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## Electric motor operating principles and circuits

### Three-phase and single-phase a.c. systems

In electrical power supply technology, a basic distinction is made between single-phase and three-phase a.c. mains systems. The differences between these two systems are outlined below.

#### Three-phase a.c.

Three-phase a.c. (alternating current) is produced by generators and passed to electric power consumers via appropriate conductors. The mains system itself consists of the three current-carrying conductors L1, L2 and L3, a neutral conductor N, and the protective earth conductor PE.

In a three-phase a.c. mains system designated 400 V 3/N ~ 50 Hz (the variety most commonly used in Europe), the following voltage relations exist:

A voltage of 400 V is present across conductors L1-L2, L2-L3 and L3-L1. The voltage between conductors L1-N, L2-N and L3-N is 230 V in each case (refer to Fig. 1).

#### Single-phase a.c.

In a single-phase a.c. system, a voltage is carried between the live or phase conductor and the associated neutral conductor N. It does not matter which of the three phases is used for the live conductor. It will be appreciated from Fig. 1 that a three-phase a.c. mains system with a neutral conductor N and a voltage of 400 V also provides a 230 V single-phase mains supply. The quotient of the phase-to-phase voltage and the phase-to-neutral voltage is expressed by the so-called interlinking factor.

The interlinking factor is calculated as follows:

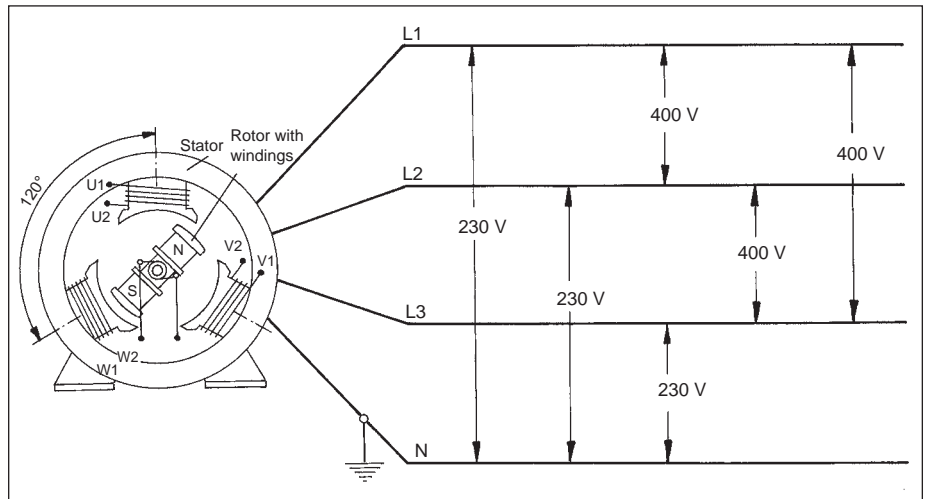


Fig. 1

$$\frac{\text{Voltage between 2 phases}}{\text{Voltage between 1 phase and N}} = \frac{400\text{V}}{230\text{V}} = 1,73 = \sqrt{3}$$

This interlinking factor of  $1,73 = \sqrt{3}$  applies to all three-phase a.c. networks having a neutral conductor N, regardless of their nominal voltage.

#### Three-phase a.c. motors

Let us now consider the options for connecting electric fan and air heater motors to the above a.c. mains systems.

As a basic rule, the availability of an electrical mains system is a precondition for connecting any item of HVAC equipment comprising an electric motor. To operate the motor on this power supply, the two must be matched, i.e. the mains voltage and motor operating voltage must be the same, as must be their frequencies.

