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A Pelton Micro-Hydro Prototype Design

by: Allen R. Inversin

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APPROPRIATE TECHNOLOGY DEVELOPMENT UNIT

**A PELTON MICRO - HYDRO
PROTOTYPE DESIGN**

by

Allen R. Inversin

JUNE 1980

Lae, PAPUA NEW GUINEA

A PELTON MICRO-HYDRO
PROTOTYPE DESIGN

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Allen R. Inversin

International Voluntary
Services, Inc.

ATDU
P.O. Box 793
Lae, PAPUA NEW GUINEA

June, 1980

Preface

Papua New Guinea is largely a nation of often small isolated villages, most at some distance from the few major arteries running out from the towns. Many of the villagers are aware of the apparently large disparities between the "easy" life in these towns and the continued austere life in the rural areas. Those who can economically and socially afford it drift to the urban areas looking for work and entertainment. Many of those who remain in the villages feel that in spite of all the promises of rural development broadcast through the media, nothing seems to change. They feel that "development" continues to pass them by. Public and private funds and other inputs continue to be poured into the towns and cities.

Electricity is clearly one of the contributing factors as well as one of the symbols of "development". In the urban environment, it carries with it a bag of mixed blessings. It provides light for evening chores, reading and studying, pool halls and bars, for movies to broaden the mind or more often to push a nightly fare of consumerism, Kung-Fu, and crime. It provides power for industry, to cut timber for lumber, fabricate steel drums, and bottle beer.

While possibly not viewed by some as a real need, is it still possible that introducing electricity into rural villages could be one factor towards rejuvenating life in these villages? Can a technically and socially appropriate system with active villager participation in the planning, installation, management, and evolution of their own scheme have beneficial effects? Is it possible in theory only or can power used for lighting community centres, churches, and outdoor areas actually contribute to community solidarity? Can it be used to operate small tools to make possible some form of employment, to power freezers to preserve fish in coastal areas, to pump water to the village from the streams below?

Can it have a psychological impact, giving the villagers the opportunity to see that through their own initiative and labour, they have been able to begin bringing beneficial changes into their own village? Might this not have a catalytic effect, that they see that they can lift themselves up by their own "bootstraps", that they begin to realize that through their own inputs it is possible to be more in control over their own destiny?

To date, these questions are largely rhetorical. Few villagers have had the opportunity to answer these questions. The principal reasons for this are technical and economical. The main power grid will never find it cost-effective to cover long distances and pierce rugged terrain to serve small scattered communities who will never consume large amounts of power. Autogeneration of power by means of petrol or diesel generating sets is still relatively expensive both in terms of installation and recurring costs and is generally technically inappropriate in the rural setting because of the lack of skills necessary for proper maintenance and repair. Micro-hydros do have the advantage of tapping the "free" power in the streams and rivers of PNG thereby minimizing recurring costs. However, commercially they are still very expensive and conventionally fairly complex. But with a country like PNG with its abundant rainfall and rugged terrain, the potential or low recurring costs seems sufficient bait to warrant work towards reducing the cost

and complexity of micro-hydro generating sets. This has been our objective. We have tried to resolve the technical and economical drawbacks preventing the use of this otherwise appropriate source of power.

Since the author is shortly finishing his present tour with International Voluntary Services (IVS) at the ATDU, this report is a document some of the results of this work to date. It is also to share this with others involved in this field of work in the hope that useful feedback might be received from these individuals and groups.

Much yet remains to be done if this work is not to end as so many other such projects have ended -- a piece of hardware lost in a recess in the workshop, whose promising future is somewhat obscured by a layer of dust and a maze of spider webs. Work has to continue on finalizing a design which can easily be made in workshops in PNG, on locating less expensive sources of those imported items still necessary, on making generating sets commercially available, and more importantly, on socially appropriate implementation of village micro-hydro schemes. This is the future work to which the author would like to contribute.

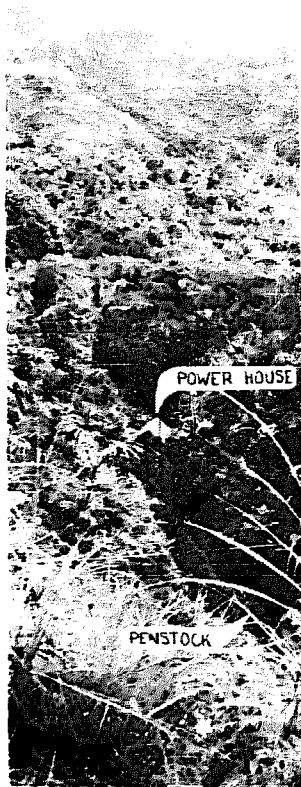
A.R.I.

Lae, Papua New Guinea
June, 1980

ACKNOWLEDGMENTS

Though I may have been at the centre of ATDU micro-hydro activities to date, others from both within the Unit and outside have directly and indirectly contributed to the work. *Ian Bean*, the DPI Rural Development Officer at the Pindiu patrol post, largely forgot about the experts and detailed theory, installed home-made micro-hydros at three remote village sites, and planted a seed by showing that it could be done before others said that it could not. *Jaime Lobo-Guerrero*, head of the mechanical engineering department at the Universidad de los Andes,

though always occupied with numerous other activities, took the time out to share his ideas and experiences on appropriate technological approaches to his micro-hydro work. *Ignacy Swiecicki*, a VITA Volunteer with a career of fluids behind him, submitted welcomed suggestions during the initial work on bucket design through his thoughtful and meticulously illustrated correspondence. *Mursalin New*, while primarily involved in the ATDU non-ferrous foundry project, made significant contributions as a result of his ability to analyze a problem, determine its essence, and resolve it through simple designs, a lost art at a time when contemporary developments are becoming generally more and more complex. *Ed Arata*, the ATDU Operations Manager, started with a few basic sectional views of a Pelton bucket and carefully and patiently carved out the final pattern, and *Lukis Romaso*, graduate engineer



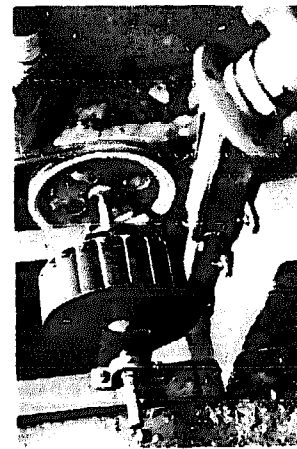
Power House



Headrace



Penstock



Banki Runner

Views of one of Ian Bean's micro-hydro installations (Gemaheng, near Pindiu, Morobe Province)

with the ATDU, made the final patterns for the prototype. *Herb Edie*, a technical officer with the Department of Electrical and Communications Engineering, with a store of practical, down-to-earth experience, gave freely of his time to clear up electrical aspects in between his often more pressing tasks. And *Jack Woodward*, former head of the Department of Electrical and Communications Engineering, and the villagers from the *Baindoang* area gave me the opportunity to participate in the implementation of the *Baindoang* micro-hydro scheme. It was this participation which triggered my interest in micro-hydro work and gave me a feel for the realities and the aspirations of the Papua New Guineans living in the remote areas of this country.

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A PELTON MICRO-HYDRO PROTOTYPE DESIGN

This report describes work to date on a modular design for a Pelton micro-hydro generating set with an electrical output up to of the order of 5 kVA and with a "typical" installation cost of about K300/kVA including penstock costs. A brief discussion of costs counters the commonly held argument of high cost for micro-hydros by presenting a design less expensive than diesel generating sets and, when recurring costs are included, less costly than both diesel and petrol. Also covered briefly are ideas on governing, bucket design and prototype performance, and cost/kW of PVC penstock pipe for different site configurations and pipe diameters.

1. INTRODUCTION

This report describes a design of a hydroelectric generating set for potential use in remote, rural areas in Papua New Guinea. With its maximum electrical power output of the order of 5 kVA, it has a capacity at the lower end of what is generally considered "micro-hydro". Though not a large quantity of power, it is far from insignificant in that setting and could be sufficient to cater to a number of different end uses. It also presents a number of advantages over larger micro-hydros (10-20 kVA or up):

- Virtually all the work can be undertaken by the villagers themselves with the minimum of technical guidance. These installations can therefore be self-help projects, with all the advantages implicit in this (low-cost, permanency, etc.).
- They can be an unsophisticated design which can be maintained by the villagers with the absolute minimum training.
- If a major repair would be necessary, the components can be carried out, obviating the need for costly technicians to fly and walk into remote areas, first to diagnose the problem and then possibly again to undertake the necessary repairs.
- They can tap smaller streams, an advantage in a country like PNG with its high and intense rainfall and steep terrain, where rivers quickly grow by huge proportions. Only minor civil works are therefore necessary.

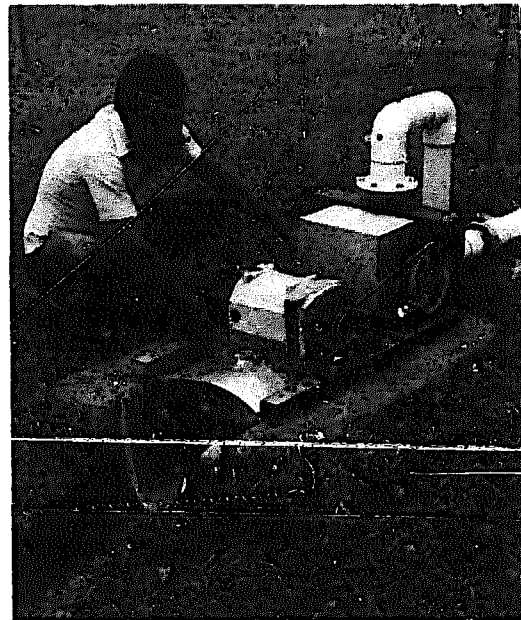


Figure 1

- They are much less costly in an absolute sense.
- And as important as the technical and economic advantages, they give the villagers a chance to determine for themselves the appropriateness of autogeneration of electricity with the minimum of capital outlay. If interest continues, a management scheme evolves, and maintenance skills are acquired and mastered, villagers can then opt for a larger plant (provided that the water resources exist). If not, the unit can be abandoned at no great loss or transferred easily to another site. This is not true with larger units.

Generally the generation of power from streams and rivers has a number of commonly accepted advantages. Potentially it is environmentally sounder, is not dependent on imported petroleum fuels with their increasing scarcity and cost, and has low recurring costs. However a commonly held argument against hydroelectricity as an alternative to petrol or diesel driven generating sets is its high cost of installation. While this is definitely true of micro-hydros if they are bought on the commercial market, it need not otherwise be the case. The design described in this report is competitive with diesel power (in terms of cost of installation/kVA). When cost of fuels, etc. is included, it is easily competitive with even inexpensive petrol generating sets.

Initial work has been confined to Pelton generating sets simply because our first experience was with these runners. It is not because Pelton units are felt to be generally more appropriate than other designs. Because they require a high head (15-20 metres on up), they potentially can require long lengths of penstock pipe available only on the commercial market at a price over which the buyer has no control. From this point of view, low head units could be more appropriate. But then, however, lower head units would require proportionally larger volumes of water. This means tapping larger streams and solving potentially more problems through more expensive and complicated civil works. In a large portion of PNG, the steep terrain with large rainfalls indicate that high head sites might generally be more appropriate. But each site presents a unique situation and has to be evaluated on its own.

This report describes primarily the mechanical and hydraulic aspects of a micro-hydro prototype but it also includes some thoughts on other aspects. It concerns primarily an electrical end-use but the potential exists for tapping its mechanical power directly for powering water pumps, woodworking equipment, freezers to preserve fish catches in coastal villages, etc. It documents what has been done to date and some other ideas. It is not final in any sense. Simplifications in its construction can no doubt be made before field installations and probably others made after field trials.

2. DESIGN

2.1 General Guidelines

If a design for a micro-hydro generating set is to be in any way appropriate in PNG, it is felt that it must meet several conditions:

- (1) Its construction must be as low-cost as possible yet as rugged as necessary.
- (2) Its fabrication must initially be of locally available steel stock and require the minimum of machining or special skills.
- (3) Its installation in the field must be straightforward and require virtually no on-site laying out.

In the description which follows, only some dimensions are noted and the drawings are approximately to scale. Precise dimensions depend on what materials are available and the method of fabrication.

2.2 Major Features of the Design

The design which has evolved to date is described in the following pages. Below are summarized some of the major features of that design:

- (1) The design is standard in that it can operate under a wide range of heads simply by selecting the appropriate pulleys.
- (2) Only drilling and virtually no machining is required. The prototype was largely held together with bolts though welding could be used almost entirely. The only parts which require machining are the keyways on the shaft, a job which could be contracted out if necessary.
- (3) The RUNNER HOUSING contains provision for one or two nozzles with no change in basic design.
- (4) To minimize difficulties which might otherwise be encountered with the installation of the generating set in the field,
 - (a) all foreseeable components of the system can be mounted on a single prefabricated steel BASE (these components include the RUNNER HOUSING and the alternator as well as possibly an emergency dump load, control panel, tool board, mechanical power take-off, etc.)
 - (b) during the laying of the concrete foundation, all the necessary formwork (a couple rectangular pieces of galvanized sheet) are an integral part of the BASE (see Figure 7). The penstock is laid after the concrete has set and the RUNNER HOUSING been mounted, starting from the HOUSING and working up the hill toward the intake.
- (5) The design is calculated to minimize alignments necessary in the field. The only adjustments necessary are lateral positioning of the Pelton runner on the shaft, pulley alignment, and belt tensioning (see p. 18).

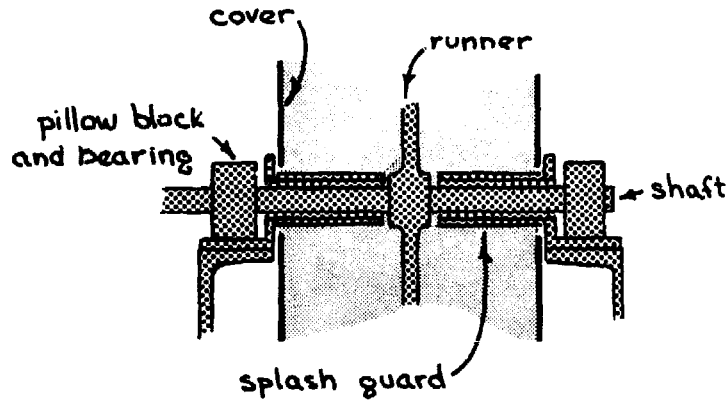


Figure 2

- (6)* Rather than the rather complicated fabrication of labyrinth seals to prevent water from following the shaft onto the bearings, the shaft is simply shielded by lengths of iron pipe as sketched in the sectional view in Figure 2. The pipes are welded to the angle pieces which in turn are bolted, with the bearing pillow blocks, to the RUNNER HOUSING. The cover is designed to accommodate this pipe.
- (7)* The nozzles are simply orifice plates screwed onto the HOUSING walls. These are trivially constructed, cost virtually nothing, are easily replaced, and introduce negligible losses (see p. 9).

The design operates at a fixed power input (see section on GOVERNING). No (costly) valves are therefore necessary. Should it be necessary to operate under a different power input (because of water shortage, expansion of the system, etc.), an orifice of different diameter can easily be inserted.

- (8) Though it is advisable to build some sort of shelter over the generating set, it has been designed so that no components (except the penstock) protrudes beyond the BASE. A tight-fitting rectangular box can fit around the BASE with its attachments (Figure 3) and, if necessary, locked in place.

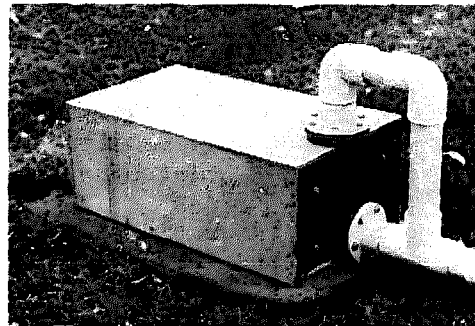


Figure 3

* These ideas come from correspondence and discussions with Dr. Jaime Lobo-Guerrero of the Universidad de los Andes, Bogota, Colombia, who has been involved in considerable work with micro-hydros. The hydraulic governing idea is also the result of joint work by him and John Burton (see Appendix D).

- (9) Any general repairs (replacing self-aligning bearings, brushes, belts, orifice plates or runner if necessary) can be easily done in the field. The final design should be such that the minimum of tools are necessary to effect such repairs.

