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ELECTROMAGNETIC CURRENT METER EVALUATION

This Technical Bulletin reports the results of a recent study on electromagnetic current meters. The work was done by the Evaluation Branch of the Center's Testing Division between 1971 and 1973.

The Testing Division of the National Oceanographic Instrumentation Center has completed evaluations of several types of electromagnetic current meters. These include the Marsh-McBirney Model 711, the Engineering Physics Co. (EPCO) Model T/S 750B, and two instruments of French design and manufacture, the Comex Mark III and the Schlumberger Model CS 24AD.[1]

OPERATION

Electromagnetic current meters (EMCMs) operate on Faraday's law of electromagnetic induction by generating a magnetic field in the water and utilizing the water as the electrical conductor. By moving perpendicular to the magnetic field flux lines, this conductor produces an electromotive force (potential) with a magnitude that is proportional to the velocity of the conductor and a direction that is mutually orthogonal to the conductor velocity and magnetic field flux lines. Manufacturers have taken advantage of this principle by designing transducers with mutually orthogonal pairs of electrodes that are positioned relative to the generated magnetic field so that they measure the potential produced by the moving water. Orthogonal electrode pairs yield two

[1] An Instrument Fact Sheet has been published on the Comex equipment. Copies are available from the Center by requesting IFS–74002, *MK III Electromagnetic Current Meter,* July 1973. Write Chief, Documentation Division, Code C634, National Oceanographic Instrumentation Center, National Oceanic and Atmospheric Administration, Rockville, Md. 20852

voltage components that define the magnitude and direction of the water velocity in a plane perpendicular to the magnetic field.

DESIGN

The similarity of electromagnetic current meters ends with the principle of operation and differs in the design of the transducer shape, electromagnet configuration and driving signal, and signal-conditioning electronics. Testing has shown that the performance of electromagnetic current meters depends primarily on these three factors. Table I summarizes the manufacturers' published characteristics of the EMCMs discussed in this bulletin; the sensors are illustrated by photographs. (Note that the design of the Schlumberger instrument incorporates the sensor into the electronics package as a single unit.)

Transducer Shape—In an EMCM, the magnetic field strength diminishes as the square of the distance from the magnet; therefore, the largest electrical potential, in terms of Faraday's law, is produced closest to the surface of the transducer. Thus, an important design consideration should be minimization of disturbances of the water in the near vicinity of the transducer and the maintenance of a uniform flow. In terms of hydrodynamic behavior, the uniformity of the flow field depends on the shape of the object, surface roughness, and characteristics of the flowing fluid. Testing has indicated that the hydrodynamic properties of EMCM transducers are of major importance in their performance.

By their presence, transducers create disturbances to the flow field that can cause erroneous measurements of velocity vector magnitudes and directions. However, measurement of the actual free stream velocity can be accomplished even though the transducer distorts the flow field provided that the amount of distortion and its uniformity remains directly proportional to the free stream velocity. As illustrated in figure 1, the cylindrical shape creates a symmetrical but nonuniform disturbance of the flow stream and it is speculated that the voltage measured by each electrode pair depends on its position with respect to this flow field. The result of this nonuniform performance is a loss of accuracy in directivity.[2]

Tests have been performed at various flow speeds and numerous transducer attack angles to the flow in order to verify the existence of this phenomenon. (See table II and the polar plots on pages 6 through 9.) These tests have shown that the output errors in directivity are repeatable and predictable under similar flow field conditions. Streamlining the shape of the probe and mounting the electromagnet coil and electrodes in the proper area of the transducers can reduce or eliminate the flow field problem by creating a uniform flow in the sensed area regardless of direction of flow.

Vortex shedding from the transducers can also be a problem. Regular and alternately shedding vortices create pressure disturbances that may result in forced vibration of the cylindrical probes at frequencies dependent on the flow velocity. Tests have proven that when this phenomenon occurs at a resonant frequency of the mounting system, severe disturbances of the hydrodynamic flow field occur. This behavior has been demonstrated at speeds of 2 knots or greater and, under these conditions, the cylindrically shaped tranducers erroneously measure the free stream vector magnitude. Suitable mounting constraints are necessary to eliminate vibration.

