REAL TIME CROSS CORRELATOR FOR SPEED MEASUREMENT OF PARTICLE CONVEYING IN PNEUMATIC PIPE LINE

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Abstract - The idea of signal processing with cross correlation technique is not a new thing. Since 1930s, the theory of cross correlation technique has been found, but is not used by the industries until 1960s, where an hardware called correlator have been invented. The cross correlation technique to find the velocity of a spinning plastic ball in and test apparatus to represent the flow of dry powders in a pipe has been developed in this paper. The flow is detected by two axially spaced electrodynamics sensor, which the length of the space is known, and will be interfaced with the computer with the interface board AX5412. This paper focuses on the software development to interface with the interface board AX5412 and to get the data from the both sensors, so that the cross correlation technique can manipulate the data. The velocity of the plastic ball can be calculated with the knowledge of the length of space between the sensors with the time shift obtained from the peak of the cross correlation coefficient.

Keyworks : Cross correlation

I. INTRODUCTION

Flow meter measurement by using the method of cross correlation will produce result by calculating statistically the similarity of two random signals sensed by sensors in cross correlation function. The position of maximum value on cross correlation function shows the time delay of the signal generated by both the sensors. This time delay is used to determine the velocity of the flow of the materials. In this paper, electrodynamic sensor is used to detect electrostatic charge being accumulated and to convert the charge into voltage signal.

Then this voltage signal will be converted into digital signal by the AX5412 Data Acquisition Card, which acts as an analogue to digital converter. This card will sample the data from the sensor and then convert them into digital data. With this digital data, the computer will be able to manipulate the data and generate cross correlation function graph to be use for velocity determination.

II. THE MEASUREMENT SYSTEM

An electrostatic charge accumulates on the particles when solid particles are entrained in a flowing stream of gas or air in a conveyor. The magnitude of the charges depends on many factors such as the physical properties of the particles, including shape, size, density, conductivity, permittivity, humidity and composition (Shackleton 1982). This electrostatic charge can be detected using electrodes or plates and converted into a voltage by the electrodynamic transducer. An AC amplifier amplifies the voltage and the output can be cross-correlated to give the flow velocity of the solids.

The transducer consists of two elements, the electrode or sensing device and the associated electronics (Shackleton 1982). Two types of electrode have found particular application to electrodynamic transducers. The ring electrode that illustrated in Figure 1 (a) has the advantage of averaging the flow velocity near to the pipe wall. An even simpler arrangement is to use pin electrodes, as shown in Figure 1 (b), which will not average the velocity over the whole pipe wall, but will give the same result as the ring electrodes if the flow is axisymmetric (Beck and Plaskowski 1987). The input of the sensor is a physical signal i.e. electrical charge while the output of the sensor is an electric signal consisting of amplified voltage, rectified voltage and averaged voltage as shown in Figure 2.

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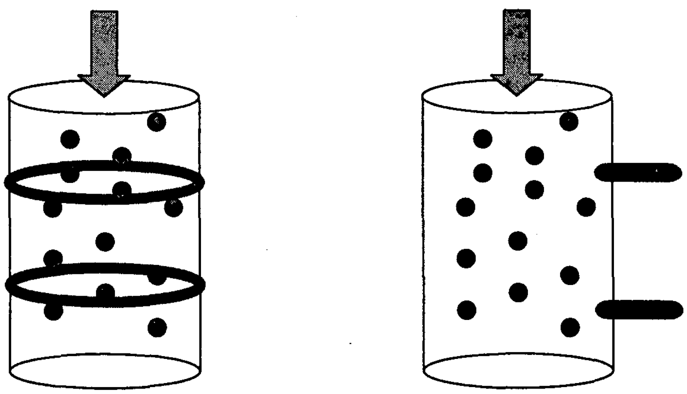


(a) Electrodynamic sensing ring electrodes

(b) Electrodynamic sensing pin electrodes

Figure 1 : Types of electrodynamic sensor

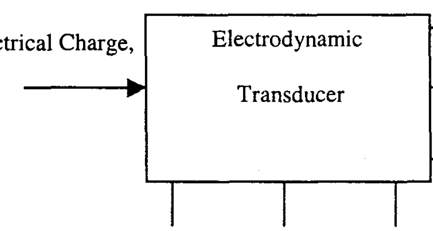


Figure 2: Electrodynamic transducer block diagram

The AX5412 is a high-speed data acquisition plug-in board for computers. It features 12-bit A/D resolution and up to 90KHz-throughput rate in DMA mode. The AX5412 may be configured via switch setting for 16 single-ended or 8 differential analogue input channels. To have a good noise immunity and higher A/D conversion accuracy, user is suggested to select differential mode. The AX5412 board is designed in two gain versions. Three kinds of A/D conversion speed are supported; low speed ADC, middle speed ADC and high speed ADC. The D/A converter, with internal reference voltage, uses programmable D/A code to output a voltage within the range of 0 to +5 V. Eight digital input and eight digital output lines are also available at the AX5412's 50-pin connector. These general-purpose digital I/O lines are TTL/DTL compatible. For timing functions, the AX5412 uses 8254 chip to provide trigger pulses for A/D converter at any rate from 2.5MHz to 1 pulse/hr. The 8254 chip has three programmable counter/timer channels.

