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Experimental Investigations of Chaotic Behaviour of Gas Solid Suspension

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Abstract

The investigations were carried out in a 2D fluidized bed to study chaos under the influence of electric field for the two modes of operation 1) field first and fluidization last and 2) fluidization first and field last. The chaotic parameter 'Auto-correlation' was studied from the measurement of pressure fluctuations and time delay analysis. It is noticed that the sampling position plays an important role (the tap position for this work are 3 cm and 24 cm from base of the bed) the electric field reduces the magnitude of time delay when the field increases from 0 to 70 kv. This is mainly due to stabilization of the bed. The autocorrelation function at 24 cm shows the lower values compared to 3 cm position.

Introduction

Transforming the solid particles from its initial state of static positions to the suspension by an upflow of gas to convert them to fluid like motion and has been referred as fluidization. Fluidized beds are widely used in the chemical and fossil fuel industries of mix particulate solids and fluids. Its advantages include the good heat and mass transfer between solid catalyst particles and gaseous reactants. However the appearance of large gas bubbles in a gas-solid fluidized bed is detrimental to the overall effectiveness of the process.

In recent years increasing attention has been directed to the interaction of dispersion systems with superimposed fields to transform the severely bubbling fluidized bed to homogenous fluidized bed. Two major superimposed fields are electric field for the particles of semi-insulating or conducting nature and magnetic field for the particles of magnetic origin.

Chaos

Usually, fluidized bed hydrodynamics are characterized using time-averaged properties, such as the average bubble diameter and rise velocity or the average bubble hold up and bed voidage. This approach neglects the time dependent dynamical behaviour that is considered to be important for the performance of the fluidized bed. When, for example, pressure (drop) or voidage at a certain position in the bed is measured, it is found to oscillate considerably and highly irregularly. Traditionally, in fluidization engineering, time series of fluctuations of pressure or voidage analyzed using statistical (e.g. averages, standard deviation) or spectral (e.g. fourier transform, power spectrum or auto correlation function) analysis. Implicitly these analysis techniques assume that the oscillations can be described by a linear summation of random variables or by a linear/quantifying chaotic systems:

Chaotic systems are governed by non-linear interactions between the system variables. Due to this non-linearity, these deterministic systems are sensitive to small changes in initial conditions and are, therefore, characterized by a limited predictability. The chaotic dynamics of a system are fully represented by its attractor in the phase space, which describes, the time evaluation of the system and which can be quantified by characteristic invariabilities. These chaos characteristics of dynamical systems can be estimated from time series of only one of the system's characteristic variables, such as pressure fluctuations in bubbling gas-solids fluidized beds, via a technique called (attractor) reconstruction (Takens 1981). Use of Chaos analysis for fluidized beds has been used to find other parameter like Kolmogorov entropy etc.

Earlier experimental work demonstrated the chaotic characteristics from pressure fluctuations data and showed that these varied with operating conditions and position in the bed (Daw and Halow, 1991; Daw etal, 1990; Hay etal, 1995; Scouten and van den Bleek etal; 1991; Scouten etal. 1992; Skrzycke, etal. 1993; Vander Stappen etal. 1993b)

Autocorrelation Function (ACF)

The auto correlation has been used to measure how different a function is from a translate itself. Autocorrelation has been used as one of the method for the determination of time delay. It is suggested to base it upon the first zero crossing or the first minimum of the autocorrelation function.

Autocorrelation function and autocorrelation coefficient has been used as a tool for the fluidization characteristics through the pressure signals.

The two methods used for the pressure signals are: 1) APF- absolute pressure fluctuation: DPF- differential pressure fluctuation.

Lirag and Litman (1971), Fan *et al.* (1981) Hay *et al.* (1995), Karamavrue *et al.* (1995, 1997) and Johnson *et al.* (2000) have studied the fluidization behavior through the autocorrelation function.

