ACCURACY IMPROVEMENT OF FLOW MEASUREMENT USING UTTF

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
ELECTRICAL ENGINEERING
(With Specialization in Measurement and Instrumentation)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work that is being presented in this dissertation report entitled **"ACCURACY IMPROVEMENT OF FLOW MEASUREMENT USING UTTF"** submitted in partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **Electrical Engineering** with specialization in **MEASUREMENT AND INSTRUMENTATION**, to the **Department of Electrical Engineering, Indian Institute of Technology, Roorkee,** is an authentic record of my own work carried out, under the guidance of **Dr. H. K. VERMA**, Professor, Department of Electrical Engineering & **Dr. B.K. GANDHI,** Professor, Department of Mechanical & Industrial Engineering.

The matter embodied in this seminar report has not been submitted by me for the award of any other degree or diploma.

Date: 29-06-07

Place: Roorkee

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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Dedicated

To

My Parents

ABSTRACT

Flow measurement is an important issue in any process industry or any hydro power plant. For determining the turbine efficiency of hydro-electric power plant, the flow of the water intake should be measured with minimum error. For the accurate control of different parameters like voltage and frequency, the flow should be monitored and controlled accurately. For the measurement of flow, different flow meters are available. Out of them ultrasonic transit time flow meters (UTTFs) are better than others in terms of operational characteristics.

The report describes the different factors which are affecting the accuracy of UTTF and suggests different error correction factors for this method. The present work concentrates on the two sources of errors which are affecting the UTTF. They are errors involved in "transit time calculation" and "the errors due to transducer placement". For transit time calculation, two new methods are proposed and the results of the new methods are compared with the already existing methods. From computer simulation it is proved that the newly proposed methods are much more accurate as compared to the already existing methods.

Next focus is on the errors due to the transducer dislocation. This work simulates the conditions of 1% variation in the transducer position and studied its effects on the accuracy. The multiple-path arrangements of the UTTF meters are studied and it is proved that the accuracy of flow measurement with 8- path method is much better than single path measurement.

The simulation environment of this work is carried out using LabVIEW and CFD softwares like FLUENT and GAMBIT. In the measurement and automation tool kit of LabVIEW, the different cases of noise are simulated. In case of CFD software, the GAMBIT is used for the purpose of designing the channel and FLUENT is used for applying different conditions and simulating the channel. The results of these simulations are applied to MATLAB for further processing like calculation of average velocity and discharge.

The future scope of this work can be a further improvement of accuracy of flow measurement. Different methods are suggested for further research in this area. The correction factor in the discharge calculation formula is to be studied for eliminating the transducer location errors. Some other areas of future research are also discussed in this report.

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CHAPTER 1

INTRODUCTION

1.1 IMPORTANCE OF FLOW MEASUREMENT

Flow measurement plays a very important role in the case of hydro-electric power plant. The power generation in hydro power plant depends upon the amount of water flowing through the turbine. As the flow varies, the power generation also varies. So, the measurement of flow is essential for controlling the power generation, calculating the turbine efficiency as well as the total efficiency of the hydro plant. Depending on the amount of load, the flow rate is to be controlled. The measured value of flow will be useful as a feed back element in the plant control. In case of any process industry, flow measurement plays an essential role in controlling the entire plant and automation of the plant operation.

In case of hydro power plant, the total efficiency is the ratio of electric power output of the generator to the hydraulic power input to the turbine. The input hydraulic power calculation depends upon the flow rate which is measured and the differential head across the turbine. So, the flow measurement is very essential in hydro-electric power plants. Flow measurement encompasses applications that range from capillary blood flow to flow over spill ways, flows of gases, plasmas, solids and so many corrosives etc.

1.2 APPLICATIONS OF FLOW MEASUREMENT [1]

- Survey work.
- Pump inspection.
- Blood flow measurement.
- Process controlling [3].
- Turbine efficiency calculation.
- Plant commissioning and start-up.
- Measurement of water distribution.
- Coolant and heating circuit monitoring.
- Flow of water through open channel in hydro power plant.
- Closed channel measurement in industries.
- Irrigation systems, etc.

1.3 PROBLEM DEFINITION

Since the flow measurement is very essential in so many industries including the hydro- electric power plant, the measurement should be accurate. There are different types of flow meters in use. Out of them, some are mechanical flow meters and some are electrical flow meters. Electrical flow meters are obviously better than mechanical flow meters in different aspects. Out of these, by considering different parameters like accuracy, installation effects, life, type of operation, robustness, power consumption etc, the Ultrasonic Transit Time Flow (UTTF) meter is the ultimate choice. Even in the case of UTTF flow meters, the inaccuracy of flow measurement is little more than 1%. But this amount of inaccuracy will also create some problems in plant controlling, automation and turbine efficiency estimation.

The input hydraulic power = ρQgh

The out put electrical power = $3VI\cos\phi$

The total efficiency of the plant = $\dfrac{3VI\cos\phi}{\rho Qgh} X100\%$ -------- eqn (1.1.)

Where Q is the discharge in the input

From, this formula, for accurate calculation of efficiency, the flow measurement should be accurate.

So, the main aim of this work is to identify the different factors which are affecting the accuracy of flow measurement and to improve the accuracy. There are different factors of inaccuracy. Out of them, this report concentrates mainly on the factors like "errors in travel time calculation" and "error due to dislocation of transducers". The error correction methods are also suggested in this report. The results of two new methods are also compared with the presently existing methods and proved that the accuracies of the new methods are more as compared to the existing methods.

The simulations of the different conditions are carried out with the help of LabVIEW and Computational Fluid Dynamic softwares. The measurement tool kit of LabVIEW and the GAMBIT and FLUENT facilities of CFD software are useful in simulating different types of conditions in the practical flow measurement.

1.4 SCOPE OF THE WORK

Chapter 2: This chapter discusses the principle of operation of UTTF, different types, advantages and disadvantages of UTTF over other type of flow meters.

Chapter 3: This chapter deals with the different factors which are affecting the operation of UTTF. The factors are transducer selection, dislocation of transducers, errors due to solid particles and bubbles in the medium, protrusion effect etc.

Chapter 4: This chapter mainly concentrates on the different methods which will improve the accuracy of the flow measurement. The factors are multiple path arrangement, curve fitting, indexing method, neural network approach, sing-around condition, different signal processing techniques etc.

Chapter 5: This chapter highlights the methods of "accuracy improvement in travel time measurement" and new methods which are proposed for travel time calculation. The LabVIEW simulation results of the new method and the comparisons of these results with the already existing methods are shown.

Chapter 6: This chapter highlights the effect of "dislocation of transducers" and compared the values of efficiencies for single to four path arrangements. The CFD simulation results are discussed here. Some suitable correction factors are also suggested here.

Chapter 7: This chapter concludes and summarizes the total work and entitles the future scope of work as the subject.

CHAPTER 2

BASICS OF UTTF

2.1 INTRODUCTION

The flow measurement can be carried out with the help of ultrasonic technology. The ultrasonic methods of flow measurement are two types. One is Doppler technology and the other is travel time technology.

Doppler technology depends upon the principle of Doppler Effect. In this method of measurement, the fluid should contain some suspended particles. The ultrasonic signal which is delivered from the sensor hits these particles and reflects back. Then the signal will shift in frequency. This shift in frequency is proportional to the amount of fluid flow. But the main concentration of this report is to calculate the turbine efficiency in hydro power plants. In that case the water is in the pure form. There are no solid particles like slurry measurement. So, Doppler method is not useful here. Then the ultimate choice is the transit time method.

This chapter mainly discusses the principle of operation of ultrasonic transit time flow meter (UTTF) and its advantage and disadvantage over other types of flow meters.

2.2 PRINCIPLE OF OPERATION

Ultrasonic transit time flow meter (UTTF), as the name itself indicates that, depends upon the principle of travel time technique. This flow meter consists of two piezo electric crystals, which generate ultrasonic signals of frequency range from 1MHz-3MHz. Both crystals can act as transmitter as well as receiver of ultrasonic signals. For measuring flow in open channels the two sensors are placed at two walls of the channel and if the measurement is in case of closed channels, the sensors are to be located at the two ends of the walls.

The principle of operation of this flow meter depends upon the travel time technique. This flow meter consists of two sensors both acts as a transmitter as well as receivers. Initially, one sensor generates the ultrasonic signal and acts as a transmitter. This signal enters into the medium and travels towards the second sensor. The other sensor which is on the opposite side of the channel will act as a receiver and that receives the signal. The time of travel is denoted as t_1 seconds. After the measurement of travel time, the second sensor acts as a transmitter and it will send the signal back to the other sensor, which will now act as a receiver. The travel time is denoted as t_2 seconds. The difference between these two travel times will be proportional to the amount of flow of the medium.

These two sensors are not to be placed in exact opposite direction to each other. They are to be placed at a certain angle with respect to the central line of axis. In this case, the travel time has to be calculated in both the directions. One is in the direction of flow and the other is against the direction of flow. The signal which is traveling in the same direction of flow will take less time to reach the other end and the signal which is traveling against the direction of flow will take more time to reach the other end. This is same as that of traveling the boat in the water. When the boat is traveling against the flow direction, it will take more time as compared to the boat which is traveling along the flow direction.

The time taken for traveling against the flow direction is denoted as up-time (t_u), and with in the direction of flow is denoted as down-time (t_d). The travel time mainly depends upon the channel width, sonic velocity in the medium and the axial velocity of the fluid flow in the channel or conduit. The derivational diagram showing the cross section of the channel and other dimensions is as shown in Figure 2.1.

2.3 CALCULATION OF AXIAL VELOCITY AND DISCHARGE

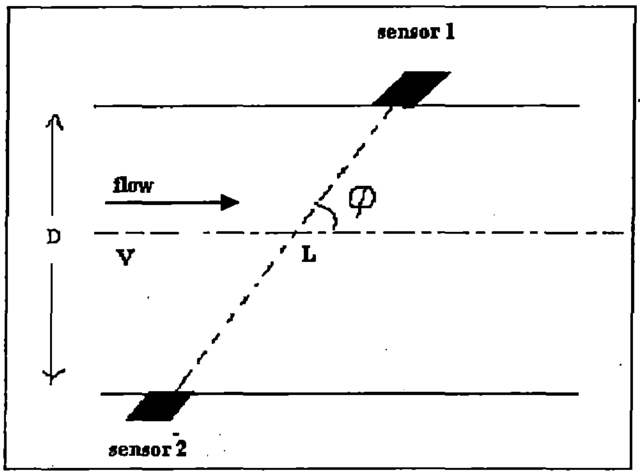

Fig 2.1: Derivational diagram for discharge calculation

t_u = upstream travel time of the acoustic signal;

$t_u = L / (C - V_{axial})$

t_d = downstream travel time of the acoustic signal;

$t_d = L / (C + V_{axial})$

The difference in the time of travel is proportional to the flow velocity. This is

$$Vaxial = \frac{L}{2\cos\varphi}\left(\frac{1}{td} - \frac{1}{tu}\right) = \frac{L}{2\cos\varphi}\frac{\Delta t}{tu.td} \quad \text{---------- eqn (2.1)}$$

Where

V_{axial} = average axial velocity of water flow

Δt = difference in upstream and downstream travel times

φ = angle between the acoustic path and the pipe's longitudinal axis

L = acoustic path length between the transducer faces

C =sound velocity in the medium

Simply we can the discharge can be find out by velocity multiplied by area of cross section of the channel.

So, $Q = V_{axial} \times A$ m3/s.

Where A is the channel cross section are in m^2/s.

The operational block diagram of the above process is shown in Fig 2.2.

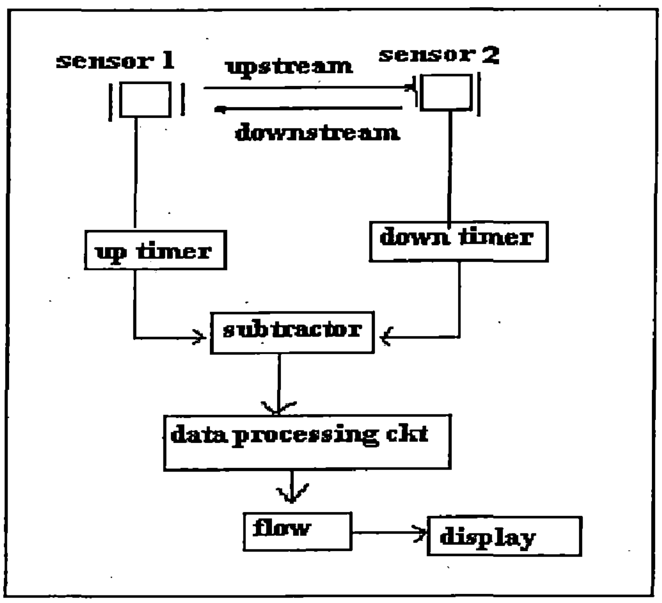

Fig 2.2: Operational block diagram of UTTF.

2.4 TYPES OF UTTF

Depend upon the position and the location of the piezo electric crystals, the UTTF meters are classified into two types.

- Clamp-on type or dry type.
- Wetted type or Wet type or inline type.
- Intrusion type

As the name itself indicates that the Clamp-on or dry type flow meter is placed on the outside of the channel. This type of flow meter is used in case of pipes only. The sensor is clamped on to the tube walls with the help of chains. The Wet type UTTF indicates that the sensor is to be placed in Wet condition. i.e., the mounting position of the sensor is inside the open channel. The sensor is to be fixed to the channel walls in order to avoid the movements. The intrusion type of UTTF is used mainly for closed channels. In this type, the pipe wall has to be drilled to fit the sensor exactly into the channel.

2.5 ADVANTAGES OF UTTF

1. Low installation effort and costs.
2. Measurement is independent of fluid conductivity and pressure.
3. No pressure loss, no possibility of leakage.
4. Installation for existing plants possible.
5. No cutting of pipes, no interruption of process, and no plant shut down.
6. No additional fittings for maintenance required.
7. No risk of contamination, suitable for ultra clean liquids.
8. No contact with medium, no risk of corrosion when used with aggressive media.
9. Cost advantages when used with large diameter pipes, high pressure systems, etc.
10. Low stocking costs, nearly all pipe sizes are covered with only 2 types of sensors.
11. Long life and robustness.
12. There are no mechanical movements in measurement. So, there are no friction effects as in the case of turbine flow meters and current meters.

3.6 DISADVANTAGES OF UTTF

1. Definitely there is a change in the accuracy of the measurement due to the presence of pipe material.
2. The color coating on the pipe will also affect the reading.
3. Solid particles and bubbles will reduce the accuracy of the flow measurement.
4. In wet type flow meters, the meter will be damaged when there is no proper maintenance.
5. As the size of the pipe increases, the size of the meter will also have to be change.

Even though it has some disadvantages this is the mostly used flow meter in process industry because of its cost effectiveness, reliability and high accuracy. The measurements can be taken are fully independent of the pressure rating in the pipe. There is no pressure loss in measurement. This meter is in non contacting state with the fluid. So it is useful for the measurement of flow of dangerous liquids and gases and the fluids with very high temperature.

CHAPTER 3

FACTORS AFFECTING ACCURACY OF FLOW MEASUREMENT

3.1 INTRODUCTION

The flow measurement is very essential in hydro power plant for calculating the turbine efficiency. There are so many factors which will affect the accuracy of the flow measurement. These factors will mislead the plant automation and turbine efficiency calculation. If the different factors of errors can be identified, the perfect corrections can be taken for the accuracy improvement of flow measurement.

The different factors of errors [1] that are to be discussed in this chapter are:

Errors due to

1. Transducer selection
2. Dislocation of transducers.
3. Variation of Fluid properties.
4. Variation of Sonic velocity.
5. Protrusion effect.
6. Effect of pipe material and thickness of pipe.
7. Effect of solid particles and bubbles.
8. Other factors.

3.2 TRANSDUCER SELECTION

There are different types of ultrasonic sensors depend upon the frequency of the ultrasonic signal and the channel width. The two transducers that are being used as sending and receiving end sensors should match with each other.

If the transducers used are of different types at both ends of the channel then the correct estimation of travel time is difficult and some times there is a chance of occurrence of errors in the measurement. The ultrasonic sensors those are manufactured by one company are different from the sensors those are manufactured by other company. So, the proper care must be taken while selecting a transducer for a particular application. The outlay of the ultrasonic sensor is as shown in Fig 3.1.

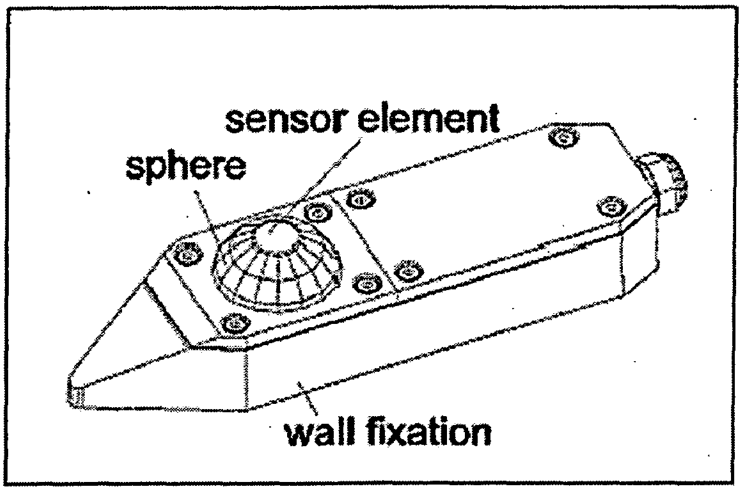

Fig 3.1: The outlay of the UTTF sensor [20]

As the channel width increases, the ultrasonic signal must travel more distance from transmitter to receiver. So, the depth of penetration should be more. This penetration depth is defined as the characteristic of the material and is a measure of how deep cans an ultrasonic wave penetrates into the material. The penetration depth is directly proportional to the wavelength and inversely proportional to the frequency of the signal. So, to have more penetration depth, the signal should have less frequency. The signal which has more frequency is unable to penetrate more into the depth.

Penetration depth α wavelength α 1/frequency ------- eqn (3.1)

The following Table shows the selection of ultrasonic sensors depend upon the path length and the range of ultrasonic frequency.

Table 3.1: Selection of ultrasonic sensors

Path length	Ultrasonic frequency required
2-15 meters	1 MHz
2-35 meters	500 KHz
5-100 meters	200 KHz

3.3 DISLOCATION OF TRANSDUCERS

In case of flow measurement on pipes or closed channels, the pipe may not have a straight portion for a very long distance. It may consist of bendings, valves, vertical and horizontal sections, motors effects etc. These factors will disturb the ultrasonic signal. If the UTTF sensors are placed nearer to any of these disturbances, the readings which we have taken from the measurement may not be true.

