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Design of Velocity Measurement Circuit for Propeller Type Sensor Used on Physical Hydraulic Models

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ABSTRACT
The studies conducted by Central Water & Power Research Station, Pune, India (CWPRS), provide hydraulically sound and economically viable solutions to various problems associated with projects on water resources. The principle tool for the studies in CWPRS is physical modeling. Water velocity is major parameter in the river and tidal physical models for assessment of performance of hydraulic structures. CWPRS designs and builds state-of-the-art instruments to meet the instrumentation needs that exist in hydraulic research and engineering studies. The propeller type sensor referred in this paper is developed and fabricated in-house. This paper deals with the circuit design and developmental aspects of a signal conditioner of water velocity measurement system using propeller type current meter for physical hydraulic model studies. An attempt is made to design and develop a signal conditioner to produce perfect shaped pulses which are further fed to counter circuit for its calculation and conversion into velocity values as per calibration chart.

Keywords:
Physical Hydraulic Model, Propeller type Current Meter, Sensor, Signal Conditioner, TTL compatibility, Velocity Measurement System.

1. INTRODUCTION

The velocity of water is vital parameter in hydraulic model studies. In physical hydraulic model studies it is required to measure velocities at several locations near the hydraulic structure so as to optimize the design and layout. The velocity can be measured accurately with the help of proper sensor and signal conditioning circuit. In early days, measurement of velocity of water in hydraulic models was carried out using either 'Pigmy' or 'Gurley' cup type current meters or pitot tube then called 'Dapodi Bar' [1]. Development of current meter using propeller sensor started in later sixties in CWPRS. A propeller probe, when placed in flowing water, rotates at a speed proportional to the flow of water. These rotations are converted into electrical pulses, amplified and counted by an electronic counter for a selected duration. Using the stored calibration information the electronic unit displays velocity in cm/sec on a LCD display. Even though, the signal conditioning and display went through a series of development from valves to ICs and telephonic counters, deketron tubes to LCD counter, the basic propeller remained a reliable sensor without appreciable change [1]. Signal conditioning is required to convert propeller sensor signal in such a way that it meets the requirements of the next stage for further processing which is counter with TTL compatible voltage levels. This paper deals with the circuit design and developmental aspects of a signal conditioner of water velocity measurement system using propeller type current meter for physical hydraulic model studies.

2. NEED OF WATER VELOCITY MEASUREMENT IN PHYSICAL HYDRAULIC MODELS

A highly sensitive, accurate and reliable current meter is required for carrying out measurement of time varying fluctuations of water velocity at various

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locations in physical hydraulic model. In these current meters, propeller type velocity sensor is used for velocity measurement. The rotation rate of the precisely calibrated propeller is directly proportional to water velocity. The main features of propeller type current meters are; direct indicating, portable, compatible to PC, battery operated, selectable counter duration and built in self-test facility [2]. Staubli [3] suggested that there is a large variety of types of current meters and applied suspensions. For hydrological purposes current meters are often mounted onto floating elements and immersed with cables from boats or cranes. Wel [4] suggested that propeller type current meter is especially designed for the measurement of turbulent velocities, therefore as many electrical impulses as possible have to be generated by the meter. Staubli [3] also observed that the propeller-type current meters are sensitive to swirl flow. Depending on the sign of vorticity in the flow, the speed of revolution of the current meter will be increased or decreased. The sensor used with propeller type of Current meter in physical models at CWPRS is of 15mm diameter and width 5 vanes. It has velocity range 5-100 cm/sec [2]. Propeller type Current Meter is more suitable than other type to water velocity sensors because of their low cost, simple to operate, highly precise and require low maintenance.

3. CWPRS DEVELOPED ITS OWN SENSOR AND DATA ACQUISITION SYSTEM

Since the precision of commercially available instruments is not meeting to unique requirements of the instruments to be used on down scaled hydraulic models, CWPRS designs and builds state-of-the-art instruments to meet the instrumentation needs that exist in hydraulic research and engineering studies. The direct indicating velocity sensor along with digital indicator is designed for accurate measurement of velocity of water at a point in hydraulic models and in open channels. Fig. 1 shows the basic block diagram of a multi channel water velocity measurement system on physical model.

