PERFORMANCE TESTING OF THE ST. LAWRENCE POWER PROJECT USING CURRENT METERS

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1   ABSTRACT

The St. Lawrence Power Project is an international hydroelectric power plant located on the St. Lawrence River, which flows from the Great Lakes to the Atlantic Ocean.

The St. Lawrence Power Project consists of several dams, including an international power dam between U.S. and Canada. Construction of the Power Dam began in 1958 and consists of 32 total generating units, with 16 units on each of the U.S. and Canadian sides of the border. In the entire power plant, there are a total of 5 turbine types (2 types on the U.S side and 3 types in the Canadian side).

The St. Lawrence River flow is shared equally between U.S. and Canada. The New York Power Authority owns and operates the U.S. side of the power project and Ontario Power Generation owns and operates the Canadian side.

Both companies are upgrading the generating units for higher efficiency and for higher output to maximize the utilization of the water resource and to make better use of high flow periods.

Historically, both utilities agreed to utilize the same methods of measuring unit flow through the generating units in order to establish equal sharing of river flows.

An analysis was undertaken to select the best-suited performance test methodology to measure the turbine/unit efficiency. The analysis consisted of a comparison between the different test methodologies and their applicability to the unit configuration; conformance the IEC-41 and ASME PTC 18 test codes; and the test cost. From this comparison, the Velocity Area Method using the current meters in the unit intake was selected. Initially, the generating units were tested in 1958 to 1961 using the Gibson method.

In 1992 to 1995, the Intake Current-Meter System (ICMS) was selected to carry out the turbine/unit performance testing and to measure the unit flows, which consists of a site-specific intake current meter system developed and used to test all generating units. The intake current meter frame and the current meters were all calibrated in a tow tank facility before and after the field testing. A test procedure was developed and a statistical sample of 25 % of each type of unit was tested.

This presentation describes the flow measurement technique (intake current meter system-ICMS), test set-up, test methods, test equipment and instrumentation and the results achieved. The final results will be used in new operating rating tables for both utilities to accurately determine the split of river flows.

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2   HISTORICAL BACKGROUND

The St. Lawrence Power Project and the power dam were constructed in the late 1950s between Massena, New York, USA and Cornwall, Ontario, Canada. The construction was a joint project between New York Power Authority (NYPA) and Ontario Power Generation Inc. (OPG) previously known as Ontario Hydro.

The Robert Moses Power Dam and the Robert H. Saunders Power Dam consist of 32 turbine-generating units, 16 units on the United States side of the border and 16 units on the Canadian side of the border. The St. Lawrence River flow available for power generation is shared equally between the two power entities. The International St. Lawrence River Board of Control has the controlling authority over the water management of the river. The outflow from the power project is determined on a weekly basis by representatives of the St. Lawrence Board. Based on the outflow, the power entities manage their share of the water to operate the turbines for electricity production.

Three types of turbines were initially installed at the Moses and Saunders power dams: two manufacturers of eight turbines each at the NYPA's Moses power plant (Allis-Chalmers and Baldwin-Lima-Hamilton); and one set of rating tables at OPG's Saunders power plant (English Electric). During the unit commissioning in the late 1950s/early 1960s, representative units of each turbine type were field tested to determine the actual installed turbine and unit performance. Average performance characteristics were then developed from the field tests for each turbine type. In 1961 the utilities issued a comprehensive report to the St. Lawrence Board detailing the unit performance test results based upon the Gibson method of flow measurement.

 At OPG's Saunders station, 12 of the turbines were upgraded to a Sulzer turbine design and one of the original English Electric turbines had its propeller blade angle modified from 21.5 degrees to 23.5 degrees. Subsequently in 2000, a revised comprehensive report for 5 types of turbines (OPG's 3 types of turbines and NYPA's 2 types of turbines) was submitted to the St. Lawrence Board detailing the revised unit performance based upon the current meter method of flow measurement.

3   DESCRIPTION OF WATER SUPPLY PASSAGES AND TURBINE RATING

Thirty-two fixed-blade propeller type turbines are installed; sixteen in the Canadian portion of the powerhouse and sixteen in the United States portion. The water supply passages to each turbine consist of three short rectangular reinforced concrete supply intakes and a reinforced concrete semi-spiral casing. Each supply intake is approximately 21 m (70 ft) in length, 5 m (17 ft) wide, and converges from a height of 18.75 m (61.5ft) to 8.25 m (27 ft) at its downstream end. (Figure 1)

The units operate at normal rated head of 25 m (82 ft) and the head varies from minimum of 22 m (72 ft) to maximum 27.4 m (90 ft). The total flow varies from 8,400 m^3/sec (300,000 ft^3/sec) to 10,200 m^3/sec (360,000 ft^3/sec). Total output varies from 1,600 MW to 2,000 MW.

4   REVIEW OF POSSIBLE TEST METHODS OF FLOW MEASUREMENT

The following selection criteria for the appropriate test method was established:

1. Expected accuracy
2. International test code acceptance
3. Suitability of unit geometry (test code requirement relative to actual unit configuration)
4. Economical factors (Unit outage, test set-up cost, test cost, and test equipment removal)
5. The safe operation of the unit.

All test methods that are recognized by the test codes were considered and the test requirements were compared to the unit configuration. These test methods are:

NO.	TEST METHOD	TEST CODE
1	Current-Meter	IEC-41 and ASME PTC-18
2	Pressure Time Method (Gibson)	IEC-41 and ASME PTC-18
3	Cole Reversible Pitometer	ASME PTC-18
4	Pitot-Static Tube	IEC-41 and ASME PTC-18
5	Pitot-Static Tube	ASME PTC-18
6	Pitot Rake	ASME PTC-18
7	Tracer Method Salt Velocity (Transit Time Method)	IEC-41 and ASME PTC-18
8	Tracer Method Dilution (Constant –Rate-Injection Method)	IEC-41
9	Ultrasonic Method	IEC-41 and ASME PTC-18
10	Standard Differential Pressure Device (Venturi Meter Method)	IEC-41 and ASME PTC-18
11	Weir Method	IEC-41 and ASME PTC-18
12	Volumetric Method	IEC-41
13	Thermodynamic Method	IEC-41
14	Model Test	

The Current-Meter and the Pressure Time Methods were selected for more in-depth comparison. All other test methods were eliminated from consideration because of many unacceptable conditions such as high uncertainty, unit configuration (short and multiple water passages) and very high cost of test set-up.

