interior of housing: Yoke ring with two symmetrical main poles and their excitation winding wrapped in fabric

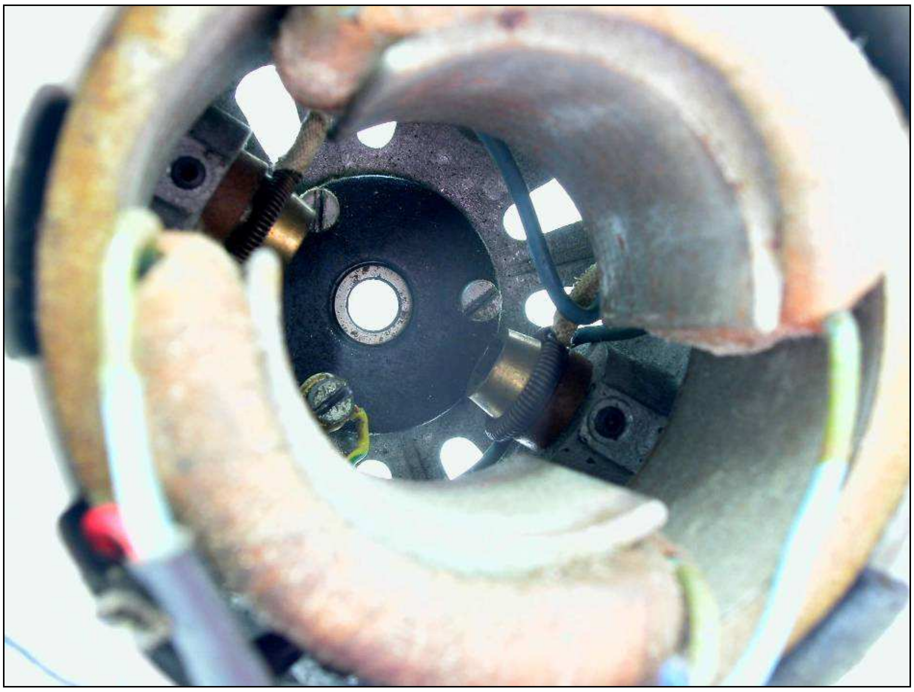


Fig. 10. View into the stator with the two main poles. In the background the two brass sleeves for the carbon brushes

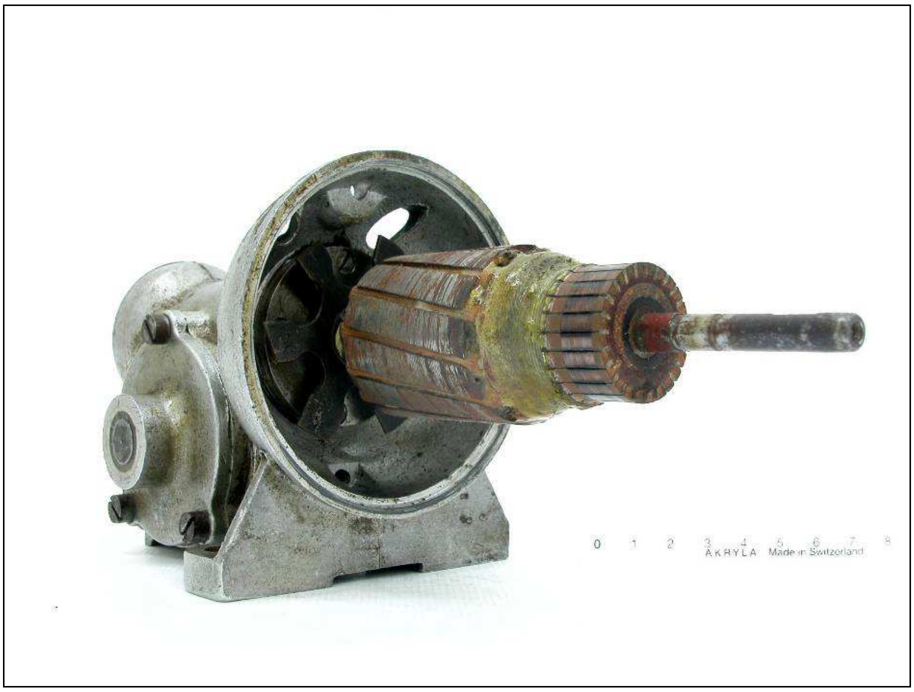


Fig. 11. Front bearing plate with the rotor and the commutator

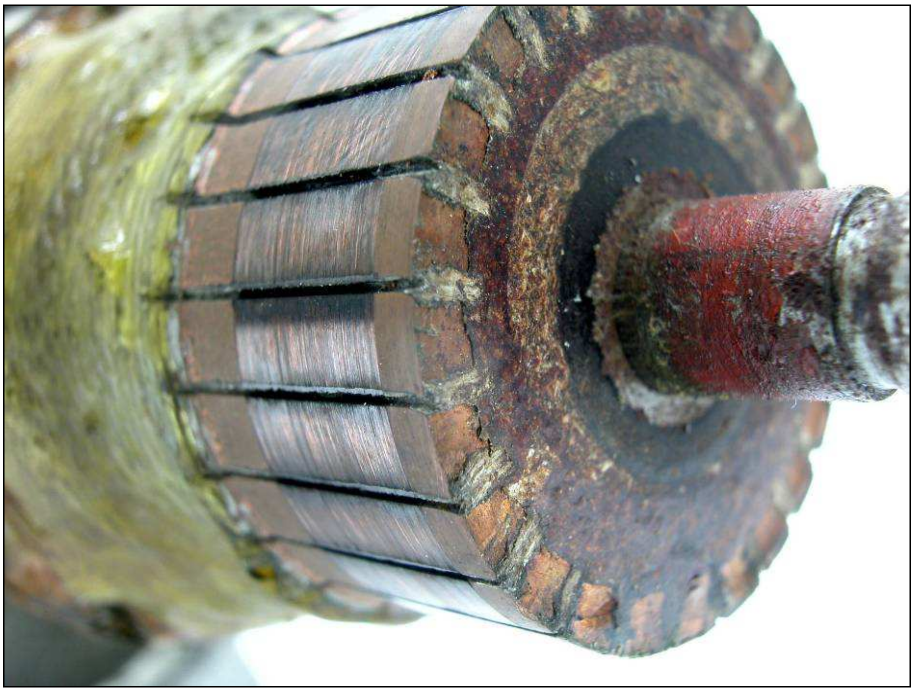


Fig. 12. Commutator with segments. The two carbon brushes slide over the commutator

Fig. 13. Rotor with slots in the sheet metal of the armature. The surfaces are corroded.

Fig. 14. Attachment of the armature winding to fan in front.

