NWRI CONTRIBUTION 86-103
ES-570
Roy (08)

Ford (15)

Study 85-344

LABORATORY DEMONSTRATION OF AN ELECTROMAGNETIC METHOD FOR RIVER VELOCITY MEASUREMENT

by

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December 1985

MANAGEMENT PERSPECTIVE

Measurement of river flow by conventional stage discharge relationships where the river bed is continually changing because of sand and gravel transport, especially dune flow, becomes unacceptably inaccurate. The electromagnetic gauge measures discharge directly and its calibration is reputedly insensitive to changes in the measuring cross section. These laboratory tests verify that the calibration of an electromagnetic gauge is not greatly affected by quite large alterations to flow cross section. Verification is still required.

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ABSTRACT

An operating laboratory model was set up to demonstrate the electromagnetic method of river gauging, as described by Hershey (1978). The model set up is documented, and the results of some flow calibration runs are presented. The discharge rating of the setup was found to be linear in terms of the measured signal voltage and the immersed depth of the electrodes. The discharge rating was not affected by a change in bed level at the metering section.

PERSPECTIVE DE GESTION

Lorsque le lit d'un cours d'eau évolue constamment en raison du transport du sable et du gravier, en particulier des dunes, le jaugeage de ce cours d'eau par l'établissement de liens entre les débits de niveau courant produit des résultats inexacts et inacceptables. La jauge électromagnétique mesure directement le débit et son calibrage est sensé ne pas être sensible aux changements se produisant dans la section de jaugeage. Les essais de laboratoire en question visent à vérifier si le calibrage d'une jauge électromagnétique est grandement influencé par les modifications importantes subies par la section de débit. D'autres vérifications restent à faire.

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RÉSUMÉ

Un modèle de laboratoire a été construit pour faire la démonstration du jaugeage d'un cours d'eau par méthode électromagnétique, tel que décrit par Hershey (1978). La construction du modèle est documenté et les données résultant de quelques calibrations de débit sont présentées. Les débits jaugés par le modèle se sont révélés linéaires par rapport à la tension du signal et à la profondeur d'immersion des électrodes. Un changement du niveau du lit à la section de jaugeage n'a pas eu d'effets sur le jaugeage.

1.0 INTRODUCTION

The Environmental Hydraulics Section of Hydraulics Divison are studying alternative methods for stream flow monitoring. Of particular interest are methods which are not influenced by weed growth or the build up of debris from bed load transportation.

The electromagnetic method of river gauging (Hershey, 1978) appeared attractive. Engineering Services Section was requested to set up a laboratory model to demonstrate the principle of such a river flow gauge in operation.

River flow is the product of the mean stream velocity and the cross section of the river channel. The electromagnetic principle is applied to the determination of stream velocity. The cross section and channel depth are measured by other means.

The laboratory instrumentation was confined to the measurement of stream velocity only. Cross section was rectangular, i.e., a flume box. Depth was measured by a hand-held scale.

This report documents the model set up and the results of some calibration runs.

2.0 APPARATUS

The apparatus listed in Table 1 was interconnected as shown in Figure 1.

3.0 METHOD

3.1 <u>Principle of Operation</u>

The river flow velocity gauge model is an application of Faraday's Law of electromagnetic induction, which relates the electromotive force (E) generated in a length of conductor moving at right angles to a magnetic field to:

- (b) the length of conductor (m)
- (T) the magnetic field intensity (Telsa)
- (v) the velocity of the conductor (m/s)

as

$$E = T \cdot v \cdot b \qquad \text{(volts)} \tag{1}$$

In practice, the output signal E is reduced by the conductivity shunt of the stream bed, called conductivity attenuation δ, where $\delta < 1$. In addition, due to the induced emf between the electrodes, a leakage current will flow through the water outside the magnetic field, further reducing the output signal. This introduces an end shorting factor β, where $\beta < 1$.

The signal measuring instrumentation amplifies the signal by a gain G to provide an output voltage E_0 on the chart recorder.

Including these factors, Equation 1 now becomes

$$E_0 = G \cdot T \cdot v \cdot b \cdot \delta \cdot \beta \tag{2}$$

The average water velocity at the metering section is the flow through the flume divided by the cross-section of the stream.