4.1   PRESSURE TIME METHOD (GIBSON) REQUIREMENTS

A detailed evaluation of the Test Code requirements for the Pressure Time Method (Gibson Method) was undertaken. In particular, Test Code conformance of the Pressure Time Method's requirements for the actual unit configuration was reviewed as summarized below in Table 1.

TABLE 1 PRESSURE TIME METHOD REQUIREMENTS					
ITEM	**TEST CODES REQUIREMENTS**	**IEC-41**	**PTC -18**	**ACTUAL UNIT CONFIGURATION**	**CONFORMITY**
1 Free surface	No intermediate free surface shall exist between the two pressure measurement section	10.4.2.1.a	4.88	The headgate slot and the stoplog slot opening are both in between the upper set of piezometer taps and the lower set of piezometer taps. In order to conform to this requirement the headgates and the stoplogs should be removed and both opening should be sealed by installing a solid temporary roof.	No
2 Leakage	The leakage through the closed gates in the test conditions shall not be greater than (5 % IEC) and (2 % ASME) of the discharge	10.4.2.1.b	4.90		Yes
3 Multiple Intake	In the Multiple intake sections, simultaneous independent pressure-time recordings shall be taken	10.4.2.1.c	4.89	3 Instruments are required (3 Intakes)	Difficult
4 Length Between Measuring Sections	The Distance between the two measuring sections shall not less than 10 m (33 ft) or twice the internal diameter of the conduit	10.4.2.1.d	4.89	Average Distance between measuring sections 13.25 m (43. 5 ft) The Intake shape is not circular but irregular rectangular shape with an average between height and width of 42.25 ft	Yes
5 Length x Flow Velocity	The minimal condition for the use of this method is that the product of (L) and (v) shall not be less than 46.5 where (L) is the length between the two pressure measurement sections in meters and (v) is the mean velocity in the test section in m/sec when the turbine is carrying full load. {500 where (L) in ft and (v) in ft/sec}	10.4.3.1	4.89	Average Length = 12.88 m (42.25ft) Average Flow Velocity = 2.5 m/sec (8.2 ft/sec) L x v = 32.2 m^2/sec L x v = 346.5 ft^2/sec	No
6 Cross Section Regularity	Within the measuring reach the conduit shall be straight and have a constant cross section and not present any significant irregularity.	10.4.2.1.d	4.88	The configuration between the upper and lower measuring sections is converging in an irregular shape.	No

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4.2   VELOCITY AREA (CURRENT-METER) METHOD REQUIREMENTS

A detailed evaluation of the Test Code requirements for the Velocity Area (Current-Meter) Method was similarly undertaken. Table 2 summarizes the conformance of the Test Codes requirements for the actual unit configuration.

TABLE 2 VELOCITY AREA (CURRENT-METER) METHOD REQUIREMENTS					
ITEM	**TEST CODES REQUIREMENTS**	**IEC-41**	**PTC -18**	**ACTUAL UNIT CONFIGURATION**	**CONFORMITY**
1 Duration of Measurement	Measurements for each current-meter position shall be at least 2 minutes	10.2.2.1	4.42	Measurement is carried out for 2 minutes each	Yes
2 Number of measuring points	At least 25 measuring points in a rectangular or trapezoidal section. If the velocity distribution is likely to be non uniform, the number of measuring points, (Z), shall be determined from $24*(A)^{1/3} < Z < 36*(A)^{1/3}$ A = Area of measuring section in m^2	10.2.2.2		Each Intake Area = 78.1 m^2 Number of point measurement per Intake = 11x 21 = 231 Minimum Code Requirement = 103 Maximum Code Requirement = 154	Yes
3 Multiple Intake	If the conduit or channel is divided into several sections, measurements shall be made simultaneously in all sections	10.2.2.2		Three Current-meter frames, one per each Intake were used	Yes
4 Types and general requirements of Current-Meters	1. Only propeller-type 2. Electrical Impulse with counting and recording devices 3. Current-Meter shall satisfy ISO 2537 4. All meters be able to withstand water pressure 5. Current-Meter propeller shall be not less than 100 mm diameter 6. Distance from the trailing edge of the propeller to the leading edge of the mounting rod shall be at least 150 mm 7. Self Compensating propellers which measure directly the axial component of the velocity	10.4.2.1.d	4.89		Yes to each item

TABLE 2 VELOCITY AREA (CURRENT-METER) METHOD REQUIREMENTS					
ITEM	TEST CODES REQUIREMENTS	IEC-41	PTC -18	ACTUAL UNIT CONFIGURATION	CONFORMITY
5 Calibration of Current-Meters	1. All current-meters shall be calibrated in accordance with ISO 3455 2. The current-meters shall be calibrated with the same type of mounting and mounting rods as that used during the test	10.2.2.4	4.45	Current-meters are calibrated regularly	Yes
6 Measurement in short penstocks and intake structures	ISO 3354 may be used as a guide	10.2.4.1		ISO 3354 is applied	Yes
7 Measurement in converging flow	Self Compensating propellers are best suited for this method	10.2.4.3		Self Compensating current-meters are used	Yes
8 Direct Integration method	This method is described in 7.2.2 and 7.3.2 of ISO 3354	10.2.4.4			Yes

5 SELECTION OF THE INTAKE CURRENT METER SYSTEM (ICMS) TO MEASURE TURBINE FLOW

In the report, "A Brief to the St. Lawrence River Joint Board of Engineers, Proposed Methods of Measuring Flow Through Turbines of the St. Lawrence Power Project, May 1957", ten methods of measuring flow were investigated. The report concluded that only two methods are suitable for flow measurement at the Moses/Saunders power plant, namely, the Gibson method and current meter method.

