Comparative Flow-Measurement Tests at Finlarig Power Station

Simultaneous flow-measurement tests by several different methods were carried out at Finlarig power station under the auspices of the British Standards Institution, by courtesy of the North of Scotland Hydro-Electric Board. The tests are described and the results discussed

By S. P. HUTTON* and G. B. MURDOCH§

PART ONE

As readers may recently have seen references to comparative flow-measurement tests at Fätschbach in Switzerland, it may be of interest to describe some earlier tests of a similar nature which were carried out in Scotland, under the auspices of the British Standards Institution, in connection with the revision of the British Standard Test Code for hydraulic turbines.‡

It was decided by the committee concerned with redrafting the code that a simultaneous comparison of several different methods of flow measurement, to be included in the Code, would yield valuable background information. After studying several possible installations a suitable site was chosen, by kind permission of the North of Scotland Hydro-Electric Board, at Finlarig, the power station of the Lawers section of the Breadalbane development in Perthshire.

At the invitation of BSI Technical Committee MEE/125, Messrs. Merz and McLellan, the mechanical and electrical consultants for the Finlarig scheme, agreed to co-ordinate the planning and general organisation of the tests. Under this general organisation specialist groups were responsible for the way in which their particular method was applied, for installing their own apparatus, for carrying out testing and for the calculation of their results afterwards. Seven different methods were used simultaneously to measure the flow rate, while an eighth, the thermodynamic method, was used to measure turbine efficiency from which flow rate could be computed, making certain assumptions. This last method is not recognised as a method of flow measurement,

* Professor of Mechanical Engineering, University College, Cardiff.
§ Head of Hydro-Electric Department, Merz and McLellan, Newcastle upon Tyne.
‡ These tests were the subject of the Leading Editorial in WATER POWER, November 1958. Finlarig power station was described in our April 1959 issue, p. 141.