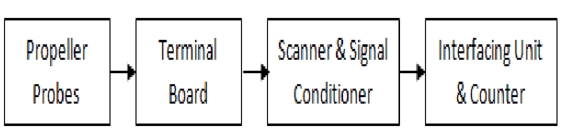
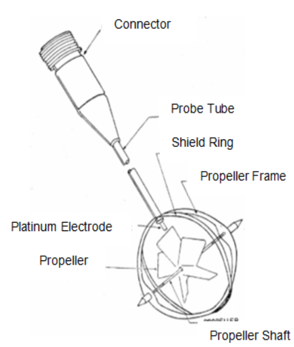


Figure 1: Basic block diagram of a multi channel water velocity logger

Range is from 5cm/sec to 100 cm/sec with 10/15/25 mm diameter propeller [2]. Accuracy is +/- 1% of full scale. Power supply is 4X1.5V AA batteries. Counting duration is 10-50 seconds (at 10 sec interval). Propellers varying in size from 6 mm to 30 mm were developed, fabricated and used in CWPRS on physical models depending on range and size dictated by physical limitations on model. Widely used sensor is with 15 mm diameter and width 5 vanes. It had velocity range of 5 cm/sec to 100 cm/sec [2].

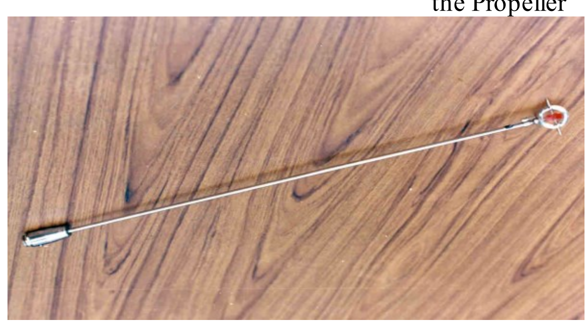
4. SENSOR AND SIGNAL CONDITIONER

The propeller rotates with a speed proportional to the velocity of flow of water. It is mounted on a stainless steel shaft and jewel bearings in the body of a frame, which also carries a platinum electrode, so that each vane while passing the electrode is at a distance of 0.5mm from it as shown in Fig. 2.



(a) Propeller Probe Assembly

(b) Closer view of the Propeller



(c) Propeller Velocity Probe

Figure 2: Propeller type Current Meter

Each time a vane passes the electrode, there is a change of resistance between the electrode and the propeller body. The electronic circuit senses this change and counts the number of times these vanes

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have passed the electrode [5]. This change is sensed as a voltage pulse which is amplified and fed to a Schmitt Trigger to get a square shape.

The frequency to voltage converter following the Schmitt trigger stage gives a voltage proportional to the no of rotations of the propeller which in turn is proportional to the velocity of flow. The instrument operates in the velocity range of 5 cm/sec and to 100 cm/sec and the circuit gives an output voltage of 180 mV for the velocity of 100 cm/sec. the voltages are fed to a commercial data logger [2].

The Platinum electrode mounted on the propeller frame is electrically joined to a connector fixed at the top of the propeller 'probe'. The changes in the value of resistance between the electrode and the propeller frame are sensed by this probe which is connected at the 'input' of the circuit as shown in Fig.3.

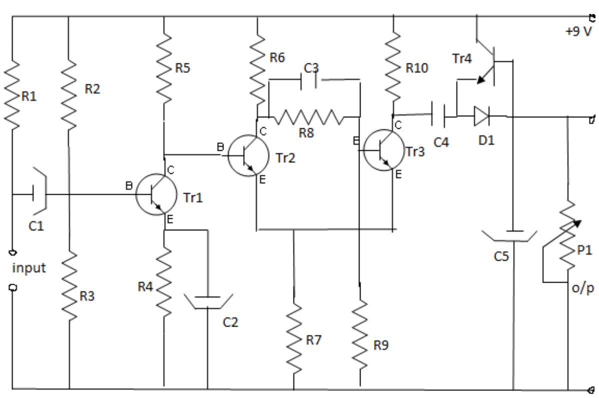

Figure 3: Conventional Circuit of Signal Conditioner

The potential at the junction of resistor R_1 and 'input' changes due to change in resistance at the input terminals as each vane of the propeller passes the electrode. This change is amplified by a common emitter amplifier stage using transistor Tr_1. The output of the amplifier is directly coupled to the Schmitt Trigger. As the collector potential of Tr_1 fluctuates due to propeller rotation, the Schmitt Trigger is set in action producing square pulses at the collector of Tr_3.