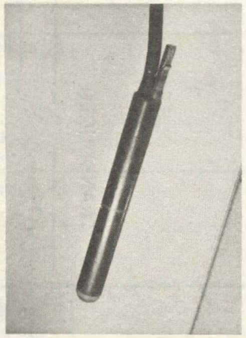
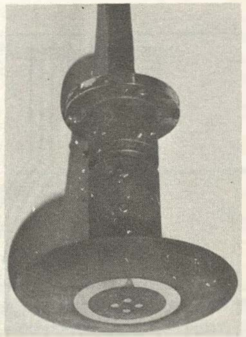
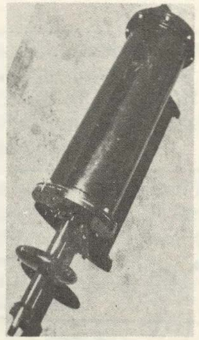
If the electromagnetic transducer has its measurement axis tilted with respect to the flow field (such as the case when a buoy-mooring line is used), a predictable change in output should occur which is a function of the cosine of the tilt angle. However, the streamlined shape, when in a tilted position at angles of 20 degrees or more, creates a flow field distortion that causes a deviation from the predicted shift due solely to the cosine function. Dynamic motions imparted to the streamlined transducer in the vertical plane or orbital water motion caused by wave action may cause flow field distortion and result in erroneous outputs. (Dynamic testing of ocean current sensors is in a preliminary stage at NOIC, and further results on the effect of this type of motion should be available in the future.)

Testing has demonstrated that different calibration curves are generated in different test facilities with the cylindrically shaped transducers. It is assumed that this behavior is due to the differing characteristics of the flow field. Tow facilities move the transducers in relation to motionless water while flow facilities move the water in a turbulent fashion past a stationary transducer. Thus, in the first case, the water appears laminar to a moving transducer and, in the latter, turbulent. It is speculated that the resulting boundary layer difference accounts for the significant calibration

[2] Directivity is defined in table II.

Table I.—**Instrument characteristics**

Manufacturer and model number	EPCO T/S 750B	Marsh-McBirney 711	Comex MK III	Schlumberger CS 24AD
Transducer shape	Cylindrical	Cylindrical	Streamlined	Streamlined
Output (full-scale)	±1 volt (±5 kt)	±1 volt (±10 fps)	±2 volts (±2 mps)	±2 volts (±2 mps)
Magnet drive	30-Hz square wave	30-Hz square wave	17-Hz sine wave	20-Hz sine wave
Electrodes	2-pair nonmetallic	2-pair nonmetallic	2-pair metallic	2-pair metallic (recessed)
Power (d-c in all cases)	±6 volts @ 20 ma	±6 volts @ 40 ma	+12-16 volts @ 65 ma	±7 volts @ 40 ma
Transducer dimensions (diameter × height)	0.75 in × 10 in (1.9 cm × 25.4 cm)	7 in × 8 in (17.8 cm × 20.3 cm)	15.6 cm × 17.0 cm (6.1 in × 6.7 in)	16.0 cm × 1.1 meters* (6.3 in × 43.3 in)

*In the case of the Schlumberger instrument, the sensor and processing electronics are in a single package.

