

STANDARDS/MANUALS/ GUIDE LINES FOR SMALL HYDRO DEVELOPMENT

3.12 **Electro-Mechanical–** **Erection, Testing and Commissioning**

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The data, information, drawings, charts used in this standard/manual/guideline has been drawn and also obtained from different sources. Every care has been taken to ensure that the data is correct, consistent and complete as far as possible.

The constraints of time and resources available to this nature of assignment, however do not preclude the possibility of errors, omissions etc. in the data and consequently in the report preparation.

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AHEC-IITR, "3.12 Electro Mechanical: Erection, testing and commissioning", standard/manual/guideline with support from Ministry of New and Renewable Energy, Roorkee, December 2012.

PREAMBLE

There are series of standards, guidelines and manuals on electrical, electromechanical aspects of moving machines and hydro power from Bureau of Indian Standards (BIS), Rural Electrification Corporation Ltd (REC), Central Electricity Authority (CEA), Central Board of Irrigation & Power (CBIP), International Electromechanical Commission (IEC), International Electrical and Electronics Engineers (IEEE), American Society of Mechanical Engineers (ASME) and others. Most of these have been developed keeping in view the large water resources/ hydropower projects. Use of the standards/guidelines/manuals is voluntary at the moment. Small scale hydropower projects are to be developed in a cost effective manner with quality and reliability. Therefore a need to develop and make available the standards and guidelines specifically developed for small scale projects was felt.

Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee initiated an exercise of developing series of standards/guidelines/manuals specifically for small scale hydropower projects with the sponsorship of Ministry of New and Renewable Energy, Government of India in 2006. The available relevant standards / guidelines / manuals were revisited to adapt suitably for small scale hydro projects. These have been prepared by the experts in respective fields. Wide consultations were held with all stake holders covering government agencies, government and private developers, equipment manufacturers, consultants, financial institutions, regulators and others through web, mail and meetings. After taking into consideration the comments received and discussions held with the lead experts, the series of standards/guidelines/manuals are prepared and presented in this publication.

The experts have drawn some text and figures from existing standards, manuals, publications and reports. Attempts have been made to give suitable reference and credit. However, the possibility of some omission due to oversight cannot be ruled out. These can be incorporated in our subsequent editions.

This series of standards / manuals / guidelines are the first edition. We request users to send their views / comments on the contents and utilization to enable us to review for further upgradation.

Standards/ Manuals/Guidelines series for Small Hydropower Development

General	
1.1	Small hydropower definitions and glossary of terms, list and scope of different Indian and international standards/guidelines/manuals
1.2 Part I	Planning of the projects on existing dams, Barrages, Weirs
1.2 Part II	Planning of the Projects on Canal falls and Lock Structures.
1.2 Part III	Planning of the Run-of-River Projects
1.3	Project hydrology and installed capacity
1.4	Reports preparation: reconnaissance, pre-feasibility, feasibility, detailed project report, as built report
1.5	Project cost estimation
1.6	Economic & Financial Analysis and Tariff Determination
1.7	Model Contract for Execution and Supplies of Civil and E&M Works
1.8	Project Management of Small Hydroelectric Projects
1.9	Environment Impact Assessment
1.10	Performance evaluation of Small Hydro Power plants
1.11	Renovation, modernization and uprating
1.12	Site Investigations
Civil works	
2.1	Layouts of SHP projects
2.2	Hydraulic design
2.3	Structural design
2.4	Maintenance of civil works (including hydro-mechanical)
2.5	Technical specifications for Hydro Mechanical Works
Electro Mechanical works	
3.1	Selection of Turbine and Governing System
3.2	Selection of Generators and Excitation Systems
3.3	Design of Switchyard and Selection of Equipment, Main SLD and Layout
3.4	Monitoring, control, protection and automation
3.5	Design of Auxiliary Systems and Selection of Equipments
3.6	Technical Specifications for Procurement of Generating Equipment
3.7	Technical Specifications for Procurement of Auxiliaries
3.8	Technical Specifications for Procurement and Installation of Switchyard Equipment
3.9	Technical Specifications for monitoring, control and protection
3.10	Power Evacuation and Inter connection with Grid
3.11	operation and maintenance of power plant
3.12	Erection Testing and Commissioning

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ERECTION, TESTING AND COMMISSIONING

1.0 GENERAL

1.1 SCOPE

Erection, setting, adjustment, centering and alignment of hydro generating unit is a very complicated and specialized job. This has to be carried by expert and experienced team of engineers, technicians and helpers.

This document has been prepared with intent to provide guide lines to SHP Owner's Supervisory Engineers, Erector's team carrying out erection, testing and commissioning of either horizontal or vertical machines up to 25 MW capacity.

The guide covers planning, pre-erection activities, erection sequence of both horizontal and vertical machine, pre-commissioning checks, commissioning checks and tests.

The erection procedures though explained quite in detail but as hydro machines are tailor made, the procedure may differ for a particular machine which has to be obtained from the manufacturer.

1.2 REFERENCE

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|----|-----------------------|--|
| R1 | IEEE: 1248, 1998 | IEEE Guide for commissioning of Electrical systems in Hydro-electrical Power Plants |
| R2 | IEC: 545, 1976 | Guide for commissioning, operation and maintenance of Hydraulic Turbines |
| R3 | Guide 5.2, NEMA, 1989 | Installation of Vertical Hydraulic Turbine – Driven Generator & Reversible G/M for Pumped Storage Installation |
| R4 | Gonchrov A N, 1975 | Hydro Power Station – Generating Equipment and its Installation, Energia Moscova-1972(translated from Russian under Israel programme for scientific translation, Jruslum |
| R5 | FIST USBR Vol3-8-2011 | Field test procedure of protective Relays |

ABBREVIATIONS

- IEC : International Electro-technical Commission
IEEE : Institute of Electrical & Electronic Engineers
FIST : Facilities Instructions, Standards And Techniques, Bureau of Reclamation, USA http://www.usbr.gov/power/data/fist_pub.html
NEMA: National Electrical Manufacturer's Association

2.0 ERECTION OF GENERATING UNIT

2.1 PLANNING OF ERECTION OF A HYDROPOWER PLANT

The entire process of erection, testing and commissioning may be divided into three main categories:

- (i) Pre-erection activities to be completed before starting of erection of the plant.
- (ii) Erection of built in parts of the plant.
- (iii) Erection of main operating components of hydro set.

2.1.1 Pre-erection Activities Mainly Cover Following

- (i) Preparation of a plan to carry out erection work and sequence of different activities.
- (ii) Preparation for site storage consisting of open, closed, semi closed storage and construction of roads, accesses for delivery of plant to assembly area.
- (iii) Methods of preservation during storage to be provided by the manufacturer.
- (iv) Erection of temporary structures, living quarters necessary for carrying out site work smoothly and speedily.
- (v) Site office facility- temporary/ permanent.
- (vi) Arrangement of construction power, water, compressed air for the erection activities. DG sets of adequate capacity to be kept as stand by in case of power failure.
- (vii) Arrangement of lighting of erection site and nearby area.
- (viii) Typical setting of various equipment received in power house in erection bay is shown in Fig 1
- (ix) Ensuring sequential delivery of equipment and materials necessary for continuity of erection work as per charts and plan.
- (x) Providing hoisting arrangement, handling mechanisms, tools and devices for erection as also making arrangement of transportation of material to the site. The material will be unloaded in unloading bay and shifted to pre identified place.
- (xi) Arrangement of safety measures protection of workers and equipment during handling, shifting and installing different components of plant.
- (xii) Arrangement of first aid and health checkups for workers.
- (xiii) The contractor shall institute a health, safety and environment management system for his operations. Such system shall identify the health and safety aspects of contractors activities and provide for the monitoring of the health and safety performance.

2.1.2 Erection of built in Turbine Parts

Erection of these items starts as soon as the underwater concrete structure has reached the required elevation below the lining of draft tube cone. At this stage permanent crane is not available as such temporary gantry crane has to be installed whose lifting capacity, travel upward, downward, forward and backward is decided by the size and weight of heaviest and largest part to be handled by the crane.

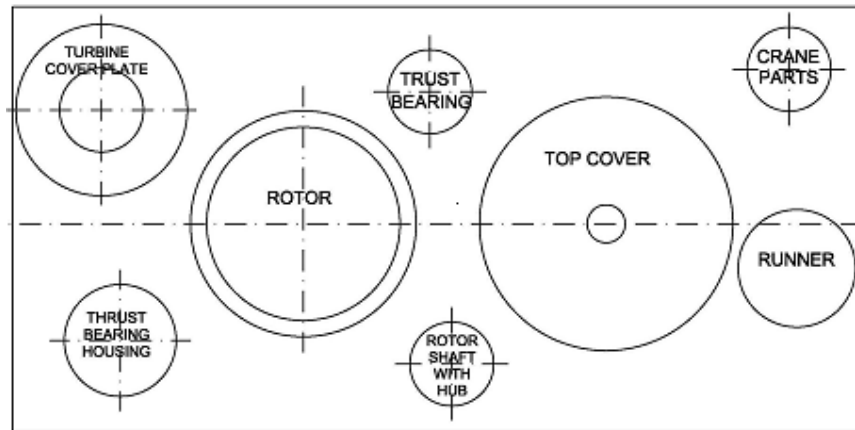


Fig 1 : Layout of Erection bay

2.1.3 Erection of Main Operating Components

Erection of main components of unit is started only after permanent crane is made available. As such civil works are planned in such a way that availability of main crane matches with the start of assembly and erection of main plant.

2.1.4 Planning

Erection work is usually planned in two stages

First stage

- (i) In first stage a well coordinated overall plan for construction of civil activities and activities related to erection of hydro mechanical items and hydro generating units is prepared.
- (ii) A PERT/CPM is to be developed for monitoring of ongoing activities and critical activities to avoid any slippage of schedule

Second stage

This is the detailed planning stage and it should include following information concerning erection of main equipment.

- (i) The amount of installation works to be completed by months according to overall coordinated construction schedule of the project.
- (ii) Major activity wise PERTs are developed showing sequence and duration of activities matching with delivery schedule and civil construction activities for monitoring by the in-charge of erection works. This should give sequence and duration of all critical as well as parallel activities for completion of erection work as per overall schedule. The in-charge should have following important information with him
 - a. The technological process of assembling and erection of unit.
 - b. Requirement as regards workers, engineers, and technicians.
 - c. Basic material and their expected deliveries to the site.

- d. The technical features of main equipment, weight and size of parts and subassemblies.
- e. Plan for labor requirement and their movement.
- f. All relevant plan, assembly and erection drawings
- g. Requirement of hoisting, requirement of each part, subassembly and assemblies.
- h. Requirement of tools, material equipment, electrical energy, compressed air.
- i. Requirement of special tools devices essential for erection work.
- j. Requirement and arrangement of safety and industrial health measures.
- k. A general layout plan showing location of equipment, dumps, assembly areas, temporary structures for erection activities etc in erection bay is shown in Fig 1.

2.1.5 Recording of Erection Work and Technical Evaluation

A record of the work carried out must be kept during erection. This record should contain

- (i) Brief technical details of equipment with the name of supplier.
- (ii) Descriptions of the main stages of work and date when started and finished.
- (iii) Records of shortcomings in the equipment noticed during erection and of the action taken.
- (iv) Records of shape checking and other log sheets recorded during erection works.
- (v) Records of quality checks during erection works as per QAP to be signed by Owner's Erector's representatives.
- (vi) All instructions passed on to the technicians during process of progress of erection work.(Separate instruction register to be maintained)
- (vii) Alterations, deviation made in various erection drawings during progress of erection work after completion of the contractor to submit as built/ as made drawings.
- (viii) Photographs of various important erection activities with dates for visual records of progress.
- (ix) Sketches and drawings of innovative techniques, tools or devices used during erection work with material details.

The technical evaluation of erection of main equipment is compiled from the original documentation for each generating set separately after it has been put in service. The evaluation must indicate the conditions, process of erection accompanied by explanatory records with diagrams and photographs. The explanatory records should contain following

- (i) Brief power and design characteristics of the equipment with data.
- (ii) Data on the weights of generating set, separate mechanisms, sub assemblies and main parts.
- (iii) Remarks concerning completeness of equipment supplied.
- (iv) Shortage and short comings list. Master shipping list to be given by Supplier to ascertain shortages in different packages received at site
- (v) Availability and quality of manufacturers' technical documentation, plans for installing of equipments etc.
- (vi) Details of hoisting devices, innovative devices used during erection.
- (vii) Technological processes used during erection (planned actual).

- (viii) Description of new advanced work procedures used during erection.
- (ix) The nature of simultaneous construction and erection work.
- (x) Number of engineers, technicians and workers employed during various assembly and erection activities (total and by qualification).
- (xi) A summary of manufacturing defects in the equipment, the amount of work and cost involved in action taken.
- (xii) A summary of cost in installing each hydro set.
- (xiii) Measured operating characteristics of generating set (power, governor response) during acceptance test when the equipment is put into operation.
- (xiv) General conclusion in installing of the hydro generating set in the plant.
- (xv) Drawings of generating set (sections) charts of installation work (directive and performance) photographs and plans of typical operations during assembly and erection.
- (xvi) Sketches and drawings of innovative tools and devices for assembly and erection of generating set.

2.2 ERECTION OF HORIZONTAL HYDRO GENERATING UNIT

Mainly two types of horizontal generating units are used these days:

- (i) Units with turbines having spiral casing.
- (ii) Tubular /Bulb type units

There may be other variations also but this guide will be confined to deal with erection of these two types of hydro units.

2.2.1 Erection of Horizontal Hydro Units with Spiral Casing

2.2.1.1 Erection of hydro turbine

The procedure of installation is as described below:

2.2.1.1.1 Spiral casing

- (i) Principal axis of the generating set are fixed by reliably secured brackets and bench marks
- (ii) The perpendicular position of each component is checked by stretching piano wires along the principal axis.
- (iii) Then proper positioning of spiral casing is done. As this is the base part of generating unit its correct positioning will determine the correct installation of entire generating set.
- (iv) Spiral casing is normally received in two parts and assembled & positioned at site.
 - (a) Lower half is installed and adjusted on beams embedded in concrete in advance.
 - (b) Then upper half is placed on it and secured.
 - (c) Correct position relative to principal axis, elevation & horizontal position relative to turbine cover plate and inlet flange are adjusted. A level or plumb line is used for this.
 - (d) Attention is required in matching centre lines of spiral casing inlet and penstock.

- (e) Once the elevation is adjusted by placing steel blocks beneath its claws, spiral casing is bolted to the supporting beams.

2.2.1.1.2 Turbine bearings

- (i) The housing of turbine bearings should be installed together with their base plates on properly cleaned and leveled surface of foundation.
- (ii) The transverse axis of the bearings are found by measurements from the centre line of spiral casing and are marked on the foundation.
- (iii) Installation of bearings is done in accordance with these marks.
- (iv) Their elevation is set by placing metal blocks beneath base plates.
- (v) The alignment of bearings and coincidence of their centre line with longitudinal axis of generator are checked by stretching piano wire through spiral casing along the bearing centre line centering of horizontal piano wire in spiral casing is checked by micrometers.
- (vi) The bearing housings are centered relative to the longitudinal axis of generating set with an end gauge inserted in the bores for the bearing shells.
- (vii) After checking of bearing housings, the foundation bolts are secured in their recesses so that they are located vertically in the centers of holes in base plates and should not move during concreting.
- (viii) The foundation bolts are then grouted
- (ix) The supporting beams of spiral casing and draft tube are also concreted, if not done earlier.

2.2.1.1.3 Guide apparatus

- (i) Trial assembly of guide vanes may be done in its design position.
- (ii) Insert bushings in the turbine cover plates and bolt them provisionally.
- (iii) The outer ring of labyrinth is mounted on the front cover plate.
- (iv) Then this cover plate is placed in position and bolted and secured.
- (v) The joint between cover plate and scroll casing is sealed with rubber cord.
- (vi) All the guide vanes are then installed in closed position of guide apparatus.
- (vii) Rear cover plate is mounted and sealed in the same way as front one, and provisionally secured with bolts.
- (viii) The clearance between guide vane ends and turbine cover plates must be uniform on both sides and total should be as per drawing.
- (ix) These are checked by feeler gauges and adjusted by tightening bolts of bushing flanges.
- (x) There should be no clearance between guide vane to guide vane when closed position.
- (xi) The levers and regulating ring is then installed. The levers are fixed to G.V. pivots by dowel pins.
- (xii) The guide vanes are turned through regulating ring to fully open position and width between each pair of vanes are measured in this position.
- (xiii) The governor lever support is installed and regulating ring is connected to servomotor rod via an adjusting rod and levers after the governor has been placed in position.
- (xiv) After satisfactory completion of guide apparatus assembly and checking the guide vane bushes are properly secured by bolts/ dowels.

2.2.1.1.4 Runner & shaft

- (i) The turbine shaft is mounted on the bearing shells together with the fly wheel which is already mounted in service bay.
- (ii) With the help of special handling device (supplied by manufacturer) the runner is mounted on the shaft by pulling through rear turbine cover plate.
- (iii) The centering of shaft relative to labyrinths is checked by end gauge before mounting of runner to avoid any damage to static labyrinth.
- (iv) The runner is secured to the shaft by a nut of special design in such a way that it does not become slack.

2.2.1.1.5 Checking & centering of rotating parts

- (i) Measure clearance between shaft and lower bearing shell with a feeler gauge. Absence of clearance indicates the shaft is resting fully on both bearings
- (ii) The horizontal position of the rotating turbine parts is then checked with a level placed successively on both bearing journals.
- (iii) The results thus obtained are checked by turning the level through 180° placing it at exactly the same points as before and repeating the measurements. The mean of two measurements should not be more than one scale division. The permissible inclination of shaft should be as per drawing in mm/m length of shaft.
- (iv) The transverse position of the bearing housings are checked at same time with level. This permissible inclination in transverse direction should be as per drawing in mm/m length of shaft.
- (v) The radial clearances between the runner and the turbine cover plates and the gaps between static & rotating labyrinths (which should not exceed values given by the manufacturer) are checked.
- (vi) The axial play of rotating turbine parts is also checked through length wise displacement of thrust bearing to its extreme position.
 - (a) The gaps in labyrinth seals should be as per drawing.
 - (b) Axial clearance between thrust collar and the shell should be as per drawing provided by manufacturer.
- (vii) The above checks should be repeated after rotating turbine by 180° and 360°. The measured values should be within permissible limits.
- (viii) The clearance between the turbine shaft and upper bearing shell is checked with a 1 mm thick lead wire of suitable length. The length of these wires is placed across the shaft at two sections beneath the shell which is then tightened well. The thickness of flattened wire indicates the clearance on top of the shaft which should not be more than 2% of shaft diameter.
- (ix) The lateral clearance between shaft and the lower shell are checked with feeler gauge in two sections over the shell length at a depth of 10 mm below the plane in which the bearing is split. These clearances should be one and half of the clearance between upper shell and shaft.
- (x) After installation draft tube cone and its elbow concreting of entire turbine is allowed except for the grouting of bearing base which is allowed after installation of hydro generator and final centering and alignment of the complete unit is carried out.