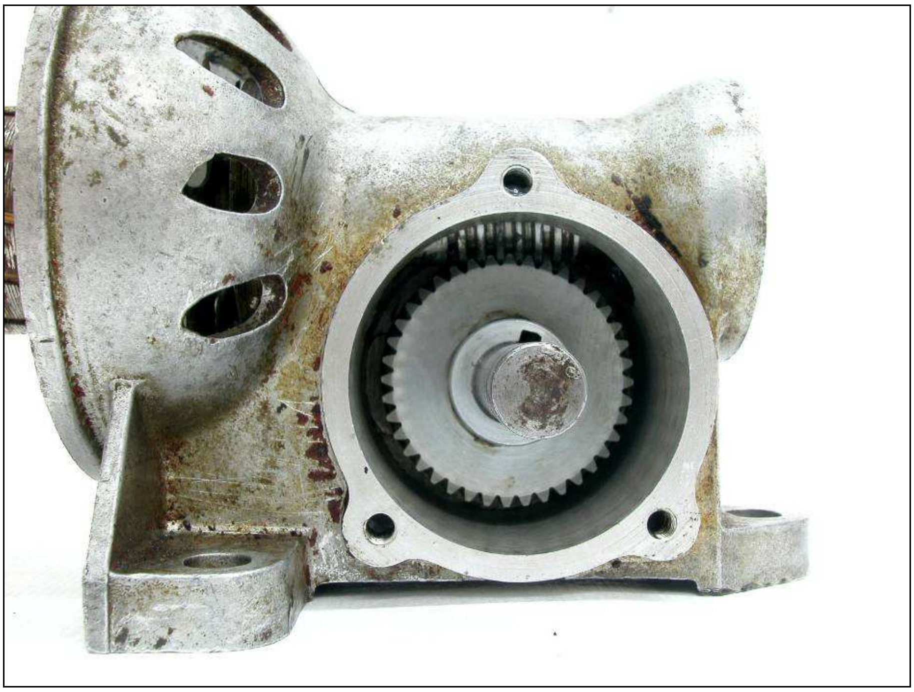


Fig. 15. View into the gears of the motor.

Three-Phase and Alternating Current Motors

"Three phase motors are driven by three-phase alternating current. This type of electrical supply consists of three separate conductors, each providing its own periodically alternating voltage, which leads or lags the other two conductors by 120°. When each of the phased voltages of the three phase system is supplied to one of three coils, a magnetic field is created in that coil that differs in time from the field in the other coils in exactly the same way as the voltage, that is, by a third of a period.
When these three coils are arranged in a circle, the sum of the magnetic fields produced by the individual coils is constant, however the direction continually changes, dependent upon the frequency or period of the three phase alternating current. This total magnetic field, consisting of the individual fields, "rotates" at a speed defined by the frequency. At an alternating current of 50 cycles per second, (that is, at 50 Hz.) the magnetic field also rotates 50 times a second (or 3,000 times a minute).
If a magnetic object is placed along a central axis in the rotating magnetic field, for example a bar magnet or a simple iron body, then this "rotor" will undergo a turning motion."[5]

Synchronous Motor

The efficiency of the rotating field motor is increased by adding the rotor's own coils in which a magnetic field is also created by the current that interacts with the field produced by the three stationary coils (stators). The rotor is a pole wheel (at least one pair of poles) or a smooth-core rotor, which is fitted with

[5] This section was taken from the German version of the Internet encyclopedia Wikipedia (www.wikipedia.de).

an excitation winding. When this excitation winding is supplied externally via slip rings with direct current, it produces a magnetic field. In the case of low power motors, the excitation coil can be replaced by permanent magnets. Since the rotor always turns synchronously with the stator field, this type of motor is called a three-phase synchronous motor.[6]

Asynchronous Motor

This is another form of motor, in which the rotor coils are squirrel-cage conductive loops that are not supplied with external power. Instead, the rotating external magnetic field induces a voltage in them, which results in a current and thus their own rotor magnetic field which links to the stator field, and assists in turning the rotor. For this to work the rotor needs to turn slightly slower than the stator field so that the magnetic field within the turning rotor constantly changes, which is in turn the condition necessary for the induction of voltage in the rotor conductors. Asynchronous motors are therefore also called three-phase asynchronous motors. The rotor coils are typically squirrel-cage windings; this design is also called a squirrel-cage induction motor. The principle of the squirrel-cage rotor can be externally simplified to a purely metallic object, which does not have to be made of iron. This works for example with a tin can, which is fitted with a shaft along its length. The effect is caused by the fact that the tin can (or other metallic object of suitable size) is effectively a bundle of cage-wound conductive loops infinite in number. This simplification allows three-phase asynchronous motors to be manufactured relatively cheaply and makes them virtually maintenance-free, which has led to the large numbers of them in circulation. By the use of a frequency converter, sometimes integrated into the body of the motor, the speed can be varied almost like that of universal motors.
The Parvalux motor documented below is a three-phase motor, which is used as a single-phase asynchronous motor by connecting the third, free line to the power supply via a capacitor (auxiliary winding).

[6] Ibid.

Example of a Single-Phase Asynchronous Motor (Condenser Motor)

Known data:

- PARVALUX condenser motor, model SD38S
- *VOLT 220 AC*: Requires 220 Volt alternating current
- *μF 2.5*: Connected condenser with capacity of 2.5 microfarads
- *Hz 50*: Required frequency of alternating is 50 hertz
- *Phase 1*: For connecting to single-phase alternating current gird.
- *AMPS 0.34*: Current consumption of 0.34 amps.
- *WATTS LEISTUNG 25*: 25 watt output.
- *T/MIN 1400*: 1,400 rotations of the rotor shaft per minute (input to gearbox!).
- *SERVICE CONT*: Motor constructed for constant operation.

Gearbox

- *T/MIN 76*: 76 rotations of the drive shaft per minute.
- *Nm 0.23*: 0.23 Newton-meters torque of the drive shaft.
- *I = 18F*: Gear reduction of the gearbox is 1:18. The gearwheel is made of fiber-reinforced plastic (F= fiber, B=bronze)

Fig. 16. Nameplate with data for motor operation

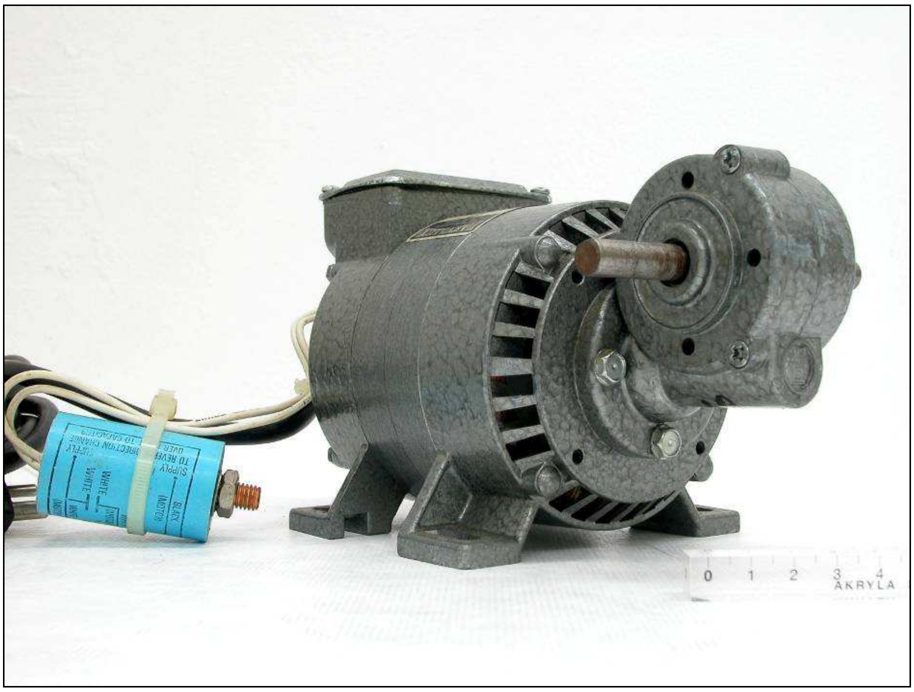


Fig. 17. View of the motor and attached condenser.