The AX750 is a screw terminal panel with stand-offs to allow tabletop operation. It provides ease of connection, via 80 barrier strip connections, for all analogue and digital I/O signals to the AX5412 interface board. The AX750 includes an integral one-meter long flat ribbon cable for direct connection to analogue input boards. The AX750 provides circuit by which user can be handled with software compensation and linearization.

The test apparatus is a wooden box sized (620 x 620 x 65) mm and in it has a rotating stick, which length is 600mm. At one end of the stick lies a plastic ball and the other end of the stick is fixed to a servo motor shaft. The motor is place at the centre of the box. The rotating stick must be light so that the motor can rotate at different speed.

At the top right of the box is an ionizer to produce static charges in the box. On top of the box lies the platform to placed two electrodynamic sensors. The distance between the sensors can be fixed at 20mm, 30mm and 40mm. The platform must be grounded to reduce the noised in the signal. Figure 3 show the test apparatus.

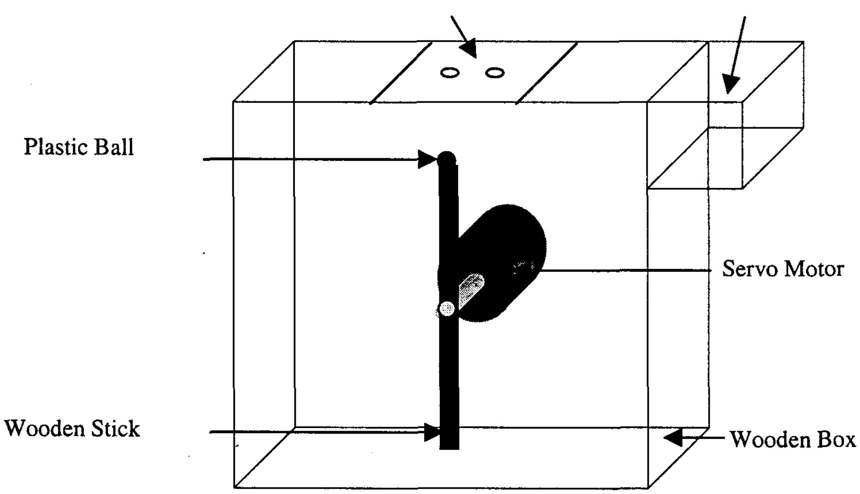


Figure 3 : Test apparatus

III. THEORETICAL PROBLEM

Pneumatically conveyed solids generate electrical charge, which can be detected using electrodynamic sensors (King 1973). The electrodynamic sensors are used for velocity measurement and this paper describes the use of cross correlation to determine the transit time, which are then converted to velocities, for the velocity measurement.

Correlation analysis is a process to quantify the degree of interdependence of one process upon another or to establish the similarity between one set of data and another (Ifeachor and Jervis, 1993). Application of correlation analysis can be found in many fields based on the following examples: -

1. Image processing for robotics vision - data from different images are compared
2. Remote sensing by satellite - data from different images are compared
3. Radar and sonar systems for range and position - transmitted and reflected wave forms are compared
4. Detection and identification of signals in noisy environments
5. Control engineering - to observe the effects of inputs and outputs in the presence of noise

Correlation analysis can be divided into two parts: -

1. Auto correlation

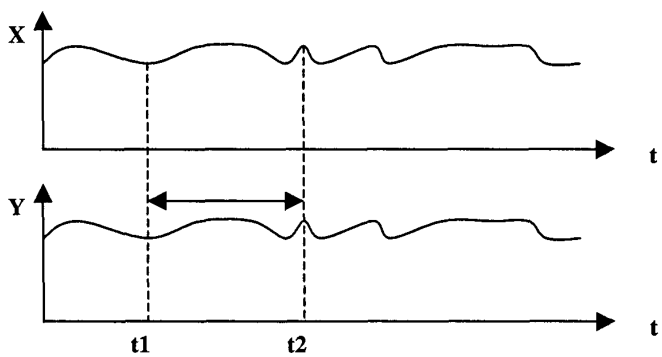
The process of auto correlation establishes the relationship between the signal and a time-shifted version of itself. The auto correlation function is a graph of correlation coefficients relating two versions of the same signal plotted against a shift in time. The instrument, which measures the auto correlation function of a signal, is called an autocorrelator.

2. Cross Correlation

Cross correlation is a process of comparing one signal with another by multiplication of corresponding instantaneous values and taking average. The cross correlation function is a graph of the value of the cross correlation coefficient against parametric time shift. This graph will measure the similarity and relationship between two different signals. The maximum value of the cross correlation function means that two different signals are more nearly the same for that particular time delay.

Cross correlation flow measurement is based on measuring the cross correlation function of the data from two transducers spaced axially along the flow stream. The time delay of the maximum value of the cross correlation function gives an indication of the flow transit time between the transducers, and from this the actual flow measurement is obtained. This paper examine some general features of the cross correlation function which are essential to the fuller understanding of cross correlation flow measurement. The cross correlation function of two sets of stationary ergodic random process data describes the general dependence of the values of one set of data on the other (Figure 4).

A typical cross correlation function for flow data is shown in Figure 5.