#### Single-speed three-phase a.c. motors with dual voltage specification

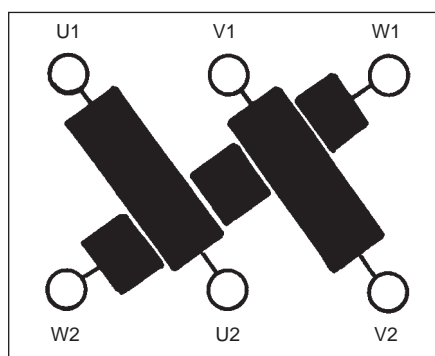


Fig. 2

Some three-phase a.c. motors for single speed operation have a dual voltage specification, e.g., 230/400 V or 400/690 V.

Terminal designations for such motors are given in Fig. 2.

The 230/400 V specification states that the motor can be run on 230 V three-phase a.c. or on a 400 V three-phase a.c. network.

Since the mains voltage is usually fixed, i.e. not freely selectable, the motor circuit can be adapted to specific application needs. Each individual winding of this motor is rated for a voltage of 230 V. However, by adopting either a star or delta connection, it is possible to run it on either 230 V or 400 V.

In a star connection windings are connected as shown in Fig. 3.

The illustration clearly shows the „star“ pattern in which the windings are interconnected. The associated diagram of the terminal board indicates where the feeder must be terminated and where the star connection is placed. Here, again, the interlinking factor between the 230 V winding voltage and the 400 V mains voltage is  $1,7 = \sqrt{3}$

With any other winding voltage, mains voltage in the star circuit must be equal to  $1,7 = \sqrt{3}$  times the winding voltage.

The interconnection of windings in a delta-connected motor corresponds to the diagram in Fig. 4.

The illustration clearly shows the triangular (delta-shaped) connection pattern. The associated diagram of the terminal board indicates where the power supply must be terminated and where the delta connections are placed. A comparison of the two connection methods reveals that, for each winding to receive a voltage of 230 V at all times, the motor windings must be connected in a star pattern on a 400 V a.c. mains system or in a delta pattern on a 230 V a.c. supply. We can thus state the following general rule:

**Note:**  
**On machines with a dual voltage specification, a star connection must be used for the higher voltage. A delta connection is indicated for the lower voltage.**

The machine's direction of rotation can be reversed by interchanging any two phases.

**Dual-speed three-phase a.c. motors with single voltage specification**

A distinction is made between

- a) pole-changing motors according to Dahlander (rotational speed ratio of 1:2)
- b) pole-changing motors with two separate windings (permitting other rpm. ratios than 1:2).

Unlike their single-speed counterparts, dual-speed motors are always designed for a single operating voltage.

**Note:**  
**Mains voltage and nominal motor voltage must coincide.**

As regards the designation of terminals, it has been determined by convention that the sequence of the numerals preceding the terminal letters indicates the rpm. level, i.e., terminals 1U, 1V and 1W are always for lower speed while the terminals 2U, 2V and 2W are for higher speed.

Figs. 5 to 8 (see next page) indicate how the windings must be interconnected and where the live conductors are terminated in each case.