The flow through the flume is the discharge (Q) of the V knotch weir, which is of the form

$$Q = k \cdot dh^n$$

where dh = water depth over the V knotch
k,n = calibration coefficients

Then for our rectangular flume, where cross section area (A) is width (b) x depth (z)

$$v = \frac{Q}{A} = k \cdot dh^n / b \cdot z \tag{3}$$

The magnetic field intensity (T) for the electrical coil is calculated as:

$$T = \frac{2\pi\ n\ I}{10\ r} \times 10^{-4} \text{ Tesla} \qquad \text{(Weast, 1971)}$$

where, for the electical coil used here (Table 1)

n = number of turns (200)

r = coil radius (cm) 22.6 cm

I = coil current = drive voltage/coil resistance

$$= \frac{9 \text{ v}\cdot\text{p-p}}{9.83 \text{ ohms}} = 0.92 \text{ A}\cdot\text{p-p}$$

$$T = 5.12 \times 10^{-4} \text{ Telsa}$$

Substituting 3 in 2

$$E_o = \frac{G\cdot T\cdot k\cdot dh^n\cdot\delta\cdot\beta}{z} \qquad (4)$$

For the apparatus used, (Table 1),

G = Instrumentation gain = 6.66×10^6

T = magnetic field intensity = 5.12×10^{-4} (Tesla)

k = V weir calibration coeff. = 1.7046×10^{-5}

dh = V weir head (cm)

n = V weir calibration coeff. = 2.41556

z = flow depth (cm) $\times 10^{-2}$ m

$\delta\cdot\beta$ = signal attenuation factors = < 1

Then

$$E_o = \frac{5.813\ dh^{2.41556}\cdot\delta\cdot\beta}{z} \text{ volts} \qquad \text{(dh and z in cm)} \qquad (5)$$

With the apparatus in operation, the quantities measured are head over the V knotch weir (dh), depth of flow in the flume (z), and output voltage (E_o).

Using dh and z, the theoretical signal output (E) can be calculated, assuming $\delta \cdot \beta = 1$, as:

$$E = \frac{5.813 \ dh^{2.41556}}{z} \qquad (6)$$

Then the attenuation factor $\delta \cdot \beta$ is estimated from

$$\delta \cdot \beta = \frac{E_o}{E} \qquad (7)$$

This value should prove constant for the apparatus. From this constant and fixed values for the controlled variables, the flow velocity (V_i) is calculated from output voltage using Equation 2 as:

$$V_i = \frac{E_o}{G \cdot T \cdot b \cdot \delta \cdot \beta}$$

$$V_i = \frac{9.775 \times 10^{-4} \ E_o}{\delta \cdot \beta} \qquad (8)$$

3.2 Apparatus Set-up

The apparatus was physically arranged as shown in Figure 1.

The flume box was set level. The weir height at the exit of the flume box was set at 12.7 cm (5.00 in) to obtain a reasonable working depth of flow in the flume. The head over the V-knotch weir was adjusted to about 10.5 cm to give a flow which filled the flume box section.

From Eq. 3, with dh of order 10.5 cm and z of order 17 cm, the flow velocity in the flume is 0.10 m/s.

From Eq. 1, with T = 5.12 x 10^{-4} Telsa and b = 0.30 m, the expected signal induced between the electrodes by the electromagnetic induction due to this flow velocity will be about 0.15 micro volts pk-pk.

The main objective of the instrumentation set up is to isolate this very small signal from the noise induced in the circuit from various other sources. This was done empirically.

First, a Low Ground Point (LGP) was established at the Hafler Power Amplifier output, which was common to hydro ground.

A metal screen was put in the flow and tied to LGP, so that the stream flow was grounded. This was necessary since the stream flowing in the wooden flume was not reliably grounded through the water supply system.

The electrodes were connected through shielded leads as a differential input to the Neff Preamplifier. The shields were connected to the L.G.P.

The oscillator output of the Ithaco Lock-in Amplifier was input to the Hafler Power Amplifier to produce a 9 V p-p sine wave at 4.0 Hz to drive the electric coil. The electric coil was placed under the flume box, 1.5 m from the inlet end of the box, and so oriented to produce a vertical magnetic field oscillating through the water flow.