- (xi) Once the concreting is completed, installation of all service water and air pipes as well as hydraulic brakes acting on fly wheel are carried out.
- (xii) Then Governor is assembled, tested and adjusted. Its elevation, horizontal position, location relative to turbine is adjusted, after which it is secured to the foundation. The governor spindle is fitted and connected to the turbine.
- (xiii) The governor mechanism is then checked for:
 - (a) Turning of manual control mechanism should be smooth.
 - (b) Verify tightness of distributor when closed.
 - (c) Check for absence of backlash in the mechanism of regulation system.
 - (d) Establish maximum opening of the guide vanes.
 - (e) Verify servomotor stroke v/s guide vane opening relation.

2.2.1.2 Erection of horizontal hydro generator

2.2.1.2.1 Erection procedure

These are several options for design & construction of horizontal hydro generator:

- (i) A low capacity hydro generator may have bearings located directly inside generator housing. Such generators are delivered on foundation frame. These are generally below 5 MW capacity.
Such generator which is delivered fully assembled or mounted on a rigid foundation frame are installed as received after alignment and adjustment of its elevation relative to the half coupling of hydro turbine shaft. The foundation bolts are then inserted into their recesses and concreted. The generator is finally aligned with turbine after concrete has set.
- (ii) Large generator is delivered in separate components viz shaft with generator rotor & exciter rotor assembled on it, stator frame, exciter frame and flywheel etc. Such generators are completely assembled in erection bay and provisionally adjusted on foundation frame, after which it is installed, aligned and coupled with turbine. In such cases, the generator assembly area should be neat and clean and provision should be there to minimize ingress of dust and moisture.

Following installation procedure for such generator are usually followed:

- (a) Generator bearing housings are fitted with foundation frame in erection bay. Shims of suitable thickness are inserted between the frame and each bearing housing.
- (b) Foundation frame then is shifted to its position in the unit after the turbine has been installed. The position of the frame is adjusted relative to the axis of generating set with the help of 40 to 50mm high blocks between foundation and frame by the side of foundation bolts.
- (c) The horizontal position of bearing is checked by leveling and alignment is checked with a wire.
- (d) The stator is then placed on the foundation frame and its position relative to bearings is checked. The position of stator is adjusted by using metal shims of suitable thickness. These shims are inserted between stator and foundation frame.

- (e) The wire for checking position of stator should be centered in the bores of bearing shells as regards the elevation and horizontal position. The rear bearing is then removed from the frame
- (f) The rotor is installed together with rear bearing on which generator shaft ends rests while the rotor is inserted into the stator. During this exercise the stator winding and rotor poles are protected against damage by rubber mats of thickness slightly less than width of air gap. This is shown in fig 2

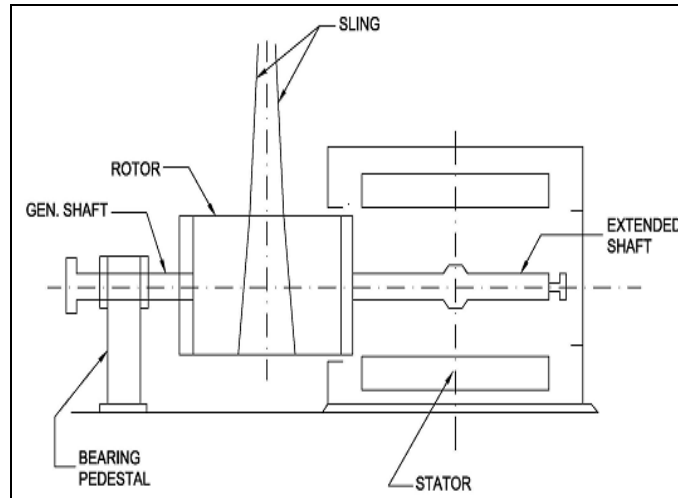


Fig 2 : Installation of Rotor of Horizontal Generator

- (g) Final alignment of the generator is done after installation of exciter. Shims are placed between the claws and generator foundation frame. Exciter is centered relative to half coupling of generator shaft and air gaps.
- (h) If a pilot exciter is provided, it is installed last and aligned with exciter.

2.2.1.2.2 Centering of horizontal hydro generating unit

- (i). This includes adjustment of position of turbine and alignment of generator rotor with it as reference base.
- (ii). Centering the generator set shaft is the final activity in aligning the generator with turbine.
- (iii). Centering the generator involves eliminating any misalignment at the joint between the shafts ensuring the horizontal position of the generator shaft and making its center line coincide with that of the turbine shaft.

Detailed procedure of alignment of horizontal hydro generating unit is given in Annexure 2.

2.2.2 Erection of Horizontal Tubular Generating Unit

2.2.2.1 Features affecting erection sequence & technology

- (i) Horizontal tubular generating set may have a single shaft or separate, each for turbine and generator.

- (ii) All parts have to be installed from above to their design position. It is therefore, necessary to have horizontal joints in all annular parts of the water passage.
- (iii) It should also be possible to remove their upper halves during installation as well as repairs during subsequent years.
- (iv) All turbine parts forming water passage from speed ring to lining of the draft tube cone, are therefore, split horizontally. Only lower halves can be concreted.
- (v) Another alternative is not to concrete even the lower halves in such case supporting structure should be strong enough. This is preferred only for small machines.
- (vi) Installation technology differs greatly depending on whether the annular parts of water passages are concreted or not and also whether there is single shaft or separate shafts for turbine and generator.
- (vii) It is preferred maximum preassembly of parts of generating unit is completed in erection bay. These preassembled components are then lowered in position with the help of EOT crane and proper handling and lifting devices.

2.2.2.2 Installation of tubular generating sets-where parts of its water passages are not concreted

The technology in brief is as under:

- (i) The ring support of speed ring, the lining of draft tube cone, the anchoring structure for tie rods and access column of speed ring are placed in their design positions and concreted in the turbine pit.
- (ii) The front part of the bulb is then lowered in the pit, placed in its design position and provisionally bolted with tie rods, this front part is assembled together with equipment and the bottom half of bearing.
- (iii) The rotor and stator of the generator preassembled in the erection bay with journal bearings, thrust bearing, speed ring and guide vanes are lowered in to the turbine pit and moved towards the head race.
- (iv) The speed ring is bolted to its support ring and generator stator to the front part of bulb.
- (v) The runner is then lowered and connected to the generator shaft. The rotating parts of the unit are centered adjusted and bolted.
- (vi) Then gate ring with its supports, throat ring, foundation ring and other turbine and generator parts are placed in their design position and secured.

2.2.2.3 Installation of tubular generating set with concreted in parts of water passage

This consists of two stages:

2.2.2.3.1 First stage

All built in annular, foundation (supports) parts are placed and adjusted and then concreted. The upper detachable halves of these parts are removed after the concrete has set.

2.2.2.3.1 Second stage

- (i) Lowering pre assembled components and other parts of turbine and generator into position.

- (ii) Centering of all rotating parts of generating set is done
- (iii) All remaining parts and sub assemblies are then placed in position and auxiliary mechanism and pipes also fitted.
- (iv) The previously removed upper halves of annular parts are again assembled and secured.

2.2.2.4 Instructions for pre-assembly in the erection bay

- (i) Annular parts of the generating unit are assembled in horizontal position and then turned to 90° for being erected in the design position.
- (ii) The front part of bulb rests on its flange during assembly and connected to intermediate generator ring. The assembly is then turned into operating position and generator cooling system and other mechanisms are inserted in to it.
- (iii) The throat ring, foundation ring and draft tube cone are assembled on special concrete supports. After assembly, they are turned into operating position, interconnected and prepared for installation.
- (iv) The speed ring is assembled in erection bay in perfectly horizontal position with the flange for distributor on top. The joints of sector which need not to be dismantled are bolted and locked together. Assembly and installation of speed ring needs more attention as it takes and transmits weight of rotating parts of generating set and bulb, axial forces exerted by water and the torque to concrete structure.
- (v) Pre-assembly of distributor (guide vanes etc.) is one of the most complicated and is carried out either on assembly stand or directly on already assembled speed ring. Its cylindricity, concentricity with inner distributor ring, and elevation are carefully checked. Due care must be taken during guide vanes installation. Free guide vanes turn is also checked before bushes & bearings are finally secured. Then levers are fitted to upper guide vane pivots. The assembled distributor must be carefully secured and prepared for installation in the unit in its design position in two halves which are bolted and secured in the design position itself.

2.2.2.5 Pre-assembly of single shaft generating unit

- (i). Turbine runner generator rotor, stator are first assembled separately and then joined together with generating set shaft and other required parts viz. lower half of intermediate ring, generator journal and thrust bearings, rods, oil supply head etc.
- (ii). Turbine runner:
 - (a) It is assembled in vertical position on an installation plate and tested hydraulically.
 - (b) Then it is turned to its operating position and transported to the preassembly site where it is connected to the shaft.
- (iii) Generator rotor:
 - (a) Rotor is received assembled with poles.
 - (b) One of its poles is removed so that rotor can turn and a lifting eye bolt is fitted in to predefined place.
 - (c) The rotor is then turned into vertical position and placed on the installation platform.

- (d) The shaft is also turned in vertical position with its flange on top and thus lowered into the previously heated rotor for shrink fitting.
- (e) The rotor is then turned into horizontal position and the pole removed earlier is again fitted.
- (f) Runner connected to the shaft.
- (g) The stator which is received in two parts is assembled in erection bay in horizontal position.
- (h) The two stator halves are then connected together.

The windings are inserted at the joints and lower half of intermediate ring is attached.

2.2.2.5.1 Pre-assembly

Preassembly of separate parts is done on a special stand equipped with jacks and provisional bearing is shown in Fig 3.

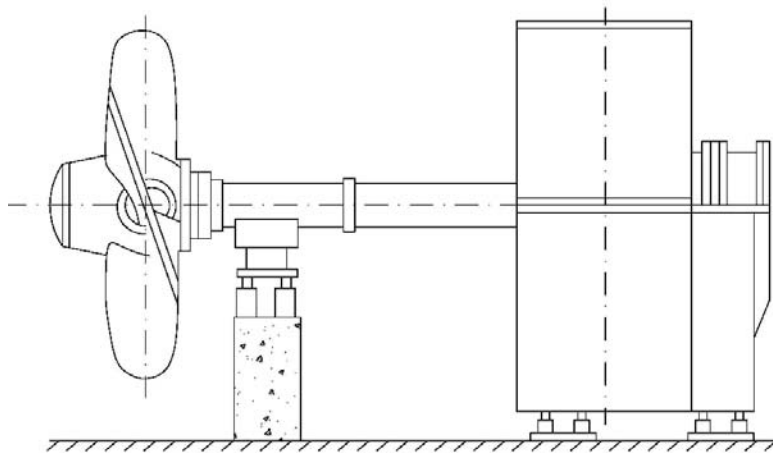


Fig 3 : Pre-assembly in Erection bay

2.2.2.6 Installation of sub-assemblies in design position in the pit of unit

- (i) The foundation parts are first lowered, centered, adjusted, aligned, secured and concreted.
- (ii) Assembled front part of bulb is lowered in the pit in desired position.
- (iii) Assembled speed ring is lowered in position in pit adjusted centered, secured to the support structure already embedded in the pit.
- (iv) The elevation, centering, concentricity relative to its axis, cylindricity are checked by stretching piano wire and dropping plumb lines from transverse axis.
- (v) Lowering of lower half of distributor duly assembled with guide vane and levers etc and connected with speed ring.
- (vi) Then upper half of the distributor gate ring and its support are lowered, adjusted in position, aligned & centered before securing.
- (vii) Subassembly of draft tube cone, foundation ring and throat ring are lowered and positioned and adjusted with adjoining assemblies.
- (viii) Annular parts of water passage are fitted with compensating ring located between gate ring and throat ring.

- (ix) After carrying adjustment and securing all the above assemblies and parts concreting is done.
- (x) Once the concrete is set, upper halves of annular parts are dismantled and removed and shifted to erection bay for installation of turbine, generator and associated parts.
- (xi) The upper half of intermediate generator ring and runner hub extension is lowered into position.
- (xii) The main sub-assembly includes runner, generating set shaft, generator rotor, generator stator, lower half of intermediate ring generator journal & thrust bearings, rods and oil supply header. The sub-assembly is moved horizontally with help of EOT crane and lifting device & slings from erection bay to unit floor opening.
- (xiii) The sub-assembly is supported on temporary columns (already placed) and the lower half of turbine bearing.
- (xiv) The generator stator is then centered and connected to speed ring.
- (xv) Boxing up of generating unit is done as follows:
 - (a) The detachable half of speed ring and man hole is then placed in position and secured.
 - (b) The generator shaft is centered with the help of level and stretched piano wire.
 - (c) Then upper parts of turbine bearing support and turbine seal are installed.
 - (d) Previously removed upper halves of annular parts of water passages are again placed in position.
 - (e) Gate ring and guide vane actuating mechanism is installed. The gate ring is connected to servomotor.
 - (f) The front part of the bulb is positioned together with air cooling system.
 - (g) The oil header and pilot exciter are also installed in their design position.

2.2.2.7 Installation of tubular generating unit with separate turbine and generator shaft

- (i) In this case turbine and generator are assembled separately in erection bay and then shifted to unit pit and installed in position thereafter they are connected together and their rotating parts are adjusted, centered and aligned.
- (ii) The procedure for installation of annular parts is the same as explained above for single shaft generating unit.
- (iii) The upper halves of the parts of water passages are removed, however, lower part of the bearing housing with shell is installed. Its concentricity with speed ring flange is then adjusted and achieved.
- (iv) Preassembled rotating part of turbine are lowered in turbine pit and placed horizontally on two supports. One is turbine bearing and other is formed by a device with spacer jack supporting shaft flange.
- (v) The hub extension is fitted and then centering of rotating parts of turbine is done.
- (vi) Following checks are done at this stage:
 - (a) Horizontal position of shaft and its concentricity with speed ring.
 - (b) Check parallelity of turbine shaft flange with respect to flange of speed ring. It must be within prescribed limit.

- (c) Clearance between the runner blades and throat ring must be uniform and as per drawing.
- (vii) During centering the position of the rotating turbine parts is adjusted on bearing side by placing shim under the claws of bearing housing and bearing shell backing.
- (viii) The position of shaft is adjusted on flange side with spacer jack.
- (ix) Installation of generator is done as per following sequence:
 - (a) Preassembly of generator is done in erection bay. It consists of rotor, stator and thrust bearing.
 - (b) This preassembly is lowered in turbine pit in its design position.
 - (c) Alignment of generator with turbine is carried out. The procedure is given in Annex 2.
 - (d) Then generator and turbine shafts are connected. The end faces of shaft
 - (e) flanges must be parallel to each other with in 0.06 mm or as per drawing
 - (f) Stator is adjusted and secured ensuring uniform gap between rotor and stator.
 - (g) Installation of bulb and all other parts of generating set is done thereafter.

2.3 ERECTION OF VERTICAL HYDROGENERATING UNIT

2.3.1 General

As compared to horizontal machine, vertical machines are more complicated in construction and delivered by the manufacturer in many parts, which are to be assembled at site and also checked for their correctness in form, concentricity of bores, verticality and horizontality. Utmost care is required for making mechanical or electrical joints of the assemblies. This work is normally done by manufacturer's Engineers and Technicians and supervised by Engineers of owner.

2.3.1.1 Erection activities are divided as below

2.3.1.1.1 Assembly in unit pit

- (i) Draft tube liner
- (ii) Spiral casing
- (iii) Turbine pit liner

2.3.1.1.2 Assembly in erection bay

- (i) Turbine
 - (a) Runner
 - (b) D.T. cone
 - (c) Stay ring
 - (d) Lower ring
 - (e) Top (Head) cover
- (ii) Generator
 - (a) Stator
 - (b) Rotor

2.3.1.1.3 Trial assembly

- (i) Guide apparatus
- (ii) Runner with out top cover
- (iii) Runner with top cover
- (iv) Generator rotor after lowering and fitting of stator in generator barrel

2.3.1.1.4 Final Assembly of unit

- (i) Turbine
- (ii) Generator

2.3.1.1.5 Erection of Auxiliaries & other associated systems

- (i) Generator coolers
- (ii) Bearing coolers
- (iii) Governing system
- (iv) Grease lubrication system
- (v) Brakes& jacks
- (vi) Top cover draining system
- (vii) Gland seals & sealing water system
- (viii) Cooling water system with PRV, strainers and valves etc.
- (ix) CO₂ fire fighting system for generator
- (x) Excitation system & AVR
- (xi) Unit control panels
- (xii) Compressed air system for governor (if required)

2.3.1.2 Assembly in unit pit

2.3.1.2.1 Draft tube cone & liner

The draft tube of low or medium head reaction turbine is normally lined only at the top i.e. at the conical transition (draft tube cone). The elbow and horizontal portion are only concreted. But in case of larger machine even elbow and part of horizontal portion are provided with steel lining.

This steel lining is received in many pieces of steel plates duly numbered matching with installation drawings. As such these are selected and placed in position welded with supports and tack welded with neighboring lining pieces. After doing this up to certain level marked in drawing, inner form, centering, leveling etc. are checked, if found correct these plates are finally welded as per welding procedure given by the manufacturer. However all precautions required for boiler quality welding are necessary. Principle of “weld little, cool more” is followed to avoid deformation of job and stress locking in welded pieces. This way the whole process of Lining pieces installation is completed. In the top most portion which is to be connected with the draft tube cone, its circularity matching with unit axis are checked and confirmed whether these are within prescribed limit of deviations.

Then draft tube cone assembled in the erection bay is lowered in the pit and welded with the draft tube steel liner.