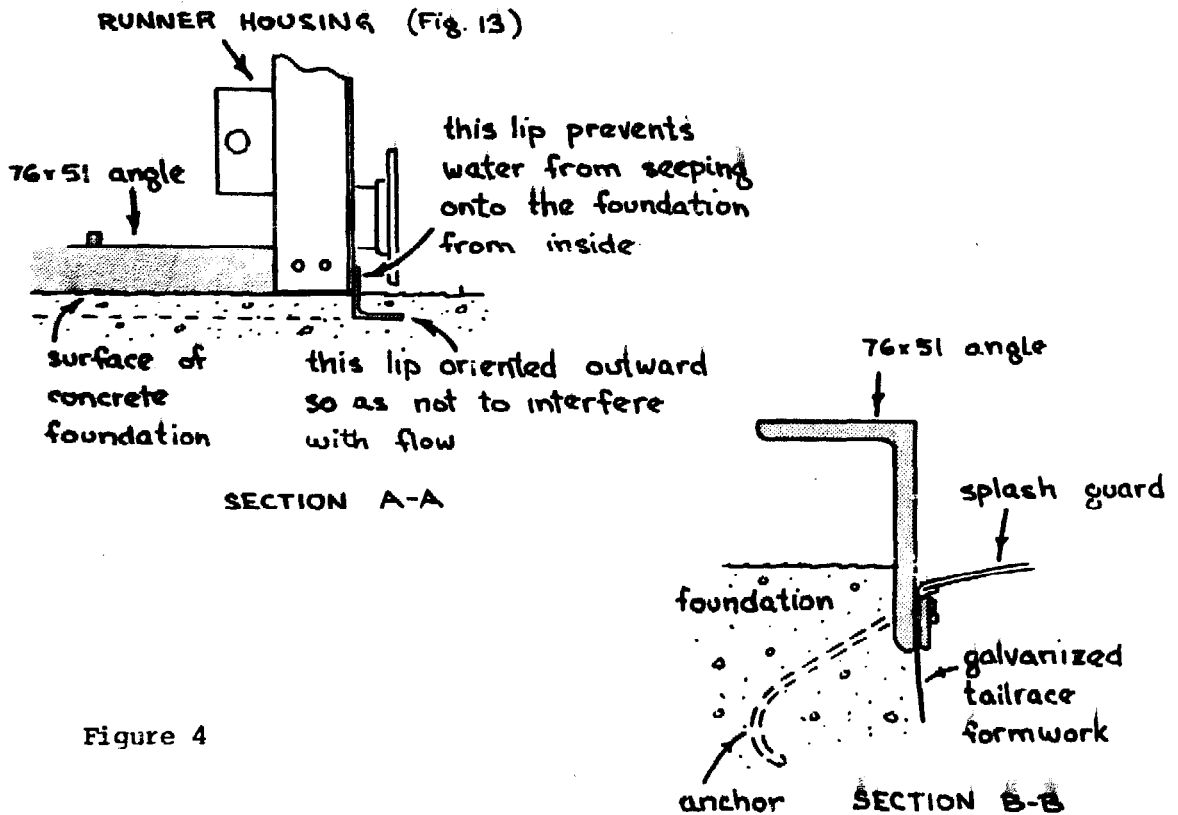
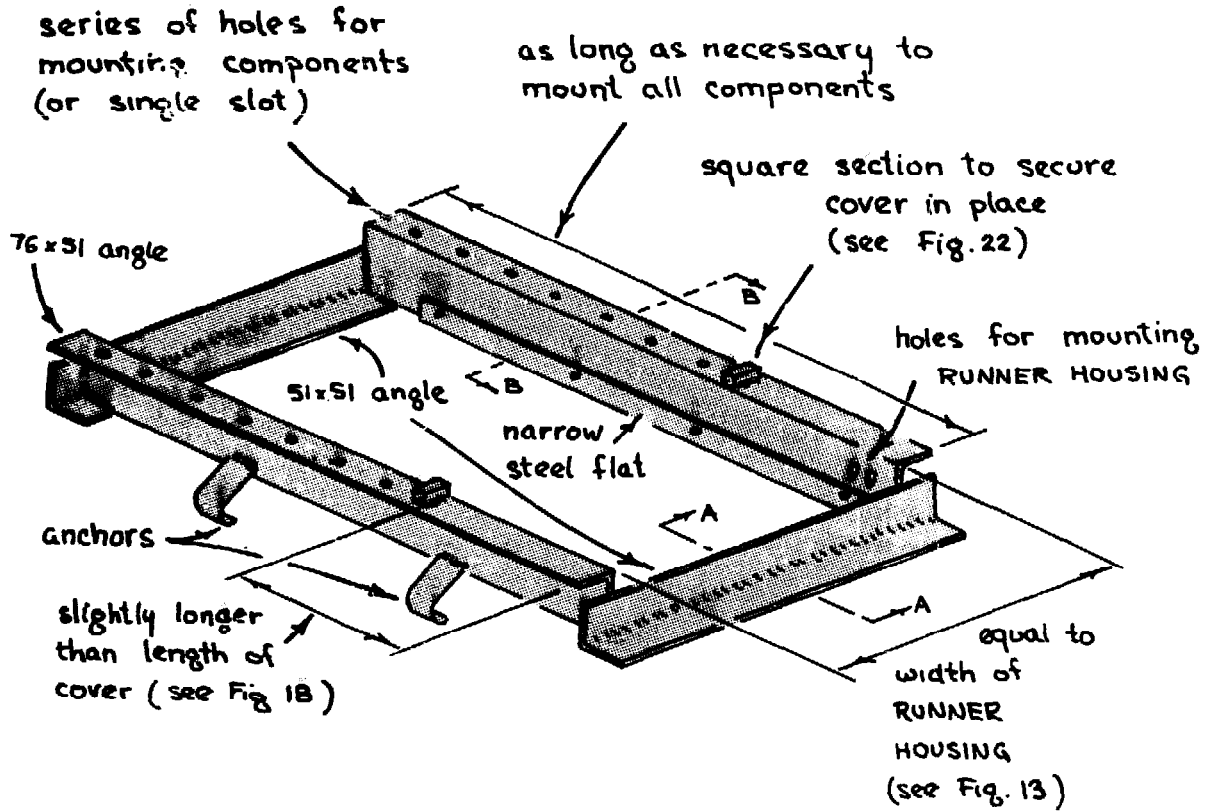


Figure 4

2.3 BASE

Two pieces of unequal angle serve as the main members of the BASE on which all components of the generating set are mounted. The two lateral pieces of smaller angle serve to keep the BASE square until it is installed in concrete. To ensure that the BASE is properly keyed into the concrete foundation, anchors can be welded as shown in Figure 4.

To secure the cover which is set over the Pelton runner, two short lengths of square section are welded to the top of the longitudinal members. These are later to be used as shown in Figure 22.

Along the bottom edge of each of the two longitudinal members and of the lateral member under the RUNNER HOUSING are screwed narrow steel flats using self-tapping screws. These serve two purposes:

- (1) to hold the galvanized sheet tailrace formwork in place
- (2) to provide a lip on which the splash guard rests

Both of these functions are illustrated in section B-B of Figure 4. It is possible to omit these flats. In this case, the tailrace formwork must itself be screwed onto the BASE and the splash guard can then rest on the upper edge of the tailrace formwork.

To mount the various components on the rails, either a series of holes can be drilled or a slot can be machined or cut with a torch. If holes are drilled, see the note on spacing of the holes on p. 17.

The formwork necessary for the tailrace within the foundation is constructed from a couple rectangular pieces of galvanized sheets which remain in place after the concrete has set. These are cut to the approximate size shown in Figure 5. This formwork is secured to the BASE by pinching it underneath the steel flats

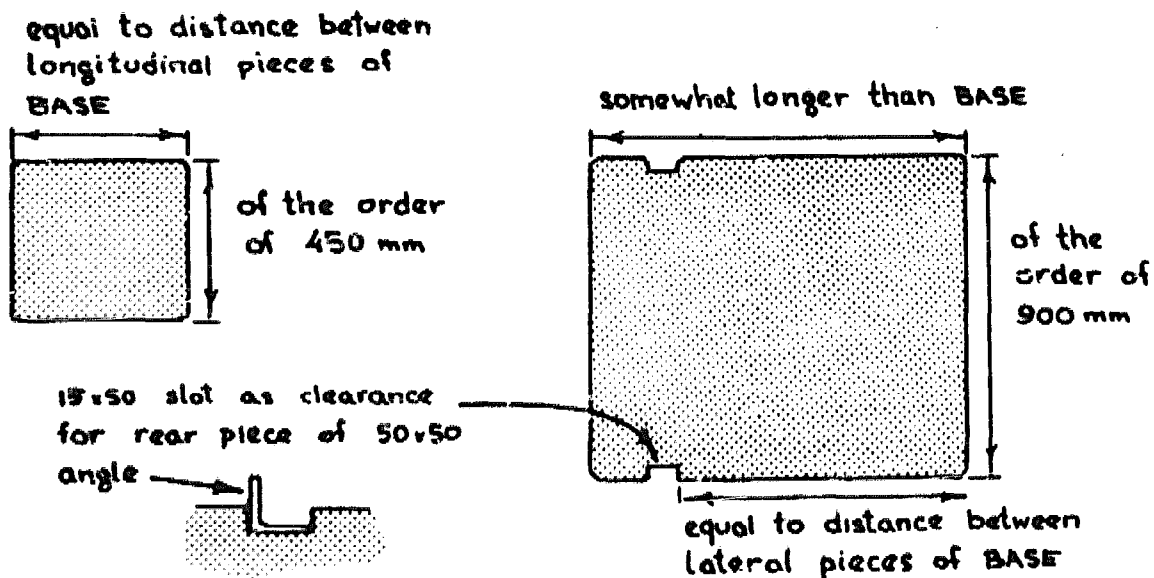


Figure 5

which run along the bottom of the BASE (Figure 4, section B-B) or if the flats are omitted, it can be screwed directly only the BASE.

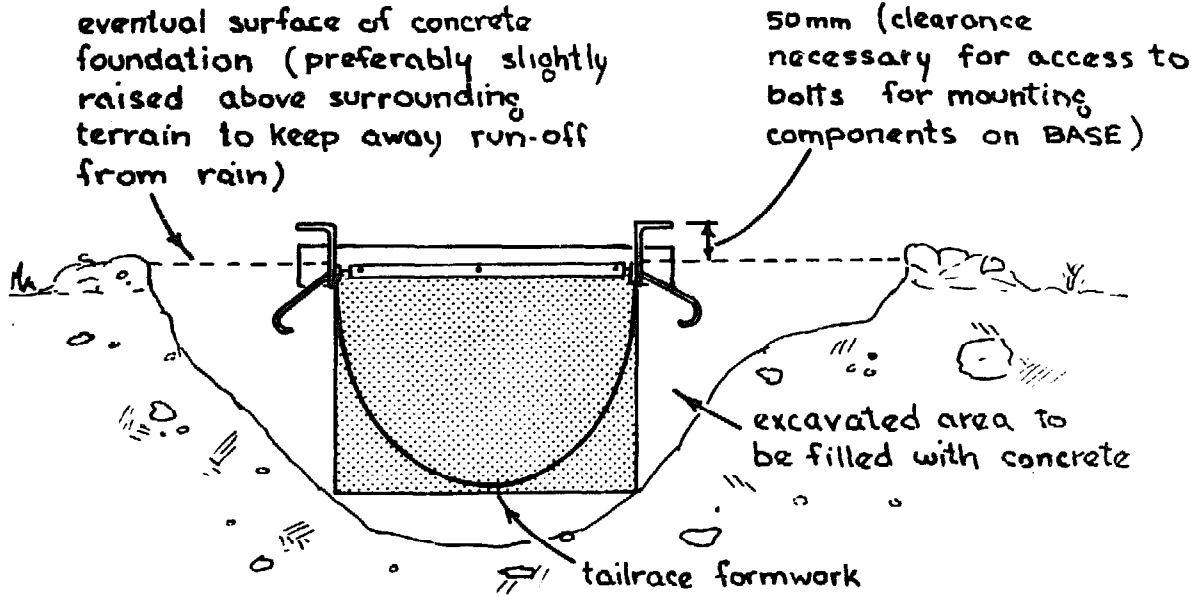


Figure 6

The formwork for the foundation itself can be the earth walls of the area excavated for the foundation (Figure 6). The outside dimensions of the foundation can be made to suit the requirements.

Once the excavation has been completed, the BASE with tailrace formwork is placed in the desired position and is supported from within the excavation by three stakes. These stakes are firmly driven into the excavated area and support the two ends of the BASE (Figure 7). These stakes are eventually imbedded completely

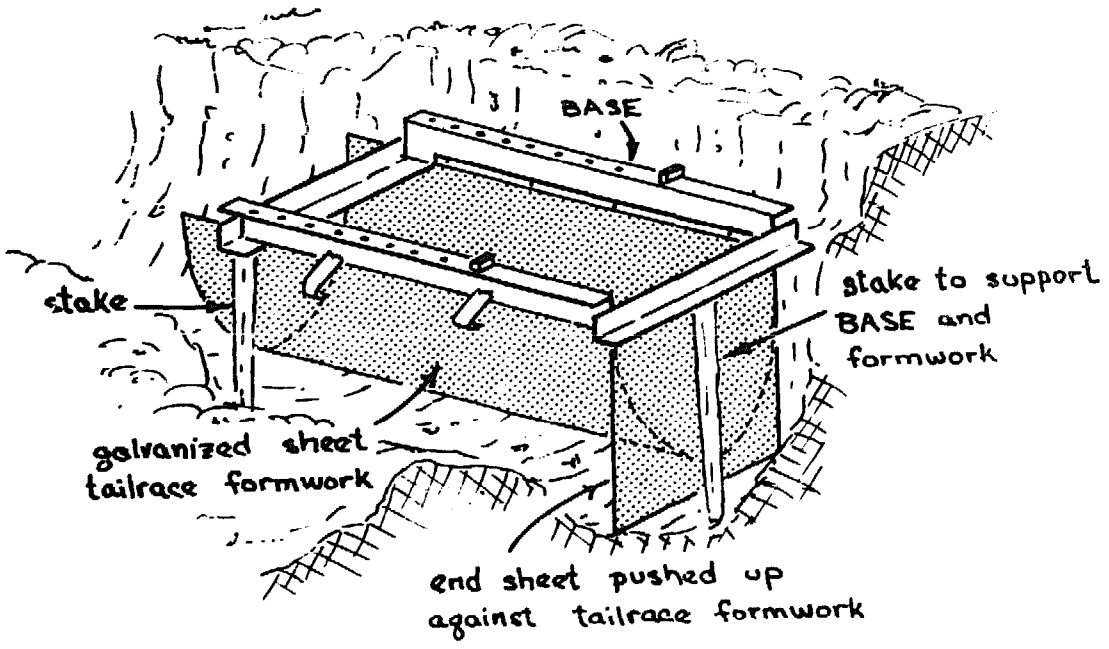


Figure 7

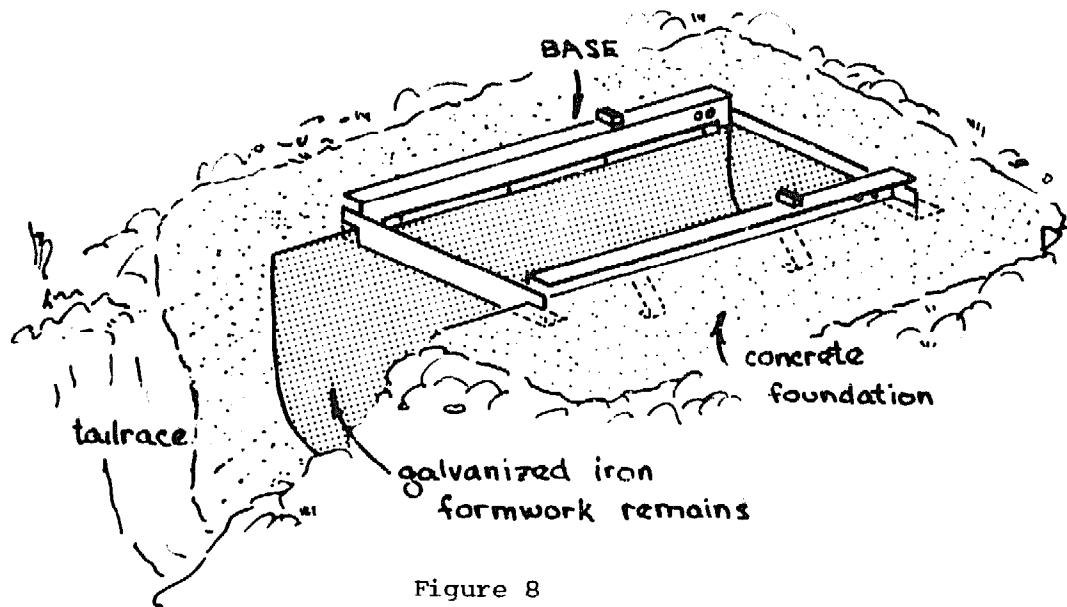


Figure 8

in concrete and not removed. Though not critical, the BASE should be fairly level. Concrete is then carefully poured to completely fill the area under the trough and built up to the level noted in Figure 6. The completed foundation is shown in Figure 8.

