

## DESIGN OF A MICROCOMPUTER-BASED FLOW MEASURING INSTRUMENT

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### ABSTRACT

The design of a direct reading flow measuring instrument that measures flow speed, direction of flow, and deployment depth is described in this paper. The objective was to design an instrument capable of current profile measurements in high velocity regimes with large sediment loads, and where rotary tidal currents are prevalent. Since the instrument had to be used continuously, and the users would not always be skilled, the unit was designed to automatically acquire, process and display the three parameters. In order to achieve these design goals, a single-chip microcomputer was used. Use of a simple, new technique to display data, reduced hardware requirement and software overheads. The speed calibration results has shown that at least upto a range of 320 cms/sec the response is linear and repeatable from one unit to another, indicating that the instrument is suitable for measurement in high flow regimes.

### INTRODUCTION

Study of water movement is essential for many ocean engineering design applications. As carriers of thermal and kinetic energy, sediments, dissolved nutrients, and pollutants -- water currents have an important influence on climatic, geological, biological, and pollution aspects of the environment (Trygve Gytre, 1976). In addition, such measurements are also required to determine the average cross-sectional current in rivers and are, therefore, valuable tools in intelligent water resource management (W.D. Gonsalves et al, 1981). The fact that most ocean engineering activities occur in relatively shallow depths, (Terene et al, 1981), where surface currents can differ considerably in magnitude and direction from currents at

depths (T.M.Georges, 1981) sharply focusses on the need for current profiling instruments for shallow water applications.

The flow measuring instrument described here is intended for in-situ measurements in high flow regimes up to a depth of 60 metres, and can be operated from simple country craft. Such an instrument must be rugged in nature, easy to deploy and retrieve, and capable of withstanding hostile marine environments. It should also use simple measuring techniques so that signal processing and data presentation in engineering units can be handled with minimum hardware complexity, in turn, giving increased reliability. The primary goal of the present work was to develop a direct reading flow meter for measurements at estuaries