So, in order to improve the accuracy of the measurement, the transducer should be placed at a certain distance from these disturbances. From practical point of view it is observed that the sensor should be placed at a distance of 10 times the diameter after a disturbance and atleast 3 times the diameter before the disturbance. So, 10:3 is the location of transducer, where the effect of these disturbances is less.

One more precaution to be taken is that the transducer should not be place on the vertically mounted tubes, because the effect of bubbles are more in the vertical plane and these will disturb the ultrasonic signal. The proper care should be taken such that the sensor is to be placed in a position where the tube is completely filled with water and there should be no water bubbles. So, the sensor must be in the horizontal plane itself. The effects of different mountings of the ultrasonic sensors are as shown in Figure 3.2.

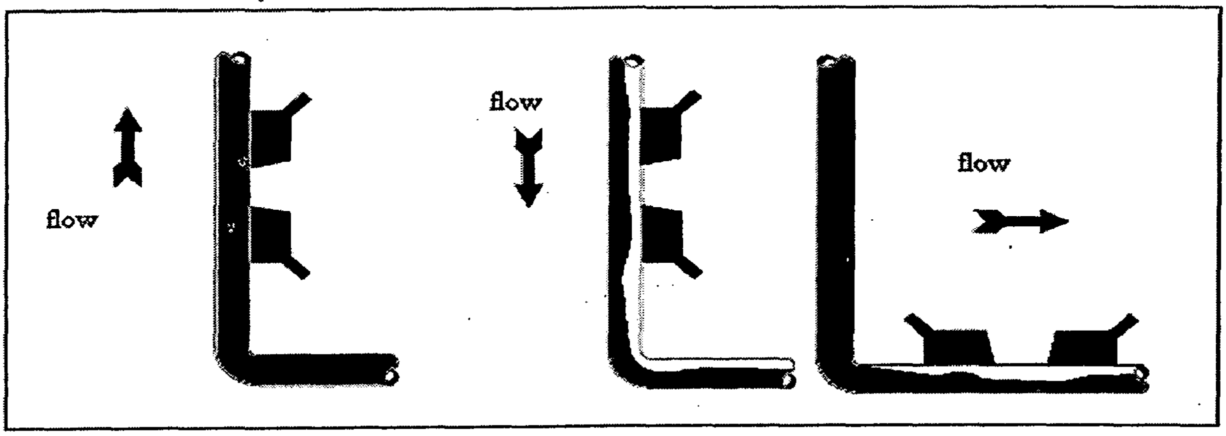

Fig 3.2. Sensor mounting locations

For achieving more accuracy, the sensors should be placed at exact distance and at an exact angle. If there is any misplacement in the sensor location or angle, the signal may not reach the receiver. So, the travel time calculation is not possible. This is true in case of both open as well as closed channels. In case of multiple path measurement, the accurate positioning of the sensor at the correct depth will also play an important role in accurate flow measurement.

The minimum height above the bottom or minimum depth below the surface required for placing the ultrasonic sensor should be

$$H_{\min} = \sqrt{\frac{LC}{2F}} \quad \text{------------- eqn (3.2)}$$

Where

If there is any variation in the temperature of the fluid, the sonic velocity may vary and the reading will be inaccurate. There is a chance that the transducer may be affected badly by the wrong selection in high temperatures.

If the fluid is of more viscous, the ultrasonic signal from transmitter may not reach the receiver. So, the accurate reading is not possible. Viscous effect is due to the changes in the viscosity of the fluid because of the local variations in the particle concentration whose size is less than signal wavelength [1]. Sound waves are pressure waves, which generate mechanical waves due to compressibility of the process product. Extremely high viscosity damps this motion. So, the accuracy of the flow measurement will be reduced.

3.5 VARIATION IN THE SONIC VELOCITY

Sonic velocity is the velocity of the ultrasonic signal in the fluid. The sonic velocity depends upon and proportional to the salinity of medium, temperature and pressure. At more temperature and pressure, the sonic velocity is also more. Mostly, the sonic velocity variation is not in wide range.

The equation for sonic velocity [22] in pure water is

$C_W = 1410 + 4.2\,T - 0.03T^2 + 1.14S + 0.018D$ ----------- eqn (3.3)

Where

T = temperature in ^{0}C

S = salinity in parts/ thousand

D = Depth in meters

The sonic velocity at 25^{0}C temperature is 1497 m/s in fresh water and is 1500 m/s in the salt water. When ever the sonic velocity varies, the travel time also varies. But in the case of transit time difference method, the sonic velocity will not affect the flow reading. The propagation of sonic velocity through steel pipe walls may be three or four times faster than the propagation through the fluid. So, this change in the sonic velocity from one medium to other medium will also affect the flow reading.

3.6 EFFECT OF SOLID PARTICLES AND BUBBLES

The fluid in which the flow measurement to be taken place is always may not be pure. This may consist of solid particles, micro organisms, silt and even small bubbles. Because of these particles, the signals may not be received at the receiving end. The signal may damage and the strength of the signal will decrease and the wave front of the signal will be disturbed. Because of these effects, the signal may become weak and some times it may be totally eliminated.

These effects are because of the reflection, refraction, diffusion, scattering and absorption the ultrasonic signals by the bubbles and solid particles [1], [21]. So, the received signal may contain much more noise. This noise will lead to wrong calculation of the travel time. Some times the time calculation is not possible. When the travel time calculation changes, the velocity reading will be inaccurate and this will give much error in the discharge measurement. The effect of solid particles on the ultrasonic signal is explained in Figure 3.4.

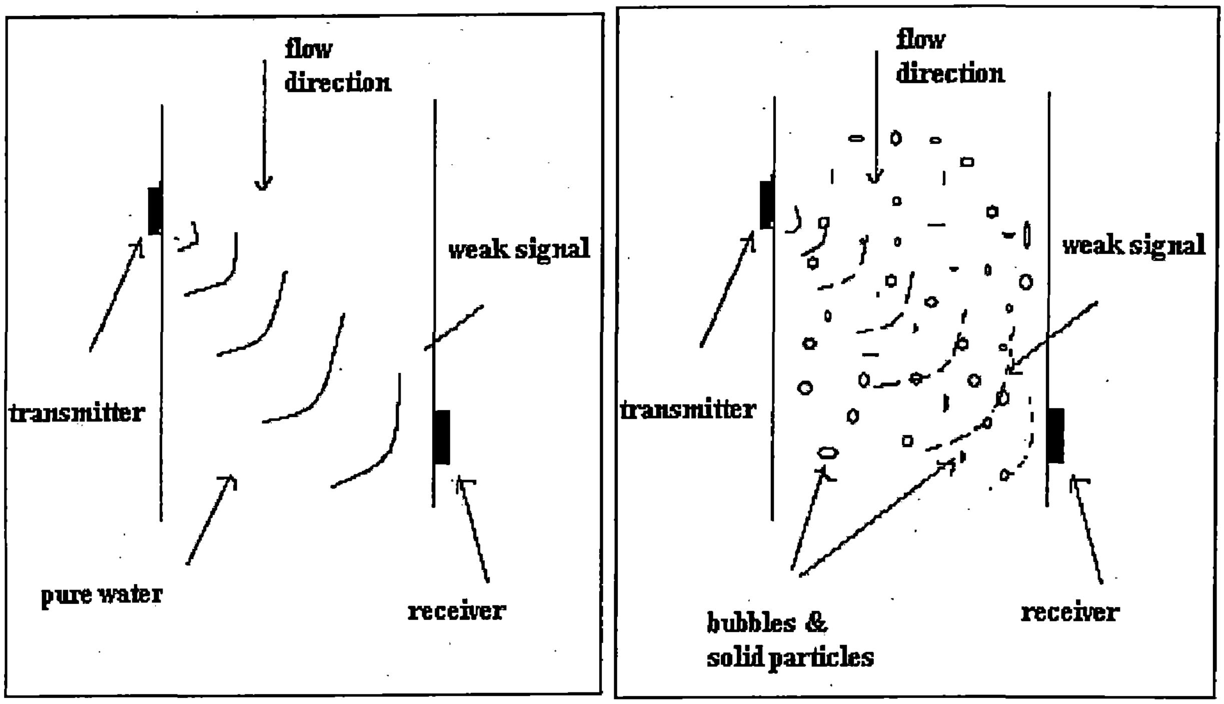

Fig 3.4: Effect of bubbles and solid particles on ultrasonic signal [1]

The scattering effect is caused by the particles with sizes greater than certain wavelength. [1]If the ultrasonic signal is obstructed by solid particles and air bubbles, a significant proportion of energy is reflected. Thus it can be concluded that the particles and air bubbles seriously affect the shape and behaviour of ultrasonic wavefront. This weak wave may not trigger the receiver, because of low amplitude and delayed in response time. So, the sing around condition is also not possible [4], [14]. Therefore, proper care must be taken in flow measurement when the bubbles and solid particles present in the medium.

3.7 PROTRUSION EFFECT

In case of open channel (wet type) flow measurement or in case of intrusive type flow measurement, the sensor is in direct contact with the fluid. If the sensor penetrates more into the medium, there is much more unmeasured zone nearer to the walls in the channel. In this zone, there is no passage of ultrasonic beam and the sonic path calculation omits this path length. So, the calculation of flow value nearer to the walls is not possible and the average velocity reading will give error. In order to eliminate this effect, the sensor should be of small size or the correction factor should be applied. The inaccuracy due to protrusion effect is more in smaller channels.

Reducing the size of the transducer will reduce the protrusion effect [17]. But, this may result in reduction in the beam directionality and the beam may be swept out by the fluid. However, it also reduces the energy of the beam. For eliminating this loss some correction factor is applied, the effect of protrusion can be nullified. The protrusion effect can be understood easily with the help of Fig 3.5.

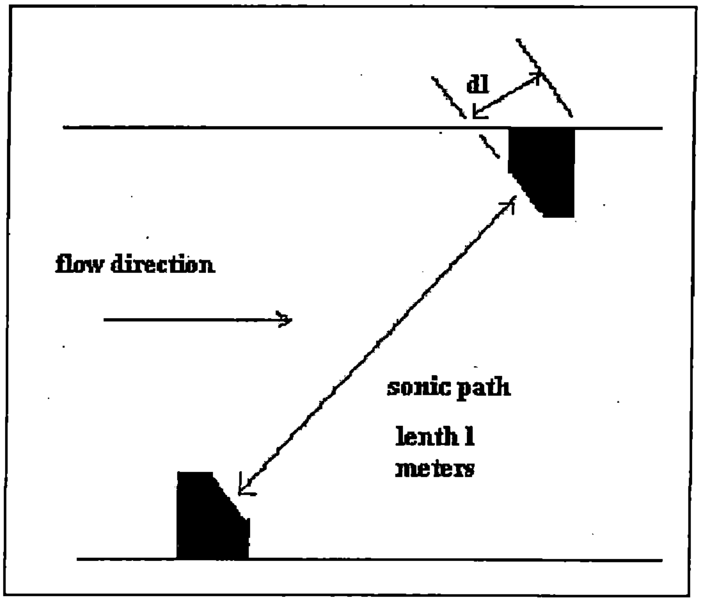

Fig 3.5: Protrusion effect

From the Figure 3.5., if the length of the transducer is dl, then the unmeasured zone at one sensor is dl. So, the total unmeasured zone in the fluid path is 2xdl. Therefore, the total measured zone is (l-2dl) m. Where l is the actual sonic path and dl is the sensor height.

The error due to protrusion effect is less than 0.3% for the case of pipes whose diameter is (1-3)m. for the pipes of diameter more than 3 meters, the protrusion effect is negligible.

3.8 EFFECT OF PIPE MATERIAL & THICKNESS

In case of clamp-on type flow meters for closed channel measurements, the sensors are clamped-on to the pipe wall with the help of chains. While taking readings, the ultrasonic signal should travel through the pipe material initially and next it enters into the medium. In some cases, because of the imperfect arrangements, there is a chance that the signal may have to travel through the air also. Because of all these factors, the signal may get damage and some times it may not reach the receiver perfectly.

The actual time of travel [22] including all factors taken into account is

$$T_t = 2\,T_w + 2T_a + 2T_s + T_l \text{ ------------ eqn (3.4)}$$

Where

T_w = travel time in wedges

T_a = travel time in air gaps

T_s = travel time in steel pipe

T_l = travel time in liquid

While measurement, the ultrasonic signal may get multiple reflections because of the pipe wall. This effect may be constructive or destructive with respect to the original signal. So, the accuracy of the flow measurement depends upon the pipe material and wall thickness. The picture showed in Fig 3.6.shows the multiple refractions of the ultrasonic signal in the pipe line arrangement.

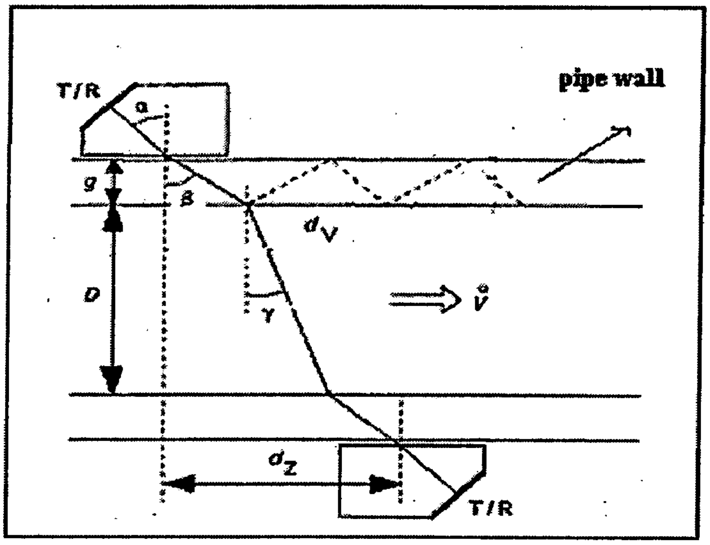

Fig 3.6: Multiple refractions of ultrasonic signal [22]

If there are any deviations in the input data which is fed to the meter, that will result in more error in the flow reading. If the pipe wall thickness was fed wrongly, then the flow reading will be wrong. So, a proper care must be taken while measuring the value of the pipe thickness. If there are any defects in the pipe, like breaks or cracks, then the ultrasonic signal will get disturb and the accuracy will get reduce. For measuring the inaccuracies in the pipe wall, the lamb wave detection technique will be useful.

The pipe material should be such that it will allow the ultrasonic signal through it without any attenuation. If tube walls have mud, the reflection of ultrasonic signal is not good in multipath method of flow measurement. In square shape tubes, nearer to corners, the mud is more. So, error in the flow measurement is more.

3.9 OTHER FACTORS

a) Every piezo electric crystal, which is used as a sensor in flow measurement, should be covered by a material for the purpose of protection. Because of this material, the signal may get reflected and some part may be refracted. From Snell's law of optics, when ever a ray travels from one media to other media it will get refracted with a certain angle. If the receiving end sensor is placed at a different angle, the refracted signal may not reach the receiving end crystal. So, some uncertainty in the transit time calculation will occur. This case is similar for bubbles and solid particles also. The Fig 3.7. explains about Snell's law diagrammatically.

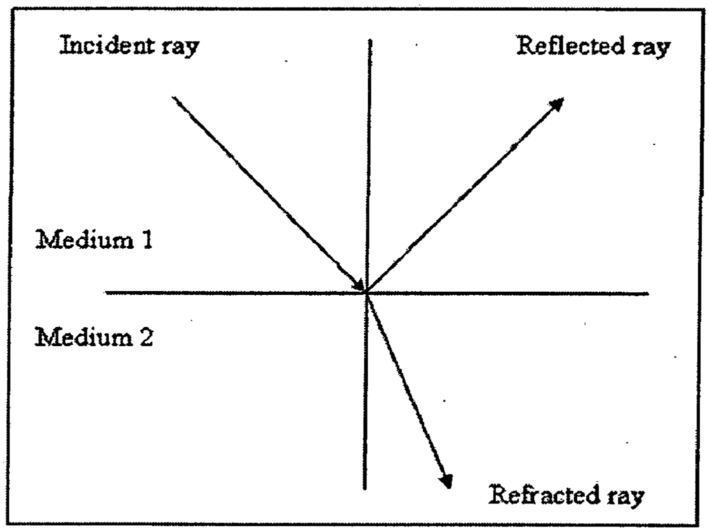

Fig 3.7: Snell's law

Snell's law states that when a signal travels from one medium to other medium, it will get some reflection and some refraction. The signal will also bend with some angle.

b) The velocity profile and the sensor locations will vary depend upon the slope of the channel and type of flows like turbulent and laminar flow etc.

c) The flow reading may not be constant in a channel at every instant of time. It will depend upon the particle concentration and bubbles. So, the reading will vary from time to time.

d) The Absorption of ultrasonic energy depends upon frequency of the beam, density of the medium and the viscosity of the medium.

e) Interference of ultrasound wave with similar waves generated by devices like pumps, electrical motors etc.

f) In open channels or closed channels, the direction of flow may not be unidirectional. There are some local flows and some reverse flows. These components can be called as cross and swirl flow components. These flow components may damage the ultrasonic signals, which are unidirectional. So, the time estimation may become difficult and there is a chance of inaccurate flow calculation.

CHAPTER 4

ACCURACY IMPROVEMENT METHODS

4.1 INTRODUCTION

After identification of the different factors which are affecting the accuracy, the necessary step to be taken is to find out the accuracy improvement methods. From these all methods, the accuracy of the flow measurement can be improved to less than 1%.

The different methods that are discussed here are

1) Multiple path measurement
2) Curve fitting
3) Cross and swirl component identification method
4) Neural network approach
5) Indexing method
6) CFD simulation approach
7) Sing- around condition
8) Multiple reflection method
9) Reciprocity correction
10) Variable frequency method
11) Cross check method
12) Exact placing of sensors
13) Correct estimation of travel time
14) Signal processing technique

4.2 MULTIPLE PATH MEASUREMENT

In case of flow measurement in open channels as well as closed channels, the velocity profile is not same all along the depth. This will vary depend upon the turbulences and roughness coefficient etc. If the measurement flow reading is taken at only one point of depth, the value definitely will include the local flow components only. So, the measurement is not accurate. For getting the average velocity along the path, the required thing is to calculate the flow along every depth of the channel. But, the measurement at every unit of height is very time consuming and even not possible.

For calculation of average velocity, there are different approaches like single path, two path, four path and eight path methods. The single path method and two path methods will also give some errors because of inaccuracy in average velocity along the path. So, according to IEC-41 standard, the proposed method for accurate flow measurement is eight-Path method [12]. With this method, the accuracy will get improve up to 1%. As the number of paths increases, the number of ultrasonic sensors required is also to be increased. That means the cost of the total operation will also increases. But the increment in accuracy will overcome the increment in the installation cost. The multiple path arrangement [17] of UTTF is as shown in the Figure 4.1.