2.4 RUNNER HOUSING

Two lengths of channel iron serve as the backbone of the HOUSING and are bolted to the BASE. These are spanned by a piece of 3 mm plate across the front of the channel pieces and a 6 mm flat across the top. The shaft, runner, bearings, and shield are mounted across the back of the channel pieces (Figure 13). Aside from the bolt holes for mounting the pillow blocks on the RUNNER HOUSING and the RUNNER HOUSING in turn within the BASE, the remaining components may be either welded or bolted together.

In cutting the steel stock, it is generally difficult to get cuts which are both clean and square to the edges without special effort or tools. Consequently the cut end of a piece of channel, angle, or flat should never be used as a reference line from which to make subsequent measurements (Figure 9). Rather a reference line (the fabricated edge of the piece) and a reference point (at the end of the reference line) should be designated for each piece. All measurements are made from this reference point and line with a ruler and square (Figure 10). If a number of micro-hydro generating sets are to be fabricated, jigs should be used to simplify the work. If so, the above point must be kept in mind in the design of the jigs.

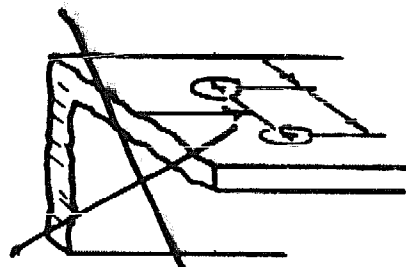


Figure 9

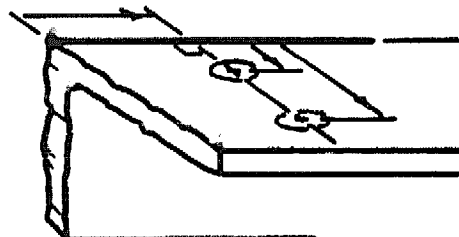


Figure 10

Provision for mounting the orifice plate nozzles is made on the front and top pieces of steel spanning the channel iron. These must be carefully positioned since, as designed, there is no provision for altering the position of the shaft. This latter point is intentional. It is felt easier for the fabrication of the unit to be precisely undertaken in a workshop by knowledgeable individuals than for the otherwise necessary adjustments to be made in the field.

As initially designed and used with the prototype, drilling is the only machine operation required in the fabrication of the nozzles. With this design, a hole about equal to or larger than the orifice to be used is drilled along the centre-line of the jet along with mounting holes (Figure 11). The runner used with the prototype can accommodate a maximum jet diameter of about 18 mm which requires a 23 mm orifice.

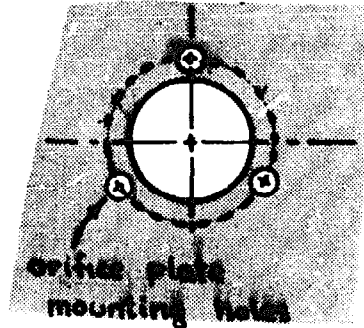


Figure 11

The orifice is carefully drilled in a piece of 3-5 mm steel so that the edges of the hole are clean and sharp. The diameter of the orifice should be 25%-30% greater than the diameter of the required jet diameter. Three mounting holes are drilled and threaded to accept screws as shown in Figure 12 (only one of the three screws is shown). Once the edge of the orifice plate has worn down sufficiently to warrant removal, the plate can simply be reversed to use the sharp edge of the second side.

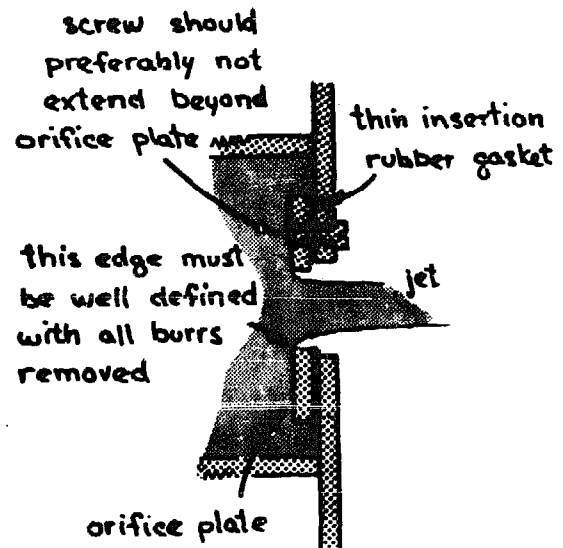


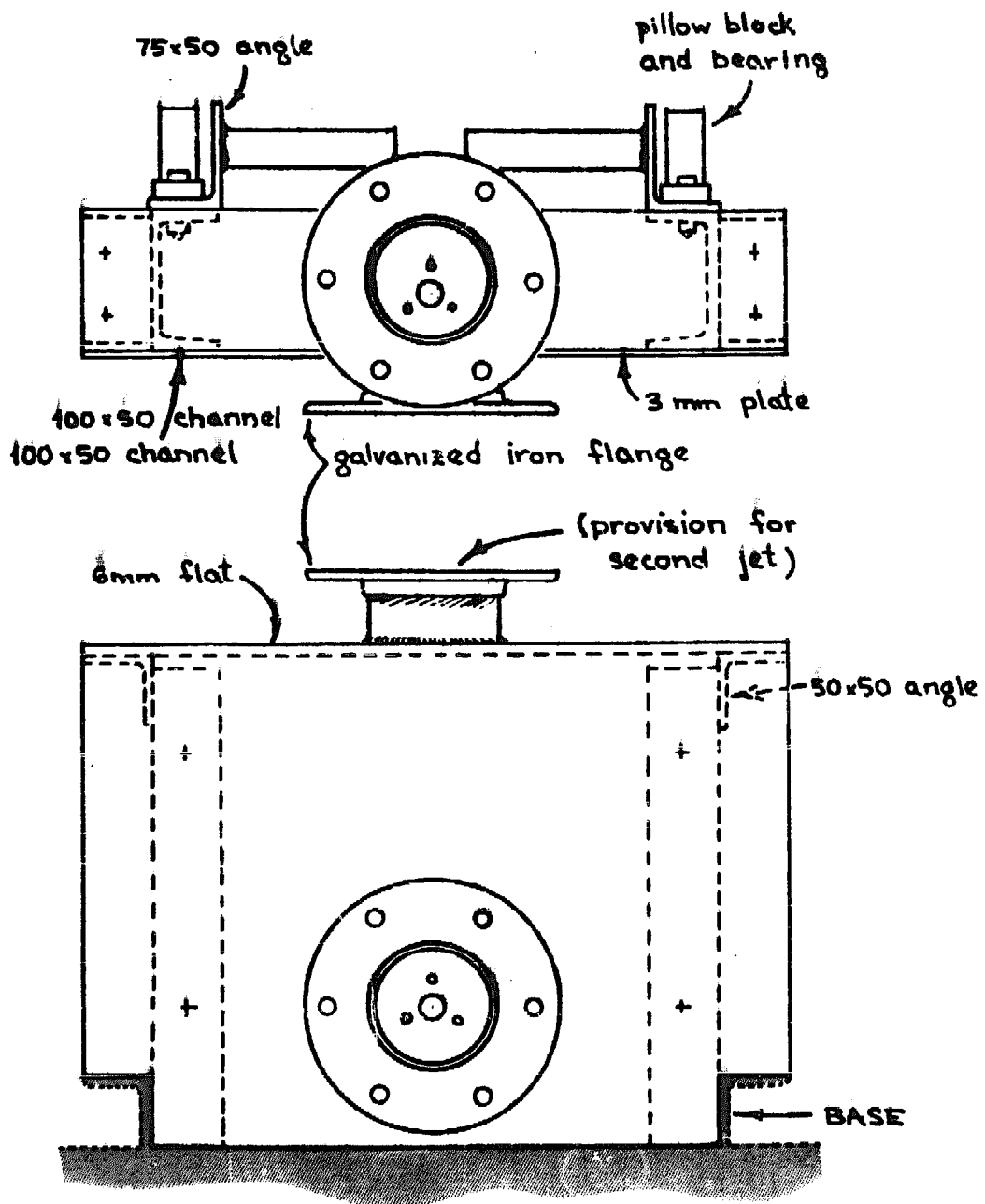
Figure 12

The design above does have a major drawback. The orifice plates can only be mounted from within the penstock. Consequently, changing or replacing the orifice plates would require that the flange bolts and HOUSING mounting bolts be removed and the HOUSING moved back from the penstock. A more appropriate design is necessary. Several suggestions are noted in Appendix C.

While laying out the mounting holes for the orifice plates, leave two permanent marks on the top and front plates in the positions indicated in Figure 14:

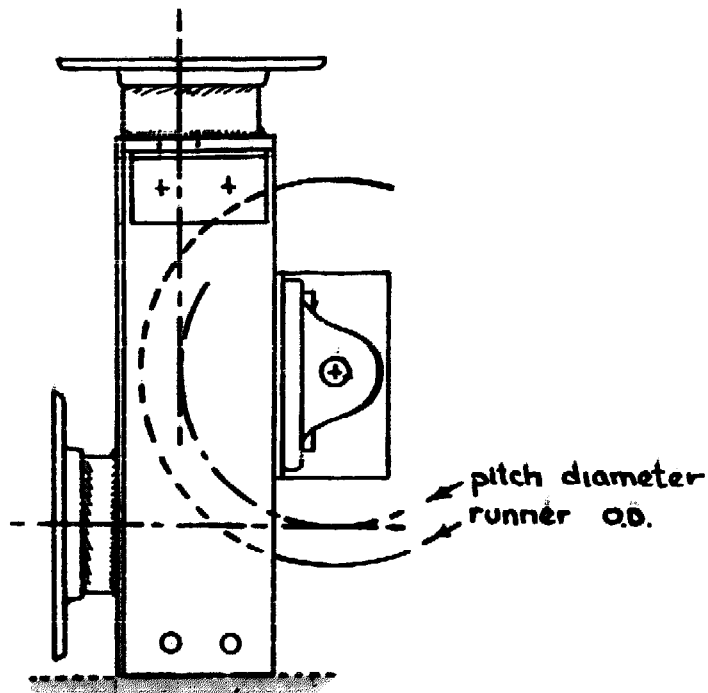
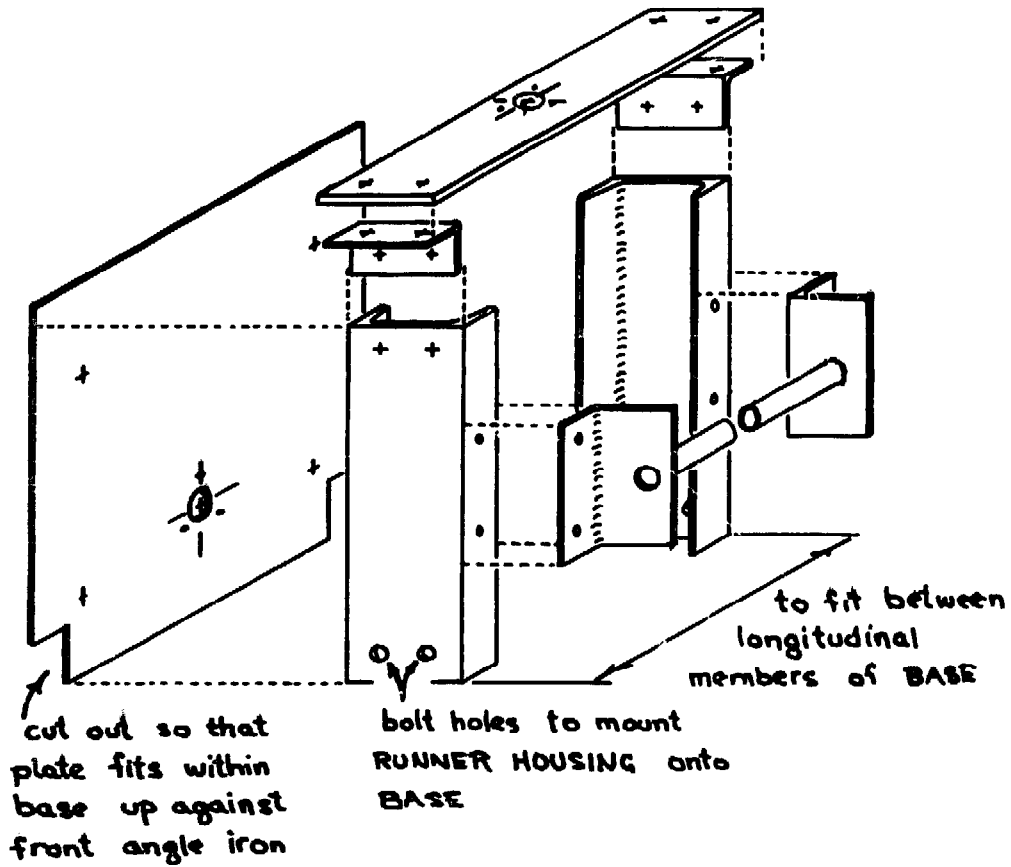
- (1) file a nick on the lower edge of the top plate and
- (2) scribe a deep, easily visible line on the back of the front plate

These lines will be used to position the runner along the shaft during installation (see p. 18).



+ position of holes for bolts if used as an alternative to welding

Figure 13. RUNNER HOUSING (scale: 1/5 actual)



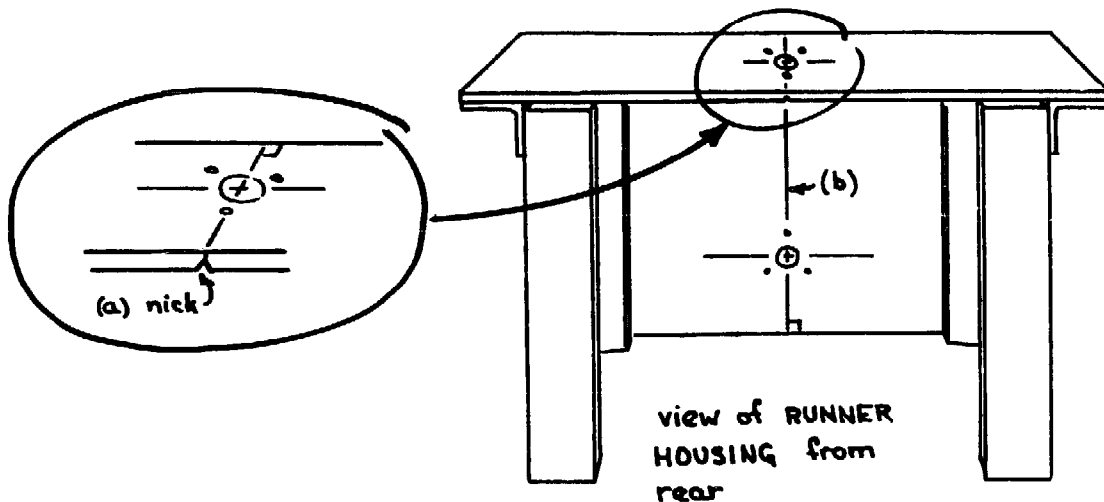


Figure 14

The shield to prevent water from striking the bearings is fairly straightforward. The two pieces of angle iron which will eventually support the shield are first drilled. Note that the mounting holes in the pillow blocks (which in turn hold the bearings) are slotted. If alignment problems are to be minimized in the field, it is best to fix the position of the blocks to prevent their movement. This can be done by drilling the mounting holes in the outside extremities of the slots (Figure 15).

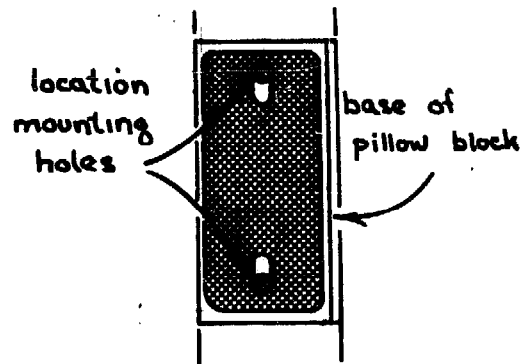


Figure 15

Once drilled these pieces should be bolted in place. One length of pipe is wedged between these two pieces and welded (Figure 16). Then the centre portion of the pipe, slightly longer than the width of the runner hub, is removed (see also Figure 2).

The runner shaft should preferably be made of stainless steel so as to facilitate replacement of bearings and runner when necessary.