The Gibson method (pressure-time method) was used in the initial rating tests at the St. Lawrence Project due to technical limitations in accommodating the current-meter method in the 1950s. The Gibson test has limitations such as non-uniform geometry, sealing the headgate slots, sealing the emergency stoplog openings, and generating safely during the load-rejection phases of the test without headgate protection. Performing the Gibson test today would also require significant outage time and scaffolding set-up in the intake area which would add significantly to the cost of the Gibson test.

A re-evaluation of the suitability and accuracy of the Gibson and current meter test methods was conducted by the power entities in the early 1990s. A summary of this analysis is shown in Tables 1 and 2 of this paper. It was determined that the Intake Current Meter System (ICMS) of measuring unit flow would be the most accurate and repeatable method to measure flow according to international standards for all field performance tests at Moses/Saunders (see IEC, ISO and ASME test codes).

The use of the Intake Current Meter System to measure flow required testing existing and upgraded turbines at both the Moses and Saunders power plants so that the rating tables would be based on the same test methods.

OPG and NYPA agreed that the ICMS system, which uses a grid of propeller meters to cover the entire intake area (see Figure 2), would yield more accurate results using today's technology in data acquisition and data analysis, as well as allowing the performance of the field tests with limited interruption of operations.

Measuring the flow accurately is of paramount importance for the determination of the proper division of water between the United States and Canada, and to provide a method for measuring the flow in the St. Lawrence River.

The Intake Velocity Area Method by the Current-Meter using the Intake Current-Meter System (ICMS) was selected for measuring flow on the following basis:

1. The expected test accuracy ($\pm$1.75%) is acceptable and it is economical relative to other alternative test methods.
2. The velocity area method using the intake current meter system in the unit intake is approved by the International Test Code IEC-41 test code (see Table 2) and is suitable for the unit configuration (see Figure 1).
3. Suitability of unit geometry (test code requirement relative to actual unit configuration)
4. Economical factors (Unit outage, test set-up cost, test cost, and test equipment removal)
5. The unit can operate safely while testing them unlike the Pressure Time method where the headgates and the stoplog openings will be sealed.

6   FIELD UNIT PERFORMANCE TESTS

The Intake Current Meter System was selected by OPG/NYPA as the most accurate method of measuring flow on the turbine-generating units at the Moses/Saunders power plant. The method utilizes current meters to integrate the velocity profile across the entire intake cross sectional area. Details of the velocity area method are shown in Section 7.

Representative units of each of the five turbine designs were tested to determine the field performance data, including unit flow, unit efficiency and unit output for all possible operating wicket gate openings. The test parameters, instrumentation, head loss curves and generator loss data are described herein.

6.1   Field Performance Test Program on OPG and NYPA Generating Units

The objective of the program was to conduct sufficient field tests on each of the five turbine types to yield a representative average performance curve on which to base the new rating tables. The field performance tests involve measurement of key parameters, including generator output, discharge, wicket gate opening, gross head, net head and differential pressure across the Winter-Kennedy piezometer taps installed in the scroll case of each unit.

Tests were carried out on the following units, which represent each of the five sets of turbines:

1. English Electric with a 21.5 degree blade angle (Saunders pre-upgrade Units 1, 2, 12)
2. English Electric with a 23.5 degree blade angle (Saunders pre-upgrade Unit 3)
3. Sulzer (Saunders post-upgrade Units 1, 3, 7, 14)
4. Allis-Chalmers (Moses Units 20, 28)
5. Baldwin-Lima-Hamilton (Moses Units 22, 26, 29).

The performance tests were carried out in accordance with International Standard IEC 41 third edition dated 1991 and ASME PTC 18, and ISO 3354. The tests were carried out for each unit using the same test

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methodology, the same test procedure, the same test equipment, the same test instruments and the same test team.

The unit efficiency performance results of the tests for the five turbine types are shown in Figures 7 and 8. A comparison of the average curve for each type of turbine is shown in Figure 9.

7   VELOCITY AREA METHOD USING THE INTAKE CURRENT METER SYSTEM (ICMS)

7.1   TEST PROCEDURE

Site inspection was carried out before the field test. The piezometers used for the test were flushed to ensure they were clear of any obstructions. Piezometers used during the test were periodically flushed to eliminate any trapped air.

Temporary stilling wells were installed to measure the static water level of the unit headwater and tailwater. The wells were made of 2.0 inch diameter steel pipes and were sealed at the bottom with the exception of a 0.1875 inch diameter hole. The wells were fixed to the concrete wall. Temporary benchmarks were established on the top of each well. One well was installed in each intake, while two wells were installed in each tailrace.

With the exception of power and flow velocity, all instruments were calibrated on site prior to the start of the test. The power meter and current meters were calibrated off-site.

The test was conducted without the trashracks. The trashracks were removed in 1982.

The performance test consisted of 35 to 40 test runs covering a range of wicket gate openings from 20% (speed-no-load) to 100 % of full servomotor stroke. Turbine flow was measured and computed using the Velocity-Area method and employed the Intake Current Meter System.

The test runs were made at 90-minute intervals. At the beginning of each run the wicket gates were set at a fixed opening. About 5 minutes were allowed for conditions to stabilize.

During the remaining 85 minutes, the data acquisition system measured all parameters simultaneously at a rate of 100 scans/minute. The three intakes were tested simultaneously with three intake current meter frames. Each horizontal level was tested for two minutes with eleven current meters. Saunders was tested at 21 levels and Moses was tested at 22 levels. Velocities were measured simultaneously in each intake at each of the horizontal measuring profiles or levels. Including velocity, the following parameters were measured using the data acquisition system:
- Station headwater elevation (Moses and Saunders)
- Unit headwater elevation
- Station tailwater elevation (Moses and Saunders)
- Unit tailwater elevation
- International tailwater elevation
- Pressure elevation at the scroll case entry
- Pressure elevation at the lower Gibson ring
- Scroll case differential pressure (Winter-Kennedy)
- Generator output
- Servomotor stroke

7.2   Turbine Flow

7.2.1   Velocity Area Method

Turbine flow was measured by the Velocity Area Method using the Intake Current Meter System as follows:

Flow = Average Flow Velocity x Area.

