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LOW FALL HYDRO-ELECTRIC POWER INSTALLATIONS.

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This subject is likely to be of interest to Punjab Engineers from the fact that there are a number of low falls on the Irrigation canals in the Province, certain of which have been or are being developed as power installations.

As the term "low fall" is comparative it will prevent misconception if the same is defined so far as it is used in this paper. It is taken as applying to the type of installation where the water is brought to the power station in an open flume which terminates in the turbine chamber or pit where the turbines are situated.

So far as the Punjab is concerned such installations are likely to be situated at falls on Irrigation canals, hence the conditions obtaining at such a site may be borne in mind.

The falls that are likely to be brought under development would probably have a head of from five to fifteen feet. Lower falls can be and have been developed so they are not ruled out as impossible but are merely considered as outside the limit likely to be brought into use for some time to come.

The electrical side of the power plant has been pretty well standardised. The generators would probably produce alternating current at a standard pressure and frequency, depending upon the duty it had to serve. Anything up to 6,600 volts would be generated at the machines while higher pressures for long distance transmission would be obtained through step-up transformers.

This remark is made with respect to the size of machines likely to be the units on a low fall plant. Large units can be made to generate at higher voltages but with the sizes of units referred to it would be disproportionately expensive to wind them for anything above the figure given.

The main interest of a low fall power station lies on the hydraulic side of the plant together with the general design of the power station. This side of such a plant has not been developed to the same degree as the electrical side hence there is more room for divergence of opinion and consequently for making mistakes. That plant for these low fall installations has not been more completely standardised is no doubt due to their low place on the list of desirable works. It naturally costs more per horse power to install a plant at a low fall than at a high one, consequently such works will only be undertaken when cheaper power from other

sources cannot be had. The high and rising cost of fuel for power purposes together with the occasional failure of supply, gives the low fall power station a more attractive appearance in the Punjab than it otherwise would have. That low falls can be economically developed for power purposes has already been proved. The main source of power for driving the New Egerton Woollen Mill at Dhariwal for many years has been a fall on the Upper Bari Doab Canal and they have a scheme under consideration for extending the available power.

The Amritsar Hydro-Electric Power Station at the Grand Trunk Road fall on the Upper Bari Doab Canal produces electricity at a fraction of an anna per unit. Sir Ganga Ram, C.I.E., M. V. O., has found it an attractive proposition to install a Hydro-Electric Power Station at the Renala Fall on the Lower Bari Doab Canal and transmit the current to a distance of fifteen miles to pump water to irrigate his land.

The Power Station proper will usually be situated on a bye-pass or side channel taking water from above the fall and returning it to the main channel after it has passed through the turbines. If the canal is in constant use when the power station is to be built, it is advisable to locate the station somewhat downstream of the fall and not too close to the parent channel. The running canal will probably have raised the water level in the sub soil to a higher level above the fall than below it, hence there is not likely to be so much trouble with water in the foundations if the site is below the fall. Its distance from the main channel should be great enough to prevent trouble with the bank of the parent canal due to water from the higher level finding its way through the soil to the low level channel.

When considering a particular scheme, the engineer must view the possible alternative designs for his power station in order to select the most suitable type. His choice will be between—

Class (1) (*a*) Vertical units directly coupled to electric generators.
(*b*) Vertical units connected by bevel gearing to horizontal electric generators.
(*c*) Vertical units connected by straight gearing to vertical electric generators.

Class (2) Vertical turbines in multiple units driving a horizontal cross shaft by bevel gearings with the generator coupled to the cross shaft.

Class (3) Horizontal turbines arranged with several units on one shaft which in turn may be coupled to a generator directly or through gearing.

Of these alternatives, illustrations are given of Class (1) (*a*), see Fig. 1, Class (1) (*b*), see Fig. 2 and Class 3, see Fig. 3.

The general trend of modern turbine practice for moderate falls and even those up to 500'-0" is towards the vertical direct coupled single rotor turbine set, Fig. 1. Where the head is sufficient to give a suitable speed of rotation this is a very satisfactory arrangement, but the type becomes disproportionately big with the low falls under consideration. To get units of three to four hundred horse power the volume of water to be passed through may need to be from 500 to 600 cusecs or more, according to the available head. Such large machines have slow rotational speeds which with direct coupled sets give a large heavy and expensive generator.

Questions of transport may at once rule out large heavy machines, particularly when, as is the case with the Punjab, the plant must be conveyed long distances by sea and by rail and possibly also by roads of inferior quality.

There are other matters to be considered, such as the necessary power house construction to accommodate and support such large heavy machines ; the accessibility of the various parts ; the means for handling large heavy machines ; and the extent to which large details must be divided up into pieces suited to the available means of transport.

In England and America the railways have provided railway trucks of special designs to carry large and heavy pieces of machinery so in those countries the machinery can be made in proportionately big units. The writer has not seen railway trucks of corresponding types in this country so it must be assumed that details of turbines and generators must be such that can go into the available railway trucks.

The rotor of a turbine is not a piece of machinery which may be divided readily into segments for transport, in fact the writer would deprecate the idea of so building a rotor for re-assembling in this country, and would prefer a multiplicity of units to a smaller number of great size.

Accessibility is a matter of importance, for when parts are difficult to get at there is always the temptation to leave them alone until depreciation has become serious. With the type under consideration, the turbine is in a flooded chamber, below the generator and it is always submerged in water and inaccessible unless the wheel pit is specially closed up and unwatered. Such conditions prevent frequent examination. Before a rotor can be lifted out for any purpose, the heavy generator above it must be dismantled, making work slow and expensive.

Low heads with large units means slow speed of rotation, yet from the point of view of the design of the electric generator a much higher speed is desirable as thereby the cost of the generator can be greatly lessened. For this reason gearing may be introduced

between the turbine and the generator. (Class 1 (*b*) and (*c*)). It may be arranged with the shafts either at right angles or parallel and it is a question which is the most suitable from a working point of view.

The essential features of a successful set of gear wheels are—

(*a*) The teeth must be correctly made to proper tooth curves, giving a rolling contact.

(*b*) The teeth must be truly concentric to the shaft.

(*c*) The teeth must be properly in mesh.

(*d*) The teeth must be so made as to engage with a minimum of shock.

(*e*) The intensity of pressure on the teeth must be such that lubrication may be effective.

(*f*) The gear should operate under full load with an unobjectionable amount of noise.

(*g*) The gears must be so enclosed that they are protected from dirt and do not themselves throw lubricant about.

It is not the author's intention to discuss these features of gearing as it would take up too much space so he will limit himself to a few general remarks as affecting their application to the type of plant under consideration.

That the teeth of the wheels may have a reasonable chance to be successful, the intensity of pressure must be such that the lubricant will remain between to prevent metallic contact. To keep the pressures low the gear wheels must be wide on the face and of a sufficiently large diameter. It is obvious that bevel wheels are more limited in the matter of width of face than those on parallel shafts, therefore they require to be larger in diameter to get corresponding results. Double helical gearing engages with less shock, is quieter and stronger but is more difficult to set correctly than plain gearing. This latter difficulty is greatly accentuated with double helical bevel gearing for with such gearing there is a serious end thrust on both shafts to be received on suitable bearings which in turn must be accurately adjustable in each case otherwise the intensity of pressure on the wheel teeth is much increased.