After checking form in draft tube cone area, elbow area and horizontal area is handed over for concreting.

2.3.1.2.2 Spiral casing

Spiral casing is also delivered by manufacturer in many pieces, whose form is maintained by providing stiffeners inside each piece. These pieces are numbered as per the assembly drawing and have to be installed in position, adjusted and secured by supports and then tack welded with the adjoining pieces.

Before starting activities on spiral casing lower ring and stay rings are assembled, adjusted and properly checked for its form, inner bore, circularity, concentricity of axis and then lowered in the pit. These are placed in position and checked for proper level, elevation, vertical axis matching with unit axis. Lower ring is adjusted and checked carefully so that location of guide vane holes are matched and set as per drawing. Any misalignment in positioning lower ring may disturb the installation of whole unit.

The spiral casing is usually assembled in two directions i.e. from nose to middle piece and from inlet piece to the middle segment.

The spiral casing should be assembled by first completing longitudinal joints in each section. The later is then welded to stay ring, the annular joints between sections are welded after this. The manufacturer shall submit the welding procedure specification (WPS) for spiral casing to the purchaser.

Up to inlet piece spiral casing is assembled along the periphery of stay ring piece by piece duly checked for its location, form and matching with other adjoining pieces. These are first tag welded and retained in position with help of stiffeners, turn buckles and supports. The welding of pieces is carried out as follows:

The joints to be welded are first gauged with gauging electrodes, then cleaned and shaped like 'V' with the help of grinding machine. After doing this welding is carried out layer by layer. After every layer proper sludge removal is ensured and then ground to make surface smooth. Dye penetration test is carried to detect pin holes, blow holes or sponginess. Once health of this layer is ensured then second layer of weld deposit is done. For every layer grinding and dye penetration test is required till the required weld deposit is achieved for joining the adjoining pieces. Principle of "weld little, cool more" is followed and only boiler quality welders are engaged for the job. In case any welder does not have valid boiler quality welding certificate, he will be tested by the purchaser and allowed to weld only if he passes the qualification test. After completion stress relieving has to be done.

After completion, welding of whole of spiral casing, ultrasonic test of all welded joints is carried out to ensure healthiness of welded joints. If any defect is found the same is repaired. Ultrasonic test should be done by qualified personnel. Staggering of joints is also ensured to avoid weak welded joints.

Care is taken while welding inlet piece whose centre line should match with the centre line of expansion joint, inlet valve and penstock. This should be perfectly circular and its diameter should match with dia. of expansion joint.

After completion all the welding, grinding and testing work all stiffeners are removed, grinding at their welded location is done to ensure smooth surface.

Before applying epoxy primer and epoxy paint, the surface of spiral casing is thoroughly cleaned, sand blasting is done such that it starts shining and then epoxy primer is applied by spray painting gun. Only after primer coating two coats of epoxy paint are applied. This will prevent rusting and thereby corrosion of spiral casing plates.

Hydraulic pressure test of spiral casing is essential to be carried out before handing over it for concreting. For this the manufacturer is required to supply a cylindrical plug matching with inner bore of stay ring with seals and bolts etc. and conical plug for blocking inlet piece on penstock side by welding it properly on the incoming side. After doing proper plugging the spiral casing is filled with water and then pressurized for two times the normal designed pressure and left as such for period agreed by the manufacturer and the owner of the plant. Outer sides of all welded joints are checked for any seepage, leakage or jets and these points are marked for rectification. After rectification the test is again carried out.

After depressurizing and dewatering through spiral drain valve, these plugs are removed and the spiral casing is handed over for concreting.

But before handing over for the concreting the upper half of spiral casing is covered with insulation consisting of felt with two layers of rubberoid glued on it with bitumen. The insulation prevents transmission of forces between the concrete of the power house structure and the spiral casing.

2.3.1.2.3 Turbine pit liner

This may be supplied by the manufacturer in two halves with vertical joints. These may either be assembled in the erection bay and shifted to unit and installed on the upper flange of stay ring, or assembled directly on the latter. The welded joint of the liner has to be perfect in order to prevent water leakage to the turbine pit. It is, therefore desirable to weld the lower flange of the pit liner to upper flange of stay ring after adjustment matching of unit axis and pit axis and fixation. Establishing the cylindricity and its centering relative to the unit axis as well as design elevations are of utmost importance.

2.3.2 Erection of Vertical Hydro Turbine

Erection activities are generally sub categorized in following manners:

- (i) Sub-assemblies to be carried out in unit pit.
- (ii) Sub-assemblies to be completed in erection bay.
- (iii) Sequence of lowering of sub-assemblies.

2.3.2.1 Sub-assemblies to be completed in pit

There are certain components of machine which are to be assembled, welded, adjusted, centered, checked for proper form in the unit pit, whereas other parts are assembled, adjusted, checked for proper form, hydraulically tested (Kaplan runners, coolers etc.) and then lowered in the pit as per sequence of erection. Draft tube liner and spiral casing are two components which are assembled, welded, checked for proper form, centered and aligned in

the unit pit itself for larger machines while for smaller machines these may be received from manufacturer in one, two pieces in their duly secured proper form which may required to be placed in design position and secured after checking of their elevation, coaxially and adjustment.

Stator for larger machine is received in two sectors or three sectors. These sectors are placed on their foundations in the generator barrel, then adjusted for elevation, unit axis, leveling and centering & joined mechanically as well as electrically.

2.3.2.2 Sub-assemblies to be completed in erection bay

- (i) Runner Assembly (Kaplan), checking of concentricity of upper crown & lower skirt, inner dia, outer dia, checking of labyrinth rotating (Francis).
- (ii) Head cover (top cover) assembly.
- (iii) Draft tube Cone.
- (iv) Lower ring & speed ring (stay ring).
- (v) Rotor components comprising of rotor spider with generator shaft, extension arms, rim punching for rim building and rotor poles are received from manufacturers work and are assembled by his Engineers and technicians in erection bay. Checking for form, size and smoothness of pole tail slots (by broaching after assembly of rotor rim), verticality of shaft, leveling of rotor, fitting adjusting and checking of brake track, assembly of rotor poles, connection and testing of rotor.

2.3.2.3 Trial assembly

- (i) Trial assembly of runner

Duly assembled runner, without top cover is lowered in pit to check radial and diametrical clearances between static and rotating labyrinths (Francis), runner blade and runner chamber (Kaplan).

- (ii) Trial assembly of guide apparatus
 - (a) All guide vanes are lowered and positioned in lower bushes in lower ring/pivot ring. Free movement of guide vanes in bushes to be checked, if not, bushes are to be carefully ground or bored to achieve required clearance.
 - (b) Free movement of guide vanes to be ensured by manual movement.
 - (c) Top cover is lowered and upper bushes of guide vane are positioned in holes for bushes in top cover.
 - (d) Regulating ring, links, levers are connected.
 - (e) Smooth operation of guide vanes from fully open to fully closed position is checked. Upper lower clearance and bedding of guide vanes is checked.
 - (f) After ascertaining proper fitting the whole guide apparatus is removed and shifted to erection bay.

- (iii) Trial assembly of rotor

After completion of assembly & checking testing in erection bay the rotor is lowered inside stator bore and kept hanging for some time with E.O.T. crane, gaps between stator and

rotor are checked as well as its position with respect to stator is also checked. After prescribed checks are carried out this is removed and shifted to erection bay.

2.3.2.4 Assembly in erection bay

There are three types of turbine runners normally used in vertical hydro machines of SHP:

- (i) Kaplan
- (ii) Francis
- (iii) Pelton

Assembly, therefore, of each type of runner will be explained one by one.

2.3.2.4.1 Kaplan runner

Suitable assembly plate is provided & fixed in erection bay.

- (i) Four metal stands of height 500 to 800 mm are placed and fixed on the above plate.
- (ii) Hub is kept on these stands in upside down position.
- (iii) The levers and links of trunion system are assembled in their design position inside the runner hub.
- (iv) The pivots are positioned and keys are inserted in the pivots and levers. The pivots are then pulled into their seats in the hub and connected to levers by permanent bolts holding the pivot. Tubular washers whose height is equal to the thickness of blade flange are provisionally placed under their heads. The fitting of the blades levers and links are checked. Clearance between outer surface of pivot flanges and bronze rings are also checked. Before removing the eye bolts it is checked that pivots have been connected to levers & links are secured to the levers and to the hub.
- (v) The stands on the assembly area are changed and the runner is turned and placed on these stand in upright position. The cross head is fitted on the piston rod from below and supported by jacks & support.
- (vi) Servomotor piston & piston rod are assembled in advance above an opening and connected by split ring. They are carefully lowered in the servomotor cylinder and the cross head is fitted to the rod with help of jacks provided under it. The links of the blade actuating mechanism are lowered and inserted into the eyes of cross head. Similar to the piston the cross head is connected to the piston rod by split ring. The pins connected to the links with cross head are inserted into the eyes.
- (vii) The hub bottom is then fitted. A gasket is inserted into the joint between the hub body and bottom to prevent oil leakage between the matting surfaces.
- (viii) The blades are placed in position after assembly and adjustment of their seals. Before fitting the blades the pivots are turned to no load position. Each blade should be inserted carefully after its flange is cautiously adjusted. The blade is connected to the pivot by several permanent bolts. The tightness of joint is checked through empty holes of coupling bolts.
- (ix) The blade located on opposite side is fitted and secured as discussed above.
- (x) The other blades are fitted in the same order.
- (xi) The hub extension is fitted after runner has been checked immediately before lowering of runner assembly in pit.
- (xii) Before lowering following checks and tests are necessary.

- (a) Checking concentricity of the runner with help of special device.
- (b) And hydraulic testing of the runner for a period defined in the erection manual provided by manufacturer and agreed by owner.
- (c) This test is required to ascertain that there is no leakage of oil through blade seals.

Installation of rotating parts of Kaplan Runner once the hydraulic test of runner is carried out it is ready for installation.

2.3.2.4.1.1 Erection of other parts

(i) Draft Tube lining

- (a) Draft tube linings of low and medium head Francis Turbine is usually provided at the top (draft tube cone) while rest of the draft tube is concreted only. For high head elbow and some portion of horizontal flare is also provided with metal lining.
- (b) The lining of D.T. Cone is fabricated from steel plates.
- (c) The lining is assembled in erection bay on blocks on pair of wedges.
- (d) The joints between various parts are made and aligned using wedges & bolts.
- (e) The correct dimensions are obtained by braces & tie rods.
- (f) A steel bracing frame is fitted at the top to ensure correct geometry at inlet portion.
- (g) After checking and fixing the shape welding is carried out. After welding again shape is checked and secured with the help of frame, braces and tie rods.
- (h) The lining is then installed in position and adjusted relative to bench mark and principal axis of generating set and secured to the concrete by tie rods and braces.
- (i) Again checking of its elevation adjustment with respect to unit axis and geometrical shape is checked before handing over for concreting.
- (j) The connection between D.T. Cone top and foundation ring is made through a compensating ring after installation, adjustment and final fixation of foundation ring and speed ring with spiral casing, since the speed ring can not be adjusted otherwise.

(ii) Throat ring or Runner Chamber

- (a) In Kaplan the draft tube cone is connected to runner chamber through a compensating ring. This ring is fitted after whole built in parts have been installed and adjusted. The reason for this is that the throat ring may be moved vertically during adjustment.
- (b) It may be necessary to hang the throat ring in unit before lower distributor ring is installed.
- (c) The upper flange of throat ring must be located at an elevation corresponding to that of the lower distributor ring.
- (d) The lining of draft tube cone is then connected to the throat ring.

(iii) Speed ring

The process is same as discussed above for Francis Turbine.

(iv) Spiral Casing

The process is same as discussed above for Francis turbine.

(v) Guide Apparatus

Installation of guide apparatus is carried out in following sequence.

- (a) Assembly and installation of pivot ring on support ring or concrete in Kaplan.
- (b) Lowering and installation of guide vanes in lower ring and checking their free movement in lower bearing bushes manually.
- (c) Installation of top cover on stay ring (some time upper ring is integral part of turbine top cover).
- (d) Installation of G.V. bush housing/bearing body in upper ring/ top cover and again check free movement of guide vanes.
- (e) Installation of regulating ring and its support in top cover.
- (f) Adjustment of upper ring or top cover to ensure smooth movement of Guide vanes.
- (g) Final setting of G.V. upper and lower bushes.
- (h) Installation of levers, links and guide vane regulating ring.
- (i) Adjustment of guide vanes and checking free movement of guide vanes along with movement of regulating ring.
- (j) Checking bedding of guide vanes at fully closed position and measurement of fully closed to fully open angle of guide vane movement.
- (k) Installation of servomotors, their adjustment, setting and check for design position and securing.
- (l) Connection of regulating ring with servomotors.
- (m) Connecting servomotors with pressure oil system through pipes and filling regulation system with oil.
- (n) Check and adjust whole regulating mechanism of guide vane opening and closing.

2.3.2.4.2 Francis Runner

- (i) For small hydro power stations, runner which do not exceed loading gauge are welded or cast in one piece and delivered fully assembled with the rings of labyrinth seals shrunk fitted and secured.
- (ii) When runner is larger these rings may be delivered separately and shrink fitted at installation site.
- (iii) One piece runners are statically balanced at Manufacturer's plant.
- (iv) Assembly of such runners involves:
 - (a) Fitting of extension hub.
 - (b) Fitting of labyrinth seal rings.
 - (c) Coupling of runner with turbine shaft.
- (v) The runner must be completely finished and tested at the Manufacturer's plant and then transported to the installation site.
- (vi) Shrinking of labyrinth seal rings for large runner at installation site is an important operation and must be carried out very carefully:

- (a) Diameter of each ring to be checked when cold.
 - (b) Ring is to be placed on the lower bend.
 - (c) Clearance between ring and bend should be checked with a feeler gauge.
 - (d) Equality of the tapers of ring and band should be established when the diameter of ring is checked.
 - (e) The ring is heated by several powerful burners simultaneously or by an electric current. Heating must be uniform over the ring circumference on.
 - (f) Ensure inside diameter of the ring is increased by a predetermined value, including a safety margin to allow the cooling of ring while it is being shrunk on. This increase may be 1.6 to 1.8 times the interference.
 - (g) The expansion of ring is checked by end gauge when desired temperatures are attained.
 - (h) With the help of slings and crane the ring is quickly placed on its seat. It is very important that inside of ring and the seal on the band be clean.
- (vii) The turbine shaft is coupled to the runner as per match marking provided by the Manufacturer on the runner and shaft flange.
- (a) The tightening of coupling bolts is to be done in such a way that uniform stressing and tightening of each bolt is ensured.
 - (b) Concentricity of the labyrinth seal rings on the upper and lower runner band is also checked. The rings must be concentric with the shaft to within 10% of the air gap on one side of labyrinth seal.
 - (c) Results of balancing of runner at Manufacturer's works must be checked otherwise there may be considerable vibrations of generating set during operation.

2.3.2.4.2.1 Installation of rotating parts of Francis turbine

- (i) The runner is coupled with shaft in the erection bay as stated above.
- (ii) Hub extension is coupled & secured just before lowering of shaft and runner assembly to the foundation ring.
- (iii) The assembly is placed in design position on the upper machined face of the foundation ring. However thorough cleaning of the flange surface must be ensured in advance.
- (iv) Measuring blocks or paired wedges are placed on it at four to eight locations depending on the weight of rotating parts. The blocks must be located in same horizontal plane. The height must be kept such that after installation the turbine shaft flange is located below design position to ensure that flange of generator shaft does not come in contact and does not disturb the centering of later during installation of generator rotor.
- (v) The runner should immediately be centered as accurately as possible according to the clearance between lower band and the speed ring.
- (vi) The clearances in lower seals are checked.
- (vii) The vertical position of rotating parts is checked by leveling the upper face of shaft flange.
- (viii) Any inclination is corrected by altering the height of blocks beneath runner lower band.
- (ix) The elevation of the rotating part is checked by leveling the shaft flange and measuring the clearance between the lower band and flange of the foundation

ring. The clearance must be equal to the design value after deduction of distance through which the runner has to be lowered to permit the turbine and generator shaft to be connected.

- (x) This centering of rotating parts is provisional. Final centering has to be more precise and is done after coupling of turbine and generator shaft in unit pit.

2.3.2.4.2.2 Erection of other parts

(i) Draft Tube Lining

Process is same as discussed above for Kaplan Turbine.

(ii) Foundation ring

- (a) Foundation ring is the base part determining the position of generating set with respect to elevation and principal unit axis.
- (b) Foundation ring may be in two or four parts which are preassembled in erection bay. Jointing of these parts is done carefully so that these may not have any projection especially on the faces of flanges.
- (c) The cylindricity of the ring is obtained with steel braces and tie rods.
- (d) The foundation ring is supported on steel blocks over D.T. cone in its designed position. These steel blocks rest on concrete portion.
- (e) Checking of its correct position in plan relative to the unit axis and to the design elevation is carried out and logged.

(iii) Speed Ring (stay ring)

- (a) The speed ring is received in two or four parts and placed on wooden blocks in E.B.
- (b) These segments are assembled, adjusted, checked for circularity at top and bottom cylinders and then joined to each other. The surfaces of joints are properly ceased and coated with protective compound before they are connected.
- (c) The cylindricity is corrected by using internal braces & tie rods, which are removed only when speed ring is concreted in.
- (d) There should be no projections at the joints and on the face of upper flange.
- (e) The face of upper flange is cleaned, checked and coated with protective compound, rubber sealing cord is also placed on it before the speed ring is fitted.
- (f) Then its installation on the foundation ring is done carefully with help of EOT crane.
- (g) Its adjustment in plan relative to the axis of generating set, using axis marked over it by manufacturer is carried out immediately after lowering it in unit pit. This is done with help of plumb line dropped along the vertical axis.
- (h) The distance between upper bore of speed ring and plumb line is measure at minimum eight points.
- (i) The speed ring is then bolted to the foundation ring.
- (j) Further vertical and horizontal adjustment of speed ring is carried out by simultaneously raising or lowering it together with foundation ring.

- (k) The speed ring can be raised or lowered with the help of EOT crane and can be moved or rotated with help of jacks.
- (l) After adjustment and checking the block foundation bolts are concreted. After setting of concrete the foundation bolts are finally tightened and speed ring is finally adjusted.