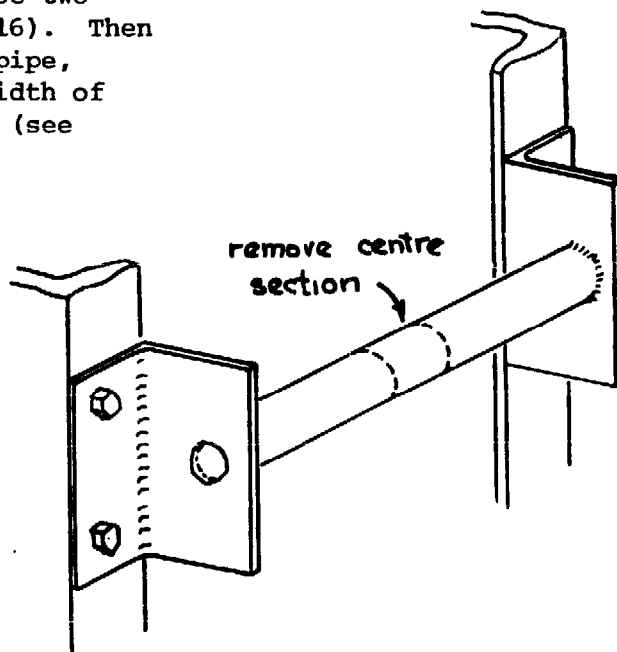


Figure 16

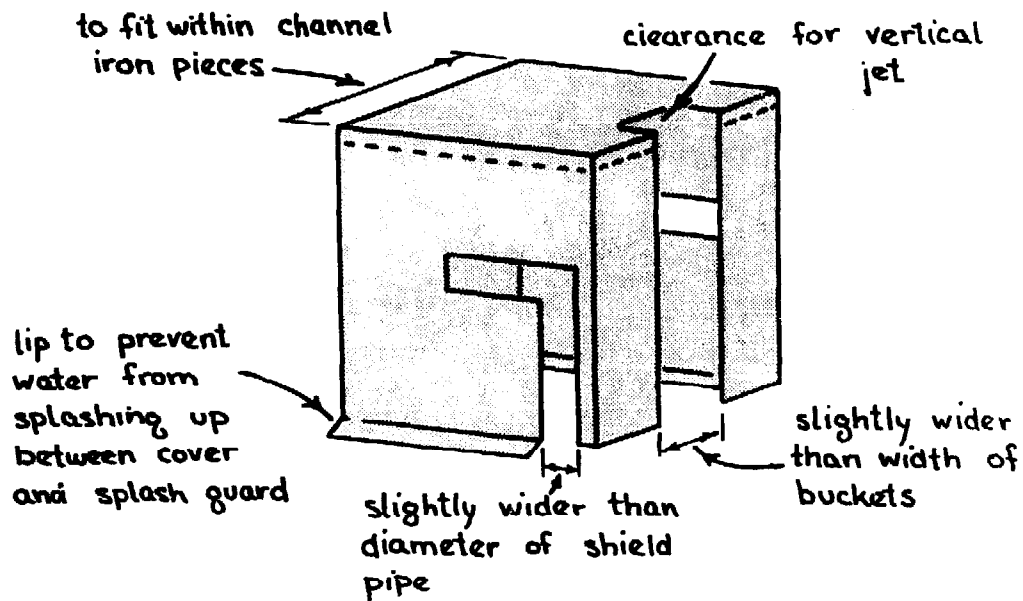


Figure 17

For the prototype, the initial cover design was constructed of thick galvanized sheet, a longer piece folded around to make the sides and a smaller piece pop-riveted (with blind pop-rivets) on top (Figure 17). This cover was fabricated to fit fairly snugly between the two vertical channel iron pieces and just under the top plate spanning these pieces (Figure 18). The cover rests on the shield pipe sections.

Though this design proved generally effective, it was noted that just below the operating speed, spent water from the buckets would get caught up in the channel members and spray out the top (Figure 19). A slight modification would be necessary. If welding is used in the fabrication of the HOUSING (as an alternative to bolts), the gap between the top flat and channel iron could easily be sealed.

But even without welding, this problem seemed eliminated by placing additional sheets over the shield pipes between the

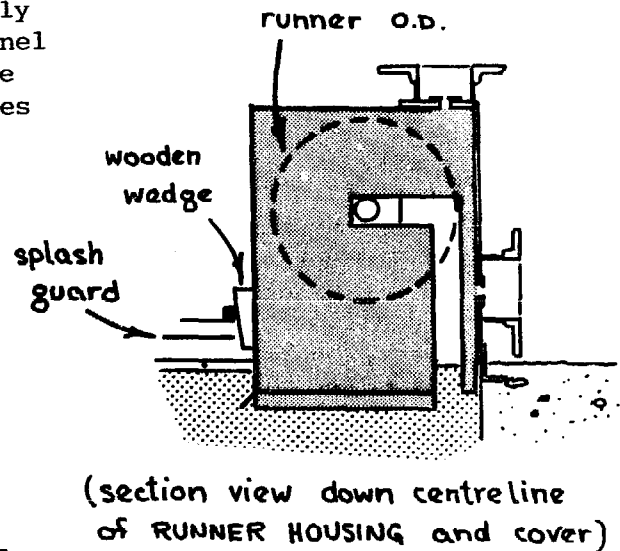


Figure 18

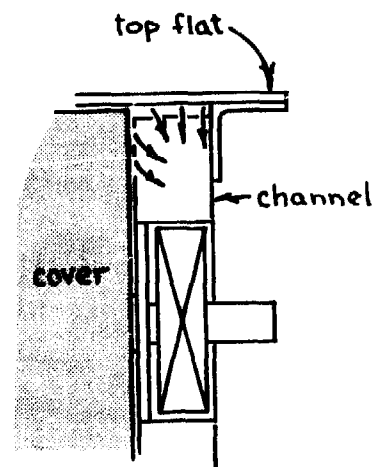


Figure 19

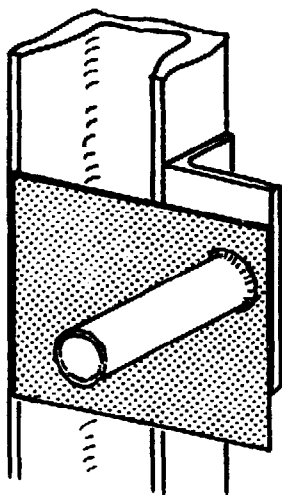
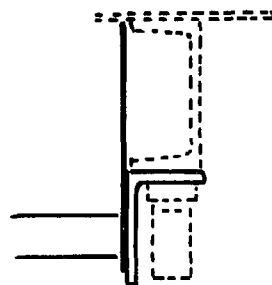


Figure 20



(top view)

Figure 21

cover and the channel pieces (Figure 20). For the trials, these were simply slipped over the shield pipes but should this solution be the most appropriate, a thin plate could be welded to the angle iron pieces (Figure 21). However it is quite possible that with a little further thought, a much more appropriate (i.e. simpler) solution could be found.

To secure the cover in place, a steel bar is inserted through the short lengths of square section welded to the BASE and a wedge-shaped block of wood is dropped between the cover and bar (Figure 22).

To guard the components from water splashing up from the tail-race, a sheet of galvanized is cut and hemmed as shown in Figure 23 to fit within the BASE (Figure 27). To install, the sheet is arched slightly and pushed in from the rear on the steel flats screwed along the bottom of the BASE (see section B-B in Figure 4).

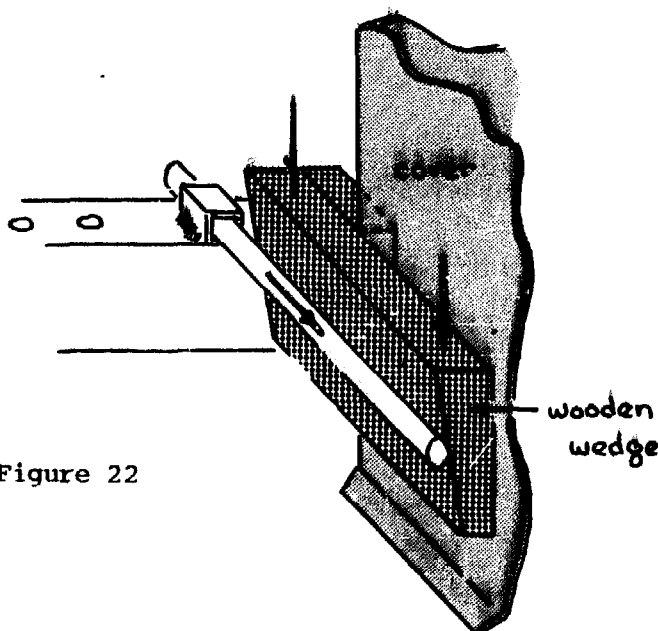


Figure 22

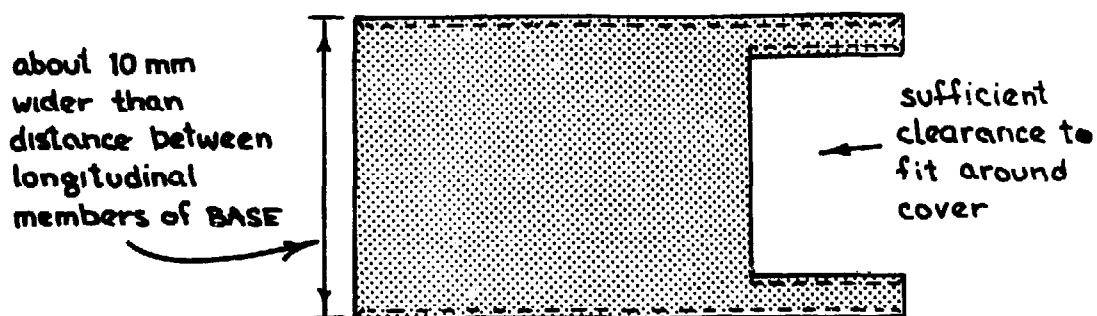


Figure 23

2.5 INLET PIPEWORK

The INLET PIPEWORK is made of PVC fittings the same size as the penstock. If only one nozzle is used, construction is straightforward. A PVC flange and insertion rubber gasket is bolted to the galvanized iron flange on the front of the RUNNER HOUSING and the penstock pipe is laid back up the hill from the flange.

If two nozzles are used, more careful fabrication of the INLET PIPEWORK is necessary (Figure 24). The two ends (shaded in Figure 25) are fabricated first, with the holes in the flanges oriented as shown. This will give more clearance for eventually tightening the flange bolts. After these two pieces are fabricated, these are bolted to the galvanized iron flanges with medium thickness insertion rubber gaskets. Then strips of thin plywood (for example) cut to fit tightly inside the fittings are inserted as shown in that figure. From the measurements indicated and those made of the pipe fittings themselves, two lengths of PVC pipe can be cut and glued. The proper depth to which these two pieces must be inserted into the fittings should be marked on the surface of the pipe. Note that it is difficult often to push PVC fittings in as far as is theoretically possible. Decide how far

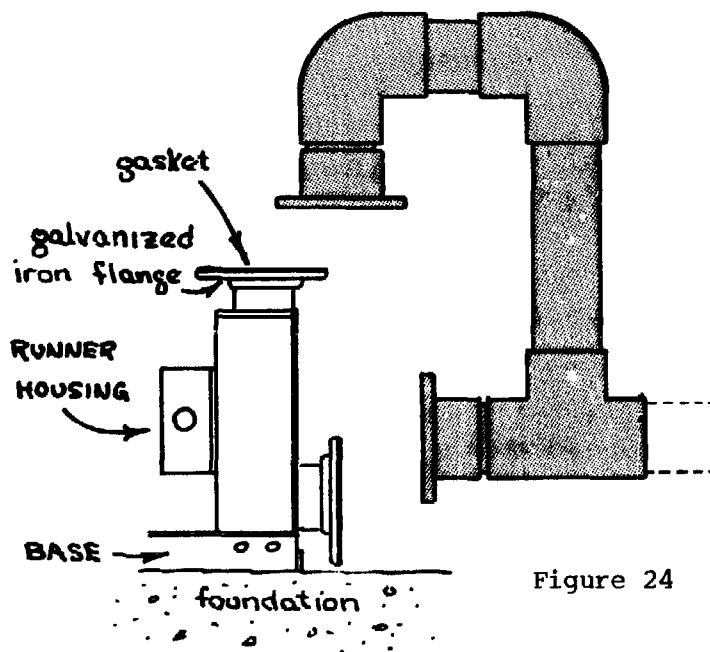


Figure 24

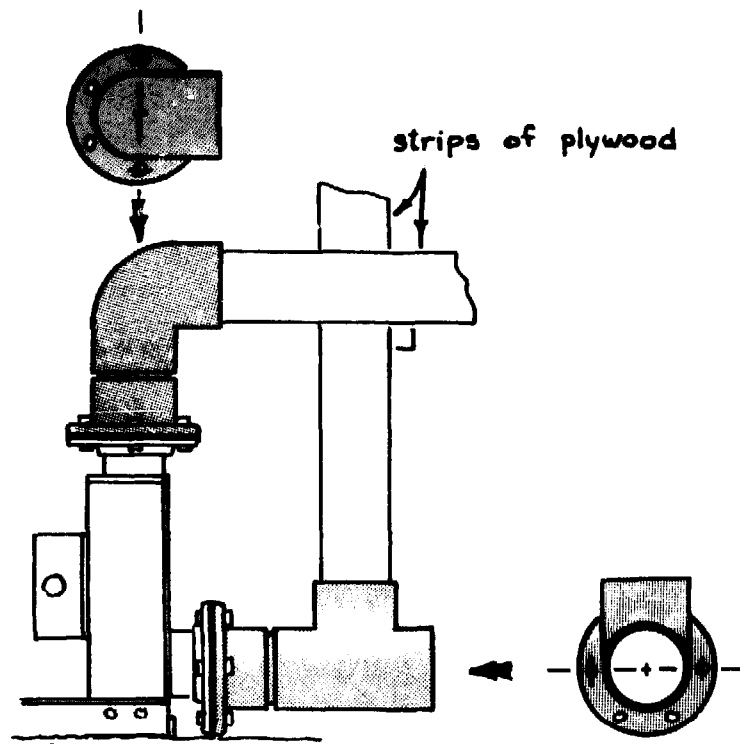


Figure 25

in the pipe can reasonably be inserted before cutting the pipe pieces to length. To insure that all the subsequent pieces of PIPEWORK lie within one plane and minimize frustrations later on, as each piece is glued, it should be clamped briefly down flat on a table top.

Even with care it is quite possible that when completed, the INLET PIPEWORK might be off slightly. This is the reason for using medium thickness insertion rubber. If the fit is off slightly, one should be able to make up for the difference by cutting thicker or thinner gaskets.

2.6 ALTERNATOR MOUNT

Because of the need to properly tension the belt, the position of the ALTERNATOR MOUNT on the BASE must be adjustable. There are at least two approaches: either the BASE or the MOUNT can be slotted.

A slot can be milled or flame cut in the BASE but the latter approach noted above permits a slot to be fabricated. Four flats of equal length can be welded as shown in Figure 26. The generating set has been designed so that the pulleys are located above the longitudinal members of the BASE. Therefore the alternator mounting holes must be located so that the alternator pulley is in the position indicated in Figure 27.

Tensioning of the belt(s) is done by tightening a machine screw mounted on a short length of heavy or reinforced angle (Figure 28) and fixed to the appropriate hole in the BASE with a bolt. Only one tensioning screw is necessary (on the side of the belt).

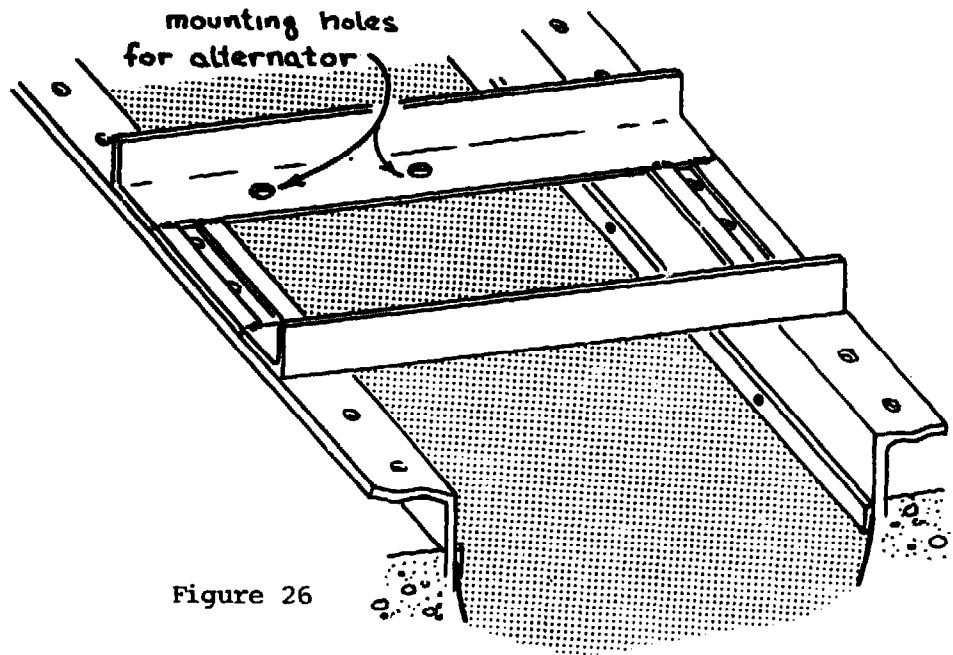


Figure 26

If the approach is taken that holes are drilled in the BASE to secure the ALTERNATOR MOUNT, these holes should be spaced so that at least three are visible through the slot at any one time. In turn, the maximum length of travel of the tensioning screw must at least equal the distance between any two consecutive holes.