It is well-known to mechanical engineers that castings will warp long after they have been made, and will often do so after they have been machined. For this reason large gear wheels will sometimes loose their accuracy by warping after they have been made, consequently such wheels when of large size are not likely to possess the accuracy so necessary if they are to work well and without serious noise.

These considerations make gearing undesirable if it can be avoided but the case is much stronger against bevel gearing than with parallel gears.

A multiplicity of vertical turbines, Class 2, geared to a common cross shaft gets over the difficulty of large units but it multiplies the objectionable bevel gears and the expense thereof. Such a system of driving a generator at a power-house although frequently used in the past has few if any supporters now.

There remains to consider Class 3, horizontal turbines arranged with several units on one shaft. This Class 3 might have been sub-divided into single horizontal units coupled directly or through gearing to the generator but for the fact that a single such unit is not worth consideration. If it would suffice for the power required it would be better employed as a vertical turbine. The horizontal turbine is only worth consideration when a number of rotors of small size running at higher rotational speed will do the work of a slow speed large vertical machine.

It is then that the type is a sound one to use. It can be arranged with a number of rotors on the shaft such as four, six or even eight. Fig. 3 illustrates a power-house designed with sets of four rotors on each shaft. In this design the turbines are placed in an open flume with sluice gates to regulate the water supply, the four rotors are in pairs, each unit of the pair facing the other that they may be in balance. The bearings for the shafts are placed outside the turbine cases in protecting caissons with stuffing boxes to exclude silt laden water so that the bearings may not be exposed thereto. The caissons extend up to water surface and are large enough for a man to get inside. Floating wood and jungle must be excluded from the turbines as it might damage them, for which purpose grids are placed at the entrance end of the flume.

The tops of the turbines must be submerged sufficiently below water in the flume to prevent the indraft of air by the formation of eddies. If the caissons protecting the bearings are made rectangular, eddies will be found on their downstream sides, so it is best to make them elliptical or round. When for some reason the turbines cannot be placed deep enough below water to prevent air being drawn in, a roof may be placed over the flume at water surface above the turbines but it must be strong enough to resist the collapsing pressure due to the column of water beneath it and to resist any uplifting effect of the incoming mass of water should the regulating gates of the turbines be closed suddenly.

The turbines stand upon the floor of the flume beneath which are passages to carry away the water that has passed through the turbines. From the fact that with these low falls every inch of head is important the discharge passages must be shaped carefully

to give low resistance to the escape of the water. For this reason the passages receiving the water from the two turbines in the design illustrated are kept separate from each other, continuing so underneath the power-house until they deliver parallel streams of water smoothly with the tail race. It has been found convenient in the design to bifurcate the passage leading from the second turbine, so that it passes on either side of the passage from the first turbine. The division walls between these passages need not have extended so far but it is convenient to extend them into the tail race far enough to accommodate double grooves to receive curries for use when entirely closing off and unwatering the passages for repairs.

Several alternative arrangements of discharge passages can be used, each equally effective, as for instance by having single passages from each pair of turbines and inclining each to one side, one going to the right hand and the other to the left to become parallel under the power-house. The designed arrangement however is easy to build up in brick work with a minimum of concrete needing forms to ram up to.

With this design it is convenient to use gearing on parallel shafts to raise the speed to suit the generators. If the turbines have a rotational speed of 80 to 140 revolutions per minute, depending on their diameter and the water head, it does not need a very high ratio of gearing to give speeds of 500 to 700 per minute at the generator shaft. A ratio of say four or six to one will do it, consequently it can be carried out with reasonable dimensions and with suitable velocities of the teeth. By placing the gear wheels upon a vertical centre line, that is to say one above the other, the floor of the generator room can be kept well up and dry.

It is a good thing to have a drainage tunnel running through the concrete floor of the generator house and to provide a connection to this from all parts needing to be kept dry. This tunnel can be made to serve another useful purpose, namely to carry away hot air from the generators, the latter being suitably built for this purpose. The amount of heat the generators give out is considerable and it may cause the generator room to get very hot.

Practically the only type of turbine now considered for low and medium falls is the compound flow or Francis turbine with Thompson regulating guide blades. The type is illustrated in Fig. 4 where there are two views, one shewing the guide blades and the other a section through the rotor. When entering the rotor, the water begins its motion in a direction at right angles to the shaft and leaves it parallel to the shaft. The guide blades direct the water in a tangential direction to strike upon the blades of the rotor and at the same time they act as valves to control the quantity of water admitted. The governor acts upon these blades to regulate the speed of the turbine.

One or two points of detail regarding turbines may here be mentioned. It is customary to make the rotors with steel blades which are laid in place in a sand mould while the boss and ring are cast on to them. To effect a good fusion between the metals, the steel blades are first cleaned and tinned where the cast iron will make contact. The author has observed that where so tinned the steel is protected from corrosion, so concludes that it would be an excellent thing to cover the blades entirely with tin, not a difficult task. Also, the turbine shafts are liable to severe wear where they pass through the stuffing boxes of the caissons, thus it is desirable to have a renewable sleeve on the shaft at this point for it is a troublesome thing to make up the shaft to its original diameter where it has been worn away. It is very necessary to have the cheeks of the moveable guide blades of the turbines faced with thick brass and to make the link joints to these blades of liberal dimensions and with brass bushes. All these parts if of steel get rusty so throwing additional work on the governor and retarding its action.

The type of governor now practically universal is that known as the oil pressure governor. A glance at Fig. 4 shews that in that design there are no less than sixteen guide blades which move about central pivots and each blade has two pins where links are connected, thus each set of blades has forty-eight pin bearings. With four rotors and the shafts making connection between the governor and the moveable guide blades, there are actually over two hundred bearings where there is motion at each movement of the governor. From this it will be seen that the governor has some heavy work to do.

The initial principle of the oil pressure governor is that of a fluid pressure machine wherein oil under pressure acts upon a piston within a cylinder to cause it to move and act upon the gates or moveable guides of the turbine thereby controlling the amount of water passing through.

The details are somewhat complex and not essential to the purpose of this paper.

The author must apologize at this point for appearing to introduce some elementary principles into his paper but he does so in order to make his argument clear.

For the purpose of acting on the blades of a turbine rotor and do work thereon, the pressure head is converted into velocity by passing it through suitable orifices. The blades of the rotor are designed to receive the water and, while moving themselves, to take the velocity out of the water, leaving it denuded of the bulk of its energy with only sufficient to enable it to get out of the way. The energy of the water is thereby transferred to the rotor.

It is not necessary that the orifice through which the water passes should be situated at the bottom of the column of water,

providing that the column is contained in such manner that the portion below the orifice shall exert a draft or suction effect at the orifice.