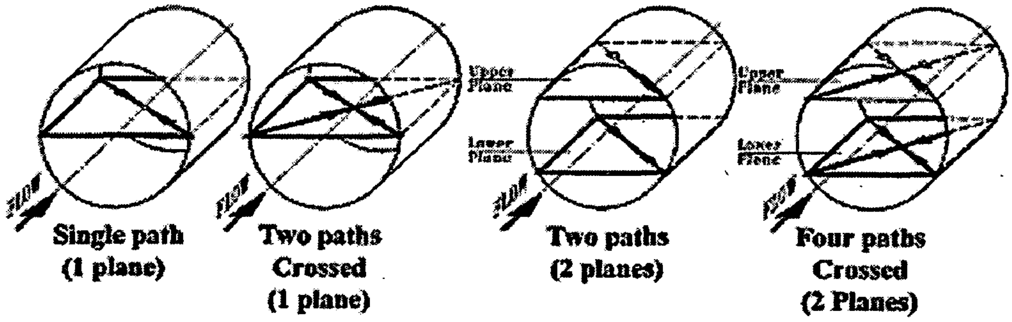

Fig 4.1: Multiple path arrangement of UTTF [17]

In case of single path measurement, the velocity reading will be affected by the local flows, cross and swirl flow components, solid particles and bubbles. But in the case of multipath measurement [23], the error due to all these components will get averaged out. In 8-path measurement, the two proposed methods for discharge calculation of open channels as well as closed channels are as explained below.

4.2.1 GAUSS-JACOBI (GJ) NUMERICAL INTEGRATION METHOD

Also called as the Tchebychev numerical integration method, this is one of the Gaussian quadrature techniques used for the application of eight-path UTTF. From Table 4.1 it is clear that the shape factor for GJ, k is equal to 1.000 for closed conduits and 0.994 for rectangular channels, indirectly suggesting that GJ is method that suits for closed pipes.

4.2.2 GAUSS-LEGENDRE (GL) NUMERICAL INTEGRATION METHOD

GL is no different from GJ, except that the abscissa and the weight are different. The shape factor from Table 4.1 can be seen as 1.0 for rectangular sections and 1.034 for

The percentage of inaccuracy in case of multiple path flow measurement is indicated in Table 4.2.

Table 4.2: Accuracy comparison in different path arrangements

Type of measurement	Percentage of uncertainty
4 or 8 path pipeline system	± 0.5% of actual flow rate
2-path pipeline system	± 1.5 % of actual flow rate
4-path open channel system	±2.0 % of actual flow rate
2-path open channel system	±5.0 % of actual flow rate

From this Table, the 8 – path arrangement will give more accuracy as compared to other paths measurement. But the 8-path measurement is not possible always. If the channel width is too less for locating the sensors, the 8-path arrangement is not possible. So, the 8- path arrangement is useful in large pipes and open channels. IEC 60041 gives a standard model for 8-path flow measurement for large diameter pipes. This arrangement of the ultrasonic sensors is as shown in Fig 4.2.

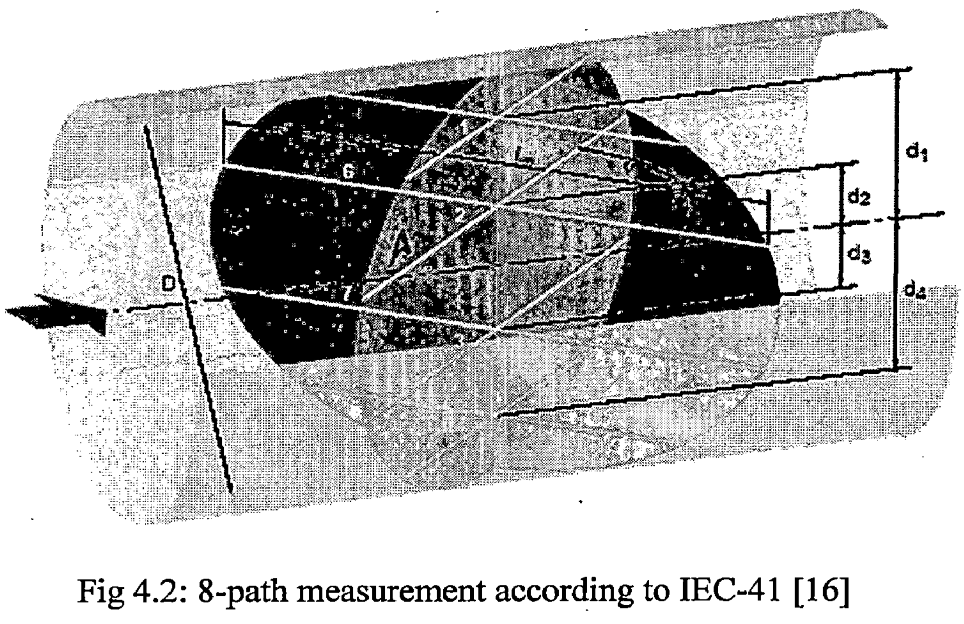

Fig 4.2: 8-path measurement according to IEC-41 [16]

The different path arrangements of ultrasonic sensors in different planes [19] can be explained with the help of Fig 4.3. Here the arrangements are shown from single path measurement to 8-path measurement in two planes. These are explained only for closed pipes with large diameter.

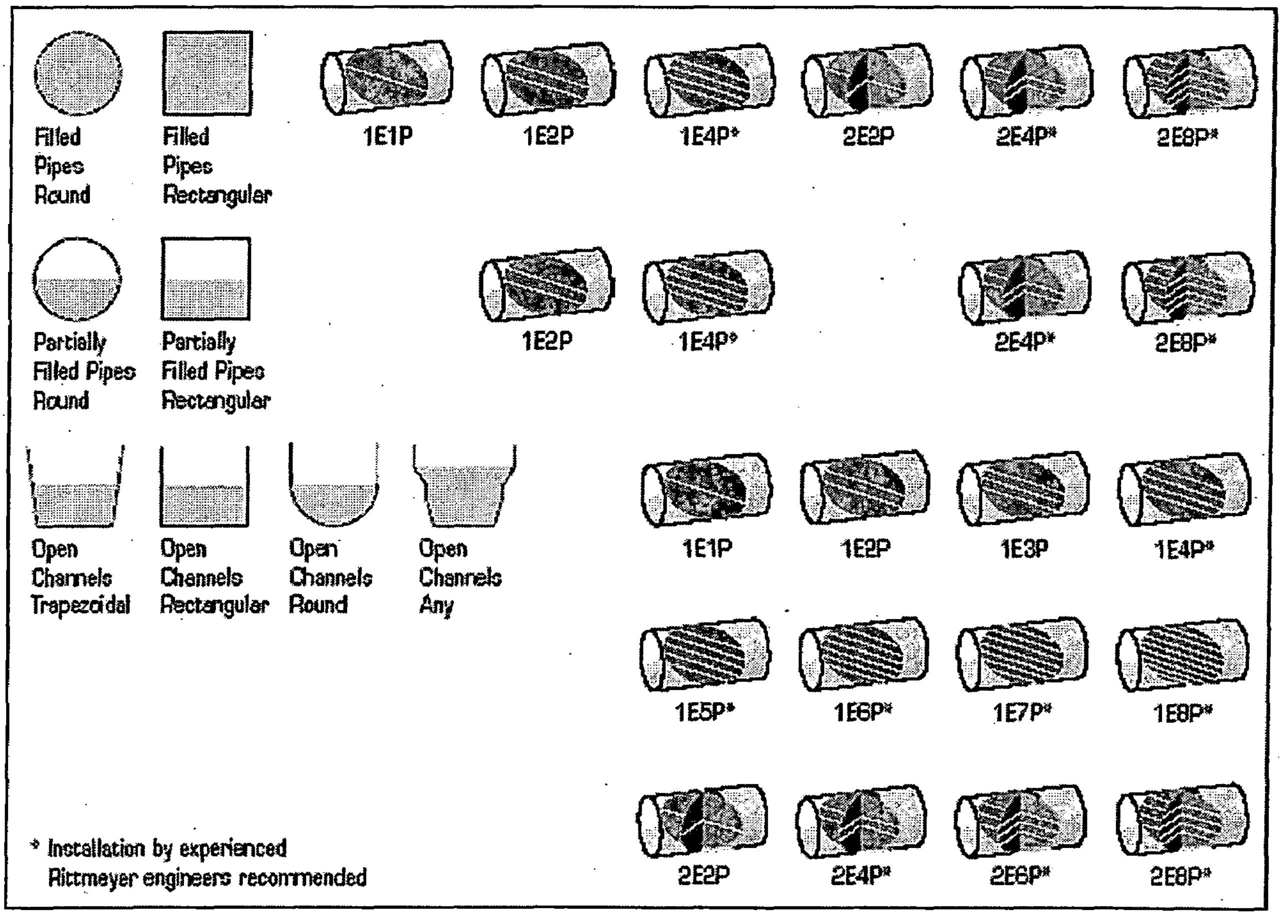

Fig 4.3: Different path arrangements of UTTF sensors [20]

4.3 CURVE FITTING

Curve fitting [9] is the estimation of flow profiles in a channel using mathematical equations. This method is mainly suitable for the channels with uniform flow distribution. If the flow distribution is non-uniform, then the curve fitting is difficult and some times not possible to estimate the velocity profile through mathematical equations. If there is any variation of single parameter, this method may not give the accurate reading. The different parameters which will decide the flow profiles are Reynolds number (Re), the width of the channel, velocity variations, swirl components etc.

The velocity profile in a smooth wall pipe based on a power law is defined as

$$V(r) = V_{\max} (1 - \frac{r}{R})^{\frac{1}{n}} \text{ --------- eqn (4.2)}$$

Where R – pipe radius

r- Distance from pipe wall

V(r) – point velocity at radial distance r

V_{max} –maximum velocity at pipe central line

This technique is impossible to apply for transitional flows. Transitional flows are the combination of uniform flow and turbulent flow.

4.4 CROSS AND SWIRL COMPONENT IDENTIFICATION METHOD

Ordinarily, for flow measurement, the sensors should be placed at a certain angle with respect to the axial flow direction. This angle may vary from 30 degrees to 60degrees depend upon the channel width. This calculation gives the amount of flow velocity. But, this way of measurement may include the some errors because of swirl and cross flow components. Some back flows will also affect the flow accuracy. The measured value of the flow is the combination of axial flow component and swirl & cross flow components.

If the effects of the swirl & cross flow components [5] are removed from the obtained flow reading, we can achieve the accurate measurement. For this, the necessary thing is to find out the velocity component due to the cross and swirl flow components only. The setup for this measurement and the cross and swirl flow components are as shown in the Figure 4.4.

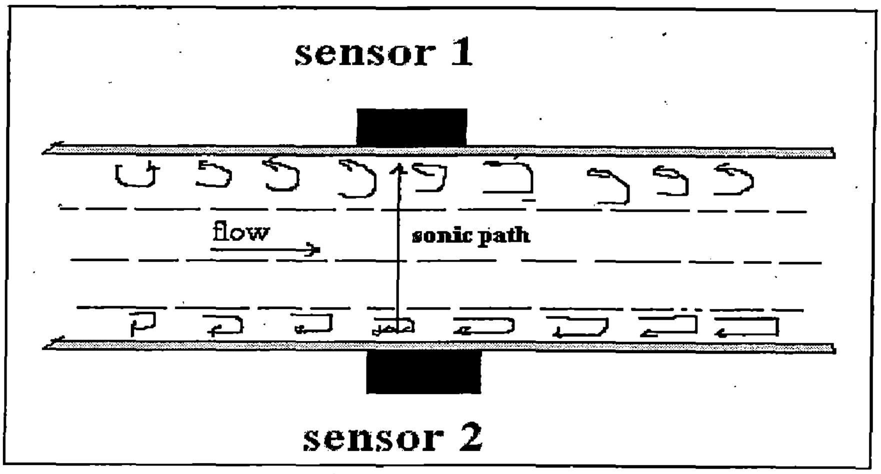

Fig 4.4: Cross and swirl component identification

In actual flow measurement, the sensors are to be placed at a certain angle. This is for the purpose of measuring the axial flow component. If the arrangement is changed such that there is no angle variation between the two sensor positions, the measured component is only due to the two foreign components only. That means it measures the flow along the sonic path as shown in Figure 4.4.

In ideal case, the flow component along this direction is zero because the flow along this path is zero. But practically, this arrangement will provide some value of flow reading, which is due to these cross and swirl components. From this value and the actual value of flow measurements, by further mathematical manipulations between these two components will give the axial component of flow, which is the required flow.

4.5 NEURAL NETWORK APPROACH

In this method of accuracy improvement, initially the network [2] is trained for different values of the travel times by maintaining the channel width as constant. After the training gets completed for a single channel, the network is to be trained for different channels of different parameters like channel width and depth etc. Once the training is completed for different conditions, the network is capable of detecting the exact time of travel when similar condition occurs. If there is any non trained condition occurs, the network will give the value which is best suitable to the present condition.

So, the accuracy can be improved by the exact measurement of travel time with the help of neural network. But the main disadvantage of this method is that the accuracy depends upon the number of training sets or number of training instants. If the training sets are too less, the measured value will contain more error. The availability of the training sets is also not possible.

The main neural network techniques that will be useful in flow measurement are pattern recognition technique and back propagation algorithm [2]. There are two different types of neural network approaches. They are feed forward approach and feed backward approach. These neural networks train their neurons for different input conditions even after training gets complete. The simple mutli-layer feed forward network is as shown in Fig 4.5.

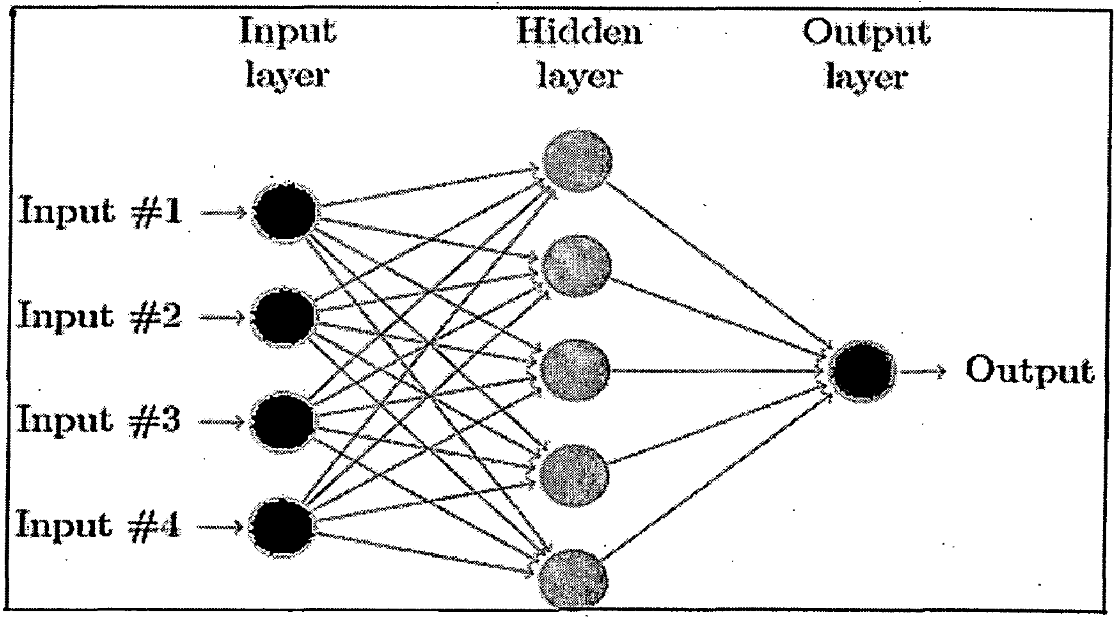

Fig 4.5: Neural network approach

4.6 INDEXING METHOD

The correction factor between the multiple-path and the single path arrangement is known as indexing. This is explained below. In case of multiple-path measurement, the velocity reading obtained is more accurate. In case of 8-path measurement, the velocity reading that is calculated is of 1% accurate. But in case of single path measurement this accuracy is very much low as compared to the 8-path measurement. So, the 8-path measurement is beneficial for accurate flow measurement. But in each and every case, the 8-path measurement is not possible. So, by multiplying the single path reading with this index value, the average velocity due to 8-path will be obtained. This is the main advantage of indexing.

The indexing factor is defined as the ratio of velocity due to multipath measurement to velocity due to single path measurement. This can be predefined for 2-path, 4-path and 8-path conversions. The disadvantage of this indexing is that in each and every time, the bubble and solid particle concentration is not same along the channel. So, every time recalibration of the coefficient is necessary. If there is no recalibration, the flow reading may include some errors and this lead to more inaccuracy in the measurement.

4.7 CFD SIMULATION APPROACH

Computational fluid dynamics (CFD) is flow simulation software, which is used to simulate the flow at different conditions. By feeding the required input data to the software (like width, height, depth of the channel, pressure, temperature, channel slope etc, through keyboard), this will provide the exact flow profile in the channel at required points. That means it will provide the velocity components all along the channel.

Since, in the case of simulation, we can't input the data like solid particles and bubbles, the data will give almost accurate result. By comparing the actual data with the theoretical data, the corrections in the practical readings can be performed. The corrections that can be performed in the practical set up like adjustment of flow sensors, valve positions etc can also be possible. This will improve the flow measurement, by eliminating the uncertainties in the flow measurement. With this method, the accuracy of the practical measurement can also be estimated.

4.8 SING AROUND CONDITION

The flow is not constant in the channel because of the variation of the particle concentration and the bubble concentration. These will vary from one time instant to other time instant. If the up time calculation and the down time calculations are at different time instants, then the readings may vary. So, in order to eliminate the effect of this delay in transit time measurement, the sing-around condition is to be used.

The ultrasonic sensors used in the flow measurement are piezo electric crystals. When the voltage of certain frequency is applied to the crystal, the crystal will vibrate with that frequency. When the receiver receives the ultrasonic signal, it will generate some sort of signal. This signal further triggers the receiver circuit and this sensor will now acts as a transmitter and generates the ultrasonic signal. That means, in sing around condition the signal itself triggers the sensors without time delay.

This is the common method, which is being used in almost all types of ultrasonic sensors. This method will eliminate the errors due to time variations and then the accuracy of the flow measurement gets improved. In some cases, the received end signal will be filtered and applied to the crystal back. But this will yield some errors. So, the application of newly generated signal to the piezo electric crystal will be preferable for more accuracy. For further improvement of accuracy, the multiple sing around condition is proposed. In this method, the sing around condition is applied for some N number of times instead of a single time and the results of each of these instants will be averaged. This is the average flow reading. This will give much more accuracy. Generally 10,000 to 20,000 sing around conditions are performed for a single measurement.