The pre-amplified signal (Neff output) was applied as a differential input to the lock-in amplifier. The lock-in amplifier is used to detect the weak flow velocity induced signal which has a frequency of 4 Hz in fixed phase relation to the reference oscillator which is driving the electrical coil. Lock-in amplifier sensitivity was set to 0.3 mV for 10 V output (Gain 3.3 x 10^4), and Time Constant was set to 125 seconds to obtain a stable signal for recording. Since the input signal was differential, the grounding bar on the lock-in amplifier input was not used.

The Tektronics Oscilloscope was used to display the 4 Hz amplified input to the electrical coil. This input was adjusted to 9 V p-p based on the power capability of the Hafler Power Amplifier for steady output with no auxiliary cooling fan.

The pre-amplified input to the lock-in amplifier was also displayed on the oscilloscope, using the 5A13N Differential Comparator input module. The 5A13N frame ground was connected to the LGP.

3.3 Operational Considerations

There are many factors affecting the development and operation of electromagnetic current meters (Der, 1977).

In general, when an electrode is immersed in an electrolyte, a charge redistribution within the electrolyte occurs at the interface with the electrode. An important consequence of this is that the electrode acquires a potential. This so-called electro-chemical potential introduces an indeterminant bias on the potential produced by the flow of the electrolyte through the magnetic field. To avoid this source of error, the magnetic field is made to alternate with a period sufficiently short to preclude the establishment of a significant electro-chemical potential on the electrode and the bias is removed by using only the AC component of the signals. The frequency of magnetic field alternation used was 4 Hz.

The impedance of the electrodes is a function of many factors determined by the volumetric properties of the fluid in which they are located, and the surface properties at the interface. These include the conductivity of the fluid, the chemical constituency of the fluid and the electrodes, the operating frequency of the system, temperature, pressure, and velocity of the fluid to name but a few. In general, it is recognized that the stability of electro-magnetic current meters is ultimately set by the stability of the electrode impedance. The input impedance of the preamplifier must be very high to minimize the effects of the electrode impedance.

In addition to the controlled magnetic field produced by the coil, there are many other uncontrolled steady state and varying electro-magnetic fluxes which induce a potential difference between the electrodes. The signal from the electrodes is therefore very noisy, and good signal conditioning is required to filter out and record only that component which is generated by the controlled magnetic field and the flow of the water.

In this instance, a lock-in amplifier, Ithaco 391A, was available to serve as the basis for the signal conditioning circuit. This device provides a reference oscillator output which is used, through a power amplifier, to drive the coil and generate a magnetic field which oscillates at the reference frequency. The signal from the electrodes, containing information at the reference frequency is input to the lock-in amplifier. The lock-in amplifier uses a heterodyne mixer to translate coherent input (i.e., at the reference frequency) to a constant IF frequency. This is then amplified and band pass filtered, then passed to a phase sensitive detector which extracts the coherent component. The detected coherent component is further amplified and filtered before it is sent to a display meter and recorder.

The controlled magnetic field was made to vary sinusoidally in time, chiefly for convenience with the available apparatus for driving the coil, and for compatibility with the lock-in amplifier. The prime flow induced voltage between the electrodes was therefore also sinusoidal, and in phase with the magnetic field. The impedance of the electrodes produces a phase shift of the flow voltage which is determined by adjustment of the phase controls to "peak" the output signal.

A further complication is magnetic induction. The electrodes and the connecting fluid path between them form a single turn transformer in which the sinusoidally varying magnetic field will induce what is known as "transformer effect" voltages. These can be minimized at zero fluid flow by adjusting the position of the electrodes relative to the coil to null the transformer coupling.

These effects are recognized major historical problems with sinusoidally driven electro-magnetic current meter systems. As a result, commercially available systems generally use a square wave to drive the magnetic coil. In this case, the form of the transformer effect voltage is a Dirac impulse function superimposed on the flow signal. The time constant of the exponential decay of the Dirac function is governed by the electrode impedance. After say five time constants, the residual error from this impulse will be quite small. The risk of a longer delay before reading is that electro-chemical voltages occurring at the electrodes begin to interfere. Circuit design compromises are required between these two extremes.

It is to be recognized that the signal processing instrumentation used in this laboratory model was chosen on the basis of available equipment for a minimum cost demonstration. This approach would not normally be chosen in the design of a prototype stream flow measurement system.

3.4 Operation

All electronic equipment was turned on and allowed to warm up and stabilize for more than 30 minutes.

The flume box as filled with water, but with zero flow.