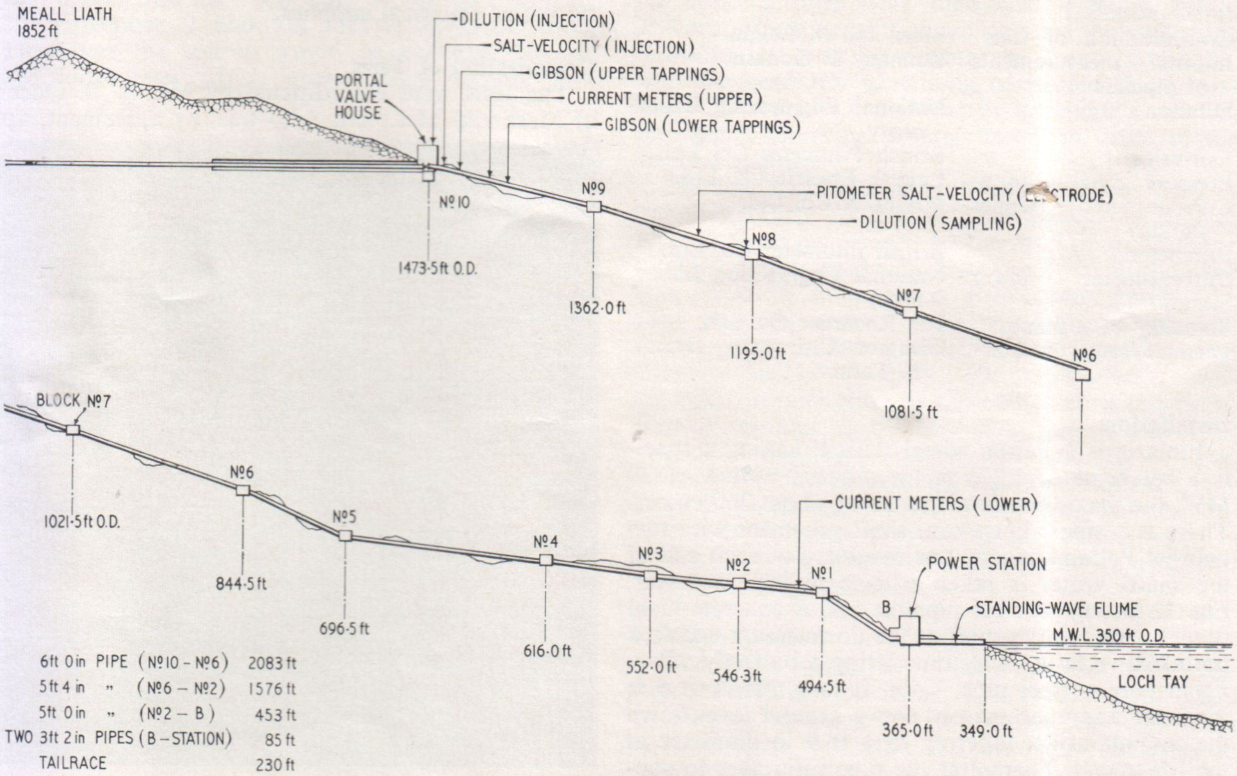

Fig. 1. Siting of test stations along the pipeline at Finlarig

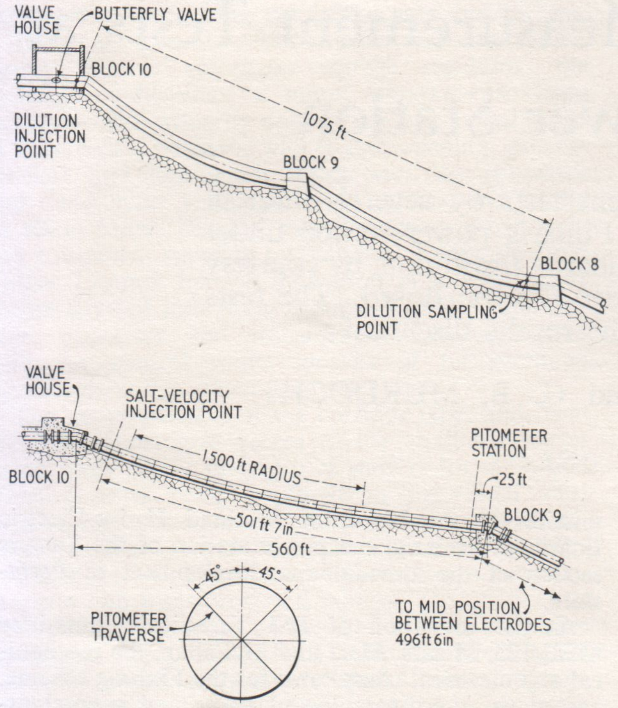

Fig. 2. Locations of dilution, pitometer and salt-velocity stations

although it is now accepted in the IEC water turbine test code as a method of efficiency measurement. The eight methods of flow measurement and the organisations responsible for carrying out these and the other measurements involved are listed below, the flow measurement methods being in the same order as the siting of the test stations along the pipeline in the direction of flow. This order is used for convenience throughout.

Co-ordination of tests	Merz and McLellan
Internal measurements of pipeline	Kennedy & Donkin
Dilution	National Engineering Laboratory
Salt-velocity	British Pitometer Co. Ltd.
Pressure time (Gibson)	English Electric Co. Ltd.
Current-meter (Upper station)	Boving & Co. Ltd.
Pitometer	British Pitometer Co. Ltd.
Current-meter (lower station)	National Engineering Laboratory
Standing-wave flume	Lea Recorder Co. Ltd.
Thermodynamic method	Glasgow University—Dr. A. S. Thom

Installation

Finlarig is a Pelton wheel station, having a specified net head of 1,275 ft for a rated output of 30 MW, the maximum flow rate being about 360 cusecs. There is a single horizontal-shaft generator with two twin-jet Pelton runners, one overhung at each end of the shaft. Water is taken from a storage reservoir, Fig. 1, through a steel pipeline and a concrete-lined tunnel with a surge shaft at the downstream end to a portal valve house accommodating a butterfly valve. From here a steel pipe, 4,400 ft long, starts at 6 ft diameter and runs mainly above ground level down the mountainside, tapering to 4 ft 9 in diameter at the lower end. Thereafter the pipe bifurcates to supply the two Pelton wheels.