The average velocity calculation with the help of sing-around condition [16] is

$$V = (-1)^n \frac{L}{2\cos\alpha}\left(\frac{1}{t_n} - \frac{3}{t_{n-1}} + \frac{3}{t_{n-2}} - \frac{1}{t_{n-3}}\right) \text{-------- eqn (4.3)}$$

Where t_n is the sing around period.

n is even for down stream and is odd for upstream.

4.9 MULTIPLE REFLECTION METHOD

In case of single path measurement, the reading will include error because of the effect of local flows. In order to eliminate the effect of local flows, the multiple reflection method is used. There are different methods in this case. One is single reflection (v method), two reflection (z- method) and multi reflection method. More than two reflections can't be useful in accuracy improvement because in this case the error becomes additive and the resultant error is more. The different multiple reflection methods are shown in Fig 4.6.

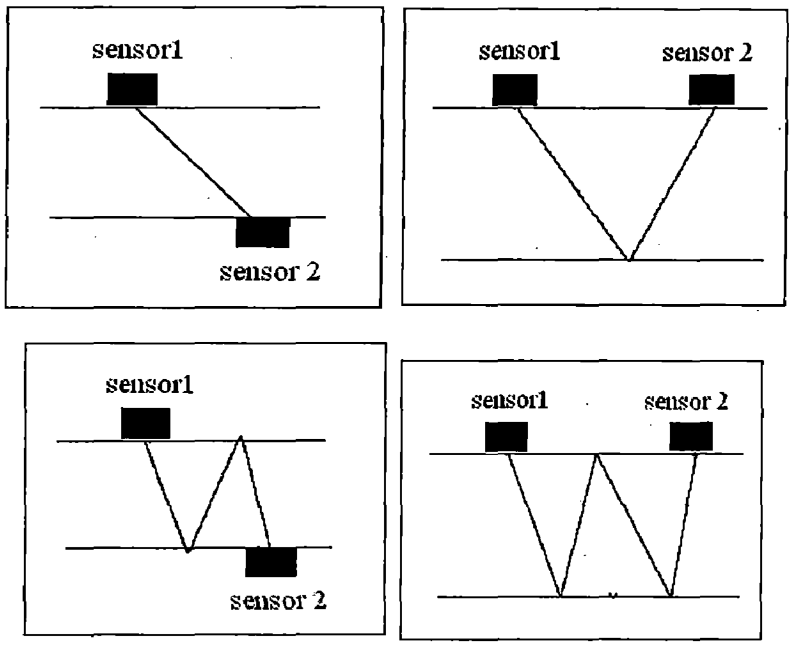

Fig 4.6: Multiple reflection method

This method will not be applicable, when the pipe wall is deposited with solid particles or in case of older pipes. [3]

4.10 RECIPROCITY CORRECTION

In flow measurement, the meter will show some reading even in zero flow condition because of the usage of longer cables from pulse generators & crystals and mismatching of transistors and transducers. At this instant, even cross correlation method will yield errors because of the different responses of the transducers. These

CHAPTER 5

ACCURACY IMPROVEMENT IN TRAVEL TIME MEASUREMENT

5.1 INTRODUCTION

This chapter mainly discusses the methods of finding out the travel time. Initially discusses about the already existing methods like threshold or zero detection technique and filtering technique. Besides these methods, two other different techniques are proposed in this chapter. They are peak detection for a modulated signal and the cross correlation technique. These two methods improved the accuracy of the flow measurement as compared to the existing methods. The LabVIEW results are shown for comparing the different simulation aspects.

This chapter concentrates on the effects of bubbles or solid particles on the transmitted ultrasonic signal. Different conditions like random amplitude, random frequency and both are observed here. All cases of random noise are discussed for both unmodulated and modulated signals. The filtering approach is also simulated using LabVIEW simulation environment and the results are compared.

5.2 EXISTING APPROACHES

5.2.1. THRESHOLD DETECTION TECHNIQUE

The accuracy of transit time flow meter depends mainly on the exact measurement of travel time. If the travel time measurement is accurate, the flow reading will also be accurate and the efficiency calculation will be more accurate. If the sending end signal is a pure sinusoidal signal, then the receiving end signal is the combination of the sending end signal and the noise. This noise is due to different factors like bubbles, solid particle interferences, reflection of signals and other noise generators.

The main principle of this method is observing the time instants of a certain threshold value in the first cycle of the sending and the receiving end signals. The time difference between these two instants will give the travel time. This time difference is in terms of integral number of cycles of the ultrasonic signal. These numbers of cycles depend upon the sonic velocity and the channel width. The threshold detection scheme that is developed in the LabVIEW is as shown in Fig 5.1.

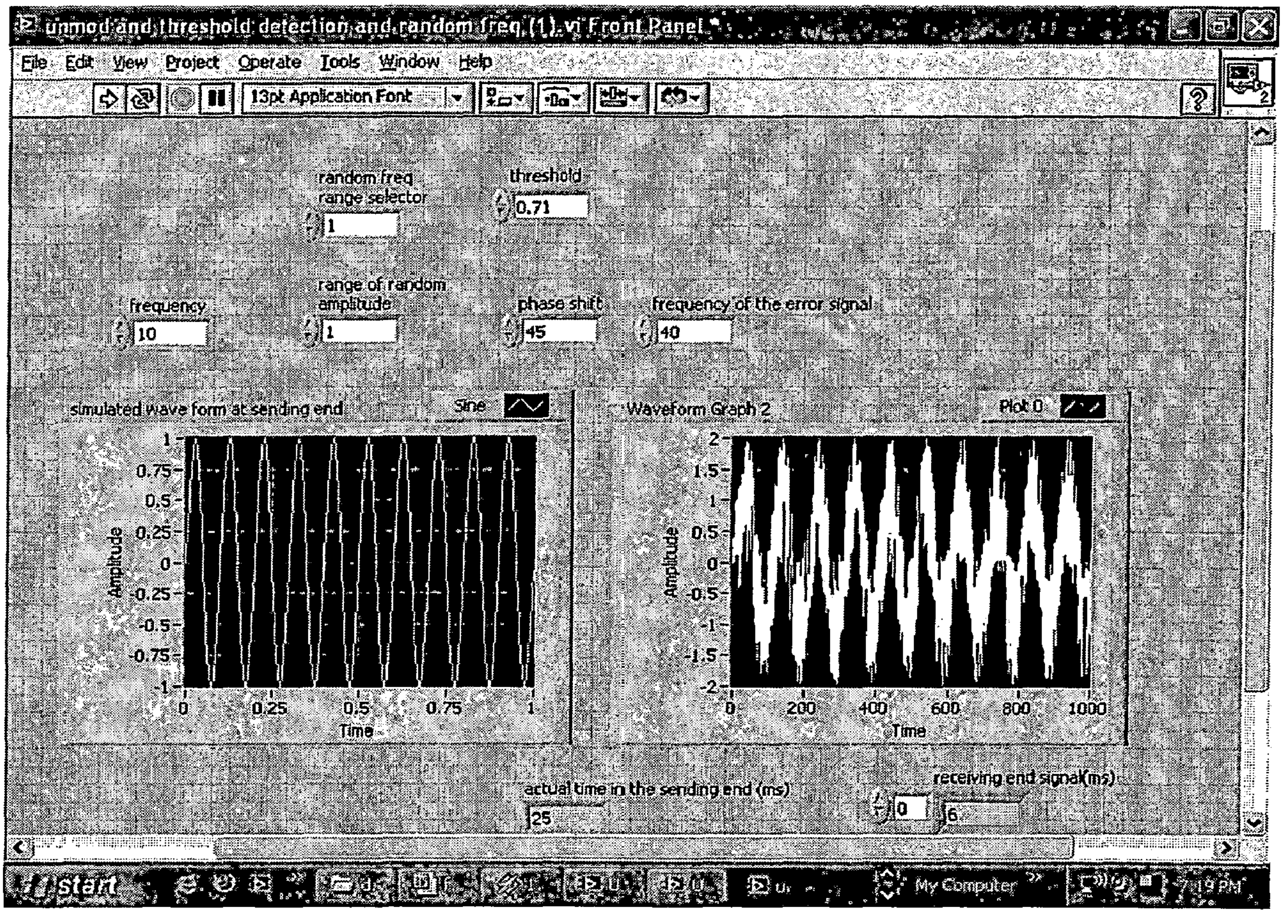

Fig 5.1: Threshold detection technique – LabVIEW simulation environment

The disadvantage of this method is that if the noise is more, the distortions in the signal are also more, and then the threshold detection will not yield better results.

5.2.2. FILTERING TECHNIQUE

This technique will also give better results in travel time estimation. In threshold detection of unmodulated signal, the receiving end signal is affected by noise. If this noise can be eliminated, then threshold detection technique will give better results. The elimination of noise is done by using filtering technique.

The frequency of the ultrasonic signal generated is of the order of MHz. The ultrasonic signal is affected by the noise due to bubbles and solid particles in the sonic path. This noise is of different frequency, which affects the signal throughout the operation. If the noise is eliminated, the calculation of travel time is easy. If the narrow band pass filter is used, which can pass only the required frequency of the signal, then the noise can be eliminated and the time calculation is more accurate. Then the discharge calculation will be most accurate. The implementation of the filtering technique in the LabVIEW is as shown in Fig 5.2.

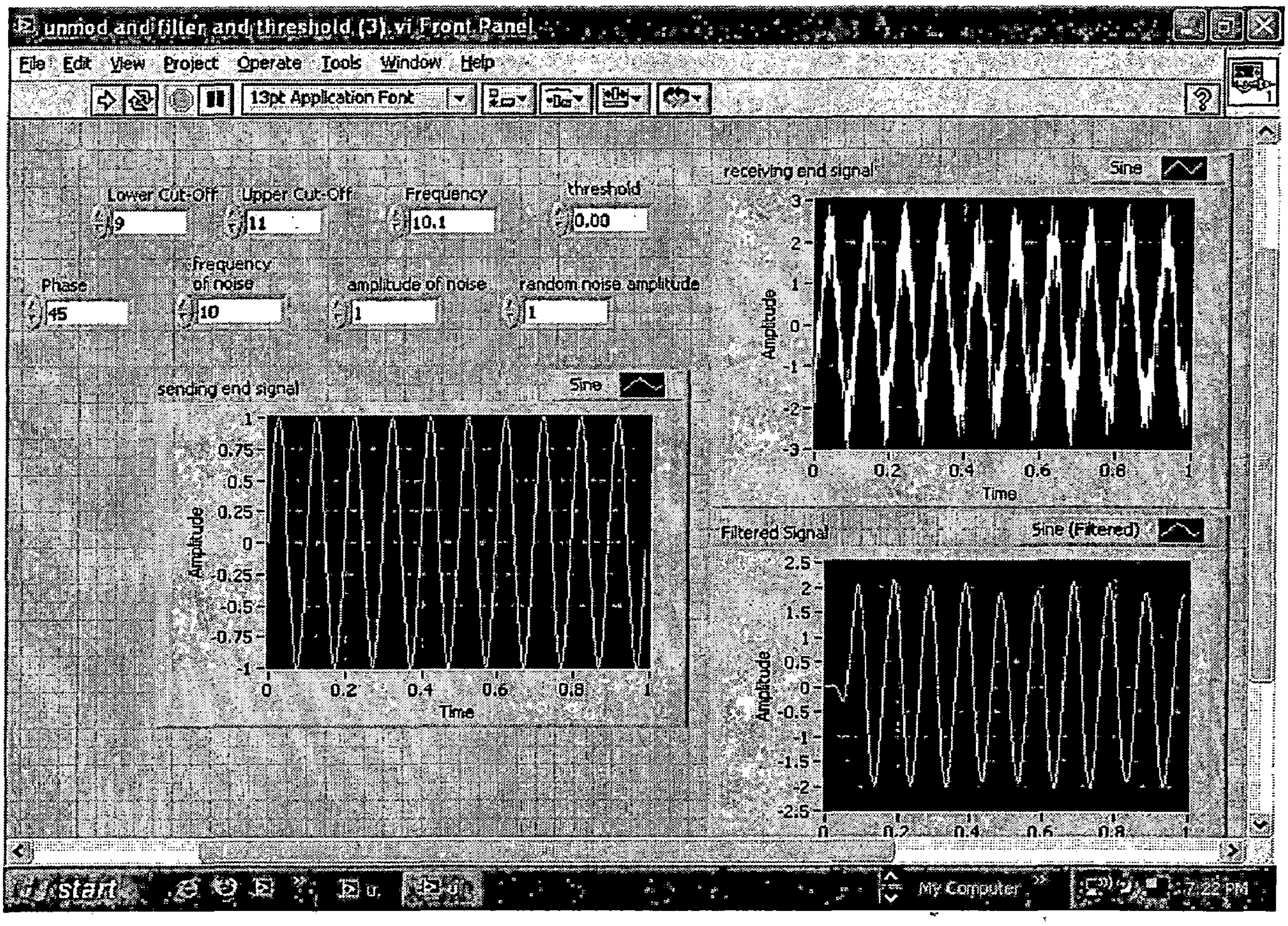

Fig 5.2: LabView simulation of filtered signal

The main disadvantage of this method is that the accuracy of the filtered signal depends upon the order of the filter. If the filter is of higher order, the accuracy is more and vice-versa.

5.3 PROPOSED METHODS

5.3.1. MODULATED SIGNAL TRANSMISSION (PEAK DETECTION METHOD)

In case of threshold detection, the detection becomes difficult and the identification of first cycle is not possible if the noise is more. So, if we can differentiate a single peak from other peaks, then the peak detection method will be easier as compared to threshold detection method. This method of calculation of travel time is same as the identification of QRS complex detection in ECG wave. The highlighting of a single peak can be done by generation of a special type of signal [9]. This signal is nothing but the triangle modulated sinusoidal signal. This is as shown in the Figure 5.3.

Initially the specially generated signal is transmitted from the sending end crystal. The peak value occurs at a certain time instant. After traveling through the medium, the signal will reach the receiving end. The receiving end signal is rich in noise. But the peak can be easily identified at another time instant, even though there is noise. When they are represented on the same scale, the time differences between the occurrences of these two peaks, is the travel time of the ultrasonic signal.

The method is more accurate as compared to the threshold detection technique because in case of threshold detection method, the measurement will be disturbed by the noise and will lead to inaccuracy. But in this method, the identification of travel time is easy as compared to the threshold technique. So, the discharge calculation through this method is more accurate. The LabVIEW simulation environment of peak detection technique is shown in Fig 5.3.

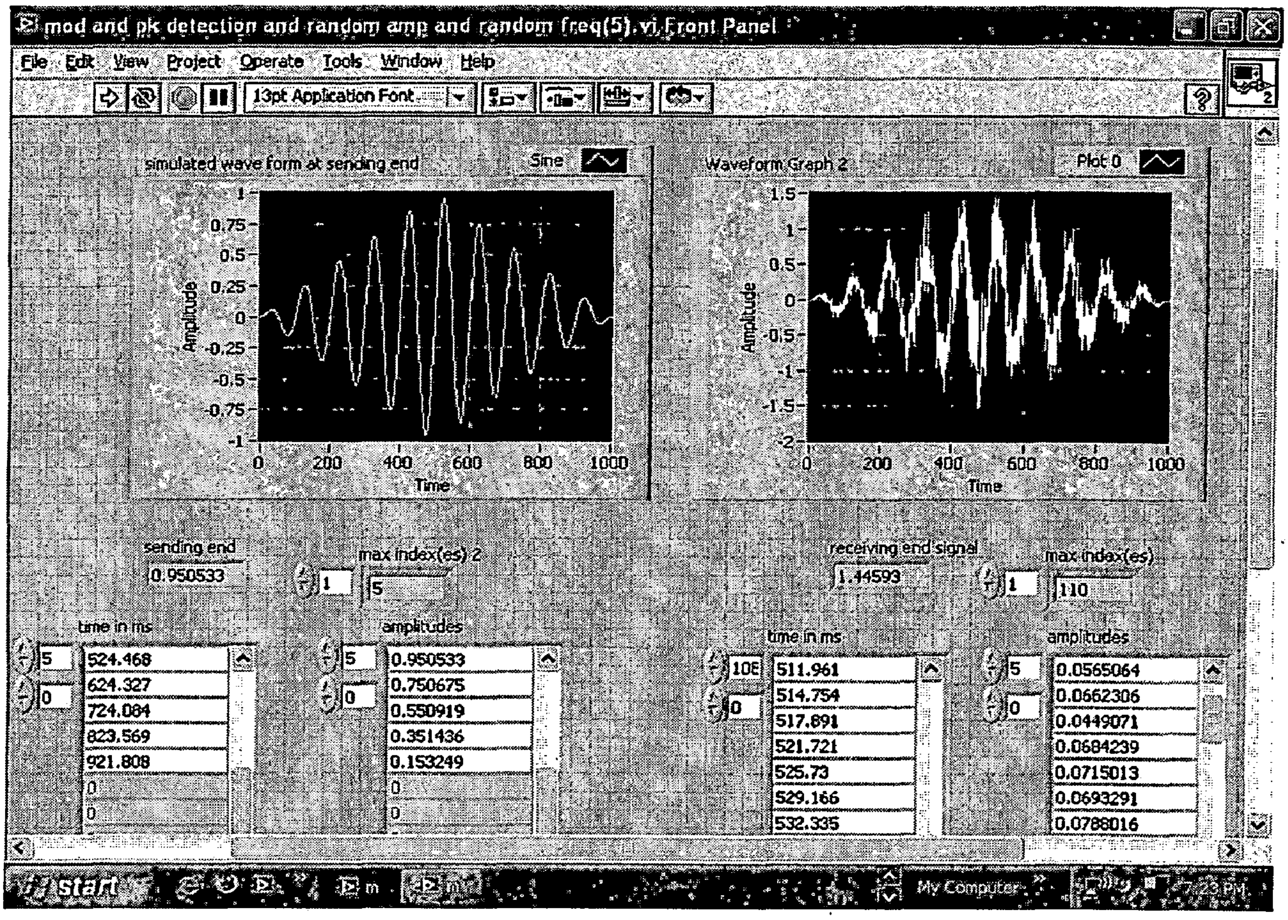

Fig 5.3: Peak detection technique using modulated signal.

5.3.2. CROSS CORRELATION TECHNIQUE

Cross correlation method is one of the best method for finding out the exact time of travel. This method actually calculates the correlation coefficient between the sending end signal and the receiving end signal. Correlation coefficient is the indication of the matching factor between the two signals. This coefficient varies from 0 to 1. When the two signals exactly match with each other, the correlation coefficient between them is 1 (in ideal case). If two signals perfectly mismatch each other, then the correlation coefficient is zero.