These are several options for coupling the runner to the alternator. One is through the use of V-belts which are readily available locally. However for the transmission of maximum power to the alternator (7-8 kW), several A or B belts would have to be used. A second option is to use flat belts. Very efficient and durable flat belts are now available.

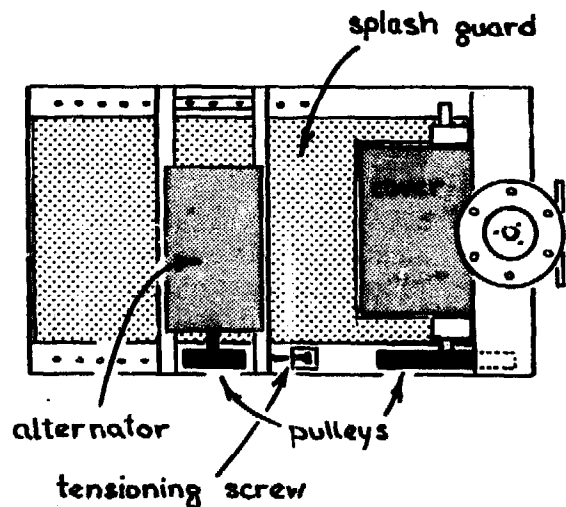


Figure 27

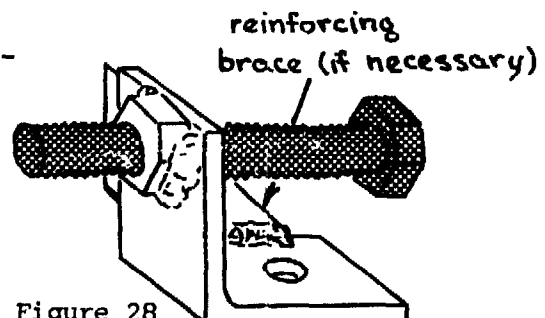


Figure 28

2.7 Alignment

After the components have been assembled, the position of two of the components is variable and has to be properly aligned:

- (1) the lateral position of the Pelton runner on the shaft and
- (2) the alignment of the pulleys and tensioning of the belt.

Proper positioning of the Pelton runner (necessary during installation and bearing or runner replacement) requires the use of the nick and line made according to Figure 14. After the bearing, shaft, and shield have been bolted in their final position, sight the nick and scribed line and move the head left or right until the nick is seen in line with the scribed line in the background. Keep the head in that position and move the runner left or right until the splitter down the middle of each bucket also coincides with the line (Figure 29).

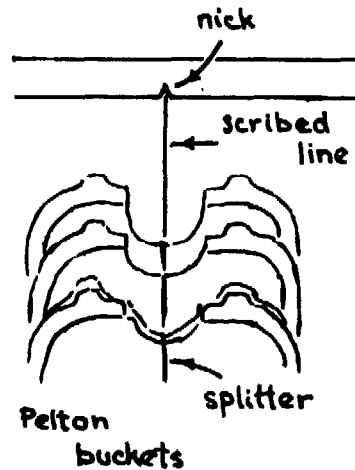


Figure 29

For the alignment of the pulleys and tensioning of the belt, the pulley on the runner shaft is secured first. The belt is placed over both pulleys and the alternator pulled back by hand to tighten the belt. Then the tensioning screw is installed and tightened. Throughout this operation, the alignment of the pulleys can be done visually by sighting along the outside face of the pulleys to make sure that all four points noted in Figure 30 are colinear.

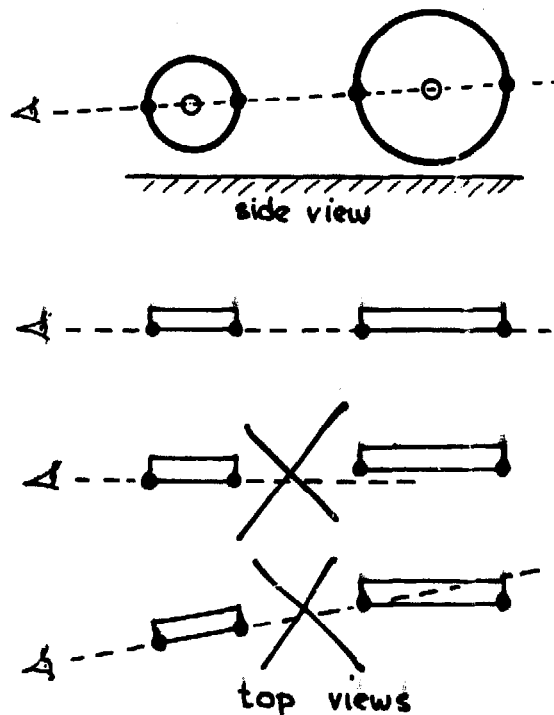


Figure 30

2.8 Regular Maintenance

In field use, it is envisioned that the minimum of regular maintenance work will be necessary for the generating set itself:

- (1) A periodic check should be made to ensure that all bolts and set screws are secure.
- (2) The bearings in both the alternator and RUNNER HOUSING are sealed and need no lubrication. The expected running life of the alternator bearings is 5000 hours (replacement cost of K20) and of the runner shaft bearings is several years (replacement cost of K20).
- (3) Brushes in the alternator have a life which varies greatly with environmental conditions but expected to be of the order of 5000 hours (replacement cost of K1).
- (4) The belts probably have to be replaced more frequently (replacement cost about K6).
- (5) The orifice plates and runner have a longer yet unknown life which is a function of the quality of the water used by the generating set (replacement cost of orifice plates would be probably a couple Kina and that of the runner estimated at K80, see p. 23).

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3. GOVERNING

For the generation of direct current, the speed of the runner is not of critical importance provided it drives the alternator sufficiently fast to attain the desired voltage and not so fast that its mechanical integrity comes into question. However for the generation of alternating current for general use, it is essential that the frequency (and therefore the speed of the runner) remains within acceptable limits.

Conventionally the speed of the runner is governed by adjusting the rate of flow of water to the runner to match the load. This is done through the activation of deflectors, valves, wicket gates, etc. usually by means of oil pressure governors. But both these flow controlling devices and the governor itself make for a much more complex system and one that requires more careful maintenance. It also adds considerably to the overall system cost, especially when considering micro-hydro generating sets. For these reasons, this approach of controlling the flow is not generally used with micro-hydros.

Rather, with micro-hydros, a commonly adopted method of maintaining the alternator speed within acceptable limits is load governing, that is, keeping the flow constant (usually at its maximum level) and ensuring through electronic means that all the power available is always consumed. If the amount of power consumed by the user changes, resulting in changes in the alternator's speed, the resulting changes in frequency, voltage, and/or current is electronically sensed. The unused power is electronically diverted into a dump load, often dissipated by heating water, thereby maintaining a constant total power usage.

There are potential advantages and disadvantages to using load controllers. Whereas advances have in theory reduced potential cost of electronic components, commercial load controllers are generally costly⁴ and add significantly to an otherwise low-cost unit as described here. They do however permit maximum use of the power available from the micro-hydro on a continual basis as well as allowing for more general end use of power. If they can be made low-cost and reliable under all foreseeable circumstances (climatic and environmental), there may well be a place for these in otherwise unsophisticated rural installations.

However close frequency control under a wide range of uses (both kind and magnitude) might be considered an unnecessary luxury. Other possibilities for the operation of a.c. systems with no controllers are possible under more restrictive circumstances. Among these are the following:

(1) Fixed constant load

This system is designed so that the power available from the water is matched to a constant electrical load. No switch is used, the switching being done by turning on the water. This method is now being used in Ian Bean's remote rural micro-hydro sites at Korbau, Gemaheng, and Nawong, all near the Pindiu

⁴Short Stoppers Electric, Oregon, U.S.A.: K200; Tamar Designs, Tasmania, Australia: K1400

patrol post in the Morobe Province. There the loads are lighting, primarily incandescent. Depending on the choice of penstock pipe diameter, this system does allow for expansion by simply increasing the effective nozzle size to provide the extra increment of power necessary for expansion of the load.

(2) Large fixed load with perturbations

Where substantially more power is available than is necessary, a large base load can be connected to the system to consume this power and possibly provide a useful purpose (e.g., heating water, drying crops, etc.). Then any lights, small motors, etc. that may be switched on when needed only impose perturbations on the system and have minor effects on the voltage and frequency.

This system is at present in use with the Baindoang micro-hydro scheme near Lae, Morobe Province. There, a 3.6 kW water heater element provides hot water for washing and an additional variable load includes lights and small motors which may be switched on whenever needed.

(3) Alternate loads through change-over switches

Whenever a major load is to be switched off during the operation of the micro-hydro unit, a change-over switch might simultaneously switch in a load of equivalent magnitude. If, for example, a micro-hydro generating set is to be run continually, it would be possible to switch off all the village lights with one switch while simultaneously switching on an equivalent water heater load.

(4) Hydraulic Governing

Another idea to achieve some control over the speed characteristics under varying loads for Pelton runners is that developed by Jaime Lobo-Guerrero and John Burton at the Universidad de los Andes in Bogota, Colombia. They have developed a hydraulic governor which, without any moving parts, modifies the power versus speed characteristics of the Pelton runner. By moving the runaway speed closer to the speed for maximum power, they have reduced the speed variation from no-load to full load. A discussion of this method is found in Appendix D.

As a precaution against runaway of runner and alternator due to an open circuit in the distribution system, a relay can be inserted in the main line (Figure 31). Should an open circuit occur, the relay

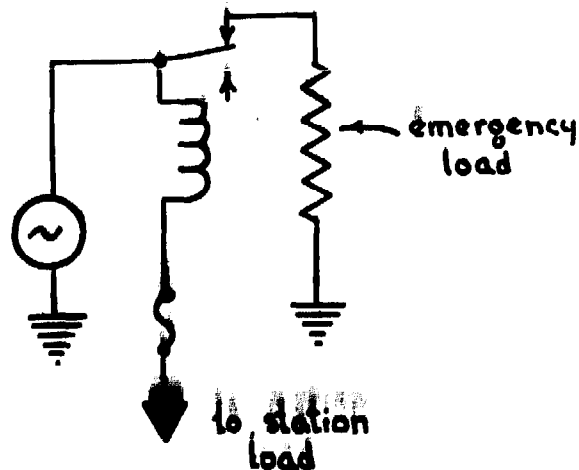


Figure 31

would de-energize, automatically switching in an emergency load capable of dissipating all available power. By properly spring-loading the relay armature, it is possible to set a threshold level for current below which the dump is automatically added into the system. This system is in use at the Baindoang micro-hydro scheme and in its first year of operation served its function three times when, due to corrosion problems with the leads to the water heater element at the station, these leads open-circuited.

4. COSTING

4.1 Basic Cost of the Prototype Design

Included below is the estimated breakdown of the costs of fabrication of the micro-hydro generating set. Several assumptions were made in this costing:

- (1) The generating set has the capacity of 5 kVA.
 - (2) For the fabrication of the unit, the necessary jigs are available and no more than several days is necessary for the fabrication of each unit.
 - (3) Though the Pelton runner used in the test was fabricated of individually cast buckets bolted to a steel disk, the cost below refers to the estimated cost, including labour, of an integral Pelton casting to be produced in PNG¹.
- (2) Costs of materials are retail costs in Lae, PNG².

The costing is as follows:

Alternator (Markon SC21d)	K320
Pelton runner	80
Steel stock	30
Inlet PVC fittings	30
Belts and Pulleys	30
Bearings and Pillow blocks	20
Stainless steel shaft	10
Misc. (bolts, insertion rubber, key stock, etc.)	10
Labour	50
	TOTAL K580

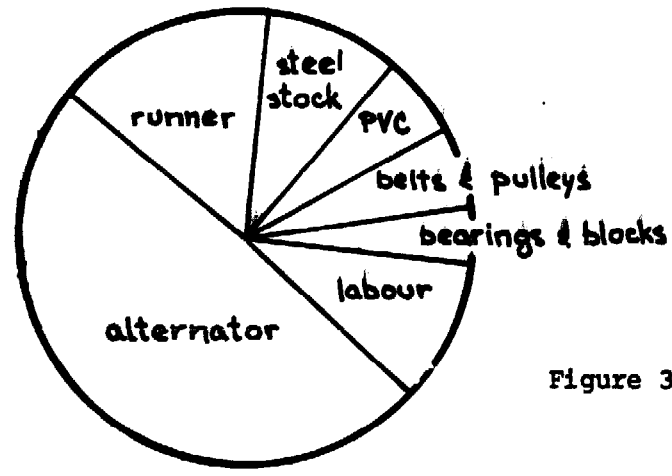


Figure 32. Cost Breakdown

¹ The ATDU is involved in development work towards the establishment of a non-ferrous foundry in PNG. Integral castings of Pelton runners are to be one of the items to be produced by this foundry.

² K1.00 = US\$1.45 = £ 0.65

The cost of K580 refers to a generating set with a capacity of 5 kW (at unity power factor). A 1-2 kVA set would only be slightly less expensive (K60 less for the alternator, K20 less for the PVC fittings, and K20 less for the pulleys and belts). Cost for a unit above 5 kVA would increase markedly due to the increase in cost associated with the larger frame size for the alternator. The alternator quoted above is driven at 3000 rpm. Using a 1500 rpm alternator would imply a longer bearing and belt life and consequently lower recurring costs but the cost of such a unit is about twice that of the 3000 rpm alternator.

4.2 Additional Costs

In order to gauge the merits of the micro-hydro generating set described in this report on an economic basis, the cost given above is not complete. An honest cost estimate must include (1) a percentage mark-up (to cover overheads in fabrication and a profit margin) and (2) the cost of the necessary penstock. It might also include the cost of installation. However this cost should be minimum since (1) the set has been designed to minimize expertise required in its installation and (2) the set is primarily considered for self-help village schemes where the labour is borne by the villagers themselves.

The penstock is an integral element of all micro-hydro installations. Since Pelton generating sets are used under higher heads, this of necessity implies a sizable length of pressure pipe and a cost which can be a considerable portion of the total cost. The actual cost of penstock pipe necessary for a micro-hydro installation is very much a function of the terrain at the actual site. In Appendix B, penstock costs are derived for different sites and for several penstock diameters. The graphs in that appendix indicate that penstock costs/kW are a strong function of pipe size and penstock gradient but loosely dependent (or in some cases, independent) of actual gross head. A precise cost is impossible to derive in the absence of information about a specific site but a realistic figure for the sake of costing might be about K150/kW (an 80 mm penstock with a penstock length three times the gross head).

4.3 Total Cost of a Micro-Hydro Installation

Costs for the 5 kVA Pelton micro-hydro generating set described in this report would then be as follows:

Hardware and Labour (p. 23)	K580
30% Mark-up	150
Penstock @ K150/kW	750

TOTAL COST = K1480

COST/kVA = K300/kVA

Whereas K300/kVA represents as realistic a base figure as any, it should be noted that penstock costs are a major component and can vary considerably. For the range of penstock gradients and

diameters considered in Appendix B, the limits on the lowest and highest¹ cost would be as follows:

<u>Lowest Cost</u> (vertical 80 mm penstock and the generation of 5 kVA)		<u>Highest Cost</u> (shallow slope, K = 4, with a small diameter penstock, 40 mm, and the generation of 0.9 kVA)	
Hardware	K580	Hardware	K480
Mark-up	150	Mark-up	120
Penstock	200	Penstock	360
—————		—————	
➡ K190/kVA		➡ K1070/kVA	

4.4 Cost Comparison with Alternatives

Whereas the lower operating costs of micro-hydro installations is generally recognized, their high capital cost often figures near the top in a list of arguments against their use. Conventional alternatives, primarily generating sets powered by internal combustion engines, are commonly considered a much more cost-effective means of providing power. In the light of the cost presented earlier, is this argument still valid? A comparison of capital costs for 5 kVA generating sets available in Lae with that of the micro-hydro described in this report would indicate that that argument should be carefully reconsidered².

Capital Costs (5 kVA sets)

Petrol	K100/kVA
Micro-Hydro	K300/kVA
Diesel	K400/kVA

Petrol generating sets have a considerable advantage in terms of initial capital costs. Yet at the current petrol costs (K0.29/litre), recurring costs for fuel alone quickly wipe out any advantage. If one were to assume a generating set operating daily for only four hours, recurring costs for the petrol alone would amount to K400/kVA per year.

¹Note that there is no limit on how expensive a micro-hydro installation might be. The highest cost referred to is that cost for the shallowest penstock gradient and smallest diameter penstock considered in Appendix B. It should be clear that for some sites with gradual slopes and/or for small power requirements, the micro-hydro prototype described in this report is simply too expensive and probably not appropriate.

²Not considered here as another alternative for power generation is tapping the "free" energy from the sun. Though this might have its appeal, even with the cost reductions of solar cells predicted over the decade of the 80's, costs will remain far from competitive with those of micro-hydros. They may present the advantage of no moving parts, of generation of power on-site, and of tapping a resource more generally available but the cost of the necessary batteries also adds considerably to the already high cost of the cells themselves.