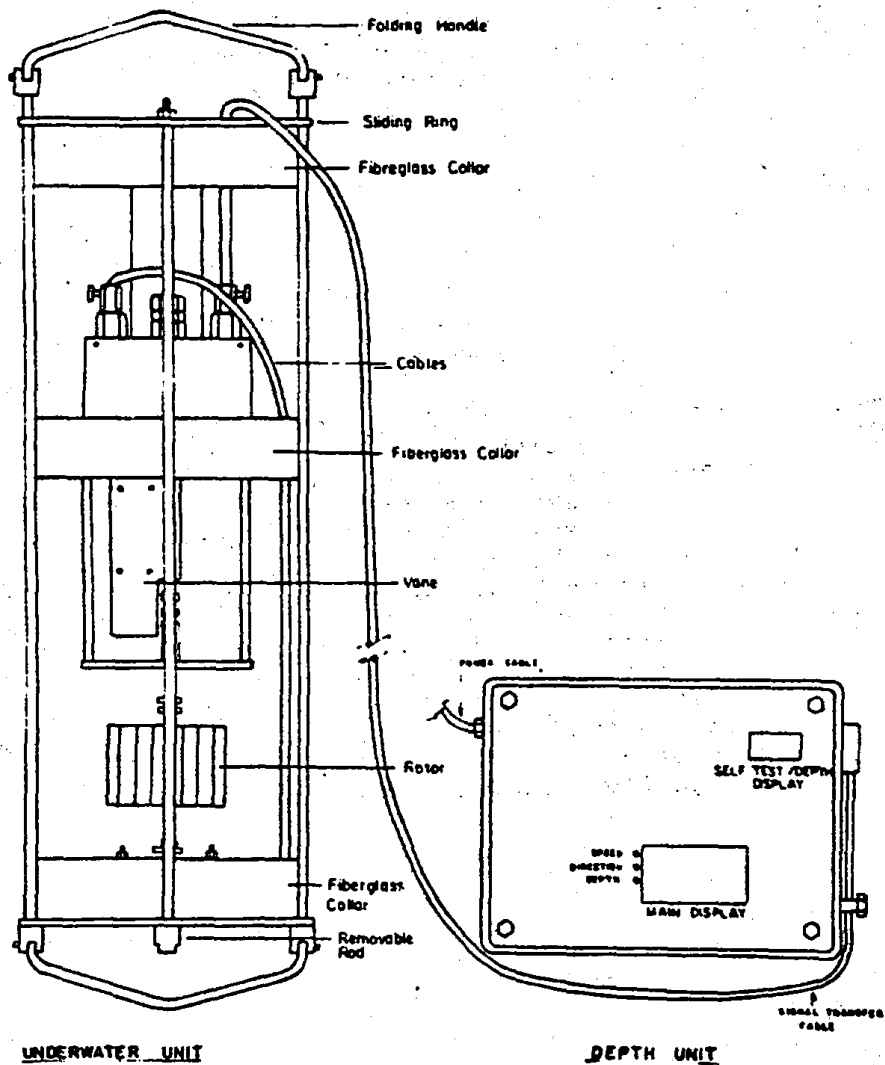


Figure 1. Instrument drawing.

and regimes with a maximum flow velocity of 450 cms/sec, with a speed accuracy of  $\pm 5$  cms/sec. The direction accuracy was to be  $\pm 7$  degrees. A rotor current meter (See Figure 1) would be able to satisfy the above demands. We, therefore, incorporated a Savonius rotor for speed sensing and a miniature vane for direction. A simple potentiometric pressure sensor gave the depth readings.

Easy deployment of the instrument at a predetermined depth required that the depth be displayed continuously. As a programmable device provides greater flexibility to handle differing processing needs and requires few components, we have incorporated a single-chip microcomputer in the design. The electronics was divided into 2 sections - signal conditioning circuitry in the underwater unit, and the timing, processing & display sections on a deck-unit. Six prototypes have been built, and are under test at the Calcutta Port Trust. Ten more are being manufactured for in-house Institute research programmes.

### DESIGN CONSIDERATIONS

The instrument design involved both mechanical and electronic design of the underwater unit and the deck-based data terminal. The criteria for the underwater unit design was ruggedness to withstand hostile marine environment and ease of deployment and retrieval. The underwater unit, designed for vertical mounting, essentially consisted of three sensors for speed, direction, and depth; and two water-proof casings for the speed electronics and for the direction. The deck-based data terminal essentially consisted of a single printed circuit board (p.c.b) seated inside a weather-proof casing. The design criteria was completely automatic acquisition, processing, display of data in engineering units, and minimal component count.

#### Mechanical design.

In the underwater unit, the Savonius rotor was used due to its simplicity in construction. In order to reduce rotor bearing wear due to sediment collection, the rotor was inverted to prevent sediment collection in the bearing caps.

The speed detection assembly consisting of a follower magnet, reed-relay, and associated signal conditioning electronics was fitted within a circular step in a housing below the rotor. Electrical connections were taken via an underwater cable whose inlet on one side of the housing was sealed by an 'O' ring. The housing was closed by an s.s.cover plate with another 'O' ring seal and was fixed below the circular plate, on whose central pivot the rotor's female end rested. It was also protected by four s.s.pillars surrounding it.

The direction sensing vane was designed as an open wedge to reduce the effect of jitter arising from turbulent flow. The neutrally buoyant vane aligned in the flow direction even if the underwater unit was tilted from the vertical. The vane was mounted between two circular

s.s. plates above the rotor. The mid-points of the rotor and vane were kept 15 cms apart so that these two measurements could be made at essentially the same point. The miniature vane, free to rotate between two teflon bearings about the instrument's axis and within the instrument frame, not only allowed easy deployment and retrieval but also prevented formation of undesirable torques on the cable and mooring line. The vane was magnetically coupled to a direction sensing (d.s) assembly shown in Figure 2. The angular position of the vane was magnetically transferred to a single-turn circular potentiometer. The 'zero' of this potentiometer and that of a north-seeking magnetic compass lay on an arbitrary reference plane passing through the axis of the d.s. assembly. An L-shaped support, whose reference line lay on the above reference plane, allowed correct alignment of the potentiometer to the 'zero' of the magnetic compass. The magnetic compass was kept