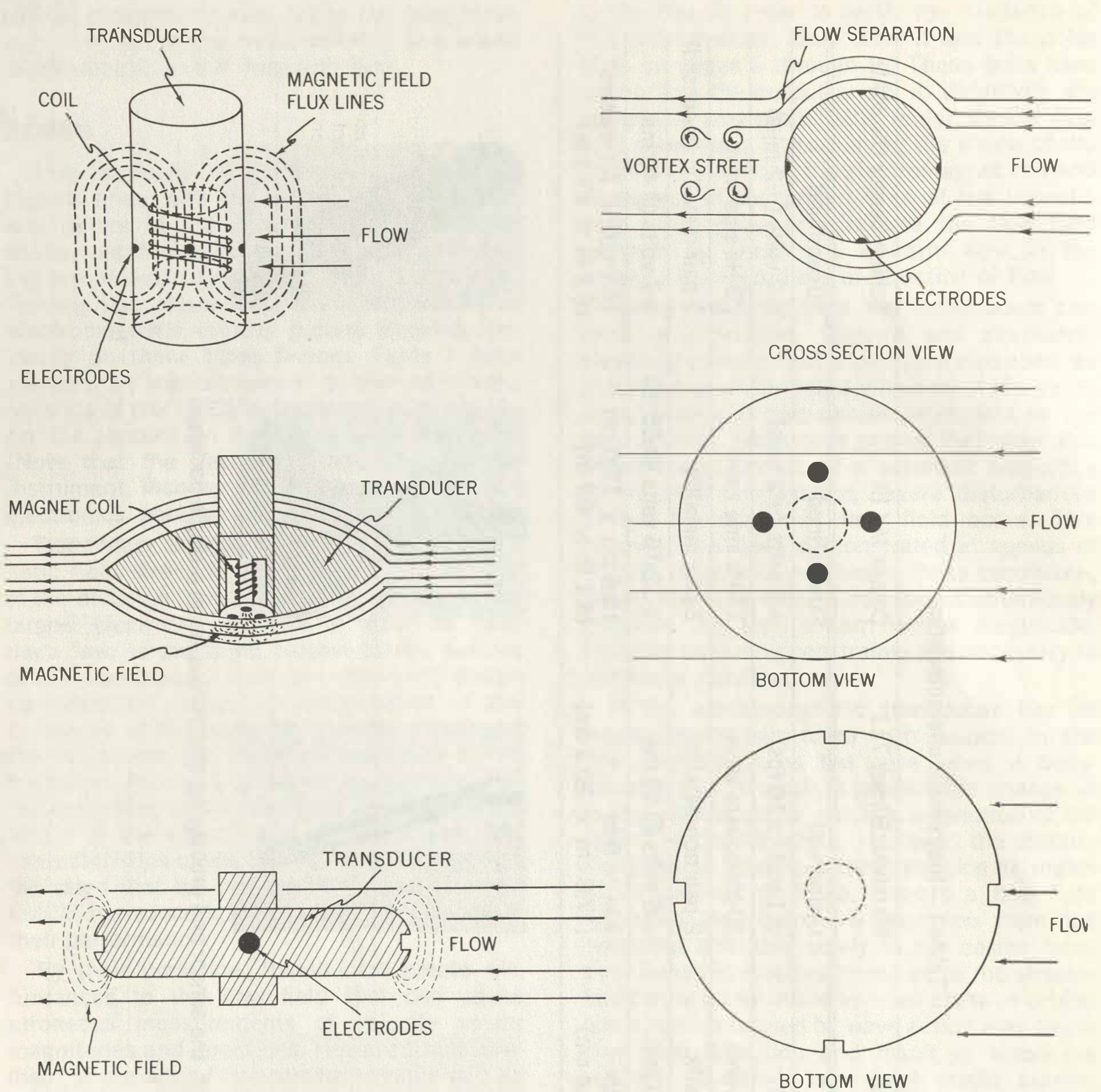


Figure 1. MAGNETIC AND HYDRODYNAMIC FIELD CONFIGURATIONS
At the top is shown the cylindrically shaped EPCO and Marsh-McBirney transducers. The lower two are the streamlined shapes of the Comex and Schlumberger respectively.

variance (10 to 15%), depending on which facility is used.

Care must be taken with all electromagnetic transducers to preclude physical interference with the flow field. Protective cages, supporting structures, mounting fixtures, and cables can result in flow field distortion that may significantly change the relation between the instrument output and the true free-stream velocity.

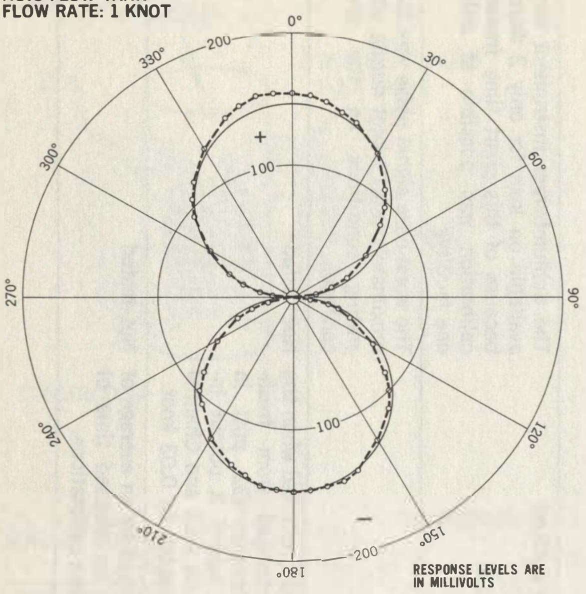
Electromagnet—Another area relating to EMCM performance is associated with the electromagnet. An obvious weakness in the design of EMCM instruments is the significant power consumption—primarily by the electromagnet, especially for long-term, self-contained operation.

Perhaps the most important aspect in electrical design relates to the electromagnet drive signal. Electrode polarization due to the resulting constant polarity precludes the use of permanent magnets or d-c powered electromagnets in these systems. Rather, a magnetic

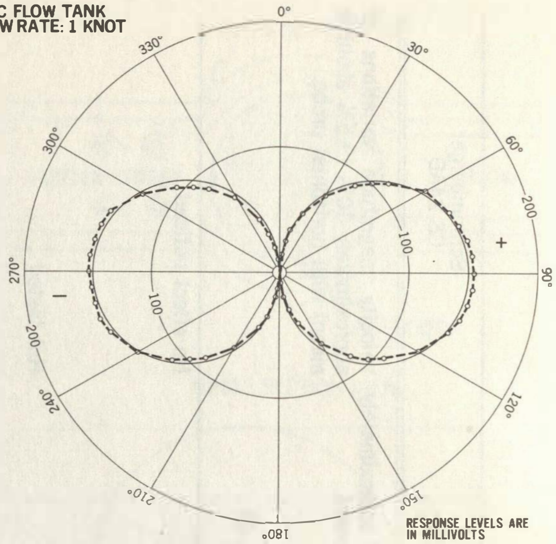
Table II.—**Table of performance characteristics**

