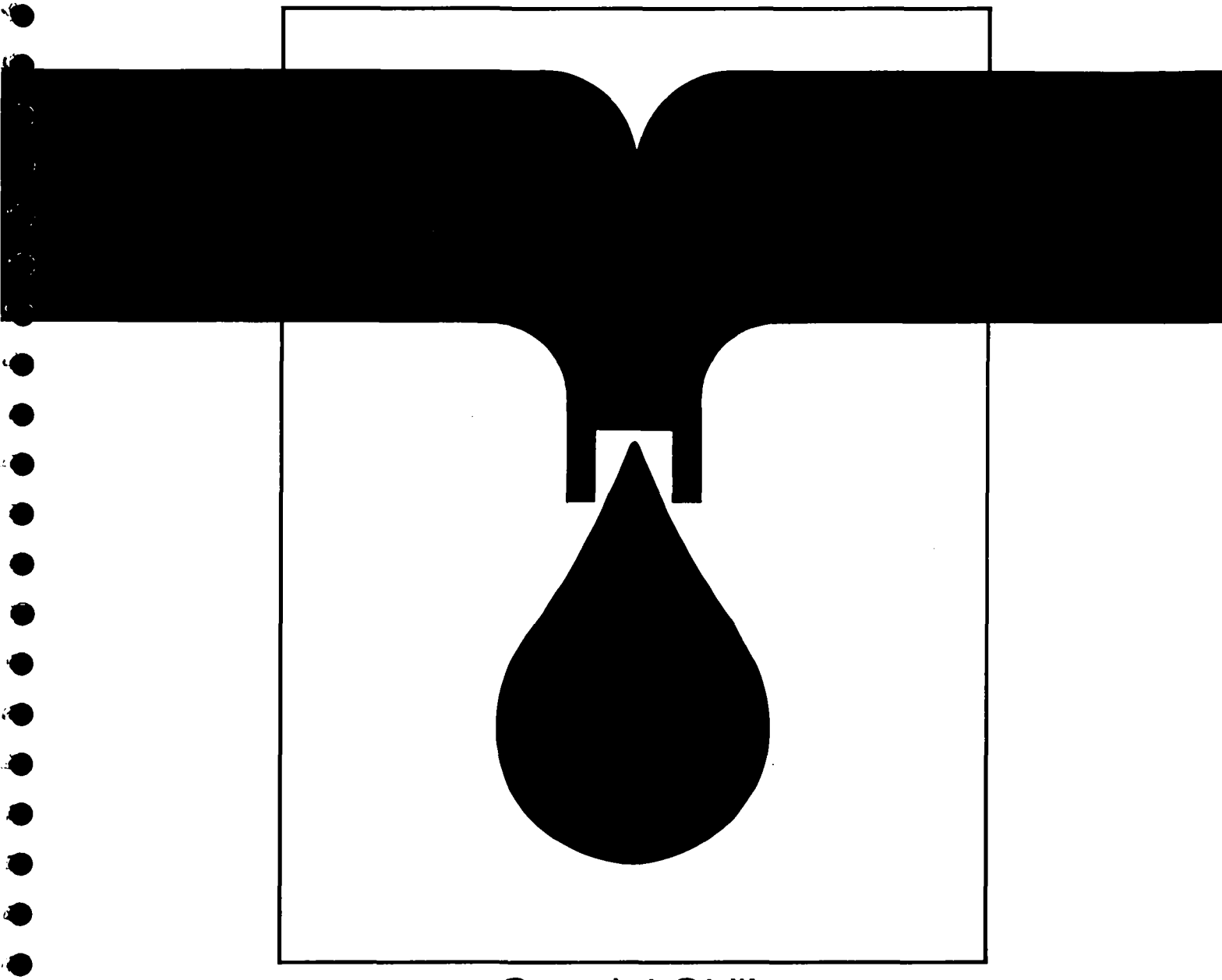
TRAINING MODULES
FOR
WATERWORKS PERSONNEL



Special Skills

3.3 b

Design and working principles of electric motors

Foreword

Even the greatest optimists are no longer sure that the goals of the UN "International Drinking Water Supply and Sanitation Decade", set in 1977 in Mar del Plata, can be achieved by 1990. High population growth in the Third World combined with stagnating financial and personnel resources have led to modifications to the strategies in cooperation with developing countries. A reorientation process has commenced which can be characterized by the following catchwords:

- use of appropriate, simple and – if possible – low-cost technologies,
- lowering of excessively high water-supply and disposal standards,
- priority to optimal operation and maintenance, rather than new investments,
- emphasis on institution-building and human resources development.