(iv) Spiral Casing

- (a) Dimensions of spiral casing determine whether manufacturer supplies:
 - (i) In sections consisting of two or more pieces, as separate piece.
 - (ii) Or individual rolled sheets which are later weld together at site.
- (b) Small spiral casing of proper rigidity may be installed in two or more parts put together in erection bay.
- (c) Spiral casing of large hydro machine is assembled in the design position at site as it is not possible to prevent deformation of large assemblies during transportation.
- (d) Assembly of spiral casing is normally done in following sequence.
- (e) Installation joining the courses of spiral casing in designed manner.
- (f) Installation and fitting of last course.
- (g) Fitting and fixation of joint.
- (h) Adjustment of installed courses.
- (i) Welding of casing the form of which is retained by providing braces and tie rods.
- (j) Welding process is carried out very patiently as per technology given by manufacturer.
- (k) Final adjustment, fixation and handing over for concreting.
- (l) For larger machines spiral casings are subjected to hydraulic pressure test by providing one cylindrical plug at inner cylinder of speed ring and one conical plug at inlet piece before handing over for concreting.
- (m) All welded surface after cleaning by grinding and polishing are checked for healthiness by carrying out following tests:
 - (i) Dye penetration tests
 - (ii) Ultrasonic test
- (n) The upper half of spiral casing is insulated before concreting. The insulation prevents transmission of forces between the concrete of powerhouse structure and the spiral casing. The weight of concrete structure above spiral casing is transmitted through stay vanes.

(v) Guide Apparatus

Installation of guide apparatus is carried out in following sequence.

- (a) Assembly and installation of pivot ring on support ring or concrete on lower speed ring flanges in Francis.
- (b) Lowering and installation of guide vanes in lower ring and checking their free movement in lower bearing bushes manually.

- (c) Installation of top cover on stay ring (some time upper ring is integral part of turbine top cover).
- (d) Installation of G.V. bush housing/bearing body in upper ring/ top cover and again check free movement of guide vanes.
- (e) Installation of regulating ring and its support in top cover.
- (f) Adjustment of upper ring or top cover to ensure smooth movement of Guide vanes.
- (g) Final setting of G.V. upper and lower bushes.
- (h) Installation of levers, links and guide vane regulating ring.
- (i) Adjustment of guide vanes and checking free movement of guide vanes along with movement of regulating ring.
- (j) Checking bedding of guide vanes at fully closed position and measurement of fully closed to fully open angle of guide vane movement.
- (k) Installation of servomotors, their adjustment, setting and check for design position and securing.
- (l) Connection of regulating ring with servomotors.
- (m) Connecting servomotors with pressure oil system through pipes and filling regulation system with oil.
- (n) Check and adjust whole regulating mechanism of guide vane opening and closing.

2.3.2.4.3 Pelton turbine

- (i) The basic methods of installation are similar to the methods of installation of reaction turbine. But due to design difference the methods of installation have certain specific features of in built parts and rotating parts. In built parts are directly lowered in unit pits setting of elevation, centering and adjustment is carried out as per design. Necessary jointing, welding and securing in position is done in the pit itself.
- (ii) The rotating parts are assembled in erection bay. The runner is placed horizontally on 600 mm to 900 mm high wooden blocks in the erection bay and following sequence is followed:
 - (a) The shaft is coupled with runner.
 - (b) The bearing is placed on the shaft.
 - (c) The device for suspending the rotating parts for installation is attached.
 - (d) Before lowering all checks for horizontality of runner, verticality of shaft and other rotating parts are carried out.
 - (e) The form of runner, its diameter, and height and centre line is also checked.
 - (f) The rotating parts are now ready for lowering in the pit.

2.3.2.4.3.1 Erection of other parts of Pelton turbine

Following sequence is followed for installation of vertical Pelton Turbine:

- (i) Checking of unit foundations.
- (ii) Installation of built in parts and their preliminary adjustment.
- (iii) Final assembly and adjustment of all built-in parts and concreting.
- (iv) Installation, testing and centering of nozzles and deflectors.
- (v) Installation of preassembled shaft and runner.

- (vi) Installation of turbine cover plate and guide bearing.
- (vii) Installation of regulating mechanism and auxiliary mechanisms.

The built in parts include the discharge chamber lining with connecting course the inlet header the turbine casing and the embedded pipes.

The operating mechanism includes the runner with shaft, the nozzles with deflector and the guide bearing.

The installation and setting of all in built parts and operating mechanism is carried out as per manufacturer's instructions.

2.3.3 Erection of Vertical Hydro Generator

2.3.3.1 Check foundations of the generator

- (i) Check if the location of support is correct with respect to the axis of the set and axis of the power station.
- (ii) Check corresponding location of all the openings, ducts and other elements of foundations.
- (iii) Check that the level marks of the foundations are correct.
- (iv) Supporting surfaces of the foundations are smooth and clean, especially at the places of support of the adjusting wedges of the stator and lower bracket.

2.3.3.2 Sequence of erection

2.3.3.2.1 Suspended type

- (i) Assemble lower bracket and mount it on the foundation plate fixed on generator foundation. Centering of bracket should be done with respect to the axis of the set.
- (ii) Assemble the braking and jacking units and associated pipe lines, valves and limit switches etc.
- (iii) Carry out assembly of stator and mount it on the stator foundation. Centering of stator should be done with respect to the axis of hydro set and stator level should be kept as indicated in the drawing, dowelling should be done to secure the position. Carry out laying, jointing and insulation of winding.
- (iv) Carry out full assembly of rotor in erection bay.
- (v) Carry out full assembly of upper bracket and thrust bearing oil bath at the erection bay.
- (vi) With the help of special device the assembly of rotor with shaft shall be carried from erection bay and lowered inside the stator bore and shall rest on the brakes.
- (vii) The centering of rotor is done primarily along the air gap at top and bottom by adjusting the height of brakes, the shaft flange level shall be adjusted.
- (viii) Mount the assembled upper bracket.
- (ix) Assemble thrust bearing and mount thrust bearing collar.
- (x) Assemble the guide bearings, adjust zero gap between pad and journal.
- (xi) Center generator shaft as per turbine shaft.
- (xii) Transfer the weight of rotor on thrust bearing.

- (xiii) Check the wobbling of thrust bearing mirror disc mounted under thrust collar.
- (xiv) Lift the rotor on jacks. Finally center and level the stator and upper bracket as per rotor air gaps.
- (xv) Carry out coupling of turbine shaft and generator shaft.
- (xvi) Carry out checking of shaft alignment and its perpendicularity.
- (xvii) Carry out repeat checks for air gap between stator and rotor by rotation and check rotor levels also.
- (xviii) Finalize centering and leveling of lower bracket.
- (xix) Adjust the gaps in guide bearing of generator.
- (xx) Carry out inspection and final assembly of thrust bearing and guide bearings.

2.3.3.2.2 Umbrella type hydro-generator

- (i) Assemble lower bracket and install it on the foundation with fixed foundation plates and center with reference to the axis of hydro set and along its height.
- (ii) Install the brakes and assemble brake pipelines.
- (iii) Carry out the assembly and installation of the stator on the stator foundation with the fixed foundation plates. Stator is centered and leveled with respect to the axis of hydro set and is adjusted at the design level.
- (iv) Carry out laying, jointing and insulation of windings.
- (v) Carry out complete assembly of the rotor at erection bay.
- (vi) Carry out assembly of upper bracket at erection bay.
- (vii) Assemble thrust bearing at erection bay and install it in the oil bath of the lower bracket.
- (viii) With the help of special device assembled rotor with the shaft is brought from erection bay and lowered into the stator bore to rest on the thrust bearing. The rotor is centered preliminarily as per the air gap. By regulating thrust bolts as well as brakes bring the shaft flange at design level.
- (ix) Center the generator shaft with turbine shaft.
- (x) Center the stator with respect to rotor.
- (xi) Perform coupling of generator and turbine shafts.
- (xii) Mount the assembled upper bracket on the stator, level and center it with respect to shaft.
- (xiii) Assemble upper guide bearing. Set zero gap between the pad and sleeve if the trust bearing is located on upper bracket.
- (xiv) Perform checking of the shaft alignment and wobbling of thrust bearing mirror disc.
- (xv) Finally center the stator as per air gap and along height.
- (xvi) Again check the centering of lower bracket.
- (xvii) Adjust air gap in the guide bearings of the generator.
- (xviii) Perform inspection and final assembly of thrust & guide bearings.
- (xix) Carry out concreting of the foundation plates of stator and lower bracket.
- (xx) Perform trial spinning of the set and box up the unit.
- (xxi) Perform dry out of the generator.
- (xxii) Perform high voltage test of the generator and testing of hydro set with load.

Detailed procedure of centering and alignment of vertical hydro unit is given in Annexure 1.

3.0 CHECKS OF ERECTION OF SHP GENERATING UNIT

These checks are for the supervision of erection of machines by Purchaser's Engineers where installation is done by other agency.

Before starting of Erection, the contractor shall finalize Field Quality Plan (FQP) with purchaser. In FQP the following will be identified:-

- (i) Stages of erection to be checked by the contractor. The inspection record shall be submitted to the purchaser.
- (ii) Stages of Erection to be checked by the purchaser's representation.

3.1 HORIZONTAL HYDRO GENERATING UNITS

3.1.1 Hydro Generating Units with Spiral Casing

3.1.1.1 Hydro turbine and accessories

3.1.1.1.1 DT cone

- (i) Check form before installation.
- (ii) Check correct position in unit pit relative to principal axis.
- (iii) Check elevation and level.
- (iv) Check horizontal position as well as verticality.

3.1.1.1.2 Spiral casing

- (i) Check form before installation.
- (ii) Check correct position in unit pit relative to principal axis.
- (iii) Check elevation.
- (iv) Check horizontal position relative to turbine cover plate and inlet flange.
- (v) Check matching of centre lines of spiral casing inlet and penstocks.

3.1.1.1.3 Turbine bearing

- (i) Check foundation surface, these must have proper level.
- (ii) Check transverse axes of bearing with respect to centre line of spiral casing.
- (iii) Check elevation of bearing housing.
- (iv) Check alignment of bearing, the centre line of bearing should coincide with longitudinal axis of generator.
- (v) Check centering of bearing housing relative to longitudinal axis of generating set.

3.1.1.1.4 Guide apparatus

- (i) Check trial assembly of guide apparatus.
- (ii) Check clearance between guide vane ends and turbine cover plates. This must be uniform on both sides and total should be as per drawing.
- (iii) Check there is no clearance between guide to guide vane when in closed position.
- (iv) Measure width between each pair of guide vane in fully open position of guide vanes.

- (v) Check guide vane servomotor for its alignment, positioning, elevation and its connection with regulating ring and also check for proper installed of links & levers between regulating ring and guide vanes.

3.1.1.1.5 Runner and shaft

The centering of shaft relative to labyrinths is to be checked by end gauge before mounting of runner.

3.1.1.1.6 Checking and centering of rotating parts

- (i) Measure clearance between shaft and lower bearing shell with a feeler gauge.
- (ii) Check horizontal position of the rotating turbine parts by placing levels successively on both bearings. Repeat the same after turning the level through 180°.
- (iii) The two measurements should not be more than one scale division.
- (iv) The permissible inclination of shaft should be as per drawing.
- (v) Transverse position of bearing housings is also to be checked. The permissible inclination in transverse direction should be as per drawing.
- (vi) Check radial clearances between the runner and turbine cover plates.
- (vii) Check gaps between static and rotating labyrinths.
- (viii) Check axial play of rotating turbine parts through length wise displacement of thrust bearing to its extreme position:
 - (a) The gap in labyrinths seals should be as per drawing.
 - (b) Axial clearance between thrust collar and sleeve should be as per drawing.
- (ix) The above checks should be repeated after rotating turbine by 180° & 360°
- (x) Check clearance between turbine shaft and upper bearing shell with 1 mm thick lead wire of suitable length.
- (xi) The thickness of flattened wire indicates the clearance on top of shaft. This should not be more than 2% of shaft diameter.
- (xii) Check lateral clearance between shaft and lower shell. These should be one & half times the clearance between upper shell and shaft.

3.1.1.1.7 Governor

- (i). Check governor for its positioning, elevation, horizontal position, location relative to turbine.
- (ii). The governor mechanism should be checked for:
 - (a) Turning of manual control should be smooth.
 - (b) Verify tightness of distributors when closed.
 - (c) Check for absence of backlash in the mechanism of regulating system.
 - (d) Measure maximum opening of guide vanes.
 - (e) Verify servomotor stroke v/s guide vane opening – relation should be as per design.

3.1.1.2 Hydro generator and accessories

From design and construction point of view normally following two types of horizontal hydro generators are available.

3.1.1.2.1 Shop assembled

- (i). Low power hydro-generator with bearing located directly inside generator housing. Such generators are delivered duly shop assembled on foundation frame.
- (ii). Large generators whose bearings are located on separate pedestals are delivered with generator exciter and bearings assembled on common foundations.

3.1.1.2.2 To be assembled in erection bay

Large generators are delivered in separate components viz. shaft with generator rotor, exciter rotor assembled on it, stator frame, exciter frame and fly wheel (in two parts).

First category generators are delivered fully assembled or mounted on rigid foundation are assembled unblocked after checking alignment and adjustment of its elevation relative to half coupling of turbine shaft.

Second category generators are completely assembled in erection bay and then installed in unit pit. Following checks are necessary:

- (i) Check horizontal position of bearings.
- (ii) Check position of stator relative to bearings.
- (iii) Check elevation and horizontal position by wire centered in the bores of bearing shell.
- (iv) Measure gaps between rotor & stator of generator as well as exciter.
- (v) Check centering and positioning of generator rotor and exciter rotor relative to half coupling of turbine and half coupling of generator respectively.
- (vi) Final alignment and centering to hydrogenating unit is to be checked after coupling of generator and turbine shaft. Detail procedure for this is given in Annexure 1.

3.1.2 Horizontal Tubular Generating Set

- (i) All parts forming water passage from speed ring to DT cone of this type of unit is delivered split horizontally.
- (ii) Only lower halves can be concreted.
- (iii) Alternatively if lower halves are not to be concreted, these should be provided with strong enough supporting structure.
- (iv) Horizontal tubular generating set may have a single shaft or separate each for turbine and generator.
- (v) The installation technology differs greatly depending on whether the annular parts of water passage are concreted or not and also whether these are single shaft or separate shafts for turbine and generator.

- (vi) It is preferred maximum preassembly is completed in erection bay and then lifted, carried and lowered in the unit pit with the help of EOT crane.

3.1.2.1 Single shaft generating unit

3.1.2.1.1 Checks for pre-assembly in the erection bay

- (i) Check shape and dimensions annular parts of generating unit after completion of assembly in erection bay.
- (ii) Check shape and dimensions of throat ring foundation ring and DT cone.
- (iii) Check for and dimensions of speed ring
 - (a) Check inner bore.
 - (b) Check horizontality in EB during assembly.
 - (c) Check cylindericity and concentricity.
- (iv) Check preassembly of distributor assembled with speed ring or on assembly stand for cylindericity, concentricity with inner distributor ring. Also check elevation and levels.
- (v) Check guide vane movement, it should be free.
- (vi) After assembly in pit-check for its correct positioning, elevation and levels matching with unit axis, its verticality concentricity and horizontality.
- (vii) Check assembled runner in erection bay for form and dimensions.
- (viii) Check generator rotor for its form and dimensions.

After assembly of stator, rotor and runner:

- (i) Check horizontality of shaft.
- (ii) Position of rotor and runner.
- (iii) Check air gaps between stator and rotor.

3.1.2.1.2 Assembly in pit

- (i) Before boxing up of generating unit
 - (a) Check elevation, centering, concentricity relative to axes.
 - (b) Check cylindricity by stretching piano wire and dropping plumb lines from transverse axis as soon as the speed ring is lowered, centered and adjusted to its design position.
 - (c) Check assembly of all other parts for proper positioning, elevation, centering and matching with unit axes.
- (ii) After boxing up
 - (a) Check unit alignment and centering.
 - (b) Check working of guide apparatus and free movement of guide vanes.
 - (c) Check gaps between pads and journal for all bearings.

3.1.2.2 Generating units with separate turbine and generator shaft

- (i) Turbine and generators are assembled separately in erection bay.
- (ii) Check all parts delivered for proper form and dimensions, diameter and their horizontality or verticality.
- (iii) Check all machined parts for proper machining.
- (iv) Assembly of runner:
- (v) Check for proper dimensions, diameter, horizontality and concentricity of shaft and runner.
- (vi) Assembly of generator:
- (vii) Check horizontality, elevation, stator rotor air gaps, bearing settings exciter gaps.
- (viii) After lowering of preassembled runner in pit in position following checks are done:
 - (a) Horizontal position of shaft and its concentricity with speed ring.
 - (b) Check parallelity of turbine shaft flange with respect to flange of speed ring. It must be within 0.1 mm.
 - (c) Clearances between runner blades and throat ring must be uniform.
 - (d) Centering of rotating turbine parts is to be checked.
 - (e) After lowering preassembled generator in unit pit following checks are required.
 - (f) Horizontal position of generator rotor and rotor shaft.
 - (g) Concentricity with turbine shaft.
 - (h) Parallelity of generator coupling relative to turbine coupling as recommended.
 - (i) Alignment of generator and turbine shaft is carried out before and after coupling – detailed procedure is given in Annex 2. The maximum permissible wobble of shaft should be as recommended by Supplier.
 - (j) Check gaps between stator and rotor.

3.2 VERTICAL HYDRO GENERATING UNIT

3.2.1 Hydro Turbine & Accessories

3.2.1.1 Embedded parts

- (i) Check positioning, level, elevation of embedded pipe lines and other embedments to be provided as per drawing.
- (ii) Check form, centering, elevation of draft tube and draft tube cone.
- (iii) Check leveling and centering of speed ring foundation plates.
- (iv) Check centering, leveling, elevation, axis of speed ring before and after tightening of foundation bolts.
- (v) Check spiral casing for its form, positioning, alignment of inlet piece with penstock.
- (vi) Pressure testing of spiral casing after assembly in position and anchoring.
- (vii) Checking centering, leveling, elevation and setting of axes of runner chamber (in case of Kaplan).

- (viii) Checking centering, leveling, elevation and setting of axis (in case of Francis) of static labyrinths.
- (ix) Checking shape, centering, elevation and level of turbine pit liner.

