



UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION



Technical Guidelines for the Development of Small Hydropower Plants **UNITS**

Part 4: Excitation System

SHP/TG 003-4: 2019



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Part 4: Excitation System

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Further recommendations and suggestions for application for the update would be highly welcome.

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Foreword

The United Nations Industrial Development Organization (UNIDO) is a specialized agency under the United Nations system to promote globally inclusive and sustainable industrial development (ISID). The relevance of ISID as an integrated approach to all three pillars of sustainable development is recognized by the 2030 Agenda for Sustainable Development and the related Sustainable Development Goals (SDGs), which will frame United Nations and country efforts towards sustainable development in the next fifteen years. UNIDO's mandate for ISID covers the need to support the creation of sustainable energy systems as energy is essential to economic and social development and to improving quality of life. International concern and debate over energy have grown increasingly over the past two decades, with the issues of poverty alleviation, environmental risks and climate change now taking centre stage.

INSHP (International Network on Small Hydro Power) is an international coordinating and promoting organization for the global development of small hydropower (SHP), which is established on the basis of voluntary participation of regional, subregional and national focal points, relevant institutions, utilities and companies, and has social benefit as its major objective. INSHP aims at the promotion of global SHP development through triangle technical and economic cooperation among developing countries, developed countries and international organizations, in order to supply rural areas in developing countries with environmentally sound, affordable and adequate energy, which will lead to the increase of employment opportunities, improvement of ecological environments, poverty alleviation, improvement of local living and cultural standards and economic development.

UNIDO and INSHP have been cooperating on the World Small Hydropower Development Report since year 2010. From the reports, SHP demand and development worldwide were not matched. One of the development barriers in most countries is lack of technologies. UNIDO, in cooperation with INSHP, through global expert cooperation, and based on successful development experiences, decided to develop the SHP TGs to meet demand from Member States.

These TGs were drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of these TGs may be subject to patent rights. UNIDO and INSHP shall not be held responsible for identifying any such patent rights.

Introduction

Small Hydropower (SHP) is increasingly recognized as an important renewable energy solution to the challenge of electrifying remote rural areas. However, while most countries in Europe, North and South America, and China have high degrees of installed capacity, the potential of SHP in many developing countries remains untapped and is hindered by a number of factors including the lack of globally agreed good practices or standards for SHP development.

These Technical Guidelines for the Development of Small Hydropower Plants (TGs) will address the current limitations of the regulations applied to technical guidelines for SHP Plants by applying the expertise and best practices that exist across the globe. It is intended for countries to utilize these agreed upon Guidelines to support their current policy, technology and ecosystems. Countries that have limited institutional and technical capacities, will be able to enhance their knowledge base in developing SHP plants, thereby attracting more investment in SHP projects, encouraging favourable policies and subsequently assisting in economic development at a national level. These TGs will be valuable for all countries, but especially allow for the sharing of experience and best practices between countries that have limited technical know-how.

The TGs can be used as the principles and basis for the planning, design, construction and management of SHP plants up to 30MW.

- The Terms and Definitions in the TGs specify the professional technical terms and definitions commonly used for SHP Plants.
- The Design Guidelines provide guidelines for basic requirements, methodology and procedure in terms of site selection, hydrology, geology, project layout, configurations, energy calculations, hydraulics, electromechanical equipment selection, construction, project cost estimates, economic appraisal, financing, social and environmental assessments—with the ultimate goal of achieving the best design solutions.
- The Units Guidelines specify the technical requirements on SHP turbines, generators, hydro turbine governing systems, excitation systems, main valves as well as monitoring, control, protection and DC power supply systems.
- The Construction Guidelines can be used as the guiding technical documents for the construction of SHP projects.
- The Management Guidelines provide technical guidance for the management, operation and maintenance, technical renovation and project acceptance of SHP projects.

Technical Guidelines for the Development of Small Hydropower Plants **UNITS**

Part 4: Excitation System

1 Scope

This Part of the Units Guidelines specifies the technical requirements as well as the basic requirements for the supply scope, spare parts, technical documents, inspection and acceptance, packing, transportation, storage, installation, operation and maintenance for the small hydropower (SHP) excitation system.