Our training modules are an effort to translate the last two strategies into practice. Experience has shown that a standardized training system for waterworks personnel in developing countries does not meet our partners' varying individual needs. But to prepare specific documents for each new project or compile them anew from existing materials on hand cannot be justified from the economic viewpoint. We have therefore opted for a flexible system of training modules which can be combined to suit the situation and needs of the target group in each case, and thus put existing personnel in a position to optimally maintain and operate the plant.

The modules will primarily be used as guidelines and basic training aids by GTZ staff and GTZ consultants in institution-building and operation and maintenance projects. In the medium term, however, they could be used by local instructors, trainers, plant managers and operating personnel in their daily work, as check lists and working instructions.

45 modules are presently available, each covering subject-specific knowledge and skills required in individual areas of waterworks operations, preventive maintenance and repair. Different combinations of modules will be required for classroom work, exercises, and practical application, to suit in each case the type of project, size of plant and the previous qualifications and practical experience of potential users.

Practical day-to-day use will of course generate hints on how to supplement or modify the texts. In other words: this edition is by no means a finalized version. We hope to receive your critical comments on the modules so that they can be optimized over the course of time.

Our grateful thanks are due to

Prof. Dr.-Ing. H. P. Haug
and
Ing.-Grad. H. Hack

for their committed coordination work and also to the following co-authors for preparing the modules:

Dipl.-Ing. Beyene Wolde Gabriel
Ing.-Grad. K. H. Engel
Ing.-Grad. H. Hack
Ing.-Grad. H. Hauser
Dipl.-Ing. H. R. Jolowicz
K. Ph. Müller-Oswald
Ing.-Grad. B. Rollmann
Dipl.-Ing. K. Schnabel
Dr. W. Schneider

It is my sincere wish that these training modules will be put to successful use and will thus support world-wide efforts in improving water supply and raising living standards.

Dr. Ing. Klaus Erbel
Head of Division
Hydraulic Engineering,
Water Resources Development

Eschborn, May 1987

Title: Electric motor

Table of contents:

0. Introduction

The work which has to be performed on electric motors can be subdivided into three categories:

- Installation and start-up work
- Maintenance work
- Rapair work

All three areas involve both mechanical and electrical work.

This work should be performed by qualified personnel; this will generally consist of mechanics or machine fitters, together with electricians for all electrical work. It must be expressly pointed out, however, that the electrical work may be performed only by specialist personnel. The list below details the individual skills required for the various work categories. It may be possible to find one man possessing all these skills, but in most cases two or three qualified men are required, particularly for repairs.

- Handling and checking of bearings
- Removal and installation of bearings
- Installation and alignment of the motor
- Preparation of the installation site
- Simple test for unbalance
- Cleaning and repair work on frame, as well as on rotor and stator
- Measuring procedures for testing mains and protective equipment
- Measuring procedures for testing the motor
- Knowledge and checking of motor connections in the light of the motor's use

1. Start-up

Before initial commisssioning and following lengthy periods of non-use, the insulation resistance of the windings with respect to frame must be measured. The generally valid approximate value (reference value) is:

1000 per 1 V operation voltage at a winding temperature of 75° C.

The insulation resistance is measured using an ohmmeter, the rated voltage of which must be at least 500 V DC (Fig. 1). The insulation resistance may vary depending on the type and size of the machine;

it is also governed by the operating conditions. It should be at least as many kilohms as indicated by the numerical value of the rated voltage to earth. FOr 220 V, therefore, the resistance should be at least 200 kΩ. In the case of repaired motors for electrical equipment, the insulation resistance - in accordance with VDE 0701 (regulation of the Association of German Electrical Engineers) - must even attain a value of 1 MΩ.

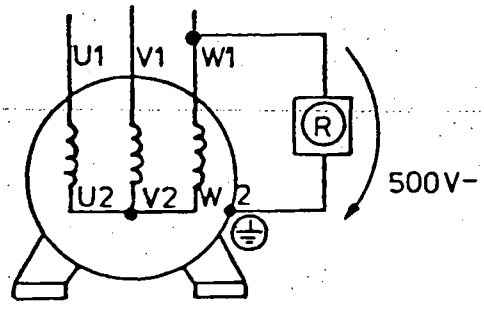


Fig. 1: Measuring the insulation resistance

In order to measure the insulation resistance of the individual windings with respect to frame, one terminal of the measuring instrument used (e. g. megger) is connected to the frame of the machine to be tested (motor). The other terminal is connected in succession to terminals u, v. and w on the motor terminal board and the measurement performed for each winding in accordance with the measuring specifications and the description of the measuring instrument.