3.2.1.2 Pre-assemblies in erection bay

- (i) Pre assembly of lower/ pivot ring and checking co-axiality of pivot and top cover holes.
- (ii) Preassembly of Top Cover
 - (a) Check dimensions of top cover.
 - (b) Check form, machined surfaces.
 - (c) Check by lowering in pit and putting on speed ring flange.
 - (d) Check fitting and free rotation of guide vanes.
 - (e) Check top and bottom clearances of guide vane.

After this checking top cover can be taken out and kept in EB

- (iii) Preassembly of runner and shaft
 - (a) Check shaft after thorough cleaning for dimension, check both flanges by surface plate, check machined surface of flanges.
 - (b) Check runner for its proper shape and dimensions, check labyrinths (upper & lower) in case of Francis Runner.
 - (c) Check diameter of assembled runner (Kaplan), carry out pressure testing of runner hub and seals for leakage, check movement of servo mechanism in EB before trial assembly.
 - (d) Check clearances between rotating surfaces of runner and associated static surfaces (runner chamber in case of Kaplan and labyrinths in case of Francis).
 - (e) Check after mounting of top cover on to turbine shaft with runner in Erection bay for its tightening, doweling, positioning, horizontality and verticality.
- (iv) Guide Bearing
 - (a) Check cleaning, form and dimensions of the bearing housing.
 - (b) Check bedding of guide pads by blue matching with bearing journal.
 - (c) Check insulation of bearing pad.
 - (d) Check mounting arrangement of bearing pad.
- (v) Guide apparatus
 - (a) Servo motors

Check servomotors for cleaning, check machined surfaces of piston and cylinder, check seals etc.
 - (b) Regulating ring

Check static portion closely.
Check rotating porting closely.

Check free movement of rotating ring after assembly
Check all levers, links, bushes for cleaning and dimensions.

(c) Guide Vanes

Check all guide vanes for dimensions machined journals and general condition of rubber seal groove etc.

Check all bushes (top and bottom) for dimensions machining and general conditions.

3.2.1.3 Assembly of vertical hydro-turbine in unit pit

- (i) Check verticality of shaft by piano wire method.
- (ii) Check centering of shaft and flange level.
- (iii) Check that top cover is tightened properly and locking pin provided. Also ensure that O-ring is also placed below top cover before positioning..
- (iv) Put grease and cup seals, before lowering top cover finally, in the pivot ring and also put cup seals in bush housings of top cover.
- (v) Check labyrinth clearances (Francis) and clearance between runner & runner chamber (Kaplan).
- (vi) Check guide vane bedding in fully closed position.
- (vii) Check servomotor stroke between fully open & closed position of guide vanes.
- (viii) Check relation between GV opening and runner blade opening (Kaplan).
- (ix) Check guide bearing for proper clearance between pad & journal.
- (x) Check IR value of guide pad insulation.
- (xi) Check working of GV grease lubrication system.
- (xii) Check working of repair seal and main shaft gland seals.
- (xiii) Check working of top cover drain system.
- (xiv) Check working of OPU and governing system.
- (xv) Check leakage of oil through servomotors, turbine guide bearing housing
- (xvi) Governing system and all oil pipe lines.

3.2.2 Hydro Generator & Accessories

3.2.2.1 Pre-assembly in erection bay

(i) Stator

Stator is received from Manufacture:-

- (a) Single piece for smaller dia machines.
- (b) Two halves or in three sectors for bigger dia machines.

After carrying out stator sector assembly, laying of coils in slots at joints, making over hang connection check following points:

- (a) Check circularity of inner bore.
- (b) Carry out dimension checks.
- (c) Check stator is properly dried out.

- (d) HV Testing of stator as per norms should be carried out to ascertain proper insulation.

(ii) Lower Bracket

This may also be received in single piece or with central part and separate arms with joint plates. After assembly:

- (a) Check for dimensions.
- (b) Check machined surface.
- (c) Check inner bore.
- (d) Check leveling of base plates.

(iii) Rotor

For smaller dia machine rotor is received in fully assembled condition but for larger diameter machine these are assembled at site in erection. But in any case poles are assembled in erection bay.

- (a) Make weight groups, poles with equal weight are inserted in slots opposite to each other except first and last poles.
- (b) Check and test all the poles duly assembled before and after soldering of flexible connections.
- (c) Check all the poles are keyed, wedged and locked properly in slots.
- (d) Check over all dimensions of rotor.

3.2.2.2 Assembly of generator

After lowering and adjusting all turbine parts the lower bracket and stator are lowered one by one and placed on sole plates

- (i) Check placement, unit axis, inner bore, elevation, setting on foundation plates before concreting of foundation.
- (ii) Rotor is lowered after centering of stator and assembly of thrust bearing static portion with thrust bearing pads and thrust collar with mirror disc with respect to turbine labyrinths or runner chamber.
- (iii) Check thrust bearing collar with mirror disc is properly resting on pads.
- (iv) Check deflection of thrust bearing housing after total load of rotor is rested on thrust bearing pads.
- (v) Check verticality, centering, unit axes of rotor shaft.
- (vi) Check level, elevation of rotor at top, bottom and middle.
- (vii) Check magnetic axis.
- (viii) Coupling of Generator and Turbine Shaft with the help of jack bolts turbine shaft is pulled up, flanges of both shafts are properly cleaned and then coupled with each other with coupling bolts.
- (ix) Check elongation of coupling bolts.
- (x) Check centering, verticality and alignment of couple shafts (Procedure is given in Annexure 2).
- (xi) Check assembly of thrust bearing & its coolers, guide bearings and their coolers.
- (xii) Check assembly of brakes.

- (xiii) Check assembly of excitation system and AVR.
- (xiv) Check assembly of upper and lower rotor fans.
- (xv) Check assembly of stator coolers.
- (xvi) Check completeness of the assembly, cleaning and painting etc.

4.0 TESTING START UP AND COMMISSIONING OF SHP

4.1 PLANNING

For small hydro plants, the specifications should stipulate that the lead equipment supplier (usually turbine supplier) is responsible for startup & commissioning activities and as such should furnish a comprehensive and coordinated schedule of start up and commissioning which chronologically details field activities.

Time duration after completion of field tests of various electrical and mechanical system should not exceed 10 to 15 days for small hydro installation.

A well planned schedule will make it possible to carry out certain tests in parallel to minimize the time duration for start up and commissioning.

4.2 START UP AND COMMISSIONING ACTIVITIES

The process of start-up and commissioning of hydro electric plant has following stages:

4.2.1 Field Tests

At this stage all systems and subsystems are individually tested

Test at this stage include following:

- (i) All critical unit clearances and dimensions are checked.
- (ii) Alignment of unit shaft system.
- (iii) Calibration and adjustment of all temperature sensing devices, pressure switches, flow switches, transducers is done. If the contractor does not have calibration facility, the same should be done at laboratory approved by the purchaser.
- (iv) Continuity of all cabling and their connection as per cable schedules are checked.
- (v) Operation of all control system in both energized and de-energized state is checked.
- (vi) Hydrostatic tests of all pressurized fluid system.
- (vii) AC/DC high potential tests.
- (viii) Bench test of protective relaying.
- (ix) Check out also include all field testing that can be performed before the turbine begins to operate.

All tests carried out must be properly documented for each system and subsystem and signed by tests engineers of manufactures and plant owner. This documentation helps the owner to identify potential problem in specific equipment before start-up and take remedial measure in advance.

4.2.2 Start-up Tests

Before starting of machine, start up tests of generating units, all other systems and subsystems should have been done during field tests. These tests are divided in two categories.

- (i) Pre-commissioning tests (Dry Condition)
- (ii) Commissioning tests (Watered up condition)
 - (a) No load tests
 - (b) Load tests or performance tests

4.2.3 Pre-commissioning Tests (Dry Test)

These tests are conducted before charging the water conductor system of the unit. These checks can be carried out in parallel with field testing.

Some typical tests are as follows:

- (i) Hydrostatic tests of generator coolers, bearing coolers and piping.
- (ii) Auxiliary equipment is connected properly.
- (iii) All the instrumentation and safety devices operate correctly.
- (iv) Insulation resistance & dielectric test of generator.
- (v) Functional checks and adjustment of generator speed switches and pressure switches.
- (vi) Functional checks of wicket gates, and excitation system.
- (vii) The fire protection system is operating.
- (viii) The generator brake and lifting jacks and their interlocks operate as required.
- (ix) The entire unit must be thoroughly inspected before charging with water for tools, other objects which might have been inadvertently left in the unit.
- (x) Check penstock man hole draft tube manholes are properly closed and tightened after providing proper gasket, o-ring etc.
- (xi) Check working of all hydro-mechanical gates & valves etc.
- (xii) Check main & auxiliary transformers and their cooling arrangement.
- (xiii) Check switchyard & switchyard equipment.
- (xiv) Check all unit auxiliaries & station auxiliaries for their proper functioning.
- (xv) Arrange all clearances from in charges of different systems & subsystems.

4.2.4 Watered up Tests (Operational Test)

- (i) The contractor shall carry out detailed inspection of machine to ascertain no abnormality is found during first hour of operation
- (ii) Unit is charged with water, leakages from penstock and DT main holes, coolers, shaft seals are checked, remedial action, if found necessary, are to be taken.
- (iii) Check penstock pressure, DT pressure, cooling water pressure and availability of water at proper pressure in each cooler
- (iv) Ensure working of flow meters

- (v) Then machine is rotated for the first time at slow-speed, ensure for any abnormal sounds or interference in machines, take immediate remedial action, if necessary.
- (vi) This is a critical stage as for the first time all equipment components are operating as an integral system at rated head and flow condition
- (vii) The first unit rotation is done at slow speed then machine is run at 25, 50, 75 and final 100% speed
- (viii) Following test at this stage are done
 - (a) On line field test of generators such as telephone interference factor, wave form deviation etc.
 - (b) Shaft run out
 - (c) Bearing temperatures stabilization (this is called bearing run also)
 - (d) Reliability of start, stop, synchronizing unit is also to be confirmed
 - (e) All protective devices, lock out relays and emergency stop system are checked at low load to ensure that they are functional

All these tests are divided in two categories:

4.2.4.1 No Load Tests

These test conform the operation of the generator and powerhouse auxiliaries equipment under no load conditions. These are follows:

- (i). Phase rotation check
- (ii). No load saturation test
- (iii). Short circuit saturation test
- (iv). Operational tests, check thermal relays, speed switches, RTDs, flow switches
- (v). Excitation system checks
- (vi). Point to point continuity test to verify the components are connected properly
- (vii). Insulation resistance tests to check the condition of cable insulation
- (viii). Functional test of each component and the interconnected system of components in both auto and manual mode
- (ix). Test of the software and hardware associated with the computer control system

4.2.4.2 Load Test

These tests confirm the operation of generator under load condition. These are follows:

- (i) Heat run test to determine maximum temperature rise
- (ii) Load rejection tests
- (iii) Time taken by machine in stopping after application of brakes
- (iv) Measurement of excitation field current at generator rated output
- (v) Unit capacity test

The load rejection test is performed at 25, 50, 75 and 100% rated load which confirm the unit can be safely stopped under any operating condition. During these tests pressure rise

in penstocks and speed rise of the machine are measured to confirm that both of these parameters are within design limit. Any abnormal noise, alarm, high temperature and any unusual or unexpected condition must be thoroughly investigated.

4.2.5 Commissioning Tests

The unit is operated at rated output for a specified number of days. If no major problems occur during contractually required period of operation at rated out-put, the unit is taken over by owner for commercial operation.

Performance and efficiency tests are also performed during commissioning phase.

4.2.6 Performance Tests

The performance testing is mandatory as per MNRE GOI for release of financial assistance.

4.2.7 Commercial Operation

The unit is called on commercial operation, from the date it is available to sell power to public. This date immediately follows completion of commissioning tests.

4.3 TECHNICAL REVIEW OF COMMISSIONING ACTIVITIES

Small hydropower plants are found to be having more technical shortcomings than usually considered. This is because of misconception that the small power output of the plant would require small amount of required engineering input. As a result general lack of engineering details in the project design, planning, as also in the specifications of major plant equipment is evident. These conditions lead to technical flaws that may not be discovered until start up and commissioning of unit. By this time, the flaws usually are not correctable without large, unexpected expenditure and also time over run.

Each hydroelectric plant is unique in certain aspects. If proper engineering diligence is not used during initial design stages, the owner will receive a poorly designed plant that cannot produce expected energy due to lack of water, improper turbine setting or net head rating or improper sized generator.

If proper engineering diligence is not applied during installation of equipment, startup and commissioning will become a difficult exercise of turbine generator equipment problems, connected plant wiring, control system failures and protective relay trips.

To avoid such an eventuality the owner may employ knowledgeable engineers or engineering firm to carry out technical review at every stage of design & engineering manufacturing, shop assembly, shop tests, installation, field testing as also start up and commissioning of the plant.

Some items require technical review before the start up process begins while for other items review take place during start up and commissioning activities.

4.3.1 Review before Unit Start Up and Commissioning

4.3.1.1 Combined electrical / mechanical review

- (i) Review factory & field test certificates for all major pieces of equipment.
 - (a) Turbine
 - (b) Governor
 - (c) Speed increaser
 - (d) Intake gates, draft tube gates, spillway gates, inlet valves
 - (e) Generators
 - (f) Main power transformers
 - (g) Generator switch gears (medium voltage)
 - (h) Low voltage switch gears
- (ii) Unit or plant control switch boards
- (iii) Confirm that manufactures have provided detailed written installation instructions for all major pieces of equipment, including detailed dimensional record sheets and quality assurance plan followed during erection.
- (iv) Review all detailed dimensional record sheets in conjunction with a visual inspection of all major pieces of equipment.

4.3.1.2 Mechanical review task

- (i) Verify that hydrostatic tests have been performed on all pressurized fluids systems.
- (ii) Review operational check out sheets for each mechanical system, including calibration sheets for all level switches, flow switches, pressure switches etc.
- (iii) Review unit alignment check out sheets.
- (iv) Review bearing setting, centering, gaps check out sheets.
- (v) Review generator air gap check out sheets.
- (vi) Review functionality check out sheets for brakes, cooling system, oil pressure unit system, gland seal's repair seals, top cover drainage system, greasing system etc.

4.3.1.3 Electrical review tasks

- (i) Review system ground resistance test certificate and ensure adequate ground connection as per relevant ISS.
- (ii) Review surge protection of powerhouse/ switchyard.
- (iii) Confirm that phasing check has been performed across generator circuit breaker.
- (iv) Review the station battery/ battery charger arrangement and operational check out sheet.
- (v) Verify that all relays are bench tested and that the settings are as per design and that CT shorting screws have been removed.

4.3.2 Review or Inspection during Unit Start Up and Commissioning

4.3.2.1 Mechanical review

- (i) Observe first mechanical rotation of unit.
- (ii) Observe and review results of bearing temperature run.

- (iii) Observe and review results of unit load rejection tests.
- (iv) Observe turbine index test, verify that results are consistent with manufacturers promised performance.
- (v) Verify unit alignment and balance.
- (vi) Monitor for excessive vibration and GB run out.

4.3.2.2 Electrical review

- (i) Observe unit manual starts, stops and synchronization.
- (ii) Observe unit automatic starts, stops and synchronization.
- (iii) Observe one manually initiated emergency stop sequence.
- (iv) Observe unit stops by activation of each lock out relay.

4.3.2.3 Review of PLC used for unit control

- (i) Identify manufacturer's recommended chassis and logic ground points and see whether they are to be connected collectively or grounded separately. If connected collectively confirm how common mode noise is prevented from entering the PLC.
- (ii) Verify the grounded resistance value for chassis and logic grounds are consistent with the manufacturer's recommendation.
- (iii) Ensure that surge protection are provided on all inputs to the I/O racks that will be susceptible to voltage transients including all cables routed to devices located outside the powerhouse.
- (iv) Ensure that the 120 V AC power for PLC is reliable and free of voltage transients usually an inverter fed by 125 V DC station batteries.
- (v) Confirm that the final PLC software coding has been well documented and that the document is available for future plant maintenance and trouble shooting.

Finally it should be ensured that written installation instructions which include detailed dimension records sheets have been provided by manufacturer. These sheets are used to record important installation information e.g. the installed generator air gap, installed turbine clearances, installed turbine, generator speed increaser shaft alignment. The completed dimensional record sheets should be compared with manufacture's tolerance requirement to confirm proper installation of the equipment. These will also be used during future unit maintenance outages.

CENTERING AND ALIGNMENT OF VERTICAL HYDRO GENERATOR

1.0 PROCEDURE

1.1 Centering of Rotor

- (i) Alignment of rotor during installation is ensuring rubbing surface of thrust bearings and the shaft mirror disc face are perpendicular to rotor centre.
- (ii) The procedure for rotor centering is as follows.
 - (a) First centering of turbine shaft is checked since its flange and centre line from reference bases centering of the generator rotor
 - (b) The generator is then provisionally centered relative to turbine shaft.
 - (c) Then perpendicularity of rubbing surfaces of thrust bearing and shaft flange face to the generator shaft centre line is checked.
 - (d) Then final alignment of generator and turbine is done.

1.2 Procedure for alignment of unit

- (i) Set elevation of thrust bearing
- (ii) Carry out rotational check of gen. shaft
- (iii) Calculate maximum throw and direction
- (iv) Minimize throw by scrapping insulated surface of mirror disc.
- (v) Couple generator shaft with turbine shaft
- (vi) Again check elevation & level of thrust bearing
- (vii) Carry out rotational checks
- (viii) Find out run out at LGB & coupling flange
- (ix) If throw is still more again carry out scrapping of insulated surface of mirror discs. Again check by rotation method and repeat till throw is within limit
- (x) Check throw and its direction at TGB
- (xi) Minimize throw by providing shim between coupling flange
- (xii) Check throws at LGB, coupling flange and TGB, ensure these are within limit. This is necessary to establish unit axis.
- (xiii) Check verticality of shaft with respect to duly leveled thrust bearing at correct elevation.