Five of the flow-measurement stations were in the upper section of the 4,400-ft length of pipeline between blocks 10 and 8 (see Fig. 1). In order along the pipe, these were dilution, salt-velocity, pressure-time (Gibson), upper current-meter, and the pitometer method. The lower current-meter station was at the bottom end of the pipeline upstream of the power station, and finally the standing-wave flume was installed permanently in the tailrace. The thermodynamic apparatus sampled water from immediately upstream of the turbines and downstream in the tailrace.

Preparations for certain of the tests were made before the scheme was constructed. In other cases, to minimise drilling of the pipe, test stations were located, wherever possible, near manholes for which duplicated covers were made and provided with the necessary glands for cable and pressure connections. The original pipeline contractors, P. & W. McLellan Limited, undertook the installation of additional fixing supports and other modifications to the pipeline, under the supervision of the civil-engineering consultants, Messrs. James Williamson and Partners.

As, in general, accessibility was difficult and power supplies were only available at the portal valve house, most of the test stations were sited at the top end of the pipeline and served by the mountain road to the valve house. Because of the resulting concentration of apparatus, the sequence of installation had to be carefully planned in order to complete the operation in the minimum time. With carefully co-ordinated use of the necessary welding and ancillary equipment, the installation was completed in two weeks, the last day being severely interrupted by an electrical storm which cut off the power supplies to the valve house for two days. Although this had no significant effect on the final results, it inevitably reduced the time available to carry out trials and necessary adjustments for those groups depending on mains electrical supplies.

Organisation of Tests

The tests were co-ordinated by Mr. B. B. Queen of Merz and McLellan, who was, by agreement, ap-