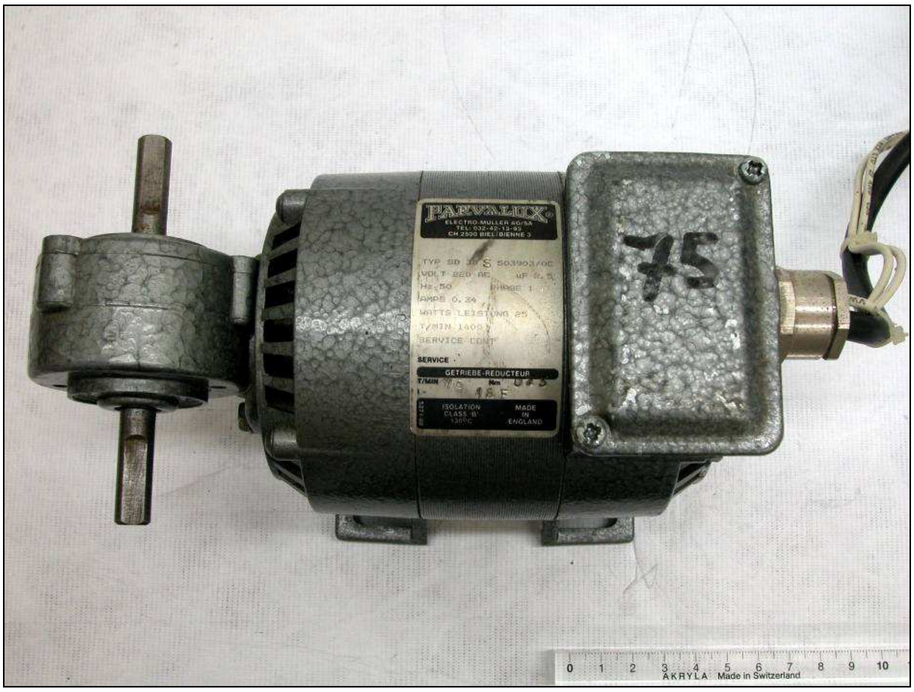


Fig. 18. View from above showing cover of terminal box.

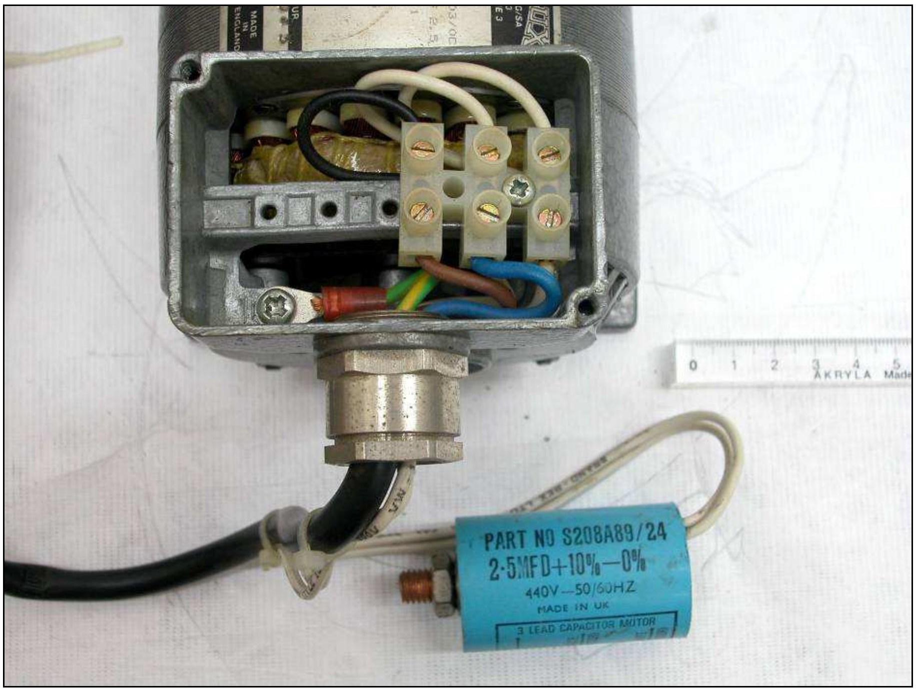


Fig. 19. Open terminal box.

Fig. 20. Operating data of condenser with 2.5 microfarads.

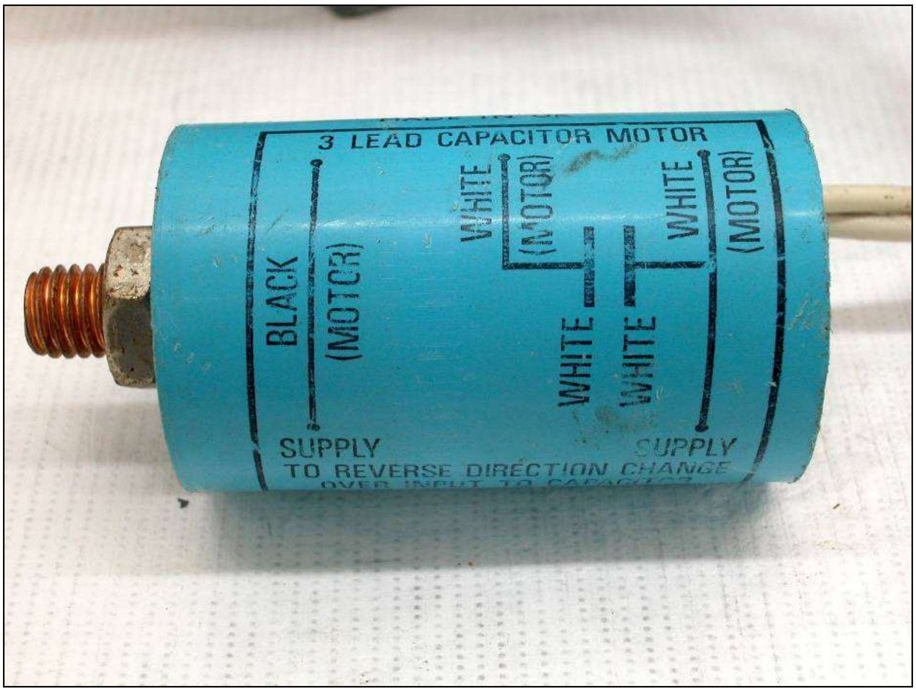


Fig. 21. Wiring diagram of condenser.

Fig. 22. Open motor housing. Left: rear end plate; center: Stator; right: rotor with front end plate and gearbox.

Fig. 23. Stator with winding for three-phase current at 120° (three phases).

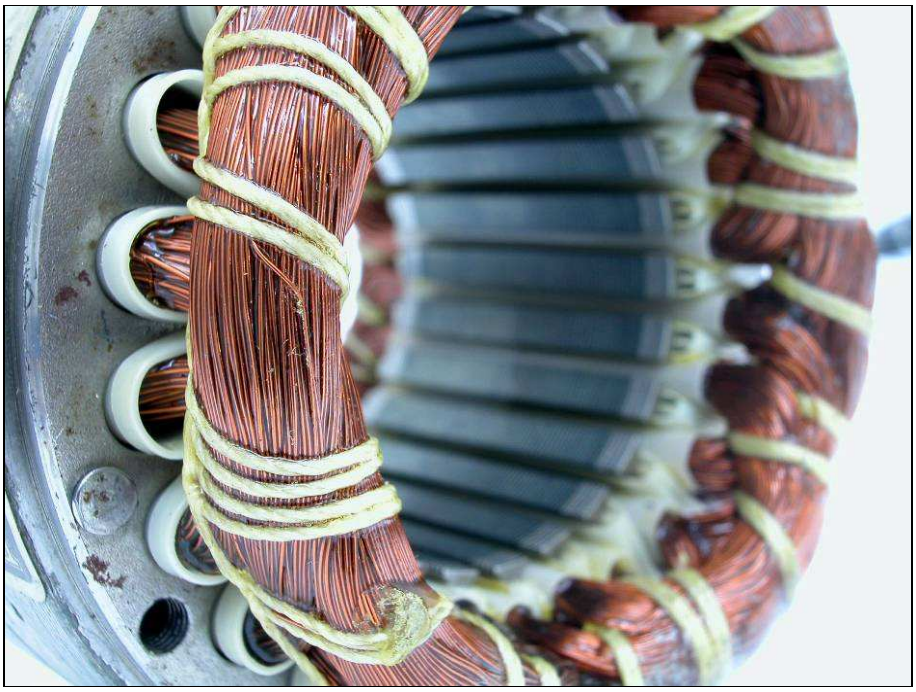


Fig. 24. Detail of winding of the stator.