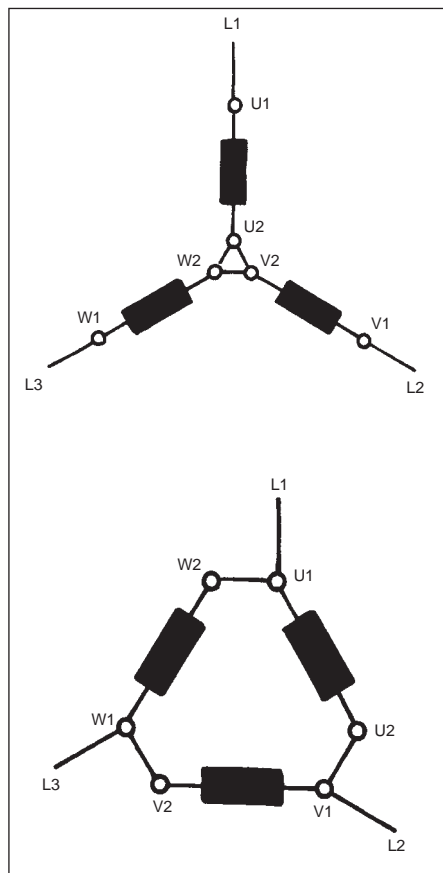


Fig. 3

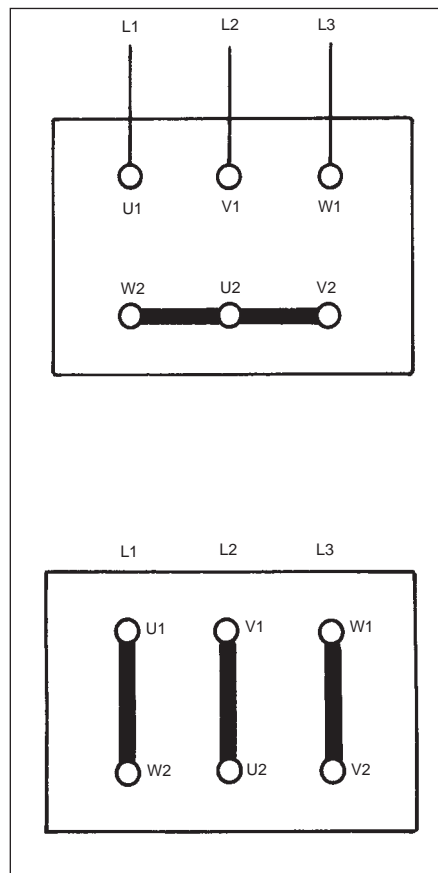


Fig. 4

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### Dahlander winding

To run the machine at lower rotational speed, power supply is connected to terminals 1U, 1V and 1W. The other terminals (2U, 2V, 2W) remain unconnected (Fig. 5). To use higher speed, power supply is assigned to terminals 2U, 2V and 2W.

Important: Terminals 1U, 1V and 1W must be interconnected in this case.

Failure to provide this jumper („star connection“) will result in destruction of the windings (Fig. 6).

**Note:**

**In contactor-controlled systems, the „star“ contactor must always be switched on *before* the mains contactor for the high speed!**

### Two separate windings

Here, again, power supply is connected to terminals 1U, 1V and 1W for the lower speed, with terminals 2U, 2V and 2W remaining unconnected (Fig. 7). For higher speed, the power supply must be wired to terminals 2U, 2V and 2W.

**Note:**

**A star connection („jumper“) must not be used in this case.**

Failure to observe this rule would result in destruction of the windings.

From the comparison of the connecting diagrams for motors with Dahlander winding and units with separate winding, it becomes clear that the difference between the circuits must be carefully noted when selecting switching devices.

**Note:**

**A switching device for a Dahlander motor must never be used on a motor with two windings and vice versa!**

Once again, two phases are interchanged to reverse the motor direction. If a pole-changing switch („pole changer“) is used, it is recommended to effect phase interchange upstream of the switching device since changing phases on the motor would involve re-wiring 2 x 2 terminals, i.e. the risk of confusing conductors is much higher in this case.

