Chapter 4
Maintenance and Repair of Electro-mechanical Equipment

Most of the electro-mechanical equipment in an MHP scheme is located in the power-house. The equipment may include an expansion joint, a gate or butterfly valve, a manifold or adapter, the turbine, end-use equipment such as a generator or agro-processing units, and instrument and control systems. Extensive maintenance and repair of this equipment may become necessary as a result of normal wear or ageing, inappropriate operational practices, faulty design or installation, or an accident. Before commencing disassembly of any unit, always study the layout of the unit carefully. Do not remove any components of the unit that do not need to be removed because there is always a possibility of creating additional damage during disassembly or reassembly. If the parts of the units can be assembled in different positions, the mating surfaces should be marked before disassembling in order to ensure that the components are reassembled in their proper positions after the repairs have been carried out.

4.1 Valves

Valves are usually provided in an MHP plant to open or shut off the water supply completely. They should not be used to control the flow. The most common types of valves are gate or butterfly valves. Butterfly valves have mostly been used in Nepal in recent years, since they are easier to install and operate. Considerable force may be needed to operate gate valves. Figure 4.1 shows typical butterfly and gate valves.

The main sources of damage to valves are silt, rusting, lack of lubrication, using too much force to open and close them, and wear and tear. The damage may be in the form of bent or broken spindles, damaged threads, damaged seat, leakage from the valve joint or body, and difficulty in operating the valve. A small amount of water leaking from the penstock to the turbine may not be a serious problem. If the flow is large, however, then it should be stopped, otherwise the turbine will rotate.

Leakage from the stuffing box or gland can sometimes be reduced by tightening the bolts around the spindle. If the packing is badly worn, however, then it should be replaced. The bolts should be unscrewed and the handle removed. The surfaces should be cleaned with a wire brush and new rings of sealing packing should be cut to size to fit the groove around the spindle. The number of rings needed can be determined from the available length of the spindle. When cutting new rings of packing, the length should be such that

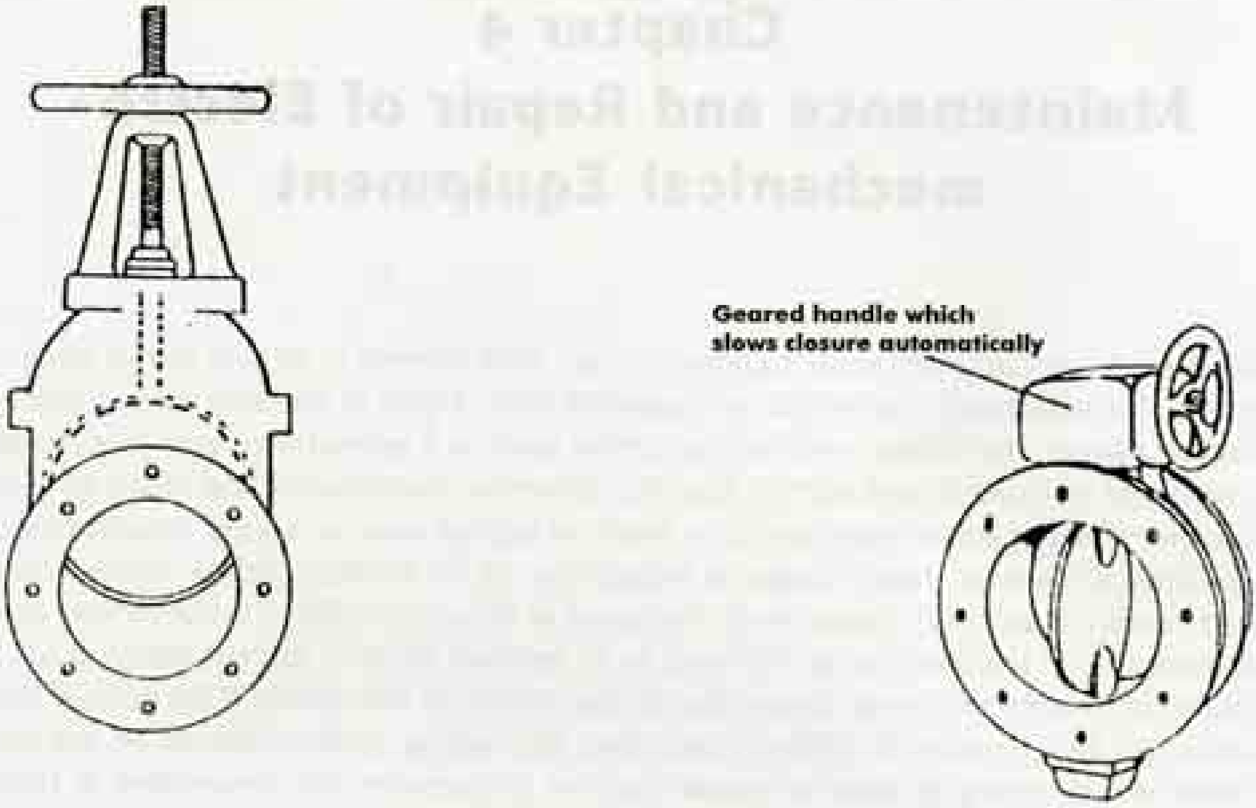


Figure 4.1: Typical Valves Used In MHP Plants

the gap between the ends of the rings when assembled is the minimum possible and there is no possibility of overlapping. Otherwise, the sealing will not be correct.

Gaskets are also provided at other joints in the valve, but most of them are not in contact with a moving part and damage is usually rare. If a joint with a gasket is leaking, then the bolts should be removed, the surfaces cleaned, and a new gasket of the same size and material installed.

If the valve does not close properly or leaks, some silt or rust may have deposited at the seat. In this case, the whole valve assembly should be removed and dismantled and the mating surfaces cleaned properly with a wire brush or emery paper if necessary.

Some valves, especially butterfly valves, may have a gearing system to transfer the motion at right angle and facilitate operation. This gearing system should be kept properly lubricated and oil replenished at the time of extensive maintenance or whenever the valve is disassembled for cleaning or repairs.

If the spindle of a valve is bent, it is usually difficult to repair and should be replaced. In general, many workshops are able to fabricate a spindle.

4.2 Turbines

Either crossflow or Pelton turbines are used in most MHP plants. Crossflow turbines are usually used for low heads, up to about 50m, whereas Pelton turbines are used for larger heads. Essentially, the turbines convert the potential and kinetic energy of the flowing water into mechanical power to be used for other purposes such as driving a generator or an agro-processing unit.

4.2.1 Crossflow Turbines

Figure 4.2 shows a typical section through a crossflow turbine. Damage can be caused to the turbine, especially to the runner, bearings and shaft, by improper installation or operation, silt or small stones in flowing water, and lack of timely routine maintenance or minor repairs leading to extensive damage to the part concerned as well as to other parts. For example, if a bearing is worn out and is not replaced, the subsequent damage may extend to the bearing housing, the shaft, and the seals. The causes and types of damage to crossflow turbines, and the appropriate repair processes, are outlined briefly in Table 4.1.

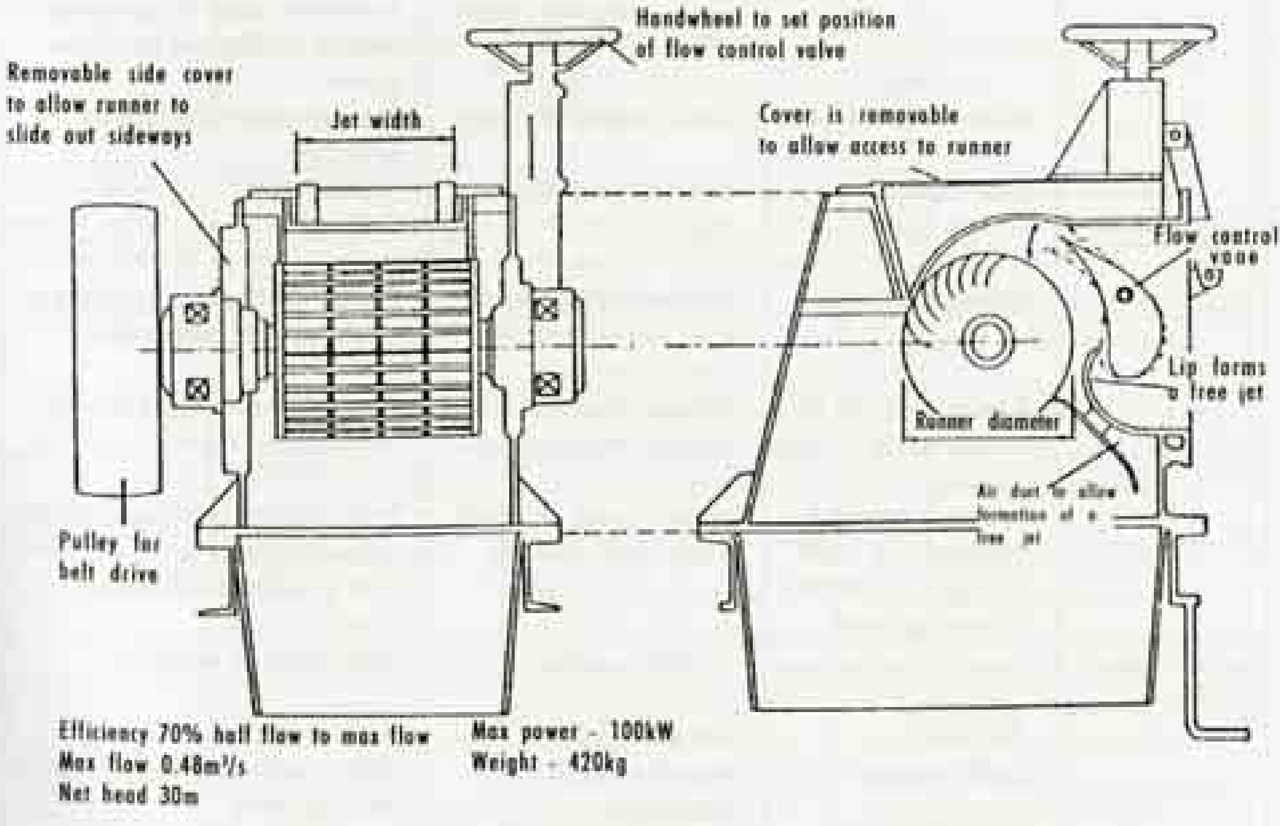


Figure 4.2: A Cross-Section through a Crossflow Turbine Showing the Main Components

Table 4.1: Types of Damage, Causes, and Appropriate Repairs for a Crossflow Turbine

Type of Damage	Cause	Identification / Assessment	Repairs
Vane assembly not functioning properly	- Bent spindle	- Rotate wheel/handle to check if it operates freely - Disassemble and check straightness	- Replace spindle
	- No lubrication	- Dismantle and check quality of grease	- Remove old grease - Clean with kerosene - Apply fresh grease - Assemble and check working
	- Vane jammed	- Remove turbine cover - Check for foreign material or rust	- Remove foreign material if any - Remove rust and clean surfaces
	- Bushes worn out	- Check bushes	- Replace bushes if damaged - Otherwise clean and assemble - Replace seals and gaskets
Runner not picking up speed	- Stones or other solids in casing	- Rotate runner and listen to noise - Open casing and inspect	- Remove covers/parts of casing and remove stones - Sometimes sides of casing also need to be removed to remove stones
	- Blades bent or broken	- Open casing and inspect	- Remove runner and take to workshop
	- Shaft bent	- Disassemble and inspect shaft	- Replace shaft *1
	- Damaged bearings	- Remove bearings from shaft and housing and check by rotating	- Replace bearings by new ones of same type and specifications
	- Runner touching the side of casing or seal housing	- Remove cover and check spacing, rotate runner as well	- Centre the runner and bearings and tighten, check nut and lock
	- Casing deformed or damaged as a result of impact or touching of rotating runner	- Inspect casing especially around seals and side	- Small amount of damage may be repaired by hammering and filling - Take to workshop if damage extensive
Turbine/runner vibrates	- Some blades damaged	- Inspect blades (as above)	- Take runner to workshop
	- Bent shaft	- Inspect as before	- Replace shaft
	- Shaft worn out	- Inspect shaft after removing it	- Take to workshop for welding and machining
	- Damaged/loose bearings	- Check bearings as before	- Replace by same type - Tighten bolts/nuts after positioning properly

*1 It is usually difficult to straighten a bent shaft.