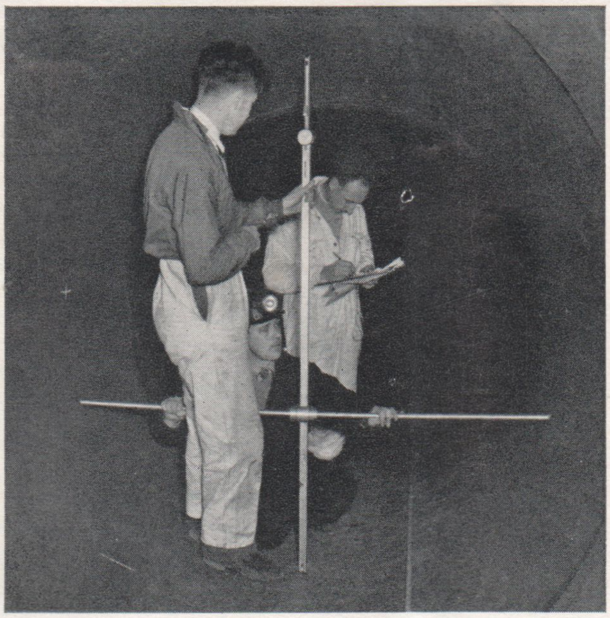

Fig. 3. Pin-gauge used in internal pipe survey

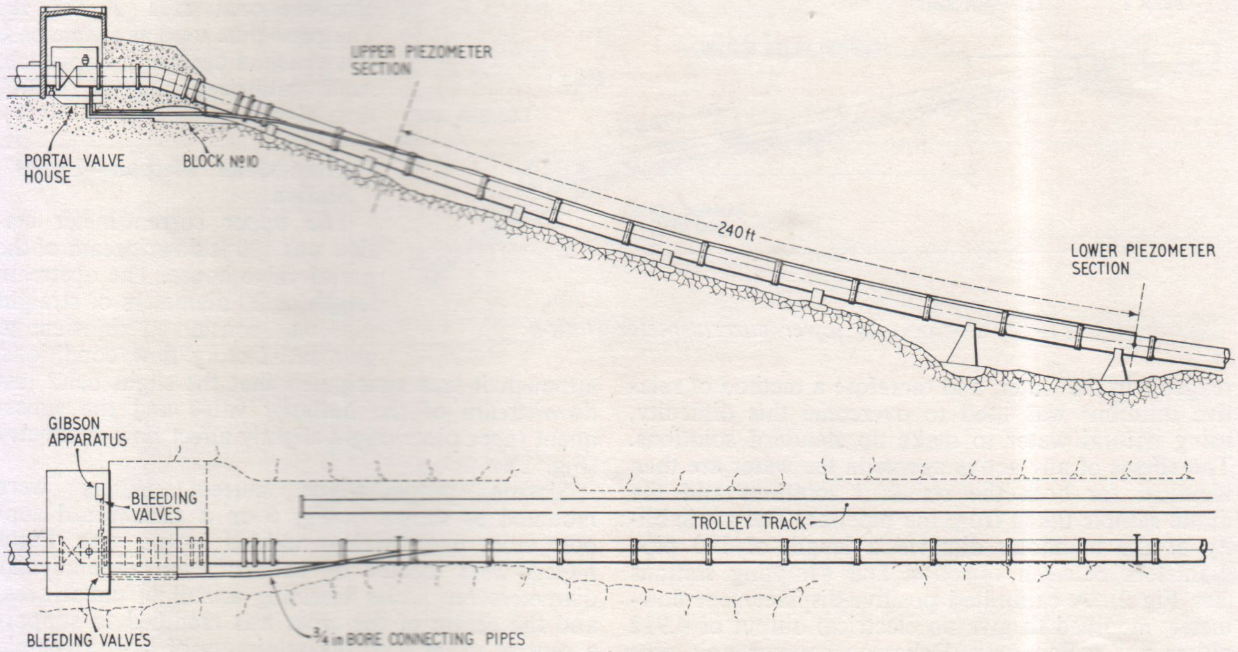

Fig. 4. Location of pressure tappings for Gibson tests

pointed Chief of Tests. His control point was set up in the power station and linked by telephone or bell signals to all groups. The daily test programme was decided on the previous evening and the necessary arrangements made with the Board's generation engineer and station charge engineers. Close collaboration was essential, because the test loads had to be within general grid requirements.

The overall programme of tests was that the first day (September 8, 1958) should be used for preliminary runs to ensure the satisfactory operation of the equipment. The main BSI tests would be completed on September 9 and 10, all teams participating. Thereafter the station would be available for any additional tests which teams might require until September 13, when dewatering the pipeline would start.

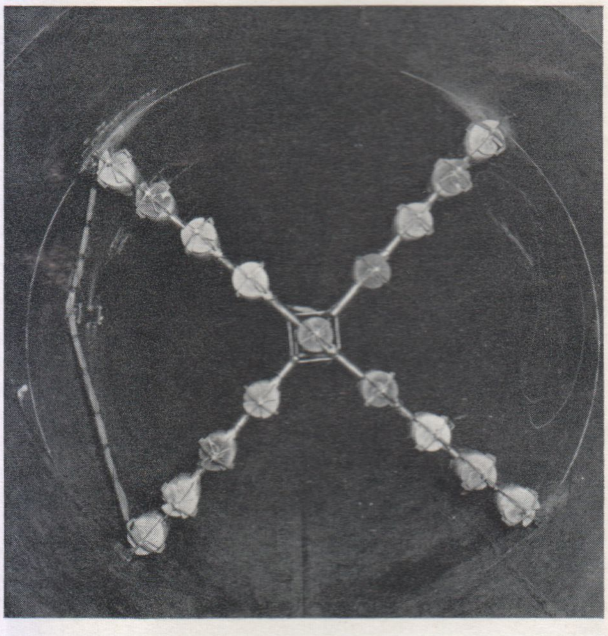

Fig. 5. Mounting of current meters at upper station

Experience showed that the complete cycle for a test comprising all methods was between 2½ and 3½ hours and that it was possible to carry out tests at three different flows during a day's testing. The larger flows were arranged to coincide with the system peak-load requirements, and load rejections were in preference made during falling load demands. The governor system was adjusted to give an output corresponding approximately to a preselected flow and the spear settings were then held constant within 0·1 mm. Turbine shut-down for the pressure-time (Gibson) test was by closing the spears gradually, with the generator remaining connected to the system. Closure was completed in less than a minute, the spears returning usually to within 0·1% of the original settings.

The first half-hour of each test cycle was used to establish steady conditions. The duration of a complete test was determined by the need to separate the dilution and salt-velocity tests, because of chemical and electrical interference. Run consecutively, the total time required for these two methods was adequate for all the other measurements apart from the Gibson method, which, for convenience, was arranged to take place at the end of each test cycle. Repeat readings at a steady flow were taken of all methods whenever possible throughout the test. Three Gibson measurements were made at each flow rate, necessitating a wait of about thirty minutes between the first, second and third load reductions.