The reasoning following upon this is that the head of the water may affect the velocity of the water passing through the orifice from a position either above or below. Assume now that when the water has passed the turbine it has parted with its energy entirely. The water could not get away and would check more water passing through. On the contrary if exterior energy acted upon the water to get it away quickly enough it would not only prevent the dead water from choking the exit from the turbine but if carried to a sufficient extent it might by hurrying the water away cause negative pressure and thereby act as a suction head on the discharge side of the turbine. It is therefore clear that if the water can be hurried away from the turbine fast enough by using some external energy it will have the effect of augmenting the head available at the fall.

We will now consider the conditions usually found at the low falls on irrigation canals. The quantity of water flowing is not constant throughout the year. When water is plentiful in the river, the canal will get the maximum it can carry but as the amount available falls off, it may drop below the capacity of the canal thus at such times the volume may drop as low as a half of the maximum or less. Where there are several main distributaries on a canal, they will probably be worked in rotation, each in turn getting full discharge for a period of say ten days to be followed by a period of reduced or nil discharge.

Where a power station is situated at a fall there must be means for regulating the water allowed to flow over the fall so that the upstream level may be retained at the minimum permitted over the turbines to maintain proper submergence. It follows that as the discharge of the canal falls off the water level below the fall will recede whereas the upstream level is maintained at somewhere near its full supply level. Fig. 5 is a reproduction of a diagram prepared by Mr. E. S. Crump, Executive Engineer of the conditions to be expected at the Renala Fall on the Lower Bari Doab Canal. From this it will be seen that with full supply of 5,400 cusecs passing, the working head is 6′ 0″ but with conditions of short supply the available head may be as much as eight feet or more. Full supply conditions cannot be expected for more than seven or eight months of the year, thus it would not be satisfactory to put down plant to use the whole of the water under full supply conditions because when the supply is less and the head is more, the whole of the water could be used by half or a third of the turbines, thus the balance of the plant would be idle for a large part of the year. Suppose a given turbine would develop 200 H. P. at 6′ 0″ head with 70 per cent.

efficiency. Of the 30 per cent. lost part will be water losses and part will be machine losses. The latter will remain nearly constant and will be approximately 20 per cent. of the head. When the head is increased to 8′ 0″ that loss bears a less percentage thereto, falling from 20 per cent. to 15 per cent. The water losses are also likely to be less so the turbine efficiency may rise to 78 per cent. or 80 per cent. But at the increased head the amount of water that can pass through the machine will be increased in the ratio 195 : 226 or say by 16 per cent. thus as the head itself is increased from 6′ 0″ to 8′ 0″ the turbine which gave 200 H. P. would yield well over 300 H. P. If however we expect to work under these conditions each machine would need to have a generator capable of converting 300 H. P. into electric energy yet for seven or eight months in the year it could only work under two-thirds full load. It can thus be seen that with these varying heads one or other part of the combination must work for a large part of its time much below its capacity and therefore the general efficiency of the plant is lower than it might be.

It is clear from the above that it would be poor economy to put down turbines of the usual design to utilise the whole of the water at the lowest head, for the supply will drop from 5,400 cusecs to 2,000 cusecs, thus much of the plant would be idle a large part of the time. If then, plant is put down to use say half the maximum quantity a big volume of water will spill over the fall and its energy be lost.

If the wasted energy in this water could be directed to exert itself upon the discharge water leaving the turbines it could accelerate the same and so augment the available head as previously indicated. The question then is can this be done and how? Given that it can so be applied, the turbines might be designed for a greater head than six feet, say 7.5 feet or 8 feet, the difference in head being made up by the augmenting scheme when the water is in excess, while the machine would work at the natural head when the discharge falls off and the head is increased. The generators would then be designed for a higher capacity and fewer machines would be needed, thus both turbines and generators would at all times work to their rated capacity.

Now as to the method. Clement Hershall applied a Venturi tube with perforations beyond the throat to create a suction draft on a small turbine. A species of water ejector was used by Henry Ford on a plant at his estate to get the same effect. He reported that while it did what he required, the device was crude and needed developing. In both of the above cases the control was by a hand operated gate. In 1920 L. F. Moody filed a patent for the application of an ejector at the lower part of the turbine case and in the same year the author filed a patent embodying several

applications of the ejector principle to turbines. Part of these were disallowed as being anticipated by the Moody patent which at the time had not been published and was therefore unknown to the writer but part of them were accepted. Particulars of the Moody Ejectors Turbine were published in the April number of Mechanical Engineering, 1922, in a report prepared by Mr. S. Logan Kerr who experimented thereon, according to which the power output of the turbine was increased by 36·7 per cent. by the use of the ejector. Another method of using the water spilt over a fall to serve the same purpose is to build the weir hollow of an ogee shape with an opening near the toe. The discharge from the turbines goes into the hollow part of the weir and the energy of the water passing over the fall acts upon the discharge water to increase the suction head. In each of these the principle is the same, namely to use the energy of waste water to increase the suction head on the underside of the turbines, thereby augmenting the head, and so increasing the amount of work the turbines can do. This compensates for the loss of head when the discharge is high.

Illustrations are given of the Moody (Fig. 6) and Ashford (Figs. 7 and 8) methods of carrying this principle into effect. In the latter the gates admitting water into the augmentor are controlled by the governor in such manner that when the turbine speeds up, the water to the augmentor is first closed and then the turbine gates are operated, and the order of movement is reversed when the turbine slows down. That is to say if the turbine is running light and load comes upon it to check its speed, the governor first opens the usual turbine gates to admit more water. When they are wide open and still more power is wanted, the governor opens the augmentor gates to increase the head. The water acting with its full velocity on the water leaving the turbine, accelerates the latter and so increases its velocity thereby applying an induced or suction head to the underside of the turbine runners. The efficiency of a device of this kind is not important as it only comes into use when there is an excess of water otherwise running over the spillway at the fall.

Considering the initial low velocities obtainable with the water on these low fall installations and the need for getting the highest speed possible with the turbines to reduce the ratio between the turbine and the generator, it is necessary to use every expedient to get higher speeds. Considerable work has been done of recent years to get higher relative speeds of the runner to the water velocity. To get this result the trend has been to depart somewhat from the form of runner hitherto used and to approach the screw propeller type and using it in connection with a form of casing that shall give the highest possible rotary speed of the water vortex. These higher turbine speeds are obtained with a slightly lower efficiency but that may not be a disadvantage under some circum-

stances. The general comparative appearance of ordinary and high speed turbine runners in section are shewn in Figs. 8 and 9. With these screw propeller type of runners it has been found possible to raise the speeds for a six-foot fall from 80 to 120 revolutions per minute, a fifty per cent. increase. Such types of turbine runners used with the methods indicated for augmenting the actual water head will get still better results and it is likely that we must look towards such combinations together with special shape of water passages to get the best possible results. In this way low falls of water may be developed so that each part of the combination will work under favourable conditions, the overall results be more efficient and the type of power plant become, financially, a more attractive proposition than it hitherto has been.

