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**Single-phase motors**

Often focus is on basic knowledge of three-phase motors. This is partly because Grundfos sells far more three-phase motors than single-phase motors. Grundfos does, however, also manufacture single-phase motors up to 2.2 kW 2-pole and 1.5 kW 4-pole. Single-phase motors work on the same principles as three-phase motors, but have lower starting torques and need help to start. The various motor types are defined by the starting method used.

A standard single-phase stator has two windings placed at an angle of 90° to each other. One of these windings is known as the main winding, while the other is called the auxiliary winding or starting winding. Depending on the number of poles, each winding may be distributed across several subcoils.

Shown here is an example of a two-pole, single-phase winding with four subcoils in the main winding and two subcoils in the auxiliary winding.

It should be remembered that designing a single-phase motor will always be a matter of compromise. The design of any given motor depends on what is most important for the individual task. This means that all motors are designed according to the relative importance of e.g. efficiency, torque, duty cycle etc. Single-phase motors CSIR and RSIR can be very noisy due to a pulsating field, compared to “two-phase” PSC and CSCR motors which have much more silent running characteristics, because they use a capacitor during normal operation. The “run-capacitor” balances the motor which results in more smooth operation.
**Basic types of single-phase induction motors**

Home appliances and low-power business appliances use single-phase AC supply, and in some places three-phase supply is not available. This is why single-phase AC motors are widespread, particularly in the USA. AC motors are often the first choice because of their durable construction, maintenance-free operation, and low cost.

As the name would suggest, a single-phase induction motor operates on the principle of induction - which is also true for three-phase motors. There are, however, differences: single-phase motors are normally operated on 110-240 volt AC, and the stator field does not rotate. Instead, the poles alternate as the single sine-wave voltage swings from positive to negative.

In single-phase motors, the stator field is permanently lined up in one direction, and the poles change their position once each cycle. This means that a single-phase induction motor will run once started, but cannot start itself.

The poles change position once in each cycle
2. Single phase motors

Basic types of single-phase induction motors

Theoretically, a single-phase motor could be started by spinning the motor mechanically and applying power immediately. In actual practice, however, all motors use automatic starting of some sort.

Single-phase induction motors are often known by the names of the starting method used. There are four basic types: Capacitor start/Induction run (CSIR), Capacitor start/Capacitor run motors (CSCR), Resistance start/Induction run (RSIR) and Permanent-split capacitor motor (PSC).

The figure below shows the typical torque/speed curves for the four basic types of single-phase AC motors.

**Capacitor start/Induction run motors (CSIR)**

Also known as CSIR (Capacitor start/Induction run) motors, this is the largest group of single-phase motors.

CSIR motors are available in sizes ranging from fractional to 1.1 kW. Capacitor start motors feature a special capacitor in a series with the starting winding. The capacitor causes a slight delay between the current in the starting winding and main winding. This cause a delay of the magnetisation of the starting winding, which result in a rotating field effective in producing torque. As the motor gains speed and approaches running speed, the starting switch opens. The motor will then run in the normal induction motor mode. The starting switch can be a centrifugal or electronic switch.

CSIR motors have a relatively high starting torque, between 50 to 250 per cent of the full-load torque. This makes them a good single-phase motor choice for loads that are difficult to start, e.g. for conveyors, air compressors, and refrigeration compressors.
2. Single phase motors

Basic types of single-phase induction motors

Capacitor-start/Capacitor run motors (CSCR)

Known as a CSCR motor for short, this type of motor combines the best features of the Capacitor-start/Induction run motor and the permanent-split capacitor motor. Even though their construction makes them somewhat more expensive than other single-phase motor types, they are the perfect choice for demanding applications. A CSCR motor has a start-type capacitor in series with the starting winding, just like the capacitor-start motor. This provides high starting torque.

CSCR motors also resemble Permanent-split capacitor (PSC) motors insofar as they have a run-type capacitor which is in series with the starting winding once the start capacitor is switched out of the circuit. This means that the motor can handle high breakdown or overload torque.

CSCR motors can be designed for lower full-load currents and higher efficiency. One of the advantages of this feature is that it allows the motor to operate at smaller temperature rises than other, similar single-phase motors.

CSCR motors are the most powerful single-phase motors and can be used for quite demanding applications, e.g. high-pressure water pumps and vacuum pumps and other high-torque applications which require 1.1 to 11 kW.
Basic types of single-phase induction motors

2. Single phase motors

Resistance start/Induction run motors (RSIR)

This motor type is also referred to as Split-phase motors. They are usually cheaper than other single-phase motor types used by industries, but also have some limitations in terms of performance.

The starting device of RSIR motors comprises two separate windings in the stator. One of these is used exclusively for starting and is wound with a smaller wire size with higher electrical resistance than the main windings. This causes a time delay for the rotating field, which in turn makes the motor start. A centrifugal or electronic switch disconnects the starting winding when the motor reaches approximately 75% of the rated speed. The motor will then continue running according to standard induction motor principles.