This Document applies to the synchronous machine excitation system.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEEE Std 421.1 *Standard Definitions for Excitation Systems for Synchronous Machines*

IEEE Std 421.2 *IEEE Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control Systems*

IEEE Std 421.3 *High potential test requirements for excitation systems for synchronous machines*

IEEE 421.4 *IEEE Guide for the preparation of excitation system specifications*

IEEE Std 421.5 *IEEE Recommended Practice for Excitation System Models for Power System Stability Studies*

IEC 60034-16 *Excitation Systems for Synchronous Machines*

IEC 60529 *Classification of Degrees of Protection Provided by Enclosures*

SHP/TG 001 *Technical guidelines for the development of small hydropower plants —Terms and definitions.*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEEE Std 421.1, IEEE Std 421.2, IEEE Std 421.5, IEC 60034-16, IEC 60529, SHP/TG 001 and the following apply.

3.1

static excitation system

excitation system employing the static excitation power unit

3.2

brushless excitation system

excitation system employing the excitation power unit operated by an alternator-rectifier exciter with rotating rectifiers

3.3 excitation regulator

device used to realize the real-time closed-loop regulation of the voltage at the terminals of the synchronous generator, the reactive power, power factor and rotor current according to a certain regulation rule

4 Service conditions

4.1 Environmental conditions

4.1.1 The equipment shall be installed indoors or in weather-protected locations, shall be used in the environment with clean air and without explosive risk; and there shall be no gas or conductive dust which could corrode the metal and damage the insulation in the ambient air.

4.1.2 The altitude shall not exceed 2 500 m. When the equipment is used in places with an altitude over 2 500 m, the reduction of the dielectric properties and the decrease of the air cooling effect shall be considered, hence the user shall negotiate with the supplier.

4.1.3 The ambient temperature for the excitation equipment shall be:

- a) The indoor ambient temperature 5°C shall be -5°C to 40°C;
- b) The storage temperature shall be -15°C to 40°C;
- c) The daily average value of the ambient temperature shall not be higher than 35°C.

NOTE If the indoor ambient temperature exceeds the aforesaid range, the user shall declare this to or negotiate with the supplier.

4.1.4 The monthly average maximum relative humidity of the service site shall not be higher than 90% (without condensation) in the wettest month, meanwhile the monthly average minimum temperature shall not be higher than 25°C in the same month.

4.1.5 Dustproof measures shall be considered for the system equipment according to the different installation sites; temporary protection measures shall be taken especially at the initial stage of the construction and when the local control unit is put into operation in phases. The reference values for the dust parameters on the service site of the equipment shall be that the quantity of dust with grain size bigger than 0.5 μ shall be less than 18 000 grains/L.

4.1.6 The system equipment shall be able to bear the following vibration:

- a) The acceleration shall not be more than 10 m/s² when the vibration frequency is in the range of 10 Hz to 500 Hz;
- b) Special considerations shall be given for the equipment structure when the equipment is used in earthquake-prone regions.

4.2 Power supply conditions

Within the following power supply voltage and frequency range, the static rectifier excitation system and devices shall be able to ensure that the generator could operate continuously and stably for a long term under the rated working conditions;

- a) For AC 380(415)/220 V system, the allowable deviation of the voltage shall be -15% to +10% of the rated value and the allowable deviation of the frequency shall be $\pm 10\%$;
- b) For the DC 220/110 V system, the allowable deviation of the voltage shall be -15% to +10% of the rated value.

4.3 Other conditions

Other special service conditions shall be determined by the supplier and the user through negotiation.

5 Technical requirements

5.1 Performance requirements

5.1.1 Long-term load capacity

When the field voltage and current of the generator are not greater than 110% of its rated field voltage and current, the excitation system shall be able to operate continuously.

5.1.2 Field forcing voltage and current amplification

The field forcing voltage and current amplification of the excitation system shall be considered as per the following situation:

- a) For the unit with a capacity less than 5 MW or the brushless excitation system, it should not be less than 1.5;
- b) For the excitation system of the unit with a capacity of 5 MW to 10 MW, it should not be less than 1.8;
- c) The special requirements, if any, shall be determined by the supplier and the user through negotiation.