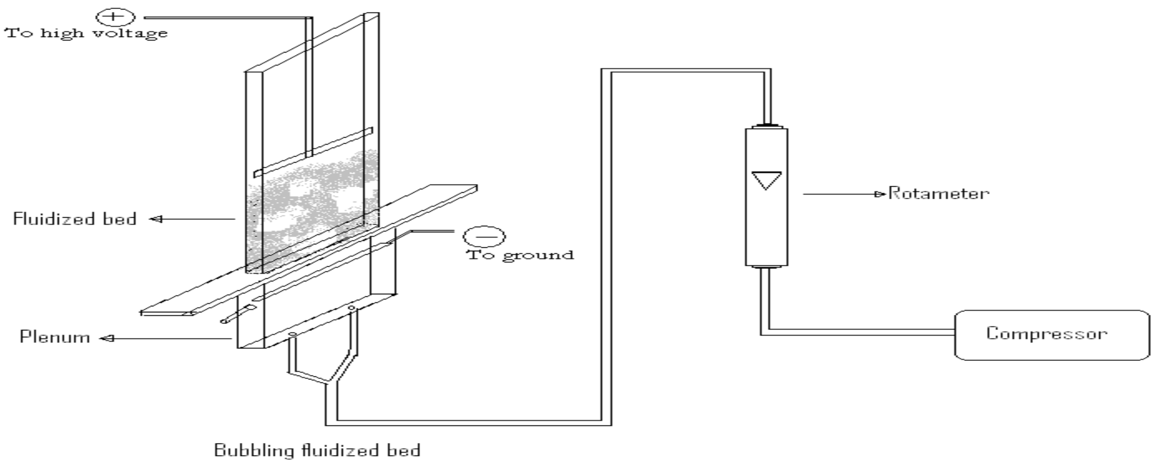
Lirag and Litman (1971) noticed characteristic trends of both random and periodic signal for the fluidization of glass particles (d_p 500 μm) and U/U_{mf}=1.6. A maximum is obtained at zero time lag and the function becomes sinusoidal with a fairly constant period as the time lag is increased. Fan *et al.* (1981) confirmed the presence of periodic component in the pressure fluctuation of fluidized bed as reported by Lirag *et al.* (1971). These authors found sinusoidal shape for the auto correlation function.

Hay *et al.* (1995) obtained a symmetrical structure and decreasing amplitude for the autocorrelation of pressure measurement through the variation of autocorrelation coefficient Vs time. Such systems have been reported as non-linear dynamic systems.

Karamavruc and Clark (1997) have studied the effect of probe spacing on the auto correlation coefficient and found no variation due to probe spacing. However the increasing gas velocity gave low levels of autocorrelation coefficient.

The slug frequency has been calculated by estimating the time between τ=0 and the first he auto correlation coefficient. A value of 1.72 Hz was obtained. The number of frequencies involved in the system increases as the flow rate increases. The differential pressure measurement carried by the same author (Karamavruc *et al.* 1995) found a sharp peak at τ=0 and crossing of the pressure signal at various positions to the zero axes. The variation of auto correlation coefficient with time lag gave a high degree of correlation at τ=44.45 and this corresponds to a bubble frequency of 2.7 Hz. Johnsson *et al.* (2000) died the auto correlation function for single bubble, multiple bubble, exploding bubble regime and transport conditions. Among these regimes single and exploding bubble regimes gave a periodic autocorrelation on a scale, which is similar to the bubble frequency. The multiple bubble regime and transport condition gave a first decay in auto correlation with time lag.

Experimental Set Up and Procedure



The present investigation has been aimed in studying the effect of electric field in an axial mode on the auto-correlation function. The studies have been carried out for two modes of operation 1) field first and fluidization last 2) fluidization first and field last.

The present study gives the coverage to the parameters: position of the tapping point and the effect of electric field intensity.
The experimental studies were carried out in a two dimensional unit with a width of 20 cm, depth of 1.5 cm and height of 60 cm. Experiments were carried out in presence and absence of electric field for a bed height of 22cm of settled bed. The fluidizing particles of 275 micron glass beads were used and the fluidizing gas was air. The electric field intensity of 20kv, 40kv, 55kv and 70kv were used in the present studies. The pressure fluctuations at 3cm and 22 cm were measured by absolute pressure transducer. A fine mesh screen (10 micron) was attached to one end of the tube placed at the sampling point to avoid the solids penetration in the transducers thereby avoiding their obstructions. The magnitude of pressure fluctuations from the transducers were observed in a data acquisition system and finally stored in a storage oscilloscope. The numbers of points in one slot were 2500 and such 12500 points were taken for one time series analysis. For statistical and spectral analysis the packages used are MATLAB AND TISEAN and for the chaos analysis the package used is RRCHAOS.
For The modes of operation the procedure adopted is as follows:

Mode
Field first and fluidization last: in this case the electric field intensity of the desired value is applied first and the gas velocity was slowly increased to attain the bubbling condition. The pressure fluctuations were recorded through the system as mentioned earlier.

Mode
Fluidization first and field last: in the case of operation the bubbling conditions were attained first and the field was suddenly applied. Pressure fluctuation data was again recorded.