The cross correlation function is the dependence of one set of data on the other set with times separated by τ

Figure 4: The cross correlation concept

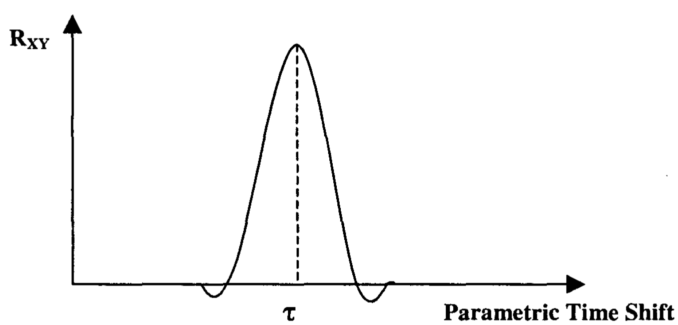


Figure 5 : Typical cross correlation function

Velocity measurement of particles moving in a pipe using cross correlation can be realised in hardware (cross correlator) and software (computer programming). Both methods can be used on-line and off-line to the measurement system.

The basic concept is that some pattern in the flow stream travels without distortion between transducer A and transducer B, as shown in Figure 6. This assumption of no distortion in the pattern enables the basic principles of cross correlation flow measurement to be presented in an easily understandable theoretical framework.

The cross correlation method of flow measurement is based on the determination of the transit time of a measurable disturbance moving along the pipe over an exactly known distance. The measurable properties, such as the variation of temperature, pressure, capacitance, electrical conductivity, or other physical parameters, are detected by a sensing element and converted into electrical signals.

Referring to Figure 6, $x(0, t)$ denotes the transducer output signal derived from channel A-the amplitude of the signal is directly related to the instantaneous value of the measured parameter of the fluid at point A. Similarly, $y(L, t)$ is the signal related to the value of the measured parameter at point B. If the time taken for the fluid to travel from point A to point B is τ, then $x(0, t)$ and $y(L, t)$ can be related by the expression

$$y(L, t) = x(0, t-\tau). \quad (1)$$

The cross correlation function $R_{xy}(L, \tau)$ of $x(0, t)$ and $y(L, t)$ is given by

$$R_{xy}(L,\tau) = \lim_{T\to\infty}\frac{1}{T}\int_0^T x(0,t-\tau)y(L,t)dt \quad (2)$$

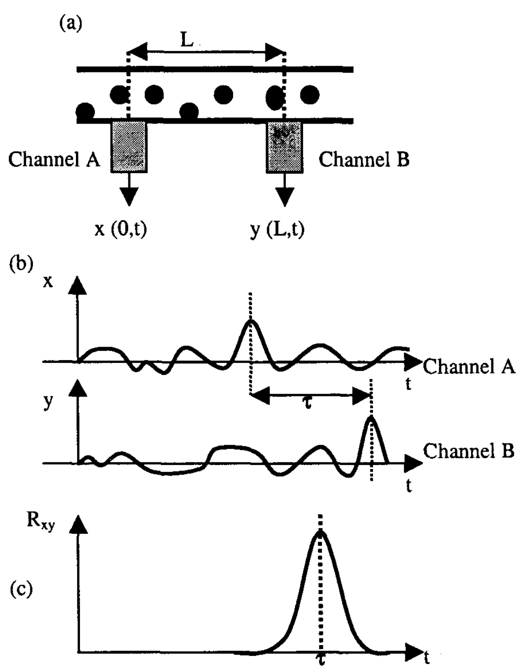


Figure 6 : Basic concept of velocity measurement. Figure a, shows principle of cross correlation flow measurement. Figure b, shows an upstream and downstream signal. Figure c, shows the cross correlation function for both signals.

The maximum value of $R_{xy}(L, \tau)$ will occur at $\tau = \beta$, when the correlation delay time is equal to the transit time β of the measured parameter of flow between the points A and B. Thus the velocity of the flow is given by

$$u = \frac{L}{\tau^*} \quad (3)$$

Where u is the flow velocity, L is the distance between A and B and τ^* is the value of τ corresponding to the peak value of $R_{xy}(L, \tau)$.

If the velocity profile across the pipe diameter is uniform, then the volumetric flow rate can be obtained by multiplying u, which is determined from equation (3), by the cross sectional area of the pipe.

IV. SOFTWARE IMPLEMENTATION

The whole application development is basically done in Visual Basic Programming.

The programming language built into Visual Basic has easy-to-use graphics statements, powerful built in functions for mathematics and string manipulations and sophisticated file-handling capabilities. Moreover, Visual Basic makes it easy to build large programs by allowing modern modular programming techniques. This means programs can be break into easy-to-handle, and therefore less error prone, modules. This way concentrate on how each module does its job and how the pieces of the program communicate with each other inside the application. In this paper there are three divisions in the application which sums up the whole application for the real time cross correlation flowmeter. These three divisions are driver development, cross correlation algorithm, and finally the graphical user interface (GUI).

The procedure for computing the cross correlation sequence between x (n) and y (n) involves shifting one of the sequences, say x (n) to obtain X (n-1), multiplying the shifted sequence by y (n) to obtain the product sequence y(n)x(n-1) and then summing all the values of the product sequence to obtain R_{yx} (l). This procedure is repeated for different values of lag, l. This paper describe an algorithm that can be easily programmed to compute cross correlation sequence of two finite-duration signals x(n), $0 \le n \le N - 1$, and y(n), $0 \le n \le M - 1$.

