## Paper No. 5048.[1]

# "Efficiency Tests of Large Modern Pelton Wheels."

By Eric Norman Webb, D.S.O., M.C., M. Inst. C.E.

*Correspondence.*

Mr. Henry Headland, of Arapuni, New Zealand, observed that many novel and interesting features had been incorporated in the design of the machines,[2] particularly in the way of foolproof protection; from the details given in the Paper those devices had been used to advantage in making testing-conditions ideal. The hydraulic conditions existing at Shanan for the machines under consideration gave a specific speed of 5·12, which was ideal for the type of turbine installed (namely, a single-jet Pelton wheel with a ratio of pitch diameter to jet diameter of 10. A check of the leading dimensions of the machines showed that they complied with normal standard practice, and it was satisfactory to know that the accepted rules of design could be followed safely for machines of large output. Mr. Headland.

In machines of the type under consideration two items contributed mainly to the value of the final overall efficiency; namely, the design of the buckets and the nozzle. In view of the high values of efficiency obtained at all loads it would be useful if the Author would give a little more information concerning the design of those particular items.

For an efficient machine the jet should not be so large that it interfered with the back of the buckets, and the buckets themselves should be so designed that the jet was gradually deflected by the bucket-curves through an angle of 180 degrees, and then freely discharged without striking the wheel. The surface of the bucket should be perfectly smooth and of minimum area to reduce friction-loss. Those requirements were to a certain extent conflicting, and a sketch showing the leading dimensions of the buckets, including the width of out-cut and the values of the various angles, would be a useful addition to the Paper. From the data given in the Paper it was estimated that the lip of the buckets should be undercut at an angle of 73 degrees if impact of buckets on the jet were to be avoided. If a calculation were made for the number of buckets required to develop the specified output it could readily be seen that the machines had been designed for maximum efficiency apart from

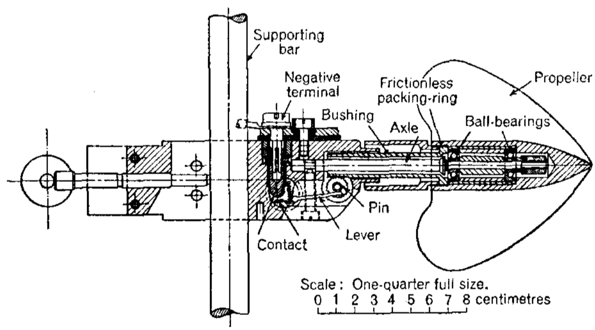
[1] Journal Inst. C.E., vol. 5 (1936–37), p. 259 (December, 1936).

[2] Additional information was published in *The Engineer*, vol. cliii (1932), p. 48.

Mr. Headland. other considerations. The minimum number of buckets required was fifteen, so that there were actually about 50 per cent. more than were actually required. Experience showed that within limits the efficiency of a given wheel increased with the number of buckets, and apparently that was the reason for casting two buckets on the one lug so that all the buckets could be accommodated on the disc.

It was stated in the introduction to the Paper that a special stainless steel was used for the buckets, presumably in anticipation of trouble with corrosion at the backs of the buckets ; after 2 years' operation, experience should have proved whether stainless steel had been effective in overcoming that trouble. In one case, ordinary cast bronze steel, nickel steel and stainless steel had all proved so unsatisfactory under a head of 800 feet that the efficiency of the machine had obviously been affected. An analysis of the special steel used for the

*Fig. 12.*

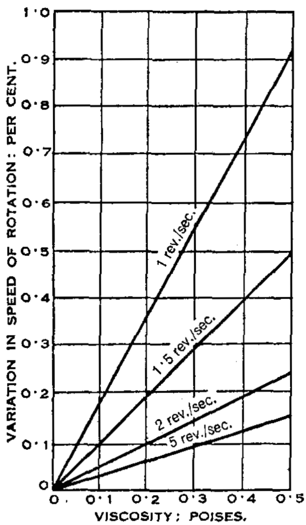



Shanan buckets would probably show that it contained about 14 per cent. chromium, 0·2 per cent. nickel, and 0·35 per cent. manganese, with a Brinell hardness of approximately 200, and heat-treatment at 800° C.

Limitations of space had probably prevented the Author from giving full particulars of the equipment used, and it was assumed that the current-meters were the Texas type Mark V, a cross-section of which was shown in *Fig. 12*. A short description of the construction and operation of the instrument might be of service to those who were not familiar with the apparatus.

The instrument consisted essentially of a two- or three-bladed propeller, in the hub of which was mounted a pair of oil-immersed ball bearings, the entrance of water to the chamber being prevented by a frictionless packing-ring. In the ball-races an axle was fitted which transmitted the rotation of the propeller through a bushing with a single or double thread and thence to a toothed wheel, on which one or two pins were arranged, so that by combination of the thread and pins signals could be obtained every 5, 10, or 20 revolutions as required. The toothed wheel and pins operated a lever which carried a contact arm and contact, all of which were housed in a chamber in the main body of the instrument. The contact and negative terminal provided for the opening and closing of a 4-volt signal-circuit, which was completed through the meter supporting-bar. Instruments of that type were usually calibrated in still water, and were particularly accurate; as pointed out by the Author, velocities could be obtained accurately to within 0·001 metre per second. Apart from errors due to oblique currents, which would be Mr. Headland.