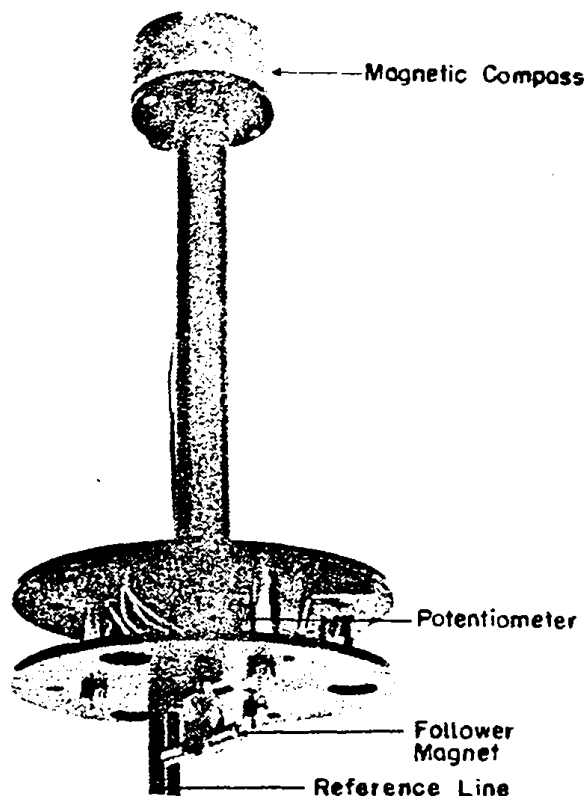


Figure 2. Direction sensing assembly.

sufficiently distant from the vane magnetic coupling arrangements. Immediately above the vane, a brass water-proof casing housed the d.s. assembly. The whole arrangement was fixed within four s.s. rods, and two s.s. annular rings. The top ring slid freely on the rods, allowing easy insertion of the underwater unit into the cage. The fourth rod was

removable and locked the unit at either end. This method allowed the sensors and other fragile parts to be protected from external shock. Further, fiberglass reinforced collars covered by neoprene rubber seals protected the system from external impacts. Folding steel handles at either end of the cage permitted easy transport and a means of maintaining the underwater unit vertically during high velocity measurements. The cage could support 500 Kgs of dead weight.

The data terminal was mounted in a weather-proof housing. A perspex closing lid with rubber sealing served as the front panel. In order to achieve readability of the displayed data, we had kept the two sets of 3-digit, 7-segment data display leds in a dark background. For this purpose, the perspex sheet, except the area immediately in front of the leds, was further covered by an opaque sheet and each set of leds was maintained at the bottom of a blackened tube provided with a red filter. The tube was inclined to prevent sunlight obscuring the leds. The blackened tube provided a dark background to the leds. The filter in front of the leds prevented display washout in the presence of moderate ambient light and increased the contrast ratio of the display (J.E.Gillberg, 1980). An 8-pin Amphenol connector at one side of the data terminal allowed its decoupling from the underwater unit when the instrument was not in use.

#### Electronic design.

The electronic design involved rotor-signal conditioning, generation of precise time delay, acquisition, processing, and