As mentioned above, certain limitations apply to RSIR motors. Their starting torques are low, often between 50 to 150 per cent of rated load. The motor also develops high starting currents, approximately 700 to 1000 % of rated nominal current. As a result, overly long starting times will cause the starting winding to overheat and fail. Of course, all this means that this motor type should not be used in situations where high starting torques are required.

RSIR motors are designed for single voltage, which naturally limits the range of potential applications. Their maximum running torques range from 100 to 250% of normal. It should also be mentioned that thermal protection is difficult because it is hard to find a protector with trip-off time fast enough to prevent the starting winding from burning out.

RSIR motors are well suited for small grinders, fans, and other applications with low starting torque and power needs from 0.06 kW to 0.25 kW. They are not suitable for applications which require high torques or high cycle rates.
**Permanent-split capacitor motors (PSC)**

As the name suggests, permanent-split capacitor motors (PSC motors) have a run-type capacitor which is left permanently in series with the starting winding during operation. This is to say that they do not have a starting switch or a capacitor which is used only for starting. Thus, the starting winding becomes an auxiliary winding when the motor is up to running speed.

The design of PSC motors means that they cannot provide the same initial boost as motors with separate capacitors. Their starting torques are quite low, between 30 to 90% of rated load, so they cannot be used for applications which are hard to start. This is offset by their low starting currents - usually less than 200% of rated load current - which makes them the perfect choice for applications with high cycle rates.

Permanent-split capacitor motors offer many benefits. Their running performance and speed can be tailored to meet specific needs, and they can be designed for optimum efficiency and high power factor at rated load. As they need no starting mechanism, they can be reversed easily. Finally, they are the most reliable single-phase motors available. These advantages are the reason why Grundfos uses PSC single-phase motors as standard for all applications up to 2.2 kw 2-pole and 1.5 kW 4-pole.

Permanent-split capacitor motors can be used for many different applications, depending on their design. Low-inertia loads such as fans and pumps would be a common example.
2. Single phase motors

Single-phase dual-voltage motors

Single-phase dual-voltage motors comprise two main windings, a starting winding, and a run capacitor. They are widely used in the USA, where the single-phase supply is either 1 x 115 V/60 Hz or 1 x 230 V/60 Hz. With the right connection, this motor type can be used for both supplies.

Dual-voltage motor. Connections to high and low voltages
Special conditions

A number of special conditions apply to single-phase motors compared to three-phase motors. Single-phase motors should never run idle because they become very warm at small loads, therefore it is not recommended to run the motor less than 25% of full-load.

PSC- and CSCR-motors have a symmetrical/circular rotating field at one load-application point, which of course means that the rotating field is asymmetrical/elliptic at all other load-application points. When the motor runs with an asymmetrical rotating field, the current in one or both windings may be bigger than the mains current. These currents cause a loss, and so one or both windings (which is often seen in case of no load) will become too warm, even though the mains current is relatively small. See the examples to the right.

Example of asymmetrical operation, where the current in the two phases is bigger than the mains current.

Example of run of currents as a function of the load. Please note that in the operating and starting phases the currents are bigger than the mains current at 0% load.
2. Single phase motors

Voltage issues

It is important to be aware that voltages can be higher than the mains voltage inside the motor. This is also true for symmetrical operation. See the example to the right.

Voltage variants

It should be noticed that single-phase motors cannot usually be used for as big voltage intervals as the three-phase motors. Thus, it may be necessary to produce variants that can handle alternative voltages. This will involve design changes such as alternative windings and different capacitor sizes.

In theory, the size of the capacitor for a different mains voltage (same frequency) should be equal to the square of the voltage ratio:

\[
\frac{C_2}{C_1} = \left(\frac{U_1}{U_2}\right)^2
\]

Thus, if a motor for a 230 V mains applies a 25 µF/400 V capacitor, the motor variant for the 115 V mains will need to apply 100 µF marked with a lower voltage, e.g. 200 V.

\[
\frac{C_2}{C_1} = \left(\frac{U_1}{U_2}\right)^2 \Rightarrow C_2 = C_1 \times \left(\frac{U_1}{U_2}\right)^2 = 25 \mu F \times \left(\frac{230 V}{115 V}\right)^2 = 100 \mu F
\]

In actual practice, cost and space considerations may make it necessary to select a smaller capacitor, e.g. 60 µF. In such cases, the windings must be adapted to suit the relevant capacitor. It is important to be aware that the motor’s performance will not be as good as with 100 µF - for example, the locked-rotor torque will be lower.
Summary
As we have seen, single-phase motors work according to the same principles as three-phase motors. They do, however, have lower starting torques and lower voltages (110-240V) than three-phase motors. Moreover, single-phase motors need help to start, a fact which gives rise to the different motor types. The most common single-phase motor supplied by Grundfos is the permanent-split capacitor motor; the reasons being that it requires the least maintenance and that pumps do not require very large starting torques. Single-phase motors should not run idle, in fact, many of them should not run at less than 25 per cent loads, as this will cause temperatures to rise inside the motor, which can lead to breakdowns.