In UTTF measurement, the receiving end signal is at some time difference with respect to sending end signal. By shifting the sending end signal forward in steps and the correlation coefficient can be calculated with respect to receiving end signal. The result obtained will be in terms of the percentage of matching between these two signals. Maximum correlation coefficient at a certain phase shift is the indication of perfect matching of the two signals and that phase shift will be the exact phase shift of the receiving end signal. From this phase shift, the amount of time shift can be calculated.

This method of calculation of travel time is much more accurate as compared to the above methods. So, the discharge calculation is more accurate.

5.4 CASE STUDY

In this practical case, the observed time shift is of "N integral number of cycles + 45 degrees phase" and the frequency of the ultrasonic signal that is transmitted is 10 Hz and the amplitude is unity. The assumption here is that the noise is in the range of 40 Hz. Actually the noise is varying in terms of random amplitude or random frequency or both. In all the cases, the observed variation is of 0 to1 on unit scale. That means the noise is varying from 0-100% of the original signal. The observed threshold detection is at 70.7% of the receiving end signal. This threshold value is chosen for the sake of practical convenience.

The second study is the case of unmodulated signal with filter. In this case the filter that is used is narrow band pass filter. The ultrasonic signal is of 10 Hz frequency and the noise is varying from 0 to 40 Hz. So, the filter is designed such that the upper cut off frequency is 10.1 Hz and the lower cut off frequency is 9.9 Hz. This filter allows only the frequency that is lying in between these two cut off frequencies.

The third study is the case of cross correlation method. The receiving end and the sending end signals are cross correlated and the correlation coefficient is observed. This case is repeated for different time shifts in the sending end signal. When ever the correlation coefficient is more, then the two signals almost match with each other. This shift in time is the correlation time.

From all these calculations the time is normalized and the calculations are converted with respect to 1M Hz signal. The percentage error is calculated at each and every instant and the errors in all the cases are compared.

The above process is repeated for the case of modulated signals also. In case of modulated signal case, the signal that is to be generated is triangle modulated sinusoidal signal. The signal is as shown in Figure 5.3. The advantage of this technique is to make the peak detection easier. In this case also, all three studies regarding random variation of noise are studied.

5.5 RESULTS & DISCUSSION

The received end signal at the transmitter consists of a lot of noise. This noise is because of the solid particles or bubbles in the ultrasonic path. If these particles are more, the noise is also more and vice versa. Therefore, the received end signal is rich in random noise, random frequency or both. The LabVIEW simulation conditions, which are explained here, mainly concentrates on the randomly varying noise which is superimposed over the original signal.

The signal that is transmitted is divided into two categories

(i) unmodulated signal

(ii) modulated signal

In these two categories, there are further three cases to be studied.

(a) Noise of random amplitude

(b) Noise of random frequency

(c) Noise of random amplitude and random frequency.

The percentage errors in travel time due to these noises are calculated and are represented graphically. The variation of noise is observed in steps of 20% of the original signal. All values are taken in per unit. The % error is the indication of the percentage error in travel time calculation. This can be calculated from the ideal travel time that is actually given and the travel time which is obtained from simulation. The percentage difference between these two travel times is the % error. This is represented in the graph.

In each and every graph, the % error values are calculated for the cases of no filter, with filter and with cross correlation. The results of the three cases are compared.

In unmodulated signal transmission, the no filter case is the indication of threshold detection technique. In case of modulated signal transmission, the no filter case is the indication of peak detection. This variation is because of the possibility of easier identification of the peak in modulated signal transmission.

In case of random amplitude, the frequency of the noise is constant and in the case of random frequency, the amplitude of the noise is constant.

5.5.1. UNMODULATED SIGNAL TRANSMISSION

Unmodulated signal is a simple sinusoidal signal and is the sending end signal from the ultrasonic transducer.

(a) NOISE OF RANDOM AMPLITUDE

Here the noise is varying randomly in terms of amplitude only. In this case, the frequency is assumed to be constant. The noise amplitude is varying from 0% to 100% in steps of 20%. The results of the unmodulated signal without filter, with filter and with cross correlation are observed and compared. The comparison result is as shown in the Figure 5.4.

Noise amplitude variation = 0 to 100% Noise frequency variation = constant

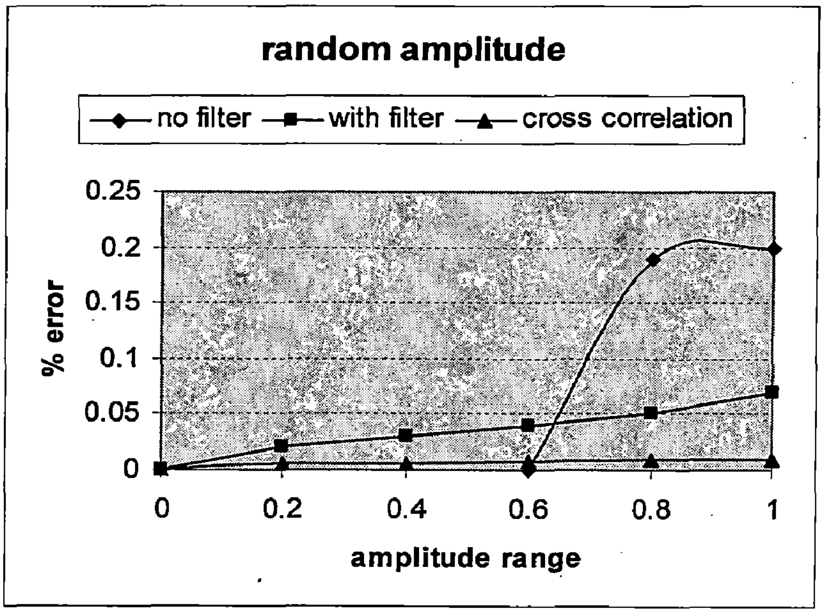

Fig 5.4: Unmodulated signal – Noise of random amplitude

From this graph, the result shows that the % error is more for the case of unmodulated signal transmission without filter and the maximum error is 0.2%. In the case of filtered signal, the maximum % error is 0.07% and in the case of cross correlation, the maximum % error is 0.01012%. So, as compared all the three methods, cross correlation method of measurement is giving better result. The simulation results in terms of percentage errors and noise variations for all the three cases are mentioned in Table A1 in appendix A.

(b) NOISE OF RANDOM FREQUENCY

Here the noise is varying only in frequency. There is no change in the amplitude of the noise signal. The frequency variation is observed from 0 to 100% in steps of 20%. The results of the unmodulated signal without filter, with filter and with cross correlation are observed and compared. The comparison result is as shown in the Figure 5.5.

Noise amplitude variation = constant   Noise frequency variation= 0-100%

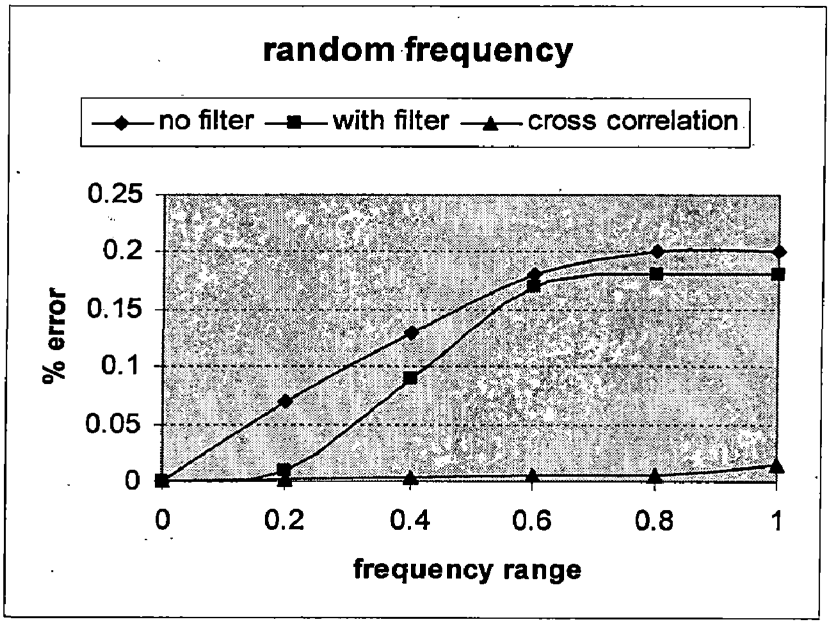

Fig 5.5: Unmodulated signal – Noise of random frequency

From this result, it is observed that the maximum error in no filter case is 0.2%. The maximum error with filter is 0.18% and in case of cross correlation, the maximum error is 0.0148%. There is a very drastic improvement in the accuracy. The simulation results in terms of percentage errors and noise variations for all the three cases are mentioned in Table A2 in appendix A.

(c) NOISE OF RANDOM AMPLITUDE & RANDOM FREQUENCY

Here the noise is varying randomly in terms of amplitude and frequency. Both of these two are varying from 0% to 100% of original signal. The results of the unmodulated signal without filter, with filter and with cross correlation are observed and compared. The noise is varying in steps of 20%. The comparison result is as shown in the Figure 5.6.

Noise amplitude variation = 0-100%   Noise frequency variation= 0-100%

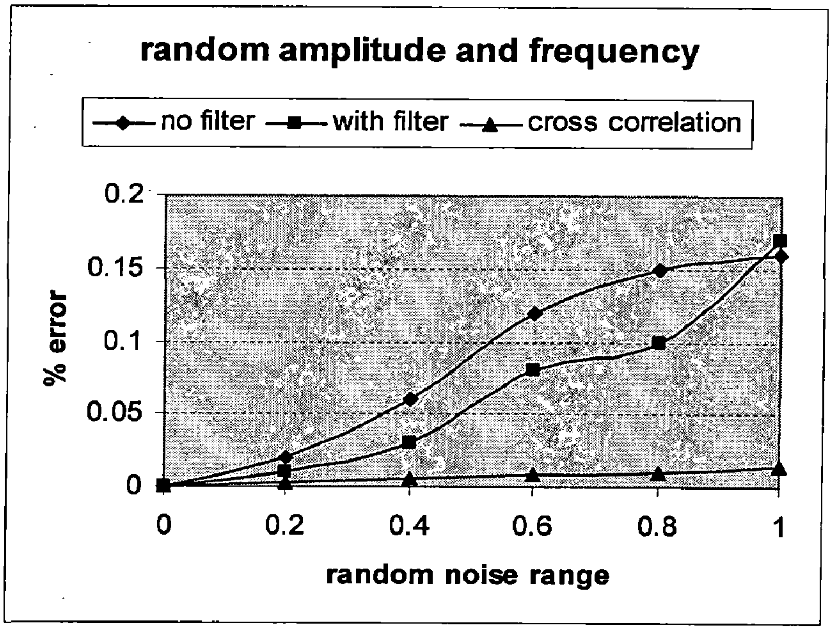

Fig 5.6: Unmodulated signal – Noise of random amplitude and random frequency

From this result, it is observed that the maximum error in no filter case is 0.16%. The maximum error with filter is 0.17% and in case of cross correlation, the maximum error is 0.01623%. There is a very drastic improvement in the accuracy. The simulation results in terms of percentage errors and noise variations for all the three cases are mentioned in Table A3 in appendix A.

5.5.2. MODULATED SIGNAL TRANSMISSION

The ordinary sinusoidal signal is modulated by a triangle wave and the obtained signal is used here as a sending end signal. Simply, the obtained signal is called as a modulated signal.

(a) NOISE OF RANDOM AMPLITUDE

Here the noise is varying randomly in terms of amplitude only. In this case, the frequency is assumed to be constant. The noise amplitude is varying from 0% to 100% in steps of 20%. The results of the unmodulated signal without filter, with filter

In each case, the modulated signal is giving better result as compared to the unmodulated signal.

Noise amplitude variation= constant Noise frequency variation= 0-100%

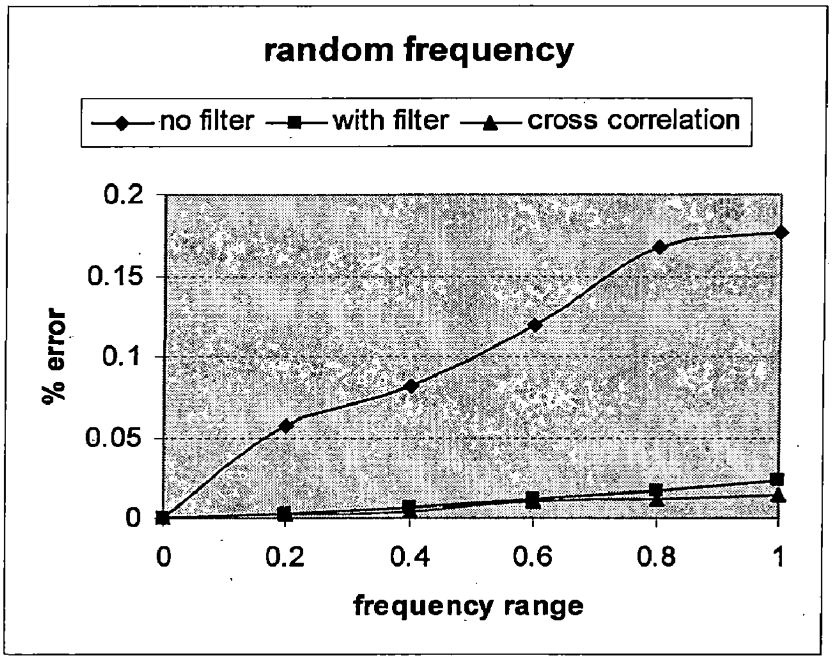

Fig 5.8: Modulated signal – Noise of random frequency

From this result, it is observed that the maximum error in no filter case is 0.1767%. The maximum error with filter is 0.02304% and in case of cross correlation, the maximum error is 0.0142%. There is a very drastic improvement in the accuracy. The simulation results in terms of percentage errors and noise variations for all the three cases are mentioned in Table A5 in appendix A.

The percentage error in case of unmodulated signal of random frequency with filter is 0.18% and in modulated signal case, the percentage error is 0.02304%. So, there is a very drastic improvement in the accuracy of the measurement. Similar is the case of cross correlation method also.

(c) NOISE OF RANDOM AMPLITUDE & RANDOM FREQUENCY

Here the noise is varying randomly in terms of amplitude and frequency. Both of these two are varying from 0% to 100% of original signal. The results of the unmodulated signal without filter, with filter and with cross correlation are observed and compared. The noise is varying in steps of 20%. The comparison result is as shown in the Figure 5.9.

Noise amplitude variation= 0-100% Noise frequency variation= 0-100%

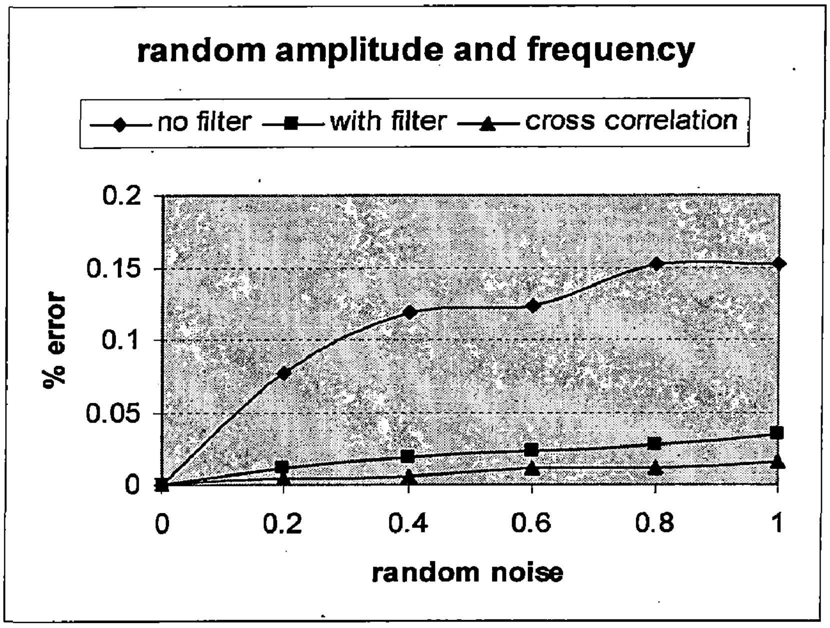

Fig 5.9: Modulated signal – Noise of random amplitude and random frequency

From this result, it is observed that the maximum error in no filter case is 0.1525%. The maximum error with filter is 0.03411% and in case of cross correlation, the maximum error is 0.0148%. There is a very drastic improvement in the accuracy. The simulation results in terms of percentage errors and noise variations for all the three cases are mentioned in Table A6 in appendix A.

5.6 SUMMARY

From the study of all the above cases, the observations that can be made are

i. The % error is more in no filter case.

ii. The usage of filter reduces the % error in time calculation.

iii. The peak detection with modulated signal gives better result as compared to threshold detection with unmodulated signal.

iv. As compared to above two cases, the percentage error is lowest for cross correlation technique. So, the ultimate choice in travel time calculation is cross correlation technique. This is true for both modulated and unmodulated signal case.

CHAPTER 6
ERROR DUE TO DISLOCATION OF TRANSDUCER

6.1 INTRODUCTION

This chapter mainly discusses the different errors that are occurring because of the transducer dislocation. The ultrasonic signal is very accurate and it has very narrow beam. If there is any variation in the transducer position, the transmitted signal may not reach the receiver. So, some times this will include errors. The dislocation of transducer may be due to human errors like failing in locating the sensor every time at the exact location. There may be some variations in terms of centimeters. But this much variation will also cause large errors in the measurement. The CFD software is used to analyze all these conditions and the errors due to the dislocation of transducers are tabulated.

Secondly, this chapter concentrates on the effect of multipath measurement and accuracy improvement in multipath arrangement as compared to single path arrangement. And the errors due to dislocation of transducers are also calculated in each and every case.

6.2 CASE STUDIES

In this case, the open rectangle channel is selected having the following dimensions

CASE 1:

Length = 20 m

Width = 15 m

Depth = 2 m

Percentage variation in the transducer position = 1% i.e., 2 mm.

Velocity from the CFD data is 0.744 m/s

Discharge from the CFD data is 22.32 m^3/s.

The CFD simulation diagram of the open rectangular section taken in this section is as shown in the Figure 6.1. The velocity profile at the output end of the channel is shown in Figure 6.2.