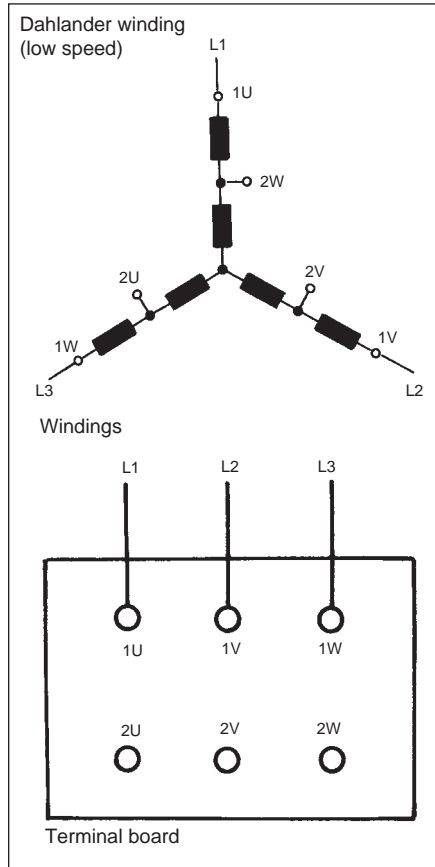


Fig. 5

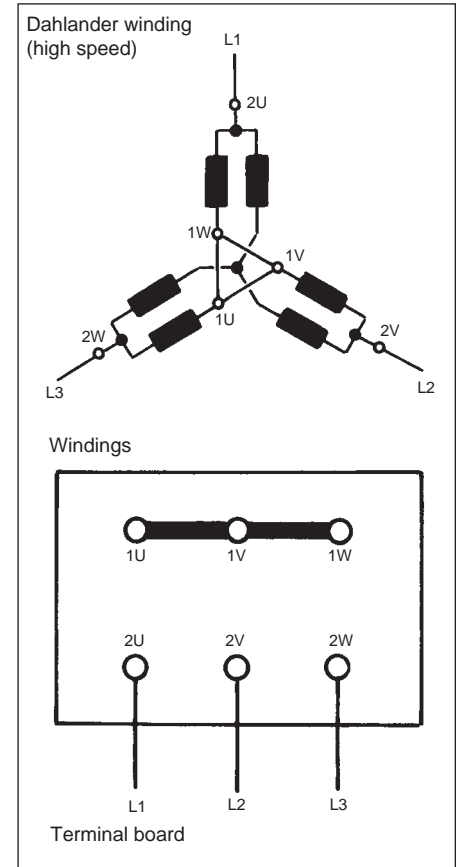


Fig. 6

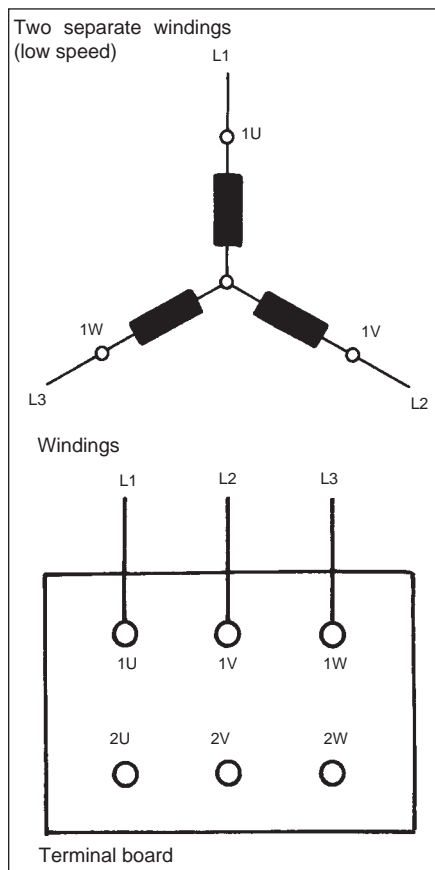


Fig. 7

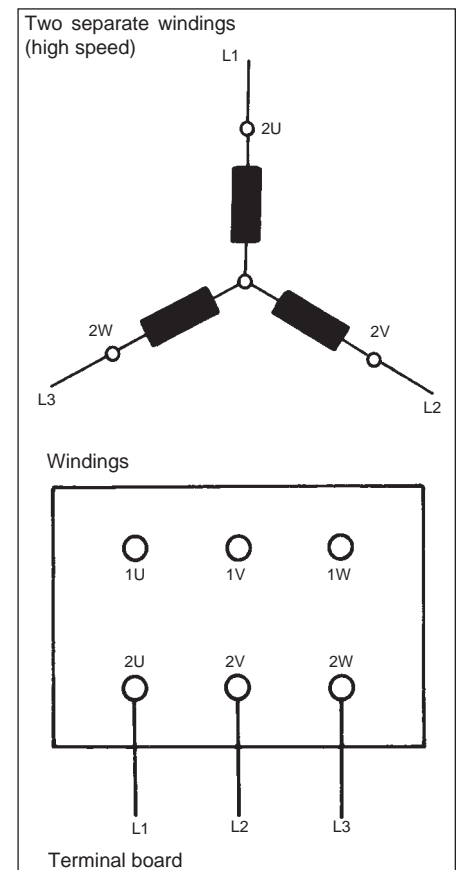


Fig. 8

### Single-phase a.c. motors

Single-phase a.c. motors are available for single- or multi-speed operation, or stepless rpm. control.