The F/V converter consists of C_4, C_5, Tr_4, D_1 and P_1.the output voltage of the converter circuit is given by the equation:

$$V_o = E\, f\, P_1\, C_4$$

Where E is the amplitude of input square pulses and f is the repetition frequency of the input square pulses.

The output can be controlled by P_1 or C_4. This results in ease in adjusting the value of the output at the time of calibration of the system.

The ripple content in the output voltage due to the discharging of capacitor C_5 into P_1 is given by the equation:

$$V_{ripple} = E\, C_4 / (C_4+C_5)$$

The time constant Tp of the circuit is given by the equation:

$$Tp = P_1\, (C_4+C_5)$$

Any increase in the value of C_4 or C_5 would have the advantage of reducing ripple content as also the disadvantage of increasing the time constant. Thus a compromise has to be made for an optimum combination of low ripple voltage V4, maximum output voltage V_o and a small time constant Tp. To ensure the stability of the least significant digit of the reading, the time constant Tp works out to 3 seconds. Since the typical tidal cycle is of the order of 600 seconds, this is considered suitable.

5. MODIFIED SIGNAL CONDITIONER

Digital revolution drives a strong demand for advances in analog electronics. The discrete component size, soldering problems, chances of stray electrical pickup, parasitic capacitance, stray inductances effect etc. are some problems with the old circuit. Therefore the use of discrete components in the conventional signal conditioner circuit was replaced by IC's. Parameters like high speed, small size, low power consumption, small parasitic resistance and capacitance, easy replacement are some important factors considered before designing this circuit. Fig. 4 shows a water velocity sensor and various electronic components of the signal conditioning instrumentation system.

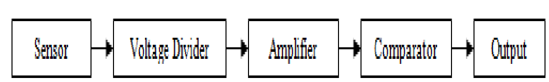

Figure 4: Water velocity sensor and its associated signal conditioning instrumentation system

To measure signal from the propeller vane, it is required to use very high speed, high gain, and large bandwidth operational amplifier. In this circuit a 14-pin quad op-amp digital IC LM 324 is used as comparator. It is used in open loop mode with single power supply of +5 Volts. The highest frequency component present in the signal will decide the sampling frequency of the data acquisition system. Circuit diagram of signal conditioner using op-amp is shown in Fig. 5.

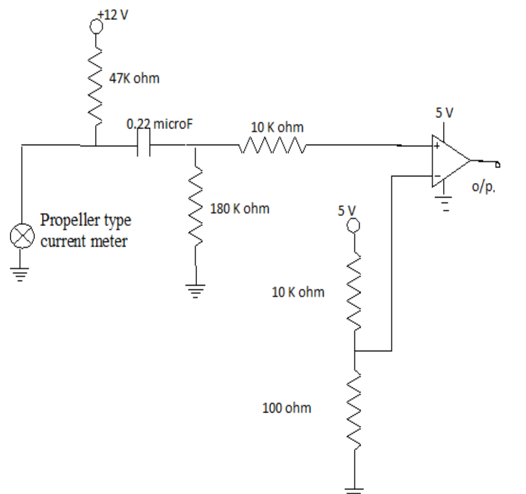

Figure 5: Signal Conditioner using LM 324 OP-AMP

Propeller type current meter is connected at the non inverting terminal of the op-amp. A 0.22 micro farad capacitor removes the DC quiescent output voltage from the sensor, feeding only the tiny pulses output from the sensor into the op-amp. Initially capacitor starts charging through 47 kΩ and 180 kΩ resistors. It discharges through velocity probe. The voltage at pin no. 3 of LM 324 changes according to the change in resistance of the propeller mete. The output of the propeller sensor is a voltage signal, which is very small in value from few milli-volts to several milli-volts (mV) as shown in Fig. 6. This amplitude is related to the sensitivity of the sensor.