The average flow velocity was determined by measuring the velocity profile using the Intake Current Meter System (ICMS). The ICMS consists of several current meters mounted and spaced across a supporting frame. (See Figures 2, 3, 4). The frame is raised and lowered in the stoplog openings of the unit intakes while the unit is operating at steady state conditions (e.g. – constant wicket gate opening and head). The current meters measure the point velocities at pre-determined positions along each horizontal level or profile. The velocity profiles and the average velocity at each level were calculated horizontally using a numerical integration technique in accordance with the test code, ISO 3354. Using these horizontal averages, the average vertical velocity was calculated by the same numerical integration technique, resulting in the overall average velocity of the intake.

Number of measuring points per horizontal profile	=	11
Number of horizontal measuring profiles	=	22
Number of measuring points per intake	=	242
Number of intakes	=	3
Total Number of measuring points	=	726

The current meters were 100 mm diameter, component propeller Type A Ott meters. Two models were used during the test, V-Arkansas and C-31. The meters are suitable for axial and oblique flow up to 45 degrees (see Figures 5, 6).

All instruments were selected to be of high precision and accuracy. All instruments were calibrated on site prior to each test and critical instruments were calibrated after each test at regular intervals for axial and oblique flow conditions. Current meters were calibrated before and after the tests by an independent laboratory (Environment Canada – Canada Centre for Inland Waterways CCIW). The entire current meter frame was also calibrated at CCIW's tow tank facility to accurately determine the frame blockage factors used in calculating flow. The frame blockage factor consisted of a local and a proximity component and was consistently applied to all units tested for parity.

The field metering section width and height were obtained from construction drawings. The dimensions were checked on-site before the test. The elevation of the bottom of the intake was checked by measuring the distance from the headworks deck to the intake bottom. The intake width was checked by measuring the open width at the headworks deck. These values were used to calculated the cross-sectional area of the metering section (see Figure 1).

7.3   Calculation of Head

All headwater elevations used to calculate head were referenced to Benchmark Moses. Benchmark Moses is located on the third floor landing (one floor below the Headworks entrance), International Great Lakes Datum 1985 (IGLD 1985).

All tailwater elevations for were referenced to Benchmark Power.   Benchmark Power is located on the tailrace deck by the erection bay, (IGLD 1985).

A temporary benchmark was established at the scroll case entrance measuring station (net head) using closed loop instrumental levelling from the reference benchmark Power (IGLD 1985).

Any additional temporary benchmarks and measuring points were established using closed loop instrumental levelling from the reference benchmarks.

Prior to and immediately following each test, the elevations of the zeros of all headwater and tailwater gauges were determined by running a level run to known power plant benchmarks. Headwater (forebay) measurements were made using precision pressure transducers installed in gauge wells on individual unit intake piers and at the Moses and Saunders station intake gauge wells. Tailwater elevations were similarly measured at the unit tailwater, Moses and Saunders power plants, as well as the International tailwater at the centerline of the Moses/Saunders power plant. Scroll case differential pressure was measured at the Winter Kennedy taps on each unit for the purpose of relative flow measurements (index tests).

The gross head is the head that is used for the rating tables. The gross head equals station headwater minus the average of the station tailwater and the international tailwater.

To convert from the net effective head upon which the turbine manufacturers' model test curves are based, the head loss due to friction between the forebay and scroll case entry and the residual velocity head in the tailrace were established. The friction loss between the forebay and scroll case entry was derived from field measured values on all units tested at Moses/Saunders. The residual velocity head in the tailrace was computed from the cross-sectional area of the tailrace immediately downstream from the draft tube of each unit and the discharge through the unit.

7.4   Headwater Elevation

7.4.1   Station Headwater Elevation (St. Lawrence)

Station headwater level (to determine gross head) was measured by a linear depth pressure transducer installed in the permanent headwater gauge stilling well. (Figure 1).

7.4.2   Unit Headwater Elevation

Four linear depth pressure transducers installed in four separate temporary stilling wells measured unit headwater level. Three temporary stilling wells were located in the emergency stoplog gain slots of each intake. The fourth temporary stilling well was located on the nose of the pier between intakes.

7.5   Pressure Elevation at Scroll Case Entry

The pressure elevation (to determine net head) at the scroll case entry was measured using a linear pressure transducer. The transducer was connected to the manifolded piezometers at the scroll case entry.

7.6   Tailwater Elevation

7.6.1   Station Tailwater Elevation

The station tailwater elevation (to determine gross head) was measured by a linear depth pressure transducer located in the permanent station tailwater gauge stilling well. The stilling well is a 12 inch pipe (see Figure 1).

7.6.2   Unit Tailwater Elevation

The unit tailwater elevation (to determine net head) was measured by two linear depth pressure transducers placed in two temporary stilling wells. The wells were located on the east and the west side of stoplog openings of the draft tube exit on the tailrace deck (see Figure 1 for details).

7.6.3   International Tailwater Elevation

The international tailwater elevation (to determine gross head) was measured using a linear depth pressure transducer located in the permanent station tailwater gauge stilling well. The stilling well is a 12 inch pipe located on the operating floor in the middle of the power house.

7.7   Lower Gibson Pressure

The pressure elevation (as a backup for net head) at the lower Gibson ring was measured using a linear pressure transducer. The transducer was connected to the manifolded piezometers.

7.8   Wicket Gate Servomotor Stroke

Wicket gate opening was measured by means of a linear displacement transducer on the servomotor piston rod and an angle positioner mounted on the wicket gate stem of each unit tested. Full servomotor stroke was calibrated over the entire operating range. The wicket gate angle was measured during calibration of the servomotor stroke linear displacement transducer to an accuracy of $\pm\,0.5$ degrees.