This does not include the cost of airfreight to the more remote areas which can without much difficulty double this figure. In addition, in areas where minimum mechanical skills exist, the life of internal combustion engines is severely limited.

Provided that a suitable site is available, it therefore seems apparent that micro-hydro generating sets, if fabricated locally, can easily be the most generally appropriate alternative for power generation.

5. APPENDICES

5.1 Appendix A: Bucket Design and Prototype Performance

For use in the prototype, twenty-one buckets with the profiles and dimensions indicated in Figure 34 were cast and then bolted to a steel disk to fabricate a 200 mm pitch circle diameter (p.c.d.) runner. Fabrication of the runner by such a method permitted the option of changing the angle of rake of the buckets to check experimentally the results obtained from theory. The actual design for the buckets is the result of a synthesis of information from various references and from personal correspondence with various individuals with experience in fluids and turbine design.

Some test runs were also previously made with a runner of 300 mm p.c.d. made in the same manner with 23 buckets of identical dimensions as used with the 200 mm runner. The rake $r = 0.0$ mm. All tests were made using an orifice plate nozzle.

In the summary of the test results which follow,

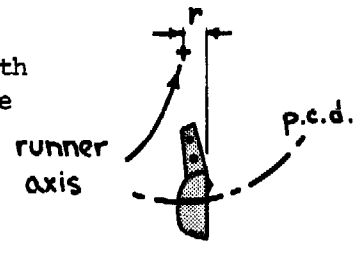
η = efficiency of conversion measured with respect to the power available in the jet, i.e. $\frac{\dot{m}v_j^3}{2}$

r = bucket rake = distance between the plane containing the upper surface of the bucket and the runner axis (mm)

h = net head under which the runner is operating (m)

d_j = jet diameter (mm)

ϕ = speed ratio = bucket speed / $\sqrt{2gh}$



The torque available from the runner was measured with a prony brake. Because of the characteristics of the brake used, there was up to $\pm 5\%$ scatter in the torque readings. By making a number of readings, an attempt was made to arrive at the true values. However any unexpected trends found in the graphs *might* be attributable to difficulty in getting precise reproducible results with the equipment on hand.

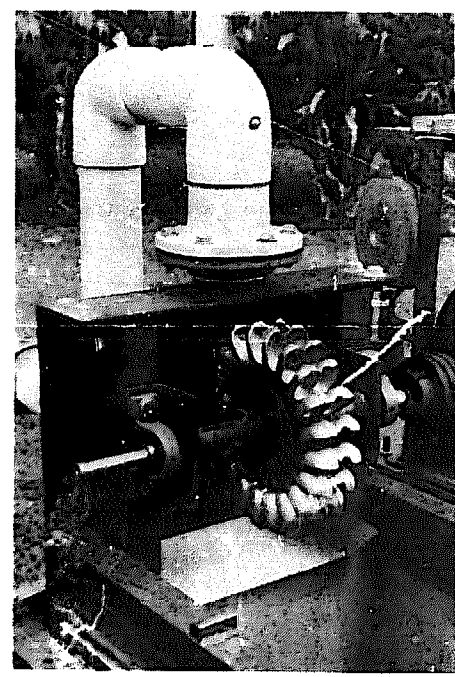


Figure 33

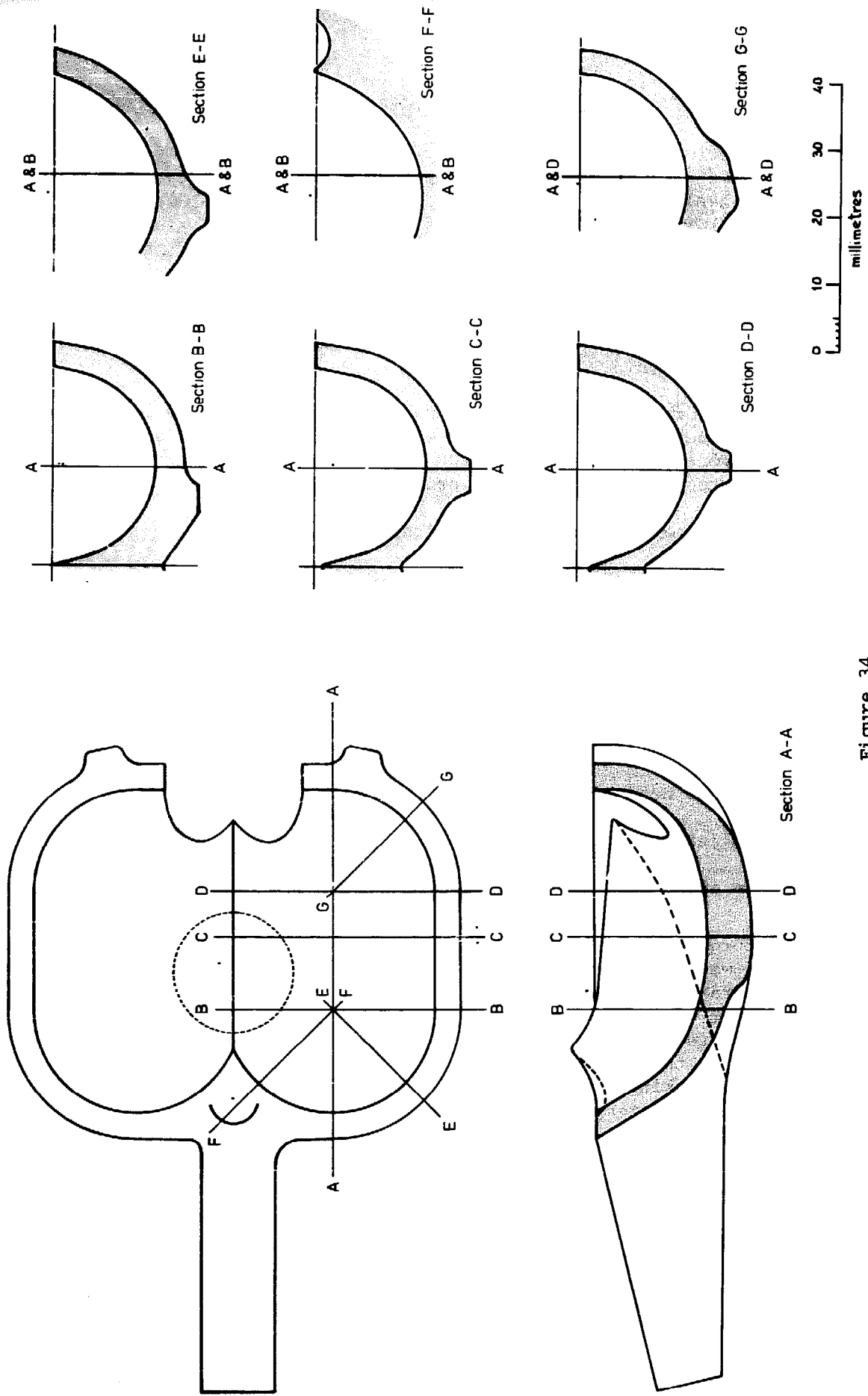


Figure 34

(1) General Runner Performance

With a single jet, a maximum runner efficiency of about 73% was attainable with the 200 mm p.c.d. runner and up to 77% with the 300 mm runner. This occurred at a speed ratio between about 0.40 and 0.46 depending on the actual operating parameters. With a single jet, runaway occurred at $\phi = 0.76$.

(2) Effect of Rake

Changes in bucket rake over a range of values produced no significant changes in the profile of the power curves. Figure 35 illustrates the slight effect of rake on maximum efficiency of the runner.

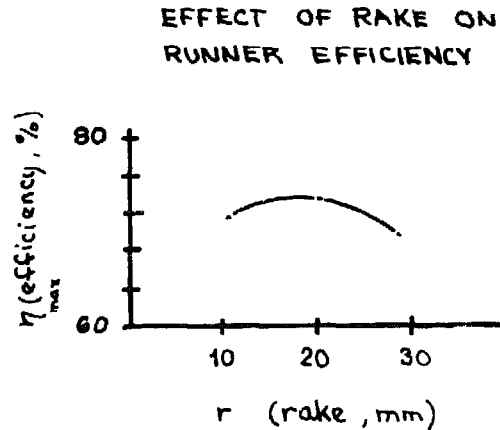


Figure 35

(3) Effect of Increasing Jet Diameter

The bucket was designed to accommodate an 18 mm jet. No difference in runner efficiencies with the small (12.5 mm) and large (18 mm) jets indicates that the runner might yet accommodate a somewhat larger jet before a significant reduction in efficiency occurs.

(4) Effect of Inlet Configuration

To permit for the provision of a second (vertical) jet with the simplest construction, several right angle bends before the jets are necessary. This clearly introduces turbulence into the jet, turbulence which increases with both jet diameter and head. With a maximum jet diameter (18 mm) and a net head of about 40 m (Figure 36), a power loss of 10% was noted when compared to the power available using the horizontal jet (Figure 37).

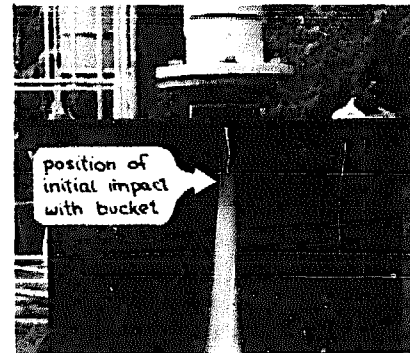


Figure 36

(5) Effect of Interference from Cover

Though the clearance within the cover around the perimeter of the runner is small, the axial width of the cover is that generally prescribed in references on Pelton units. Experimentally, removing the cover made a negligible improvement, if any, on efficiency.

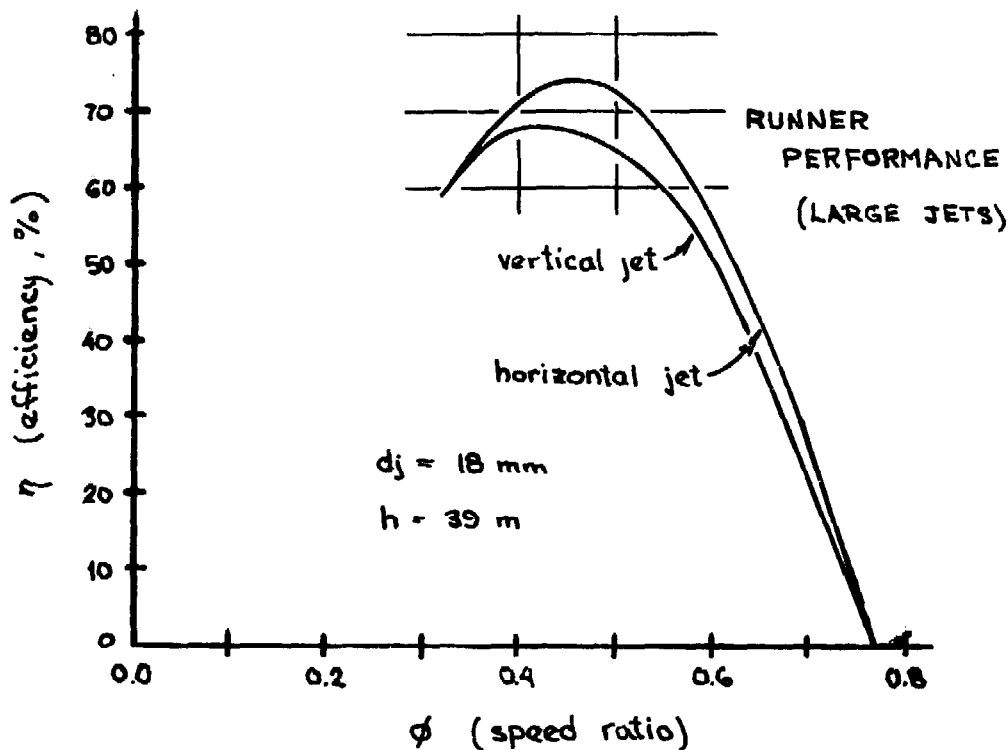


Figure 37

(6) Effect of Multiple Jets

Simultaneous use of both jets led to no observable increased deterioration in performance due to an increased volume of spent water under the cover (Figure 38). As would be expected, runaway speed dropped slightly due to interference of the two jets at that speed. It might be possible that more interference would be observable if the maximum diameter jets (18 mm) had been used. However the capacity of the pump at the test site did not allow for this test.

(7) Overall Efficiency

A 3 kVA Markon alternator (SC21b) was coupled to the runner with an A-section V-belt from an 8" to 3" pulley. The output was fed into a resistive load bank. The alternator was run at slightly less than half its rated output.

The efficiency of conversion of the power in the jet to both mechanical and electrical power as a function of the speed ratio is shown in Figure 39. At $\phi = 0.44$, the efficiency of conversion to mechanical power was 72% and the efficiency of conversion from available power in the jet to electrical power was 56%. This implies a combined efficiency for the transmission of power through the belt and pulleys and conversion to electricity of 78%. (Given that the rated efficiency for the alternator itself at full load is about 76%, the value of 78% seems relatively high. However, the power in the jet, at the runner shaft, and at the alternator output were verified independently a number of times and apparatus used in making the measurements seemed correctly calibrated.

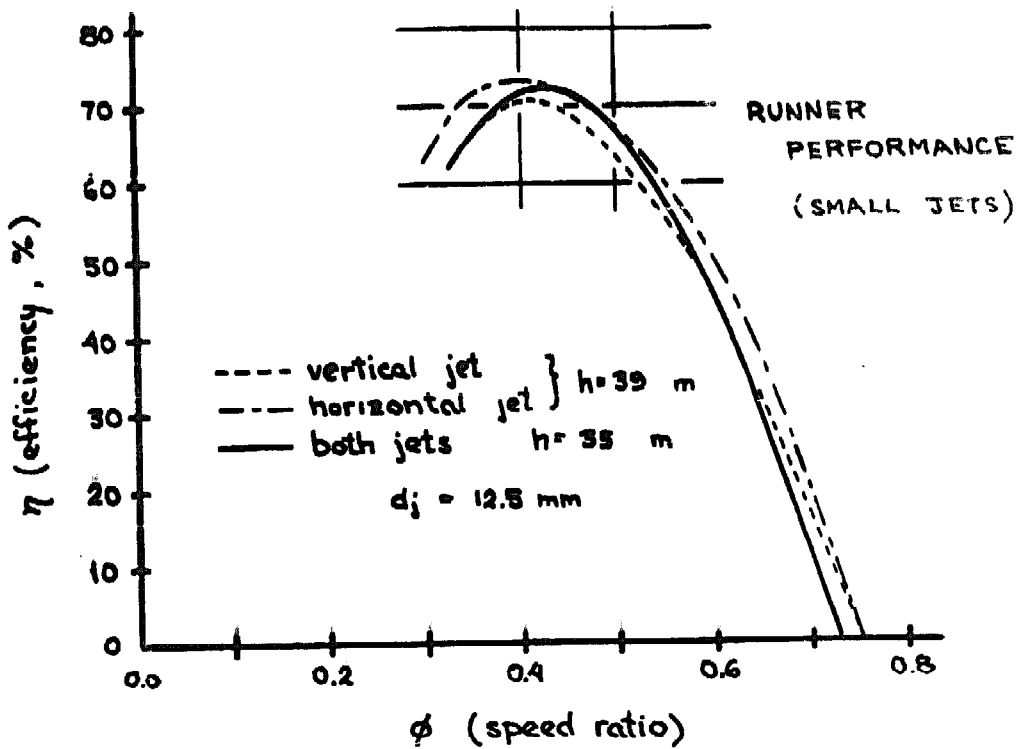


Figure 38

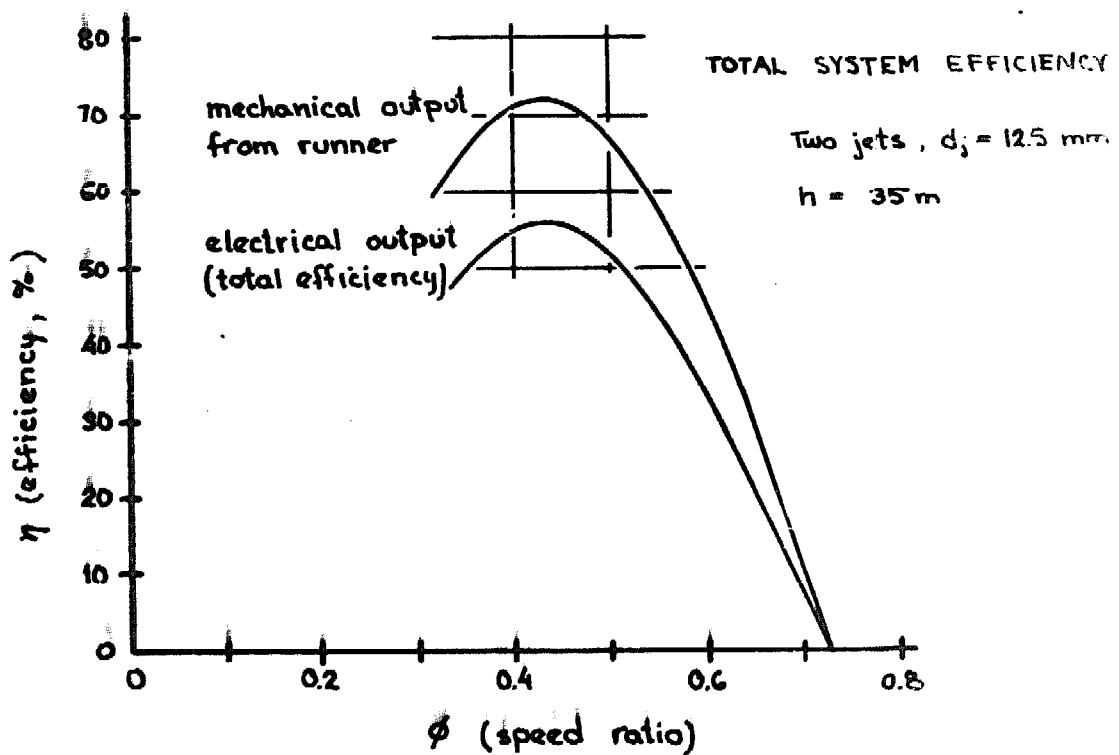


Figure 39

5.2 Appendix B: Maximum Available Power and Minimum Penstock Costs for Various Penstock Configurations

Each of the four graphs (Figure 40) is for a different dimensionless penstock length, K , defined as

$$K = \frac{\text{penstock length}}{\text{gross head}}$$

For a given penstock gradient, the graph provides both the maximum electrical power available and the penstock cost/kW electrical power output as a function of gross head for three penstock diameters. It also provides the jet diameter and flow rate necessary to obtain that power.