The motor terminal board with its terminal designations and connections for windings and capacitors is depicted in Fig. 9. Such motors are designed for a 230 V operating voltage only. It is immaterial whether the motor is connected between a phase and neutral (N) of a 400 V mains system or between two phases of a 230 V supply. Moreover, when connecting phase and neutral (N) conductor, it does not matter which terminal is used for either. Direction of rotation will be the same.

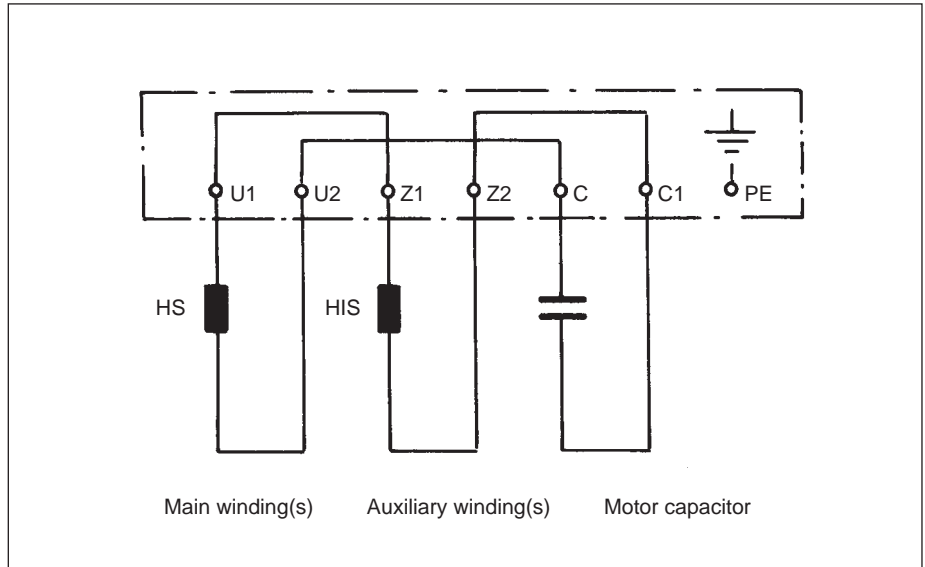


Fig. 9

A change in operating direction can be achieved by reversing the auxiliary versus the main winding. This involves rewiring the jumpers on the terminal board. Since jumpers between U1 and Z1 and between Z2 and C1 are permanently provided on the terminal board, direction of rotation is defined.

The speed can be selected via an appropriate assignment of the power supply terminals.

#### 1. Low speed

It is evident from the diagram that the main winding HS is connected in series with the auxiliary winding HIS. The motor capacitor C is connected in parallel with the auxiliary winding (Fig. 10).