Fig. 25. Iron cores of the stator slots in the form of layered strips of metal.

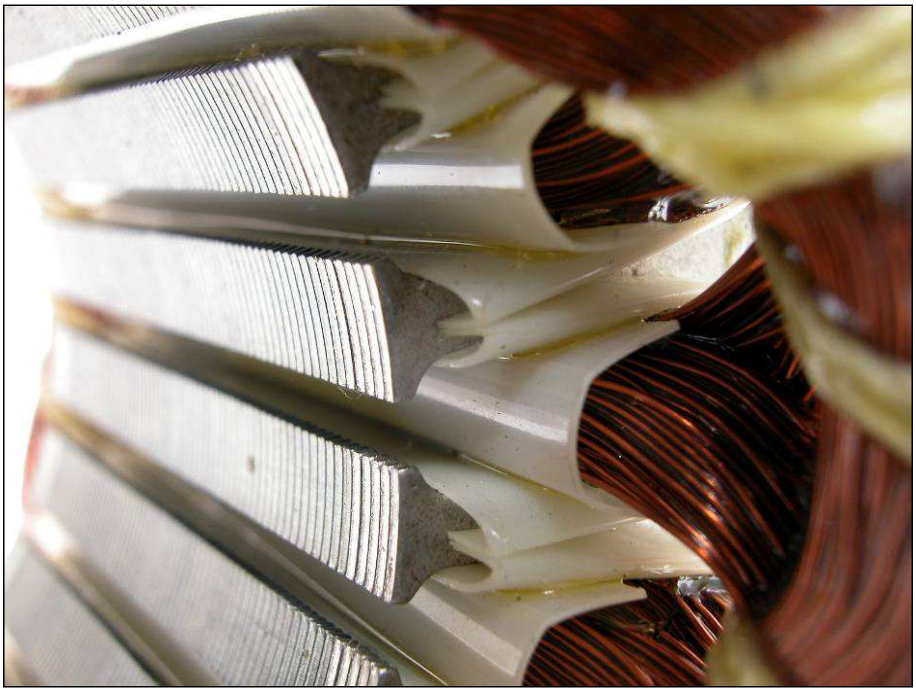


Fig. 26. White plastic insulation between the iron cores and the stator slots. These strips of plastic can become a conservation problem when they become brittle.

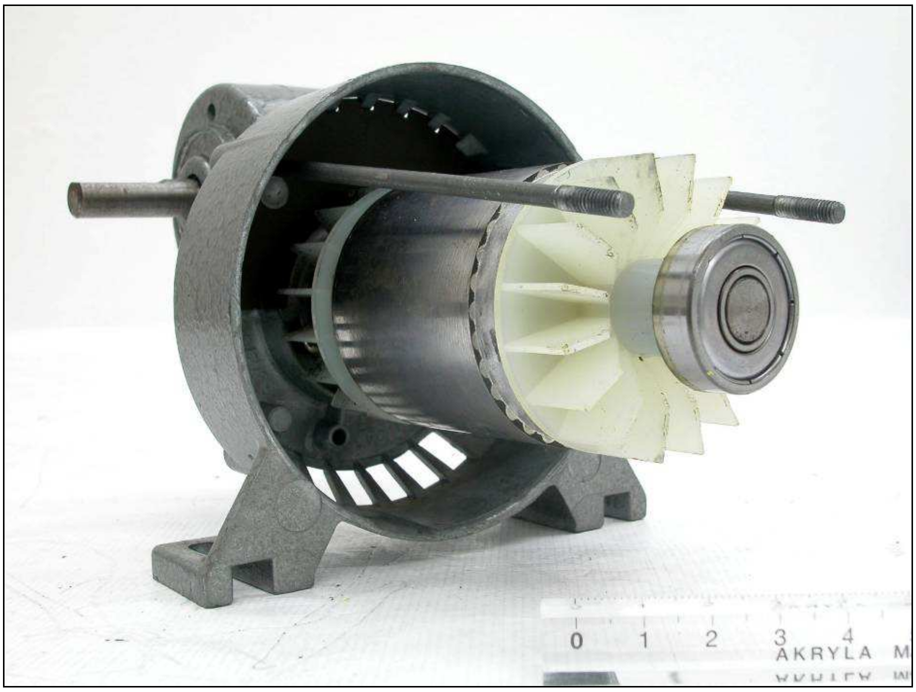


Fig. 27. Front end plate with rotor (squirrel-cage rotor). Induction of the stator's rotating field causes a separate magnetic field within it.

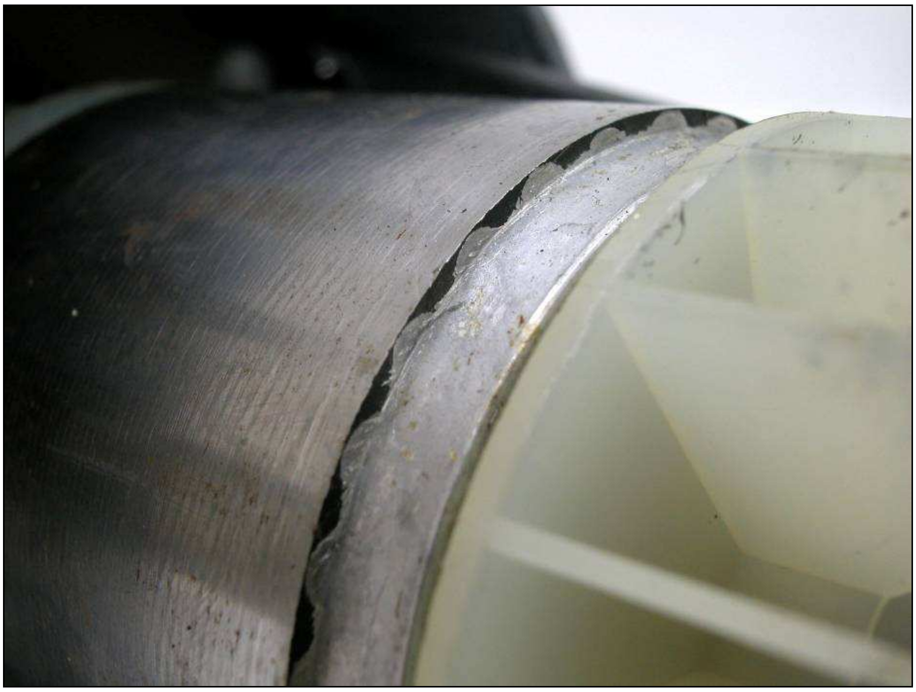


Fig. 28. Detail of rotor: The rotor coils are squirrel-cage conductive loops.