1.3 Coupling of Shafts

- (i) Before coupling of generator shaft and turbine it is to be checked that requirements shown in Table-1 are met:
- (ii) Coupling
 - a. Force of tightening of all bolts should be identical
 - b. Elongation of bolts, required to ensure proper tightening
 - c. Soundness of flange connection is checked by feeler gauge of 0.03 mm thickness

Table 1 : Allowable deviation in shaft coupling

S. No.	Type of Deviation	Allowable Deviation in mm
1.	Shift of Gen. shaft axis with turbine shaft axis	0.01 mm
2.	Non parallelity of mating surfaces of both flanges at shaft dia. Upto 600 mm Upto 1000 mm Upto 1500 mm	0.020 0.025 0.030

1.4 Setting Elevation of Thrust Bearing

- (i) Elevation of upper bracket should be such that the runner is at desired level
- (ii) Allowance for deflection of upper bracket due to weight of rotating parts and initial thrust should be taken into account.
- (iii) Mount thrust bearing on upper bracket
- (iv) Check perpendicularity of thrust collar with shaft
- (v) Set elevation of bearing, by providing shims under flexible support

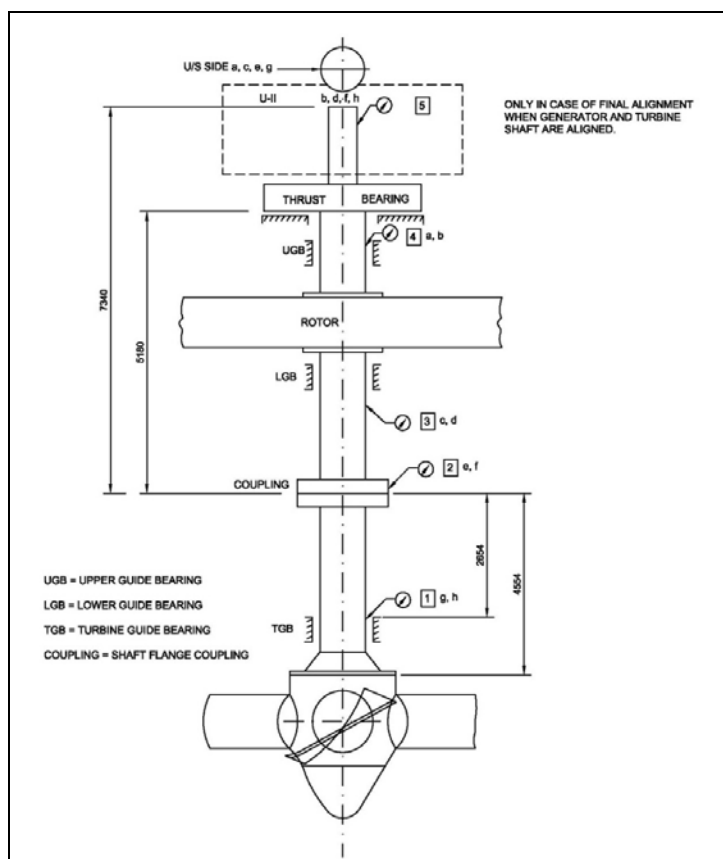


Fig 1 : Position of Dial Indicators

1.5 Rotational Checks

- (i) Arrangement to turn rotor by 360° in steps of 45° smoothly
- (ii) In machines having high pressure lubrication of TH.B. It is possible to rotate machine manually.

- (iii) In other machine mechanical arrangement is made and rotation is done with the help of EOT crane. For lubrication of thrust pads in such case is ensured by using Molybdenum-di-Sulfide Grease (Molysulf Grease)
- (iv) Mount dial Gauges at UGB, LGB, Flange & TGB to find out run out (Fig 5)
- (v) Throw and its direction is calculated by resultant method (Table 2 & Fig 6)

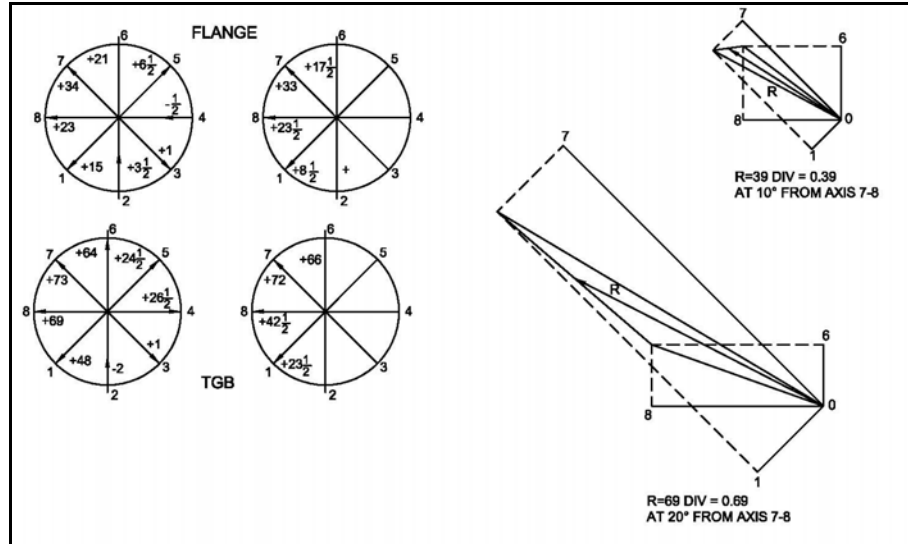


Fig 2 : Resultant Method of Throw Calculation

1.6. Shimming or Scrapping

Amount of Scrapping or Shim Thickness (Fig 3 & 4)

$$t = \frac{\text{Maximum resultant throw} \times \text{diameter}}{2 \times \text{effective length}}$$

- (i) For correcting gen. shaft
 - (a) t = amount of scrapping/shimming
 - (b) Max. throw at coupling flange for correcting gen. shaft
 - (c) Eff. Length = distance between insulated surface of mirror disc and coupling flange
 - (d) Diameter = Dia. of thrust bearing mirror disc.
- (ii) For correcting turbine shaft
 - (a) Max throw at TGB(t= amount of shimmming/ scrapping)
 - (b) Eff. Length = Between Flange and TGB (Dial Gauge Locations)
 - (c) Diameter = Dia. of coupling flange

Shimming or scrapping to be done at coupling shaft joint. Shimming is done in the direction of throw while scrapping is done in opposite direction. Exact replica of flange on some hard sheet is prepared with marking of bolt holes locations. Shim cutting is done carefully avoiding holes. There should be appropriate gap between two shims so that they are not over lapped. Rounding of sharp edges is also to be ensured to avoid high points.

**Table 2: Resultant Method of Alignment
(Actual Example of Unit-I of a Power Station)
(Vectorial Resultant – at Fig.)**

Position of Dial Gauge	Upstream Side Dial Gauge								Erection bay Side Dial Gauge							
	No. of Point at Shaft	UGB a	LGB c	Flange e	TGB g	c-a	c-a	g-a	UGB b	LGB d	Flange f	TGB h	d-b	f-b	h-b	No. of Point at Shaft
0 ⁰	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
45 ⁰	1	+ ½	Dial Gauge was not fixed	- 32	- 46	Dial Gauge was not fixed	- 31.5	- 45.5	0	Dial Gauge was not fixed	+ 1	+ 1	Dial Gauge was not fixed	+ 1	+ 1	3
90 ⁰	2	0		- 40	- 85		- 40	- 85	+ 3½		+ 3	+ 30		- ½	+ 26½	4
135 ⁰	3	0		- 40	- 86		- 40	- 86	+ 6½		+ 13	+ 31		+ 6½	+ 24½	5
180 ⁰	4	0		- 30	- 65		- 30	- 65	+ 7		+ 28	+ 71		+ 21	+ 64	6
225 ⁰	5	+ 1		- 8	- 22		- 9	- 23	+ 7		+ 41	+ 80		+ 34	+ 73	7
270 ⁰	6	- ½		+ 15	+ 26		+ 15½	+ 26½	+ 7		+ 30	+ 76		+ 23	+ 69	8/0
315 ⁰	7	0		+ 6	+ 17		+ 6	+ 17	+ 3		+ 18	+ 51		+ 15	+ 48	1
360 ⁰	8/0	- 1		+ 4	+ 14		+ 5	+ 15	+ 1		- 6	- 1		- 7	- 2	2

- Note: (a) The readings of upstream side dial gauges are not acceptable as closing error is more.
(b) Erection bay side readings are fine because:
(i) Closing error is negligible
(ii) Curve plotted along X-Y axis is nearer to sine curve
(iii) These are confirmed in subsequent rotation also.
As such further calculations and correction is based on these.

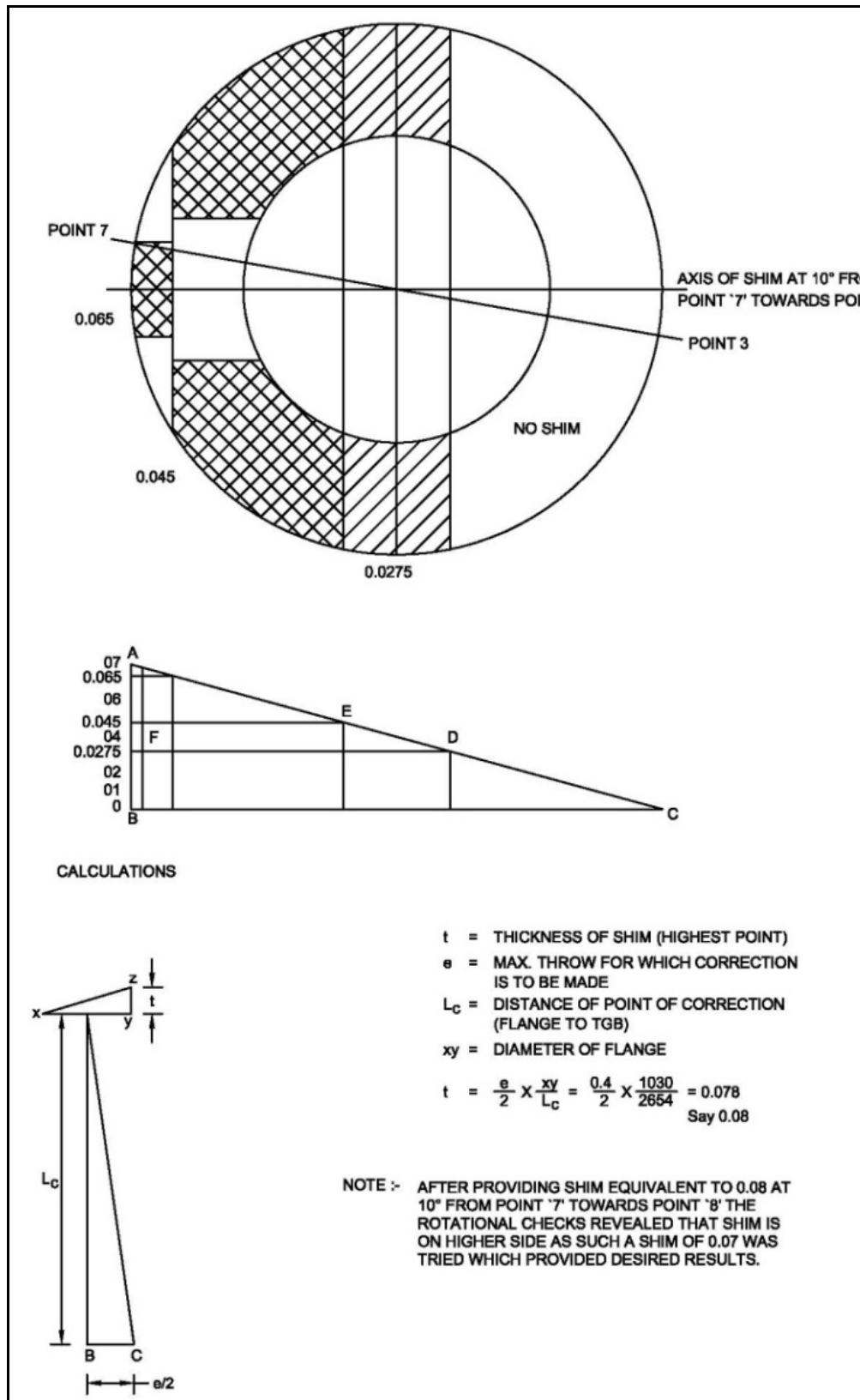


Fig 3 : Calculation of Shims between Flanges

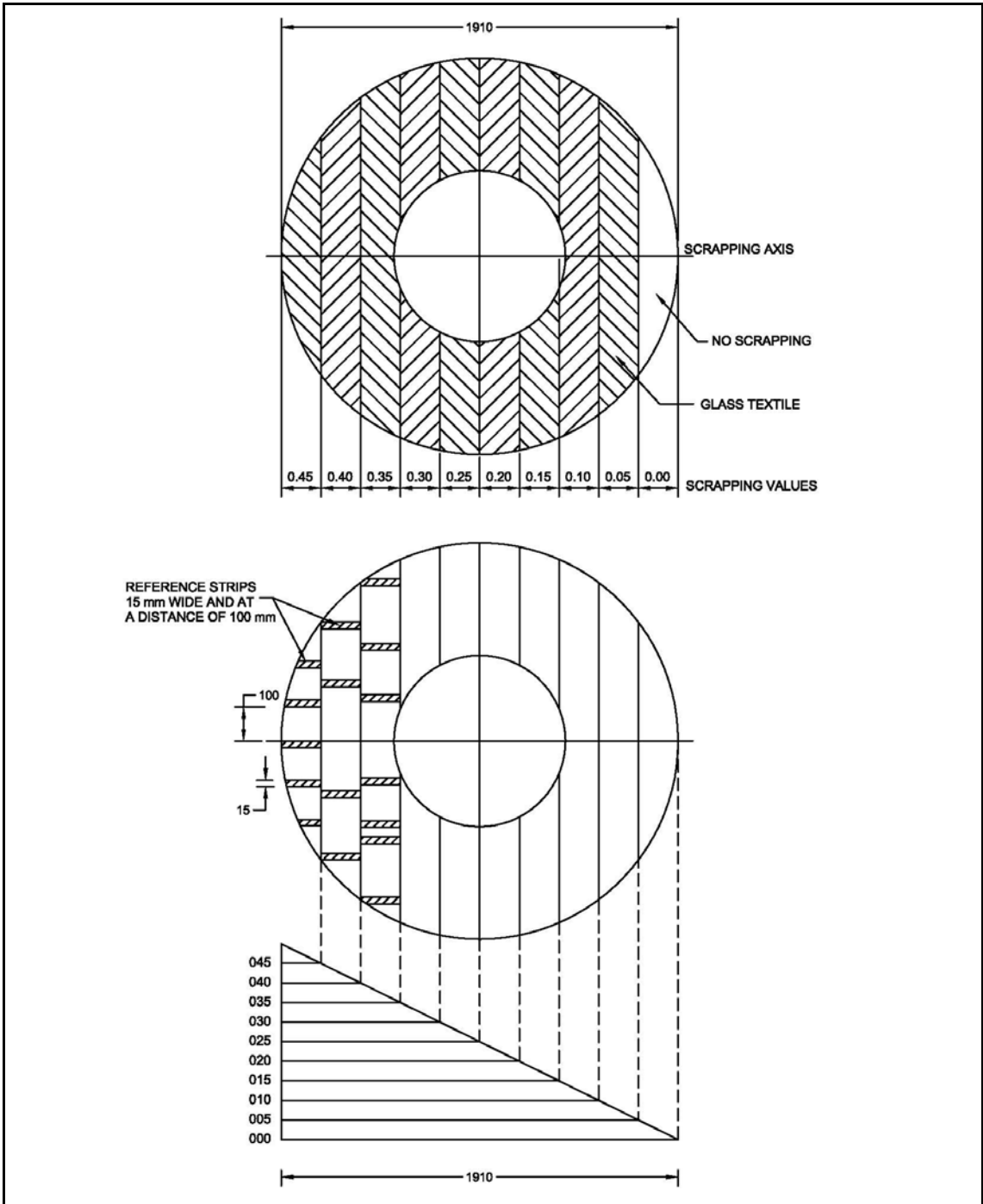


Fig 4 : Illustrative Example of Scrapping at Textolite surface on the back of mirror disc coupled with thrust collar

1.7. Checking Verticality of Shaft (Fig 5)

Four piano wires with dash posts are placed as shown in the figure. Precession stick micrometer is used to measure a_1, b_1, c_1, d_1 and a_2, b_2, c_2, d_2 . The whole procedure of calculation of deviation is given with the figure its self. If the deviation is less than 0.05 mm/m of shaft length, them verticality is taken to be normal otherwise corrective measure has to be taken.

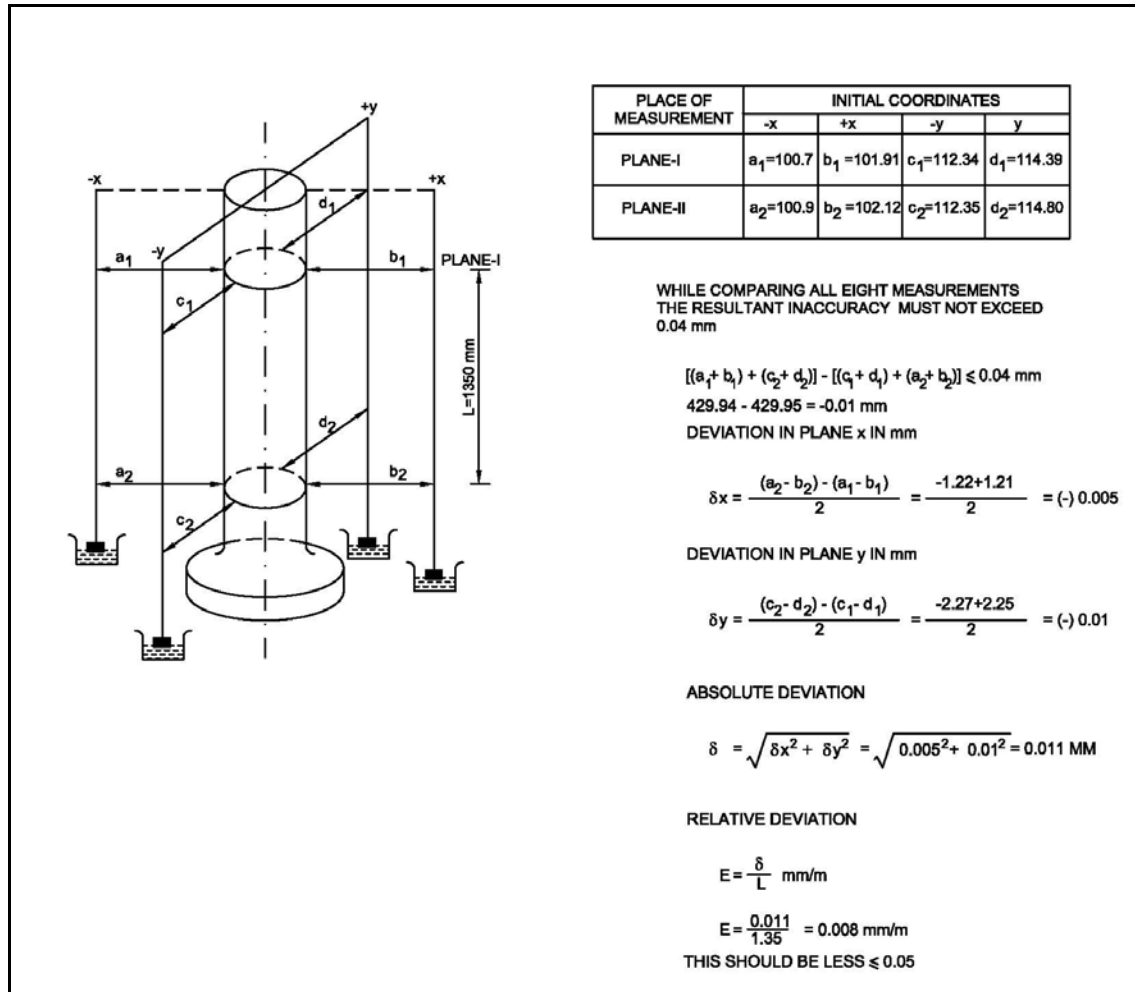


Fig 5 : Checking Verticality of Generator Shaft

VII. Load Sharing of the Thrust Bearing

There must be uniform distribution of load between all thrust pads. Over loading of any pad may cause destruction of babbit material and failure of thrust bearing. The load is equalized after the generator shaft wobble has been eliminated or after the turbine and generator shaft has been connected and the unit has been aligned.