The phase control on the lock-in amplifier was set to zero. The position of the electrodes in the water relative to the coil was adjusted manually to obtain a zero signal, that is to nullify the in phase, "transformer effect" voltages. The method was to first adjust the electrodes to obtain approximately zero output on the oscilloscope display of the pre-amplified electrode signal. A fine adjustment was then made to obtain a zero display of the lock-in amplifier output. This adjustment was found to be delicate, but a null of 0.2 volts at the output was obtainable.

Water supply to the V-knotch weir head box was turned on and adjusted to give a maximum flow through the flume box.

The phase control on the lock-in amplifier was adjusted to "peak" signal output. This measured phase shift relative to the reference signal due to the electrode circuit impedance.

The water supply was shut off, and zero flow condition established in the flume. Zero flow output was checked at the new phase setting, and fine adjustments made to the electrode position if required to re-establish zero signal output. The zero flow signal was recorded.

This completed the set up of the measurement system.

Water supply to the V knotch head box was adjusted to obtain a range of flow velocities, allowing at least 15 minutes for all parameters to stabilize before reading. Output voltage (E_0), V knotch head (dh), and flow depth (b) were logged. Voltage was recorded on the chart recorder. In general, the time constant control on the lock-in amplifier was set at 125 sec to obtain a long time-averaged output signal for the recorder. The V knotch head was measured by point gauge to ±0.1 mm, and flow depth was measured by steel rule to ±0.5 mm.

At each measurement of output voltage, phase was adjusted to ensure peak signal voltage was read. Some variation in phase adjustment was anticipated, reflecting some instability of the electrode impedance.

At zero flow, the zero flow output was checked and compared to the initial value.

The preceeding operational sequence was repeated several times to assess repeatability of results, and over periods as long as 48 hours to assess stability of operation.

To assess the influence of changes in bed level at the metering section, a wooden trapezoidal shaped insert was placed in the flume between the electrodes. This insert forced a flow contraction over the shallower bed level. It was fully flooded below the insert, and the immersed depth of the electrodes was unchanged from the earlier measurements.

The system was run at high flow for approximately 20 hours to check stability of reading, and two cycles of varying flow were done to confirm repeatability.

Measurements are summarized in Table 2.

Values for E (Eq. 6) and (Eq. 7) were calculated from the recorded measurements, and indicated stream flow velocity (V_i was calculated from Eq. 8.

4.0 DATA ANALYSIS

It was expected that the attenuation factor $\delta \cdot \beta$ should be constant within the limits of the apparatus.

Table 2 lists all the readings taken during the evaluation.

Three readings were rejected as obviously illegitimate. All were at very low flows and may be taken to reflect the difficulty in obtaining a stable null signal at zero flow.

Of the remaining 28 readings, the mean value of $\delta \cdot \beta$ is 0.0984, and the 95% confidence interval using the "t" test of significance is ±0.0049. This gives a relative error of ±5.00%.

Table 3 lists the mean values of $\delta \cdot \beta$ with similar 95% confidence interval for each measurement episode. These are arranged in ascending order.

It appears that the readings of the episode 17 October should be rejected as being suspect. Of the 5 remaining episodes, the mean value of $\delta \cdot \beta$ is 0.0955, and the 95% confidence interval is ±.0038, giving a relative error of 3.99%. Similarly, the 99% confidence interval is ±.0051, giving a relative error of 5.39%.

Although the overall spread of readings shows that the factor $\delta \cdot \beta$ is constant within 5.39%, there are evident unexplained differences between episodes of the order of 18%. This is thought to relate to the care with which a zero flow reading is established at the beginning of the episode, and with which the phase shift is monitored during the episode.

In both zero flow null and phase shift adjustments, the operational factor affecting accuracy was the length of time required. The time constant of the lock-in amplifier was set to 125 sec to obtain a suitably time averaged signal output. Three time constants or 6.3 minutes was required to get 96% of the full signal following a change of setting. Thus considerable care and patience was required of the operator to ensure that zero flow null and phase shift adjustments were accurately established.

From continuity of flow,

$$Q = V \cdot A$$

where A is a reference flow section area defined by the channel width (b) and the immersed depth of the electrodes (z).

From Eq. 2,

$$E_0 = K \cdot V \cdot b$$

where K is defined as an instrument constant combining gain (G), magnetic field density (T) , and attenuation factors $\delta \cdot B$.