If the insulation resistance of the windings with respect to one another is to be measured, the connecting elements between the winding terminals on the motor terminal board must first be removed. It must be ensured that there is no longer a conductive connection between any of the windings. The two terminals of the measuring instruments are then connected in succession to the winding terminals u and v, u and w, and v and w, with the measurement then being performed for each pair.

The measuring voltage of the megger should be as given below for the following rated motor voltages:

Rated voltage	$\leqq$	500 V :	250 V DC
Rated voltage	$\leqq$	1500 V :	625 V DC
Rated voltage	$\leqq$	4500 V :	1250 V DC
Rated voltage	$>$	4500 V :	2500 V DC

The measured value, when compared with the reference value for the same temperature, first of all provides information as to the condition of the insulation. Although the modern synthetic-resin high-voltage insulation EPITHERM absorbs no moisture, condensate must be expected on the surface of the winding, the connectors and the supporting elements. Discharges could therefore occur when the rated voltage is applied. A high-voltage winding should therefore always be heated to 45° C, even if the measured insulation resistance is adequate. In the case of machines having a rated voltage of less than 1000 V, drying is necessary only if the insulation resistance is too small.

Only dry, warm air should be used to dry the windings. The temperature must not exceed 75° C and adequate air changes must be ensured. The manufacturer must be consulted if other drying methods have to be used.

Once the motor has undergone a final check (bearing grease/oil, slip rings and commutator, brushes and brush holders), the mains cables are connected. When L 1, L 2 and L 3 are connected to the motor terminals U, V and W, the motor will rotate in the clockwise direction, as seen from the drive end. Motors which are suitable only for one direction of rotation and which require constructional measures if the direction is to be changed bear an indication to this effect on the rating plate, e.g. only UVW or only WVU (see Module 2.3, Section 3.3).

In the event of a change in the direction of rotation, the operating instructions must be observed here in every case, and must be observed in principle in the case of DC machines. If the motor is used to drive machines which may be operated in one direction of rotation only, particular attention must be paid to the motor's direction of rotation. In such cases it is advisable to check the

motor's direction of rotation with the driven machine disconnected. The coupling can then be closed and the drive system started up.

2. Maintenance

With careful maintenance, maximum usage and minimum upkeep costs can be achieved for electric machines. Particular attention should be paid to parts subject to wear; these are the bearings, slip rings, commutator, brushes and brush holders.

For rolling bearings, the relubrication intervals given in the operation instructions must be observed.

For sleeve bearings, attention must be paid to oil level, oil changes and inspection of the bearing shells at specific intervals, as well as to checking of the oil rings for free running. More details will be found in the operating instructions.

The slip rings of asynchronous and synchronous machines must be examined with regard to the condition of their contact faces. In the event of severe scoring the rings must be skimmed and polished.

The commutators of DC machines must be observed in particular detail. It is their true running which influences spark-free commutation. Permissible deviations, measured at the periphery, are as follows:

Long shaft	(oval)	$\leq$ 0.05 mm
Short shaft	(protruding copper segments)	$\leq$ 0.02 mm

High mica must be always be undercut with a saw. In the case of larger deviations the commutator must be skimmed. The mica must be undercut to a depth of 0.5 times the mica thickness, with a maximum of 0.8 mm. The edges of the copper segments must be chamfered.

As far as brush maintenance is concerned, it is important to ensure that the brushes can move freely in the brush boxes and that they are of adequate length. Brush wear should be between 0.3 mm and 0.7 mm per 100 operating hours.

For general maintenance of every motor it is recommended to draw up a maintenance schedule similar to that shown in the table on the next page. The motor should be monitored daily for smooth running, noise and temperature. Should faults occur, their cause can be pinpointed and eliminated on the basis of the table given.