Performance Characteristics	EPCO Model T/S 750B	Marsh-McBirney Model 711	COMEX Mark III	Schlumberger CS 24AD
Directivity*	Velocity magnitude variations of approximately 10% (±5% about a mean) with horizontal probe rotation of 360 degrees. The magnitude of error is dependent on flow velocity and angle. (See page 2.)	Velocity magnitude variations of approximately 10% (±5% about a mean) with horizontal probe rotation of 360 degrees. The magnitude of error depends on flow velocity and angle. (See page 2.)	Velocity variations of approximately 4% (±2% about a mean). (See page 2.)	Velocity magnitude variations of approximately 10% (±5% about a mean) with horizontal probe.
Vibration	Probe and test fixture vibration in a flow stream may create a 20% increase in output. Vibration frequencies and amplitudes critical to this phenomenon have only occurred at speeds greater than 2 knots.	Same as EPCO	No effect noticed	No effect noticed
	Vibration induced into the probe or electronics at 30 Hz (the magnetic field frequency) resulted in a resonance of the output signal and rendered it useless.	Same as EPCO	No effect noticed	Not tested
Calibration	Differences in calibrations at various facilities have not been resolved, and extreme caution should be exercised in using calibration numbers.	Same as EPCO	No difference noticed	The Schlumberger instrument was available on loan for only 2 days; because of this short time frame, calibration was possible at only one facility.
Noise	The EPCO unit is more susceptible to spurious noise sources than the others.	See page 10.	See page 10.	The worst-case signal noise was approximately ±0.19 knot during operating conditions on the tow carriage.
Zero drift	None noticed	None noticed	The largest shift occurred when the probe was changed from freshwater to saltwater (32 ppt) in which case Channel X output increased by 0.04 knot and Channel Y output decreased by 0.03 knot.	Not tested
Long-term stability	Not tested	Not tested	The gain changed by an average of +7.5% after an elapsed time of 43 days between calibrations.	Not tested

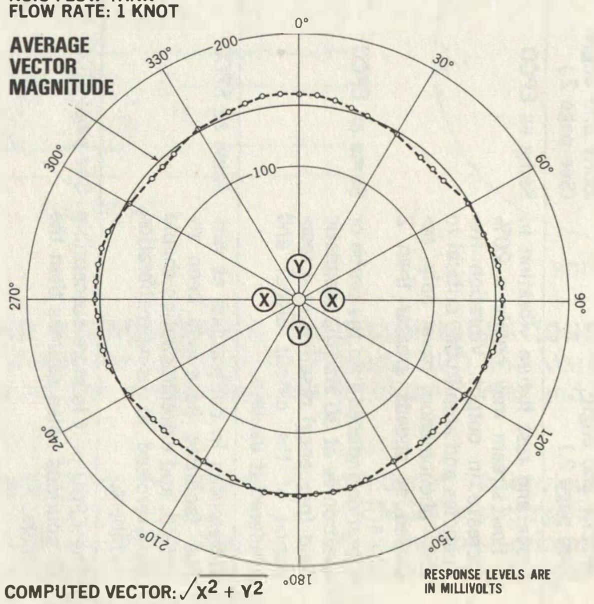
* Directivity is defined in the addendum on page 11.



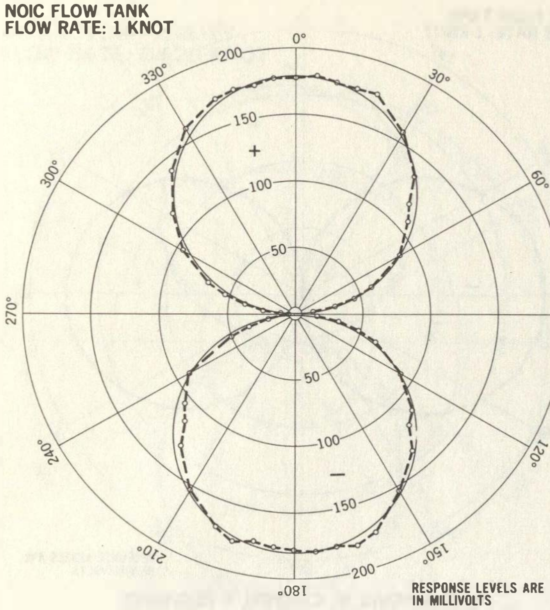
MARSH-McBIRNEY MODEL 711, CHANNEL X RESPONSE