Table 4.1 Cont.......

Type of Damage	Cause	Identification / Assessment	Repairs
	- Side plate or bearing housing bolts loose - Loose foundation bolts - Shaft broken	- Check nuts and bolts - Check vibration on base and bolts - Inspect shaft as before	- Tighten nuts/bolts - Replace damaged ones - As above - Redo concrete to fix foundation bolts properly - Take to workshop for welding and machining - Replace shaft
Leakage at sealing	- Sealing flange bolts loose - Packing worn out - Loose bolts on non-contact seal	- Inspect bolts of sealing flange - Dismantle packing flange and inspect - Dismantle runner - Check if the sealing bolts are loose	- Tighten bolts but not too tight - If leakage continues, replace packing - Replace packing by one of same size and material - Tighten the bolts after positioning
Leakage from control vane (valve)	- Packing worn out - Bush of vane shaft worn out	- Open side cover of vane shaft and inspect packing - Dismantle shaft and check bush by measuring diameter	- Replace packing by same size and material - Replace bush with new one of same size
Casing badly rusted	- Corrosion - Damaged paint	- Inspect affected area - As above	- Remove rust and repaint - Use putty/filler before painting
Bearings too hot	- No grease or old grease	- Open bearing cover and inspect grease	- Clean bearings - Apply fresh grease as necessary
	- Too much grease	- As above	- Check and reduce grease if necessary
	- Rollers or balls worn out	- Remove bearings, turn them, listen to the noise	- Replace bearings by new ones of the same size and quality
	- Worn out housings	- Open housings, check for wear	- Replace with new housing of same size
	- Misalignment of housing	- Open top cover of bearing housing and check if it fits properly without bolts	- Adjust the bearing block or insert shims to improve alignment if the housing is separate from the casing
		- Remove pulley, place a spirit level on the shaft axially and check whether the bubble is in the centre	- If the housing is bolted to the casing, loosen the bolts of bearing housing and raise/lower the housing to get proper alignment

Small crossflow turbines are generally assembled from the base upwards. To dis-assemble a small crossflow turbine proceed as follows.

- Disconnect couplings or remove belts from the runner shaft.
- Separate the whole turbine from the penstock and the draft tube (if installed).
- Remove the bearings from the runner shaft by unbolting from the casing and slackening the socket head screws locking the bearing sleeves to the runner shaft.
- After removing the side sealing plates, the runner can be taken out from the base of the casing.
- To remove the guide vane, remove the retaining bolt and washer from the end of the guide vane shaft and drive the shaft out with a hammer and a blunt drift.

Assembly is usually a reversed sequence of disassembly. To reassemble the turbine, proceed as follows.

- Replace the damaged gaskets or seals with new ones and replace any worn or damaged parts with equivalent new units. (It is better to replace all seals after any disassembly.)
- Position the guide vane in the casing and drive the shaft and key into position with a mallet or a light hammer. Fit the retaining bolt and washer to the end of the shaft and tighten.
- Place the runner in the casing and fix the sealing plates.
- Bolt bearing housings in position and centre the runner. If unsealed bearings are used, clean the bearings well with kerosene prior to assembly and half fill with a good quality bearing grease. Do not overfill.
- After centring the runner, tighten socket head screws to secure bearing sleeves to runner shaft.
- Check that the runner rotates freely and does not touch the housing.
- Replace and apply tension to belts or coupling. If V-belts are used, increase tension until each belt can be deflected about 15 mm for each metre of span when pressed with the full force of a finger at the mid point between the two pulleys. If a flat belt is used, follow the manufacturer's recommendations to obtain proper tension.

4.2.2 Pelton Turbines

Pelton turbines (Figure 4.3) are fast running machines that work under a much higher head than cross-flow turbines; thus they have to be precision made. The runner of a Pelton turbine consists of buckets cast from cast steel or bronze that are fixed to the runner disk by welding or bolting. One or more jets of water diverged from the penstock manifold hit the buckets. The flow in each jet is controlled separately using a spear valve and nozzles. Usually, automatic jet deflectors are also provided for each jet that can deflect the flow and stop the turbine in an emergency.

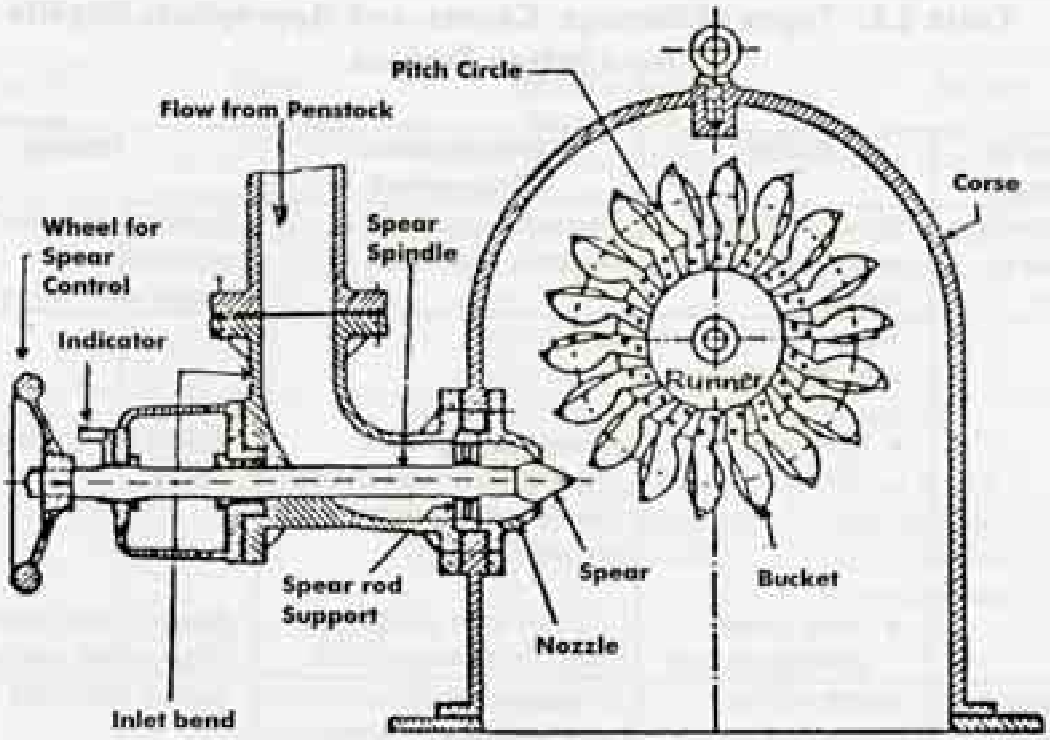


Figure 4.3: Cross-Sectional View of a Single Jet Pelton Turbine

The sources of damage to Pelton turbines are mostly similar to those for crossflow turbines. They include such things as a stone blocking the nozzle or hitting the buckets, inappropriate operation, inappropriate design, and low quality equipment or components. The types of damage that can occur to various parts or components of a Pelton turbine are listed in Table 4.2, together with suggestions and procedures for repairs. The procedures for dismantling and assembling these turbines are given below.

To disassemble a Pelton turbine with the runner directly mounted on the generator shaft proceed as follows.

- Remove the casing access cover.
- Remove the bolt or tapered sleeve holding the runner to the generator shaft. (Refer to section 4.2.3 for removal instructions for tapered sleeves.)
- Remove the runner from the shaft

Assembly is the reverse of the above procedure. Prior to assembly, clean all mating surfaces well, especially the shaft and runner mating surfaces. Replace all gaskets and any worn or damaged parts with equivalent new ones. Smear the shaft and runner mating surfaces with grease and reassemble.

Table 4.2: Types of Damage, Causes, and Appropriate Repairs for a Pelton Turbine

Type of Damage	Cause	Identification/ Assessment	Repairs
Inadequate flow from nozzle assembly	- Stone or other material stuck in nozzle	- Dismantle spear valve assembly and inspect	- Remove foreign object without damaging nozzle/spear surface
	- Spear valve not opening properly • Bent screw	- Dismantle spear valve assembly and inspect screw - Turn the screw to check bending	- Replace screw if damaged*[1]
	• Foreign object jamming the bush	- Remove spear spindle from bush and mating surfaces	- Remove foreign material - Clean surface and reassemble
Proper jet not forming	- Nozzle end tip damaged as a result of silt/erosion	- Dismantle nozzle tip, measure internal diameter, and check roughness	- Replace if damaged
Leakage from spear valve assembly	- Packing/seal worn out	- Dismantle spear valve sealing unit	- Replace packing/O-ring
	- Spear spindle damaged	- Remove the retaining nut, inspect spindle	- Weld spindle if pitted and re-machine
	- Retaining nut loose/damaged	- Check spindle for damage	- Replace retaining nut if damaged
Play in spear spindle	- Threads damaged	- Dismantle spindle and inspect threads on both surfaces	- Replace damaged parts (bush or spindle) - Re-machine spindle threads if damaged
Jet deflector not functioning properly	- Cover bent	- Dismantle and inspect for damage	- Straighten bent part
	- Deflector plate slipping	- As above	- Weld and re-machine
	- Plate/spindle worn out	- As above	- Weld and re-machine or replace

*[1] It is usually not possible to straighten a shaft properly. Therefore, replacement is the best solution.

Table 4.2 Cont.......

Type of Damage	Cause	Identification/ Assessment	Repairs
Magnet not holding	- Solenoid damaged/burnt out - No power supply (AC/DC)	- Check resistance/ continuity using multimeter - Check power supply both input and output of solenoid circuit - Check rectifiers and other components	- Rewind solenoid if damaged - Replace damaged components and restore power
Runner not rotating freely	- Shaft bent - Bearing damaged - Bearing not gripping shaft • taper sleeve/neck washer damaged - Bearing block slid - Bearing check nut loose/damaged	- Take out runner and inspect shaft for bending - Take out bearing, clean, rotate and listen to sound, inspect play (worn rollers) - Open check nut, take out washer and inspect - Remove block, check for damage (cracking, wear) - Open cover of bearing block and inspect check nut	- Replace shaft - Replace bearing - Clean, refit after properly aligning and insuring same clearance around shaft - Replace locking washer - Replace block if seriously damaged - Replace if damaged or tighten if loose
Runner/turbine vibrates	- Broken bucket - Runner unbalanced - Bearing damaged - Loose tapered sleeve - Shaft scoured/pitted - Foundation or bearing block bolts loose	- Take out runner and inspect - Remove casings cover, rotate runner slowly and let it stop normally. if it stops in the same position repeatedly or it rotates backwards then it is unbalanced - Inspect bearing - Remove bearing cover and inspect nut - Check tightness of nuts - Remove and inspect shaft - Check whether foundation bolts loose in concrete	- Replace bucket by one of same size - Get runner balanced - Get runner balanced at a proper workshop - Replace bearing if damaged - Clean and apply grease - Tighten check nut using spring washer - Replace check nut/sleeve if damaged - Get shaft welded and machined - Dig out and re-build the foundation

Table 4.2 Cont.......