*Fig. 13.*




referred to later, the only inaccuracy which was liable to occur in practice was that due to the viscosity of the oil used, which might give rise to errors of up to 1 per cent. in the rate of rotation, the error increasing with the viscosity and decreasing with the speed of rotation, as shown in *Fig. 13.*

For velocities in excess of 1 foot per second the screw-type meter registered accurately near the walls of a pipe, but to get within 2·5 inches of the wall either a 4-inch propeller was used, or the standard 5-inch propeller was suitably shrouded, which would probably give rise to a slight error in the registration. A change of shape of the propeller by deformation during operation might affect the rating curve, and although no mention of that point was made in the

Mr. Headland. Paper, errors due to that cause could be detected by checking the shape of the screw against a plaster cast.

The Author had used two instruments in carrying out the tests, although a large number would have resulted in a saving of time and greater precision, because the results would have been less dependent on the existence of a steady flow. On the other hand, however, that would have involved the use of more adequate equipment, including an electric chronograph for recording time and current-meter signals on a chart. It was assumed that the Author had used a telephone or buzzer together with a stop-watch, and as the speed of rotation would not exceed 7 revolutions per second at maximum velocity that was probably satisfactory with contact-signal at every 10 or 20 revolutions, although the liability of personal error was not eliminated. The method of supporting the instruments during tests did not seem very satisfactory, and it would perhaps have been somewhat better to have used some rigid form of traversing gear with stream-lined rods, because high lateral stresses on light circular rods due to water flow might cause vibration of the mounting, which would result in the meter giving readings less than the actual flow.

The minimum number of measuring points for a pipe having an internal area of $A$ square feet was given by the relation $n = 4{\cdot}3\sqrt{A}$, which for the case under consideration gave 19, so that 21 points, as provided, should be adequate. Judging from the polar diagrams subsequently obtained it was possible that more accurate results would have been obtained if additional measurements had been taken towards the outside of the pipe where the greatest valuations in flow and maximum velocity existed, instead of utilizing an equal distribution of measuring points along the diagonal axes of the pipe.

The magnitude and nature of the error in approximating the total flow on the assumption that the velocities varied regularly as concentric circles was useful to know when making a rapid field-check on turbine-efficiency. In connexion with the other two analytical methods of arriving at the areas of the polar figures, it should be pointed out that, while those approximations agreed, they usually gave a somewhat higher result than the measurement of the actual area of the figures with a planimeter, in which case it might be possible that the values of $Q$ obtained with the Ott meter might agree more closely with those expected from the curve forecasting the jet-diameter $d$ and the formula $Q = 0{\cdot}97(\pi d^2/4)\sqrt{2gH_c}$ (p. 271 §). The known calibration of the jet based on experience and model-

§ Page numbers so marked refer to the Paper. (Journal Inst. C.E., vol. 5 (1936–37) (December, 1936).)—Acting Sec. Inst. C.E.

tests had served as a very useful guide to the accuracy of the Ott meter gaugings, and such a substantial check was unfortunately not usually available in efficiency-tests on other types of turbines. Mr. Headland.

A comparison of the results of the tests between the machines with clean and lime-encrusted buckets showed a possible loss of efficiency of up to 1 per cent., and illustrated how important it was to maintain the buckets in good condition.

The flow of water in the pipes as illustrated by the polar diagrams for No. 1 and No. 4 machines were such that the efficiency figures obtained might be expected to be optimistic. As pointed out by the Author, the conditions were similar to those obtained in the Arapuni turbine-tests (p. 280 §). In the latter case it was probable that the disturbance produced at the intake, which was practically at right angles to the flow in the headrace, together with the subsequent downward bend in the penstock, continued down the full length of the pipe. Such a disturbance might persist for more than thirty diameters, which in the case of the 12-foot diameter Arapuni penstocks would give a length of 360 feet, the approximate overall length being 450 feet. The location of the measuring instruments would, however, bring them into the zone of the disturbance produced at the intake. At Shanan, the Author stated that the diameter of the pipe was sufficiently small to provide retardation to any rotational movement which would eventually be damped out in a sufficiently long stretch of straight pipe, but the bifurcation, as well as the vertical and horizontal bends, together with the Johnson and butterfly valves in the pipe, would also bring the current-meters into the region where the disturbance produced by those items still existed.