LOW FALL HYDRO-ELECTRIC POWER INSTALLATIONS

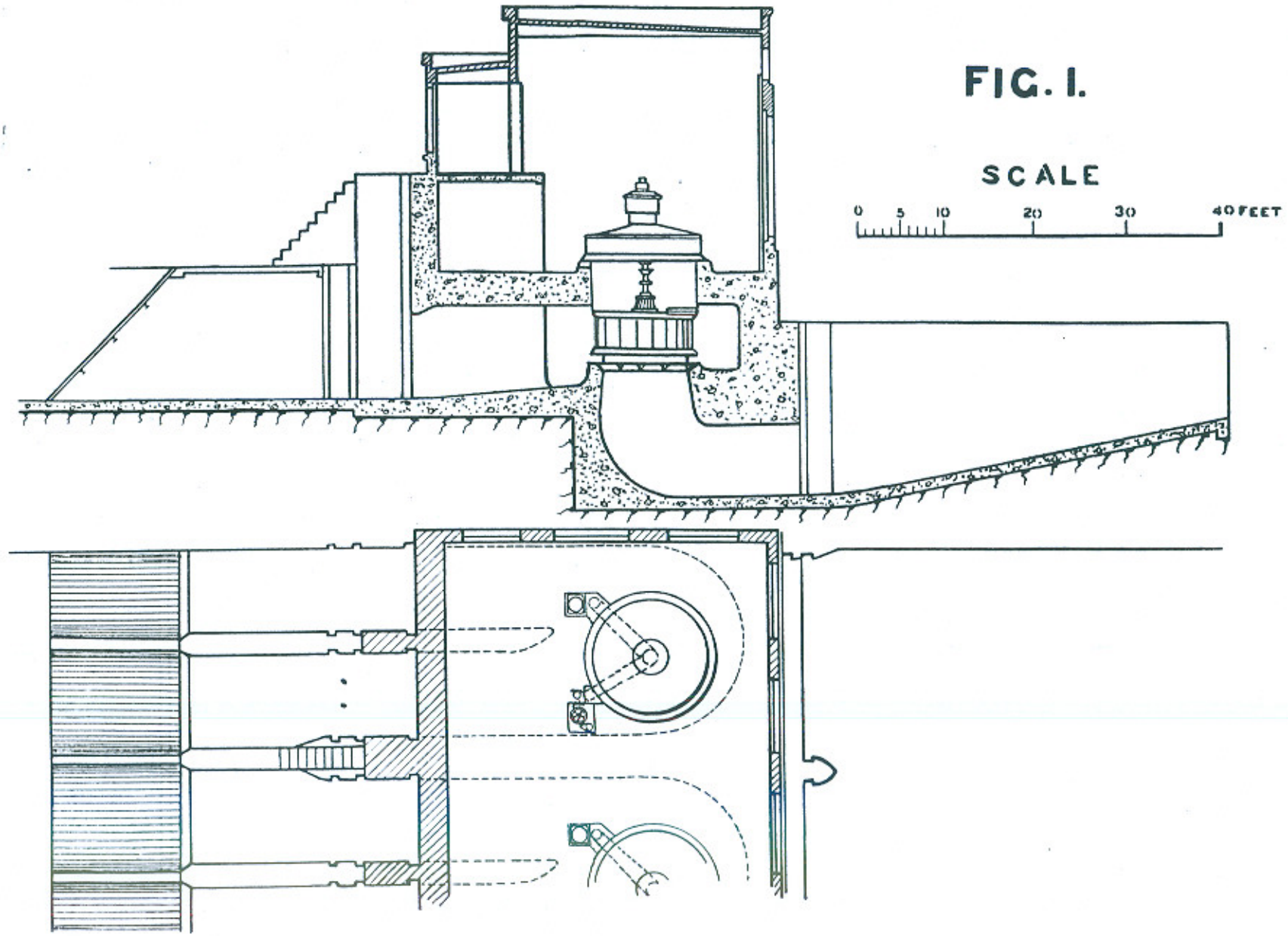
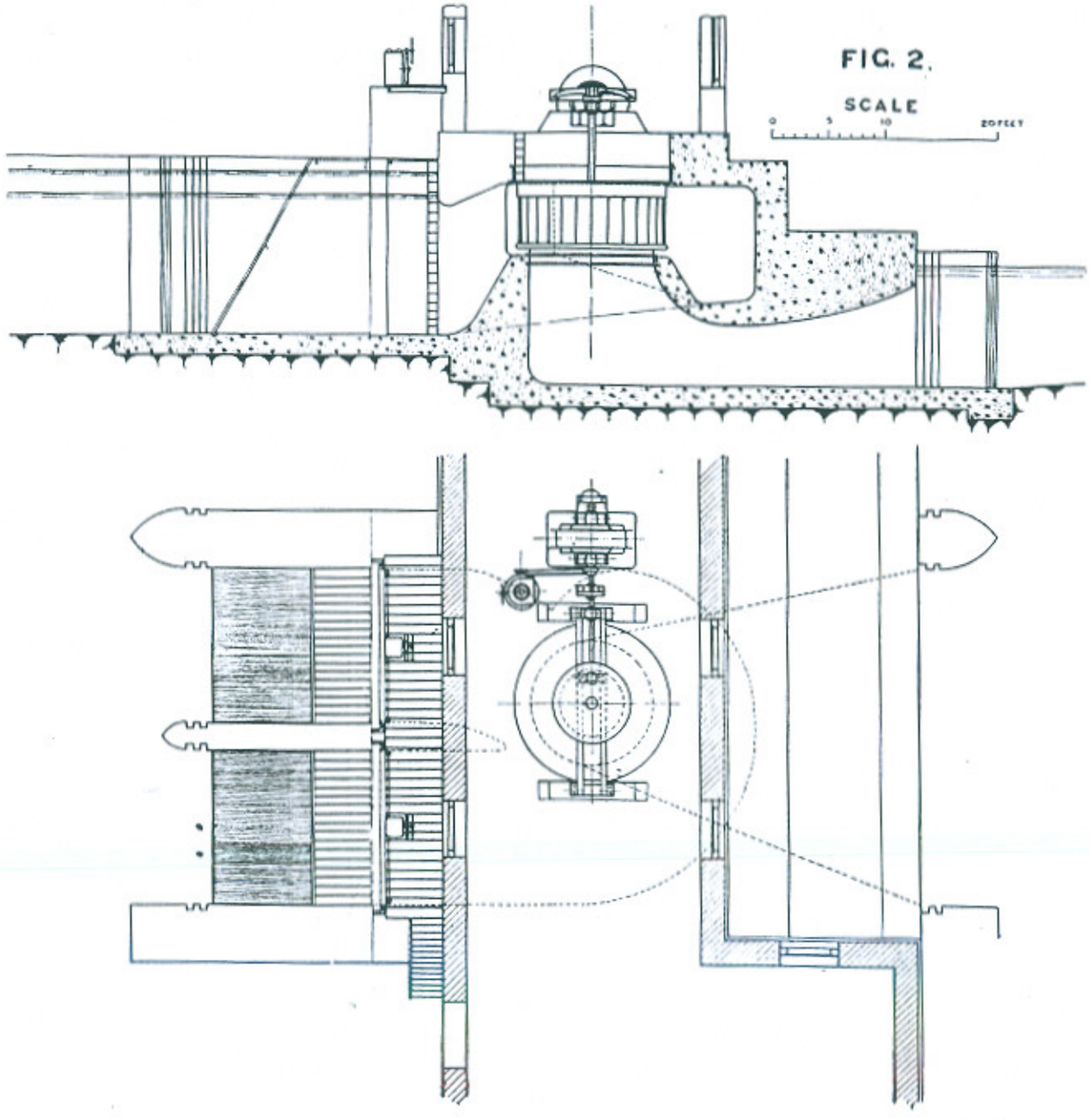