Type of Damage	Cause	Identification/ Assessment	Repairs
	- Jet not properly centred	- Remove top covering and measure perpendicular distance between centre of nozzle and casing and centre of bucket and casing to see if the two are the same	- Move runner side ways to centralise the jet - Tighten nuts/bolts
Leakage from casing • At casing joints	- Loose bolts - Gaskets between casing flanges damaged	- Inspect bolts - Remove and inspect gaskets	- Tighten as necessary - Replace if damaged
	- Casing flange deformed	- Remove and inspect casing/flange for deformation pitting/cracking	- Repair deformation by hammering and filing - Fill holes/cracks with sealing epoxy putty
• At shaft entry point	- Sealing system damaged	- Remove turbine cover and inspect the sealing assembly for deformation and damage	- If deformation is small repair it by hammering and filing - Otherwise replace or send to workshop
	- Clearance between two discs too large	- Remove sealing component on the shaft - Remove cover and inspect clearance between the two sealing discs	- Adjust the clearance (about 2-3 mm)
	- Gasket between casing and sealing disc may be damaged	- Remove both sealing discs and inspect gasket	- Replace gasket if damaged - Tighten bolts

To disassemble a Pelton turbine with a belt or coupling drive proceed as follows.

- Remove the belts or coupling
- Remove the access cover in casing
- Unbolt sealing device discs from casing
- Remove bearings from runner shaft and casing. (If bearings are provided with tapered sleeves, refer to sections 4.2.3 and 4.2.4 below.)
- Remove runner and shaft from the casing.

To reassemble, proceed as follows.

- Clean runner shaft well and remove rust or other deposits from bearing mounting area with fine abrasive paper. Replace any worn or damaged components with equivalent new units.
- If unsealed bearings are used, wash in kerosene and half fill bearings with a good quality bearing grease. Do not overfill. Replace all gaskets and any worn or damaged parts with equivalent new units.
- Install runner and shaft in casing and position bearings on shaft.
- Lock bearing inner race to runner shaft. (If tapered mounting sleeve is used, refer to section 4.2.3 and 4.2.4 below for instructions).
- Bolt sealing device discs into place (Figure 4.4).
- Rotate runner and ensure that it is rotating freely and not touching any other component.
- Install access cover and belts or coupling. If V-belts are used, adjust tension as described above in section 4.2.1. If a flat belt is used, follow the manufacturer's recommendations for proper tension.

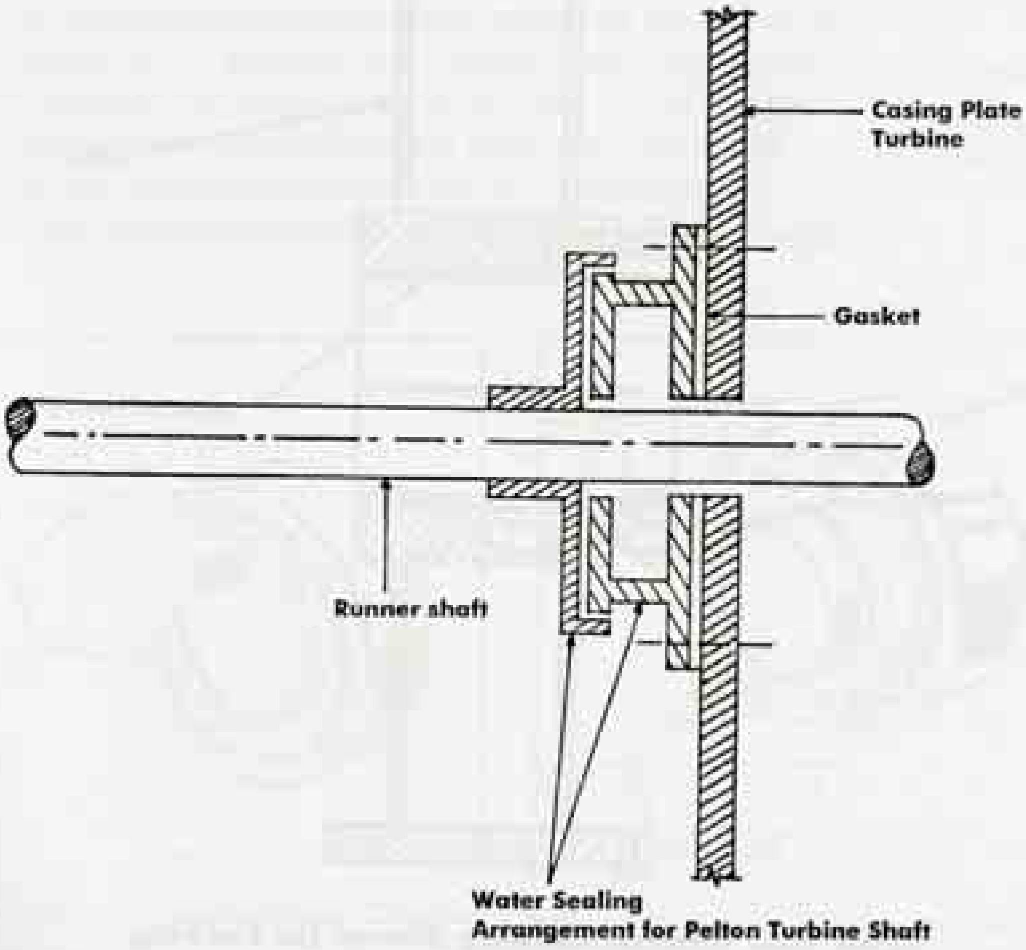


Figure 4.4: Non-Contact Seal for Pelton Turbine Casing

4.2.3 Tapered Locking Sleeves

The general layout of a tapered locking sleeve used for bearings or pulleys is shown in Figure 4.5. To remove the tapered locking sleeve, first remove the screws or bolts from the sleeve. Fit bolts to the jacking bolt holes provided on the hub in between the clamping bolt holes and torque evenly until the sleeve is removed. The bolts used for tightening the sleeves should not be used as jack bolts, and damaged or incorrectly sized bolts should not be used.

To re-assemble, proceed as follows. Clean all the mating surfaces well, apply a film of grease to the outside of the tapered sleeve, and re-fit. Re-fit bolts to clamping holes and tighten uniformly. The gap marked (x) in Figure 4.5 must be approximately five mm after the bolts are tightened.

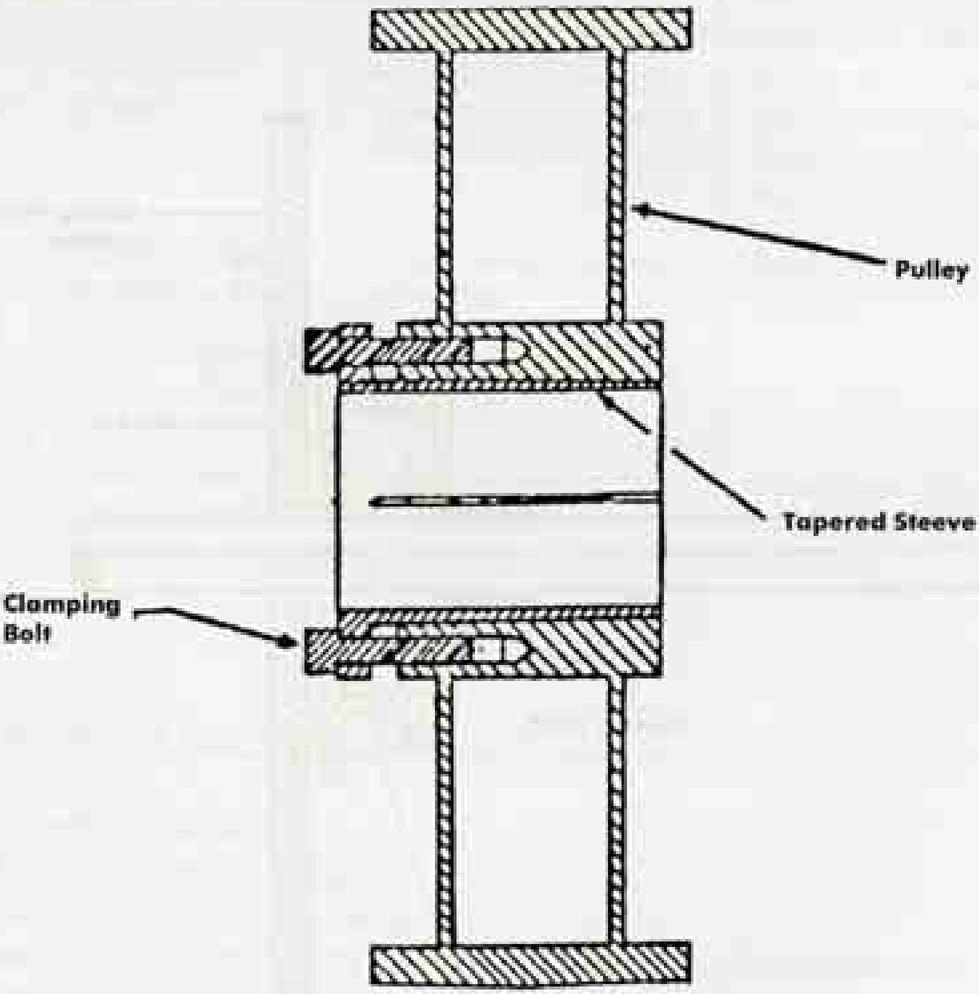


Figure 4.5: Tapered Locking Sleeve for Locking Pulleys and Runners to Shafts

4.2.4 Bearings Fitted with Tapered Adapter Sleeves

Large runners are sometimes fitted with tapered adapter sleeves to mount the bearings as these ensure a good grip between the bearings and the shaft. To remove these sleeves from the shaft, loosen the locking ring and tighten the check nut with a 'C' spanner or a blunt ended drift. The bearing can now be removed from the shaft.

Before re-assembly, clean all components well with clean kerosene. There are two techniques for re-tightening bearing sleeves, the reduction of clearance method, and the axial drive-up method, both described below. The reduction of clearance method is the better technique, but needs accurate feeler gauges. If these are not available the axial drive-up method should be used.

Reduction of Clearance Method

- Before fitting the bearing to the shaft, measure and note down the bearing clearance (between the rollers and the outer ring of the bearing) using accurate feeler gauges as shown in Figure 4.6. Rotate the bearing a few times to ensure that the rollers are sitting in their correct positions before measuring the clearance.
- Apply a thin film of grease to the outside of the adapter sleeve. Fit the bearing and adapter sleeve to the shaft and locate it in the correct position.
- Gradually tighten the locking ring and check the clearance as shown in Figure 4.6 until the clearance reduction shown in Table 4.3 is achieved.
- Tighten the withdrawal ring and secure the rings with tab washers.