As noted in paragraph (*c*) of the conclusions (p. 279 §), the existence of spiral flow would have an appreciable effect on the value of the velocity obtained, for, since the instruments were calibrated in still water, oblique or turbulent flow introduced certain errors which reduced the reliability of current-meter measurements. If the turbulence were not too pronounced the use of two instruments with different registration coefficients might be used as an index to the amount of correction to be applied to the more accurate of the two meters.

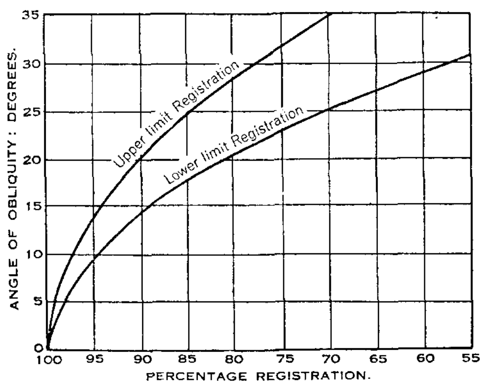
The Author had not indicated whether a two-bladed conical screw or the three-bladed cylindrical screw had been used during the tests. Whilst the former was self-cleaning, an advantage with lime-bearing water at Shanan, it gave less accurate results where oblique currents were involved. The shape of the screw, however, was not the most

§ *Ibid.*

Mr. Headland. important feature, and where steady oblique currents were known to exist it was advisable to allow the axis of the meter to swing in line with the flow and to make an accurate observation of the angle rather than to operate the meter crosswise to the current; the latter resulted in the propeller being struck at an oblique angle by streams whose velocity varied rapidly in magnitude and direction, and also involved a non-uniform distribution of the velocity-elements over the plane of the blades. In consequence current-meters definitely under-registered the forward components of oblique lateral and vertical currents, which were to a certain extent influenced by interference of the meter-supports.

In *Fig. 14* the range of possible error at the maximum velocity

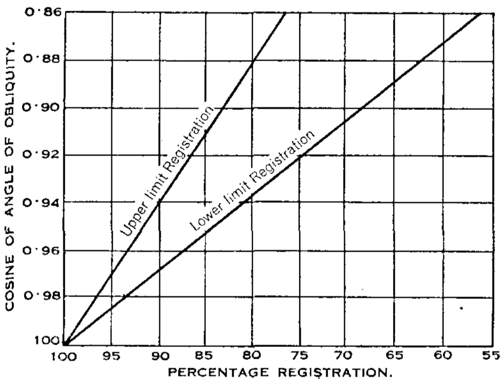
*Fig. 14.*




in the pipe was shown plotted against the angle of obliquity, whilst in *Fig. 15* those curves were shown with the cosine of the angle as ordinates. They were straight lines, indicating that the meters integrated correctly all cosine-components, independently of variations in the obliquity.

The unreliability of pitot-tube measurements under flow-conditions experienced in large pipes was now well recognized, but recently an instrument known as the "pitot-sphere" had been developed for which was claimed freedom from errors due to obliquity and turbulence. The measurement consisted of a comparison of the pressure distribution at five points on the surface of a 12-millimetre diameter sphere, from which the direction of flow, velocity, and static pressure could be calculated. The method had been used for pipes up to 600 millimetres in diameter, with satisfactory results compared with other methods of measurement. The instrument had the advantage of being simple to operate and inexpensive, and there seemed to be no reason why it should not be used with pipes of larger diameter. Mr. Headland.

*Fig. 15.*




The AUTHOR, in reply, observed that it was hardly practicable or permissible to go into details of the bucket design, concerning which Mr. Headland's comments were generally correct. Buckets of stainless steel had been adopted to obtain (*a*) great resistance to the usual wearing and corroding influences, and therefore sustained high efficiency over long periods, and (*b*) increased resistance to any incipient cavitation or cognate effects. After 4 years' operation on commercial load, it had been reported that the bucket-tips and splitting edges were as sharp as when installed, and that only the slightest signs of wear of any kind had been discernible anywhere, whilst the original polish had remained undiminished. The Author.

The current-meters at Shanan had been of the two-bladed conical-propeller type. It was believed that the rod carrying the propellers was amply stiff to prevent any vibration at the velocities measured; certainly no vibration of the rod could be detected by usual physical means. It was doubtful whether any increase in the number of measuring points within the area already covered would have affected the results. Additional points in the outermost annulus and next the skin, however, were most desirable, and would be valuable for checking the somewhat arbitrary value of the velocity accepted for the flow next the skin. The only practicable means for effecting that would appear to be the pitot-tube in one of its later and more reliable forms. The tendency to spiral flow at the metering station could not have been other than slight, and the angularity correspondingly small. Without some other equally reliable form of check-measurement, it was not possible to estimate what effect

The Author. such angularity as actually existed might have had on the accuracy of the velocity measurement. A reliable pitot-tube velocity-meter would be a great boon, and there seemed reason to expect that to become a practical reality of the near future. The Author had had no experience of the "pitot-sphere" referred to by Mr. Headland.