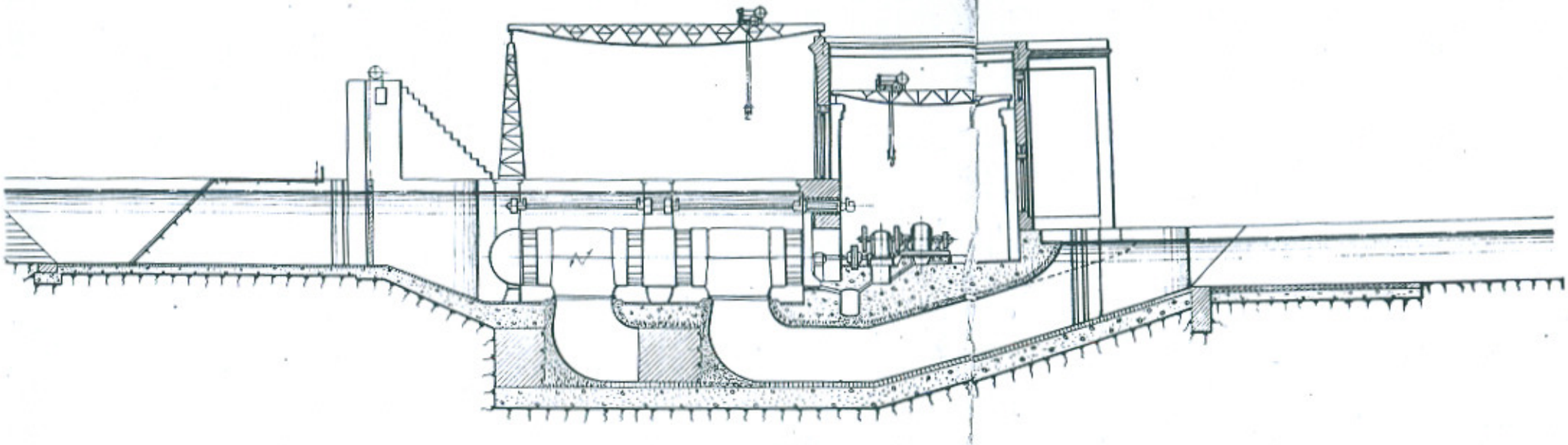
FIG. I.

LOW FALL HYDRO-ELECTRIC POWER INSTALLATIONS

FIG. 2.



LOW FALL HYDRO-ELECTRIC POWER INSTALLATIONS



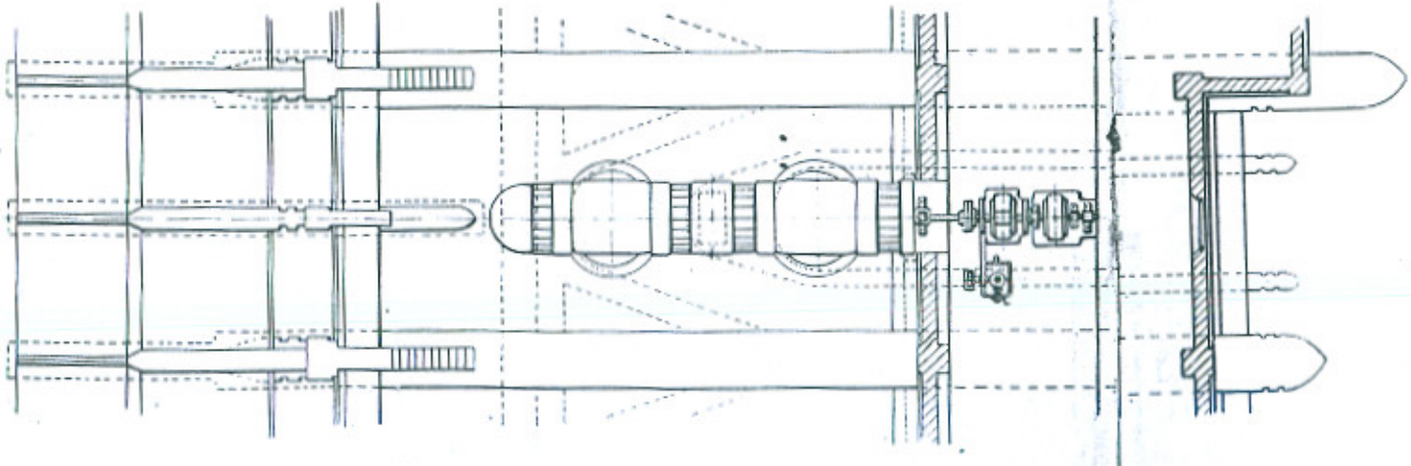


FIG. 3.

SCALE

0 5 10 20 30 40 FEET

LOW FALL HYDRO-ELECTRIC POWER INSTALLATIONS

FIG. 4.