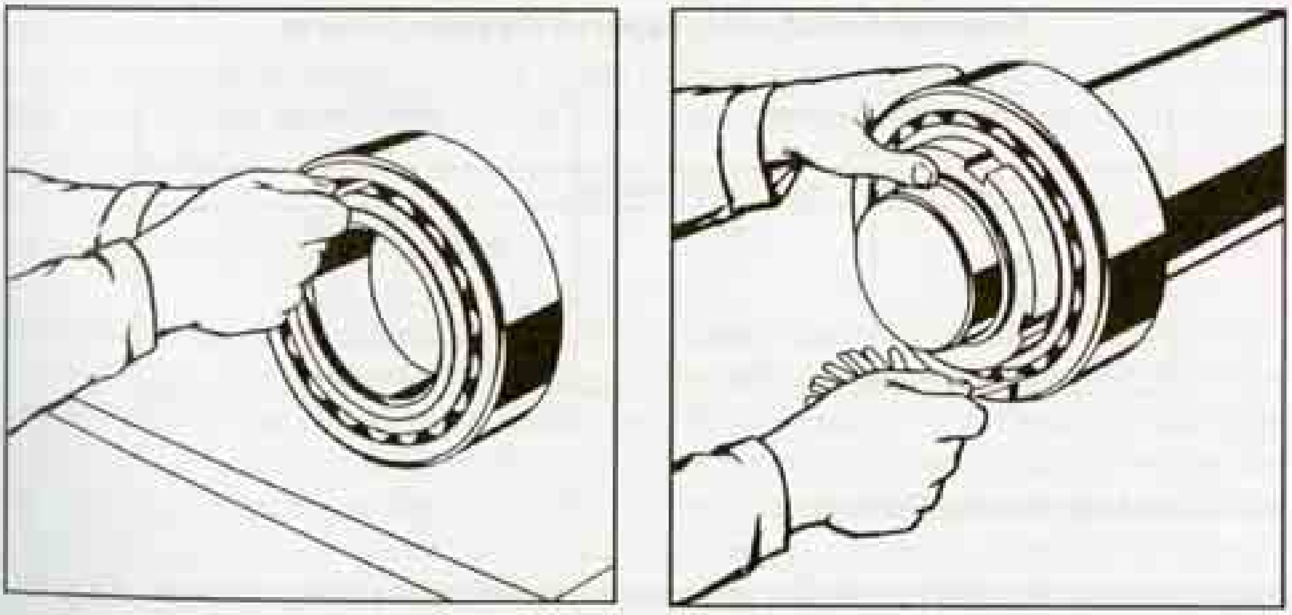


Figure 4.6: Checking Clearance of a Spherical Roller Bearing with Adapter Sleeves

Table 4.3: Reduction in Clearance for Spherical Roller Bearings Mounted with Tapered Adapter Sleeves

Shaft diameter (mm)		Reduction in radial clearance (mm)		Minimum permissible clearance after mounting (mm)
more than	up to and including	min	max	
30	40	0.020	0.025	0.015
40	50	0.025	0.030	0.020
50	65	0.030	0.040	0.025
65	80	0.040	0.050	0.025
80	100	0.045	0.060	0.035

Axial Drive-up Method

- Apply a thin film of grease to the outside of the adapter sleeve and fit the bearing and adapter sleeve to the shaft.
- Tighten the locking ring with a spanner or blunt-ended drift until it is just firm.
- Measure and note the distance from the bearing inner race to the end of the adapter sleeve with a vernier calliper.
- Tighten the locking ring until the measurement made in step 3 is reduced by the axial drive-up amount shown in Table 4.4.
- Tighten the withdrawal ring and secure the rings with tab washers.

Table 4.4: Axial Drive-Up Amount for Spherical Roller Bearings Fitted with Tapered Adapter Sleeves

Bearing bore diameter (mm)		Axial drive-up (mm)
more than	up to and including	
30	40	0.35 - 0.40
40	50	0.40 - 0.45
50	65	0.45 - 0.60
65	80	0.60 - 0.75
80	100	0.7 - 0.9

4.2.5 Checking Bearing Damage

Bearings can be checked roughly for performance by feeling the cover of the housing for unusual temperature rise, noise, or vibrations. Noise/vibrations can be detected with the hand or with an object such as a screwdriver that can amplify the sound, as shown in

Figure 4.7. The operator should constantly monitor the condition of important bearings in this way so that he/she knows the correct sound for each bearing and can quickly notice changes in the noise or vibration level. Bearings should also be removed from the housing occasionally and rotated while holding close to the ear to listen to the noise. Any sharp crackling indicates damage to the recess or the rollers.

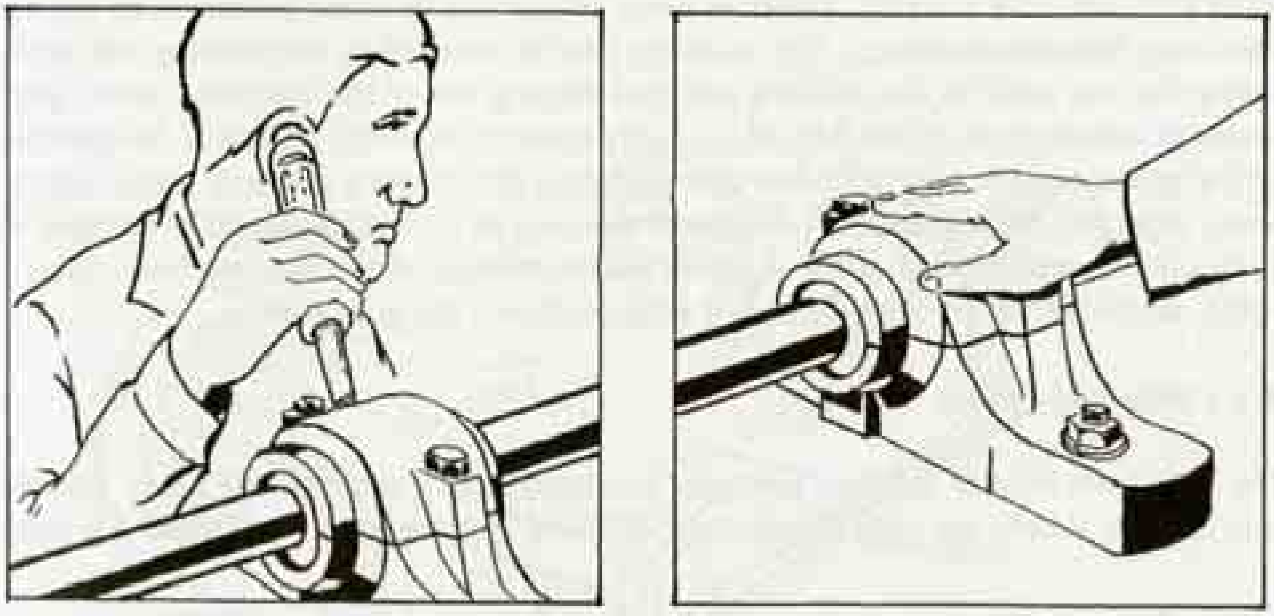


Figure 4.7: Simple Techniques for Sensing Bearing Noise and Condition

4.3 Power Drive Systems for MHP Plants

Mechanical power may be transmitted from the turbine shaft to the driven shaft of a generator or some other machine either by direct coupling or by belt and pulley systems. Direct couplings are usually used for Pelton turbines when the speed of the generator and the turbine is the same. In the case of Peltric sets, the runner is mounted directly on the generator shaft.

4.3.1 Couplings for Direct Drives

Rigid couplings can be used for direct drive systems when the speeds of the two shafts are the same. However, since there is almost always some misalignment between the two shafts, flexible type couplings are mostly used for MHP plants since these can withstand some level of misalignment and vibration. There are many different types of flexible couplings available in the market with different trade names. The main component of such couplings is usually a rubber-based joint that absorbs vibrations. Damage to the couplings, especially to the rubber components, may be caused by excessive misalignment of the shaft and resulting vibrations, loose bolts in the coupling, water, and lubricants. The damage can show in the form of deterioration of rubber and/or slipping. The damage should be inspected and assessed by watching the coupling while it is rotating for slipping, noise, and other such malfunctions; and by stopping the turbine and inspecting the rubber component thoroughly.

Usually it is very difficult to repair flexible couplings and they should be replaced when the damage becomes extensive. Rubber can deteriorate more quickly in the presence of lubricants, oils, and solvents. Therefore every effort must be made to keep such chemicals away from the couplings. The couplings can be removed by dismantling and separating the two parts of the coupling and then moving one of the machines, either generator or turbine, from its position. It is usually easier to move the generator. Reassembly and alignment of the two machines after replacing the coupling are fairly skilled operations, especially the alignment. A skilled and experienced technician should be engaged to carry out the replacement of the coupling and reassembly of the two machines. Alignment can be performed using a straight edge as shown in Figure 4.8.

4.3.2 Belts and Pulleys

The belts used in MHP schemes generally belong to one of two different types. Usually one or more V-belts are used for plants of 20kW or less (Figure 4.9); whereas flat belts

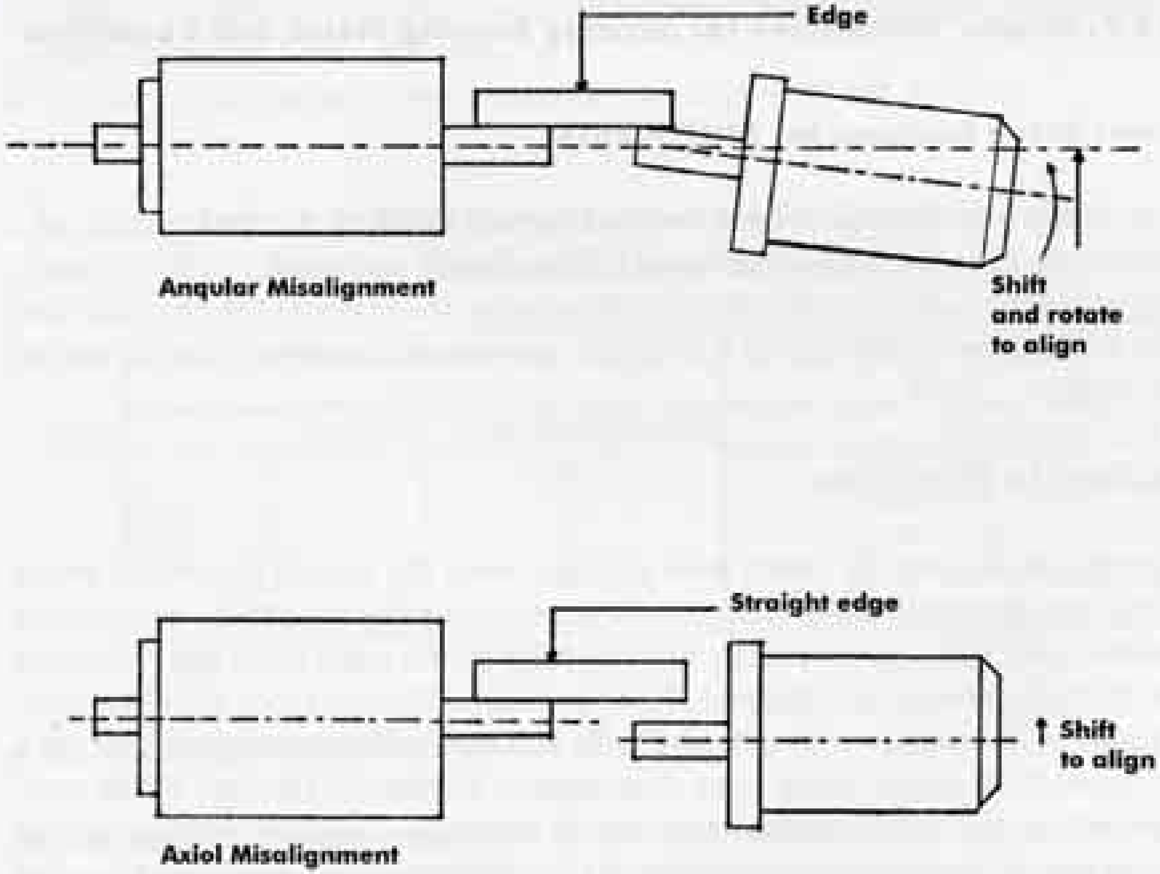


Figure 4.8: Aligning Two Directly Coupled Shafts Using A Straight Edge

are mostly used for larger plants. Belts are fitted over the pulleys provided on both the shafts. If a flat belt is used, the surface of the pulley will be almost flat with a small rounded 'crown'. If a V-belt is used, the appropriate number of grooves will be provided on the outer surface of the pulleys which are usually fixed to the shafts with the help of keys or in some cases by tapered sleeves.