By combining the two above, the flow (Q) may be expressed in terms of the measured voltage (E_0) and the immersed depth of the electrodes (z), as

$$Q = (E_0 \cdot z)/K$$

Table 4 lists the measured data along with values for Q calculated from the V knotch weir calibration coefficients, and the parameter $E_0 \cdot z$.

Figure 2 plots Q versus $E_0 \cdot z$ for the run of 21:11:85 with the bare flume and for the runs of 27/28:11:85 with the bed level insert in place.

These sets of data correlate closely indicating that the discharge rating of the measurement system is not affected by change in bed level, provided that the depth of the flow is measured relative to the datum represented by the bottom of the immersed electrodes.

The plot further indicates that the discharge rating is linear and that the instrument constant K is approximately 30.6.

5.0 CONCLUSIONS AND RECOMMENDATIONS

1. The laboratory set up of apparatus described demonstrated the operation of the electromagnetic principle as applied to the measurement of average stream flow. The range of flows during evaluation runs was from zero to 4.5 l/s. The discharge rating for the instrumentation set up was found to be

$$Q = (E_0 \cdot z)/30.6$$

where

Q = discharge (l/s)
E_0 = measured voltage (volts)
z = immersed depth of electrodes (cm)

2. The discharge rating was found to be unaffected by a change in bed level at the metering section.
3. The demonstration set up is not feasible as a basis for a full scale prototype flow measuring system. Commercially available systems should be evaluated for this.

ACKNOWLEDGEMENTS

The authors express appreciation for the contributions of D. Fekyt for providing initial equipment set up and preliminary measurements, R. Desrosiers for advice on the availability and application of the lock-in amplifier and G. Dolanjski for advice on the selection and application of the Hafler power amplifier.

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TABLE 1

Apparatus for Electromagnetic River Flow Velocity Gauge

Item	Manufacture and Model	Relevant Characteristics
V-knotch weir	NWRI/HD Lab	$Q = .000017046\ \Delta H^{2.41556}\ m^3/s$ (ΔH in cm)
Flume Box with sharp crest exit weir	NWRI/HD Lab Fir plywood box	Length - 2.44 m Width - 30.3 cm Depth - 20.0 cm Weir Height - 12.7 cm
Grounding screen		
Electrical Coil	NWRI/D. Fekyt	Number of turns - 200 Electrical resistence - 9.83 ohm Shape - Square Dimension - 35.6 cm - mean/side Equivalent Radius - 22.6 cm
Signal Electrodes	NWRI	3 mm dia. stainless steel rod with perforated heat-shrink PVC jacket
Coil Power Supply	Hafler DH-220 DC Power Amplifier	110 watts/channel Minimum distortion 1 to 20,000 Hz
Signal Pre-Amplifier	Neff 122	Gain 200 (Adjustable) Differential Input
Lock-in Amplifier	Ithaco 391A	0.1 to 10 Hz (Brown Card) operation Normal Mode Sensitivity 1 μV to 100 mV Time Constant 1.25 mg to 125 ms
Recorder	Phillips	Two pen chart recorder Scale range: Speed 10 m/hr to 300 mm/min.
Oscilloscope	Tektronics 5111 5A13N Comparator 5A22N Differential 5A12N Time Generator	