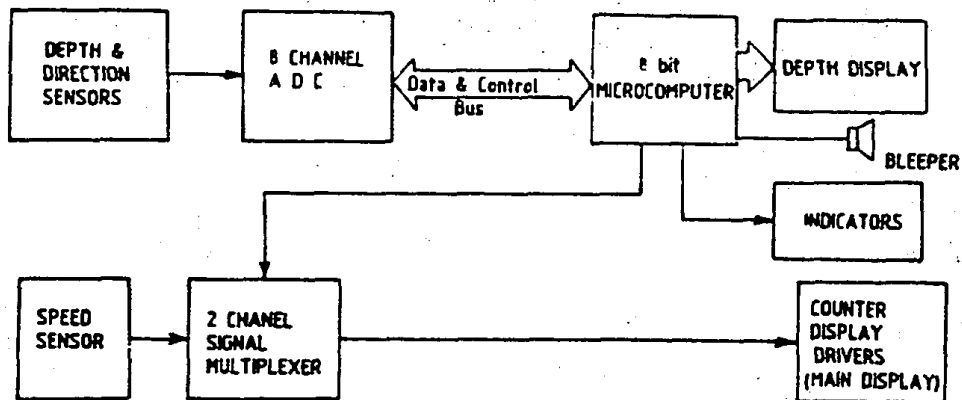


Figure 3. Schematic block diagram of electronic circuitry.

continuous display of depth on an auxiliary display, flow direction determination, and display of the three parameters in a given sequence on a main display. The pulse count interval could be ascertained only after tow-tank tests and flexibility had to be provided for its variation. The programmable timer and timer interrupt facility on the Intel 8748 was used for this purpose. A schematic block diagram of the

electronic circuitry is shown in Figure 3, and the instrument operation is schematically shown in Figure 4:

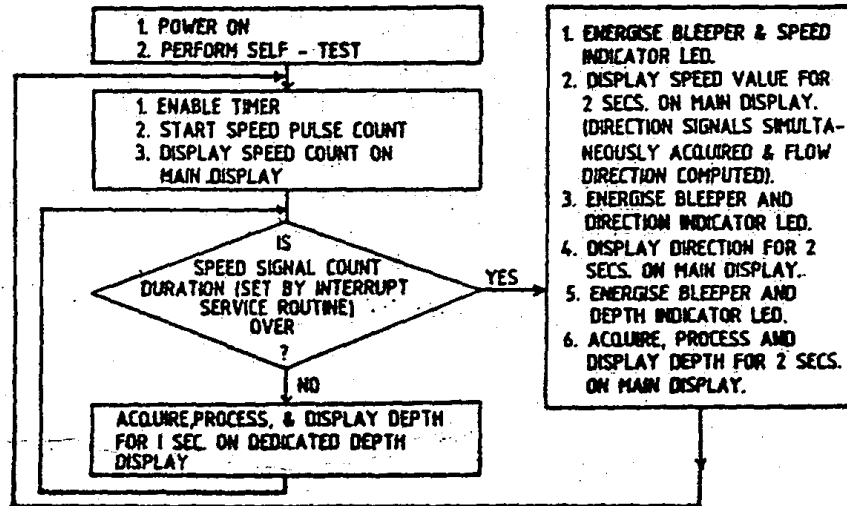


Figure 4. Flow chart showing instrument operation.

(i) Speed signal conditioning.

The advantages of reed-relays are high on-off resistance ratio and long life time under inhospitable conditions (P. Brown, 1983). However, being an electro-mechanical device, the reed-relay suffers from contact bounce, i.e., immediately after a contact closure the two contact surfaces vibrate together, while still in contact, resulting in the generation of noise on the reed-relay's output signal. If, therefore, the reed-relay output was directly applied to a pulse counter, multiple transitions resulting from noise might cause registration of a higher flow speed reading. In order to circumvent this problem, the filtered output of the reed-relay had been applied to a CMOS Schmitt trigger, ideally suited for very high noise immunity because of the hysteresis built into it.

The Schmitt trigger is characterised by two threshold voltages at which its output trips between states. Any spurious effect on the input signal must be greater than the threshold difference to cause multiple transitions (Gerald Buurma, 1980). A CMOS Schmitt trigger should provide enough hysteresis to overcome almost any spurious signal due to reed-relay contact bounce. If, however, the spurious signal happened to be greater than the threshold difference, multiple transitions could occur at the Schmitt output. To avoid this, the Schmitt output was further conditioned via an edge-triggered monostable. Upon recognition of the appropriate edge, the monostable output remained high for 25 milliseconds, irrespective of any further transitions at its input within this period. Spurious effects less than this duration were, therefore, prevented from triggering the counter.