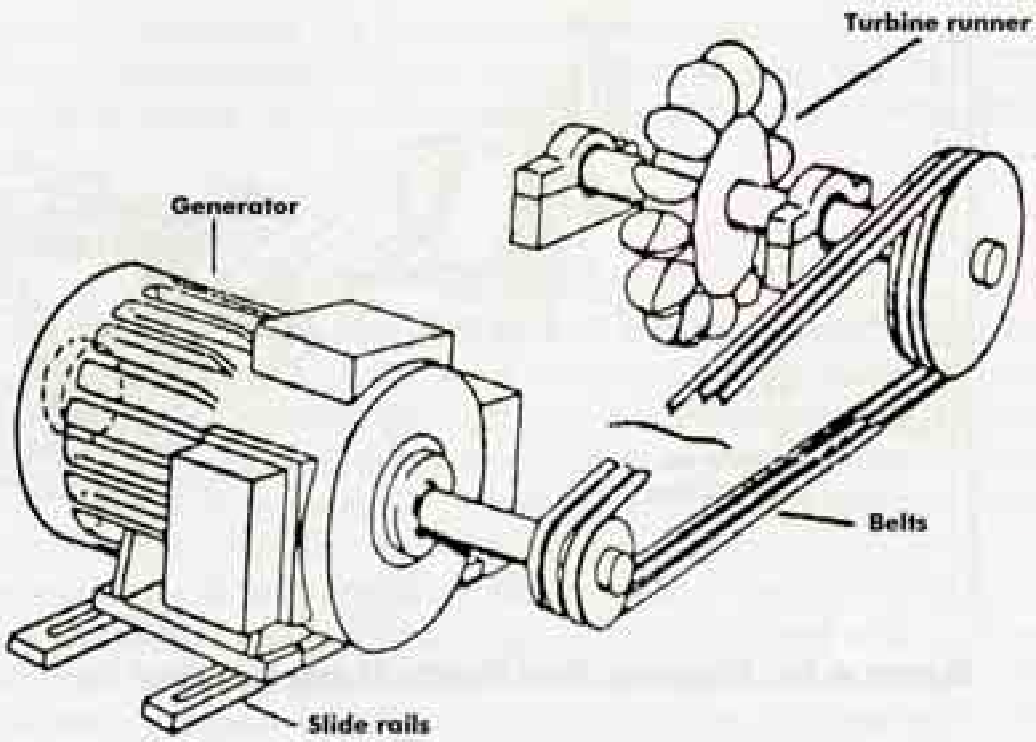


Figure 4.9: Sketch of a V-Belt Drive System

Damage to the pulleys and the shafts may be caused by improper installation — including misalignment between the two shafts or pulleys, improper handling during assembly and removal of the pulleys or belts, rusting, and loose belts or loose keys. Damage to the pulleys may be in the form of a broken or bent arm leading to further misalignment, which may in turn result in belts being thrown off, or pulleys becoming loose or slipping on the shaft and causing damage to tapered sleeves or even scouring the shaft.

If the arms are made of mild steel, damage can be repaired in a workshop by straightening or even welding. If the arms are made of cast iron, then they cannot be repaired and should be replaced. If the diameter of the hole that fits on the shaft has become too large or gone out of shape, then the surface of the hole should be machined and a bush can be pressed into it in a workshop to make it fit the shaft diameter. If tapered sleeves are damaged as a result of misalignment or slipping of the pulleys, they should be replaced.

Damage to the pulleys may also be caused by the two shafts not being parallel, i.e., having angular misalignment. In such cases, a skilled and expert technician should be hired to realign the two shafts properly. This can be done using a string as shown in Figure 4.10.

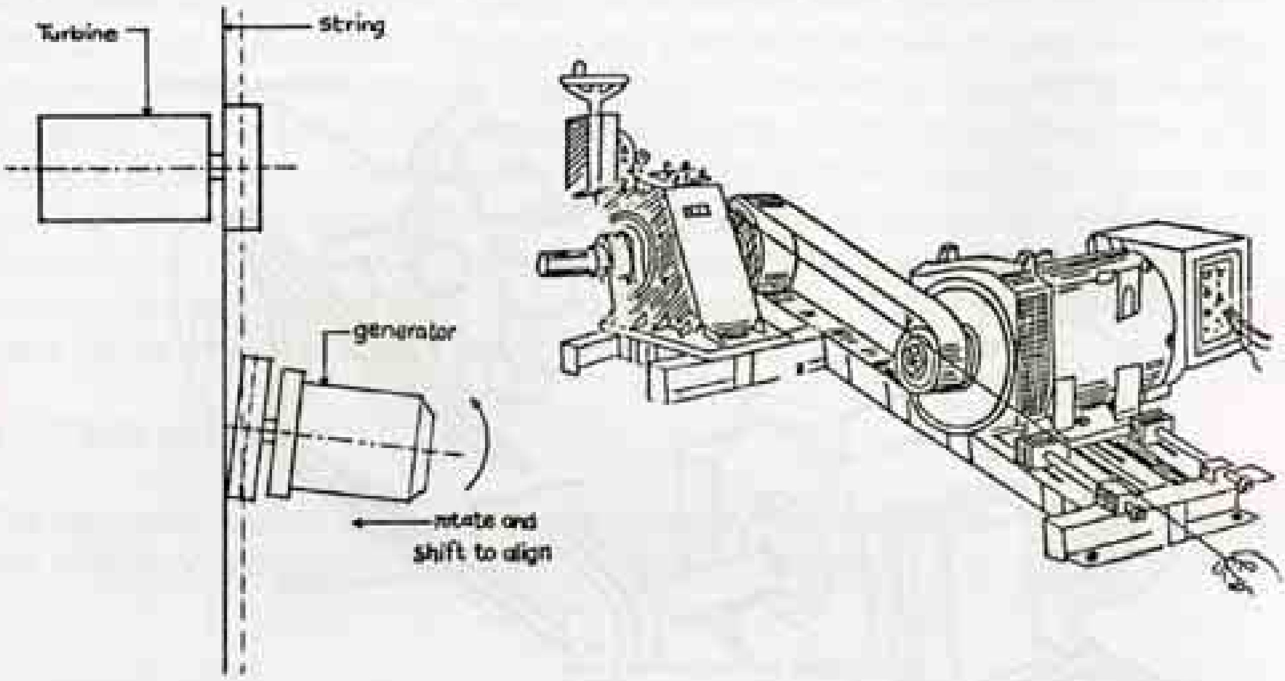


Figure 4.10: Aligning Two Shafts Using a String

Damage can be caused to the belts by, amongst others, misalignment, mishandling, the presence of grease or another substance on the surfaces, a bad joint in a flat belt, improper tension, and a rough surface on the pulley. The damage can appear in the form of belts becoming longer and therefore slipping, wearing out, or cracking. Slightly damaged V-belts can be left in position until they are damaged badly. This is allowable since more than one belt is usually used. Once they are damaged extensively they must be replaced, they cannot be mended. It is not a good idea to mix old V-belts with new V-belts since the new V-belts may be shorter as the belts stretch through use. It is recommended that all the belts should be changed at the same time. Old belts may, however, be stored and re-used to replace single extensively damaged belts once the new belts have stretched.

Flat belts can be joined using thermal and chemical equipment, but this cannot be done at the site. Thus if a part of a flat belt, especially a nylon type flat belt, gets damaged; it can be taken to a workshop where the damaged portion can be removed and another piece joined to it using special equipment. Flat belts used for MHP plants, especially for generation of electricity, should not be joined with bolts. Solvents and lubricants can also damage the belts and care should always be taken to keep such chemicals away from the belts. If solvents or lubricants do come into contact with a belt, they should be wiped off as quickly as possible and the belts washed with soap and water.

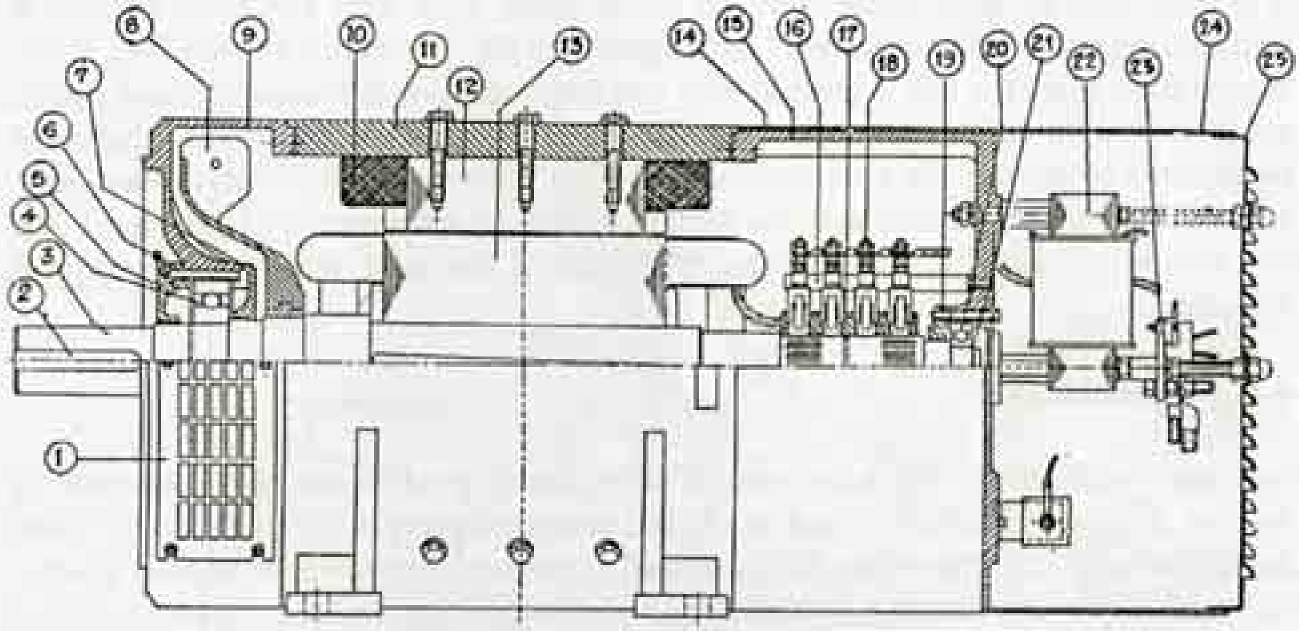
It is important to apply proper tension to the belts, both from the point of view of transmitting power efficiently and of prolonging their life. The correct tension for a V-belt is such that, when the belt is pressed with one finger applying full force, it should deflect about 15 mm for each metre of the span. The tension on both V-belts and flat belts can be adjusted by moving the two machines nearer or further away from each other. However, the two machine shafts will also need to be aligned if the machines are moved, and this should be carried out by a skilled technician at the same time as the tension is adjusted.

4.4 Generators

Two main types of generators are used for MHP plants: synchronous generators with or without brushes (Figures 4.11 and 4.13) and induction generators (Figure 4.14). These days, electronic load controllers (ELC) are used in conjunction with synchronous generators. ELC sense any variation in frequency and divert excess available power to ballast heaters as required. In this way, the load on the generator and turbine is maintained at a constant maximum all the time and both the voltage and frequency are constant. Induction generators are actually reversed induction motors. They are robust in construction and available cheaply and in a wide range of sizes. Even very small sizes of induction generators are available freely. Induction generator controllers (IGC) have also been designed recently. IGC sense variation in the output voltage and divert any excess power to ballast heaters, thus keeping the load, voltage, and frequency constant.

Damage may be caused to the generators by both mechanical and electrical mishaps. If the shaft is vibrating too much this will cause mechanical damage to the generator. If an excessive load has been connected to the generator, the windings may heat up causing a short circuit or the rectifiers or diodes may burn out. A low turbine speed can also damage the generator as it will cause the frequency to drop and the windings to heat up.

The common problems associated with brush type and brushless synchronous generators and induction generators are listed below in Tables 4.5, 4.6, and 4.7, together with their causes, methods of identification, and suggested methods of repair.