Table 1: Maintenance work

Assembly	Daily	Weekly	Every 3 months	Annually (minor overhaul)	Every 5 years (major overhaul)
Bearings	Every 50 000 operating hours: fit new bearings				
Bearing insulation				Visual inspection Measure after 1st year	Measure
Heat exchanger, cooling fins (surface)			Clean		Clean
Coupling		Align after 1st week		Check alignment	Check alignment
Terminal boxes, earthing				Clean interior, tighten screws	Clean interior, tighten screws
Stator winding				Visual inspection, measure insulation resistance	Clean, check interference fit of supporting element and slot wedges, measure insulation resistance
Filter for type AN			Clean		
Monitoring equipment	Record measured data				If possible, remove and check operation
Motor as a whole	Pay attention to running noises and quiet running			Tighten screws	Remove rotor, check stator cores for interference fit, check cage bars for fracture, clean

Table 2: Fault finding in three-phase machines (1)

Problem	Possible cause	Location procedure or remedy
Fails to start either when coupled or uncoupled, no noise	Break in at least two supply lines, no voltage	Check autotransformer starter, switches, fuses, supply lines and terminals
Fails to start either when coupled or uncoupled, hums	Break in one supply line	Check autotransformer starter, switches, fuses, supply lines and terminals
	Rotor sticking	Remove foreign bodies from air gap
	Bearing seized	Replace bearing
Fails to start under load or starts too slowly under load, speed under load too low or starts without load, does not pull load through; magnetic noise in all cases	Starting torque too great	Reduce driven-machine load for starting, uncouple motor and check during no-load running
	Mains voltage too low	Measure mains voltage, set correct value
	Voltage drop in supply line too great	Check cross-section of supply line
	Several breaks in rotor winding	Check rotor winding, repair or replace
	Break in one supply line after starting	Check supply line
Runs with double slip frequency with fluctuating stator current, hums upon starting	Break in rotor winding	Check rotor winding, repair or replace
No-load current too high	Mains voltage too high	Measure mains voltage, set correct value
Stator winding heats up quickly; motor also hums when running	Breaks in parallel wires or phases of stator winding	Measure resistances of all winding phases, replace stator core and winding
	Mains voltage too high	Check mains voltage and no-load current

Table 2: Fault finding in three-phase machines (2)

Problem	Possible cause	Location procedure or remedy
	Cooling inadequate because ventilating passages contaminated	Expose and clean ventilating passages
	Direction of fan rotation incorrect	Check fan and direction of rotation
	Direction of motor rotation incorrect	Interchange two mains terminals
Stator winding becomes too hot under load	Cooling inadequate because ventilating passages contaminated	Expose and clean ventilating passages
	Direction of fan rotation incorrect	Check fan and direction of rotation
	Direction of motor rotation incorrect	Interchange two mains terminals
	Load too great	Measure stator current, reduce load, use larger motor
	Number of starts or total flywheel effect too great	Reduce number of starts
	Voltage too high, therefore core losses too great	Do not exceed 105 % of rated voltage if not otherwise specified on rating plate
	Voltage too low, therefore current too high	Check mains voltage and voltage drop to machine
	Break in a supply line or phase	Check current of all phases
	Rotor rubbing in stator	Investigate magnetic pull by comparing running when connected to mains with running following disconnection
	Duty type does not correspond to rating plate	Adhere to duty type as stated on rating plate or reduce load

Table 2: Fault finding in three-phase machines (3)

Problem	Possible cause	Location procedure or remedy
Stator winding temperatures rise	Windings heavily fouled, ventilating passages blocked	Clean
	Cooler not vented	Vent cooler
	Cooler or cooling-water lines fouled	Clean
Local temperature rises	Interturn short circuits in stator winding	Individual coils look scorched, repair winding
	Break in parallel wires or phases of stator winding	Individual coils look scorched, measure resistances of all winding phases, repair winding
Local temperature rises in rotor	Breaks in rotor winding	Repair or renew rotor winding
Abnormal noise	Mechanical causes	Noise generally reduced when speed decreases
	Electrical causes	Noise disappears when motor is switched off, consult manufacturer
Motor runs unevenly when coupled and smoothly when uncoupled	Fault in transmission components or driven machine	Check power transmission, coupling and alignment
	Faults in gear drive	Align drive, check position of pitch circles of pinion and wheel
	Sinking of foundation	Realign machine unit, restore proper foundation condition
	Drive components or driven machine poorly balanced	Rebalance

Table 2: Fault finding in three-phase machines (4)