5.1.3 Allowable field forcing time

The allowable field forcing shall not be less than for 10 sec. duration nor more than for 50 sec. duration.

5.1.4 Voltage response time

With regard to the voltage response time of the excitation system, the rise time shall not be more than 0.1 s and the drop time shall not be more than 0.15 s.

5.1.5 Voltage regulation accuracy

The excitation system shall ensure that the regulation accuracy of the terminal voltage of the generator is higher than $\pm 1\%$ (for the unit with a capacity more than 5 MW), $\pm 2.5\%$ (for the unit with a capacity of 0.5 MW to 5 MW) or $\pm 5\%$ (for the unit with a capacity less than 0.5 MW).

5.1.6 Voltage regulation ratio

The excitation system shall ensure that the voltage regulation setting of the generator terminals is $\pm 10\%$, the range is not more than 1% and the regulation characteristic has favourable linearity.

5.1.7 Frequency voltage characteristics

The excitation system shall ensure that the allowable variation of the generator voltage is $\pm 0.5\%$ of the rated value whenever the frequency value changes by 1% under the no-load operation condition of the generator.

5.1.8 No-load voltage regulation range

The excitation regulator shall ensure that the voltage could be stably and smoothly regulated within the range of 30% to 110% of the no-load voltage.

5.1.9 Pre-set voltage variation rate

The variation rate of the voltage pre-set value shall not be higher than $(1\% U_N)/s$ nor lower than $(0.3\% U_N)/s$.

5.1.10 Transient voltage regulation ratio and voltage recovery time

Transient voltage regulation ratio and voltage recovery time of the excitation system shall meet the following requirements (Low-voltage units: the rated voltage of the generator is 690 V and below; High-voltage units: the rated voltage of the generator is more than 690 V):

- a) Sudden load rejection: The transient voltage amplification (overshoot) under the sudden rejection rated load of the turbine generator at the rated power factor is that, 20% for the low-voltage units; not more than 15% of the rated value for the high-voltage units; the frequency of oscillation shall not be more than three times and the regulation time shall not be more than 5 s;
- b) Sudden load increase: When the rated reactive load is suddenly applied to the turbine generator, the transient voltage is that, -20% of the rated value for the low-voltage units; -15% of the rated value for the high-voltage units;
- c) The voltage recovery time after the sudden load changes shall correspond to two types of transient voltage increase or decrease as specified in a) and b) and shall not be more than 1.5 s and 2.5 s respectively;
- d) Step response: When the high-voltage generator is under no-load condition and the step response is $\pm 10\%$, the voltage overshoot shall not be more than 50% of the step amount, the oscillation shall not be more than twice and the regulation time shall not be more than 3 s;
- e) Voltage build-up from zero: If the excitation system is suddenly put into operation so that the terminal voltage of the turbine generator rises up from zero to the rated value when the turbine generator is operating under the no-load condition and the rotation speed is within the range of (0.95 to 1.05) of the rated speed, the voltage overshoot shall not be more than 10% of the rated voltage, the frequency of oscillation shall not be more than three times and the regulation time shall not be more than 5 s.

5.1.11 Normal working conditions

The excitation system shall be able to function properly under the following power supply conditions:

- a) Voltage range: The excitation system shall be able to maintain normal functioning when the fluctuation range of the AC operating power supply voltage of the excitation system is 70% to 130% within a short time (not exceeding the duration of the field forcing); the standby operating power supply shall be used to

ensure that the aforesaid requirement is met when the operating voltage fluctuation exceeds the aforesaid range;

- b) Frequency range: The excitation system shall be able to maintain normal functioning when the frequency at the terminals of the generator is within the range of 45 Hz to 70 Hz.

5.1.12 Rotor overvoltage limiter

The excitation system shall be designed with consideration given to the overvoltage in the excitation circuit of the generator rotor and to ensure that the instantaneous value at the outgoing terminal of the magnetic field winding shall not be more than 65% of the test voltage peak specified in 5.1.16.

5.1.13 Excitation initiating

Excitation initiating methods include the excitation initiating with the residual voltage and the excitation initiating by separate excitation:

- a) Excitation initiating with the residual voltage: The excitation shall be reliably initiated when the voltage at the generator terminals is greater than 2% of the rated value;
- b) Excitation initiating by separate excitation: The capacity of the excitation initiating power supply employing the static rectifier excitation shall not be greater than 10% of the no-load excitation current of the turbine generator.