Parts List

1. Ventilation grid D.E
2. Extension key
3. Shaft
4. Ball bearing D.E
5. External bearing cap D.E
6. Conical head grease nipple
7. Internal bearing cap D.E
8. Fan
9. D.E shield
10. Field shell
11. Rolled shell
12. Pole brick assembly
13. Rotor assembly Circular band N.D.E
14. Circular band N.D.E
15. N.D.E. shield
16. Brush holder spindle
17. Slipring assembly
18. Brush holder assembly
19. Inside bearing cap N.D.E.
20. Ball Bearing N.D.E.
21. Circlip
22. Mx. unit assembly
23. Terminal board
24. Circular band mx.
25. Ventilator

Figure 4.11: Cross-Sectional View of a Synchronous Brush Type Generator

Table 4.5: Common Problems of Brush Type Synchronous Generators and Suggested Methods of Repair

Problem	Cause	Identification/Assessment	Repairs
No voltage output from generator	- Loss of residual magnetism	- Disconnect field wires and run the generator. Check the residual voltage across the generator output terminals. It should be approximately 5% of the rated voltage and be balanced between each pair of lines.	- If the residual voltage is less than 5% of the rated voltage, the generator field should be 'flashed' by connecting a 12 volt battery across terminals F1 and F2 for about 5 seconds making sure that F1 is positive and F2 is negative
	- Wrong field connections	- Check to ensure that the positive terminal of the rectifier is connected to F1 and the negative terminal to F2	- Switch connections if necessary
	- Open circuit in excitation unit	- Check continuity of the compounding transformer windings - Check connection between the compounding transformer and rectifier	- Correct as necessary
	- Faulty rectifier	- Flash generator field and check the output voltage at the terminals while generator is rotating. If output voltage is less than 5%, stop the unit and check the rectifiers with a multimeter.	- Replace rectifier if faulty
	- Carbon brushes may not be making good contact with slip rings	- Check contact between carbon brushes and slip rings	- Replace carbon brushes if worn
	- Short circuit or open circuit in armature winding	- Measure armature resistance	- Rewind if damaged
Low or high voltage from the generator on no load	- Low or high speed	- Check the speed	- Adjust speed by regulating flow
	- Incorrect connections between compounding transformer tappings and rectifier	- Check connections	- Correct connections if necessary

Table 4.5 Cont.......

Problem	Cause	Identification/Assessment	Repairs
	- Internal short in one of the field coils - Compounding transformer air gap too narrow/wide - Compounding transformer may be defective	- Measure resistance of each coil - Check gap - Check output voltage of each winding	- Rewind or change coil if necessary - Adjust air gap - Replace defective parts
Output voltage fluctuating	- Unbalanced currents in compounding transformer windings	- Check connections between compounding transformer tappings and rectifier tappings, they should be the same. - Check air gap between the two cores compared to specifications	- If balance is slightly out, up to about 5% can be compensated for by adjusting the air gap within the compounding transformer - Increase air gap to increase generator voltage output
	- Load current is unequal between phases and not according to the generator rating	- Check load current on each phase	- Rearrange load between phases to balance
	- Generator overloaded	- Check the load current	- Reduce load if higher than rated load on each phase
	- D-windings are reversed	- If the voltage falls excessively when the load is applied, check D-windings for wrong polarity. After reconnection, check the voltage at the slip rings and output terminals.	- Correct D-winding connection. The slip ring voltage should be a few per cent lower than the voltage at the output terminals (Figure 4.12).
Overheating of generator or some parts	- Overloading of generator	- Check the load and compare to rated capacity	- Reduce load if overloaded
	- Insufficient ventilation	- Check screens and fan	- Clean generator and generator air inlet screens. Remove items that may be blocking the flow of cooling air to the generator while running - Provide additional ventilation to the powerhouse if necessary
	- Internal short circuits	- Measure resistance	- Rewind if there is an internal short circuit
	- Bearings worn out, damaged, or incorrectly installed	- Check bearings	- Refit or replace with new unit if necessary

Table 4.5 Cont.......

Problem	Cause	Identification/Assessment	Repairs
	- Too much or not enough grease in bearings	- Check grease	- Remove old grease and add fresh grease, half filling the bearings
Vibration of generator	- Bearings worn out	- Check bearing sound while rotating and after removal	- Replace with new bearings of same size and type
	- Bearing loose in housing	- Check whether bearing is loose in housing	- Remove the bearing by dismantling the side covers
		- Replace bearings in housing and check play	- Replace housing if too much play
	- Loose foundation bolts	- Check all foundation bolts	- Tighten if necessary - Reconcrete foundation bolts if foundation damaged
	- Pulley or rewound generator rotor out of balance	- Remove belts and rotate pulley. If it stops in the same position each time either the pulley or the generator rotor is out of balance. Remove the pulley and try the same test. If the generator rotor stops in a different position each time, the pulley is out of balance	- Return the pulley to the manufacturer for rebalancing
		- If the generator rotor stops in the same position each time the rotor is out of balance	- Return generator to the manufacturer for rebalancing