The various methods of flow measurement will now be briefly described.

Dilution Method

The basic principle of this method has been described fully elsewhere.[1] The chemical salt used at Finlarig was sodium dichromate, the chromium radical being detectable by volumetric analysis in concentrations as low as 3 parts per million. Although otherwise satisfactory, it may be reduced by

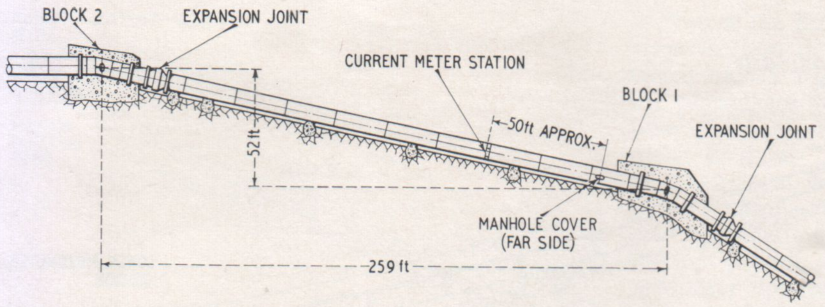

Fig. 6. Position of lower current-meter station

reagents in the water, and therefore a method of relative dilution[2] was used to overcome this difficulty, using natural water to make up standard solutions. The effects of any active agents in the water are then identical for both the standard solutions and the dilute sample taken from the pipeline. The availability of the manholes dictated a length of 180 pipe diameters between injection and sampling stations (see Fig 2). A calibrated positive-displacement flowmeter, modified to give an electrical output of 4,912 pulses per gallon on a Dekatron counter unit, was used to measure the injection flow rate. Its calibration curve has an expected accuracy of better than $\pm 0{\cdot}25\%$. The injection and sampling arrangements are shown in Fig. 2, ten samples being taken during each test run every 20 sec and at least two test runs being made for each flow during the six main BSI tests.

Salt-Velocity Method

The original Allen salt-velocity method is well known.[3] The technique used commercially by the British Pitometer Co. Ltd. is similar in principle although it differs in detail from the considerably refined method now used by Hooper[4] in the USA. Because the test length at Finlarig was considered adequate the salt-velocity apparatus utilised a single electrode, the moment of injection being recorded by the closing of electrical contacts on the main injection valve. The injection and sampling points were arranged as shown in Fig. 2. The time base on the recording chart was from a two-second contact actuated by a one-second pendulum. The internal dimensions of the pipes were accurately checked with specially made measuring jigs (Fig. 3).

The Pressure-Time (Gibson) Method

A commercial Gibson apparatus was used[5, 6]. Manometer connections to the $\frac{3}{8}$-in square pressure tappings in the pipe wall were in $\frac{3}{4}$-in solid-drawn steel tube, the arrangement being as shown in Fig. 4. Once steady conditions had been achieved, the turbine spears were closed in about 53 sec and kept shut until a sufficiently long recording of pressure fluctuations had been obtained. Turbine leakage, which could not be measured during the tests, was determined from volumetric measurements in the tailrace with the turbines at a standstill.

The 240-ft test length was chosen assuming that the closure time would be 43 sec. In fact, it was 53 sec and a $1\frac{1}{2}$-in riser therefore had to be inserted in the second leg of the manometer. The pipe-factor (8·858) was determined from measurements made during the internal survey of the pipe, which gave the test length as 242 ft 4·7 in and the average cross-sectional area 27·365 ft^2. The pendulum used as a time base was checked against a stopwatch, itself calibrated against B.B.C. time signals.

Current-Meter Method—Upper Station

The upper current-meter station was 120 ft downstream of the portal valve house. The upstream length of 20 diameters of straight pipe was considered sufficient to give satisfactory flow conditions, although it was anticipated that the slight bend just downstream of the butterfly valve and the subsequent taper piece might slightly affect flow symmetry (Fig. 2).