5.1.14 De-excitation

Except for the excitation system for the small turbine generator which realizes de-excitation by shutting down, the other excitation systems shall have the de-excitation capacity and ensure reliable de-excitation.

5.1.15 Noise requirements

With regard to the excitation equipment (excluding the rotating exciter) employing forced cooling, the noise value per cabinet (sound power level at the position 1 m from the cabinet) shall not be greater than 80 dB (A).

5.1.16 Withstand voltage test

The electric circuits of the excitation system shall be able to sustain the withstand voltage test without impairing the insulation.

With regard to the electric circuit (except for the rotating electrical machinery) directly connected to the magnetic field winding or through the rectifier, the test voltage shall be 10 times the rated field voltage but shall not be less than 1 500 V when the rated field voltage of the turbine generator is 500 V or lower.

With regard to the electric circuit not directly connected to the magnetic field winding, the test voltage shall be 1 000 V when the rated voltage is 60 V or lower, and shall be 2 times the rated voltage plus 1 000 V but shall not be less than 1 500 V when the rated voltage is higher than 60 V.

The test voltage for on-site acceptance of the hydropower station shall be 75% of the specified test voltage; the repeatable and repaired test voltage shall be 65% of the specified test voltage.

The test voltage shall be an effective value of the power frequency alternating current sine wave. Its wave form should be close to the sine wave and the test time is 60 s.

5.1.17 Grounding terminal

The metal structure of the self-contained excitation system shall be fitted with the grounding terminal, and legibly marked with the symbol \oplus . The grounding terminal shall not be used for other purposes.

5.2 System function requirements

5.2.1 Excitation regulator shall have the following basic functions:

- a) The unit with a capacity of more than 5 MW may have two regulation channels which may be double automatic channels or one automatic channel plus one manual channel for the redundancy of the equipment;
- b) Two regulation channels shall be mutually standby and be traceable for each other, and could be switched over automatically and manually. When switching, the voltage at the terminals of the turbine generator or the reactive power has no obvious fluctuation;
- c) Function of communicating with the host computer. The microcomputer-based excitation regulator shall have the function of communicating with the host computer. The communication may be realized with the point-to-point method;
- d) Local and remote operation function;
- e) Over-excitation limiting function;
- f) Under-excitation limiting function;
- g) V/F limiting function (optional);
- h) Difference regulation function;
- i) Manual/automatic excitation switch-on function;
- j) Grid voltage trace function;
- k) Capable of meeting the basic requirements of the monitoring system;
- l) PSS function (optional);
- m) Provide for VAR or PF Control System for the microcomputer-based excitation regulator (optional).

5.2.2 Power rectifier of the excitation system shall have the following functions:

- a) Cooling fan has the functions of automatic switching and alarm in case of wind stop;
- b) Fuse failure alarm function of the fast acting fuse;
- c) Pulse vanishing detection and alarm function.

5.2.3 De-excitation equipment shall be designed as per the following requirements:

- a) Linear de-excitation should be used for the unit with a capacity of less than 5 MW or with an excitation current of less than 500 A;
- b) The excitation system shall provide the connection point for shunt tripping the circuit breaker at the outlet of the turbine generator when the de-excitation switch trips off by mistake in the grid-connected operation process.

5.2.4 Rotor overvoltage protection shall be designed as per the following conditions:

- a) The unit with a capacity more than 5 MW or with an excitation current of more than 300 A shall be provided with the excitation winding overvoltage protection;
- b) The overvoltage protection for the electronic jumper with the single branch shall not be connected to the fuse in series.

5.2.5 The main detection functions shall include: detection of the trigger pulse, detection of the synchronous circuit of the excitation regulator, detection of the Voltage Transformer disconnection, detection of the fast acting fuse of the power rectifier and detection of the fault of the regulation channel.

5.2.6 The excitation system shall be able to output the following signals:

- a) Loss or fault of the regulated power supply for the regulator;
- b) Fault of the regulator channel;
- c) Loss of the power supply for the operation control circuit of the excitation system;
- d) Fault of the power rectifier cabinet;
- e) Action of excitation limiter;
- f) TV disconnection.