The algorithm computes R_{xy} (l) for positive lags. According to the relation $R_{xy}(-l) = R_{yx}(l)$, the values of R_{xy} (l) for negative lags can be obtained by the same algorithm for positive lags and interchanging the roles of x (n) and y (n). If $M \le N$, R_{xy} (l) can be computed by the relations

$$R_{xy}(l) = \begin{cases} \sum_{n=l}^{M-1+l} x(n)y(n-l), & 0 \le l \le N-M \\ \sum_{n=l}^{N-1} x(n)y(n-l), & N-M < l \le N-1 \end{cases} \quad (4)$$

On the hand, if $M > N$, the formula for the cross correlation becomes

$$R_{xy}(l) = \sum_{n=l}^{N-1} x(n)y(n-l), \quad 0 \le l \le N-1 \quad (5)$$

The formulas in (4) and (5) can be combined and computed by means of the following simple algorithm illustrated in the flowchart in Figure 7. By interchanging the roles of x(n) and y(n) and recomputing the cross correlation sequence, the values of R_{xy} (l) obtained corresponding to negative shifts l.

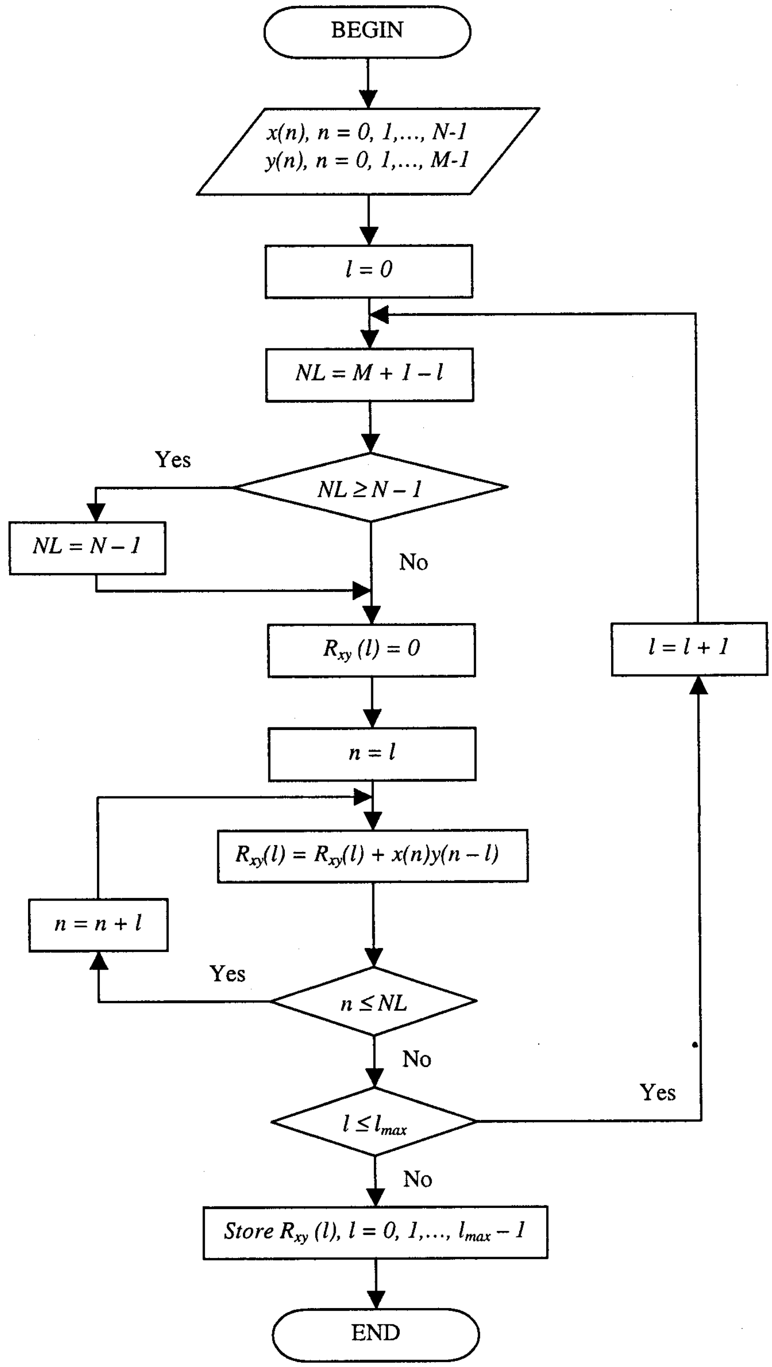


Figure 7 : Flowchart for software implementation of cross correlation

V. RESULT

During this project, the test apparatus that was built previously seems to be working. The signal obtained from the electrodynamic sensors can not be used for analysis because the noise level of the signal is very high. Furthermore the peak that was cause by the effect of the plastic ball passing by the sensors are very weak in the range of milivolts.

Offline analysis means that the data to analyse are from previous experiments and that there are save into excel files. Figure 8 shows one set of data obtained from two electrodynamic sensors which is also used to find the velocity of moving particles inside a pipe. Signal 1 is leading the Signal 2. Each peak in the graphs represents the particles with static charge passing by the sensors. Figure 9 shows the cross correlation function for both of these signals. The maximum value of the cross correlation coefficient means that two different signals are more nearly the same for the particular time delay. Figure 9 clearly shows that the peak of 287.1499 happens at the time of 10 ms. Hence if the distance between these two sensors is 20 mm apart, then the velocity is 2 m/s, as shown in Figure 9.