File
ELFLOMET

TABLE 2
ELECTROMAGNETIC RIVER VELOCITY METER
EXPERIMENTAL DATA

DATE	TIME	MEASURED			CALCLATED		
		dH	z	Eo	E	d.B	Vi
d:m:y	h:m:s	cm	cm	Volt	Volt		m/s
16:10:85		9.55	16.19	8.85	83.64	0.106	8.18
		8.40	15.40	6.90	64.50	0.107	6.30
		6.90	14.76	4.60	41.84	0.110	4.09
		5.45	13.97	2.90	25.00	0.116	2.44
		3.56	13.34	0.95	9.36	0.101	0.92
	(discard)	0.27	12.38	0.20	0.02	10.068	.00
					Mean	0.108	
Second test run							
17:10:85		8.80	15.70	9.25	70.79	0.131	6.92
		3.75	13.40	1.15	10.57	0.109	1.03
		6.10	14.25	4.15	32.18	0.129	3.15
					Mean	0.123	
Set up for WRB Demo							
21:11:85		10.05	16.40	7.90	93.40	0.085	9.13
		9.38	16.00	7.20	81.04	0.089	7.92
		8.08	15.40	5.30	58.72	0.090	5.74
		5.74	14.30	2.30	27.69	0.083	2.71
					Mean	0.087	
Set up to check long term stability							
25:11:85	12:57:	10.40	16.50	9.20	100.84	0.091	9.86
	14:02:	10.40	16.50	9.40	100.84	0.093	9.86
	17:02:	10.40	16.50	9.70	100.84	0.096	9.86
					Mean	0.094	
Check Null signal and adjust Phase							
26:11:85	09:30:	10.41	16.60	10.40	100.46	0.104	9.82
Reduce dH to reduce flow							
26:11:85	10:36:	10.00	16.50	9.60	91.72	0.105	8.97
	16:07:	10.01	16.50	9.60	91.94	0.104	8.99
27:11:85	08:08:	10.00	16.50	9.75	91.72	0.106	8.97
					Mean	0.105	
Install wooden "dune" and retune set up							
27:11:85	13:37:	10.00	10.90	12.60	138.85	0.091	13.57
	17:53:	10.00	10.90	12.60	138.85	0.091	13.57
28:11:85	08:24:	10.00	10.90	12.67	138.85	0.091	13.57
	10:10:	9.20	10.40	10.60	118.97	0.089	11.63
	11:36:	7.70	9.60	7.25	83.85	0.086	8.20
	16:18:	6.90	9.20	5.67	67.13	0.084	6.56
	(discard)	2.33	7.60	0.10	5.90	0.017	0.58
						0.089	
Readjust Null Phase from 8.0 to 6.0							
		10.09	10.90	12.87	141.88	0.091	13.87
		9.43	10.50	11.23	125.08	0.090	12.23
		7.92	9.70	7.83	88.83	0.088	8.68
	(discard)	3.71	8.00	1.00	17.25	0.058	1.69
						0.090	

TABLE 3
ELECTROMAGNETIC RIVER VELOCITY METER
DATA ANALYSIS

COMMENT	MEAN d.b	SAMPLES	95 % CONF INT (+/-)	RELATIVE ERROR (+/-)
	.0868	4	.0053	6.11%
	.0890	9	.0058	6.52%
	.0933	3	.0063	6.75%
	.1048	4	.0030	2.86%
	.1080	5	.0069	6.39%
DISCARD	.1230	3	.0523	42.52%
OVERALL	.0955	25	.0038	3.99%

File
ELFLO2

TABLE 4
ELECTROMAGNETIC RIVER VELOCITY METER
EXPERIMENTAL DATA

DATE	TIME	MEASURED			CALCULATED	
		dH	z	Eo	Q	Eo . z
d:m:y	h:m:s	cm	cm	Volt	l/s	volt-cm
16:10:85		9.55	16.19	8.85	3.97	143.28
		8.40	15.40	6.90	2.91	106.26
		6.90	14.76	4.60	1.81	67.90
		5.45	13.97	2.90	1.02	40.51
		3.56	13.34	0.95	0.37	12.67
		0.27	12.38	0.20	.00	2.48
Second test run						
17:10:85		8.80	15.70	9.25	3.26	145.23
		3.75	13.40	1.15	0.42	15.41
		6.10	14.25	4.15	1.34	59.14
Set up for WRB Demo						
21:11:85		10.05	16.40	7.90	4.49	129.56
		9.38	16.00	7.20	3.80	115.20
		8.08	15.40	5.30	2.65	81.62
		5.74	14.30	2.30	1.16	32.89
Set up to check long term stability						
25:11:85	12:57:	10.40	16.50	9.20	4.88	151.80
	14:02:	10.40	16.50	9.40	4.88	155.10
	17:02:	10.40	16.50	9.70	4.88	160.05
Check Null signal and adjust Phase						
26:11:85	09:30:	10.41	16.60	10.40	4.89	172.64
Reduce dH to reduce flow						
26:11:85	10:36:	10.00	16.50	9.60	4.44	158.40
	16:07:	10.01	16.50	9.60	4.45	158.40
27:11:85	08:08:	10.00	16.50	9.75	4.44	160.88
Install wooden "dune" and retune set up						
27:11:85	13:37:	10.00	10.90	12.60	4.44	137.34
	17:53:	10.00	10.90	12.60	4.44	137.34
28:11:85	08:24:	10.00	10.90	12.67	4.44	138.10
	10:10:	9.20	10.40	10.60	3.63	110.24
	11:36:	7.70	9.60	7.25	2.36	69.60
	16:18:	6.90	9.20	5.67	1.81	52.16
		2.33	7.60	0.10	0.13	0.76
Readjust Null Phase from 8.0 to 6.0						
		10.09	10.90	12.87	4.54	140.28
		9.43	10.50	11.23	3.85	117.92
		7.92	9.70	7.83	2.53	75.95
		3.71	8.00	1.00	0.40	8.00