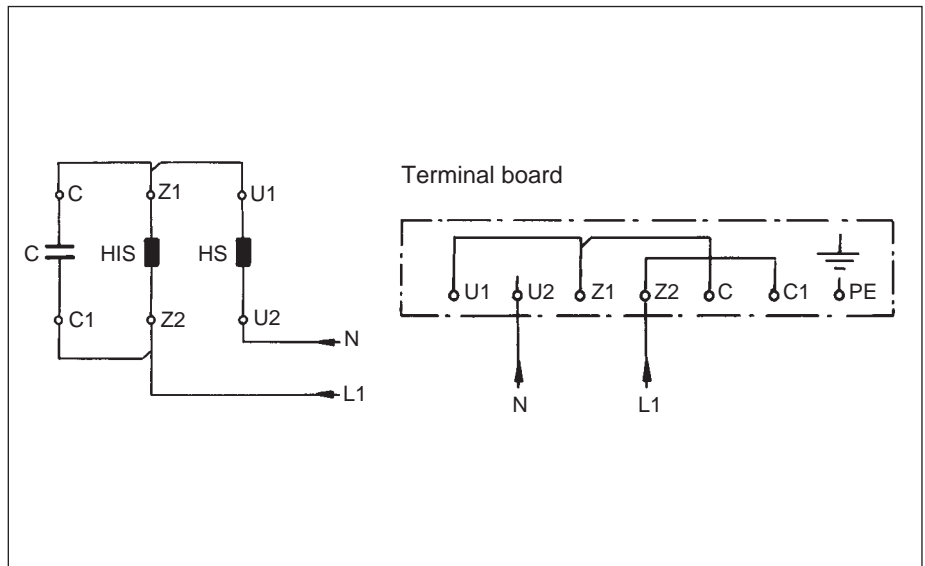


Fig. 10

#### 2. High speed

It will be appreciated from this diagram that the main winding HS is connected in parallel with the auxiliary winding HIS, while the motor capacitor C is connected in series with the auxiliary winding (Fig. 11).

These motors can also be steplessly speed controlled via an rpm. controller. In this case the circuit configuration for the higher speed must be adopted and the controller be connected to the motor terminals U1 and U2.

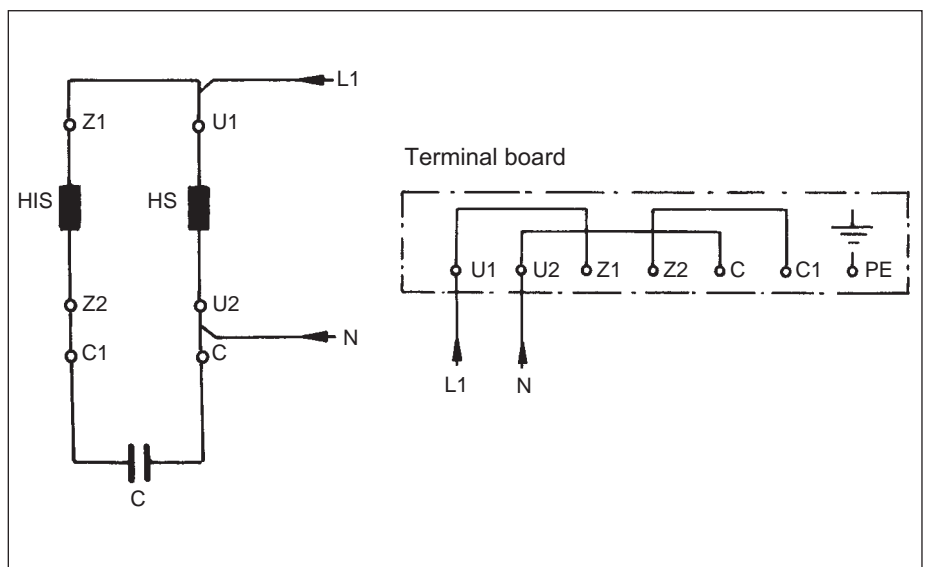


Abb. 11

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## Switching devices for a.c. motors

The function of switching devices is essentially twofold, viz.

1. to energize and de-energize the fan motor.
2. to protect the motor from overloads and hence, destruction. Switching devices performing this latter function are referred to as motor protecting switches or protecting switch combinations.

### Motor protecting switches for single-speed motors without thermal contact

A motor protection switch can operate a single-speed three-phase a.c. motor. It comprises a switching and tripping mechanism. The tripping mechanism (overcurrent or bimetal relay) responds to the motor input current and interrupts the power supply when the current consumption begins to exceed the motor's nominal current.