Figure 10 shows both of the signals in one graph, the signal from the first sensor (blue line) is leading the signal from the second sensor (green line) at approximately 10 ms.

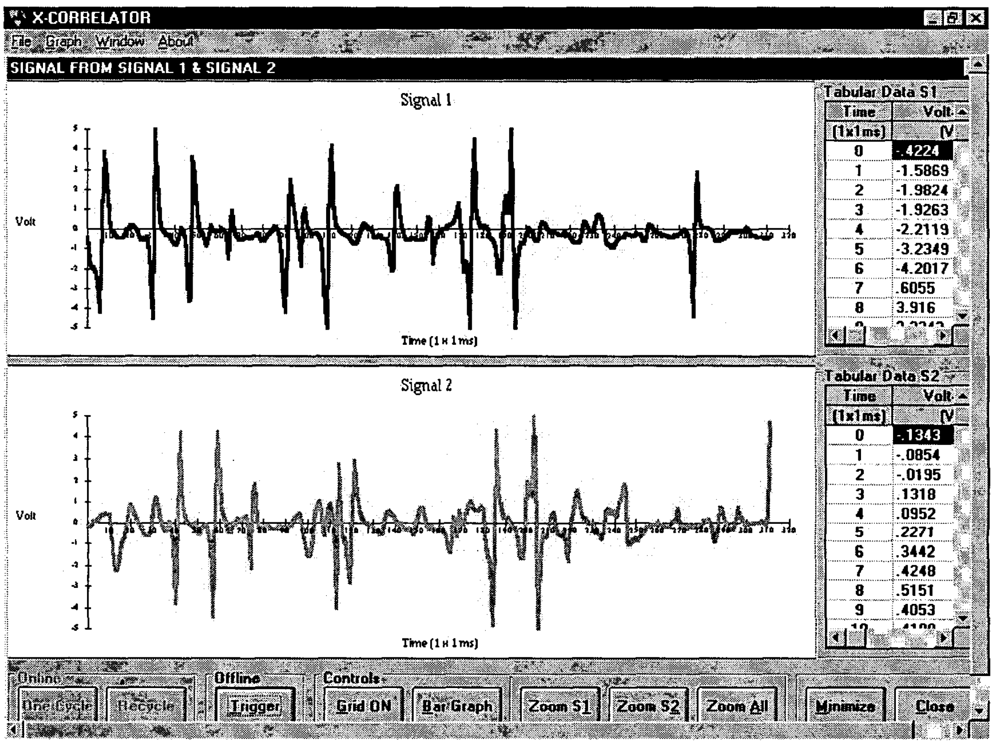


Figure 8 : Signals from offline data

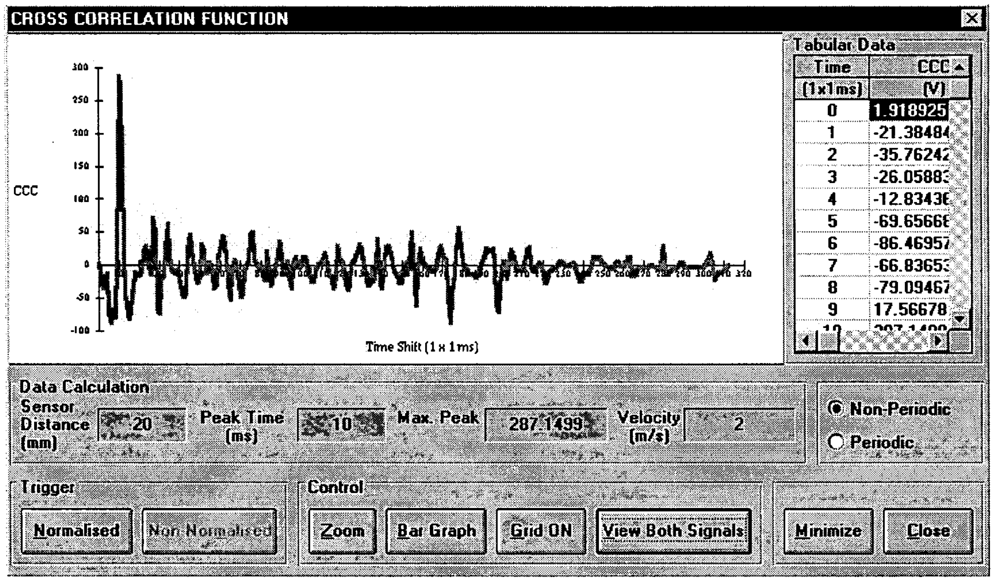


Figure 9 : Cross correlation of the offline data

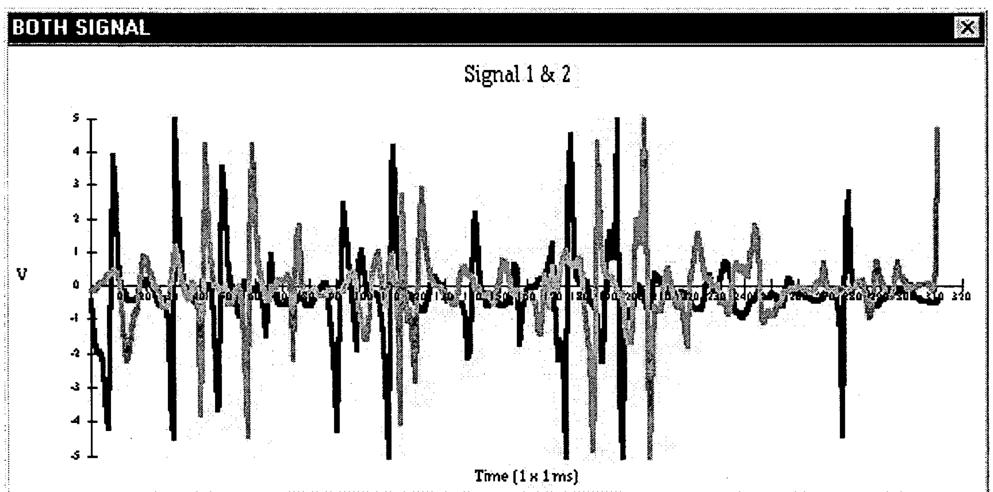


Figure 10 : Both signals in one graph

In this analysis, two signal generators have been used to generate two signals for the data acquisition card. The main purpose of this experiment is to verify that the application can handle real time data acquisition. Here a square and a triangular wave from both the signal generators have been generated at the same frequencies but different amplitude. The single cycle control and also the recycle control has been used, and the data is real time.

The result is shown in Figure 11. The cross correlation function was tried and the result of it is a sine wave. For non-periodic option, the sine wave is truncated to zero. This is shown in Figure 12. The result is as such because when the data from one of the data array or sequence is shifted out one by one and a zero will be shifted back in at the end of the array. That is why the sine wave is truncated to zero. As for the periodic option, the sine wave is continuous and at the same amplitude. This is because when the data is shifted out at one of the data array, the data that shifted out will be shifted back in to the array making it a close loop shifting of data. This is why the result of this option is a continuous sine wave as shown in Figure 13.