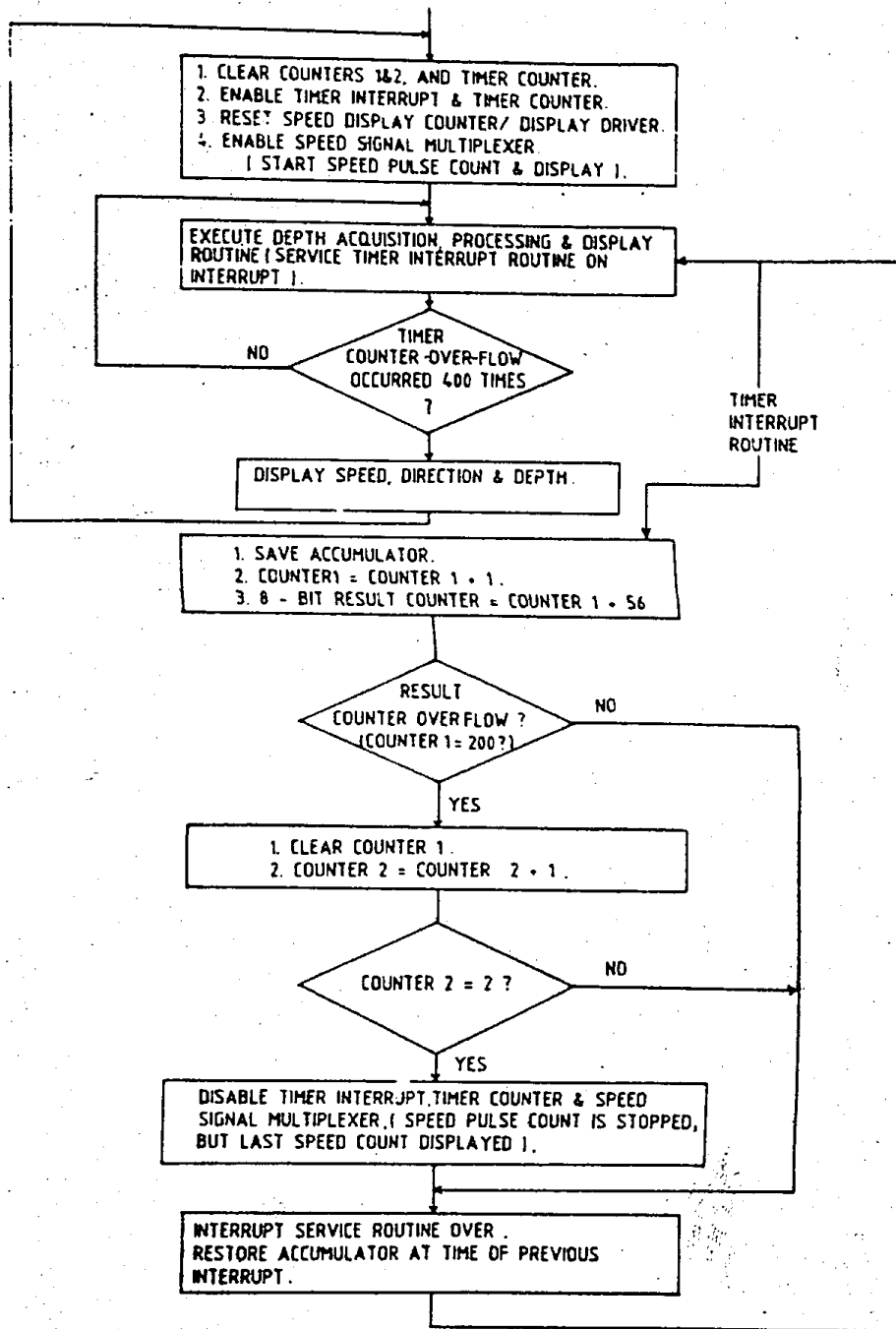


Figure 5. Algorithm for simultaneous servicing of speed and depth.

(ii) Time delay generation and display of depth.