The wicket gate angle may be calculated using the following equation:

$$A_{ng} = c0 \;+\; c1 \times (SMS) \;+\; c2 \times (SMS)^2 \;+\; c3 \times (SMS)^3 \;+\; c4 \times (SMS)^4$$

7.9   Power Output

Generator output was measured by means of a high accuracy three-phase watt-hour meter (Yokogawa watt/watt-hour transducer). The same watt-hour meter was used for all tests. In addition generator output (3 phase 2 element) was measured using a Scientific Columbus watt/watt-hour transducer. The instrument and the transformers were calibrated to ensure the measurement accuracy. Generator performance in terms of efficiency for various percentages of rated output was taken as the average of the generator manufacturer guarantees. The generator efficiency was determined from data supplied by the generator manufacturer at unity power factor.

7.9.1   Index Piezometer Taps Calibration (Scroll Case Differential Pressure)

The scroll case differential pressure was measured by a linear differential pressure transducer connected to the Winter-Kennedy piezometer taps located in the scroll case. The low-pressure tap is located between the guide vanes. The high-pressure tap is located in the outside of the scroll case opposite the low pressure tap.

The Winter-Kennedy scroll case differential pressure relationship was calibrated using measured differential pressures and corresponding measured flows. Measured flows were determined as described in 4.1.1 and the least squares method was used to determine the calibration constant and exponent of the standard Winter-Kennedy relationship.

$$Q = k \times (DP)^n$$

where:
Q   =   flow (m^3/sec)
DP   =   scroll case differential pressure (psi)

8   <u>CONCLUSION</u>

The current meter method was an effective and accurate means of measuring flow at the St. Lawrence Power Project's turbine-generating units. The ICMS system to utilize the current meters proved to be very useful in achieving accurate test data on turbine unit performance and to provide the baseline data to derive the rating tables used to calculate St. Lawrence River flows.

FIGURE 1   GENERAL UNIT CROSS SECTION SHOWING MEASURING LOCATIONS
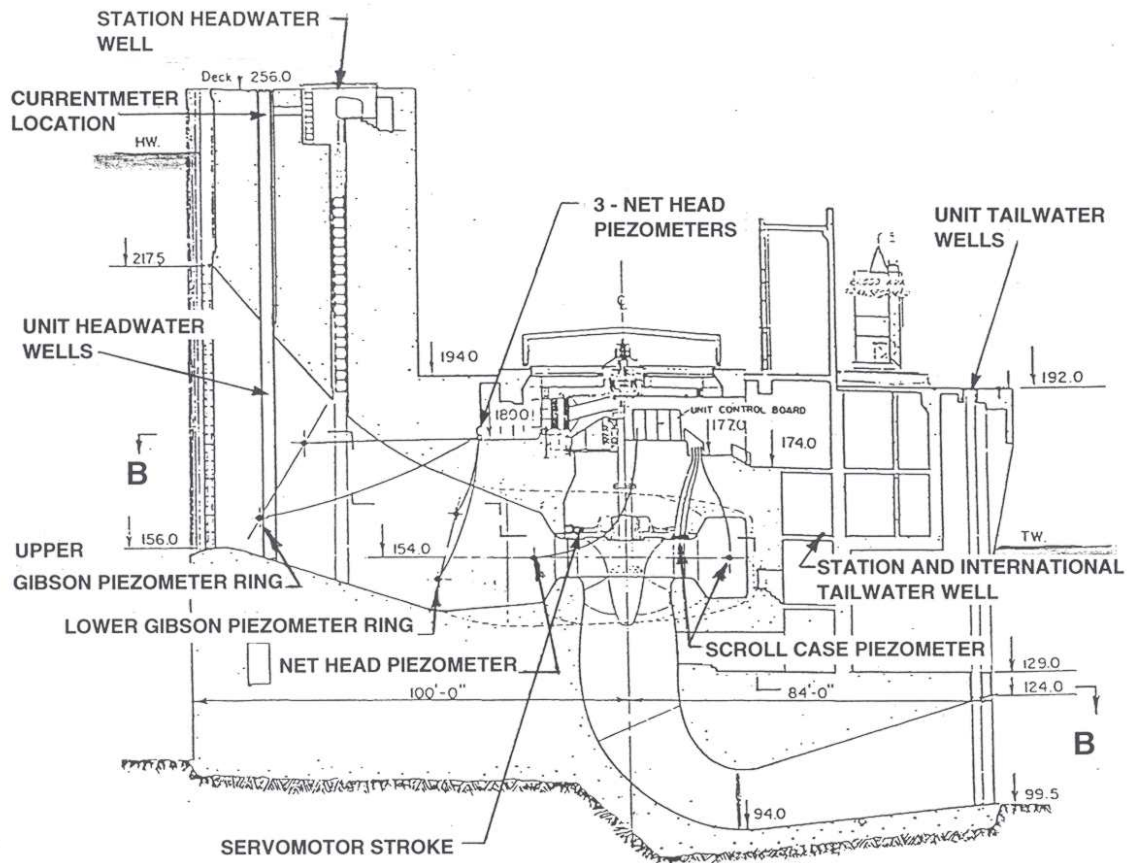
SECTION A - A
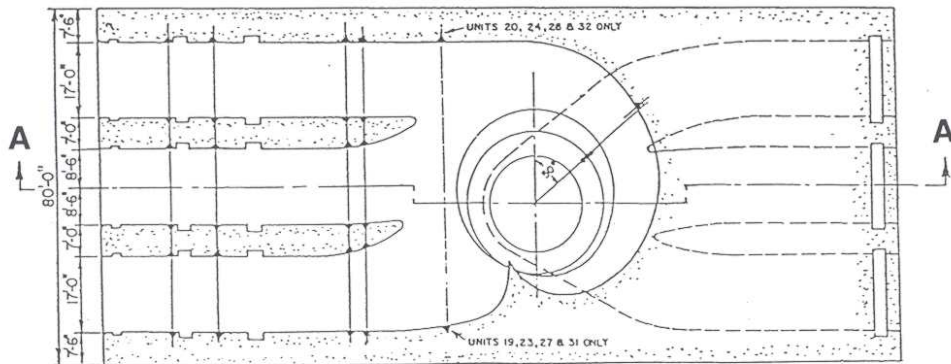
PLAN B - B