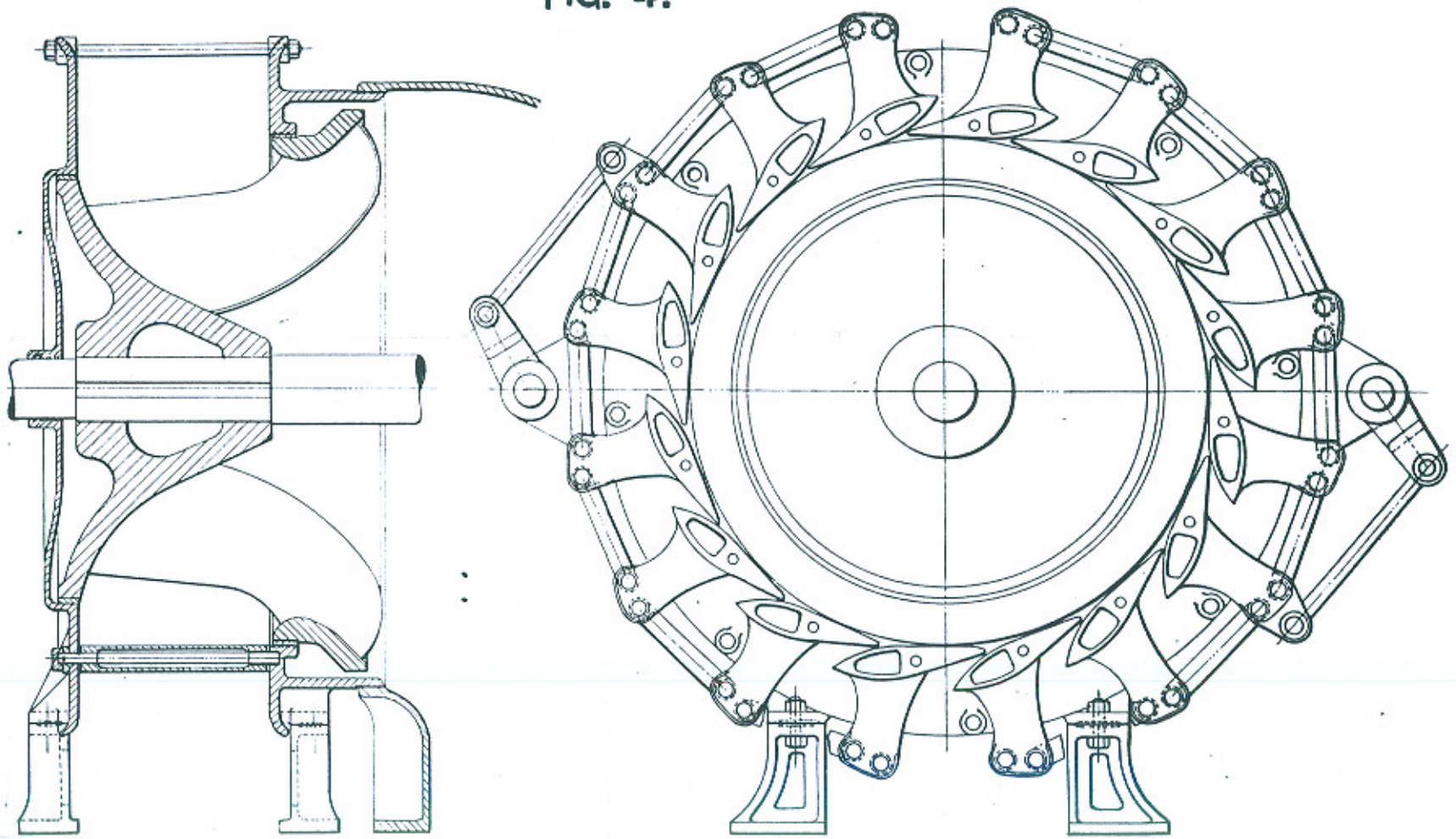
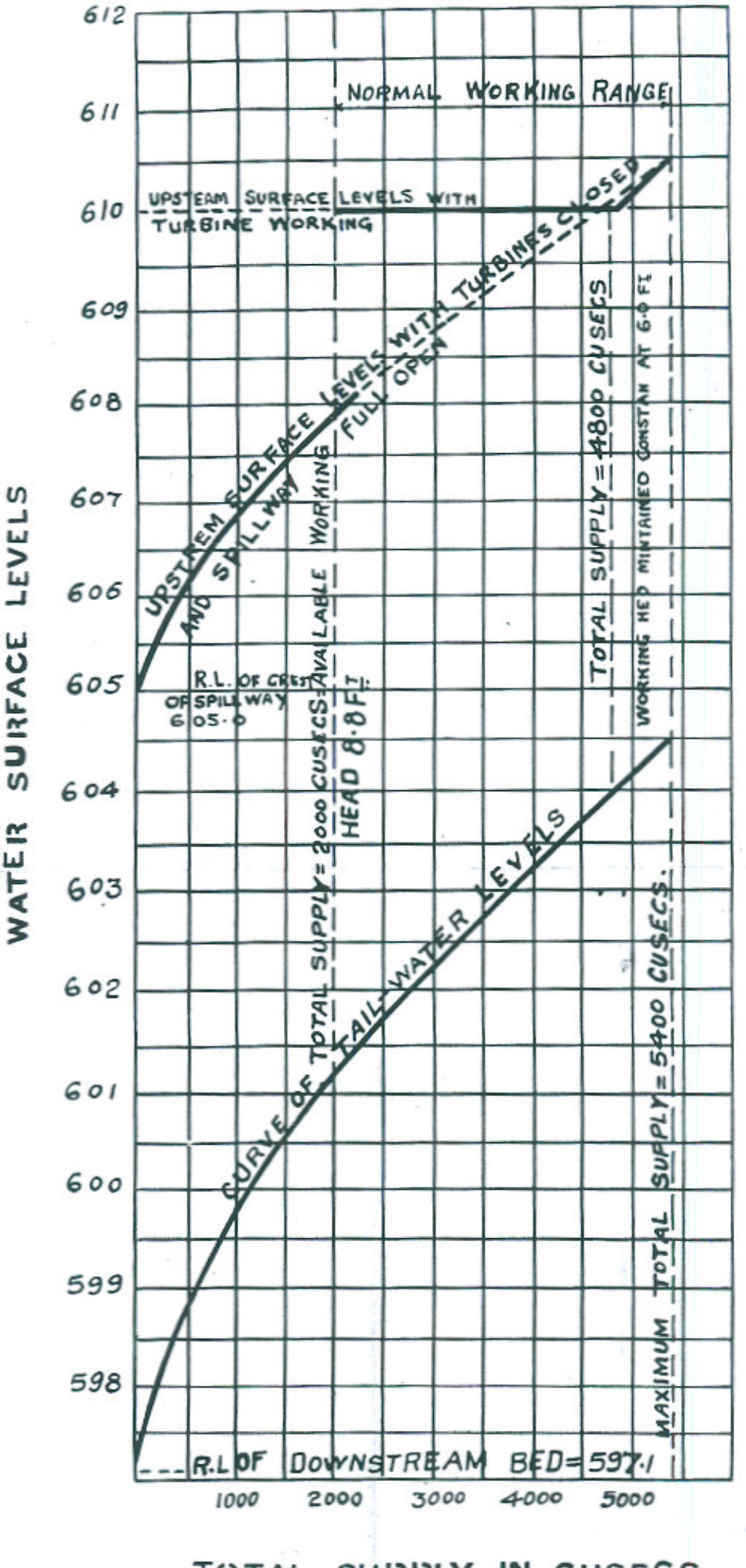


FIG. 5.