Uniform distribution of load is achieved by tightening supporting screws against the elastic plates beneath the shoes carrying rotor weight. This is done by striking the spanner with sledge hammer.

The load distribution is adjusted in this manner by first checking that all supporting screws are tightened equally. The position of locking device of each support screw is then marked with the vertical lines on it and on the thrust bearing housing or on the support stand.

A sledge hammer of approximately 8 kg weight is then used to strike hard once or twice at the end of 600 to 700 mm long spanner placed on the head of supporting screw considered. The process is carried out on all shoes with the same force. The position of all pads are measured after each round with a slide caliper and distances between the lines on the locking devices and on thrust bearing housing are recorded. This tightening process is repeated several times until distances between the lines are increased equally by hammer blows on all supporting screws. Another round of tightening the screws is then performed with lighter sledge hammer. Adjustment is considered completed if the distance between the lines has not changed in one round.

The load can be adjusted by using a dial indicator also as shown in Fig. 6.

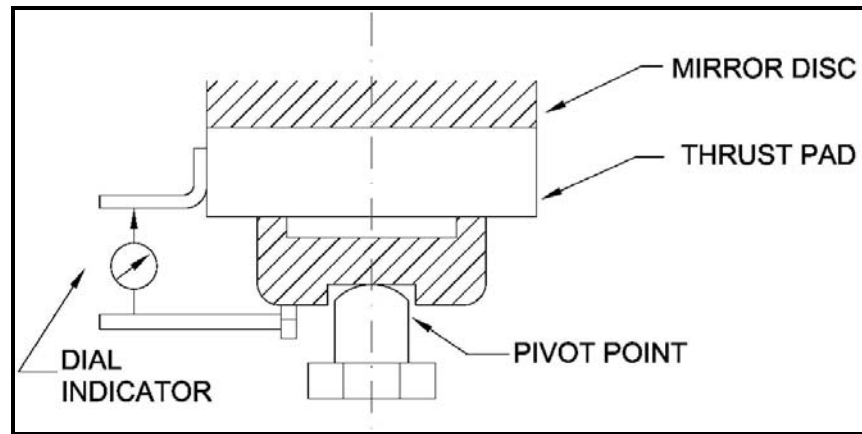


Fig. 6 : Load sharing of thrust pads

The support screws must be locked after completion of this activity.

ALIGNMENT OF HORIZONTAL GENERATING SET**1.0 PROCEDURE**

- (i) The centre line of turbine bearing with respect to longitudinal axis of generator is checked by stretching a horizontal wire through spiral casing and along bearing centre line. Correct position of wire inside spiral casing is checked with inside micrometer.
- (ii) Bearing housings are centered with respect to longitudinal axis of generator by an end gauge which is inserted into the bores of bearing shell
- (iii) Ensure clearances of guide vanes at both ends are uniform and are as per drawing in mm. Feeler gauge is used to check these. These can be adjusted by tightening bolts. When distributor is closed there should be no clearance in guide vanes.
- (iv) Measure clearance with feeler gauge between shaft and the lower bearing shell to ensure correct position of rotating parts of turbine.
- (v) If there is no clearance, it indicates that the shaft is resting on both bearings.
- (vi) The horizontal position of shaft is checked by placing a level successively on both bearing journals. Then turn the level by 180° and place in the same position as before and check level. Arithmetic mean of two measurements should be taken, if two differ (more than one division). If difference is more investigate reasons and take remedial measure.
- (vii) The permissible inclination in shaft should be as per drawing in mm per m length of shaft.
- (viii) The permissible inclination in transverse direction should be as per drawing in mm / m of shaft length. Inclination should also be checked with level.
- (ix) The radial clearance between runner and the cover plates which should not exceed recommended limits and these should be uniform.
- (x) The radial gaps in static and rotating labyrinths should be as per drawing.
- (xi) The axial gaps in labyrinth seals should also be measured and these should be within 0.2 to 0.3 mm. These are measured by pushing the rotating parts to extreme positions.
- (xii) All the clearances and gaps are measured again after turning the rotating parts through 180° and 360°. These should be within permissible limit.
- (xiii) 1 mm thick lead wire of 30 to 50 mm length is used to measure clearance between turbine shaft and the upper bearing shell. Length of this wire is placed across the shaft in two sections beneath the shell which is then tightened well. The thickness of flattened wire thus indicates the clearance on top of the shaft which should be 0.2% of shaft dia.
- (xiv) The lateral clearance between the shaft and the lower shell are checked at a depth 10 to 12 mm below the plane in which bearing is split. These should be half of clearance between shaft and upper bearing shell.
- (xv) The adjusted shaft of turbine will be reference base for alignment of generator shaft.

1.1 Preliminary alignment of generator shaft

Alignment consists

- (i) Removal of misalignment of turbine shaft and generator shafts (Fig 1)
- (ii) Making generator shaft horizontal.
- (iii) Making centerlines of generator and turbine shaft coincide.

- (iv) Alignment is carried out relative to half couplings of turbine and generator shafts.
- (v) Wobbling at half coupling should not be more than 0.2 mm.

1.2 Procedure for preliminary alignment

- (a) The turbine and generator shafts are forced to their outer most position after the generator is assembled and clearance between half coupling is ensured. This clearance should be 5 to 6 mm (or as designed)
- (b) A straight edge is pressed against the turbine or generator shaft along generator axis in four diametrically opposite positions. Clearance if any is checked and equalized. For this shims are provided beneath foundation frame.
- (c) By measuring clearances between faces of half coupling at four points, alignment of shafts at joint is checked. (Refer Fig 2)
- (d) The position of generator is first checked in vertical plane than in horizontal.
- (e) Misalignment is corrected by placing shims under foundation frame.
- (f) After this foundation bolts are tightened and locked.

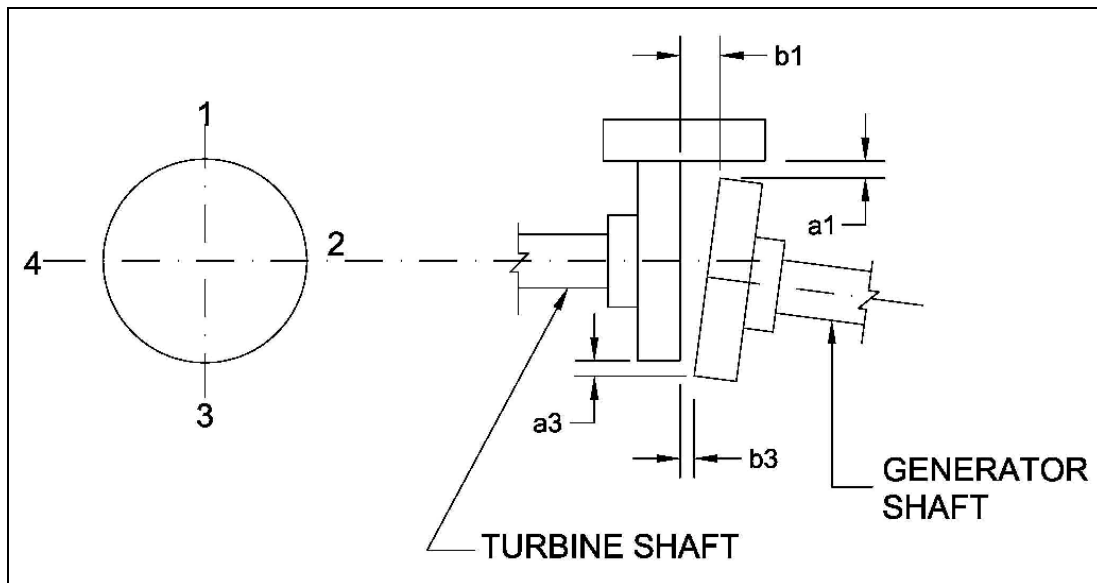


Fig. 1 : Misalignment of turbine and generator shafts

1.3 Procedure for final alignment

- (a) Check positions of half coupling.
- (b) Measure clearances between half couplings in the initial position and after turning through 90°, 180°, 270° & 360°

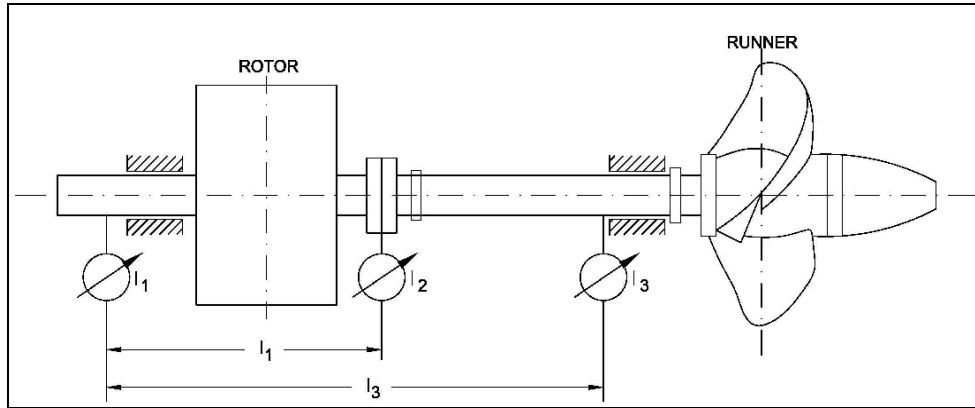


Fig 2 : Location of dial gauges for checking alignment

- (c) The position of half coupling should be same of initial position and after rotation by 360°
- (c) For radial displacement of half couplings is measured by mounting a dial indicator on a bracket fixed at turbine half coupling (Fig 3).

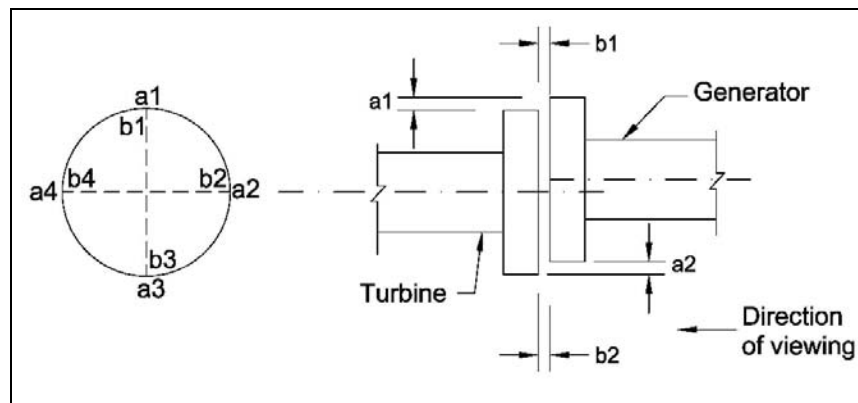


Fig. 3 : Radial displacement of half coupling

- (d) Determine alignment and inclination of generator axis first in vertical, then in horizontal plane. Record measurement in Table-3.

Table 3 : Table for recording measurement

Site of measurements	Clearance “b” between half-coupling ends, mm						Distances “a” of half-couplings, mm				
	Positions of rotating parts of generating set										
	0°	90°	180°	270°	360°	Mean Clearance	0°	90°	180°	270°	360°
Top $a_1;b_1$	+	+	+	+	+	+	+	-	-	-	+
Bottom $a_3;b_3$	+	+	+	+	+	+	-	-	+	-	-
Right $a_2;b_2$	+	+	+	+	+	+	-	+	-	-	-
Left $a_4;b_4$	+	+	+	+	+	+	-	-	-	+	-

Note: The “plus” sign indicates that measurements were carried out at this point.

- (e) Compute displacements of generator rotor, for ensuring correct position.
- (f) Move generator rotor in correct position and check axis.
- (g) Check position of stator.
- (h) All measurements of clearances and displacement should be recorded viewing from generator side.
- (i) Magnitude ‘a’ are measured in one position and after turning rotating parts by 90°, 180°, 270° & 360°
- (j) End clearance ‘b’ is measured at four points in order to eliminate the effects of axial displacement of the rotor. The mean clearance is then calculated for each position of generator rotor (Fig 11).
- (k) The measurements are satisfactory if both [(a₁ + a₃)-(a₂+a₄)] and [(b₁ + b₃)-(b₂+b₄)] are within 0.02 mm.
- (l) All measurements are repeated till good set is achieved.
- (m) Permissible deviations in alignment of horizontal hydro generating unit are given in table-4.

Table 4 : Permissible deviations in alignment of horizontal hydro generating unit

Rotational speed of generating set, rpm	Permissible skewness and eccentricity, mm
Up to 500	0.15
Up to 750	0.10
Up to 1500	0.08

- (o) If, after alignment radial and end clearances at diametrically opposite point are within limit as shown in table, the alignment is taken as adequate otherwise repeat alignment procedure and compute more accurately.
- (p) Computing eccentricity of generator shaft with respect to turbine shaft (measurement ‘a’) and its direction and computing inclination and its direction (measurement ‘b’) is done as explained below: (Fig 4)
Displacement of generator shaft axis due to eccentricity relative to turbine shaft:

$$\begin{array}{ll} \text{Horizontal plane} & h_x = (a_2 - a_4) / 2 \\ \text{Vertical plane} & h_y = (a_1 - a_3) / 2 \end{array}$$

- (q) The displacement of bearings due to inclination of shaft is given by difference between end clearances. They depend on the location of bearings and dia. of coupling ‘D_c’.

- (i) Front bearing in horizontal plan

$$\begin{array}{l} k_{x1} = (b_2 - b_4) l_1 / D_c \\ k_{x2} = (b_2 - b_4) l_2 / D_c \end{array}$$

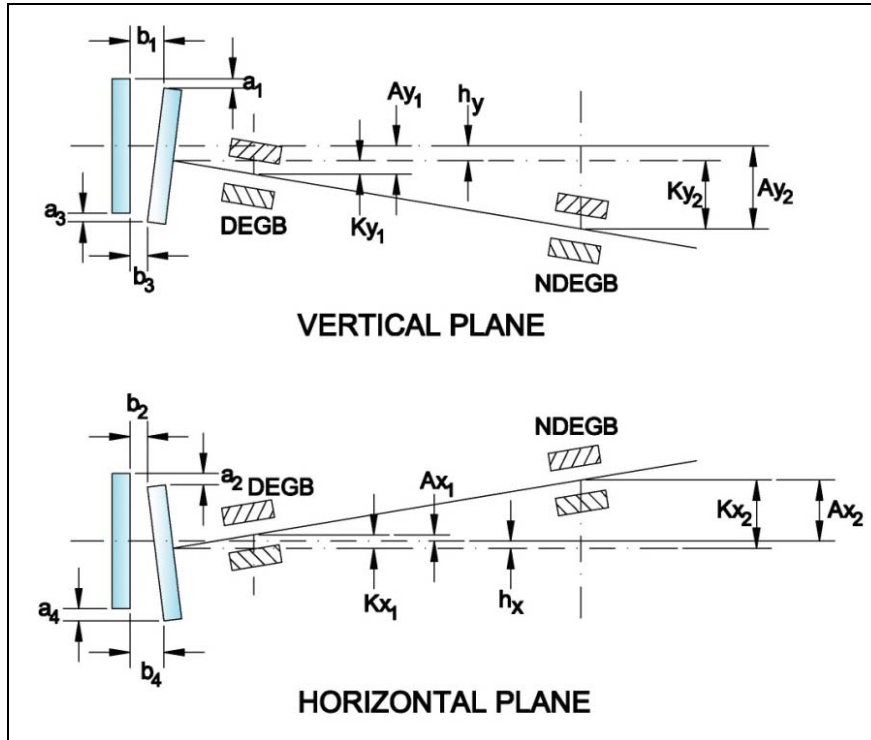


Fig 4 : Determining Displacements of Generator Bearings

(ii) Front bearing in vertical plane

$$k_{y1} = (b_1 - b_3) l_1 / Dc$$

$$k_{y2} = (b_1 - b_3) l_2 / Dc$$

Correct position of the generator rotor can be obtained by moving its bearings by following distances:

(i) Front bearing – horizontal plane

$$A_{x1} = (a_2 - a_4) / 2 + (b_2 - b_4) l_1 / Dc$$

$$A_{x2} = (a_2 - a_4) / 2 + (b_2 - b_4) l_1 / Dc$$

(ii) Front bearing – vertical plane

$$A_{y1} = (a_1 - a_3) / 2 + (b_1 - b_3) l_1 / Dc$$

$$A_{y2} = (a_1 - a_3) / 2 + (b_1 - b_3) l_2 / Dc$$

- (r) The rotor must be moved up and to the right if the computed displacement is positive.
- (s) The rotor must be moved down and to left if the computed displacement is negative.
- (t) The air gaps of generator are checked after completing alignment. These should be equal all around the circumference.
- (u) The turbine and generator half coupling are connected after completing alignment of generator shaft.