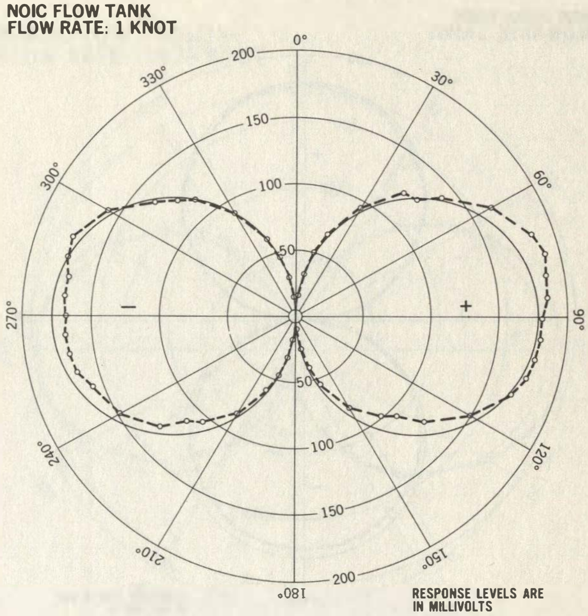
MARSH-McBIRNEY MODEL 711, CHANNEL Y RESPONSE



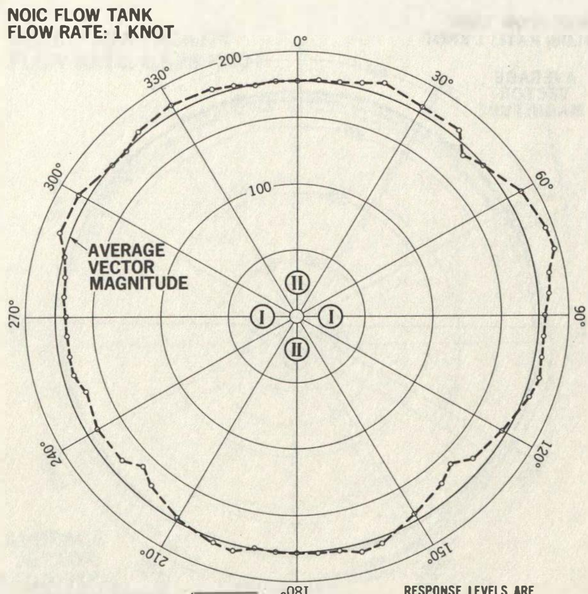
MARSH-McBIRNEY MODEL 711, DIRECTIVITY



EPCO MODEL T/S 750B, CHANNEL I RESPONSE

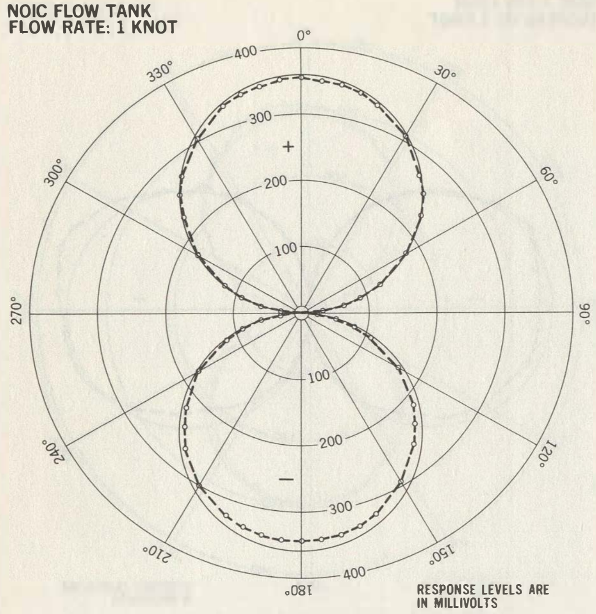


EPCO MODEL T/S 750B, CHANNEL II RESPONSE

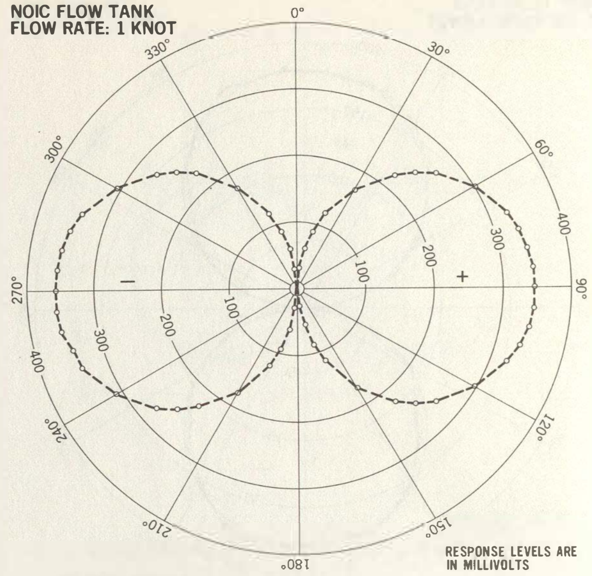