Problem	Possible cause	Location procedure or remedy
Motor runs unevenly when uncoupled	Unbalance	Uneven running continues with motor decoupled and slowing down (without voltage); rebalance
	Break in one stator winding phase	Check current input of all supply lines
	Foreign bodies in air gap	Remocr foreign bodies, clean air gap
	Mounting screws loose	Tighten and lock screws
	Machine-mounted drive components (coupling disc) impairing balance of rotor	Rebalance rotor with and without coupling disc
	Resonance in foundation	Detune foundation
	Motor distorted	Check alignment

3. Operation

When an electric motor is being installed, the following points must be borne in mind:

- The design of the motor must be in line with the service environment (e.g. splash-proof type, explosion-proof type, tropicalized type etc.)
- Before the motor is mechanically connected to the machine to be driven, it must be ensured that the two units are precisely aligned, i.e. that the position of the shafts of the two machines coincides exactly. If this is not the case, oscillations and vibrations may occur which can have a destructive effect on the machines.

3.1 Duty types

The duty type is an important factor in the selection of an electric machine. A motor which is operated under load for only short periods, for example, heats up less than one which is continuously under load and can therefore be smaller. VDE 0530 (regulation of the Association of German Electrical Engineers) classifies rated duty types from S 1 to S 8.

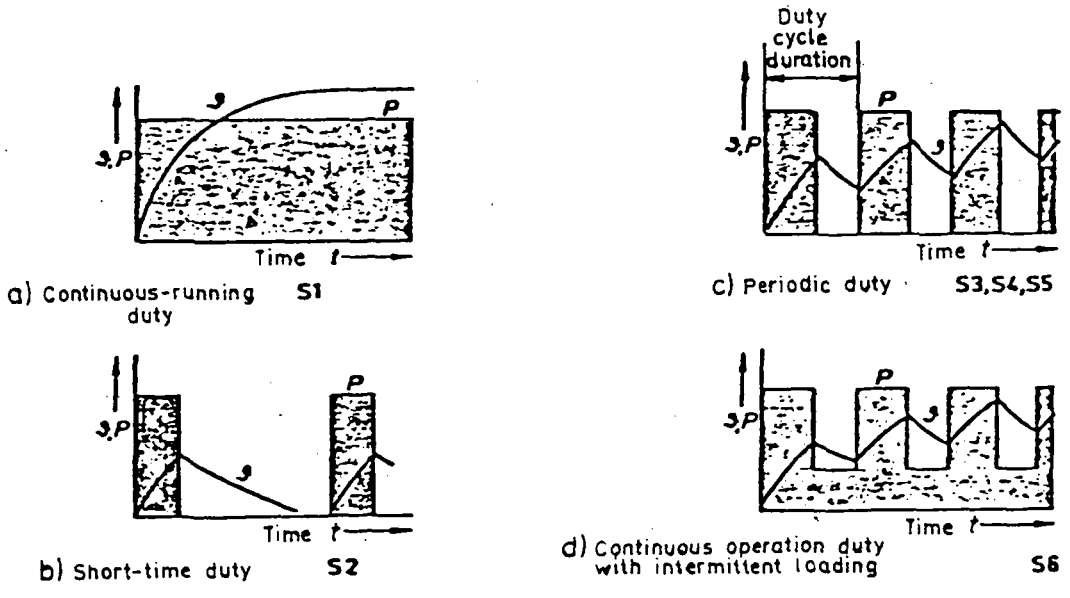


Fig. 2: Duty types

In the case of continuous-running duty type S 1, the period of operation at rated power output is of sufficient duration for the stationary temperature to be reached. Motors of this type are suitable for continuous operation, i.e. they may be continuously operated at their rated load (Fig. 2a).

In the case of short-time duty type S 2 the operating period is so short in comparison with the subsequent rest period that the stationary temperature is not reached. During the longer rest period which follows the motor cools down to its initial temperature (Fig. 2b).

In the case of periodic duty types S 3, S 4 and S 5 the operating periods and rest periods are short. The cycle time is generally 10 minutes. The rest period is not sufficient to allow the machine to cool down to ambient temperature (Fig. 2c).

Duty type S 3 applies when the starting current has no significant influence on temperature rise, S 4 when it does have a considerable influence and S 5 when the braking current also heats up the machine.

In the case of continuous-operation duty type with intermittent loading S 6, the motor cannot cool down during the no-load periods (Fig. 2d).

In the case of continuous-operation duty type with starting and braking S 7 there are practically no rest periods. The machine is energized at all times. The number of cycles per hour specified on the rating plate must not be exceeded.