Fig. 29. Rear end plate.

Fig. 30. View into the gearbox showing gear of fiber-reinforced plastic.

Shaded-Pole motor

Another type of asynchronous motor is the shaded-pole motor. It is also fitted with a squirrel-cage rotor (or cage rotor) in which torque is induced by a rotating field produced by the stator.

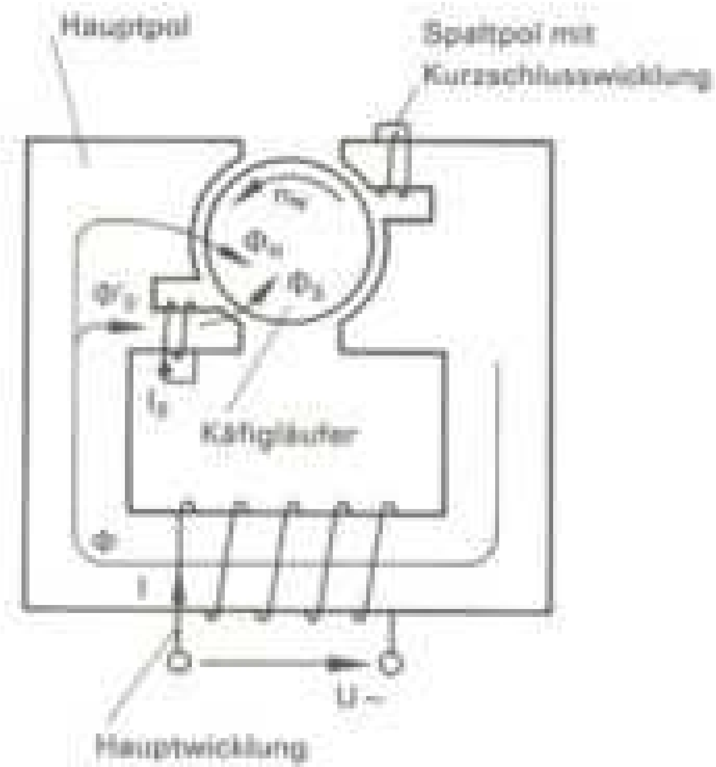


Fig. 31. Principle of the function of a shaded-pole motor.

"In the case of the shaded-pole motor, the magnetic poles are divided into a main pole and a shaded pole. A squirrel-cage winding in which currents are induced surrounds the shaded pole. The main winding is connected to a single-phase alternating current supply. […] The direction of rotation is always from the main pole in the direction of the shaded pole. […] The rotating field thus produced is sufficient to move the rotor, it is however also dependent upon load and results in a smaller start up torque compared with other three-phase motors. They often have only one stator winding, do not need an expensive and possibly unreliable capacitor and are therefore robust with a long service life."[7]

[7] This section was taken from the German version of the Internet encyclopedia Wikipedia (www.wikipedia.de).

Example of a Shaded-Pole Motor

Known data:

- Alternating current motor manufactured by SAPMI Type …050027.
- *Volts 127/220*: Required voltage of either 127 or 220 volts.
- *Vite 30 T/MIN*: Rotation speed of the drive shaft (not the rotor shaft!) of 30 rpm.

Fig. 32. Shaded-pole motor by SAPMI

Fig. 33. Paint partially removed to reveal labeling.

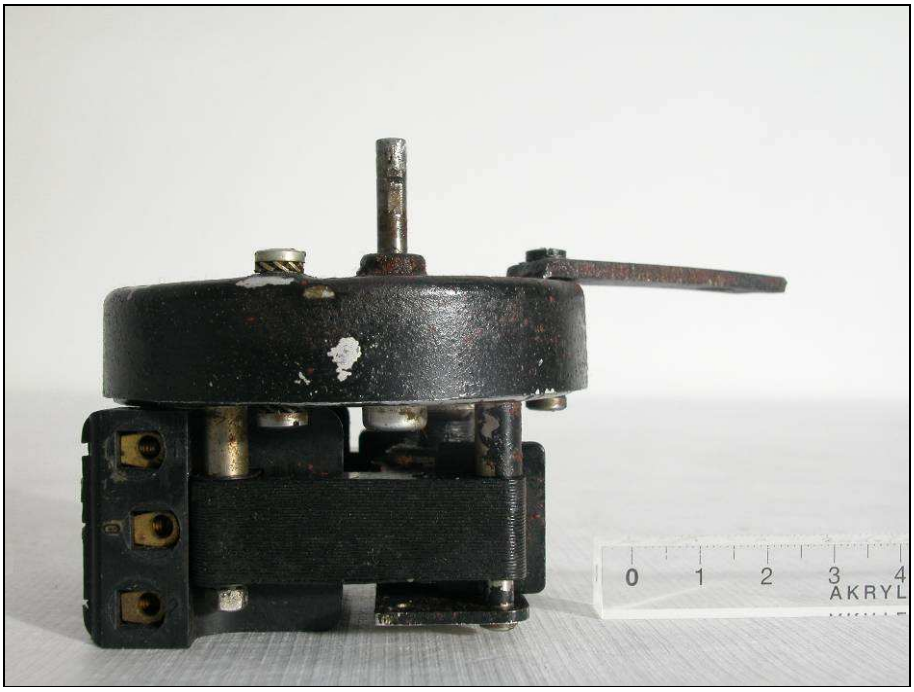


Fig. 34. Motor for either 127 or 220 volts, seen from terminal side.

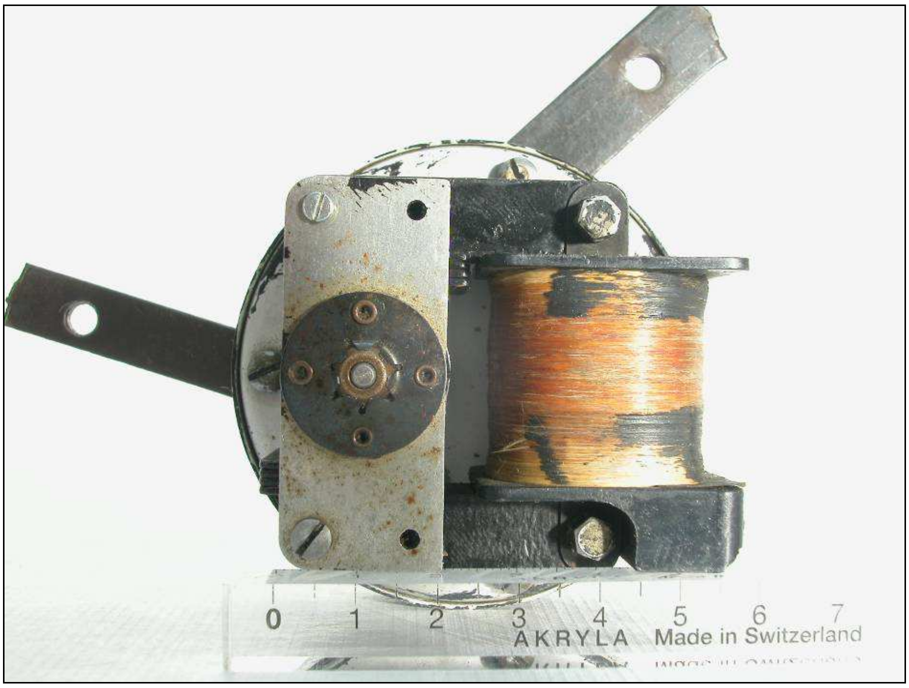


Fig. 35. Back of motor. Left: the round rotor, surrounded by the iron core. Right: iron core surrounded by the main winding.