Sixteen propeller-type current meters were mounted as shown in Fig 5 on a streamlined support cross fixed to lugs welded in the pipe. Eight meters were located on each of two perpendicular diameters on circles bisecting annuli of equal area, and the centre of the cross was modified to support a central meter with the minimum of hydrodynamic interference. The meters were a modified marine type manufactured specially for the North of Scotland Hydro-Electric Board by Kelvin and Hughes Limited. As they had water-lubricated bearings and sealed contacts driven remotely by a magnetic coupling, they were unaffected by prolonged immersion in water.

A twenty twin-core telephone cable with heavy polyvinyl-chloride insulation was used to connect the meters to the five-high-speed spark-type chart recording units. Three of the twin-cores were used as a common return to minimise the resistance of each current-meter circuit. The main cable was taken through a watertight gland in the pipewall.

The cross-sectional area of the pipe in the plane of the current meter was obtained from measurements of 18 diameters, which showed the pipe to be very slightly elliptical with major and minor axes of 71·33 and 70·58 in. The cross-sectional area was

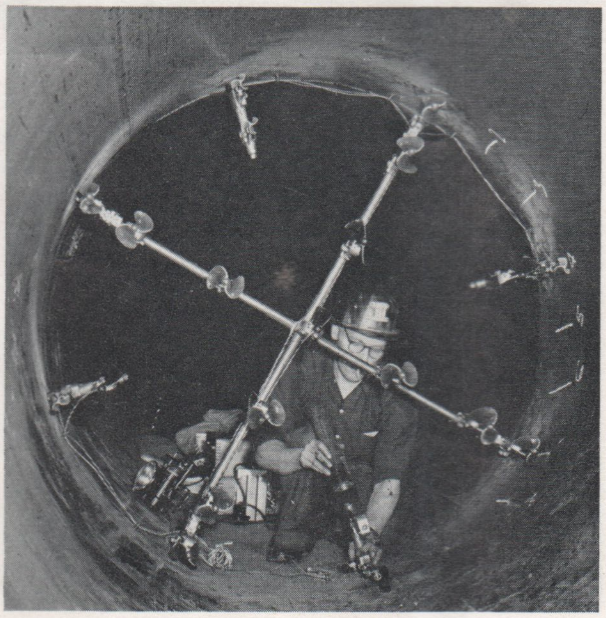

Fig. 7. Current meters mounted at lower station

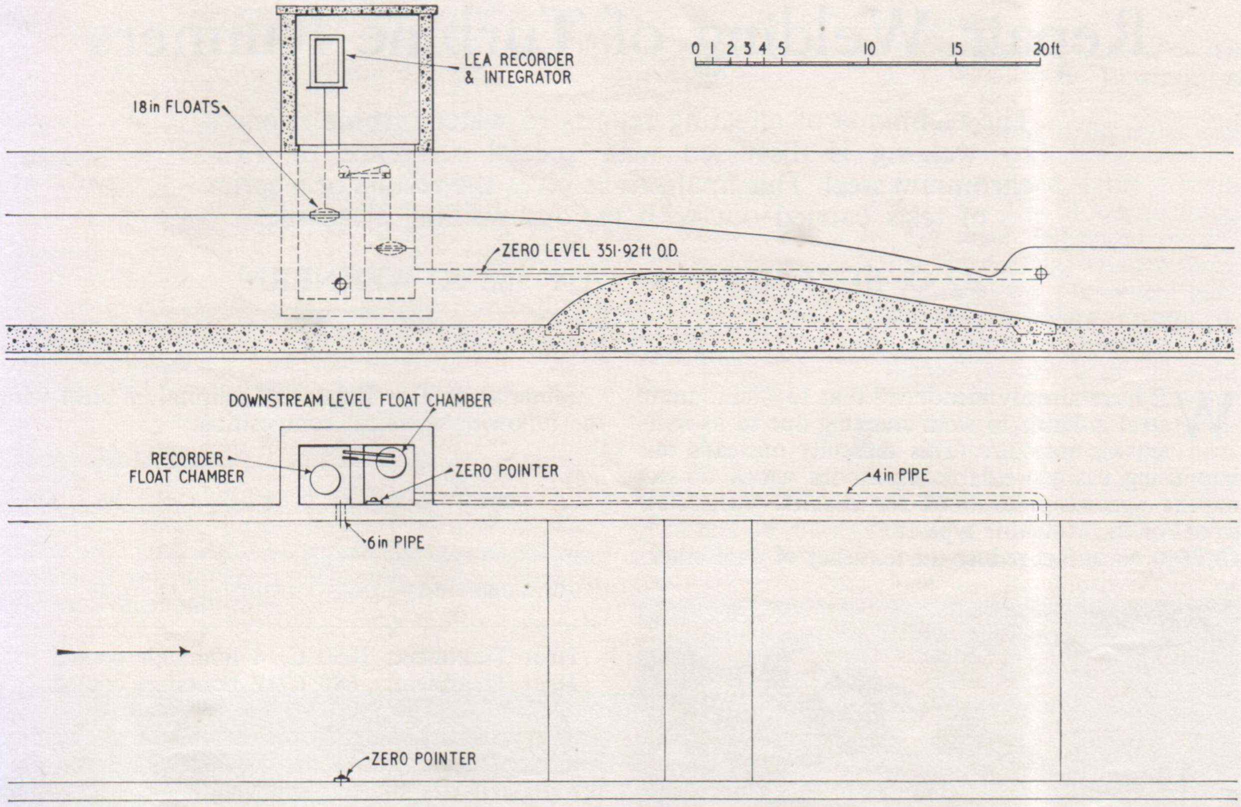

Fig. 8. Standing-wave flume in the tailrace channel

therefore based on a mean diameter of 70·85 in.

During each test series up to four measurements of flow were made, one just after steady conditions had been obtained and one a little before the Gibson test at the end of each series. The method of evaluation was in accordance with the Swiss Rules for Water Turbine Tests,[7] the mean velocity being obtained by graphical integration across the pipe. The individual velocities were obtained by converting the pulse-count rates on the recording charts to feet per second by means of calibrations which had been made in 1950/51 at the National Physical Laboratory towing tank.

Pitometer Method