FIGURE 2   MEASURING GRID LOCATIONS AND SCHEMATIC OF CURRENT-METER SUPPORTING FRAME
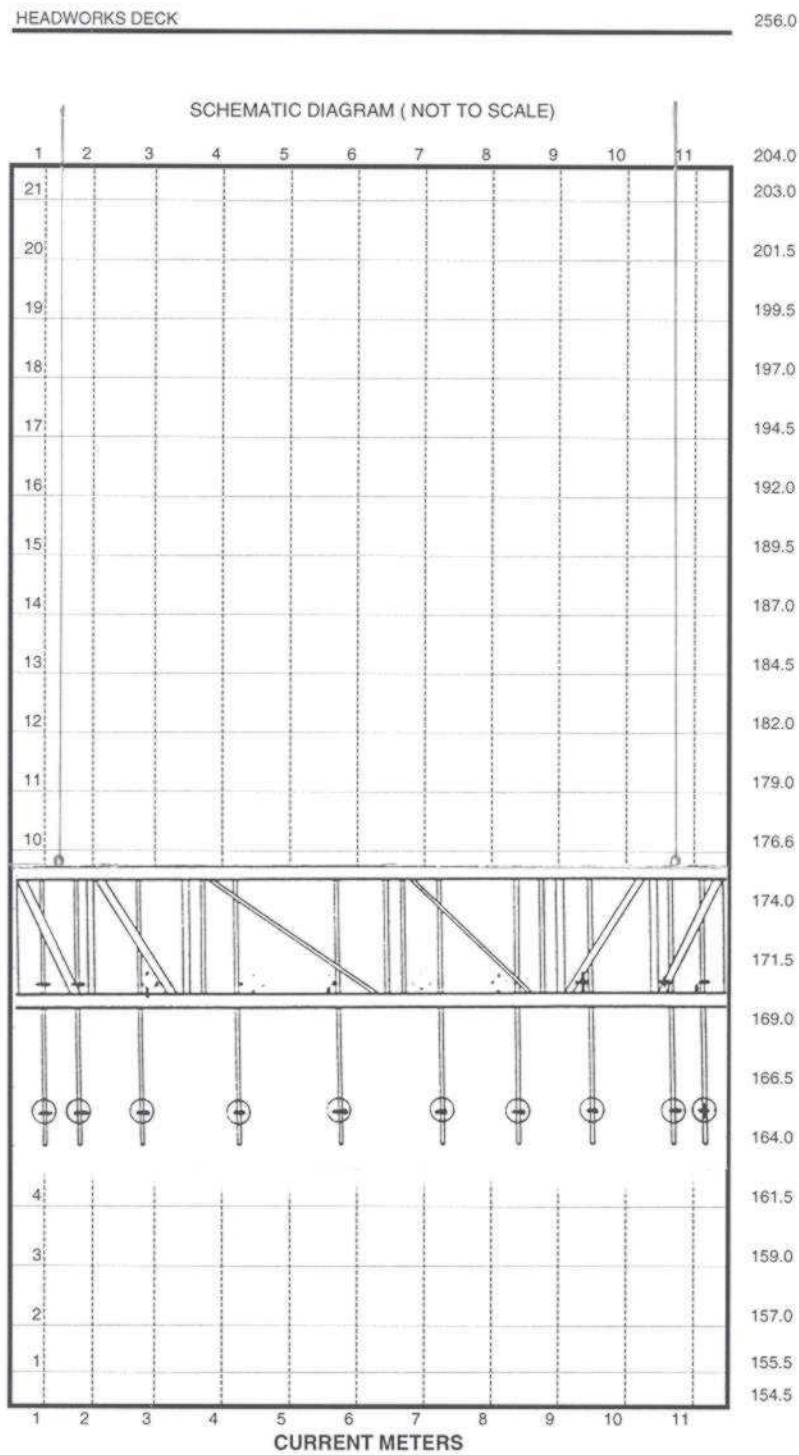
FIGURE 3   CURRENT-METER SETUP ON THE SUPPORTING FRAME

FIGURE 4   GENERAL VIEW OF THE CURRENT-METER SET UP

FIGURE 5   OTT CURRENT-METER SET UP (ARKANSAS TYPE)

FIGURE 6   OTT CURRENT-METER SET UP (C-31 TYPE)

FIGURE 7   NYPA - ST. LAWRENCE POWER PROJECT - AVERAGE UNIT RESULTS

NYPA - ST.LAWRENCE / FDR POWER PROJECT UNITS # 20, 28 (ALLIS-CHALMERS) AND UNITS 22, 26, 29 (BALDWIN-LIMA-HAMILTON)
OVERALL EFFICIENCY vs. GENERATOR OUTPUT   (gross head = 25m)