Fig. 36. Terminals: 0 and 1 for 127 volts / 0 and 2 for 220 volts

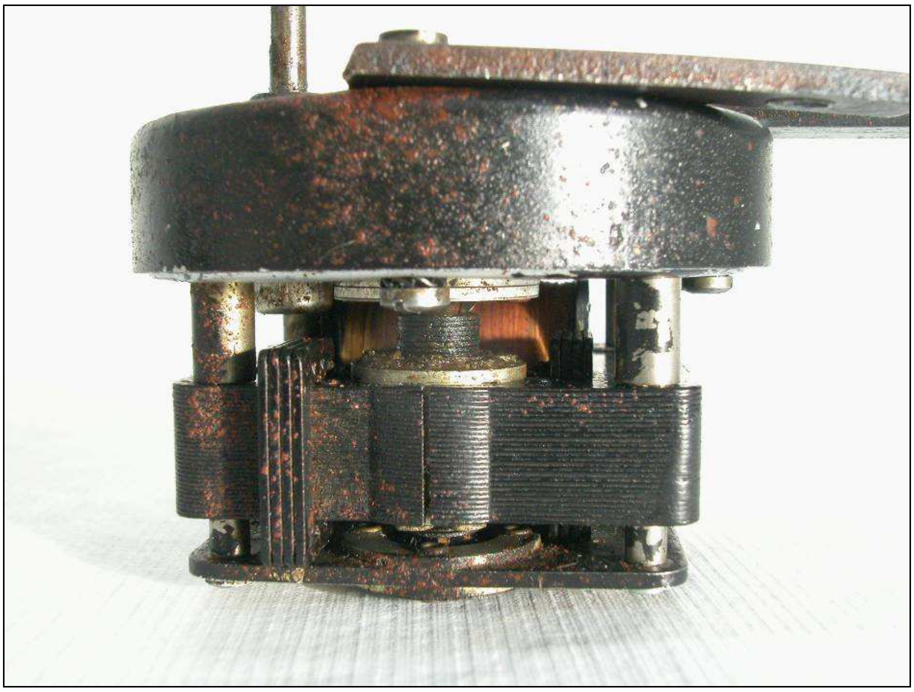


Fig. 37. Side view of motor. Below: iron core with shaded pole and rotor that turns within it.

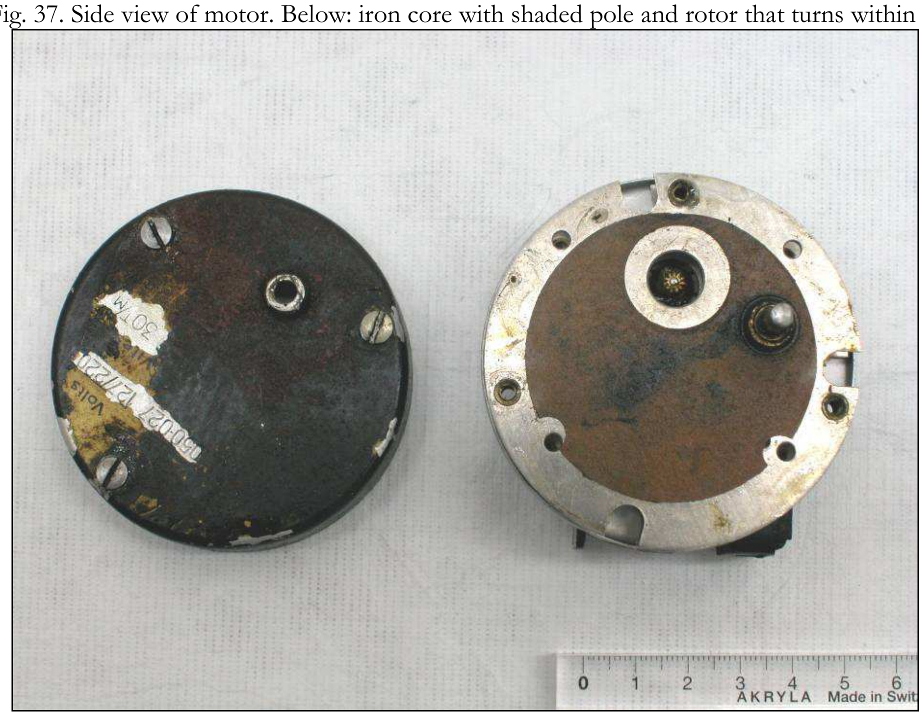


Fig. 38. Cover of housing removed.