A commercial design of pitometer was used incorporating a forward-facing hole and static-pressure holes, connected to a differential manometer. The lengths of straight pipe upstream and downstream of the gauging section were 22 and 4 pipe diameters respectively. The remainder of the pipeline upstream to the portal valve consisted of about 65 pipe diameters set at a gentle curvature of 1,500 ft radius (Fig. 2). Two U-tube manometers, one containing carbon tetrachloride and the other tetrabromethane, were used, the former for low flow rates, the density of the two fluids being checked constantly. Some damping of pressure fluctuations was necessary by means of pinch-cocks. To determine the velocity distribution, the mean velocity and the pipe factor as described in the British Standard Code,[8] five traverses each of 20 readings were taken on two diameters, covering the range of flows, together with one centre reading on the pipe axis. During the BSI tests, only a centre-velocity reading was taken.

Current-Meter Method—Lower Station

The current meters used at the lower measuring point were standard Ott propeller-type meters (Models Texas—V, 80 and 100 mm diameter), recording on a specially designed digital form of electrical counter. The number of meters installed was based on the new NEL technique of pipeflow integration,[9] which is now being widely used in Europe in preference to the standard methods. The advantages are the use of fewer meters to give the same accuracy, only six meters on each of two diameters at right angles being necessary at Finlarig. The meters were calibrated before and after the tests in a towing tank. All electrical cables were taken out through a specially modified manhole cover nearby. The lower current-meter station was situated so as to give an adequate straight length of pipe upstream (180 ft, Fig. 6), and also a high operating pressure in order to study the performance of the meters under such exacting conditions. The mean diameter was determined at the gauging section from 24 measurements round the pipe, the maximum variation being 0·6 in (1·5 mm) in an average of 57·25 in (1,453·9 mm).

For additional interest, four groups of two meters (50 and 125 mm diameter) were mounted intermediate to the main supports (see Fig. 7) in order to study the velocity distribution near to the wall of the pipe. The recording equipment is described elsewhere,[10] the shortest recording period being 200 sec and the longest, at the low flow rates, 700 sec. The meters were recording constantly and were also used to verify when steady-flow conditions had been reached and the main test could begin.

(Continued on page 404)