5.2.1 Assumptions

The penstock was assumed to be of PVC and head losses for different configurations were obtained from a nomograph for high density polyethylene pipe¹. It was assumed that PVC and polyethylene pipe had equivalent surface roughnesses. Only head loss due to friction was considered, i.e. the penstock was assumed straight.

The mean bore for class 6 PVC is slightly larger than that for the equivalent nominally sized polyethylene. The pipe diameter noted on the graphs refers to the nominal diameters for PVC pipe. The actual diameters are as follows:

<u>nominal bore</u>	<u>actual bore</u>
40 mm	45.2 mm
50 mm	56.7 mm
80 mm	83.7 mm

Pipe costs used were contractor's prices for class 6 PVC (rated at a 60 metre head) after the recent increase in February, 1980².

The efficiency of conversion (electrical power output/power available in the jet) is assumed to be 50% (the approximate value of efficiency for the prototype described in this report).

Where possible, the flow rate in the penstock was set by the appropriate choice of jet diameter such that maximum power is transmitted, i.e., pipe losses are one-third of gross head. However the maximum possible jet diameter considered was 25 mm. This is equivalent to two 18 mm jets,

¹ Granite Blue Ribbon Flow Calculator, ACI-Nylex Pty, Ltd.

² Mainland Plumbing, Lae, PNG. Cost/metre: 40 mm - K0.99, 50 mm - K1.43, 80 mm - K2.82 (K1.00 = US\$1.45 = 0.65)

the maximum possible with the prototype described in this report. Consequently, with a larger pipe, it is not always possible to harness the maximum power potentially available because this would necessitate a jet diameter greater than 25 mm. Also obtaining *maximum* power potentially available given a penstock diameter may require a jet diameter *less* than 25 mm. (A choice of jet diameter larger than that noted on the graph would lead to a greater flow rate and head loss and less power therefore available.)

5.2.2 How to Use

From the physical characteristics of the site (the penstock length and gross head), the dimensionless penstock length, K , is obtained. This indicates which of the four graphs to use. For non-integral values of K , interpolation between two graphs is necessary. Values of K larger than 4 are possible but are not included because micro-hydro installations begin looking too costly for such shallow slopes.

Then from the appropriate graph(s), the maximum possible power for various penstock diameters can be obtained. Also noted are the required jet diameter, the resultant flow rate, and the cost/kW at that power. Note that along a solid line, cost/kW and flow rate are constant. Along a dashed line, the jet diameter is constant at 25 mm.

5.2.3 Notes

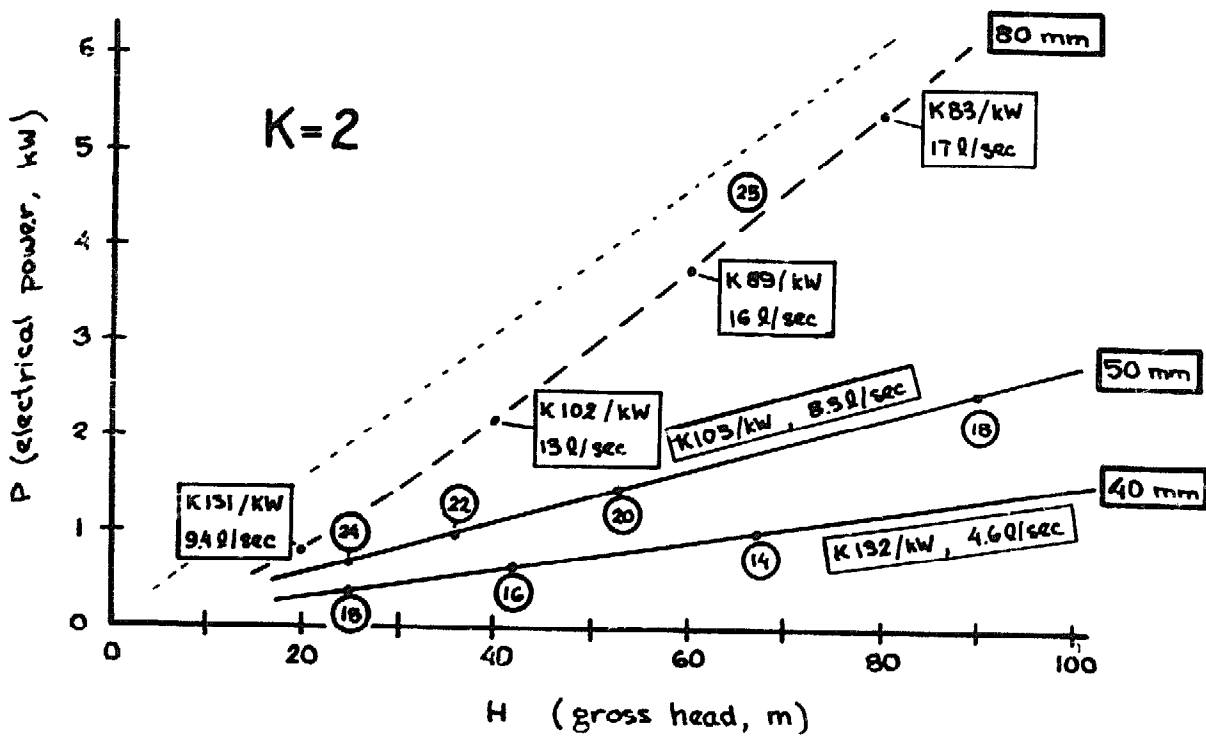
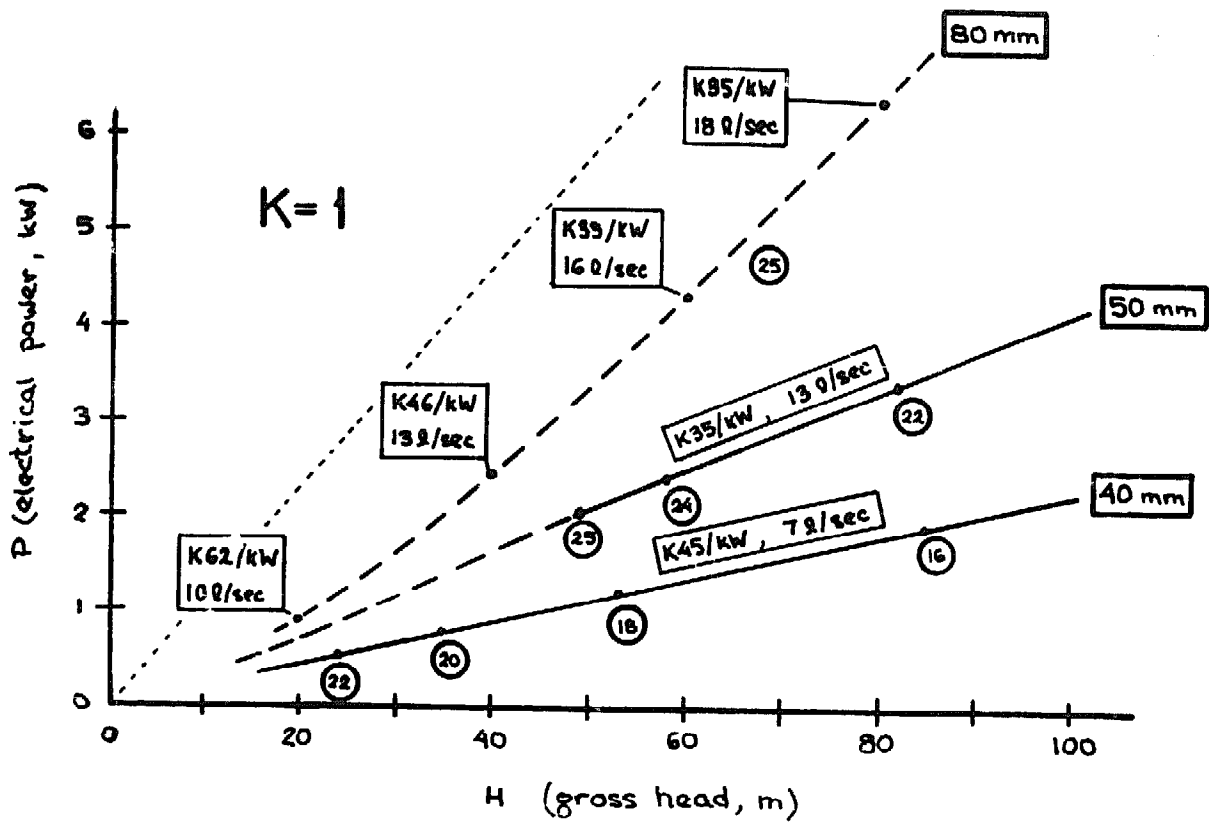
- (1) The first graph with $K = 1$ implies a vertical penstock. Though this case may never occur in reality, it is of interest because it sets the limit on the maximum power available and the minimum pipe cost/kW possible with various penstock diameters.
- (2) Only a single jet of diameter D is considered on the graphs. However if two jets, with diameters d_1 and d_2 are used, then

$$d_1^2 + d_2^2 = D^2$$

Or if both jets are of equal diameter, d , then

$$d = \frac{D}{\sqrt{2}}$$

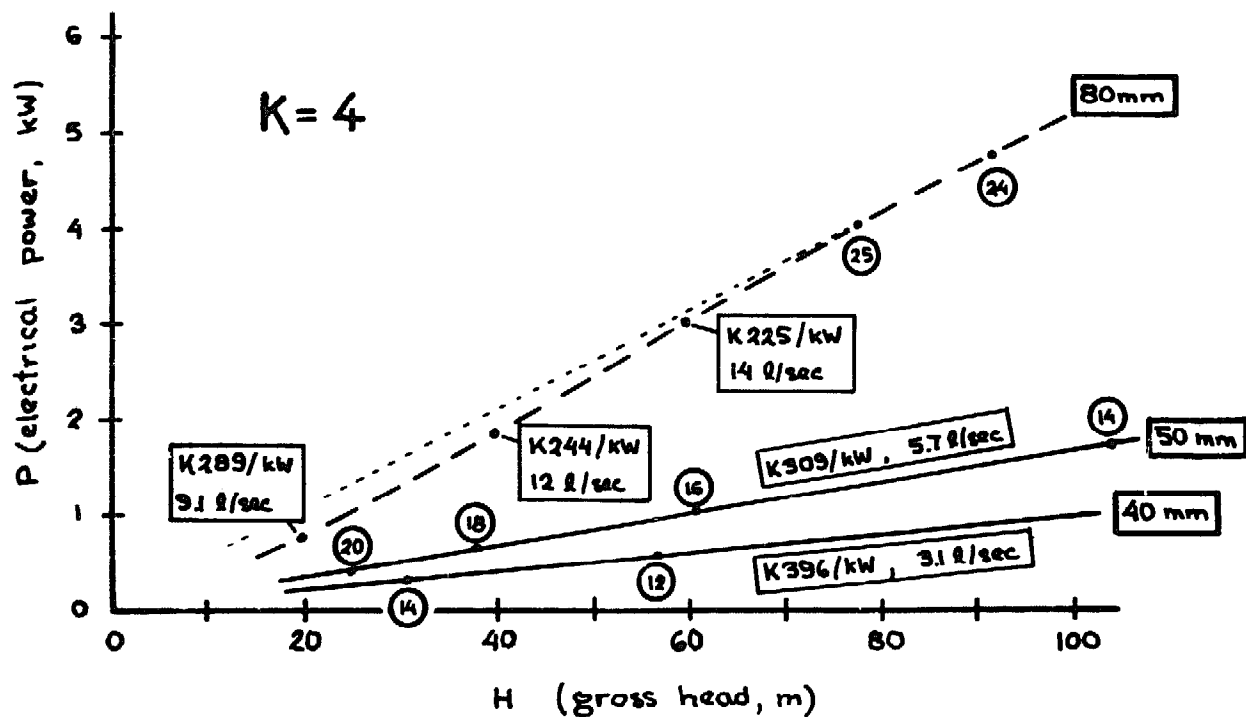
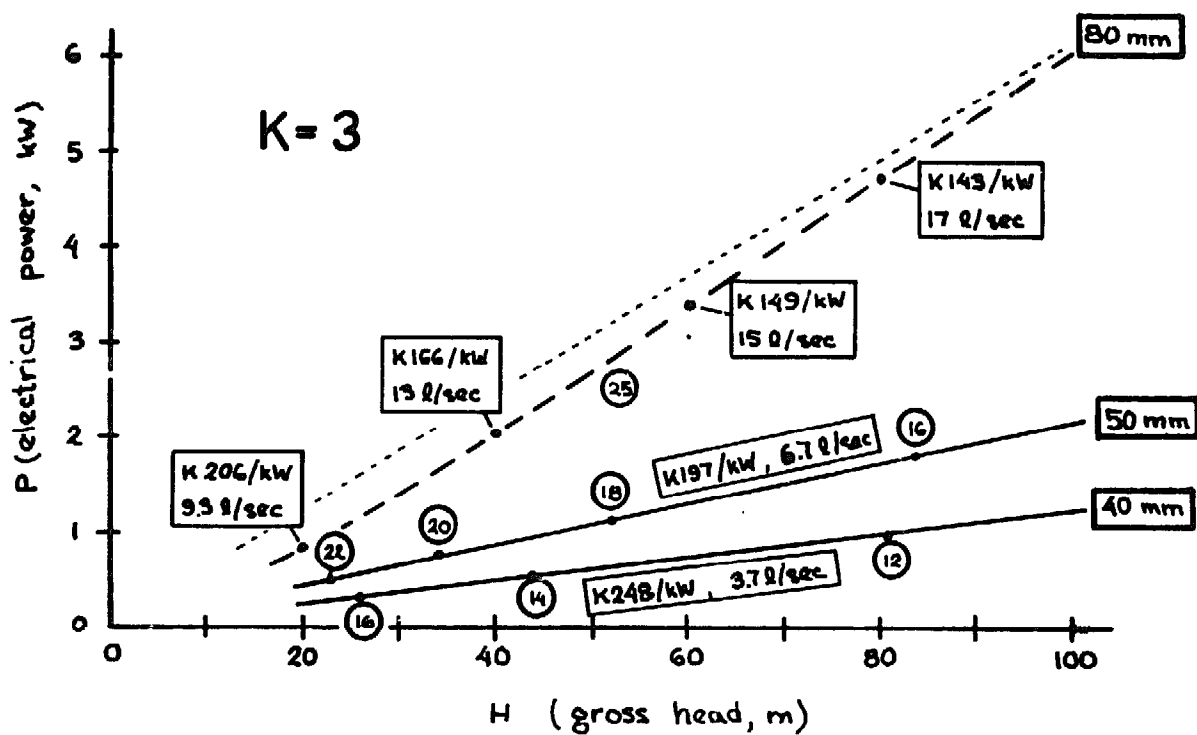
- (3) In plotting the curves, the mean inner diameter of class 6 pipe was used for all heads. But this class pipe is not meant to be used above a head of 60 meters. However a well protected (buried) penstock of class 6 pipe might still be used at higher gross heads because
 - (a) it has a safety factor greater than 2
 - (b) it if is operated at a one-third head loss, a gross head of, for example, even 90 metres means a net head of 60 metres acting at the lower end of the penstock during its operation.