FIGURE 8   OPG - R. H. SAUNDERS G.S. - AVERAGE UNIT RESULTS

R. H. SAUNDERS G.S. POST UPGRADE UNITS 1,3,7,14 (SULZER), PRE-UPGRADE UNITS # 1,2,12 (EE 21.5) AND UNIT 3 PRE-UPGRADE (EE 23.5)
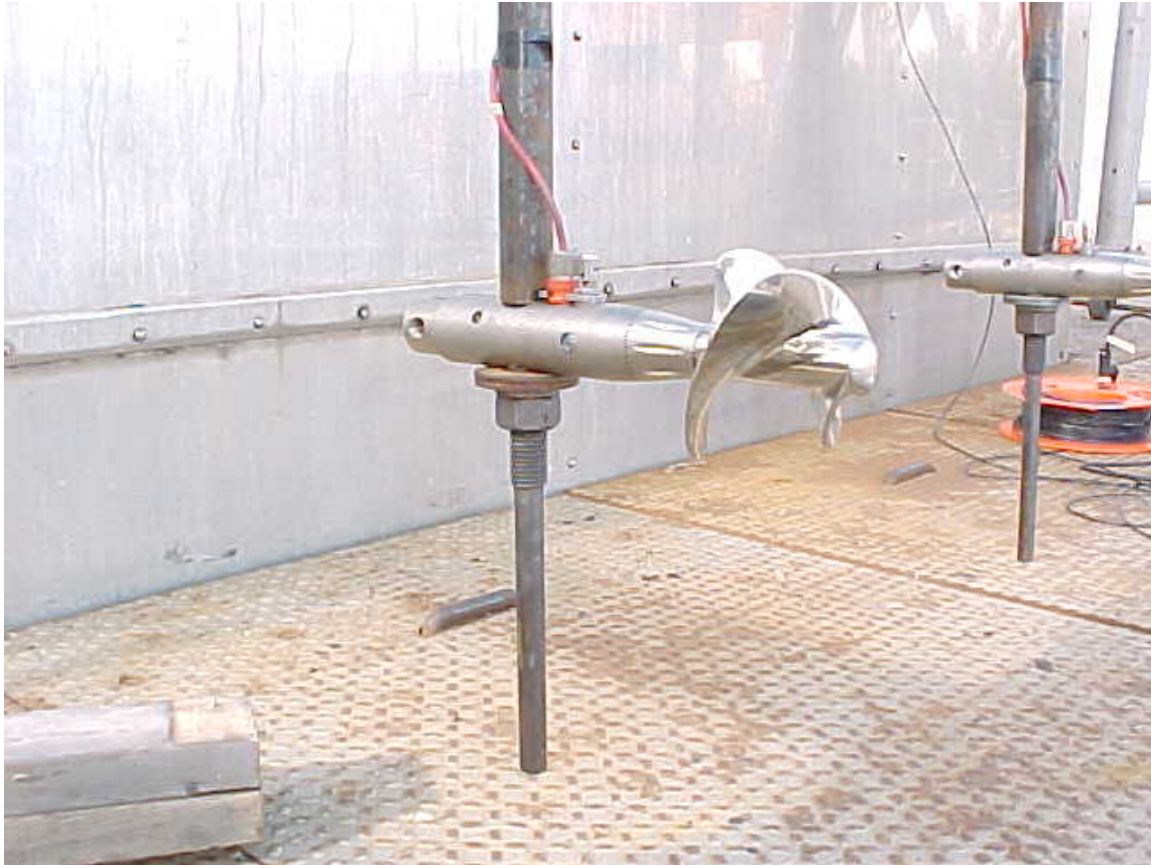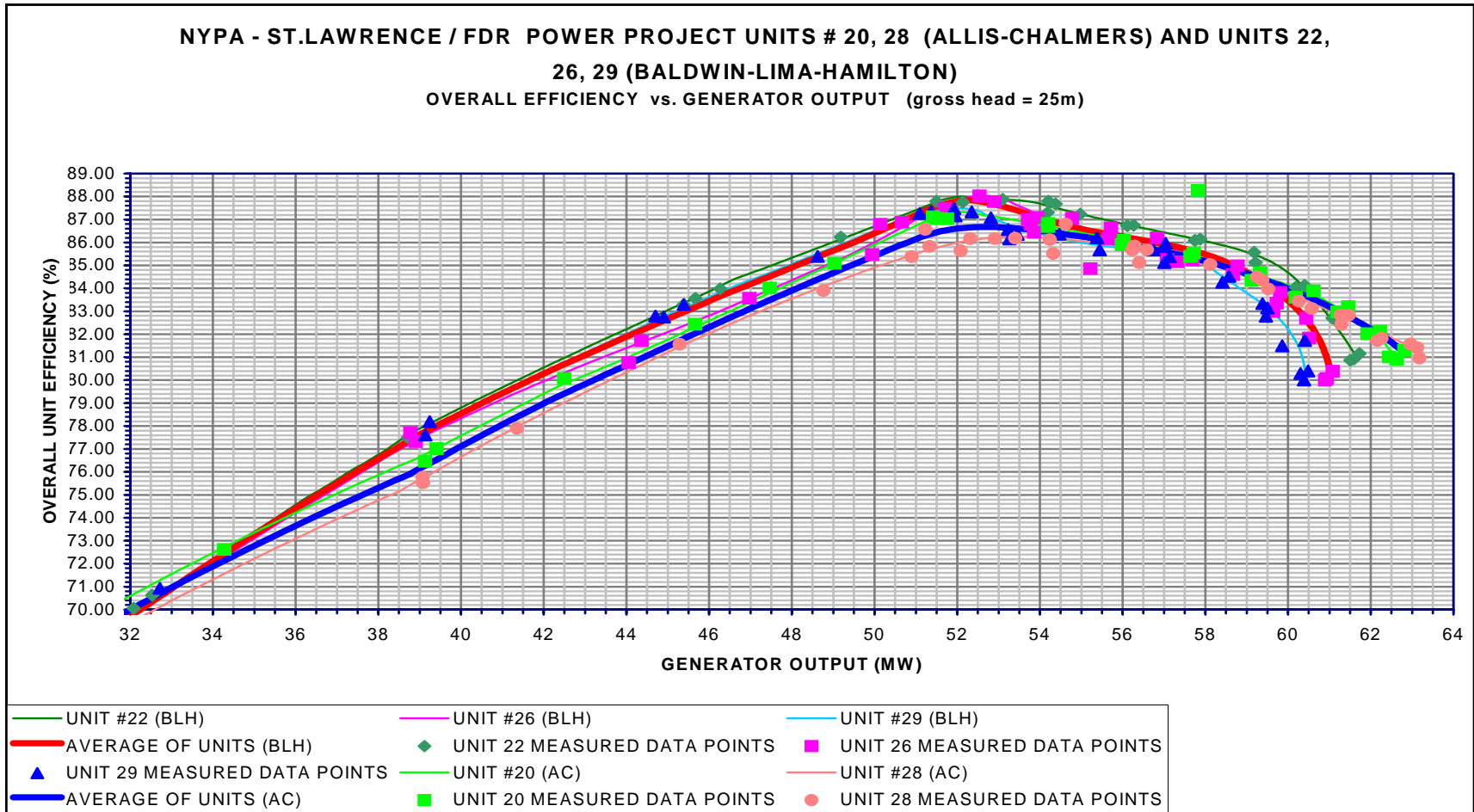
OVERALL UNIT EFFICIENCY vs. GENERATOR OUTPUT (gross head = 25m)