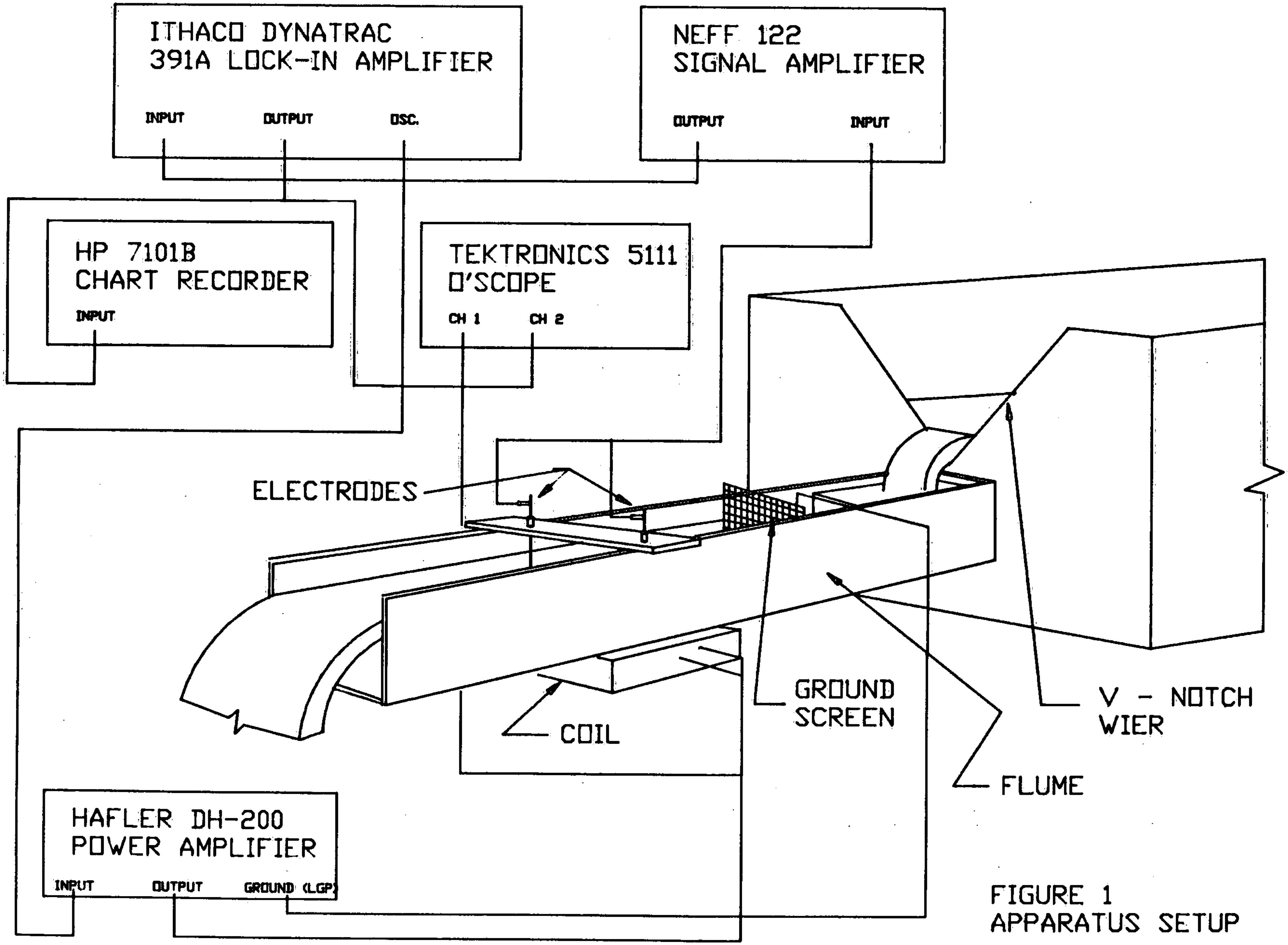

FIGURE 1
APPARATUS SETUP