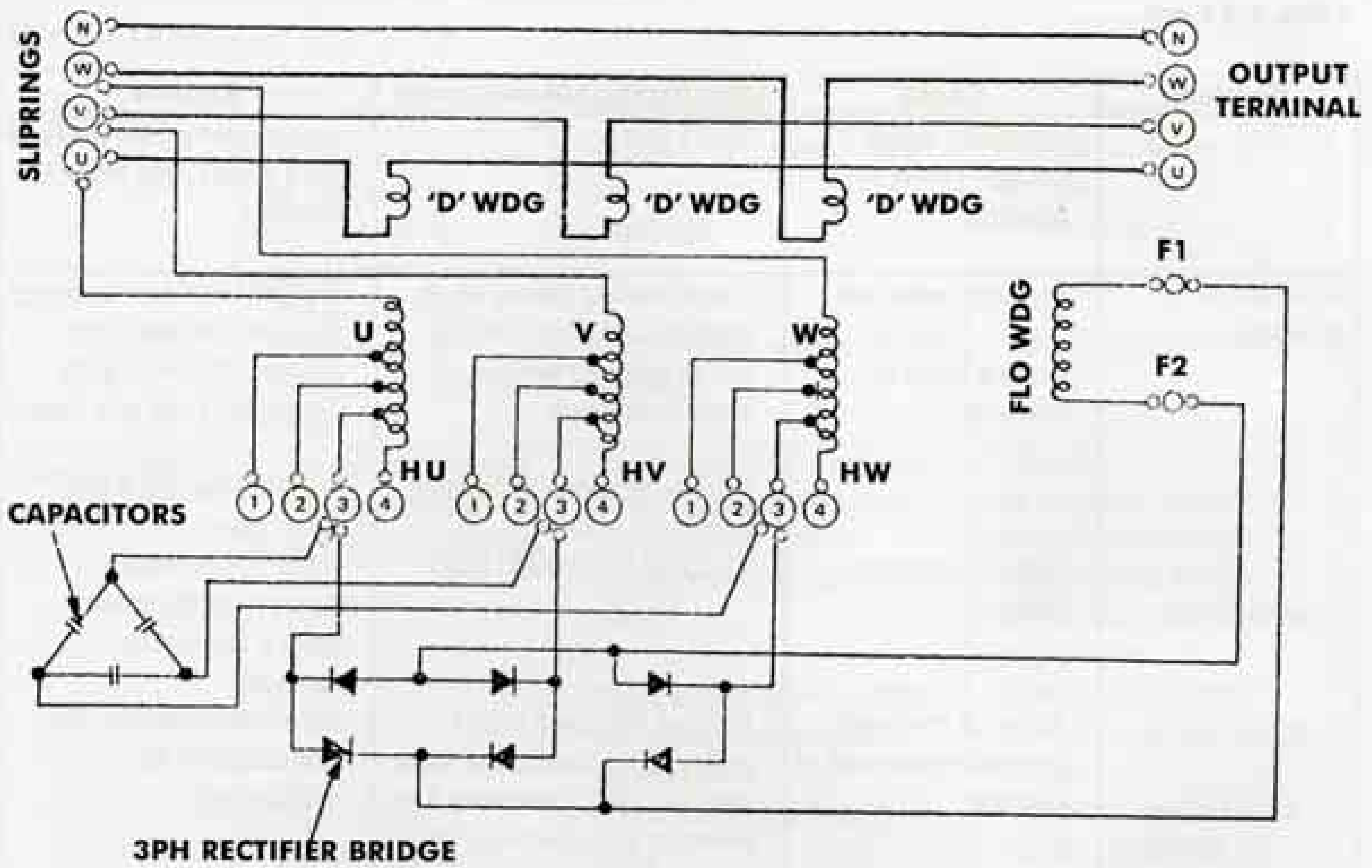


Figure 4.12: Wiring Diagram for a Synchronous Generator Showing D-Windings

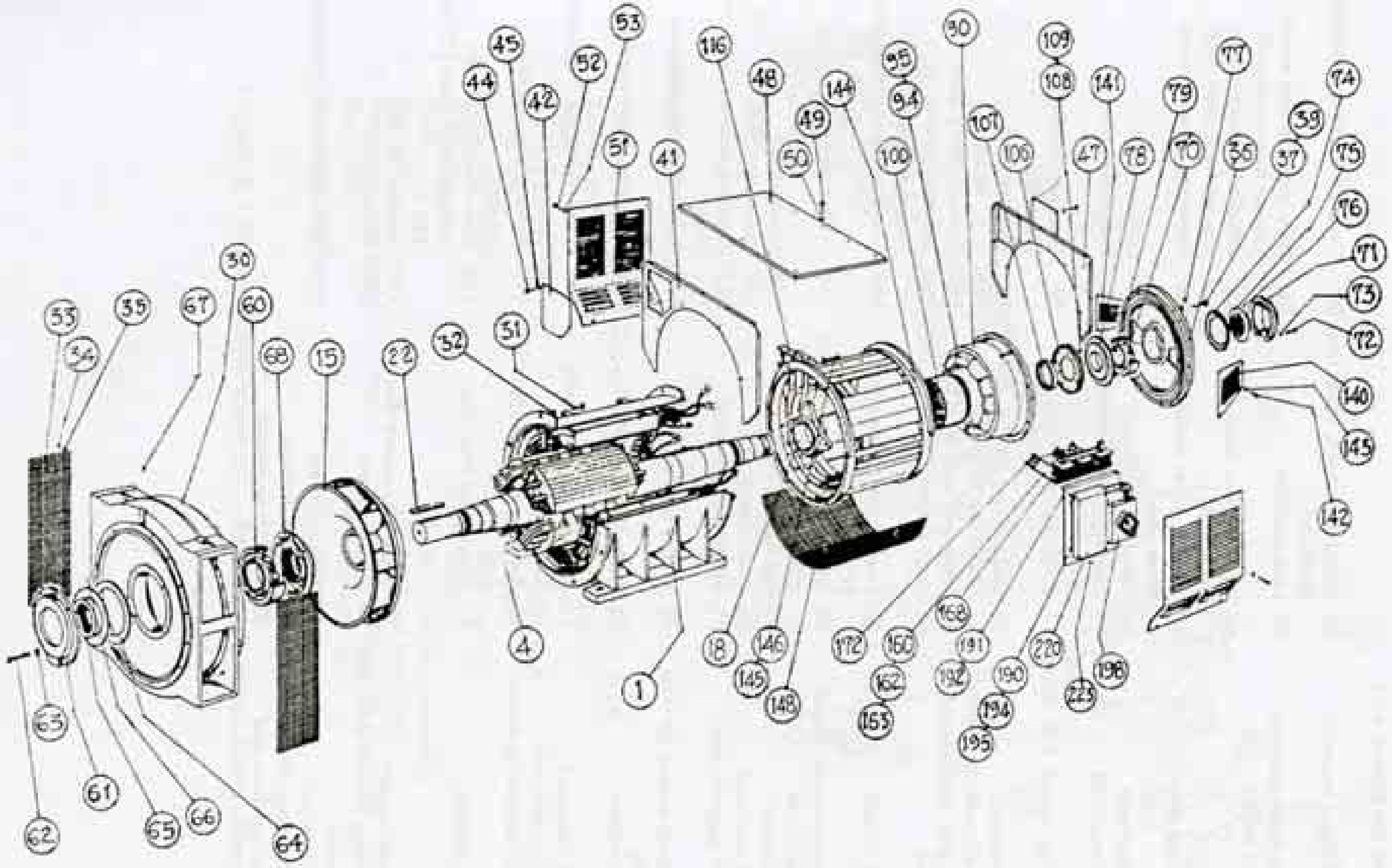
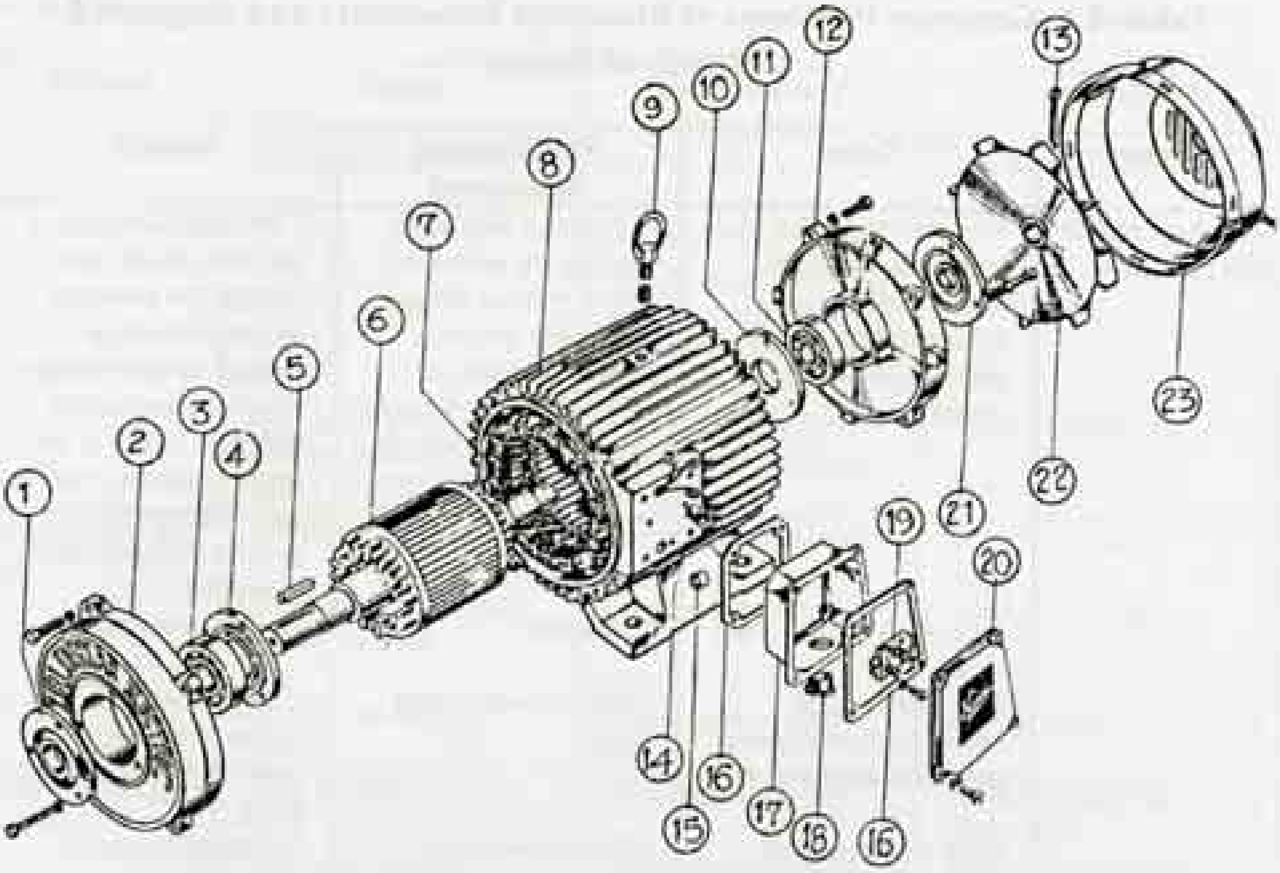


Figure 4.13: Exploded View of a Brushless Synchronous Generator

List of Parts for Figure 4.13

1. Would stator assembly
4. Wound roter assembly without exciter
15. Fan
18. Balancing disc
22. Key, shaft end
30. Drive endshield
31. Securing screws, D.E. shield
32. Lock-washers
33. Grid, air outlet protection
34. Rivet, grid attachement
35. Washer
36. N.D.E. shield
37. Attaching screws, gland support plate
39. Lock-washer
41. Hood, rear part
42. Gland support plate
43. Attaching screws, air inlet louvers
44. Lock-washer
47. Hood, rear part
48. Hood, upper part
49. Hood, connecting screws
50. Lock washers
51. Air inlet louvers
52. Attaching screws, outer cap, drive end
53. Lock-washers
54. Ball bearing, drive end
55. Outer cap drive end
56. Attaching screws, outer cap, drive end
57. Lock washers
58. Grease valve, fixed part, drive end
59. Grease valve, mobile part, drive end
60. Set screw, drive end
61. Bearing grease nipple, drive end
62. Inner cap, drive end
63. Ball bearing, N.D.E. cap
64. Outer cap N.D.E.
65. Fastening screws, N.D.E.
66. Lock washer
67. Grease valve, fixed part, N.D.E.
68. Grease valve, moving part, ND.E.
69. Set screws, ND.E.
70. Inner cap, N.D.E.
71. Spring, for pre-load
72. Exciter frame
73. Coils, exciter field
74. Split, for retaining coils
75. Exciter armature
76. Rotating diodes supporting disc
77. Supporting ring, disc
78. Fastening screws disc
79. Lock-washers
80. Diodes, direct
81. Diodes, inverse
82. Protecting resistor
83. Connection bars, assembly
84. Right diode access louver (viewed from shaft end)
85. Left diode access louver (viewed from shaft end)
86. Fastening screws, louver
87. Lock-washers
88. Frame extension
89. Securing screws, frame extension
90. Lock-washers
148. .... louver
160. Compounding plate
162. Securing screws, compounding plate
163. Compounding transformer
164. Lock-washer
165. Insulator
166. Regulation plate
167. Securing screws, (190) on (160)
168. Self-locing nut (Nytstop)
194. Securing screw, regulation plate
195. Self-locking nut (Nytstop)
196. Gromments
197. Three-phase, rectifier bridge
198. Auto-transformer (for voltage other than 220 or 380 V)
199. Rectifier bridge
200. Guard-cover
223. Self-locking nut (Nytstop)



List of Parts

1. Outside bearing cap, Drive End (DE)
2. End shield, DE
3. Bearing, DE
4. Inside bearing cap, DE
5. Shaft key
6. Rotor with shaft
7. Winding
8. Body
9. Eye bolt
10. Inside bearing cap, Non Drive End (NDE)
11. End shield, NDE
12. End Shield, NDE
13. Split pin
14. Bush
15. Earthing bolt
16. Gasket
17. Terminal box
18. Gland
19. Terminal box assembly
20. Terminal box cover
21. Outside bearing cap, NDE
22. External fan
23. Fan cover

Figure 4.14: Exploded View of a Small Induction Generator

Table 4.6: Common Problems of Brushless Generators and Suggested Methods of Repair

Problem	Cause	Identification/ Assessment	Repairs
No voltage output from generator	- Residual magnetism could be lost as a result of a heavy short, during transportation, or if standing idle for a long period	- Disconnect field wires and run the generator. Check residual voltage across the generator output terminals, it should be approximately 5% of the rated voltage and balanced between each pair of lines	- If the residual voltage is less than 5% of rated voltage, the generator field coil should be 'flashed' by connecting a 12 volt battery across terminals F1 and F2 for about 5 seconds, making sure that terminal F1 is positive and terminal F2 is negative
	- Fuse on (AVR) may have blown	- Check fuse	- Replace if necessary
	- Field wires may be connected to the wrong polarity of excitor or AVR	- Check polarity of field wires	- If they are wrongly connected change polarity, (+) to (+), (-) to (-)
	- Loose connection of excitor or field wires	- Check connections	- Tighten as necessary
	- Rectifier or diodes may be faulty	- Check continuity of diodes (rectifier) with multimeter	- Replace if necessary
	- Internal short in windings	- Test winding resistance with multimeter and test insulation with a meggar	- Send to workshop for rewinding if damaged
	- AVR may be defective	- Check residual voltage at field terminals with AVR disconnected as described above. If generator excites, AVR is defective.	- Arrange for AVR to be repaired
Generator output voltage too low at no load	- Voltage settings are too low on AVR	- Check settings and voltage	- Adjust voltage by turning potentiometer on AVR
	- AVR sensing wires connected to wrong terminals	- Check connections to AVR against generator wiring diagram	- Correct if necessary
Generator output voltage too high at no load	- Turbine speed may be high	- Measure speed	- Bring to correct (rated) speed by adjusting flow
	- Voltage settings (preset) on AVR may be high	- Check voltage settings	- Adjust voltage by turning potentiometer (electronic AVR) provided on AVR

Table 4.6 Cont.......

Problem	Cause	Identification/ Assessment	Repairs
	- AVR may be defective - AVR sensing wires (input voltage) connected to wrong terminals	- Run the generator with AVR at rated speed on no load and try to decrease voltage by adjusting AVR potentiometer. If voltage cannot be adjusted, then AVR is defective - Check connections to AVR against generator wiring diagram	- Get AVR repaired or replaced - Correct if necessary
Voltage drops with load	- Belt slipping - Electronic AVR setting may be incorrect - Unbalanced load on phases	- Check tension of belts - Reset AVR settings - Check loads on each phase	- Increase tension to proper level - Check field voltage on AVR if low - Balance loads
Generator voltage oscillates	- Belts slipping - Very long, flat belt - Faulty AVR/ELC - Loose connection to AVR - Faulty bearings - Oval pulley	- Check tension of belts - Check shaft distances - Check stability of AVR/ELC - Check all electrical connections - Check bearings - Check the rim of the pulley	- Increase tension to proper level - Reposition generator to enable the use of a shorter belt - Adjust stability of AVR/electronic governor by adjusting the potentiometer - Tighten if necessary - Replace if necessary - Replace if damaged
Overheating of generator and excessive noise	- Generator overloaded - Faulty bearings - Insufficient ventilation	- Check load - Check bearings - Check vents and screens	- Reduce if necessary - Relubricate or replace if necessary - Unsealed bearings should be half filled with a good quality bearing grease - Clean generator and generator air inlet screens. Remove items which may be blocking flow of cooling air to generator while running

Table 4.6 Cont.......