$K = \text{penstock length/gross head}$

⊙ = the required equivalent jet diameter D (mm, see p. 33)

Figure 40. Maximum Power Available vs. Gross Head



- Regime where flow rate and cost/kW is independent of head for a given pipe diameter (maximum power with one-third head loss)
- - Regime where maximum jet diameter is required (two 18 mm jets or $D = 25$ mm)
- Maximum power available with 80 mm pipe provided that the micro-hydro generating set could accommodate a larger jet diameter

It is interesting to note that if 40 mm or 50 mm class 12 pipe (rated at 120 metre head) were used for the entire penstock, the slight decrease in diameter of this pipe due to increased wall thickness would result in a 30% reduction of power potentially available. This coupled with the 50% higher cost for class 12 pipe would double the cost/kW.

- (4) The maximum size of the jet is set by the size of the mouth of the bucket. Note that in using an orifice plate as a nozzle, the actual orifice diameter is about 28% larger than the desired jet diameter. This value is based on tests using different sized orifices at the end of an 80 mm penstock.
- (5) Because of the limit on the maximum jet diameter which can be used with the design described in this report (two 18 mm jets equivalent to one 25 mm jet), more power can be transmitted through an 80 mm penstock than is actually used. The dotted line in the graphs indicates the maximum power which would be available from an 80 mm penstock if a larger jet diameter could be used.

5.3 Appendix C: Alternative Designs for Orifice Plate Nozzles

One major drawback with the design presented in the section on DESIGN is that the orifice plate must be mounted from within the penstock. This is inconvenient because it requires that the HOUSING be removed from the BASE. The design would be much more appropriate if the orifice plates could be mounted from inside the HOUSING rather than from inside the penstock. This direct approach is not generally possible. Either the flow would separate at the first edge it encounters (the hole in the HOUSING itself, (a) in Figure 41) and introduce turbulence into the jet or the hole in the HOUSING would itself form the jet (Figure 41, (b)). Several possible alternatives are noted below.

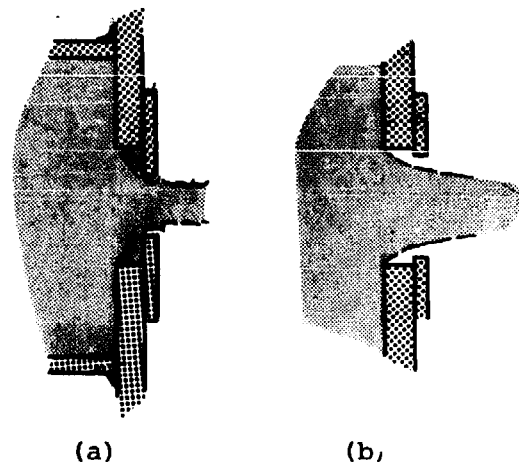


Figure 41

- (1) This design probably could be fabricated using a drill press only provided that sufficiently large diameter holes could be cleanly drilled. It would also be necessary that the leading face of the orifice plate (Figure 42) be sufficiently flat and square. Access to a lathe would simplify the work.

Basically a short length of round steel stock is cut and drilled with the appropriately sized orifice. It is then inserted and welded into a mounting plate (Figure 43). It is preferable that the leading face be flush with the HOUSING or extend slightly into the penstock. If it is too short, turbulence may be introduced into the jet. If it is too long, then the orifice will no longer be a sharp edged orifice and a jet with a smaller diameter would be formed.

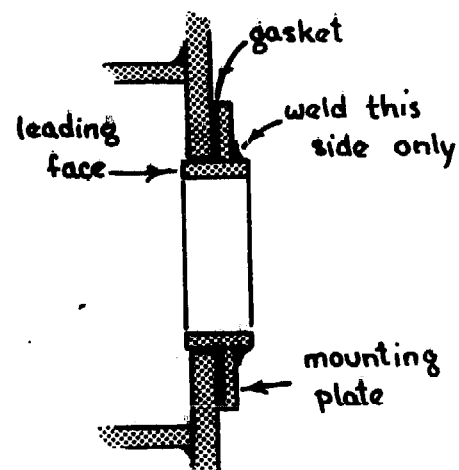


Figure 42

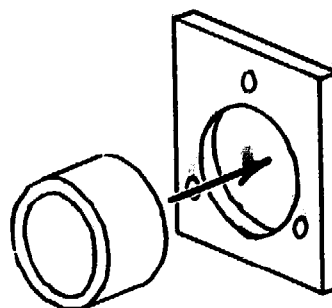


Figure 43

- (2) This design would require only drilling. It would require an elongated hole in the HOUSING wall through which the entire orifice plate with gasket is inserted (Figure 44). It would then be pulled back against the outside wall of the HOUSING and screwed in place.

The elongated hole could be machined or made by a set of drilled holes as illustrated in Figure 45.

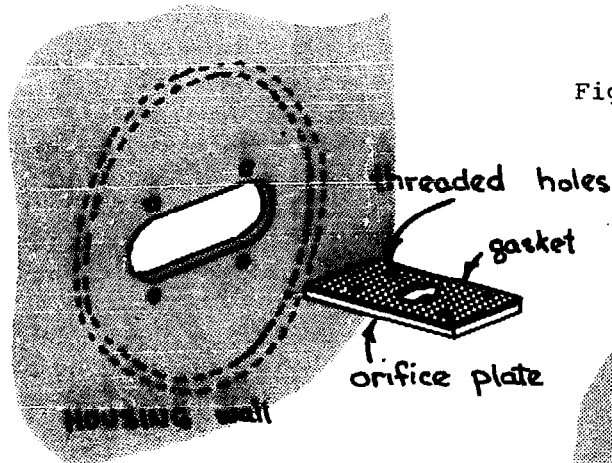


Figure 44

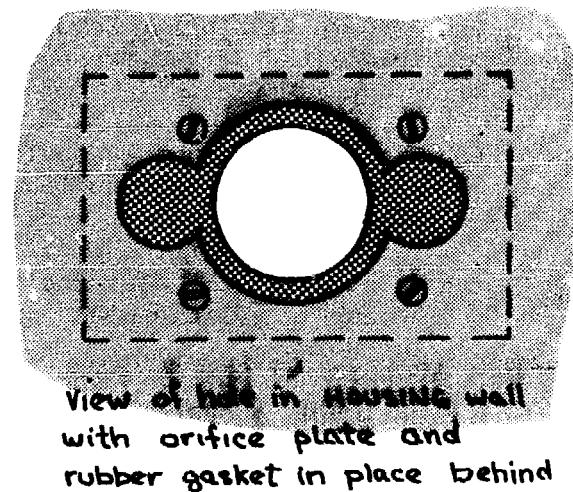
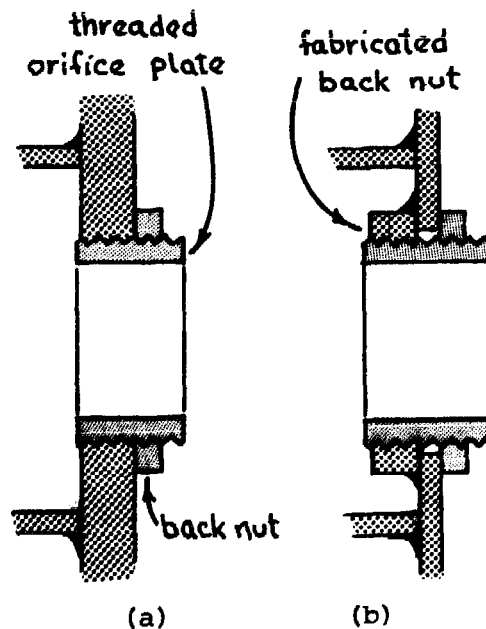


Figure 45

- (3) Another possibility to secure the orifice "plate" is to fabricate it from a threaded length of round stock. There are then a number of variations for securing this to the HOUSING wall.

(a) If the HOUSING wall is thick enough, a hole can be drilled through the wall and threaded. The orifice plate is then screwed in and held in place with a back nut. Either side of the orifice plate can be used.

(b) If the HOUSING wall is too thin, a back nut can be fabricated and welded (or otherwise) to the outside wall of the HOUSING. Then the orifice plate is installed as above (a).



5.4 Appendix D: Hydraulic Governing

The idea of hydraulic governing as developed by Jaime Lobo-Guerrero and John Burton is included here for several reasons. Not only does it illustrate the possibility of some control over Pelton power characteristics through simple means but it seems as excellent example of an appropriate technology. It is a device which addresses a need conventionally met by expensive and sophisticated hardware but it is of trivial construction, possesses no moving parts, is fail-safe, requires no exotic components or materials, is insensitive to harsh climatic or environmental operating conditions, and is low cost. Though it cannot maintain frequency within the close limits of commercial generating sets, rarely is this essential for a wide range of end uses. Setting down a new set of expected performance criteria (i.e., less stringent frequency control) other than that often adopted without thought from the West allows a fresh, more appropriate approach to the problem. The article reproduced on the following page, found in the Appropriate Technology journal, Vol. 6, No. 4, describes this method of governing.

A number of trial runs were undertaken at the ATDU with a crude hydraulic governor and the 300 mm p.c.d. runner (described on p. 27). The governor was fabricated of a heavier piece of wood slightly wider than the buckets sandwiched between two pieces of plywood and positioned as shown in Figure 46. At the end of the "trough" furthest from the jet was secured a plastic gate with a 1-2 mm clearance between it and the exiting bucket.

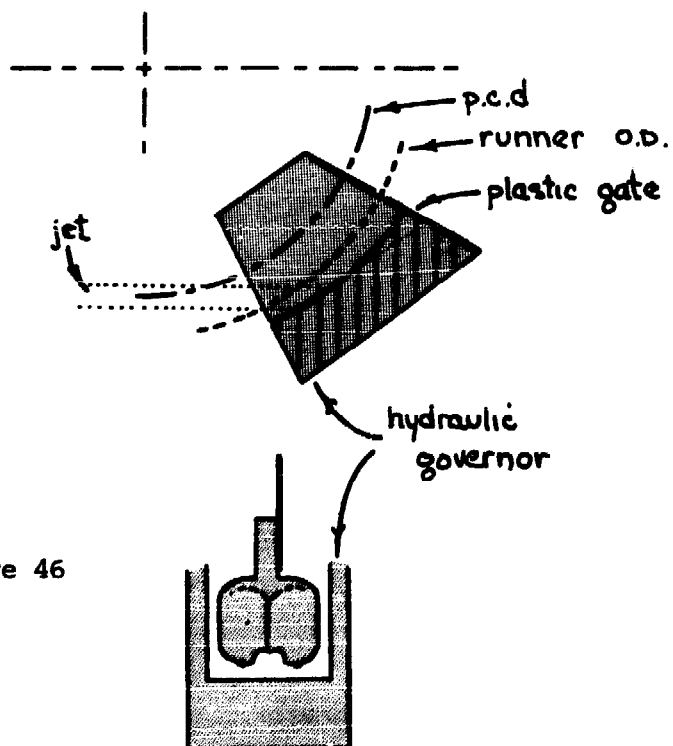


Figure 46

Hydraulic Governor for Small Pelton Turbines

Jaime Lobo-Guerrero, U., Universidad de Los Andes, Bogota, Colombia, John D. Burton, Mission Tecnica Britanica, Colombia.

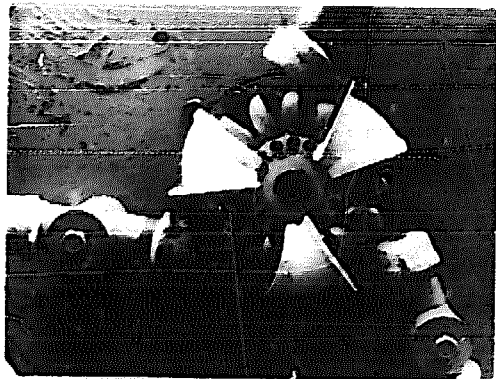
One of the problems encountered in the use of simple Pelton wheels for generating electricity in isolated communities is the lack of proper speed control. The generator speed, and thus the supply voltage, can easily increase by 50% or more between full load and no load. There is the chance, therefore, that the generator may be damaged by overspeed, and the excessive voltage would almost certainly burn out equipment connected to the supply.

If a conventional governor were used to control the Pelton spear valve, it would probably cost more than the wheel and generator put together. For this reason some designers have adopted electrical controls. As the electrical load is removed, the excess generator output is deposited in a dummy load, thus maintaining speed and keeping voltage constant.

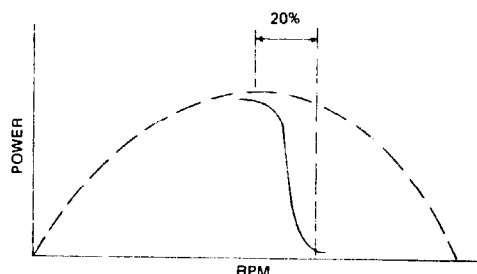
A system has been developed by the University of the Andes in Colombia, which avoids both the heavy cost of a conventional governor and the complication of electrical dummy loads. It consists simply of a cup placed around the wheel in such a way that its open end faces the turbine jet. At full load the water leaving the turbine buckets hardly enters the control cup at all. However, as the load is removed and the wheel speed increases, more and more water gathers in the cup, thereby braking the wheel and controlling further acceleration.

Photograph 1 shows the arrangement for a small, three jet Pelton. Each jet has its own 'cup' speed controller (made from P.V.C. tube formed into the appropriate shape by moulding in hot water), which is mounted around the wheel, which passes through a close tolerance plastic gate placed across the closed end of the cup furthest away from the jet.

Speed and voltage control, as can be seen from the graph, overleaf, were reasonably good with the hydraulic control.



Three jet pelton with speed control fitted.



The dotted line shows the variation of power versus speed without the control, and the full line demonstrates that the variation between no load and full load (1 kw) was held to within 20% of nominal speed.

Several hydraulically-governed Peltons have been installed in Colombia, and photograph 2 shows the three jet unit constructed by students of Bolivariana University. For simplicity, a vertical axis design was used with the wheel mounted directly on the generator shaft – this avoids the cost and complications of belts, bearings, and pulleys. Installation was undertaken, working with local people in one of the communities served by the 'Futures for Children' group. The Futures Counsellor was delighted with the small plant. During the day his wife uses the energy for cooking and at night lighting is provided at the campesinos' meeting place, where they discuss such important matters as the well-being of the children in their community.

Further details are available from ITDG, 9 King Street, London WC2E 8HN.



Complete installation of three jet pelton with speed control.

0305-0920/80/1401-0066/\$01.50/0

Preliminary tests showed some governing effect (Figure 47) but the degree of governing did not equal that quoted in the article reproduced on p. 40. A number of variations which were generally slightly more complicated in construction were attempted but these yielded no better results. The author is at present trying to get further inputs in the hope that such a device can be incorporated in the design described in this report as well as in other Pelton units.

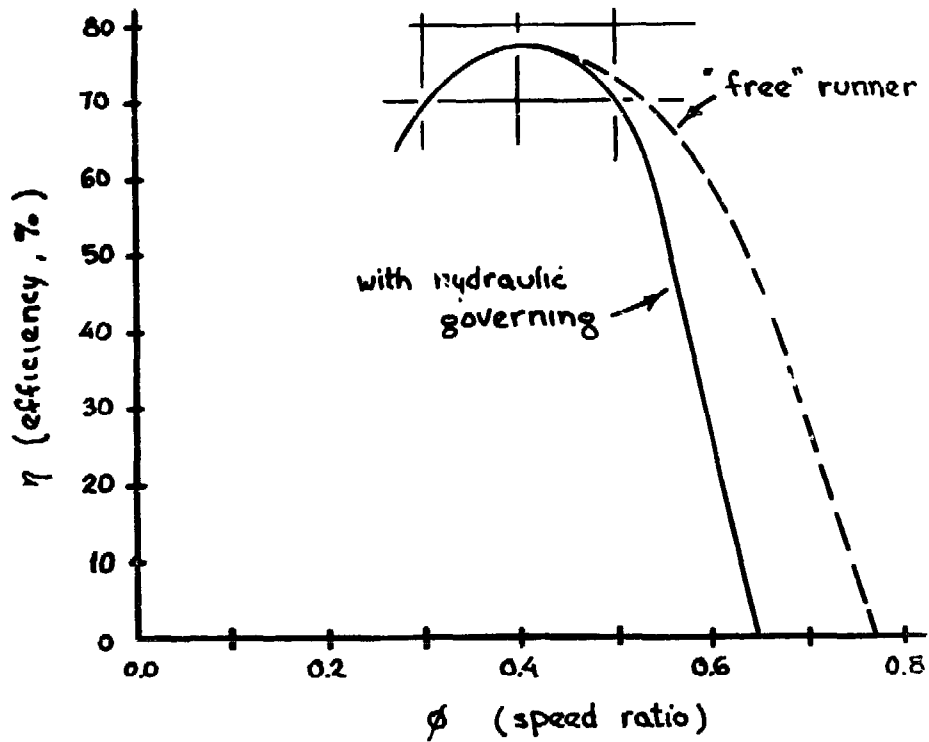


Figure 47