#### Note:

**The motor's nominal current at the relevant operating voltage is the decisive factor for selecting a motor protecting switch!**

The nominal current must lie within the setting range of the protecting switch thus the latter to be accurately

adjusted to the motor's nominal current. The protecting switch must not trip the motor unless the preset current is exceeded. On the other hand, the motor must be switched off (after a certain delay) when its current consumption rises above the setpoint of the protecting switch. The delay preceding this shutoff becomes shorter as the current increases; it amounts to about 5 seconds at 6 times the preset current.

It is implied in the foregoing that the measured current is taken as a measure of the motor temperature. However, this is true only as long as the motor coolant temperature remains below a threshold of  $+40^{\circ}\text{C}$ . If the coolant temperature rises beyond  $+40^{\circ}\text{C}$ , the motor may be destroyed even if its nominal current is not exceeded, simply because the heat generated inside cannot be dissipated quickly enough. A motor protecting switch merely responds to the motor load, relying on the fact that the current rises with the load. The current is the cause of the heat increase.

### Motor protecting switch combinations for dual-speed motors without thermal contact

Dual-speed motors are switched via protecting switch combinations. The latter differ from simple protecting switches in that they comprise two tripping mechanisms (overcurrent or

bimetal relays) as well as an rpm. switch. However, the operating principle is much the same as with a motor protection switch for single-speed machines.

### Full motor protecting switching devices for motors with thermal contact

For a truly effective motor protection, the influence of the cooling system must be taken into account. This is achieved by measuring the temperature directly at the point where it can harm the motor, i.e. within the winding.

Winding insulations come in different classes and must not be allowed to overheat beyond the limit temperature specified for each class.

For the temperature measurement, a temperature sensor (thermal contact) acting as a control transducer is integrated into the winding. The temperature in the motor winding is reliably determined by this sensor. It consists of a very small bimetallic switch that interrupts an electric control circuit shortly before the winding temperature reaches the limit for the given insulation class. To benefit from this feature, an appropriately equipped switching device must be used.

These devices as referred to as full motor protection switches for motors with thermal contact. They are availa-