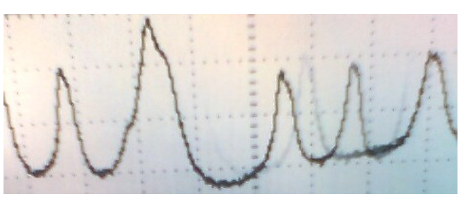

Figure 6: Propeller type Current Meter Output

Under ideal condition the resistance of the propeller probe is approximately 4 mega ohms. LM 324 takes analog voltage signal from propeller type current meter and compares it to a reference voltage, V_{ref}. Reference voltage (V_{ref}) is 50 milli volt and it is coming from a 10kΩ and 100 Ω resistive network. LM 324 output gives only two states either logic HIGH or logic LOW. When the voltage at non-inverting terminal is higher than the reference voltage, the output is set to logic HIGH otherwise the output is set to logic LOW. For each pulse from the sensor the LM 324 gives a pulse of varying widths proportional to water velocity as shown in Fig. 7.

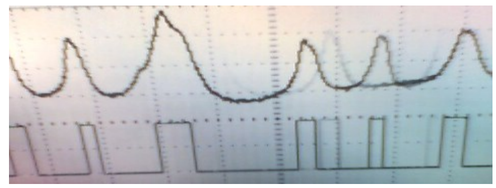

Figure 7: LM 324 Output

These pulses are then sent to a register of counter and finally to a Data Acquisition System to store the information for further data analysis and processing and display the velocity of water in cm/sec. Parameters like; switching speed, propagation delay, current consumption, fan-in, output high voltage, output low voltage, clock pulse width, clear pulse width etc. are considered before designing the circuit because in physical model studies it is required to record water velocities simultaneously from different locations at a very high sampling rate.

The propeller sensor was first analyzed with +5 V excitation supply. Because of some distortions, output was not compatible to drive the next stage therefore excitation supply is changed to +12 V.

There are a number of TTL sub-families available in the market that provide a wide range of switching speeds and power consumption. IC 74LS00, a positive edge triggered NAND gate is connected to the output of LM 324. The propagation delay from LOW-to-HIGH level output of IC 74LS00 is minimum 3 nsec and maximum 11 nsec. The propagation delay from HIGH-to-LOW level output is minimum 2 nsec and maximum 8 nsec. Low level output voltage is maximum 0.5 V [6]. Fig. 8 shows the output of NAND gate.

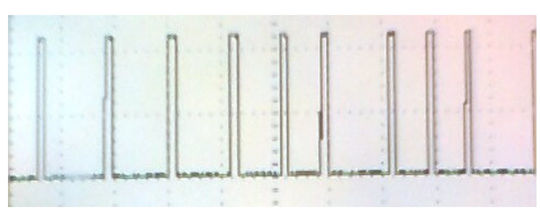

Figure 8: Output of NAND Gate

Some pulses were missing from the sensor signal as shown in Fig. 9. The upper pulses show the output of LM 324 and their corresponding NAND Gate output is given in lower pulses.

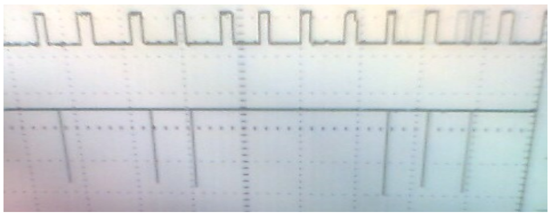

Figure 9: Missing Pulses

The output of op-amp is then analyzed with a negative-edge-triggered JK flip-flop as shown in Fig. 10.

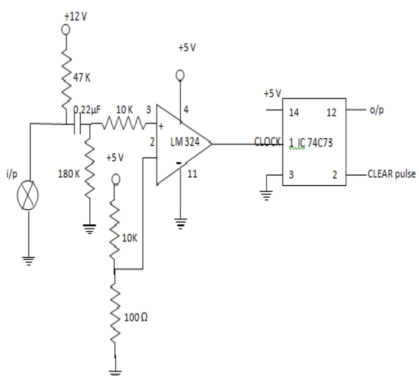

Figure 10: Propeller type Current Meter connected to OP-AMP and LM 74C73

The output of LM 324 is connected to the clock input of JK flip-flop. JK flip-flop is sensitive to the propeller sensor signal. It works on the basis of clock pulses. Whenever there is a change in the sensor signal, the value remembered by the flip-flop becomes 1 as the J input is high and the K input is low. Output of JK Flip-Flop is shown in Fig. 11. It is observed that small peaks are present in the output at top and bottom level of the pulse. These peaks are present as noise voltage in the output which can be removed by filtering the signal. The propagation delay of 74C73 is typically 14 nsec. Transition time is 7 nsec at 25^0C. Input transition rise and fall rate is typically 1.67 nsec/V [6].