Problem	Cause	Identification/ Assessment	Repairs
		- Check ventilation of powerhouse	- Provide additional ventilation if necessary
Vibration of generator	- Bearings worn out	- Check bearings as described before	- Replace with new bearings of same size and type
	- Bearing loose in housing	- Check whether bearing is loose in housing by checking play	- Replace housing if damaged
	- Loose foundation bolts	- Check all foundation bolts	- Tighten as necessary - Reconcrete foundation bolts if foundation damaged
	- Pulley or rewound generator rotor out of balance	- Remove belts and rotate pulley. If it stops in the same position each time either the pulley or the generator rotor is out of balance. Remove the pulley and try the same test. If the generator rotor stops in a different position each time, the pulley is out of balance	- Return pulley to the supplier for rebalancing
		- If the generator rotor stops in the same position each time the rotor is out of balance	- Return rotor to the supplier or a good workshop for balancing

Table 4.7: Common Problems of Induction Generators and Suggested Methods of Repair

Problem	Cause	Identification/Assessment	Repairs
Generator does not excite	- Low rpm (speed)	- Check speed of turbine. Induction generators excite at higher rpm than synchronous generators	- Increase speed by increasing flow
	- Insufficient capacitance	- Check capacitor connections - Check size of capacitors - Check type of capacitor and connection configuration, e.g., Delta, star or C-2C connection	- Tighten if loose - Replace with units of the correct size if necessary - Redo connections
	- Lost residual magnetism	- Disconnect capacitor and run generator. - Measure residual voltage between terminals, it should be approximately 5% of the rated voltage	- If residual voltage is less than 5 per cent of rated value, flash output terminals by connecting a 12V battery across the terminals for a few seconds
	- Miniature circuit breaker (MCB) between excitation circuits may be switched off	- Check wires and MCB	- If MCB is switched off then switch on
	- Load may be switched on	- Check load connection switch. Induction generators will not excite under load	- Switch off load
High voltage from generator	- Generator run under no-load conditions without IGC	- If there is no IGC connected and generator speed is excessive, high voltage can occur	- Reduce turbine speed with flow regulating valve
	- Generator output higher than ballast capacity	- Check ballast capacity	- Provide additional ballast if necessary
Low voltage	- Too much reactive/inductive load	- Check power factor or actual loads	- Reduce inductive load (e.g., tube lights and motors)
Voltage fluctuation	- Loose connection in ballast/IGC	- Check if ballast heater does not get hot. If so, check function of IGC and ballast heaters	- Repair or replace as necessary
	- Faulty IGC or ballast heaters	- Check connections and tighten if necessary	- As above
	- Fuse may be blown in IGC (if used)	- Check fuse	- Replace if necessary

Table 4.7 Cont.......

Problem	Cause	Identification/Assessment	Repairs
	- Belt slipping	- Check belt tension	- Adjust if necessary
	- Worn out bearings	- Check bearings	- Replace if necessary
Overheating of generator	- Overload	- Check the users' load	- Reduce if necessary
	- Faulty bearings or lubrication problem	- Check bearings and grease	- Grease bearings - Replace bearings if necessary
	- Low frequency/speed	- Check rpm	- Run generator at correct speed

4.5 Controls and Instrument Panel

The controls and instruments installed in an MHP scheme will to some extent depend on the size of the plant and the type of generator used. For example, very small units may only use MCB, voltmeters, ammeters, and a few safety devices; whereas larger units may use a variety of devices to control the variation and quality of output voltage and frequency and isolate the output if a high or low frequency or voltage situation arises.

Generally, an AVR or some voltage regulation system must be provided for a synchronous generator, since many MHP plants installed in the HKH region have no ELC or IGC; and speed/voltage regulation is carried out manually. Nowadays, ELCs are normally installed for synchronous generators and IGCs for induction generators, in order to keep the load and thus the speed and voltage constant. Figure 4.15 shows a typical instrument panel for a small MHP plant with a load control system.

4.5.1 Instruments for Schemes without a Load Controller

For units not equipped with an ELC or IGC, the control and instrument panel usually contains the following.

- Miniature circuit breaker (MCB) for over-current protection
- Current transformer (for current measurement)
- Ammeter
- Voltmeters
- Push buttons for connecting excitation system
- Connectors
- Indicator lamps (for individual phase output)
- Over-voltage trip (safety protection system)

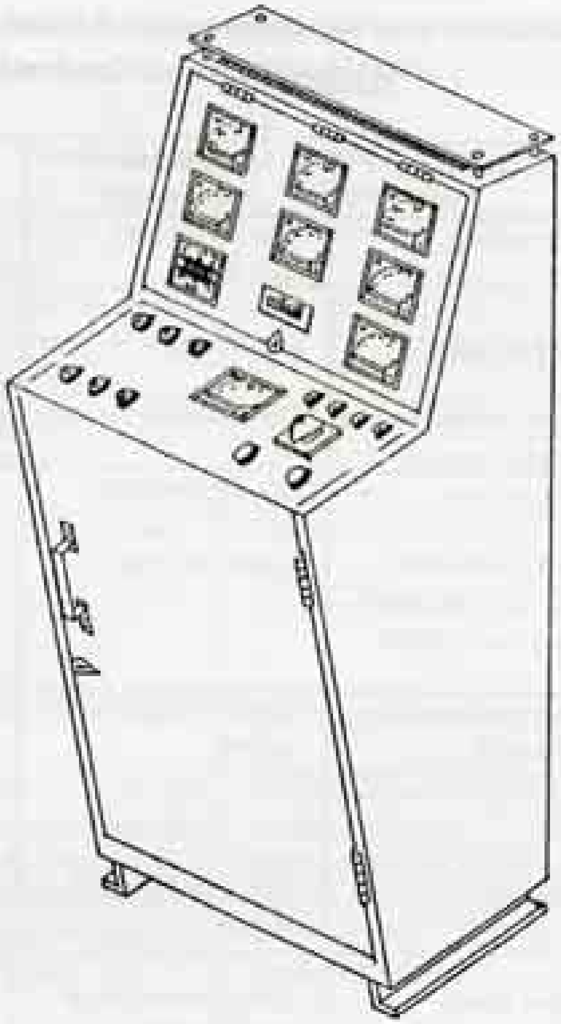


Figure 4.15: A Typical Instrument and Control Panel Including a Load Controller

Table 4.8 lists some of the common problems associated with control panels for plants that do not have a load controller installed, together with recommended solutions.

4.5.2 Instruments for Schemes with Load Controllers

For units equipped with an ELC or IGC, the control and instrument panel usually contains the following.

- Miniature circuit breaker (MCB) or miniature coil circuit breaker (MCCB)
- Thyristor (ELC electronic switch)
- Induction gate bipolar transistor IGBT(IGC electronic switch)
- Heat sink (for mounting of thyristor or IGBT switch)
- Heat sink (for mounting of thyristor or IGBT)
- Current transformer (for measuring current)

Table 4.8: Common Problems and Recommended Actions for Control Panels <u>Without</u> a Load Controller

Problem	Cause	Identification/ Assessment	Repairs
Voltage collapses after releasing push button	- Relay not holding - Relay may be faulty - Under/over-voltage setting not correct	- Check relay hold connection - Check relay - Check voltage setting	- Tighten connections if loose - Replace if necessary - Adjust voltage as necessary
Sparking/overheating of connector	- Loose connection - Undersize conductors (incorrect size may have been used during repair work)	- Check connections - Check wire size	- Tighten loose connections - Replace with appropriate size
High/low output voltage	- Over/under-voltage trip malfunctioning - Load variation - Fuses have blown	- Check settings of trip system - Check load through meters - Check continuity of fuse by meter	- Reset the settings - Test again - Replace any faulty component - Reduce load if higher on a given phase - Replace if necessary

- Ammeter (for measuring current)
- Voltmeter (for measuring output voltage)
- Frequency meter
- kW meter
- Ballast voltmeter (for ballast load indication)
- ELC or IGC main board
- Ballast fuse (to protect ELC, IGC, and ballast heaters)
- Push button (voltage/frequency over-ride for startup)
- Ballast heater (dummy output load for generator control)
- Ballast tank (housing for ballast heaters and water)
- Connector (for power output)
- Indicator lamps (for individual phase output indication)

Table 4.9 lists some of the common problems encountered with systems that have a load controller installed, and recommended solutions.

Table 4.9: Common Problems and Recommended Repairs for Control Panels Equipped with a Load Controller (ELC Or IGC)

Problem	Cause	Identification/ Assessment	Repairs
High output voltage and frequency but zero ballast voltage	- Thyristor open-circuited (damaged)	- Check thyristor	- Replace if damaged
	- Ballast fuse blown (no connection to ballast)	- Check fuse	- Replace with equivalent fuse if necessary
	- Defective ballast heater	- Inspect heaters	- Replace if necessary
	- MCB in off position	- Check MCB	- Switch on MCB
	- No supply to ELC	- Check 220V AC supply to transformer	- Restore supply
	- Defective transformer	- Check that transformer output is 18-01-18V	- If not send for repairs
Generator and ballast voltage rise together	- Belt slipping	- Check belt tension	- Tighten if necessary
	- Generator overloaded	- Check consumers' load	- Replace belt(s) - Reduce if necessary
	- Thyristor short-circuited so that ballast load and consumer load are on the generator, causing generator overload	- Check thyristors. If ballast voltage rises with generator voltage during startup, thyristor has short-circuited	- Replace if necessary
Speed fluctuation (hunting)	- Belt slipping	- Check belt tension	- Tighten if necessary - Replace belt(s)
	- ELC stability requires adjustment	- Turn 'STAB POT' slowly to check ELC stability	- Set proper stability
	- Incorrect function of AVR (new AVR only)		- Take AVR to expert/technician for testing and repairs
Ballast readings unequal when consumer load is not switched ON	- Defective meter	- Check meter	- Replace if necessary
	- Ballast fuse may be blown	- Check ballast fuses	- Replace if necessary
	- Loose ballast heater connection or faulty ballast heater	- Check connections and ballast heaters	- Replace as necessary
MCB or trip tripping	- Load too high	- Check load	- Reduce load to within rated limits
	- Current limiting or tripping device, e.g., MCB or over voltage trip (OVT) may be defective	- Check these devices	- Repair or replace as necessary

Table 4.9 Cont.......

Problem	Cause	Identification/ Assessment	Repairs
	- Incorrect voltage or frequency	- Check voltage and frequency meters	- Adjust potentiometer to correct voltage frequency
	- Defective MCB	- Check	- Repair or replace as necessary
Connector or wire burnt or sparking	- Loose connection	- Check connections	- Tighten connections, change connector if damaged
	- Short between connector terminals	- Check for shorts	- Connections should be tightened periodically
	- Ventilation to ELC may be blocked	- Check ventilation holes and screens	- Ensure air circulation during operation. Clean filters and air inlets and remove any obstacles to circulation
	- Fans not working (if provided in ELC)	- Check function of fan	- Repair/replace if required
Electric shock from ELC/ballast	- Current leakage	- Check voltage on metal casing and earth connection, live wire may be touching casing	- Check all live wires including heating elements and housings. Repair/replace as necessary
Indicators do not light	- Bulb blown	- Check bulb	- Replace if necessary
	- No supply to indicator bulb	- Check supply wires	- Repair connections to restore supply
	- Short circuit	- If MCB/fuse/trip blows immediately after switch-on, there may be a short circuit between phases or between phase and neutral	- Locate short and rewire as necessary
High/low output voltage	- Over/under-voltage trip malfunctioning	- Check setting of trip system	- Reset settings - Test again - Locate and replace any faulty component
	- Load varying	- Check load through meters	- Reduce load if high
	- Fuses blown	- Check fuses with multimeter	- Replace if damaged

4.5.3 Protection

Over-Voltage Trip (OVT) Board (or Safety Protection Board)

The over-voltage trip board protects consumers from high voltage by isolating the generator excitation in the event of high voltage output. It also protects the generator rectifier and field coil, which may otherwise burn out if the output voltage goes high.

Over speed/over-voltage may take place if:

- the load varies,
- the output fuses blow,
- there is no load controller,
- there is a sudden increase in water flow to the turbine, or
- the load controller or AVR do not work properly.

For any of these conditions first locate the cause and rectify before attempting to reconnect the load to the generator.

Earthing

All earth connections should be checked at least once a year. If possible, the resistance to earth should be measured, and the condition of all earthing conductors and plates closely inspected for corrosion and discontinuities.