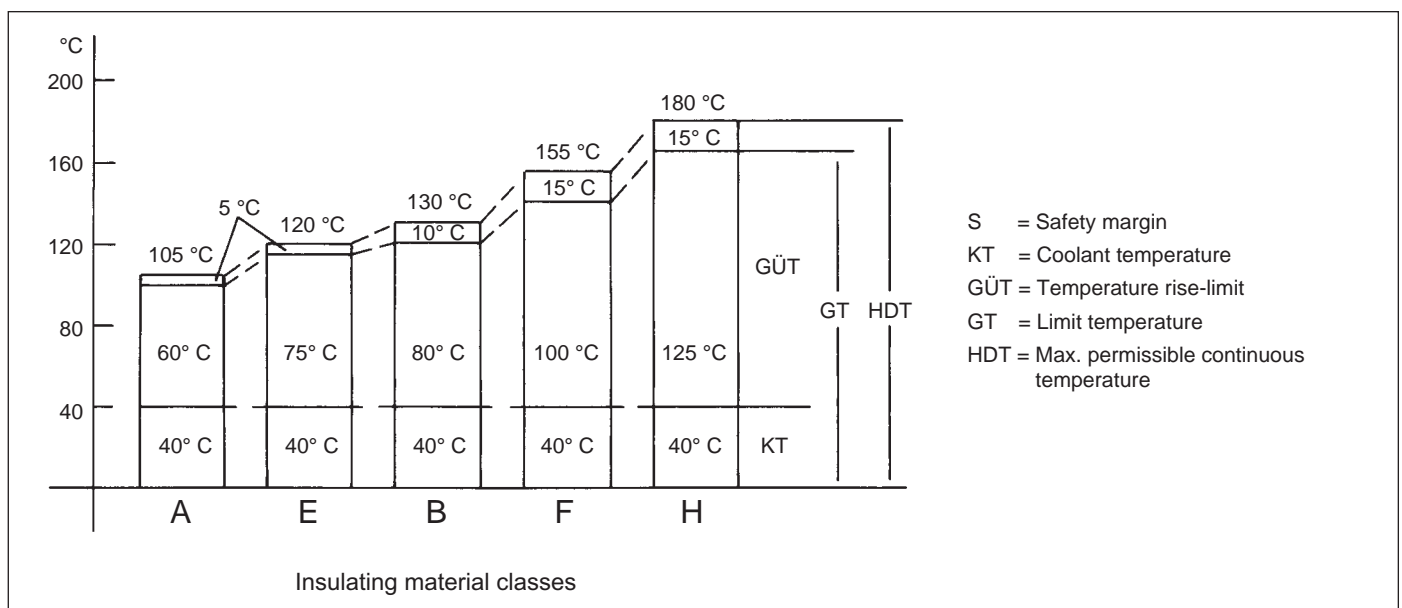


Fig. 12



ble for single-speed motors with Dahlander windings or with two separate windings.

The control action of a full motor protection switch is characterized by the fact that the motor is de-energized immediately when the thermal contact is tripped, interrupting the electric control circuit. However, the motor will not re-start automatically when the control circuit is closed again by the thermal contact. To re-start the motor, a manual switch must be set first to „0“ and then, via „E“ (this gives the starting pulse), to position „1“ or „2“ according to the desired speed.

Some full motor protection switches have additional contacts for a servo motor and a port for connection of a contact-making component (e.g. a thermostat, hygrostat, timer, etc.). Such switches can be used to energize and de-energize the motor via a contact-making component at a manually preselected speed. The motor is shut off when the control contact opens and re-starts automatically when it closes.

The additional contacts allow to run a servo (positioning) motor in a clockwise or counterclockwise direction independently of the fan motor.

While a motor protecting switch combination with a bimetal relay set to the nominal motor current can serve only one single connected motor, a full motor protection switching device for motors with thermal contact supports the connection of multiple motors. It should be noted, however, that the aggregate outputs of these motors must not exceed the maximum acceptable capacity of the full motor protection switching device. Moreover, motors thus connected in parallel must have the same operating voltage and winding type (single-speed, Dahlander or separate windings). The circuit configuration must be such that motors are connected in parallel with their three-phase a.c. terminals while the thermal contacts are connected in series.

### Switching devices for single-phase a.c. motors

Single-phase a.c. motors can be classified according to the following scheme:

1. Motors with thermal contacts wired to external terminals
2. Motors with internally wired thermal contacts.

Internally wired thermal contacts (i.e. contacts placed in the winding and inserted directly into the motor circuit) are suitable for use on low-powered motors only.

Motors equipped with such contacts can be started and de-energized via any commercially available installation switch, provided they are of the single-speed type. For dual-speed motors a special rotary switch must be used; such switches fit into any standard flush-mounting enclosure. Motor protection will be ensured at both speeds and in both operating modes. The thermal contact interrupts the motor circuit when the winding temperature reaches the acceptable limit for the given insulation class, then re-starts the motor once it has cooled down.

As an alternative to the above, a contactor-controlled system can be designed to prevent an automatic re-start once the motor temperature has returned into the acceptable range. As a general rule, motors with internally wired thermal contacts can also be operated via switching devices designed for separate connection of a thermal contact. In this case terminals for this thermal contact must be short-circuited via a jumper on the switching device.

Irrespective of whether or not the motor has its thermal contacts wired to external terminals, single-phase a.c. units can be steplessly speed-controlled via an electronic rpm. controller developed specifically for this motor type. This speed controller also allows to define two or three speed stages for the motor by connecting appropriate resistors to the control circuit. A changeover between speeds is then made via a component supp-

lying a contact output. The motor is energized and de-energized via a manual switch integrated into the controller.