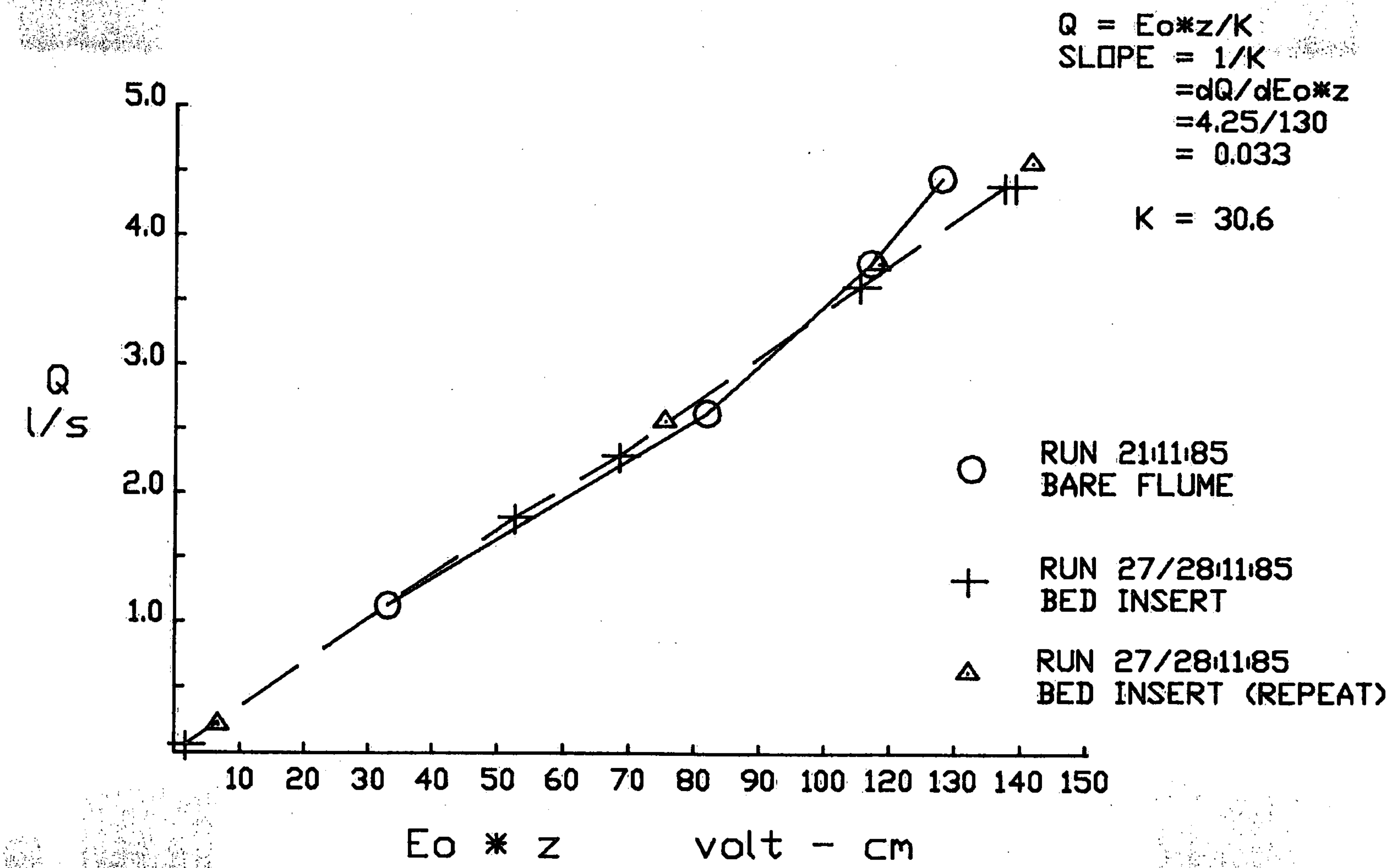

FIGURE 2
DISCHARGE RATING