In the case of continuous-operation duty type S 8 with pole changing the machine is operated continuously under load, but with frequent changes of speed.

3.2 Degrees of protection of electric motors

Electrically active parts of electric machines, transformers, switchgear and wiring systems must not be touched on account of the accident risk. Depending on the use and location of this equipment, protection against accidental contact, foreign bodies and water is required.

3.2.1 Identification by means of letters and numbers

The degrees of protection are indicated by a symbol, which is made up of the letters "IP" followed by two characteristic numerals designating the degree of protection. The first number indicates the degree of protection against accidental contact and ingress of foreign bodies, while the second number specifies the degree of protection against the harmful ingress of water (see Table 3).

Table 3: Degrees of protection of electrical equipment

First number	Degrees of protection against accidental contact and ingress of foreign bodies	Second number	Degree of protection against water
0	No special protection	0	No special protection
1	Protection against ingress of solid foreign bodies with diameter 50 mm	1	Protection against dripping water falling vertically
2	Protection against ingress of solid foreign bodies with diameter 12 mm	2	Protection against dripping water falling vertically, equipment tilted up to 15°
3	Protection against ingress of solid foreign bodies with diameter 2.5 mm	3	Protection against spray-water up to an angle of 60° to the vertical
4	Protection against ingress of solid foreign bodies with diameter 1 mm	4	Protection against water splashed from all directions
5	Protection against harmful dust deposits (dust-protected), full protection against accidental contact	5	Protection against water jets (nozzle) from all directions
6	Protection against ingress of dust (dust-proof), full protection against accidental contact	6	Protection against strong water jets or heavy seas
		7	Protection against water if equipment immersed under certain pressure and time conditions
		8	Protection against water if equipment permanently submerged

Any necessary additional letters are given after the identification letters "IP" or after the numbers. If, for example in descriptions, only one number is required for the degree of protection alongside the letters "IP", the missing number is to be replaced by an X, e.g. IP X4. If the degree of protection of one part of an item of apparatus, e.g. the terminal box of a motor, differs from that of the frame, both degrees of protection must be given, e. g. motor IP 21, terminal box IP 54.

Fig. 3 helps to define the terms used for the degrees of protection for motors.

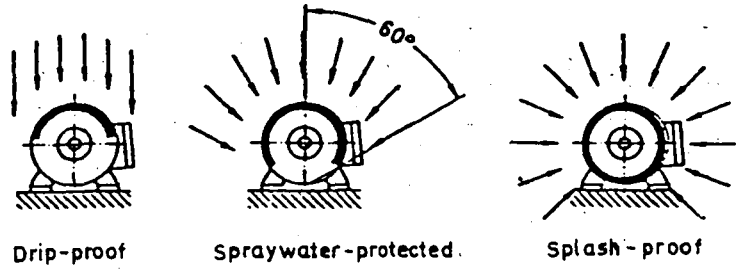


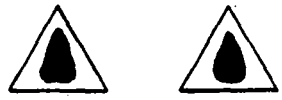
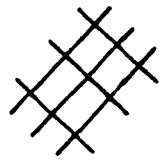
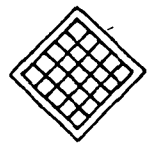
Fig. 3: Degrees of motor protection against the ingress of water

3.2.2 Identification by means of graphical symbols

In addition to general identification of the degrees of protection by means of letters and numbers, the degree of protection, e.g. protection against water and protection against dust, of installed equipment and electrical appliances is also identified by means of graphical symbols. These symbols are to be found on the items of equipment.

Electrical equipment used in damp and wet rooms, as well as that for protected outdoor installations, must be at least drip-proof (degree of protection IP 31); portable lamps must be hose-proof (IP 55). All equipment for unprotected outdoor installations must be at least spraywater-protected (IP 43), while lamps must be at least rainwater-proof (IP 35). Equipment with a higher degree of protection may also be used. In the case of degree of protection IP 68, the letter "h" indicates the installation depth in metres in the case of submersed operation under water. For example, "h3" corresponds to an installation depth of 3 m under water, i. e. to a gauge pressure of 0.3 bar.