In earlier designs (A. Joseph et al, 1981), rotor-pulse gating time was generated by dividing down a clock signal of known frequency. The primary signal for this purpose could be derived from a crystal controlled oscillator, and the gating time would, therefore, be precise. This method, however, had the drawback that flexibility in generation of any desired gating time interval was absent, and it became difficult to accommodate a deviation without change in hardware.

The time delay generation implemented in the present work utilised the processor's built-in programmable timer counter whose input signal was derived from the processor's crystal controlled oscillator. The crystal offered precision whilst programmability provided flexibility. Utilisation of timer overflow interrupt facility available with this processor for speed-pulse-gating time-delay generation not only freed the processor from the burden of execution of a dedicated time delay routine but also allowed the processor to acquire and process pressure sensor output and display deployment depth every second.

The input clock to the 8-bit timer was derived by internal division of the onboard crystal oscillator output by 480. For an on-board oscillator frequency of X Hz, the period of the input clock to the timer was, therefore,  $(480/X)$  seconds. After clearing, the timer overflowed at the 256th pulse. Therefore, the time required for a timer overflow, after its reset, would be  $(122880/X)$  seconds. The number of timer overflows corresponding to a time interval of N seconds is, therefore, equal to  $(XN/122880)$ . A crystal of 2.097152 MHz was chosen for the on board oscillator so that the programmable clock output externally available at the processor could be directly used as the clock input to the data terminal's A/D converter. Tow-tank test results indicated that the rotor pulse count interval should be 23.44 seconds for the current meter's speed output to represent flow speed in cms/sec. Substituting the values of X and N in the above formula, the number of timer overflows corresponding to a time delay of 23.44 seconds worked out to be 400. Setting a time delay of 23.44 secs, thus, amounted to allowing the timer to overflow 400 times after its reset. This could be accomplished by incrementing an overflow-counter after every timer overflow and then disabling the timer when the content of the overflow counter equalled 400. As the number 400 could not be stored in an 8-bit register, the number 56 was initially stored in the overflow register and it was incremented by one after every overflow of the timer. An overflow of the overflow-register signified that the timer overflowed 200 times. The process of storing 56 and checking the overflow of the overflow register was repeated once again. A second overflow of the overflow register meant that the timer overflow occurred 400 times.

Simultaneous servicing of depth and speed display routines was implemented according to the algorithm in Figure 5. Time delay generation and rotor-pulse counting was initiated simultaneously. The pressure sensor output signal, D, was acquired, digitized, and deployment depth in decimeters calculated using the formula  $((17031 \cdot D) / 2550) - 41$  and displayed on an auxiliary 3-digit LED display.



A continuously enabled decimal point between the units and tens digit allowed display of deployment depth in metres accurate to one decimal place. Whenever the timer overflowed, a timer interrupt was automatically generated. Upon timer interrupt, execution of depth service routine was automatically suspended and processors' control was temporarily passed on to a timer interrupt routine which checked the number of timer overflows. If it was less than 400, the accumulator content at the time of interrupt was restored and depth servicing was continued from where it was suspended. If, however, the timer overflowed 400 times, the rotor pulse-count was stopped, and after display of speed, direction & depth on the main display, the process repeated.

Sr.No.	Trolley Velocity (M/sec)	Instrument Output.	Percentage Deviation.
1	0.2907	0.2800	-3.7
2	0.4263	0.4106	-3.7
3	0.5497	0.5450	-0.9
4	0.8092	0.8400	+3.8
5	1.0714	1.1100	+3.6
6	1.4545	1.4900	+2.4
7	1.7964	1.8200	+1.3
8	2.0809	2.1100	+1.4
9	2.2950	2.3200	+1.1
10	2.6067	2.6700	+2.3
11	2.8333	2.8700	+1.3
12	3.2086	3.2700	+1.9

Table 1. Speed calibration results.

In order to find out the maximum speed the instrument would measure, a test jig with a motor was fabricated and coupled to an Aanderaa current meter. The rotor on the present instrument and that on the Aanderaa instrument were rotated at the same speed in various steps. Both readings tallied exactly upto a speed of 466 cms/sec.