ANNEXURE 3

HIGH VOLTAGE TESTING OF HYDRO GENERATOR

(Refer: IS-4722-2001)

S. No.	STAGE OF TESTING	TEST VOLTAGE (50 C/S A.C.)	DURATION
A. STATOR			
1.	Winding bars before laying in stator split.	$2U+8000V$	1 MIN.
2.	Upper & lower layers of winding bars separately after laying in stator split but before connecting.	$2U+4000V$	1 MIN.
3.	Stator winding brazed and insulated at joints after drying out.	$2U+1000V$	1 MIN.
4.	Stator winding of the assembled machine before starting.	$0.8(2U+1000V)$	1 MIN.
B. ROTOR			
1.	Assembled pole coils before mounting.	$1.15 \text{ of } V_f$	1 MIN.
2.	Pole coils after mounting on rotor and after wedging but before inter-connection.	$1.1 \text{ of } V_f$	1 MIN.
3.	Inter turn insulation of each pole on rotor before inter- connection.	$35-62.50 \text{ V}$	5 MIN.
4.	Slip ring after mounting on shaft.	$1.20 \text{ of } V_f$	1 MIN.
5.	Current carrying leads before connection with the pole winding.	$1.25 \text{ of } V_f$	1 MIN.
6.	Pole coils after interconnection and connection with slipring and current carrying leads. (after dry out).	10 times the rated field voltage(U_f) with a minimum of $1500V = V_f$	1 MIN.
7.	Pole coils of assembled machine before starting.	$0.8 \text{ of } V_f$	1 MIN.

U =generator rated voltage
 U_f =generator rated field voltage
 V_f = $10U_f$ (with a minimum of 1500V)

FIELD ACCEPTANCE TEST FOR GENERATORS

- 1.1** Field acceptance tests (all units). These tests consist of:
- (i) Stator dielectric tests. These tests consist of: Insulation resistance and polarization index, Corona probe test, Corona visibility test, Final AC high potential test, Partial discharge analysis (PDA) test, and Ozone detection (optional).
 - (ii) Rotor dielectric tests.
 - (iii) Stator and rotor resistance tests.
 - (iv) Noise and vibration measurements.
- 1.2** Special field test (one unit of series). These tests consist of:
- (i) Efficiency tests.
 - (ii) Heat run tests.
 - (iii) Machine parameter tests.
 - (iv) Excitation test.
 - (v) Over speed tests (optional).
- 1.3** Temperature rise test. This test should include
- (i) Oil and babit material of guide and thrust bearing.
 - (ii) Magnetic core.
 - (iii) Stator winding, rotor poles.
 - (iv) Air and cooling system.

ANNEXURE 5

LIST OF TESTS/ CHECKINGS OF HYDRO GENERATING UNIT

(During Pre-commissioning AND Commissioning)

- NOTE:1. Guide lines indicated here under are general and may vary from manufacturer to manufacturer.
2. Items not applicable for particular turbine can be indicated as NA.

Serial No.	Activity	Remarks. Results/test values obtained
A	Erection	
1	Checking the position /Alignment with respect to center line and axis of components	
a	Turbine	
b	Generator	
c	Gear box	
2	Individual & combined alignment of above.	
3	Positioning of Oil Pumping Unit with Accumulator	
4	Positioning of Cooling water	
5	Positioning of Drainage and Dewatering system	
6	Positioning of LAVT, NGT/NGR, Excitation transformer, local control panels, AC/DC distribution boards, etc	
7	Positioning of Control & protection, metering, battery chargers, LTAC, 11KV switchgear, Governor, SEE, Synchronizing Panels etc;	
8	Outdoor equipments like Transformers, Breakers, Isolators, LAs, CTs, PTs, MOM & Marshalling boxes, etc;	
9	Stringing of outdoor bus bars & equipments,	
10	Checking Grounding of all equipments	
11	Checking Comprehensive cabling & termination as per cable schedule	
B	Testing & Commissioning	
1	Testing of DG set & or start-up power source	
2	Commissioning of charger panels & extension of DC supply to various panels etc.	
3	Testing of fire protection systems	
4	Commission DG set in all respect	
6	(i). Test LTAC panels for good IR values. (ii). Operation of individual breakers, interlocks. (iii). Checking of change-over of incoming breakers preferential -wise by simulation etc. (iv). Charging of panels with start-up source.	
7	(i). IR & PI values of generator stator windings (1 000 v megger, min. 50 M-ohms for 1 KV, PI- min.2); dry-out if necessary.	

Serial No.	Activity	Remarks. Results/test values obtained
	(ii). Measurement of stator & field winding resistances, IR & impedance values of field winding (500 V megger, value in M-ohm & impedance as per design), healthiness of heaters. (iii). Proper operation of brakes, HP lubrication system, etc. (iv). Tan delta measurements, if contemplated.	
8	(i). Hot-oil circulation of unit & auxiliary transformers, Checking of BDV & PPM content. (ii). Measurement of winding resistances, IR & PI values (iii). (HV-E, LV-E, HV-LV: 2.5kV megger, results comparable to factory tests). (iv). Magnetic balance, proper operation of buccholtz relay, oil-level switches, PDV, temperature high & too-high alarm/ trips, local/remote operation of oil pumps, change-over, airing-out, adjustment of proper oil/water pressure & flow rates, differential pressure & its relay setting, healthiness of silica-gel, etc.	
9	(i). HT- side breakers: Filling of SF6 gas. (ii). Operational Checking, pole discrepancy, trip circuit supervision circuits, chronograph Checking, alarm, lock-out & inter-lock Checking, remote operations, protection tripping etc.	
10	(i). Alignment of isolators. (ii). Motorized operation, remote operation, inter-locks etc.	
11	Checking & ensuring Line -Line & Line -Earth clearances for all bus wires & equipments at ODY	
12	Checking & ensuring grounding of all equipment	
13	Measuring earth-mat resistance for proper value. Checking its value with the design calculations	
14	Protection relays- soft-ware loading, Checking for proper operation of all protections, adopt recommended settings	
15	Extending power supply to various auxiliary systems like OPU sets, Lube-oil systems, cooling water system, etc; adjust for required flow at recommended pressures, ensuring proper change-overs, alarm/trip settings of various associated limit/pressure/ level/flow switches & commissioning each as per schemes.	
16	Checking all individual CTs, PTs (415V/1 1kV/220kV) for proper PI -P2 positioning, ratio & polarity; IR values.	
17	Checking the synchronising scheme	
18	Dry stroking of MIV/butterfly valve/pen stock gate as the case may be; adjust for proper opening/closing times, adjust correct settings of limit & pressure settings, Checking for proper indications, alarms, trips etc. as per scheme.	
19	Dry stroking of turbine, ensure proper beddings, achieve	

Serial No.	Activity	Remarks. Results/test values obtained
	recommended conjugation of guide vane vs. blade incase of Kaplan, nozzle vs. deflector in case of Pelton runner, box-up, assemble accessories , keeping ready for initial spinning	
20	Checking of individual schemes for proper wiring, correct interlocks as per approved drawings.	
21	Checking all protection & annunciation circuits by actual simulation of devices wherever feasible & ensure operation of trip relays, opening of associated breakers, correct alarm & annunciations as per approved logic diagrams	
22	Checking operation of MIV under dry and as well as in wet conditions	
23	Filling of penstock gradually and observe for leakage in MIV, by pass and air release valves etc	
24	Filling of draft tube in case of reaction turbines from D/S & testing of DT gates.	
C	Initial Spinning, Pre -commissioning Tests	
1	Re Checking & ensuring all components of unit are boxed-up properly, & the brakes are released	-
2	Starting all auxiliaries like (i). Cooling water pumps, (ii). OPUs, GLOP, etc; & ensuring requisite pressure and flow rates at different points as per scheme.	
3	Opening MIV/Penstock gate/ Butterfly/Spherical valve as the case may be.	
4	Starting Lube oil pump & ensure requisite oil pressure buildup	
5	Open slowly the GVs/Needles just enough to start rotation of rotating parts. Observing closely for absence of rubbing sounds & ensure rotation is smooth	
6	Increasing speed gradually while closely monitoring smooth running & that temperatures & vibrations are normal - locking the governor position at no-load/ rated speed condition, allowing the machine to run at rated speed till all temperatures stabilize (not more than 1 degree C in an hour) - recording stabilized temperatures & vibrations. With the unit now running @ rated speed; there will be a slight voltage of around 100 to 200 volts on the stator terminals & corresponding milivolts on the secondaries of 11 KV PTs. Measuring and recording this voltages at PT cubicle & further at all relays, meters, excitation & other equipments as per scheme. Stopping the unit & ensure proper application of brakes.	
7	Tripping the unit with emergency push button and Checking for closure of BFV etc	
8	Braking test for verification of stopping time of the unit	
D	Short Circuit Characteristics	
1	(i). Shorting the generator line terminals at XLPE terminal and cables shall be adequately rated to withstand	

Serial No.	Activity	Remarks. Results/test values obtained
	<p>continuous over-load rating current of the unit.</p> <p>(ii). Ensuring NGT isolator is closed. Start the unit & bring the unit to rated speed.</p> <p>(iii). Slowly & gradually increase field current to achieve around 1 to 2% of stator rated current.</p> <p>(iv). Measuring and recording the presence of corresponding secondary currents at all CTs, meters, relays & other equipments fed by them.</p>	
2.	<p>(i). Shorting the secondary side terminals of neutral side CTs of Overall Differential protection at 87GT relay terminals.</p> <p>(ii). Measuring the differential (87 G) CTs current at corresponding relay terminals of 87G which should be equal. Assuming shorting is made after the line side CTS of 87G, the spill current in the operating coil circuit of the 87G relay should be zero or minimal.</p> <p>(iii). Increasing the field current gradually while continuously monitoring the spill current (which should continue to be zero) till 50% of rated current is achieved. The relay should be stable with negligible spill current. This establishes the stability requirement of the relay.</p> <p>(iv). Reducing excitation to zero & reverse the polarity of any one set of CTs feeding 87G relay (for numerical relays just shorting of one set CTs may be sufficient) & slowly increase the field current while monitoring the spill current in the 87G relay. The relay should operate at the set current (normally 10%) & trip the master trip relays.</p> <p>(v). Unit should be shut-down & excitation should be switched off.</p>	
3	<p>(i). Restoring the normalcy of reversed polarity of CTs (or remove the short as the case may be) & restart the unit. At rated speed, gradually increase the field current. At every 20% of rated stator current (I_n) & at continuous overload rating current of the stator; note down associated field current (I_f) & field voltage (V_f).</p> <p>(ii). Reducing excitation to zero, open field breaker & shut- down the unit. Plot the SCC graph of measured I_f vs. I_n values; I_f being plotted on x-axis. Compare with factory test results.</p> <p>(iii). Reducing excitation to around 50% of rated current & reverse polarity of one or two CTs of Negative phase sequence relay & ensure its operation.</p> <p>(iv). Restoring reversed polities of CTs. Remove the shorting arrangement after the unit completely comes to rest.</p>	

Serial No.	Activity	Remarks. Results/test values obtained
	(v). Do not interconnect the unit transformer.	
4	(i). Checking of Stator Earth Fault Relay (DGF) 95%:- Create a Line to Ground fault by connecting a 7/20 gauge wire from any of the R-Y-B phase terminal to the earth. (ii). Restarting the unit & bring it to rated speed. Checking for the presence of a small voltage across NGR. & then at the relay terminals. Setting of the relay may be reduced to the minimum possible. While closely monitoring this voltage, increase field current slowly till the relay setting voltage appears across the relay & causes the relay to operate & trip the unit. (iii). Allow for the unit to come to standstill before removing the simulated ground fault	
5	(i). Repeating the process by grounding one phase on neutral side to ensure 95 to 100 % E/F relay function. (ii). Disabling of starting inter-lock could be necessary.	
E	Open circuit characteristics	
1	(i). Restarting the unit & bring it to rated speed. Sufficient voltage must be available now due to residual magnetism. (ii). Checking & ensure correct PHASE SEQUENCE directly at the generator terminals. (iii). Slowly increase the field current & ensure uniform build-up of voltage on all three phases. (iv). Measure presence of PT secondary voltages at all PTs & at all meters, relays & other terminations as per scheme. At every 20% rated voltage; record Vf, If & generator voltage Vn. At 100% Vn, measure PT secondary voltages again. (v). Checking the PHASE SEQUENCE & ensure it is as per scheme for all the sets of PT secondary.	
2	(i). Reducing the setting of V/Hz relay to least possible value & ensure the operation of the relay. Slight increasing of voltage & reducing of speed may be required for this. (ii). Tripping of the unit may be blocked for this protection. Restore normal setting.	
3	(i). Reducing the setting of Over Voltage relays. (ii). Increase the voltage suitably to ensure proper operation of same.	
4	(i). Regularize transformer connections. For small units, closing of 11 KV breaker may be sufficient. Short the HT terminals after the HT CTs using same size conductors as used for regular connections. Remove the earlier shorting made on the secondaries of neutral side CTS.	

Serial No.	Activity	Remarks. Results/test values obtained
	(ii). Restarting the unit & bring it to rated speed. Slowly increase field current & monitor currents in 89GT Overall Differential relay. Currents from two sets of CTs from neutral & HT side should be equal and that in the spill circuit should be zero. (iii). Raise field current till 50 % of rated current is passing. The relay should not operate & be stable. Reduce excitation to zero. Reverse polarity of one set of CTs. Slowly increase excitation while continuously monitoring relay currents. The current in the spill circuit should be double of individual CT currents. Increase excitation till the relay operates at the set value; normally 20 % of rated current.	
5	(i). Remove the short on HV terminals. Ground any one HV terminal after the CT using a 50 mm-square cable or thereabouts. (ii). Slowly raise excitation till around 5% of rated current is passing in the grounded phase. Measure currents in the CT circuits and spill circuit of transformer (iii). Restricted Earth Fault relay terminals. CT currents should be equal & spill current should be zero. Reduce current to zero & reverse the polarity of neutral CT. Increase excitation slowly. Spill current equal to double the value of CT currents should manifest. Increase current till relay setting is reached & the relay operates, (iv). Restore correct polarity of the NCT.	
6	Measurement of bearing current/shaft voltage	
F	Over-Speed Test	
1	(i). Governor is as yet under manual control. Start the unit & slowly bring it to rated speed; ensuring picking-up of various speed relays. (ii). Set the electrical over speed relay at the guaranteed over speed value. Raise the unit speed steadily till that speed & ensure operation of the relay	
G	Excitation & Governing	
1	Removing the soft-start arrangements made in the Excitation system, run the unit at rated voltage & commission auto-operation of AVR. Removing excitation & re-excite by field flashing.	
2	Commission Auto synchronizer	
3	Commission AUTO-OPERATION of Governor Unit is now ready for Synchronizing	
H	Phasing -Out Checking & Synchronizing	
1	By this time the transmission line would have been ready & charged up to the out going gantry. Checking for healthy IR values of HT BUS. Associate transmission engineers to ensure correct settings are made for	

Serial No.	Activity	Remarks. Results/test values obtained
	Line protection relays & charge the station HT bus by closing the line breaker/s. Ensure that the PHASE SEQUENCE is proper as per the station switch-yard layout	
2	Open the line breakers & render the HT bus dead. Start the unit, excite and charge the HT bus from the unit's supply. Checking again for correct phase-sequence. Switch on the Synchroscope. It should be point at 12'O clock position, the guard relay in the Checking-synchronising relay should have picked-up & 'ready for synchronising' lamp should be glowing, Depending on 'bright' or 'dark' lamp method adopted; corresponding lamps should glow brightly or completely dark as the case may be.	
3	Open the synchronizing breaker. Charge the bus from lines' end. Keep 89G isolator open. Switch on the synchronizing scheme & match unit voltage & then its speed/frequency to that of bus voltage & carry-out 'dummy' synchronizing. Open the synchronizing breaker, close 89G isolator & carryout regular synchronizing. Load the unit in 10 to 15 steps up to 25 % of rated load. Ensure all parameters are normal & temperatures are synchronizing.	
I	Load throw of Tests	
1	Loading of the unit to 25%, 50%, 75%, 100% and 115% gradually subject to hydraulic conditions as required along with balancing at different load conditions, if required.	
2	Measurement of bracket and shaft vibrations with excitation and at loads of 25%, 50%. 75%, 100% and maximum continuous rating. Adjust the governor timings, if warranted	
3	Load throw off test at each of the above loads to ensure that speed and pressure rises are within the guaranteed limits. Record the finally set guide vane or needle opening/ closing times.	
4	All functional Checking and fine-tuning of governor controls, conjugation etc., and prove the performance. All functional Checking and fine-tuning of AVR including proper setting of all the limiters etc., and prove the performance	
J	Reliability tests	
1	After commissioning the unit shall be run for 72 hours continuously at the maximum continuous rating (MCR) that could be achieved at the available head and discharge to prove its capacity (Output) and performance guarantee figures of temperatures of stator / rotor etc.	
2	72 hours capacity demonstration test is to be conducted to prove the guaranteed continuous over-load capability by running the unit as for as possible at that MVA loading. Temperatures rises shall not exceed the guaranteed values. The Reliability test shall be considered successful, provided that each item of the plant can operate continuously at the specified operating condition during this period. Minor	

Serial No.	Activity	Remarks. Results/test values obtained
	interruptions not exceeding four (4) hours during the Reliability tests shall not affect the total duration of Reliability tests	
K	Field Acceptance tests	
	Field acceptance tests shall be conducted to meet the functional guarantees specified for Turbine and Generator. The tests shall be conducted as per IEC-60041. The measurement so made will be the basis for the assessment of values guaranteed.	
L	Taking over:	
	After the successful completion of the "Reliability test" the unit will be taken over by the 'Owner' for 'commercial operation'. In case the rated head or discharge is not available to operate the unit at full capacity, the unit shall be provisionally taken over after completion of Reliability tests at available head or discharge. The Contractor shall prove the unit at full capacity immediately when the rated head and /or the discharge is available after which the unit will be 'Taken over' by the 'Owner'	
M	Protocol on Tests	
	A protocol on tests carried out at site including acceptance tests shall be prepared and supplied.	