COMPUTED VECTOR: $\sqrt{I^2 + II^2}$

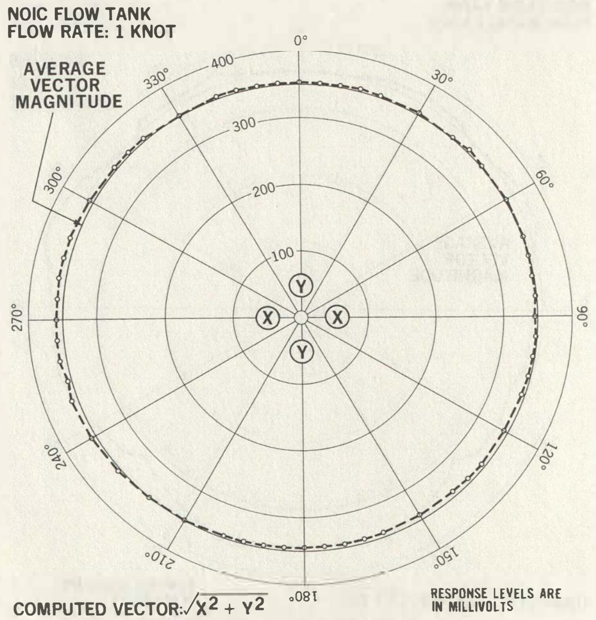
EPCO MODEL T/S 705B, DIRECTIVITY



COMEX MARK III, CHANNEL X RESPONSE

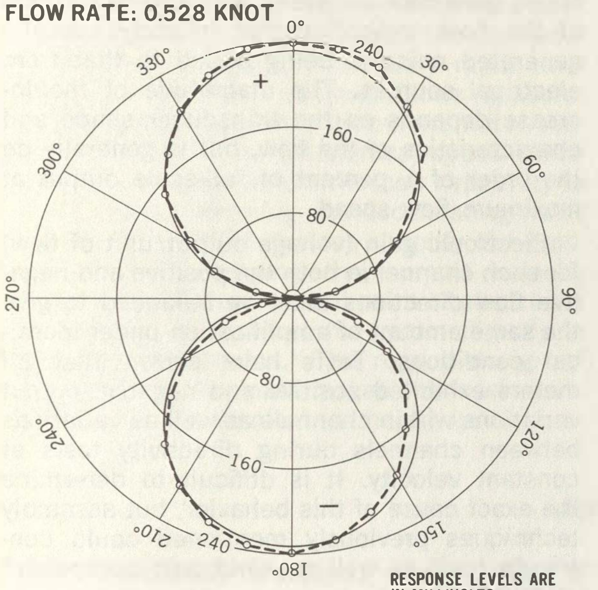


COMEX MARK III, CHANNEL Y RESPONSE



COMEX MARK III, DIRECTIVITY

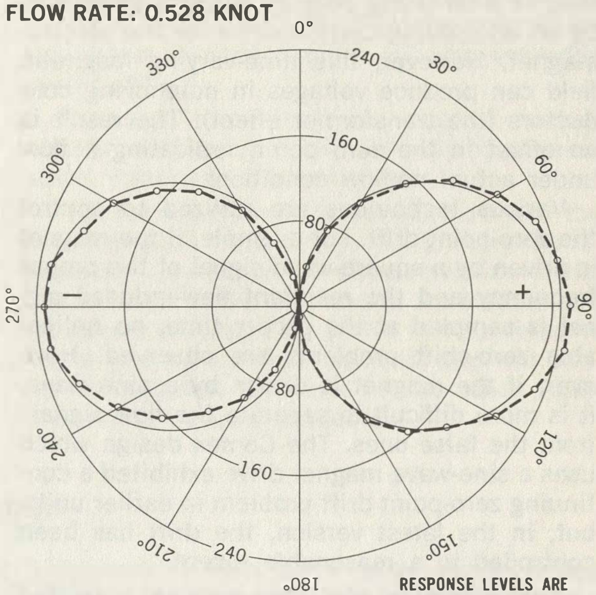
NSRDC TOW FACILITY
FLOW RATE: 0.528 KNOT