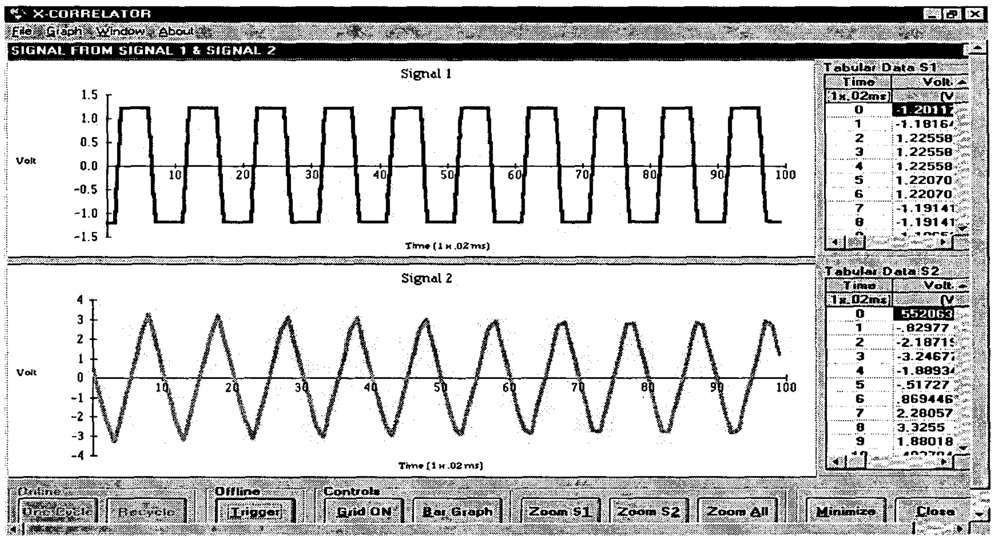


Figure 11 : Result from signal generator

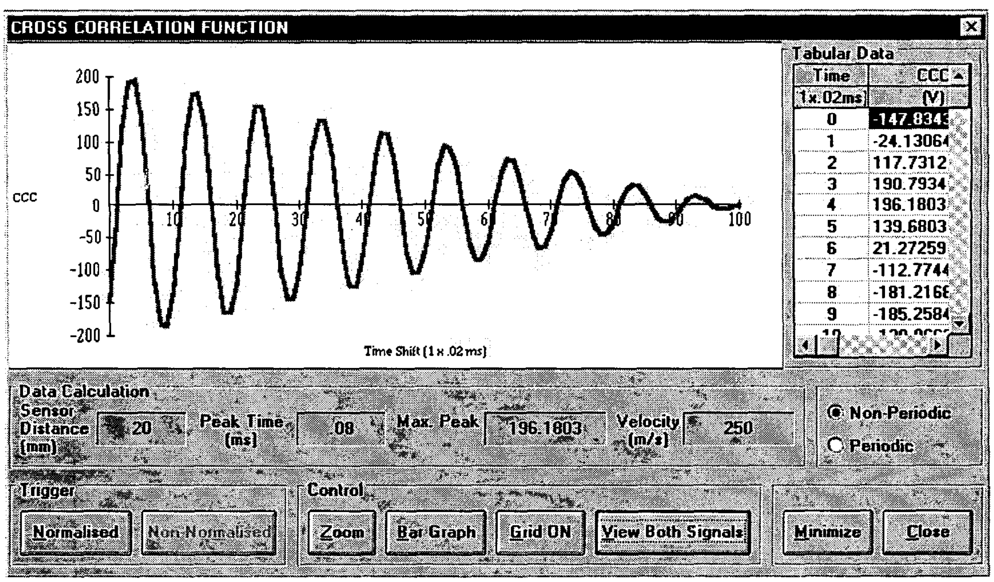


Figure 12 : Result of non-periodic cross correlation

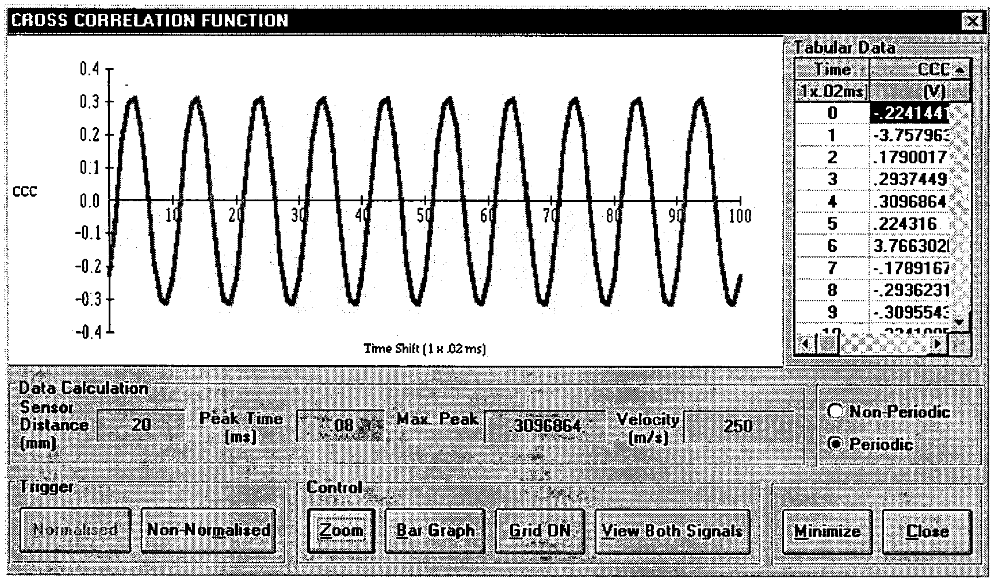


Figure 13 : Result of periodic cross correlation

This project only manages to get one set of data out from the test apparatus. This set of data is obtained when the sensor is placed on a 40-mm plate. The physical setup of the test apparatus for differential connection is shown in Figure 14. As for experiment physical setup for single ended connection is shown in Figure 15. But for this application the connections have set to differential connection setup. If the user want to change this connection setup, it can be done by changing the parameter for the driver functions. The result of the experiment is shown in Figure 16. From these data a cross correlation function is performed to see the time delay and to find the velocity. Figure 17 shows the result from the cross correlation.