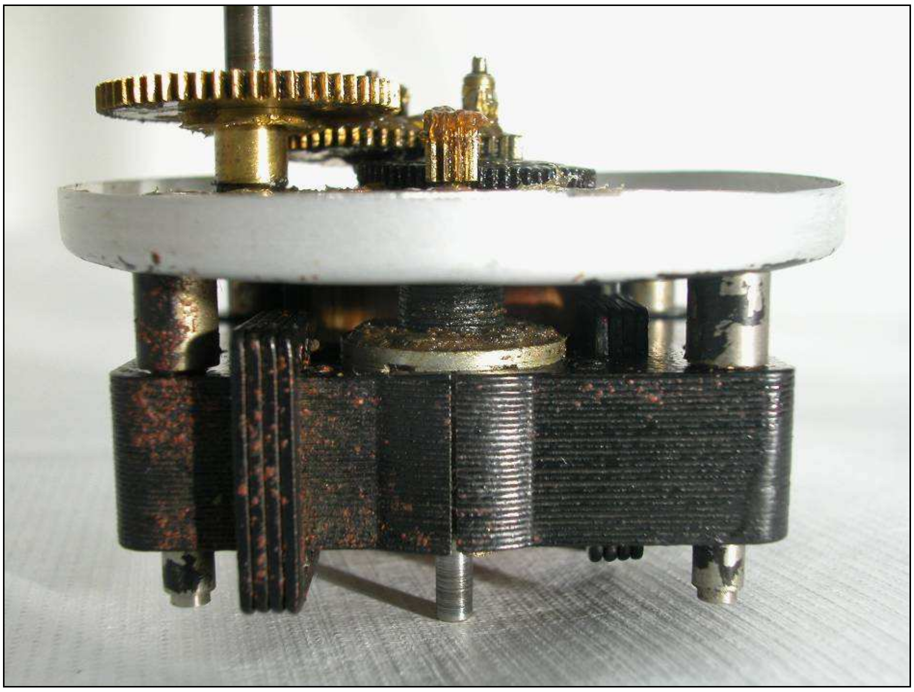


Fig. 39. Exposed gears

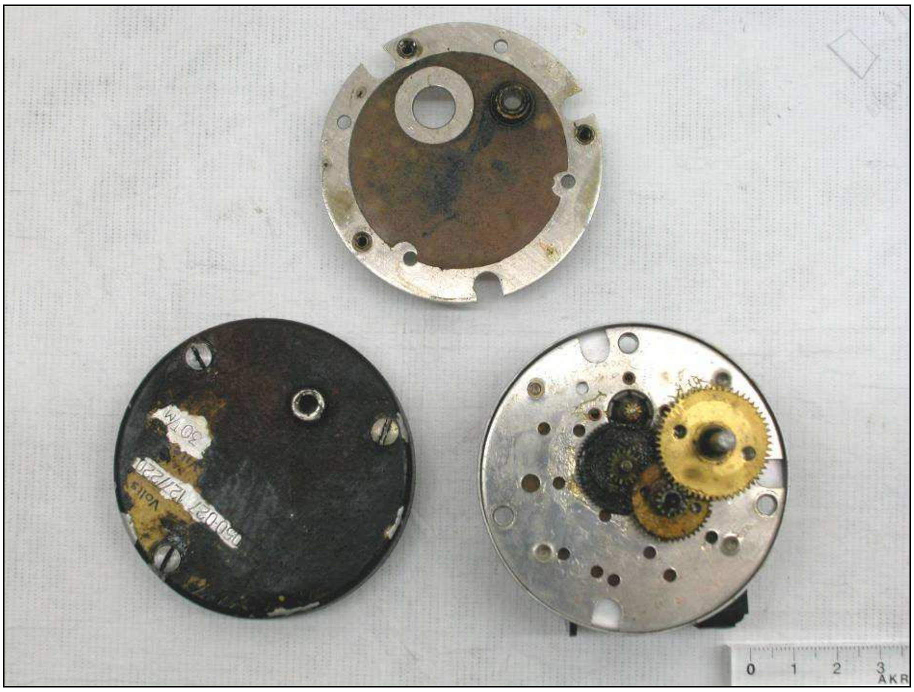


Fig. 40. Top view of open gearbox.

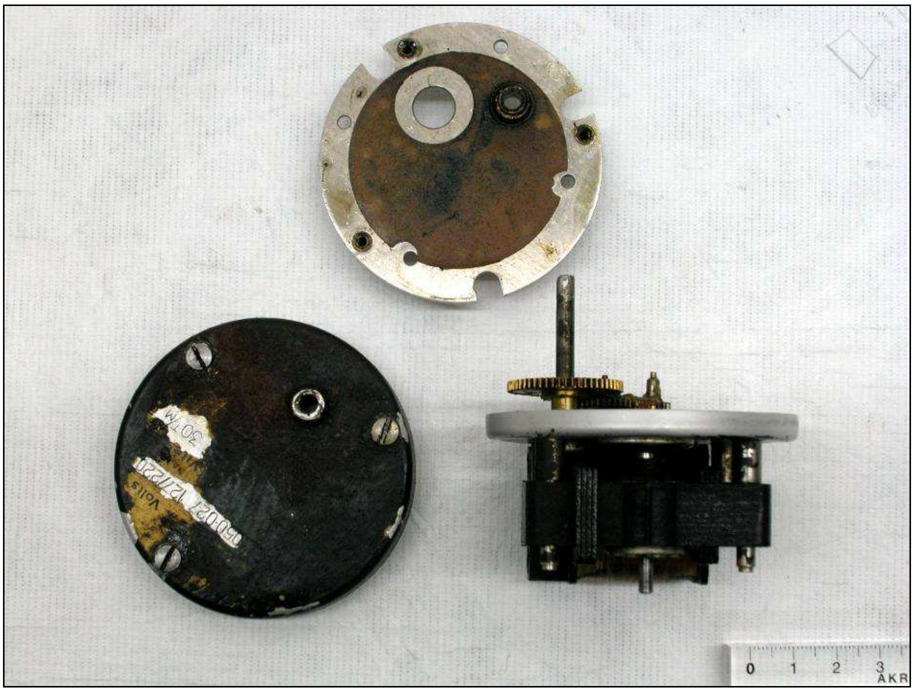


Fig. 41. Side view of open gearbox.

Fig. 42. Base plate with squirrel-cage rotor and its drive gear.

Fig. 43. Base plate with squirrel-cage rotor.

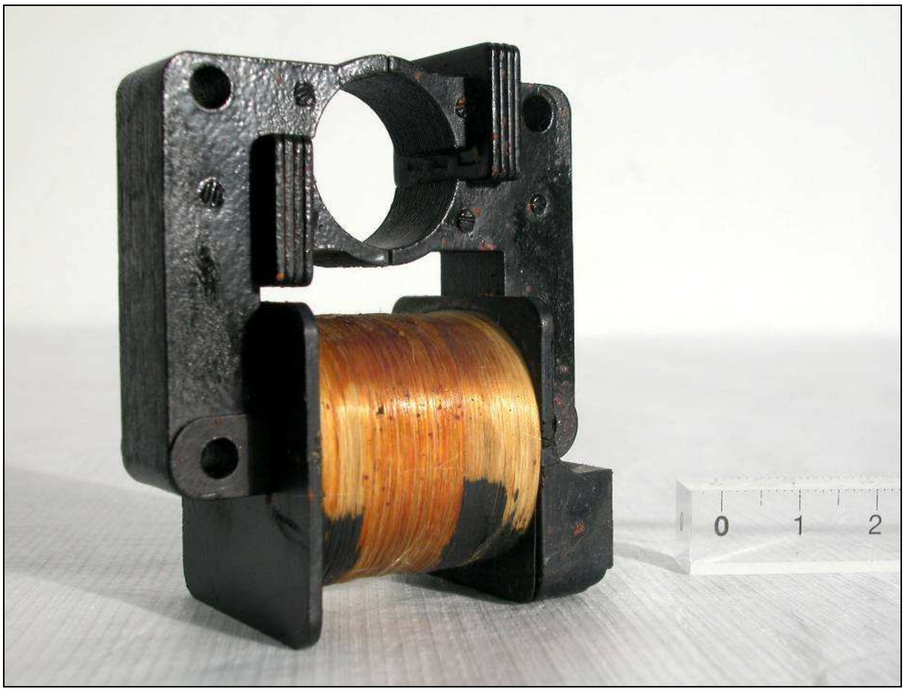


Fig. 44. Bottom: Main winding and iron core. Top: Main pole and shaded pole with squirrel-cage windings.

Fig. 45. Bottom: Main winding and iron core with terminals. Top: Main pole and shaded pole with squirrel-cage windings.

Fig. 46. All the components of a shaded-pole motor

Components

- *Commutator* or *collector* or *pole changer* or *changer*: Mechanical switch for changing the direction of current in a circuit. In the case of motors, a cylindrical element consisting of copper segments that are insulated from one another and connected to the rotor winding. It effects a periodic switching and frequency change in the electric current flowing both in and out via brushes that slide across its surface.[8]
- *Armature*: The armature consists of an iron core with wire wound around it. This is the part of the motor fitted with the coils in which the voltages are induced that will determine the way the machine works. In the case of the electric motor, this can be either the stator or the rotor.[9]
- *Field magnets*: The field magnets are electromagnets fitted to the inner circumference of the body of the motor (stator) that produce a static magnetic field.
- *Rotor*: The rotating part of the motor.
- *Stator*: The stationary part of the motor.
- *Stator terminals*: The terminal connections of the stator.
- *Power*: The power of a motor is given by the product of the current (in amperes) and the operational voltage (in volts) and is expressed in watts.
- *Delta connection*: A type of connection for three-phase motors in which the end of one winding is connected to the beginning of the next, in series.
- *Star connection*: A type of connection for three-phase motors. One end of each of the windings is connected with the others at the star point; the other ends are connected to an electrical supply, the alternating voltages of which are phase-shifted by 120° with respect to one another.[10]
- *Rotational speed*: Rotation of a shaft per unit of time.
- *Rotational speed after gearing*: Rotation of the geared shaft per unit of time.
- *Gearing*: The reduction or multiplication of the speed of a motor with the aid of various gear wheels housed in a gearbox.
- *Direction of rotation*: Direction of rotation of the drive shaft as seen from the front or the rear.
- *Current consumption*: Amount of current drawn under load in amperes.