RESPONSE LEVELS ARE IN MILLIVOLTS

SCHLUMBERGER MODEL CS 24AD, CHANNEL X RESPONSE

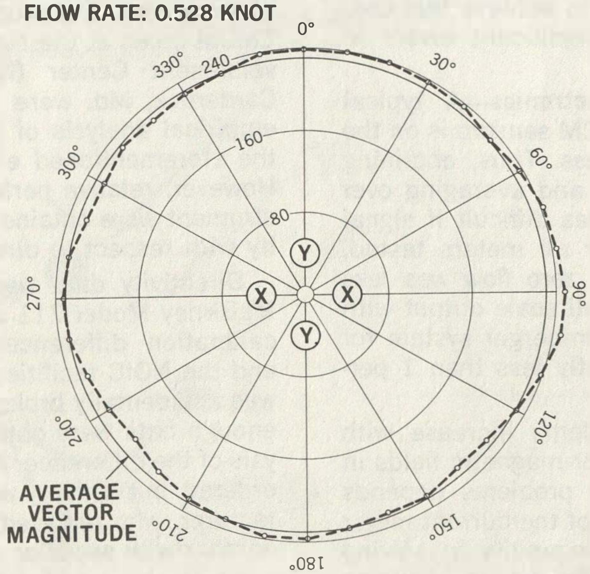
NSRDC TOW FACILITY
FLOW RATE: 0.528 KNOT



RESPONSE LEVELS ARE IN MILLIVOLTS

SCHLUMBERGER MODEL CS 24AD, CHANNEL Y RESPONSE

NSRDC TOW FACILITY
FLOW RATE: 0.528 KNOT



RESPONSE LEVELS ARE IN MILLIVOLTS

COMPUTED VECTOR: $\sqrt{X^2 + Y^2}$

SCHLUMBERGER MODEL CS 24AD, DIRECTIVITY

field of alternating polarity is used, generated by an alternating current drive for the electromagnet. However, this time-varying magnetic field can produce voltages in nonmoving conductors (the transformer effect). The result is an offset in the zero point, indicating a flow under actual no-flow conditions.

Various techniques are utilized to control the zero-point drift. For example, if the magnet is driven by a square-wave signal of the proper frequency and the resultant flow-induced signal is sampled at the proper time, no noticeable zero-shift problems are observed. However, if the magnet is driven by a sine wave, it is more difficult to separate the flow signals from the false ones. The Comex design which uses a sine-wave magnet drive exhibited a continuing zero-point drift problem in earlier units, but, in the latest version, the drift has been controlled to a reasonable extent.

Selection of an electrode material is related to the type of magnet drive signal. The proper combination of the two is thought to minimize noise as well as zero drift (due to the transformer effect and temperature and salinity changes in the water.) (See table II.)

The assembly of the transducers is critical, and extreme care is necessary in placing the electrodes exactly 90 degrees apart and to center the electromagnet coil so that the field is uniform and of equal strength with respect to each electrode. Failure to achieve this configuration can result in significant errors in directivity response.

Signal-Conditioning Electronics—A typical response time of most EMCM sensors is on the order of one second or less. Thus, obtaining turbulence measurements and averaging over short periods often becomes difficult if signal noise levels are high. For all meters tested, system electrical noise at zero flow was less than one-half percent of full scale output with the exception of the Schlumberger system for which the figure was slightly less than 1 percent of full scale.

Noise elimination problems increase with the presence of electrical or magnetic fields in the area. Resolving these problems depends on the rejection capability of the current meter electronics and operator ingenuity in solving ground-loop problems and/or investigating noise sources. In some cases, noise characteristics inherent in the test facility prevented satisfactory velocity calibrations on the EPCO T/S 750B unit (saturation of the measurement channels) and made analysis of the output signals from the Schlumberger system difficult.

Noise generally increases with the magnitude of the flow, indicating that hydrodynamically generated noise is being added to that from electrical sources. The magnitude of the increase depends on the transducer shape and characteristics of the flow, but is generally on the order of 1 percent of full-scale output at maximum flow speed.

Electronic gain (voltage output/unit of flow) for each channel in both the positive and negative flow directions must be balanced to give the same amount of amplification under identical conditions. Tests have shown that all meters exhibited positive and negative output variations within channels as well as variations between channels during directivity tests at constant velocity. It is difficult to determine the exact cause of this behavior, but assembly techniques previously mentioned could contribute to it as well as electronic component stability.

TESTING SUMMARY

Operational difficulties, investigation of noise sources, and various other difficulties associated with the electromagnetic current meter test program consumed large quantities of time. Manufacturer repairs and replacements necessitated retesting and rescheduling of programs. Data on the EPCO T/S 750B EMCM taken at the Navy Ship & Research Development Center (NSRDC) tow facility at Carderock, Md. were inadequate to make an empirical analysis of performance because of the aforementioned electronic noise problem. However, relative performance data on the instrument were obtained at the NOIC flow facility with respect to directivity.