612
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NORMAL WORKING RANGE
UPSTEAM SURFACE LEVELS WITH TURBINE WORKING
UPSTEAM SURFACE LEVELS WITH TURBINES CLOSED AND SPILLWAY WORKING FULL OPEN
R.L. OF CREST OF SPILLWAY 605·0
AVAILABLE HEAD 8·8 FT.
TOTAL SUPPLY = 4800 CUSECS
WORKING HED MINTAINED CONSTAN AT 6·0 FT
CURVE OF TOTAL SUPPLY = 2000 CUSECS
TAIL-WATER LEVELS
MAXIMUM TOTAL SUPPLY = 5400 CUSECS.
R.L OF DOWNSTREAM BED = 597·1
1000
2000
3000
4000
5000
WATER SURFACE LEVELS
TOTAL SUPPLY IN CUSECS

LOW FALL HYDRO-ELECTRIC POWER INSTALLATIONS

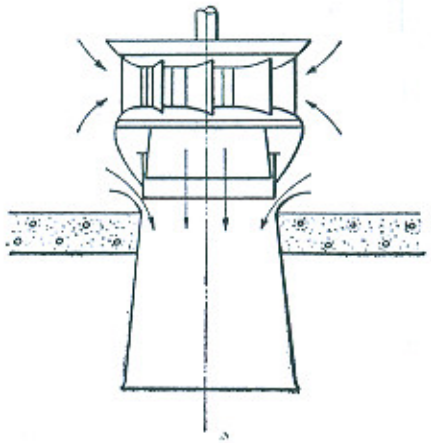


FIG. 6.

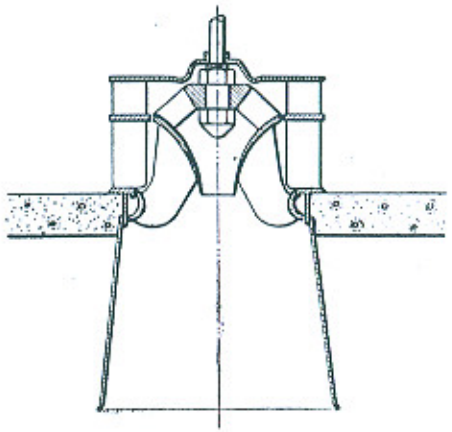


FIG. 7.

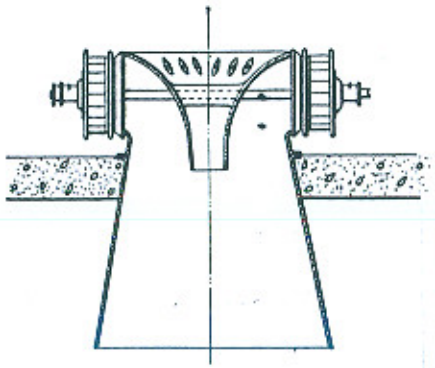


FIG. 8.

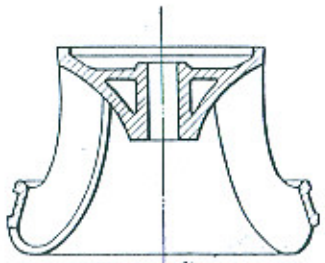


FIG. 9.

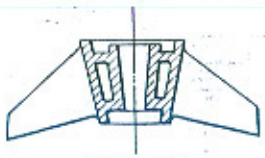


FIG. 10.

DISCUSSION.

THE AUTHOR introduced the paper and in doing so referred to a few fundamental principles of hydraulics which greatly affected the problems connected with low fall hydro-electric power installations.

The fact that both the velocity and the volume of water passing through a given orifice depended upon the head above the orifice, meant that to get a given power, the lower the head, the bigger the turbine had to be and the slower it would run. This further meant that the lower the head of water available, the greater would be the cost of the turbine per horse power.

This was not the whole of the matter, for slow speeds of revolution were not suitable for electric generation, thus means had to be introduced to raise the speed of rotation suitably for electric generators, and there was a practical limit to the extent that this could be done by gearing.

On the Punjab canals the water levels were very variable and such that when the greatest volume of water was flowing, the available head was least. At such times there was a surplus of water, thus if suitable means could be made available to use this excess the advantage would be great. This problem had confronted the Author at the Amritsar Hydro-electric scheme. In this scheme the project originally was to unite two falls on the canal by deepening the canal between them to produce a single fall of 9′ 6″. Unfortunately the scheme was sanctioned in two parts, first the building of the power house for the full fall, to be followed by the deepening of the canal between the two falls. This latter work however had not yet been done so that the station worked on a 5′ 0′ fall only. At times of low supply the available head became much as 8′ 0″ and it would seem that in such a case if the energy of the surplus water now running to waste at times of large supply and low heads could be made effective, great advantage would result.

The author considered various means of utilising this excess water, the possibilities appearing to be—

(*a*) to deliver the tail water into the depression upstream of a standing wave at a rapid or weir ;

(*b*) to make the rapid or weir hollow with outlets at the tail end so placed that the water passing over the weir would create a suction draught on the hollow space, the water leaving the turbines being discharged into this hollow place ;

(*c*) to apply the ejector principle using the excess water by passing it into the tail race in such manner as to create a suction effect on the discharge side of the turbine.

The last of these alternatives seemed to be the most promising and was brought out more particularly in the paper.

The idea of using excess water to assist the turbine was not new in itself. Clement Hershall applied the "Venturi" principle with openings to receive the turbine discharge just beyond the throat of the "Venturi" and thereby gained a useful amount.

The need for higher turbine speed with low heads to suit them for driving electric generators lead to the thought that by the application of the "Venturi" principle to the turbines themselves embodying into the design the equivalent of the contracting tube, higher velocities through the turbine throat might be obtained, so that by placing suitably designed rotors right in the throat the greatest possible speed of rotation could be got.

The Author suggested that by combining these several principles into the design of turbines and their water passages, much might be done to make the low fall turbine a more promising proposition, than hitherto it had been.

The Author then drew attention to the need for a suitable system of voltage regulation on the electric generators. Hitherto, the electrical engineer had thrown all the responsibility for control on to the mechanical engineer, requiring him to govern the speeds of the machines within a very close limit. This entailed the use of powerful and expensive governors. In a small plant the governor might be practically as costly as the turbine itself, therefore, if this expensive element could be dispensed with, much advantage would result. The electrical engineer must step in and produce a constant voltage generator with a wide variation of speed.

MR. E. S. LINDLEY said that an aspect of canal falls hydro-electric installations not touched upon was that of canal closures. This aspect however, was not quite so important as in old days as canals had now to keep open for longer periods. Still, however, they had to be closed periodically and therefore in order to guarantee an uninterrupted power supply it would seem that a steam stand by plant was necessary.

Lately a concession had been granted to one syndicate for several falls on different canals in the Punjab which would work in parallel so that closures on one canal would be arranged when the others were running. In this way it was hoped to avoid stoppage of the supply of energy.

Because of the need of stand by plant, the power to be derived from canal falls was not so suitable for town supplies and for industrial purposes as for lift irrigation. In the latter case, the periods of lift irrigation would exactly correspond with the periods of running in the canal.