Legend:
- UNIT #1 POST-UPGRADE(SULZER)
- UNIT #3 POST-UPGRADE (SULZER)
- UNIT #7 POST-UPGRADE (SULZER)
- UNIT #14 POST-UPGRADE (SULZER)
- AVERAGE OF UNITS POST-UPGRADE (SULZER)
- UNIT #1 PRE-UPGRADE (EE21.5)
- UNIT #2 PRE-UPGRADE (EE21.5)
- UNIT #12 PRE-UPGRADE (EE21.5)
- AVERAGE OF UNITS PRE-UPGRADE (EE 21.5)
- UNIT 1 PRE-UPGRADE MEASURED TEST DATA POINTS
- UNIT 2 PRE-UPGRADE MEASURED TEST DATA POINTS
- UNIT 12 PRE-UPGRADE MEASURED TEST DATA POINTS
- UNIT 3 PRE-UPGRADE MEASURED TEST DATA POINTS
- UNIT 3 PRE-UPGRADE (EE 23.5)
- UNIT 1 POST-UPGRADE MEASURED TEST DATA POINTS
- UNIT 3 POST-UPGRADE MEASURED TEST DATA POINTS
- UNIT 7 POST-UPGRADE MEASURED TEST DATA POINTS
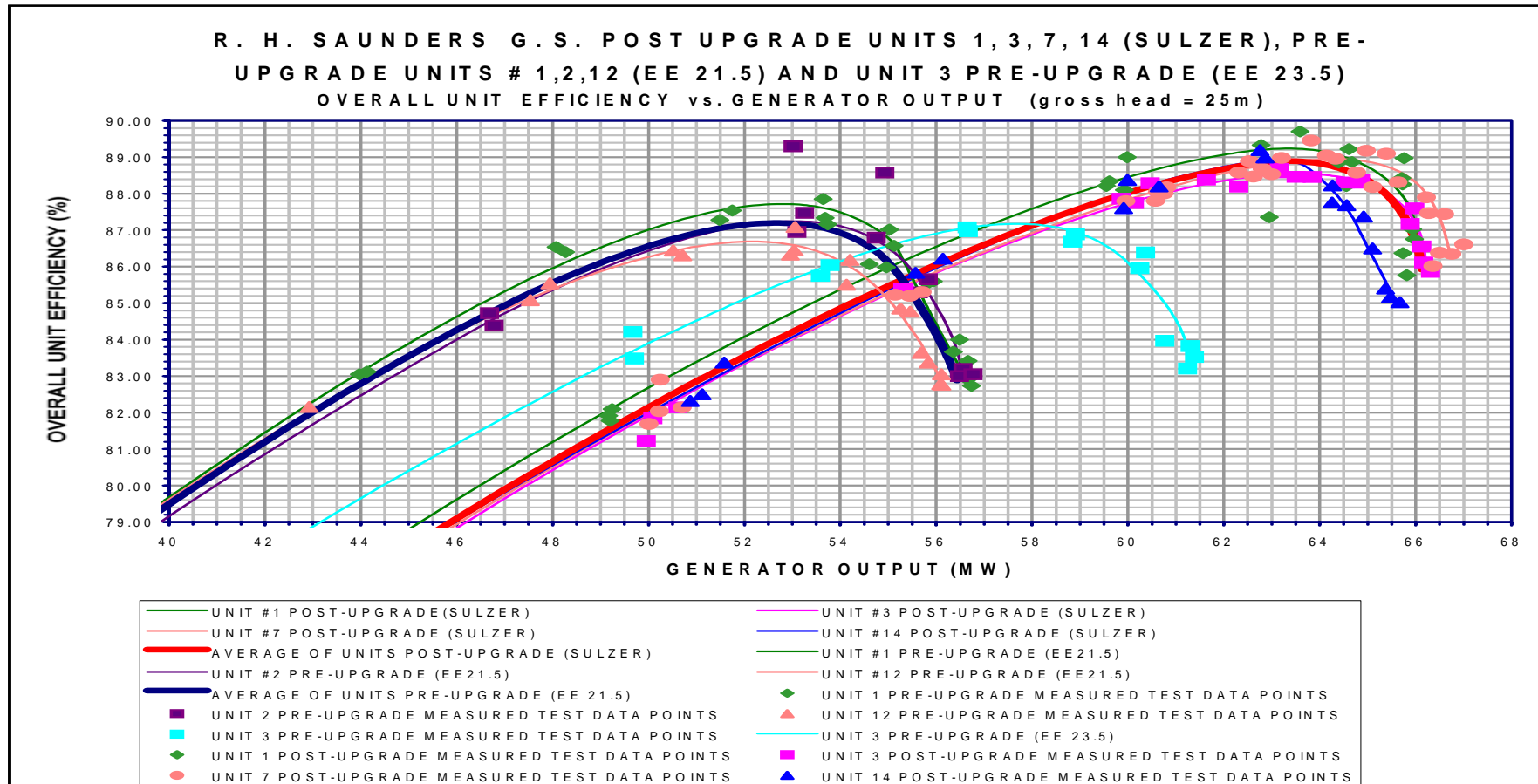- UNIT 14 POST-UPGRADE MEASURED TEST DATA POINTS

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FIGURE 9   OPG /NYPA - AVERAGE TEST RESULTS

NYPA - ST. LAWRENCE / FDR POWER PROJECT and OPG - R.H. SAUNDERS
AVERAGE TEST RESULTS (ALL UNITS)
OVERALL UNIT EFFICIENCY vs. GENERATOR OUTPUT (gross head = 25m)