Table 4: Graphical symbols for IP degrees of protection

Degree of protection	Symbol	Scope of protection corresponds to: IP
Drip-proof		Protection against high atmospheric humidity, vapours and dripping water falling vertically: IP 31
Rainwater-proof		Protection against drops of water from above up to 30° above the horizontal: IP 33
Splashwater-proof		Protection against drops of water from all directions: IP 54
Hose-proof		Protection against water jets from all directions: IP 55
Watertight		Protection against ingress of water not under pressure: IP 67
Submersible		Protection against ingress of water under pressure: IP 68
Dust-protected		Protection against ingress of dust not under pressure: IP 5X
Dust-proof		Protection against ingress of dust under pressure: IP 6X

3.2.3 Protection classes

In addition to the protective measures taken, items of apparatus are also allocated to protection classes. These classes indicate protective measures to be taken in order to guard against direct and indirect contact. There are three protection classes: I, II and III.

Table 5: Equipment protection classes as per VDE 0720

Protection class	I	II	III
Symbol			
Protective measures	Protective earth conductor	Protective insulation	Protective extra-low voltage
Examples	Electric motor	Domestic appliances, lamps	Inspection lamps, small apparatus up to 42 V

4. Bibliography

The sources of the tables used in Module 3.3b, together with the literature consulted, are given below.

Passages have in some cases been taken word for word from the sources given.

a) AEG-Telefunken — Hilfsbuch der Elektrotechnik
Band 2 Anwendung

b) Flesdorff/Hilgarth — Elektrische Energieverteilung
Teubner Verlag, Stuttgart

c) Loher & Söhne — Der neuzeitliche Drehstrommotor,
4th edition.

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH
Dag-Hammarskjöld-Weg 1 + 2 · D 6236 Eschborn 1 · Telefon (06196) 79-0 · Telex 407501-0 gtz d

The government-owned GTZ operates in the field of Technical Cooperation. Some 4,500 German experts are working together with partners from some 100 countries in Africa, Asia and Latin America in projects covering practically every sector of agriculture, forestry, economic development, social services and institutional and physical infrastructure. – The GTZ is commissioned to do this work by the Government of the Federal Republic of Germany and by other national and international organizations.

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TRAINING MODULES FOR WATERWORKS PERSONNEL

List of training modules:

Basic Knowledge

0.1 Basic and applied arithmetic
0.2 Basic concepts of physics
0.3 Basic concepts of water chemistry
0.4 Basic principles of water transport
1.1 The function and technical composition of a watersupply system
1.2 Organisation and administration of waterworks

Special Knowledge

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2.2 Hygienic standards of drinking water
2.3a Maintenance and repair of diesel engines and petrol engines
2.3b Maintenance and repair of electric motors
2.3c Maintenance and repair of simple driven systems
2.3d Design, functioning, operation, maintenance and repair of power transmission mechanisms
2.3e Maintenance and repair of pumps
2.3f Maintenance and repair of blowers and compressors
2.3g Design, functioning, operation, maintenance and repair of pipe fittings
2.3h Design, functioning, operation, maintenance and repair of hoisting gear
2.3i Maintenance and repair of electrical motor controls and protective equipment
2.4 Process control and instrumentation
2.5 Principal components of water-treatment systems (definition and description)
2.6 Pipe laying procedures and testing of water mains
2.7 General operation of water main systems
2.8 Construction of water supply units
2.9 Maintenance of water supply units Principles and general procedures
2.10 Industrial safety and accident prevention
2.11 Simple surveying and technical drawing

Special Skills

3.1 Basic skills in workshop technology
3.2 Performance of simple water analysis
3.3a Design and working principles of diesel engines and petrol engines
3.3b Design and working principles of electric motors
3.3c –
3.3d Design and working principle of power transmission mechanisms
3.3e Installation, operation, maintenance and repair of pumps
3.3f Handling, maintenance and repair of blowers and compressors
3.3g Handling, maintenance and repair of pipe fittings
3.3h Handling, maintenance and repair of hoisting gear
3.3i Servicing and maintaining electrical equipment
3.4 Servicing and maintaining process controls and instrumentation
3.5 Water-treatment systems: construction and operation of principal components: Part I - Part II
3.6 Pipe-laying procedures and testing of water mains
3.7 Inspection, maintenance and repair of water mains
3.8a Construction in concrete and masonry
3.8b Installation of appurtenances
3.9 Maintenance of water supply units Inspection and action guide
3.10 –
3.11 Simple surveying and drawing work

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH

P. O. Box 5180
Dag-Hammarskjöld-Weg 1+ 2
D 6236 Eschborn/Ts. 1
Telephone (06196) 79-0
Telex 407501-0 gtz d
Fax No. (06196) 79-1115