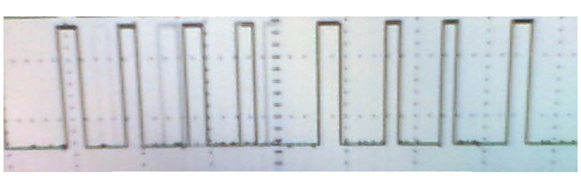

Figure 11: Output of JK Flip-Flop

To improve the noise immunity of the input signal, the output of LM 324 is also analyzed with a positive edge-triggered D type flip-flop(IC 74LS74) with 10 Hz filter to get perfect shaped pulses which can be counted by an electronic counter. The propagation delay of IC 74LS74from LOW-to-HIGH level output and from HIGH-to-LOW level output is typically 25 nsec. LOW level output voltage is maximum 0.5 V and HIGH level output voltage is typically 3.4 V. Output level High is accepted only on the positive going edge of the clock pulse (i. e. propeller's output). The rising edge of the clock signal changes its output as shown in Fig. 12. The shape of the pulses found compatible to drive the next stage of electronic counter to count total number of revolutions for a selected duration.

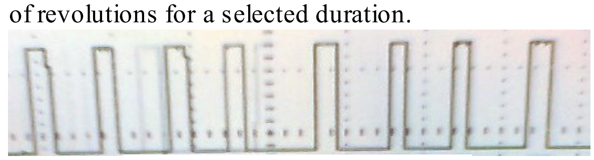

Figure 12: Output of D Flip-Flop

6. RESULTS AND DISCUSSIONS

Greater resolution, high sensitivity and high accuracy are the most important factors in the designing of Signal Conditioner circuit for water velocity measurement system. This signal conditioning circuit for the measurement of flow of water was successfully fabricated on PCB and was analyzed using IC LM 324, IC74LS00, IC 74C73, and IC74LS74. Noise levels sometimes produce a false output switching; therefore a low pass filter of 10 Hz was added to the circuit to remove noise signals present in the propeller output. Circuit was first analyzed with NAND Gate. Some pulses were missing from the sensor signal. Then IC LM 324 Output was connected to the negative-edge-triggered JK flip flop (IC 74C73). Some frequencies are present as noise in the output. LM 324 then connected to the positive-edge-triggered D flip flop (IC 74LS74) with 10Hz filter. The final circuit with D type flip flop as shown in Fig. 13 was more suitable for interfacing unit of Data Acquisition System.

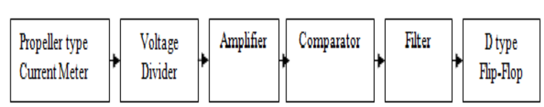

Figure 13: Modified Signal Conditioner

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High level language software can be used with this signal conditioner circuit to read number of channels, reset the flip flop with a reset pulse after each sample and count the pulses of each channel. The calibration data is used for conversion of velocity data into cm/sec. The information on parameters like; number of channels, sampling period, number of scans etc. can be incorporated in the DAS software for further processing and analysis [7].

7. CONCLUSION

Earlier signal conditioner circuit was made up of using discrete electronic components whereas new signal conditioner is replaced with Digital ICs. The signal conditioner is modified so that the output of the D flip flop is buffered to drive TTL load of the electronic counter. Such modification removed unwanted glitches and improved the shape of the pulse which resulted in perfect TTL compatibility.

This modification helped in counting the number of pulses and in term velocity of the water in very precise manner. This circuit improved the behavior of registers useful for storing pulses in computer by incorporating new electronic circuits and software programming. The developed signal conditioner serves as a good tool for future research in water velocity measurement system on physical hydraulic models.

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