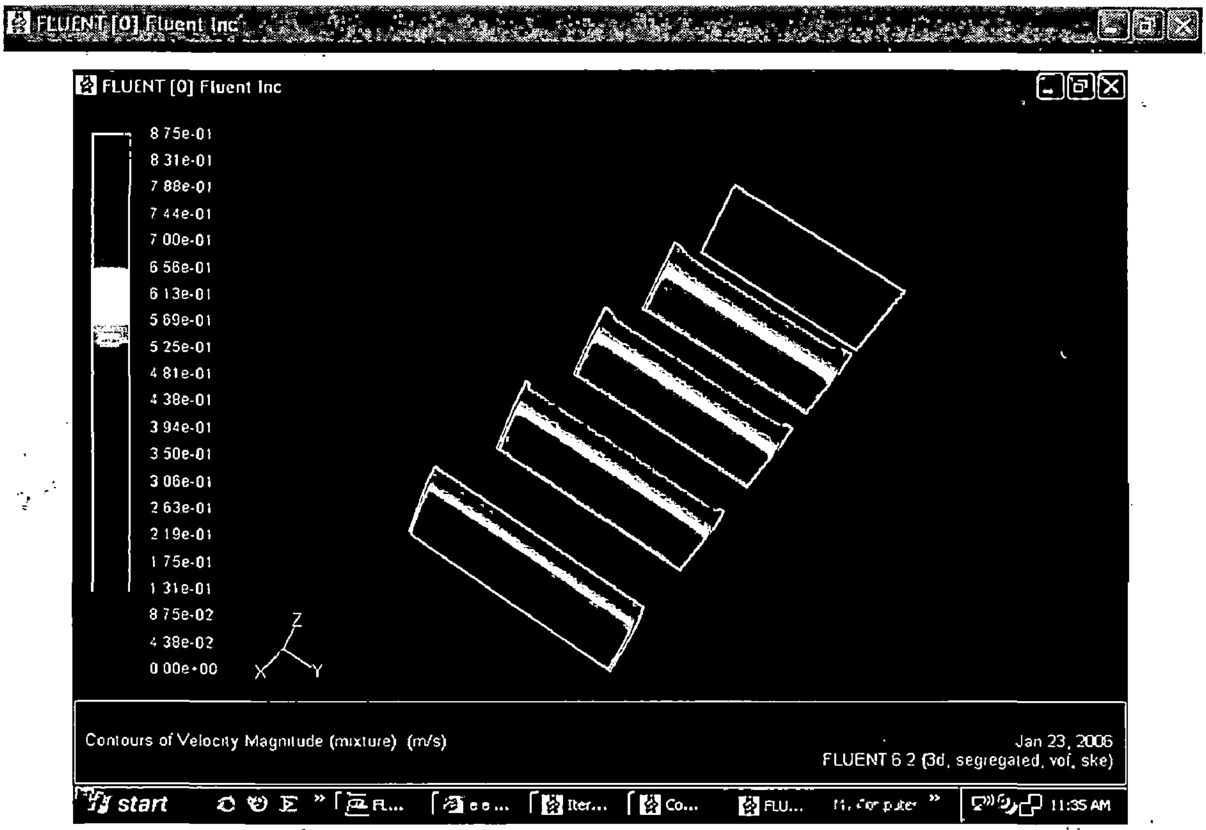

Fig 6.1: CFD simulation diagram of the channel in case I

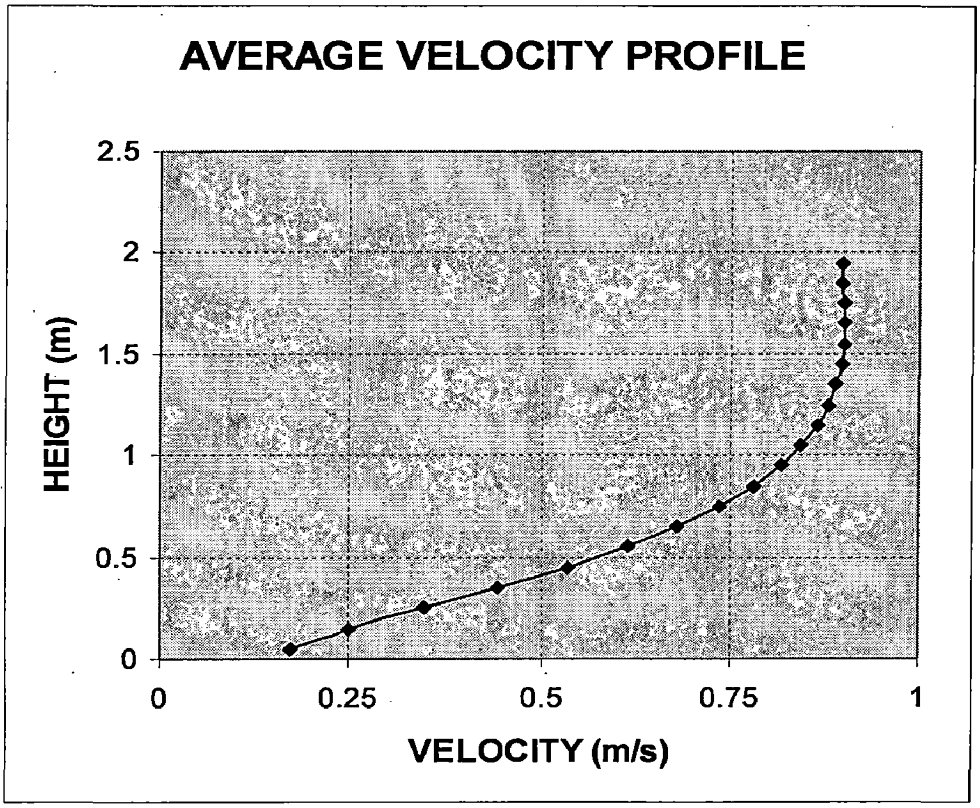

Fig 6.2: Average velocity profile of channel in case I

CASE 2:

Length = 5 m

Width = 3 m

Depth = 2 m

Percentage variation in the transducer position = 1% i.e., 2 mm.

Velocity from the CFD data is 0.7046 m/s

Discharge from the CFD data is 4.2276 m^3/s.

The CFD simulation diagram of the open rectangular section taken in this section is as shown in the Figure 6.3. The velocity profile at the output end of the channel is shown in Figure 6.4.

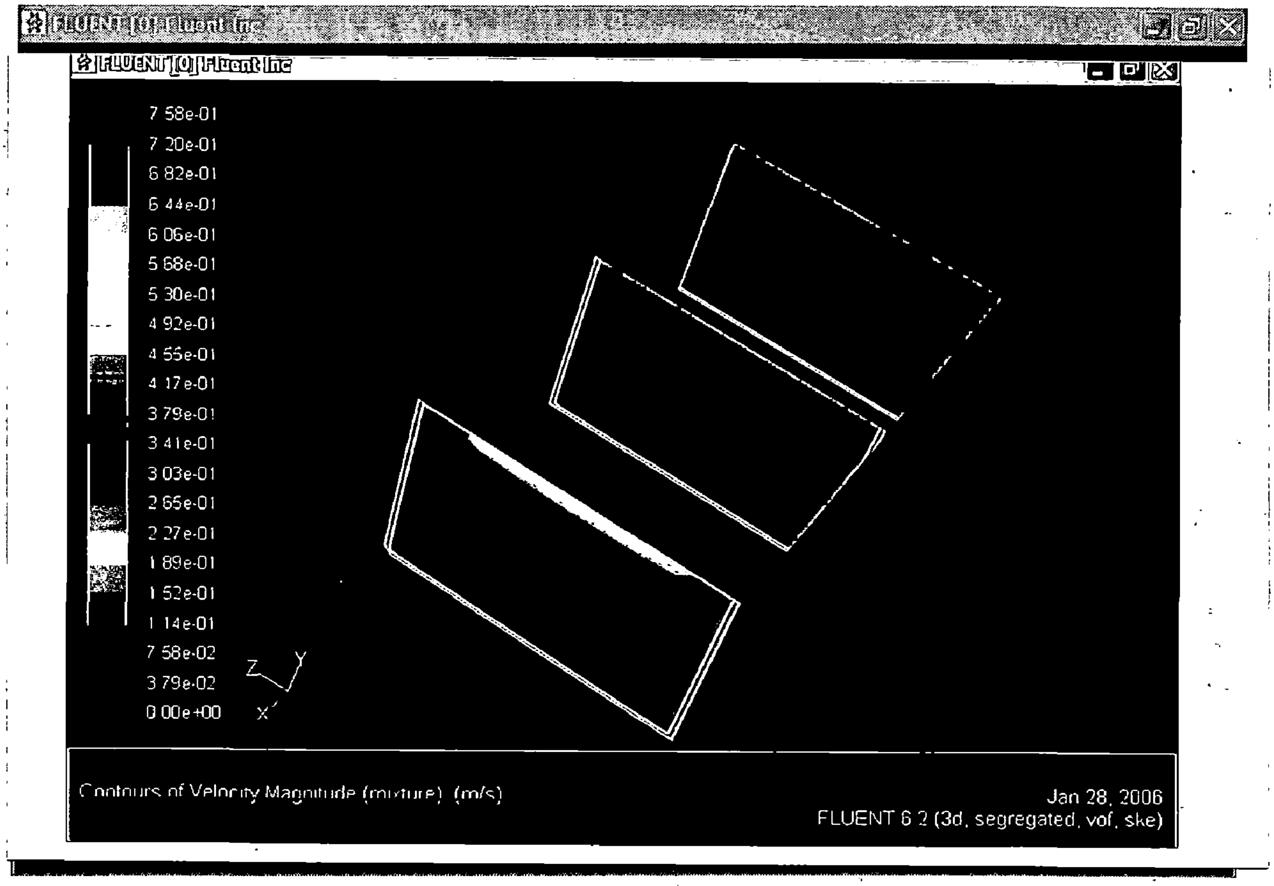

Fig 6.3: CFD simulation diagram of the channel in case II

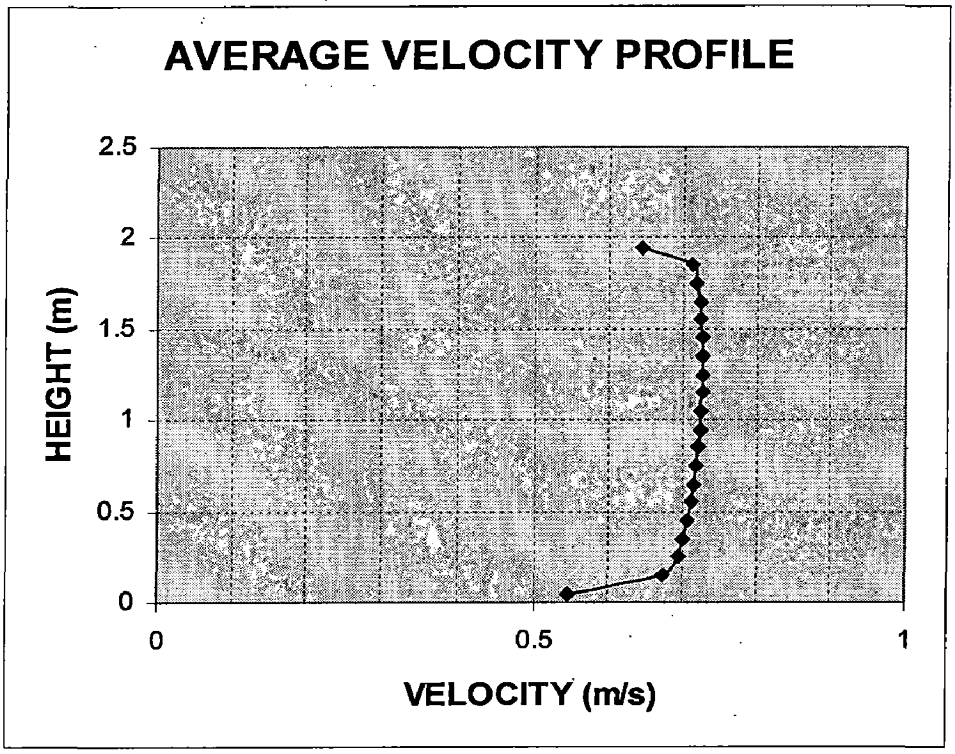

Fig 6.4: Average velocity profile of channel II

To Study the effects of single path, two path and four path measurements and compare the errors in all these cases, computed velocities at the following positions are used.

a) In the case of single path measurement the position of the sensor is at a height of 0.6d.
b) In two path measurement the sensors are at 0.2d, 0.8d & 0.3d, 0.7d.
c) In four path measurement the sensor positions are according to Gauss-Legendre rule at $\pm$ 0.861136d, $\pm$ 0.339981 for the paths 1,4 and 2,3 respectively.

6.3 ERRORS CALCULATIONS FOR CASE I

Velocity from the CFD data is 0.744 m/s

Discharge from the CFD data is 22.32 m^3/s.

6.3.1. SINGLE PATH MEASUREMENT

a) **<u>Measurement with exact position</u>**

In single path measurement, the velocity is calculated at a single depth in the entire channel. The standard depth of single path measurement is at 0.6d. In this case, the depth of the channel is 2 meters. So, the 0.6d is at a height of 1.2 meters.

From CFD simulation, the average velocity at a height of **1.2m** is **V = 0.862 m/s.**

Discharge at this velocity, **Q = 25.86 m^3/s.**

The % deviation in the discharge as compared to CFD result is **= 15.86%**

b) <u>Measurement with a position variation of 1%:</u>

Let the variation in the transducer position is 1% in the actual depth of the channel.

i.e., 1% in 2 meters = 2 mm away from the central axis of the channel

So, the new position of the sensor is at a height of 1.22m.

The channel velocity at a height of **1.22m** is **V = 0.875 m/s.**

Discharge at this velocity is **Q = 26.25 m^3/s.**

The % deviation in the variation of 1% in the actual depth **= 1.50%.**

6.3.2. TWO PATH MEASUREMENT

a) <u>Measurement with exact position</u>

0.3d & 0.7d measurement:

In two path measurement, the velocity is calculated at two depths in the entire channel. The standard depths in two path measurements are 0.3d, 0.7d. In this case, the depth of the channel is 2 meters. So, the sensors are to be located at the heights of 0.6 meters and 1.4 meters depth of the channel.

From CFD simulated profile the average velocity at a height of **0.6m, V = 0.698 m/s.**

and at **1.4m is V = 0.895 m/s**

The average velocity is **V_{avg} = 0.796 m/s**

Discharge at this velocity is **Q =23.895 m^3/s**

The % deviation in the discharge as compared to CFD result is = **11.47%**

0.2d & 0.8d measurement:

In two path measurement, the velocity is calculated at two depths in the entire channel. The standard depths in two path measurements are 0.2d, 0.8d. In this case, the depth of the channel is 2 meters. So, the sensors are to be located at the heights of 0.4 meters and 1.6 meters depth of the channel.

From CFD simulated profile the average velocity at a height of **0.4m, V = 0.490 m/s.**

and at **1.6m is V = 0.902 m/s**

The average velocity is $\mathbf{V_{avg}}$ **= 0.696 m/s**

Discharge at this velocity is **Q =20.88 m^3/s**

The % deviation in the discharge as compared to CFD result is = **-6.451%**

b)Measurement with a position variation of 1%

Let the variation in the transducer position is 1% in the actual depth of the channel.

i.e., 1% in 2 meters = 2 mm away from the central axis of the channel

Since the error in the case of 0.3d & 0.7d is more as compared to 0.2d & 0.8d, the previous method is discarded. So, the new positions of the sensors are at the heights of 0.42m, 1.62m. In this report the effect of variations are studied separately.

(i) Variation in path 1

The variation here is from 0.4m to 0.38m

From CFD simulated profile the average velocity at a height of **0.38m, V = 0.474 m/s.**

and at **1.6m is V = 0.902 m/s**

The average velocity is $\mathbf{V_{avg}}$ **= 0.688 m/s**

Discharge at this velocity is **Q =20.64 m^3/s**

The % deviation in the variation of 1% in the actual depth = **-1.10%**

(ii) Variation in path 2

The variation here is from 1.6m to 1.62m

From CFD simulated profile the average velocity at a height of **0.4m, V = 0.490 m/s.**

and at **1.62m is V = 0.903 m/s**

The average velocity is V_{avg} = **0.696 m/s**

Discharge at this velocity is **Q =20.88 m^3/s**

The % deviation in the variation of 1% in the actual depth = **0%**

6.3.3. FOUR PATH MEASUREMENT

(a) Measurement with exact position

In four path measurement, the velocity is calculated at four depths in the entire channel. The standard depths in four path measurements are according to Gauss-Legendre method. In this case, the depth of the channel is 2 meters. So, the sensors are to be located at the heights as shown in the Table 6.1.

Table 6.1: Methods of discharge calculation

		Gauss-Legendre method		Gauss-Jacobi method	
		Paths 1 and 4	Paths 2 and 3	Paths 1 and 4	Paths 2 and 3
d/(D/2)		± 0.861136	± 0. 339981	± 0.809017	± 0.309017
W		0.347855	0.652145	0.369317	0.597667
k	**Circular section**	0.994		1	
	Rectangular section	1		1.034	

Then the original equation used for discharge measurement will be as follows: (described in detail in section 2.3.2)

$$Q = k\frac{D}{2}\sum_{1}^{n} W_i \bar{v}_{ai} L_{wi} \sin \varphi$$

Where

φ is the angle made by the i^{th} path with flow direction,

L_{wi} is the distance from left wall to right wall along the i^{th} ultrasonic path,

$L_{wi} \sin \varphi$ = B, i.e., is the distance from left wall to right wall (breadth),

$\bar{v}_{ai}$ is the flow velocity averaged along i^{th} path,

W_i is the weighting factor of i^{th} path depending on the numerical integration method,

n is the number of UTTF paths,

D is the depth of the channel,

k is the correction factor depending on the numerical integration method and the shape of the conduit

Q is the discharge measured m^3/s.

Since, the study is on rectangle channels, the Gauss-Legendre method is preferable.The sensors are to be located at different depths of the channel. The different positions are mentioned in Table 6.2.

Table 6.2: Sensor positions according to Gauss-Legendre method in case I

Path	**The actual height of sensor location in meters**	**The velocity in this path in m/s**
Path 1	0.138864	0.238
Path 2	0.660019	0.693
Path 3	1.339981	0.889
Path 4	1.861136	0.896

In this case, the discharge formula is simplified as

Q= 15 [0.347855 (path 1 + path 4) + 0.652145 (path 2 + path 3)] m^3/s.

Discharge in this measurement is **Q = 21.436 m^3/s.**

The % deviation in the discharge as compared to CFD result is = **-3.96%**

(b) Measurement with a position variation of 1%

Let the variation in the transducer position is 1% in the actual depth of the channel.

i.e., 1% in 2 meters = 2 mm away from the central axis of the channel

In this report the effect of variations are studied separately.