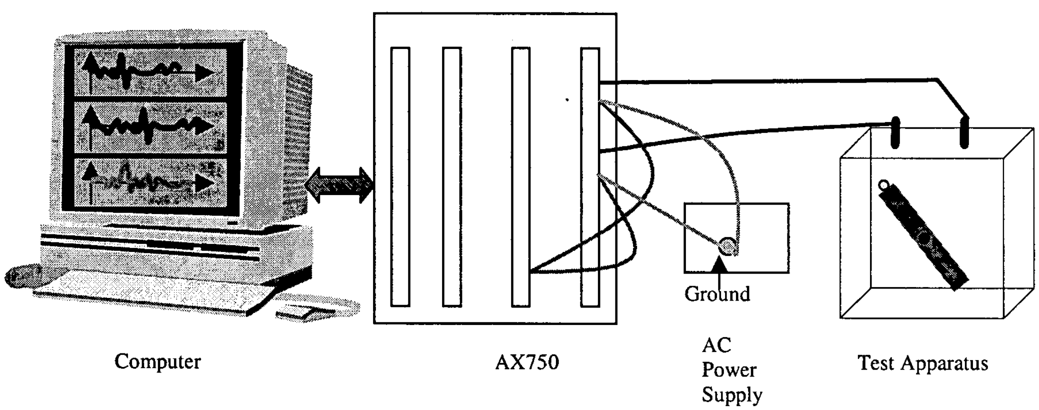


Figure 14 : Experiment physical setup for differential connection

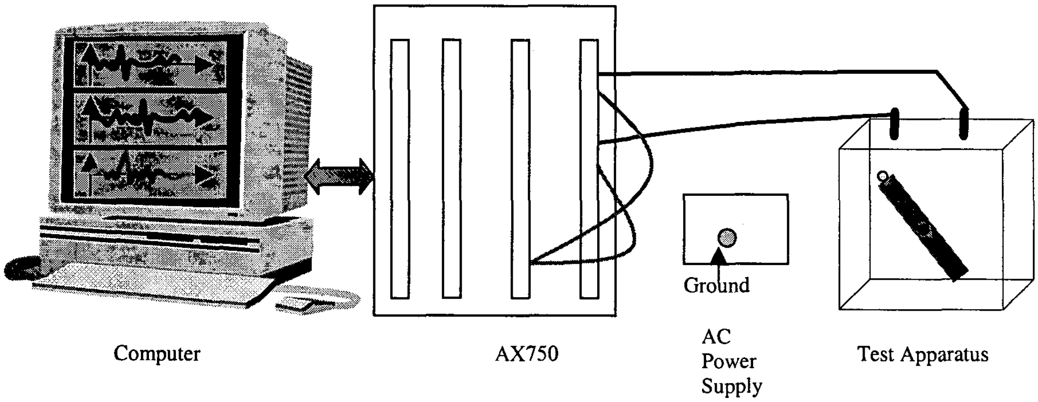


Figure 15 : Experiment physical setup for single ended connection

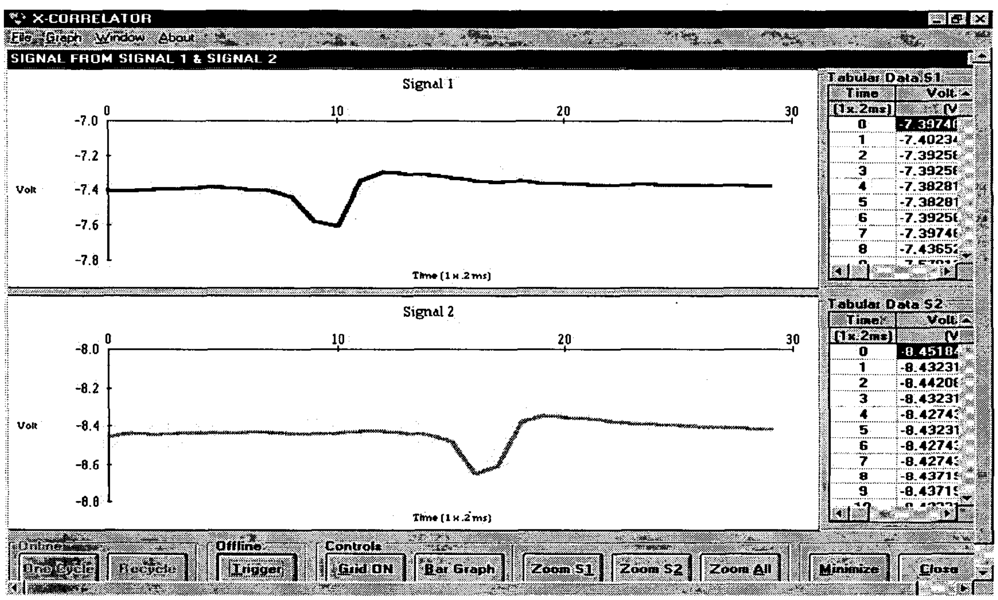


Figure 16 : Result from the test apparatus

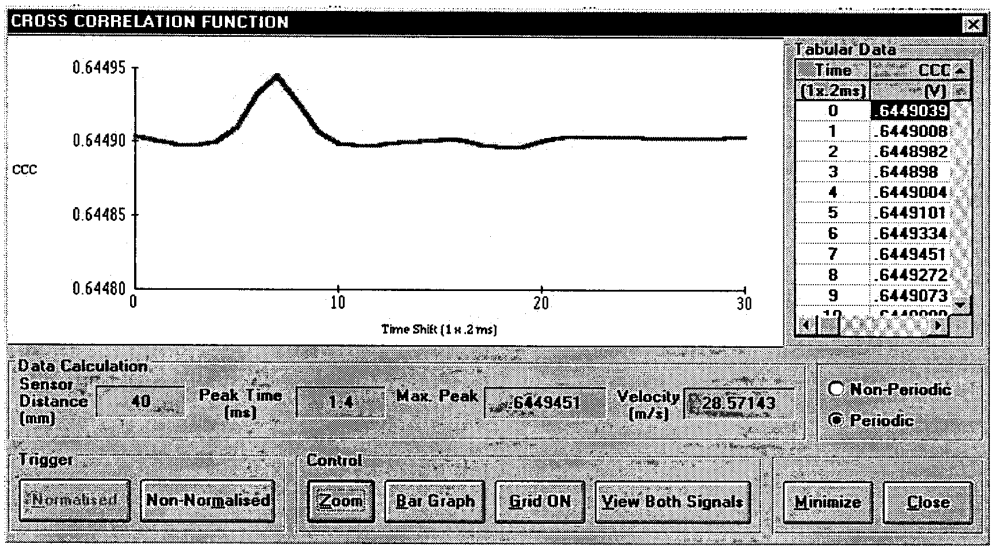


Figure 17 : Result of cross correlation for the test apparatus

There is a significant peak occurs during the time delay of 1.4 ms. The velocity of the rotating ball is 28.57143 m/s. This result has been compared with the result from previous experiments using manual calculation on the oscilloscope. Two methods have been used to calculate the velocity. A first method is using the test apparatus to get the signal for the oscilloscope and from there the time delay is obtained. The sensor distance divided with the time delay and the result is same with the previous experiment, which the time delay is 1.4 ms and the velocity is 28.57143 m/s for the 40-mm plate. For the second method, the formula, velocity = $2\pi j$ / ΔT has been used, where $2\pi j$ is the circumference of the test apparatus and ΔT is the time needed for the ball to rotate one full circle. The result is 27.50 m/s

VI. CONCLUSION

This application have a good potential in the future for determining not only the velocity of moving particles but a whole lot more of attributes such as the flow density and many more. This application also can be used for experiments or other purposes that involved data acquisition and cross correlation function. For future development a better electrodynamic transducer using different circuitry to obtained better signal with less noise could be built and another way is get a better data acquisition with fast throughput rate per channel. This will ensure that the throughput rate stated in the manual is not divided to each channel but each channel has the maximum throughput rate as stated. A data acquisition board must be captured the data in parallel format and not sequentially because this will ensure that the data captured per channel is really real time.

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