He pictured the Punjab fifty or hundred years hence with the canals flowing through the head reaches in which the subsoil water level would be high, and not beginning to irrigate till the high lands were reached. The canals would not extend into "khader" tracts in which the subsoil water would be near the surface, but instead, the water would be passed into tracts which were desert at present. All electric power capable of being generated economically (including possibly, power derived from generating stations in the hills) would be transmitted through a net work of transmission lines and used for lift irrigation in places where subsoil water level would be high (thus also helping to combat water logging) and the surplus power would be used for pumping beyond the limits to which the canals would run. When this time came, the map would be painted even greener than it was at the present time.

MR. H. W. NICHOLSON referring to page 61 of the paper where the author stated that the generators would probably produce alternating current, said that the difficulty was that reduced pressure head on the turbines caused a corresponding drop in speed and frequency. He thought that it might be better to generate direct current as in the case of the Chester Hydro-electric installation in England and transform to alternating current for long distance transmission afterwards.

With regard to the remarks on page 63 as to transport difficulties, recently a 250 tons dragline excavator had been transported by rail from Karachi in crocodile trucks.

The design of the power house in canal hydro-electric installations needed very careful consideration. Owing to buoyancy effects it was possible to get turbines and shafting out of alignment, which might have serious results.

With regard to the remarks on page 65 as to roofing over the flume above the turbines, he thought that the provision of a local dome over the inlet might be better.

No mention was made in the paper of hydro-electric installations at canal headworks. Such installations would get over the difficulty of canal closures and in connection therewith double tail races might be provided, one to the canal and one to the river.

Another means of utilising energy from canal falls would be by coupling the turbines direct to centrifugal pumps which would be used for lift irrigation. Such plants might be built in one piece with a single shaft on which two impellers were provided, one in the pump and the other in the turbine.

MR. F. H. BURKITT asked the author if it was not practicable to use stream wheels to generated power. The speaker had seen one at Tajawalla which had cost not more than Rs. 150.

The Author's diagram of the exit from a turbine would be improved by expanding at the tail.

With regard to transport of heavy parts of plant and machinery there were many falls which were far away from railways and it might be necessary to transport them across rough country. He would like to know whether there were suitable caterpillar wagons for this.

MR. T. MILLER-BROWNLIE complimented the Author on providing a paper which was of exceptional interest. The problem of low fall power installations of the type suitable for the Punjab was comparatively new and any fresh information available in connection with its solution would have an immense value. The most successful hydro-electric power installations at present were those of America and Switzerland but they were derived from high falls. A considerable amount of research was necessary to obtain efficient plants for the development of power from the numerous low falls of the Punjab.

L. ISHAR DASS said that there are many falls on the Upper Swat Canal, the water from which was used for operating gird wheels driving flour mills (chakkis). Two years ago he was instructed to try to devise means to improve the output of one of the mills, and after making certain alterations and adjustments he was able to bring up the output to 50 maunds per day or 300% more than its original capacity. Unfortunately, the speaker was no mechanical engineer and the gird wheel afterwards broke down. He had no doubt however that the efficiency of water driven country gird wheels could be much improved if the problem was properly tackled. The changes he made were to make the spindle central; he also altered the curvature of the blades and increased the area of impact. The alterations were made by a local blacksmith.

MR. F. L. MILNE speaking as regards regulation of voltage due to varying speeds said that this difficulty was got over on a small scale in motor car practice. Mr. Nicholson had rightly pointed out that with alternating current the frequency varied with the speed of the prime mover and consequently the speed of the driven motors was affected by the speed of the prime movers. There were also other factors to contend with, such as "synchronising" and "power factor." However, as the speed of the turbine varied directly as the square root of the head, whereas the output varied as the square root of the cube of the head, there would, automatically, be a slight tendency towards compensating for voltage drop owing to reduced load.

He recommended the consideration of automatic gates of the shutter type for use in head and tail races. He understood that patents were now pending for gates of this type up to 15 feet deep, which were guaranteed to keep the head constant within six inches, for discharges up to 80,000 cusecs.

MAJOR E. P. ANDERSON, R. E., replying to the point raised by Mr. Burkitt said that caterpillar wagons were used in certain theatres of the late war. He thought that the Headquarters of the Royal Tank Corps could give full information as to where they might be obtained, even if they did not possess any themselves.

THE PRESIDENT asked the Author whether wooden turbines for use on low falls could not be made locally.

THE AUTHOR replying to the discussion, said that with regard to the voltage regulation of generators driven by low fall turbines, he agreed with the remarks of Mr. Nicholson and Mr. Milne and pointed out that several methods were in use to overcome similar difficulties. One of these, the slipping belt method, was used in Stone's system of train lighting whereby the variation in the speed of the driving pulley was corrected by the automatic adjustment of the belt. In another system the armature was moved in relation to the magnetic field and a third system wherein storage batteries were introduced was found in general use in motor car lighting. These several systems had not exhausted the possibilities.

He agreed with Mr. Lindley that the real use for hydro-electric installations at canal falls would be found in connection with agriculture in which case the discontinuation of supply at times of canal closure would not be of vital importance. For example, if the power was used to drive pumps for lift irrigation, the pumps would have the same period of closure as the canal, without injury to crops. Certainly, the linking up of several power stations would ensure a continuous supply of energy. Such a system was working satisfactorily in America where they had several plants feeding one system, so that if one plant had to shut down from any cause, the remainder took up the load. Such developments, however, could only be in connection with bigger schemes than he had in mind when preparing his paper. Every thing indicated that these canal falls would ultimately be developed for the production of power for use in pumping water to irrigate high level areas which the canals could not serve by gravity, thus helping to paint green the map of the Punjab.

Mr. Nicholson had referred to the Chester hydro-electric scheme. That plant was used for charging storage batteries from which Chester was supplied with electricity. That scheme might be considered to be an enlarged case of the motor car lighting system and it was an effort to solve the same kind of problem as the Author had presented in his paper. He agreed with the remark of Mr. Nicholson regarding the buoyancy of the power house foundations but the point was rather outside the scope of the paper. As to the roofing of the flume he agreed that a dome over the turbine inlets would help to prevent the formation of undesirable eddies. The suggestion that turbine plants could be introduced at canal headworks with double tail races to discharge alternatively into the canal or into the river below the undersluice was good.

He had actually suggested such an arrangement in connection with the design of the Morala headworks of the Upper Chenab Canal but his effort to get a hydro-electric plant introduced into that work was not successful and he was greatly pleased that the matter should again be suggested.

There was nothing against the idea that a water turbine and centrifugal pump should be combined as a single unit and it would be a simple matter to work out such a design.

He had done some work on stream wheels for lifting water from canals both by buckets and by pumps. Such appliances were useful where but a small power was required. Undershot water wheels had been cleverly used on low falls in the past and might be further developed for use in suitable situations. Mr. E. S. Crump had designed and built a stream wheel for use at Balloki to drive a water scoop and it worked successfully on a very low fall.

He agreed with Mr. Burkitt that the shape of the turbine exit pipe was very important for, if badly formed, much of the heed could be lost there. He was interested in L. Ishar Das's remarks on gird wheels in which there was considerable room for improvement in design, and if improved they would be valuable for use in the Punjab.