(i) Variation in path 1

The variation here is from 0.138864m to 0.118864m

The channel velocity at a height of **0.118864m** is **V = 0.222 m/s.**

Discharge at this velocity is **Q = 21.30 m^3/s.**

The % deviation in the variation of 1% in the actual depth = **-0.592%.**

(ii) Variation in path 2

The variation here is from 0.660019m to 0.640019m

The channel velocity at a height of **0.640019m** is **V = 0.675 m/s.**

Discharge at this velocity is **Q = 21.21 m^3/s.**

The % deviation in the variation of 1% in the actual depth = **-1.05%.**

(iii) Variation in path 3

The variation here is from 1.339981m to 1.359981m

The channel velocity at a height of **1.359981m** is **V = 0.892 m/s.**

Discharge at this velocity is **Q = 21.426 m^3/s.**

The % deviation in the variation of 1% in the actual depth = **-0.04%.**

(iv) Variation in path 4

The variation here is from 1.861136 m to 1.881136 m

The channel velocity at a height of **1.881136m** is **V = 0.899 m/s.**

Discharge at this velocity is **Q = 21.408 m^3/s.**

The % deviation in the variation of 1% in the actual depth = **-0.13%.**

6.3 ERRORS CALCULATIONS FOR CASE II

Velocity from the CFD data is 0.7046 m/s

Discharge from the CFD data is 4.2276 m^3/s.

6.3.1. SINGLE PATH MEASUREMENT

b) Measurement with exact position

In single path measurement, the velocity is calculated at a single depth in the entire channel. The standard depth of single path measurement is at 0.6d. In this case, the depth of the channel is 2 meters. So, the 0.6d is at a height of 1.2 meters.

From CFD simulation, the average velocity at a height of **1.2m** is **V = 0.725 m/s.**

Discharge at this velocity, Q = **4.35 m^3/s.**

The % deviation in the discharge as compared to CFD result is = **2.895%**

b) <u>Measurement with a position variation of 1%:</u>

Let the variation in the transducer position is 1% in the actual depth of the channel.

i.e., 1% in 2 meters = 2 mm away from the central axis of the channel

So, the new position of the sensor is at a height of 1.22m.

The channel velocity at a height of **1.22m** is **V = 0.729 m/s.**

Discharge at this velocity is **Q = 4.374 m^3/s.**

The % deviation in the variation of 1% in the actual depth = **0.551%.**

6.3.2. TWO PATH MEASUREMENT

a) <u>Measurement with exact position</u>

0.3d & 0.7d measurement:

In two path measurement, the velocity is calculated at two depths in the entire channel. The standard depths in two path measurements are 0.3d, 0.7d. In this case, the depth of the channel is 2 meters. So, the sensors are to be located at the heights of 0.6 meters and 1.4 meters depth of the channel.

From CFD simulated profile the average velocity at a height of **0.6m, V = 0.713 m/s.**

and at **1.4m** is **V = 0.726 m/s**

The average velocity is **V_{avg} = 0.7195 m/s**

Discharge at this velocity is **Q =4.317 m^3/s**

The % deviation in the discharge as compared to CFD result is = **2.114%**

0.2d & 0.8d measurement:

In two path measurement, the velocity is calculated at two depths in the entire channel. The standard depths in two path measurements are 0.2d, 0.8d. In this case, the depth of the channel is 2 meters. So, the sensors are to be located at the heights of 0.4 meters and 1.6 meters depth of the channel.

From CFD simulated profile the average velocity at a height of **0.4m, V = 0.702 m/s.**

and at **1.6m** is **V = 0.725 m/s**

The average velocity is V_{avg} = **0.7135 m/s**

Discharge at this velocity is **Q =4.281 m^3/s**

The % deviation in the discharge as compared to CFD result is **=1.263-%**

b)<u>Measurement with a position variation of 1%</u>

Let the variation in the transducer position is 1% in the actual depth of the channel.

i.e., 1% in 2 meters = 2 mm away from the central axis of the channel

Since the error in the case of 0.3d & 0.7d is more as compared to 0.2d & 0.8d, the previous method is discarded. So, the new positions of the sensors are at the heights of 0.42m, 1.62m. In this report the effect of variations are studied separately.

(i) <u>Variation in path 1</u>

The variation here is from 0.4m to 0.38m

From CFD simulated profile the average velocity at a height of **0.38m, V = 0.702 m/s.**

and at **1.6m is V = 0.725 m/s**

The average velocity is V_{avg} = **0.707 m/s**

Discharge at this velocity is **Q =4.281 m^3/s**

The % deviation in the variation of 1% in the actual depth = **0%**

(ii) <u>Variation in path 2</u>

The variation here is from 1.6m to 1.62m

From CFD simulated profile the average velocity at a height of **0.4m, V = 0.702 m/s.**

and at **1.62m is V = 0.724 m/s**

The average velocity is V_{avg} = **0.713 m/s**

Discharge at this velocity is **Q =4.278 m^3/s**

The % deviation in the variation of 1% in the actual depth = **-0.07%**

6.3.3. FOUR PATH MEASUREMENT

(a) <u>Measurement with exact position:</u>

In four path measurement, the velocity is calculated at four depths in the entire channel. The standard depths in four path measurements are according to Gauss-Legendre method. In this case, the depth of the channel is 2 meters. The sensors are to be located at different depths. The different locations and the velocities at the respective depths are mentioned in Table 6.3.

Table 6.3: Sensor positions according to Gauss-Legendre method in case II

Path	**The actual height of sensor location in meters**	**The velocity in this path in m/s**
Path 1	0.138864	0.662
Path 2	0.660019	0.715
Path 3	1.339981	0.727
Path 4	1.861136	0.708

In this case, the discharge formula is simplified as

Q= 3 [0.347855 (path 1 + path 4) + 0.652145 (path 2 + path 3)] m^3/s.

Discharge in this measurement is **Q = 4.25 m^3/s.**

The % deviation in the discharge as compared to CFD result is =**0.529 %**

(b) Measurement with a position variation of 1%

Let the variation in the transducer position is 1% in the actual depth of the channel.

i.e., 1% in 2 meters = 2 mm away from the central axis of the channel

In this report the effect of variations are studied separately.

(i) Variation in path 1

The variation here is from 0.138864m to 0.118864m

The channel velocity at a height of **0.118864m** is **V = 0.642m/s.**

Discharge at this velocity is **Q = 4.228m^3/s.**

The % deviation in the variation of 1% in the actual depth = **-0.517%.**

(ii) Variation in path 2

The variation here is from 0.660019m to 0.640019m

The channel velocity at a height of **0.640019m** is **V = 0.714 m/s.**

Discharge at this velocity is **Q = 4.247 m^3/s.**

The % deviation in the variation of 1% in the actual depth = **-0.07%.**

(v) **Variation in path 3**

The variation here is from 1.339981m to 1.359981m

The channel velocity at a height of **1.359981m** is **V = 0.729 m/s.**

Discharge at this velocity is **Q = 4.254 m^3/s.**

The % deviation in the variation of 1% in the actual depth = **0.09%.**

(vi) **Variation in path 4**

The variation here is from 1.861136 m to 1.881136 m

The channel velocity at a height of **1.881136m** is **V = 0.696 m/s.**

Discharge at this velocity is **Q = 4.238 m^3/s.**

The % deviation in the variation of 1% in the actual depth = **-0.28%.**

6.5. SUMMARY

From the above calculations it is concluded that the accuracy of the flow measurement is more in case of multiple path method as compared to the single path method. The two path is better than single path method of measurement and the four path method is better than two path method.

It is possible to make the discharge calculation more accurate as compared to the Gauss-Legendre method of measurement. This correction factor should be involved for this accurate discharge calculation is according to the sensor locations in the channel. If there is any related to sensor position in the channel, then the accuracy of the flow measurement can be further improved. So, the method suggested through this work is to use the velocity profile equation for the discharge measurement.

Similarly, the calculations shown above explain about the importance of accurate position in the flow measurement. If the sensor is located at a deviation of 1% from its actual position, the maximum percentage error is at the bottom of the channel because at that point the velocity profile will have more slope. This error can be called as the relative error with respect to the actual error because this is the additional error because of the variation. The range of this relative error is less than 1%. If proper is taken, this error can be eliminated. So, proper care must be taken in mounting the sensor.

CHAPTER 7

CONCLUSION & FUTURE SCOPE

7.1 CONCLUSION

Flow is an important physical quantity, which is useful in calculating the turbine efficiency in hydro-electric power plant. So, the measurement of flow should be very accurate. Ultrasonic Transit Time Flow meter (UTTF) can be one of the best suitable flow meter for many industrial applications. But the inaccuracy of the UTTF flow meter is little more than 1.0%. For accurate calculation of discharge, the measurement of flow should be more accurate.

The total report discusses about the different factors which are affecting the accuracy of the flow measurement using UTTF. The accuracy improvement methods are also suggested in chapter 4. Out of the different methods discussed, this report concentrates mainly on two problems. They are the inaccuracies involved in "travel time measurement" and "transducer positioning".

In travel time measurement, there are two methods already in use. But the accuracies of the present methods are not good. So, two new methods are proposed in this report. The new methods are cross correlation technique and the modulated signal approach. The accuracy is more in case of cross correlation method as compared to the older techniques like threshold detection technique and the filtering technique. In case of modulated signal approach, the peak detection method will give better result as compared to the threshold detection method. The accuracy of the measurement in the case of modulated signal approach is better than the unmodulated signal. The results of the existing methods and the proposed methods are compared and are represented graphically. From these results, the conclusion is that the newly proposed methods are more accurate as compared to the existing methods.

The second case that is discussed in this report is the effect of multiple path measurement. The results proved that the accuracy of the discharge calculation is more in case of multiple path measurement as compared to the single path measurement. If there is any deviation in the sensor position, the flow measurement will be inaccurate. The percentage variation of accuracy of the flow measurement with the deviation of 1% in the transducer position is calculated. This work highlights the importance of accurate positioning of transducer. The correction factors in discharge calculation according to transducer positions are also discussed for improvement of discharge measurement accuracy. So, the accuracy of the flow measurement can be improved by following the above two corrective measures.

7.2 FUTURE SCOPE OF THE WORK

Even though this work improves the accuracy of flow measurement in two cases, there are further more methods to be developed for further improvement of accuracy to bring it lower than 1%. The different future research areas of accuracy improvement methods are enlisted below:

a) From the discussions above, the accuracy of flow measurement depends upon the sensor positions in the channel. If the discharge calculation method involves the term of transducer location, then the accuracy will be improved further. That means some correction factor in the discharge calculation must be proposed depending upon the sensor location. This method of finding out the correction factor should be calculated for simple rectangle channel, trapezoidal channel, tubes and the channels with some slopes and some bends.
b) Exact curve fitting equations should be proposed in case of different types of channels according to the channel depth and Reynolds number.
c) The indexing method as explained in chapter 4 should be developed. This method will reduce the effort of multiple path measurement in each and every case.
d) Studying of the effect of a single large bubble in the ultrasonic path and finding the travel time. This bubble will almost absorb the ultrasonic signal.
e) Calculation of discharge in the case of semi filled or half filled pipes with the help UTTF technique and the measurement should be more accurate.

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APPENDIX A
SIMULATION RESULTS

UNMODULATED SIGNAL:

Table A1: Noise of random amplitude

NOISE AMPLITUDE RANGE	% ERROR		
	NO FILTER	WITH FILTER	CROSS CORRELATION
0	0	0	0
0.2	0	0.02	0.0055
0.4	0	0.03	0.0057
0.6	0	0.04	0.0074
0.8	0.19	0.05	0.00923
1	0.2	0.07	0.01012

Table A2: Noise of random frequency

NOISE FREQUENCY RANGE	% ERROR		
	NO FILTER	WITH FILTER	CROSS CORRELATION
0	0	0	0
0.2	0.07	0.01	0.00262
0.4	0.13	0.09	0.0042
0.6	0.18	0.17	0.0062
0.8	0.2	0.18	0.00625
1	0.2	0.18	0.0148

Table A3: Noise of random amplitude & frequency

NOISE AMPLITUDE & FREQUENCY RANGE	% ERROR		
	NO FILTER	WITH FILTER	CROSS CORRELATION
0	0	0	0
0.2	0.02	0.01	0.00482
0.4	0.06	0.03	0.0064
0.6	0.12	0.08	0.01178
0.8	0.15	0.1	0.01182
1	0.16	0.17	0.01623

MODULATED SIGNAL:

Table A4: Noise of random amplitude

NOISE AMPLITUDE RANGE	% ERROR		
	NO FILTER	WITH FILTER	CROSS CORRELATION
0	0	0	0
0.2	0.01139	0.00492	0.00278
0.4	0.06435	0.0582	0.00321
0.6	0.1442	0.0593	0.00555
0.8	0.16152	0.0651	0.00833
1	0.16457	0.0654	0.0085

Table A5: Noise of random frequency

NOISE FREQUENCY RANGE	% ERROR		
	NO FILTER	WITH FILTER	CROSS CORRELATION
0	0	0	0
0.2	0.0566	0.00212	0.00321
0.4	0.0824	0.00694	0.0041
0.6	0.1195	0.01156	0.0102
0.8	0.16749	0.0165	0.00118
1	0.1767	0.02304	0.0142

Table A6: Noise of random amplitude & frequency

NOISE AMPLITUDE FREQUENCY	% ERROR		
	NO FILTER	WITH FILTER	CROSS CORRELATION
0	0	0	0
0.2	0.0766	0.0112	0.0022
0.4	0.11942	0.01882	0.0055
0.6	0.1225	0.02312	0.0088
0.8	0.1518	0.02779	0.001024
1	0.1525	0.03411	0.0148

APPENDIX B
LabVIEW SOFTWARE

This section deals with the introduction to LabVIEW software and description of its various distinctive features.

B.1 INTRODUCTION TO LabVIEW

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a graphical programming language that uses icons instead of lines of text to create applications. In contrast to text-based programming languages, where instructions determine the order of program execution, LabVIEW uses dataflow programming, where the flow of data through the nodes on the block diagram determines the execution order of the VIs and functions. VIs, or virtual instruments, are LabVIEW programs that imitate physical instruments.

In LabVIEW, a user interface is built by using a set of tools and objects. The user interface is known as the front panel. Then code is developed using graphical representations of functions to control the front panel objects. This graphical source code is also known as G code or block diagram code. The block diagram contains this code. In some ways, the block diagram resembles a flowchart.

B.2 INTRODUCTION TO VIRTUAL INSTRUMENTS

LabVIEW programs are called virtual instruments, or VIs, because their appearance and operation imitate physical instruments, such as oscilloscopes and multimeters. Every VI uses functions that manipulate input from the user interface or other sources and display that information or move it to other files or other computers.

A VI contains the following three components:

- **Front panel**—Serves as the user interface.
- **Block diagram**—Contains the graphical source code that defines the functionality of the VI.

- **Icon and connector pane**—Identifies the interface to the VI so that you can use the VI in another VI. A VI within another VI is called a subVI. A subVI corresponds to a subroutine in text-based programming languages.

B.2.1 FRONT PANEL

The front panel is the user interface of the VI. The Fig B.1. Shows the example of a front panel.

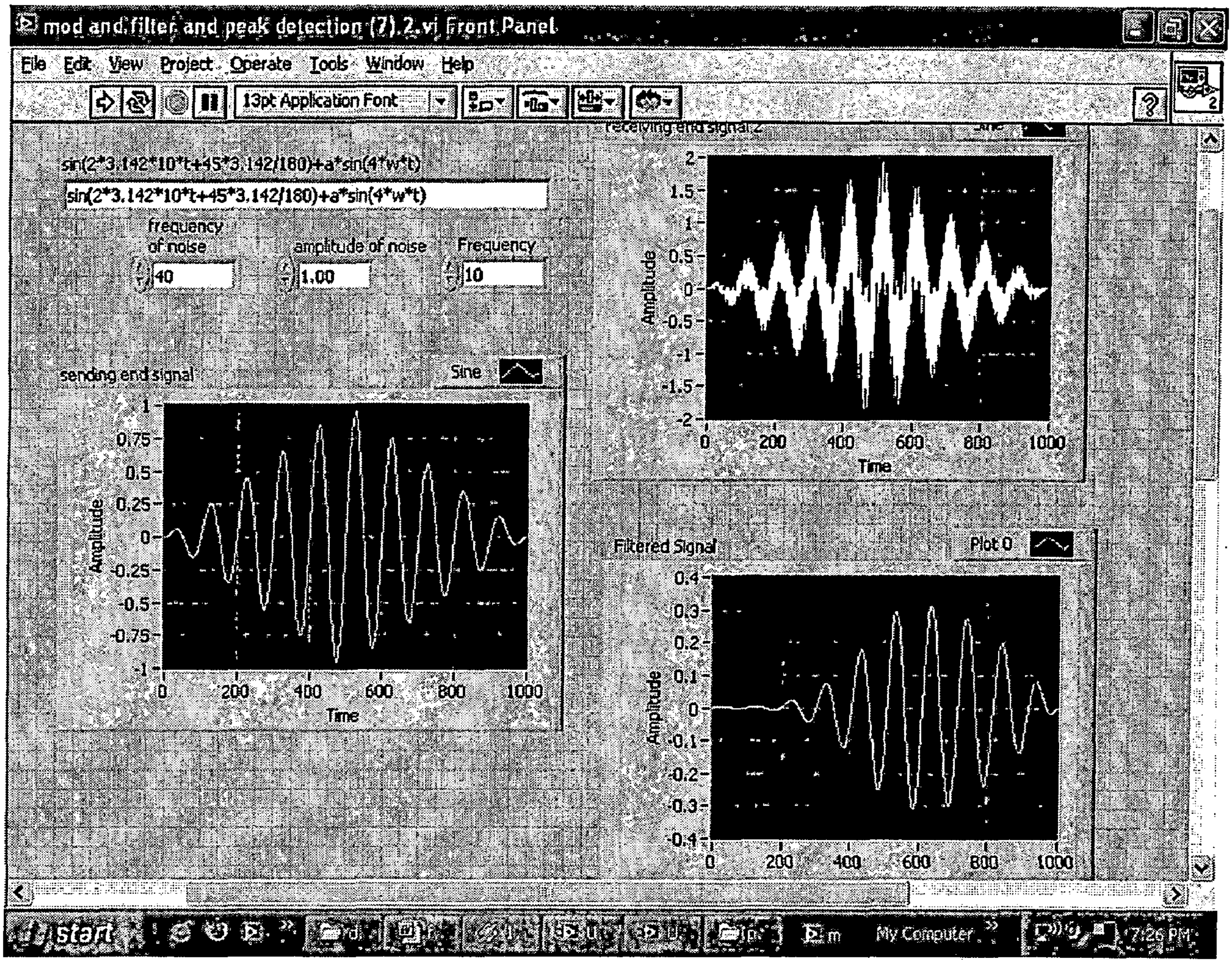

Fig B.1 Front Panel Example

The front panel is built using controls and indicators, which are the interactive input and output terminals of the VI, respectively. Controls are knobs, push buttons, dials, and other input mechanisms. Indicators are graphs, LEDs, and other output displays. Controls simulate instrument input mechanisms and supply data to the block diagram of the VI. Indicators simulate instrument output mechanisms and display data the block diagram acquires or generates.