Six prototypes of the instrument were later calibrated in the ship's testing tank at C.W. & P.R.S, Pune, for velocities from 29 to 320 cms/sec. The instrument's speed resolution was 1 cm/sec. All current meters showed the same trend. A typical result from one current meter is shown in Table 1.

(iii) Flow direction determination.

Flow direction was determined using the two signals derived from the d.s. assembly. Let  $\theta_c$  be the angle registered by the compass -- the angle between the reference plane and the earth's magnetic north. Let  $\theta_v$  be the angle registered by the potentiometer at the same instant -- the angle between the reference plane and the plane of symmetry of the vane. The vane represented the direction towards which currents flowed. When  $\theta_c$  was greater than or equal to  $\theta_v$ , then  $(\theta_c - \theta_v)$  gave the

direction of flow with respect to the earth's magnetic north. When  $\theta_v$  was greater than  $\theta_c$ , then  $360 - (\theta_v - \theta_c)$  gave the direction of flow. The potentiometer and the magnetic compass were both excited from a single voltage source and the same voltage was used as a reference to the A/D converter (ADC). This technique ensured that any drift in sensor excitation voltage was automatically taken care of by the ADC, and circumvented the need for a precision voltage source to excite the sensors.

Let  $T$  be the difference between  $\theta_c$  and  $\theta_v$ . Then, direction =  $((360 * T) / 255)$  if  $\theta_c$  is greater than or equal to  $\theta_v$ , else direction =  $(360 - (360 * T) / 255)$ . As the ADC was of 8-bit accuracy, the direction resolution was limited to 1.41 degrees. Rounding of the direction value allowed it to be displayed as a whole number.

The static performance of the direction sensor was evaluated in the laboratory by plotting d.s. assembly outputs for different vane positions. The measurements were repeated with the vane rotated in an anticlockwise direction. The direction errors were comparable to the speed errors. These errors can be attributed to the combined effect of the magnetic compass inaccuracies, potentiometer friction, and the inertia of the potentiometer's coupling magnet. It is expected that this error may be reduced by the use of a plastic potentiometer and a light-weight coupling magnet. In a flow field, one should expect a moderate amount of jitter on the vane. Averaging successive direction values will further reduce this difference.

#### (iv) Data display.

Though liquid crystal displays (l.c.d) provide excellent readability and require the least amount of power, compared to any currently available type of display (S.S.Eaton, 1980), we used 7-segment leds for data display due to their long life and high reliability.

In conventional displays associated with microcomputer based systems, data was either converted to bcd format and input to 7-segment converter chips, or it was directly converted to 7-segment format. In both cases, the number of lines used was large. In the present work, data was serially input to a single-chip display device interfaced to 7-segment leds. This technique not only reduced hardware but required a smaller software overhead, compared to conventional methods of data display (A. Joseph, 1986).

#### CONCLUSIONS

We have described the design of a microcomputer-based, direct reading flow meter which incorporated many useful features. Comparison with Aanderaa recording current meter showed that the present instrument can measure a maximum speed of 466 cms/sec. Speed calibration results showed that at least in the measurement range of upto 320 cms/sec the response is linear. Calibration results of six similar units showed that this linear response is repeatable, though percentage deviations differed slightly from unit to unit. The percentage deviation decreased as speed increased. This indicated that the instrument is suitable for

measurements at high flow regimes. A relatively higher percentage deviation exhibited at low speeds may, perhaps, be reduced by an increase in speed output resolution. This is possible by an increase in the number of reed-relay counts for speed detection. The software flexibility provided in the present design allows easy setting of a new pulse count time if calibration is found to change at a later date. The use of a small vane, free to rotate within the instrument frame, is expected to allow easy deployment and retrieval. The ability to display the updated depth value every second, unaffected by the measurement of the other parameters, is thought to be a useful feature which may allow the underwater unit to be deployed at any desired depth. Though the present method is to display a spot value of direction, while the displayed speed is a time-averaged value, it is possible to display a direction value which had been acquired and averaged during the rotor pulse count period.

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