Directivity data were taken on the Marsh-McBirney Model 711 at the NOIC facility, and calibration differences between the NSRDC and the NOIC facilities were found. The probe was accidentally broken during a test, and not enough data were obtained for empirical analysis of the difference. A replacement probe was ordered, but delivery was delayed by the manufacturer, who reported that he was developing another with superior directivity response.

Evaluation of the Comex test results indicated a shift in electronic gain with time. Preliminary tests on a Schlumberger unit indicated a malfunction in the compass circuit, and it was returned to France for repair. Another Schlumberger unit was briefly tested, and preliminary results are reported herein.

REMARKS

Electromagnetic current meters offer several advantages when compared with the mechanical transducer types. A relatively rapid time response (less than 1 second) allows measurements of high-frequency turbulent water motions. The inertia of mechanical speed transducers (rotor impellers) limit their capability to respond to accelerating and decelerating water masses. The EMCM devices simplify the problem of time-averaging the current velocity vector since two orthogonal pairs of electrodes can be used to measure the vector directly in Cartesian coordinates.[3] The rugged design of the EMCM instruments makes them less susceptible to mechanical damage during prolonged usage. Also, the EMCM types are less likely to be affected by fouling and corrosion, which is a serious problem for the rotor when implanted in certain areas for any extended period of time.

However, electromagnetic current meters are still considered to be in the developmental stage, especially the transducers.

It is the intention of this report to make the oceanographic community—particularly the researchers—aware of the characteristics of the instruments based on results from field and laboratory testing. The Center will continue to investigate EMCM developments and will publish subsequent technical reports when additional data become available.

ADDENDUM

Directivity is defined as the ability of an instrument to provide a polar vector whose magnitude and angle accurately reflect both the rate of water flow and its relative direction. This polar vector results from a transformation of the X and Y Cartesian coordinate measurements in a plane perpendicular to the longitudinal axis of the probe, as indicated in figure 2. (Directivity is sometimes called the "cosine response" since each channel output should obey such trigonometric behavior as the probe is rotated about its vertical axis.) Thus, in accordance with figure 2,

$$V = \text{Vector magnitude} = (X^2 + Y^2)^{1/2}$$

and

$$\theta = \text{Vector direction} = \tan^{-1} \frac{Y}{X}$$

where

X = Voltage measured from X pair of electrodes
Y = Voltage measured from Y pair of electrodes
V = Resultant vector magnitude
θ = Resultant vector direction

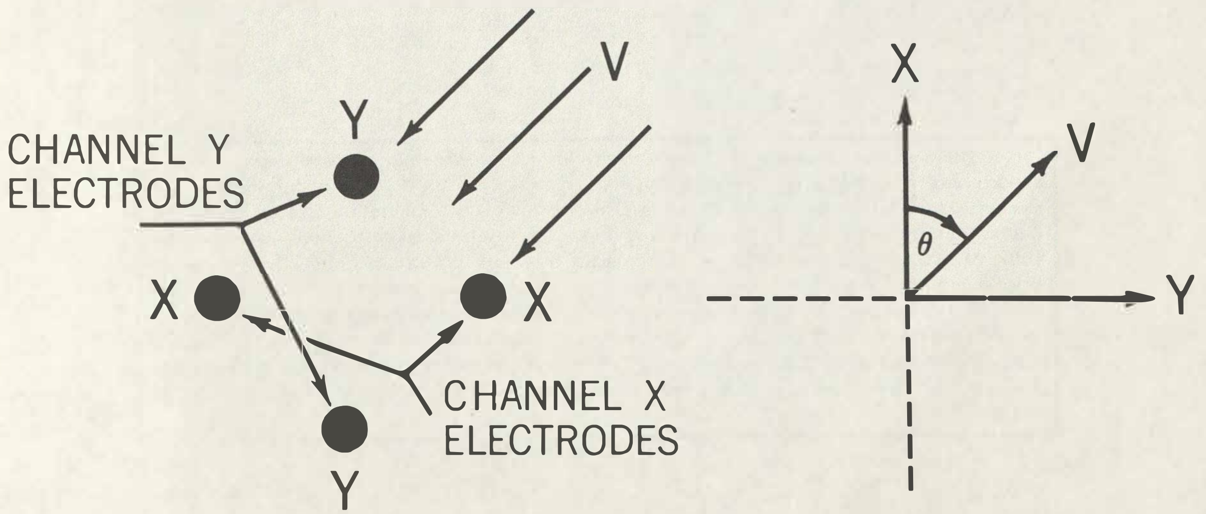


Figure 2. POLAR VECTOR TRANSFORMATION

[3] The mechanical instruments require an additional speed transducer for determining relative current direction. This requirement creates the problem of correlating information from two transducers with different responses to obtain vector information.

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