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[8] BROCKHAUS 1993. Vol. 3, p. 182
[9] BROCKHAUS 1993. Vol. 1, p. 100.
[10] BROCKHAUS 1993. Vol. 5, p. 137.

Identification by Means of Nameplate

The nameplates of motors vary greatly according to country of origin and year of manufacture. The diagram in "Fig. 47. Nameplate of electric motor" shows a contemporary German nameplate whose key is given below.

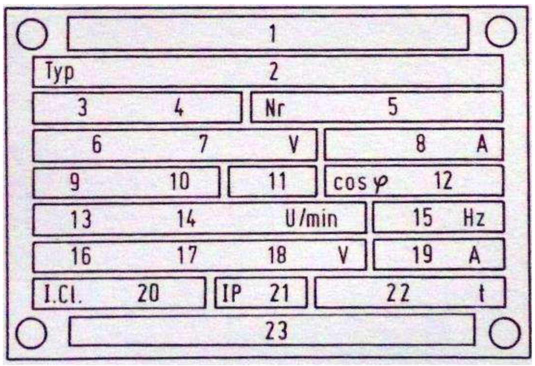

Fig. 47. Nameplate of electric motor[11]

Key:[12]

1. Manufacturer
2. Type, size
3. Type of electricity, e.g., direct current, three-phase 3~
4. Mode of operation, e.g., generator Gen, motor Mot.
5. Serial number, year of manufacture
6. Winding configuration, e.g., Y-star connection, Δ delta connection
7. Rated voltage
8. Rated current
9. Rated power with units
10. Rated power with units
11. Mode of operation
12. Power factor
13. Direction of rotation
14. Speed
15. Frequency
16. Err. Excitation for direct current machines Lfr. Rotor for asynchronous machines
17. Rotor winding connection
18. Excitation voltage
19. Excitation current, rotor current
20. Insulation class, such as E, B, H
21. Protective system
22. Weight
23. Additional remarks

Further abbreviations:

- *Asynch*: Asynchronous motor
- *Synch*: Synchronous motor
- *RPM* or *T/MIN* or *vitesse*: Revolutions per minute (in the case of motors fitted with gearing, the motor speed will differ from that of the drive shaft)
- *~ 50 Hz*: Alternating current at a frequency of 50 hertz
- *VOLT*: Input voltage in volt
- *WATTS*: Power consumption of the motor in watt
- *2.5 µF*: Motor fitted with a capacitor with an electrical capacitance of 2.5 microfarad (µF).
- *PHASE 1*: Single-phase motor. Can be connected to a single-phase power grid.
- *AMPS*: Current consumption in ampere.
- *Nm*: Torque of the drive shaft in Newton-meters (Nm).
- *Service Continuu*: Motor has been designed for continuous operation.

[11] Fischer 1999, p. 386.
[12] Fischer 1999, p. 387.

Preservation of Electric Motors

Electric motors wear out from operation: windings can burn through and bearings wear out. Such damage from operation can only be minimized by limiting operation. The problem of corroding metal parts in motors, which seriously endangers the preservation of the motor, can be prevented. Seyfert calls the latter "environmental factors in disintegration."

Operational Factors

"Operational factors are effects of mechanical forces that cause water and material fatigue. In universal motors this primarily means abrasion of the brushes and commutator and wear on the bearings. The useful life of brushes in kitchen appliances, for example, ranges from about 50 to 500 hours of operation. The lifespan of roller bearings can be as long as 40,000 hours of operation. It can, however, be assumed that these figures pertain to operation under ideal conditions, which is not necessarily the case with household appliances.
The heating of the motor caused by operation will also influence useful life, since variations in temperature cause the conductive materials, the insulation, and the armature stampings to expand by different amounts, which will subject the insulation to mechanical strain.
The problems of preservation caused by operation can be avoided by stopping the motor. The only other options are maintenance, repair, and replacement."[13]
The repair of standard motors, with the possible exception of micromotors, can usually be done without problems by a specialized electromechanical workshop. If the repairs are done carefully, moreover, the exterior of the motor will not be affected.

Environmentally Conditioned Factors

"Environmental factors include above all dirt, pollutants, moisture, and ambient temperature. They can cause or accelerate various kinds of degradation as well as malfunction during operation. Unlike operational factors, some of these will affect nonoperational motors.
In the case of moisture, the particular form of damage caused by iron corrosion is especially relevant; it can affect rotors and stators because of their sheet-metal constructions. The surfaces of the layered strips of metal rust, even inside, because capillary action can draw corrosion-causing electrolytes from the surface. This destroys the insulating layer and, in advanced stages, can cause deformation of the component as the products of corrosion become voluminous. Because the strips of metal are close together and as a rule cannot be disassembled, it can be difficult to identify such damage in its early stages.

[13] Seyfert 2001, pp. 159–64.

Fig. 48. Corrosion of metal on the rotor of a universal motor.

The condition of the insulation or impregnation paint on the windings also plays a role. Moisture that penetrates can remove the insulation and lead to short circuits and fires in running motors or cause corrosion of the windings in stopped motors. The insulation or impregnation paints are based on natural resins, drying oils, artificial resins, and modified artificial resins."[14]

Care and Maintenance

Motors that are being used should be cleaned at regular intervals. If a motor is operated frequently, it will draw in a lot of air through its ventilator, which will mean increased dust deposits. Seyfert therefore advises: "For care in a museum, the first task is to remove pollutants and foreign bodies."[15] This can be done by either dry or damp methods, depending on the materials of the motor. Caution is advisable with all kinds of solvents, which can not only remove labeling but also attack plastics inside the motor.

Conservation and Preservation

"The conservation of universal motors is, as a rule, quite unproblematic, because they are usually protected within housings. The climatic conditions to which they are subject are, however, important. Moisture or temperatures below the dew point, particularly in combination with aggressive gases, can trigger the aforementioned corrosion of the sheet iron. . . . It is also recommended that relative humidity be kept a steady level, as low as possible. The use of drying agents such as silica gel is quite simple in motor and equipment housings, so that it need not diminish the aesthetic effect of the object. For the

[14] Seyfert 2001, pp. 159–64.
[15] Seyfert 2001, pp. 159–64.

drying agent to be effective over the long term, however, any ventilation openings of the housing have to be sealed. Vapor-phase inhibitors can be employed in similar ways. It must simply be determined whether an inhibitor will have long-term effects on all of the materials found in the object, such as plastics, paint layers, lubricants, and thin coatings of metal such as iron or copper."[16]

Repair and Preservation of Operation

"Electric motors can exceed their rated output for brief periods. The upper limit on this is the breakdown torque of the motor in the case of a three-phase motor and the maximum stress on the commutator in the case of direct current motor. If operation is continuous, performance will also be limited by heating."[17]
Motors for continuous use are labeled as such on the nameplates, for example, "service continu."
"Restricting operation can perhaps prevent failures and extend the life of a universal motor, but it will not prevent wear entirely. Abrasion of the carbon brushes is necessary in any case as they should be seen as expendable material when in operation, since they work as a kind of lubricant.
A galvanic application of copper to work commutator lamellae can be viewed as a theoretical possibility as a measure to supplement the existing material. Galvanic coatings have been used successfully as layers to protect against surface wear in restorations of other materials."[18]
For repairs of all kinds it is strongly recommended that one work with a specialized electromechanical workshop.

[16] Seyfert 2001, pp. 159–64.
[17] Seyfert 2001, pp. 159–64.
[18] Seyfert 2001, pp. 159–64.

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