5.2.7 The excitation system shall have the functions of indicating the excitation current, field voltage and voltage at the terminals of the generator.

5.3 Other technical requirements

5.3.1 Exciting transformer shall meet the following requirements:

- a) The automatic switch or the fast acting fuse shall not be installed on the high voltage side of the exciting transformer;
- b) The asymmetry of the three-phase voltage of the exciting transformer shall not be more than 5%;
- c) Shielding and grounding shall be applied between the primary and the secondary windings;
- d) The short circuit impedance of the exciting transformer should be within the range of 4% to 8%;
- e) The wiring group of the three-phase exciting transformer should be of Y/d mode;

5.3.2 The voltage transformer and the current transformer shall meet the operating requirements of the excitation system and the accuracy level shall not be lower than 0.5.

5.3.3 The protection level of the excitation equipment is:

- a) The protection level of the excitation regulator cabinet shall be higher than IP30;
- b) The protection level of the excitation power rectifier cabinet shall be higher than IP20;
- c) The protection level provided by the enclosure of the exciting transformer (indoor installation) shall be higher than IP20.

6 Supply scope and spare parts

6.1 Supply scope

6.1.1 Excitation device should include the regulation control, power rectification and de-excitation protection units or loops.

6.1.2 Other equipment within the supply scope shall be determined by the supplier and the user according to the order requirements.

6.2 Spare parts

The supplier shall provide the necessary spare parts for the damageable components, among which the quantity of spare parts for the power rectifier components and the fast acting fuses shall not be less than 30% of the usage amount; the supply scope and the quantity of other spare parts shall be determined by the supplier and the user through negotiation.

7 Technical documents

The supplier shall submit the necessary technical documents to the user; the contents, quantity and delivery time shall be determined by the supplier and the user through negotiation. The attached technical documents include the following contents:

- a) Technical specification;
- b) Operation instruction;
- c) Delivery test report and the compliance certificate;
- d) Unit and the overall debugging outlines;
- e) System schematic and the operation schematic diagram;
- f) List of the main parts and the wiring diagram of the panel/cabinet;
- g) Outside view and the installation drawing of the equipment;
- h) Delivery list;
- i) Technical data of the sub-contracted products;
- g) Other necessary technical data for the installation, operation and maintenance;

8 Tests

8.1 Delivery test

The following delivery tests shall be carried out as follows. The product could be delivered only after passing the tests.

8.1.1 Standard test items

See Table 1 for the standard test items.

8.1.2 Other test items

Other test items shall be determined by the supplier and the user through negotiation.

8.2 Site tests

8.2.1 Standard test items

The contents specified in this document (see Table 1).

8.2.2 Other test items

Other test items shall be determined by the supplier and the user through negotiation.

8.3 Type tests

With regard to the new trial-produced excitation equipment or the finalized excitation equipment, the type test shall be carried out for the excitation system when the process or the key component (or material) changes might influence the product performance. The type test items include:

- a) Measurement of the ceiling voltage amplification, response ratio and response time of the excitation system;
- b) Measurement of the voltage setting range at the terminals of the synchronous generator;
- c) Measurement of the steady-state voltage regulation ratio;
- d) Measurement of the voltage regulation ratio;
- e) Measurement of the adjustment range of the manual control unit;
- f) Test of the sudden load increase and the sudden load rejection;
- g) Test of the automatic/manual switching;
- h) Test of the rated voltage establishment;
- i) Test of the excitation system operation and the operational reliability when the DC, AC voltage and frequency for control vary within the specified range;
- j) De-excitation test;
- k) Test of the rated current of the rectifying installation;
- l) Measurement of the excitation equipment noise;
- m) Maximum and minimum ambient temperature test;
- n) Trial operation test;
- o) All the delivery test items.