B.2.2 BLOCK DIAGRAM

Once the front panel is built, the code is developed using graphical representations of functions to control the front panel objects. The following VI contains several primary block diagram objects—terminals, functions, and wires. Fig B.2. shows the view of block diagram .

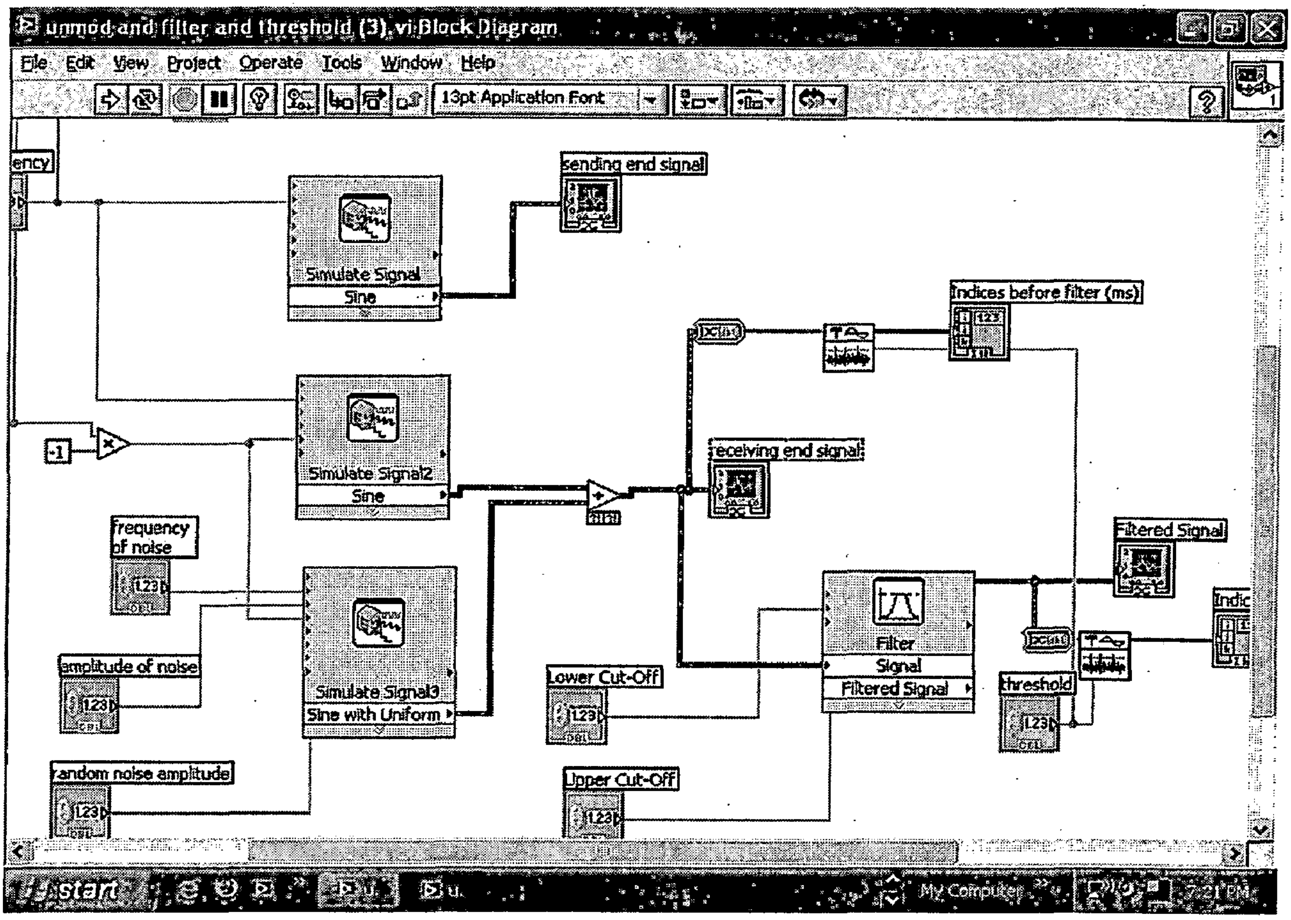

Fig B.2 Block Diagram Example

APPENDIX C
CFD SOFTWARE

CFD is a flow measurement software, consists of two softwares GAMBIT and FLUENT. Out of these two GAMBITS is designing software and FLUENT is simulating software. The CFD modeling overview is shown in Fig C.1.

C.1. STAGES OF CFD ANALYSIS

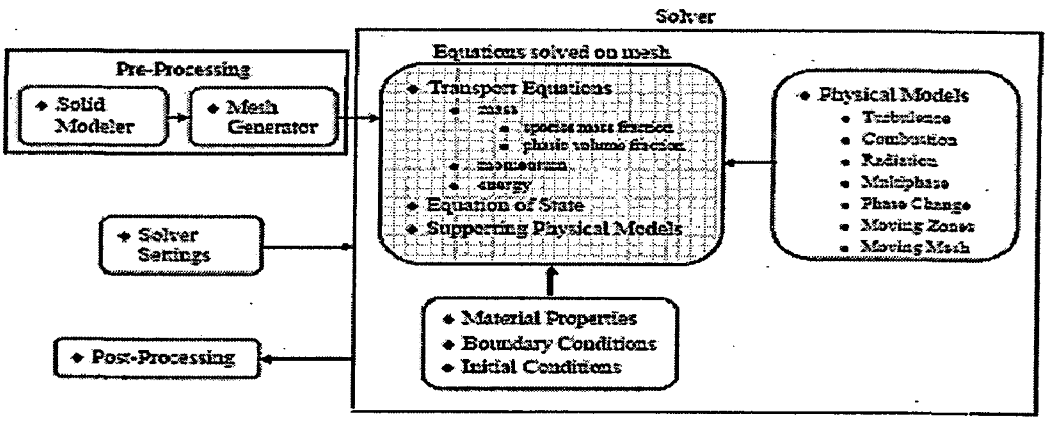

Fig. C.1 Overview of CFD modeling

<u>Stage 1 Modeling Geometry</u>: The first step in performing a CFD analysis is to create the shape of the fluid that needs to be analyzed. This can be done by GAMBIT.

<u>Stage 2 Meshing</u>: In the second stage the fluid is then sub-divided into numerous cells. In many CFD packages, meshing can be done while the shape is being defined.

<u>Stage 3 Preprocessing</u>: Once meshing has been completed, boundary conditions are then applied to the fluid. This generally means specifying known velocities or pressures at specific points of the fluid.

<u>Stage 4 CFD Analysis</u>: This step involves using a computer to solve mathematical equations of fluid motion. This is done by FLUENT.

<u>Stage 5 Post Processing</u>: Post processing is done to make sense of the data generated by the CFD analysis. In solving the equations, a computer would have generated a fair amount of data for each cell.

C.2 GEOMETRY MODELING IN GAMBIT

C.2.1. CREATING THE GEOMETRY

When you click the **Geometry** command button on the **Operation** toolpad, GAMBIT opens the **Geometry** subpad. The **Geometry** subpad contains command buttons that allow you to create, move, copy, modify, summarize, and delete vertices, edges, faces, and volumes. The **Geometry** subpad also contains a command button that allows you to perform operations involving groups of topological entities. The front panel of GAMBIT is as shown in Fig C.2.

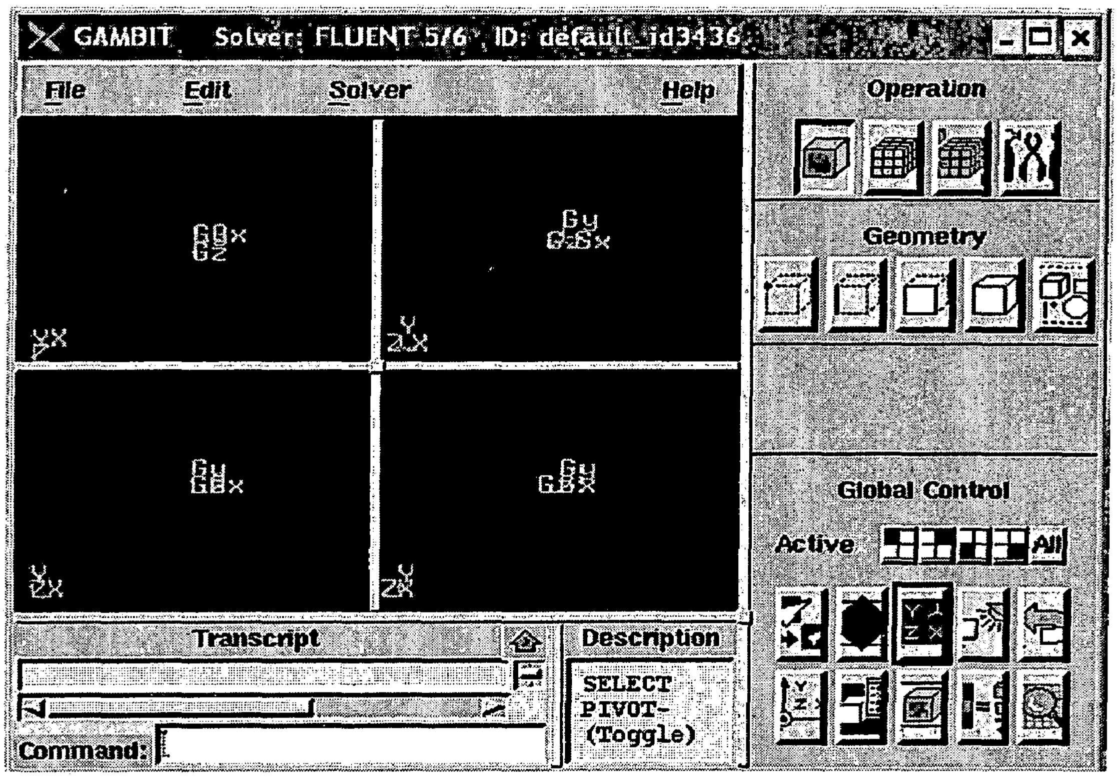

Fig C.2: Front panel of GAMBIT software

C.2.2. MESHING THE MODEL

The **Mesh Volumes** command allows you to create a mesh for one or more volumes in the model. When you mesh a volume, GAMBIT creates mesh nodes throughout the volume according to the currently specified meshing parameters.

C.2.3 SPECIFYING ZONE TYPES

Zone-type specifications define the physical and operational characteristics of the model at its boundaries and within specific regions of its domain. There are two classes of zone-type specifications: 1. Boundary types 2. Continuum types Boundary-type specifications, such as WALL or VENT, define the characteristics of the model at its external or internal boundaries. Continuum-type specifications, such as FLUID or SOLID, define the characteristics of the model within specified regions of its domain. The front panel of FLUENT is as shown in Fig C.3.

C.3 SIMULATING OPEN CHANNEL FLOWS BY FLUENT

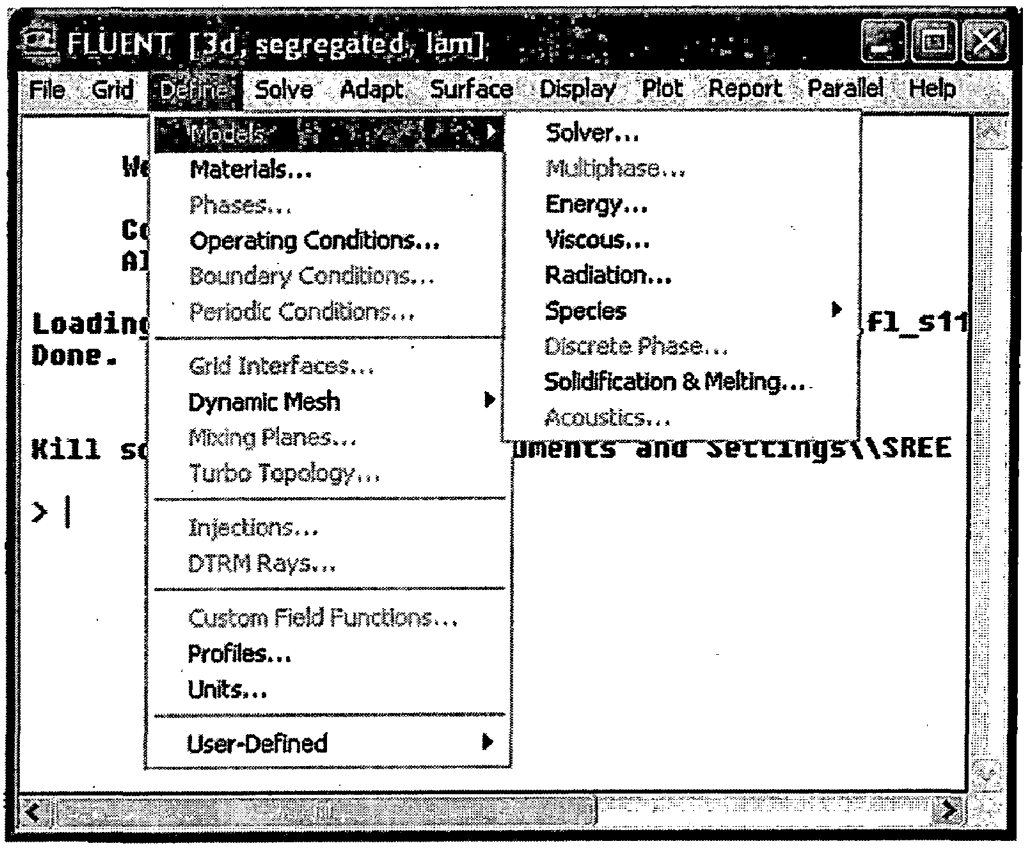

Fig C.3.: Front panel of FLUENT software

C.4.1 SETTING THE PARAMETERS

FLUENT can model the effects of open channel flow (e.g., rivers, dams, and surface-piercing structures in unbounded stream) using the VOF formulation and the open channel boundary condition. These flows involve the existence of a free surface between the flowing fluid and fluid above it (generally the atmosphere).

In such cases, the wave propagation and free surface behavior becomes important. Flow is generally governed by the forces of gravity and inertia. This feature is mostly applicable to marine applications and the analysis of flows through drainage systems. Using the VOF formulation, open channel flows can be modeled in **FLUENT**. To start using the open channel flow boundary condition, perform the following:

1. Turn on gravity.

   (a) Open the **Operating Conditions** panel.

   Define →Operating Conditions...

   (b) Turn on **Gravity** and set the gravitational acceleration fields.

2. Enable the volume of fluid model.

   (a) Open the **Multiphase Model** panel.

   Define →Models →Multiphase...

   (b) Under **Model**, turn on **Volume of Fluid.**

   (c) Under **VOF Scheme**, select either **Implicit**, **Explicit**, or **Geo-Reconstruct**.

3. Under **VOF Parameters**, select **Open Channel Flow.**

Table 3.1: Open Channel Boundary Parameters for the VOF Model

Boundary Type	**Parameter**
pressure inlet	Inlet Group ID; Secondary Phase for Inlet; Flow Specification Method; Free Surface Level, Bottom Level; Velocity Magnitude
pressure outlet	Outlet Group ID: Pressure Specification Method; Free Surface Level; Bottom Level
mass flow inlet	Inlet Group ID; Secondary Phase for Inlet; Free Surface Level; Bottom Level

C.4.2 DEFINING THE BOUNDARY CONDITIONS

In order to set specific parameters for a particular boundary for open channel flows, turn on the **Open Channel Flow** option in the corresponding boundary condition panel. Table 1 summarizes the types of boundaries available to the open channel flow boundary condition, and the additional parameters needed to model open channel flow.

Defining Inlet Groups: Open channel systems involve the flowing fluid (the secondary phase) and the fluid above it (the primary phase).

If both phases enter through the separate inlets (e.g., `inlet-phase2` and `inlet-phase1`), these two inlets form an inlet group. This inlet group is recognized by the parameter **Inlet Group ID**, which will be same for both the inlets that make up the inlet group. On the other hand, if both the phases enter through the same inlet (e.g., `inlet-combined`), then the inlet itself represents the inlet group.

Defining Outlet Groups: Outlet-groups can be defined in the same manner as the inlet groups.

Setting the Inlet Group: For pressure inlets and mass flow inlets, the **Inlet Group ID** is used to identify the different inlets that are part of the same inlet group. For instance, when both phases enter through the same inlet (single face zone), then those phases are part of one inlet group and you would set the **Inlet Group ID** to 1 for that inlet (or inlet group).

In the case where the same inlet group has separate inlets (different face zones) for each phase, then the **Inlet Group ID** will be the same for each inlet of that group.

When specifying the inlet group, use the following guidelines:

- Since the **Inlet Group ID** is used to identify the inlets of the same inlet group, general information such as **Free Surface Level**, **Bottom Level**, or the mass flow rate for each phase should be the same for each inlet of the same inlet group.
- You should specify a different **Inlet Group ID** for each distinct inlet group.

For example, consider the case of two inlet groups for a particular problem. The first inlet group consists of water and air entering through the same inlet (a single face zone). In this case, you would specify an inlet group ID of 1 for that inlet (or inlet group). The second inlet group consists of oil and air entering through the same inlet group, but each uses a different inlet (`oil-inlet` and `air-inlet`) for each phase. In this case, you would specify the same **Inlet Group ID** of 2 for both of the inlets that belong to the inlet group.

Setting the Outlet Group: For pressure outlet boundaries, the **Outlet Group ID** is used to identify the different outlets that are part of the same outlet group. For instance, when both phases enter through the same outlet (single face zone), then those phases are part of one outlet group and you would set the **Outlet Group ID** to 1 for that outlet (or outlet group).

In the case where the same outlet group has separate outlets (different face zones) for each phase, then the **Outlet Group ID** will be the same for each outlet of that group.

When specifying the outlet group, use the following guidelines:

- Since the **Outlet Group ID** is used to identify the outlets of the same outlet group, general information such as **Free Surface Level** or **Bottom Level** should be the same for each outlet of the same outlet group.
- You should specify a different **Outlet Group ID** for each distinct outlet group.

  For example, consider the case of two outlet groups for a particular problem. the first inlet group consists of water and air exiting from the same outlet (a single face zone). In this case, you would specify an outlet number of 1 for that outlet (or outlet group). The second outlet group consists of oil and air exiting through the same outlet group, but each uses a different outlet (`oil-outlet` and `air-outlet`) for each phase. In this case, you would specify the same **Outlet Group ID** of 2 for both of the outlets that belong to the outlet group.