Table 1 Factory inspection and on-site acceptance test items

S/N	Test items	Factory inspection	On-site acceptance
1	Test of the exciting transformer	√	√
2	Test of the magnetic field circuit breaker	√	√
3	Test of the power rectifier	√	√
4	Test of the nonlinear resistance	√	
5	Test of the silicon controlled jumper	√	√
6	Insulation measurement and dielectric test of the various components of the excitation system	√	√
7	Test of the basic units and the auxiliary units of the automatic exciting regulator	√	
8	Total static characteristic test of the automatic exciting regulator	√	√
9	Loop tests for the operation, protection, monitoring, signal and port of the excitation system	√	√
10	Test of the excitation initiating, pressure rise, pressure drop and conversion field depression characteristics		√
11	Measurement of the voltage setting range and the pre-set voltage variation speed in the various regulating channels of the automatic exciting regulator		√
12	Measurement and recording of the generator voltage-frequency characteristics with the automatic exciting regulator		√
13	Switching test of the automatic/manual modes and the two sets of the automatic regulation channels	√	√
14	Test of the regulating range of the manual control unit	√	√
15	5% or 10% step response tests under the no-load condition of the generator		√
16	Detection of the cooling system for the rectified power cabinet	√	√
17	Noise test	√	√
18	Current sharing test of the power unit for the excitation system	√	√
19	Measurement of the generator voltage regulation ratio with the automatic exciting regulator		√
20	Test of the reactive load adjustment and the load rejection of the generator		√
21	De-excitation test of the generator under the no-load and the rated working conditions		√
22	Detection of the temperature rise for all the parts of the excitation system		√
23	Setting and action correctness tests for the auxiliary function units and the protection/detection units	√	√
24	12hrs continuous current test of the excitation device under the low voltage and high current condition	√	
25	72hrs continuous trial operation of the excitation system under the rated working condition		√

9 Nameplate, packing, transportation and storage

9.1 Nameplate

The materials and engraving method of the nameplates shall ensure that the texts are not obliterated during the entire service period and the nameplate shall contain the following items:

Supplier name, equipment name and equipment model; rated output voltage and rated output current; operating control power supply; product number and delivery time.

9.2 Packing

9.2.1 The packing shall be determined by the supplier and the user through negotiation. Special requirements of the equipment, if any, shall be marked on the packing container.

9.2.2 The product shall have internal packing and external packing containers, the plug-in box shall be firmly locked and fastened, the packing container shall be fitted with the dustproof, rainproof and anti-vibration measures, and shall be provided with the hoisting facility and marks.

9.2.3 The inspections of the product before packing mainly include:

- a) Whether the accessories, spare parts, compliance certificate and relevant technical documents of the product are complete;
- b) Whether the product appearance gets damaged;
- c) Whether there is dust on the product surface.

9.2.4 The packing of the products for export shall comply with the provisions of the relevant national inspection and quarantine regulations.

9.2.5 The packing guarantee time shall not exceed 12 months from the delivery date.

9.3 Transportation

The supplier and the user shall specify the transportation tools suitable for the equipment and the requirements in the transportation process. The transportation and handling shall be carried out according to the marks on the packing containers.

9.4 Storage

9.4.1 The products shall be stored in the dust-free and rainproof warehouses with ambient temperature of -25°C to +55°C, relative humidity of not more than 85% and without acid, alkali, salt and corrosive or explosive gases or strong electromagnetic field.

9.4.2 From the date of delivery by the supplier, the supplier shall guarantee that the products are free from corrosion and accuracy reduction due to improper packing within 12 months under the storage conditions specified in 4.1.

10 Installation, operation and maintenance

10.1 Installation

The product shall be installed by the experienced and well-qualified competent professionals.

10.2 Operation and maintenance

Before going into formal operation, the relevant tests shall be carried out, and the specified requirements shall be met.

The operation and maintenance shall comply with the provisions of the normative references, the installation, use and maintenance instructions provided by the supplier as well as the relevant operation specifications for the hydropower station.

The supplier shall provide the technical support for solving the problems occurring in the installation, use and maintenance process for the equipment, and shall train the user's personnel on the aspects of the equipment installation, use and maintenance.

11 Quality guarantee period

Under the premise that the product is properly stored, installed and used, the product quality guarantee period shall be one year after the date on which the 72 hour trial operation is completed, or two years after the delivery date of the last batch of goods, whichever comes earlier. If the equipment gets damaged or is unable to function properly due to the manufacturing quality during the quality guarantee period, the supplier shall repair or replace it free of charge.



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