Result and Discussion
Figure ACF 1 to Figure ACF 18 shows the variation of autocorrelation function with time delay at 3 cm and 24 cm tap position for the gas velocity of 10cm/s in absence and presence of electric field. The system shows a chaotic behaviour and the oscillations are more intense at the bottom due to the travelling of the waves after the bursting of the bubbles. Near to the surface at 24 cm the free board region allows easy passage for bubble and shows very small value of time delay (0.146).
Field First Fluidization Last mode (FF)

The increase in filed intensity from 0 to 70 KV for field first mode at 3cm tapping point Figure ACF.1 (E=0 KV), ACF.2 (E=20 KV), Figure ACF.3 (E=40 KV), Figure ACF.4 (E=55 KV) Figure ACF.5 (E=70KV) and the tapping point at 24cm Figure ACF.6 (E=0KV), ACF.7 (E=20KV), Figure ACF.8 (E=40KV), Figure ACF.9 (E=55KV) and Figure ACF.10 (E=70KV) shows the system becomes less oscillatory due to interparticle attraction. The field intensity of E=70 KV shows the periodic behaviour and the system approaches towards the stabilized conditions. The time delay is very small. The magnitude of time delay at 3cm for field first mode (FF) has a value of 0.54 and 0.048 at 24cm.

Fluidization First Field Last mode (FL)

For the field last mode (FL) at 3cm and 24cm the variation of ACF with time delay gives different values of time delay when electric field intensity increases from 0 to 70KV. Figure ACF.11(E=0KV) (same as Figure 1), Figure ACF.12 (E=20KV), Figure ACF.13 (E=40KV), Figure ACF.14 (E=55KV), Figure ACF.15 (E=70KV) at 3cm tap position and Figure ACF.16 (E=0KV) (same as Figure 6), Figure ACF.17 (E=20KV), Figure ACF.18 (E=40KV), Figure ACF.19 (E=55KV), Figure ACF. 20 (E=70KV) at 24cm shows the variation of ACF with time delay. The time delay value 0.054 at 3cm reduces to 0.0094 at E=70 KV. The instantaneous application of electric field in field last mode to a fluidized bed suddenly collapses the bubbles and converts the bed in an electrically stabilized bed. Figure ACF.20 shows the time delay as a function of electric field intensity. The time delay decreases with the increase in field intensity due to interparticle attraction and the formation of the chains. The oscillations completely die out at high field intensity and the fluidized bed turns to an electrically frozen bed.

Field First Fluidization Last mode (tap position=3 cm)

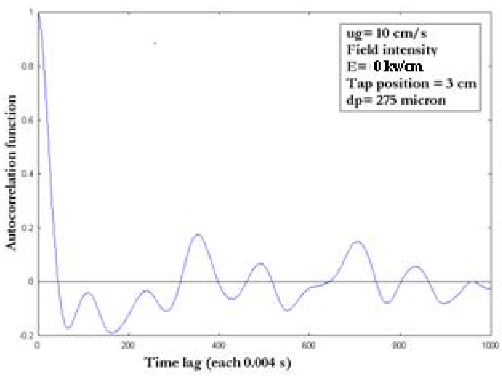


Figure 1

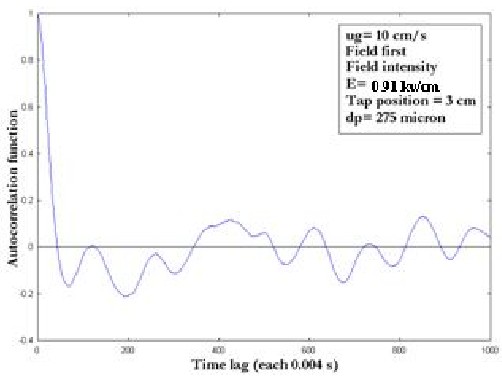


Figure 2

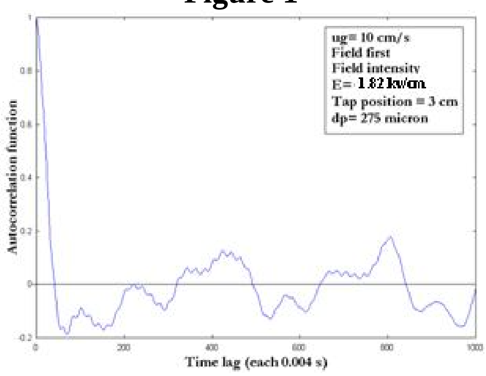


Figure 3

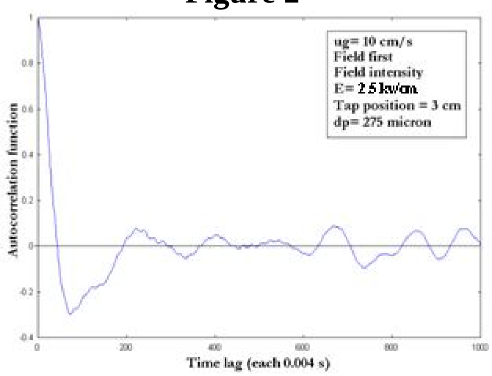


Figure 4

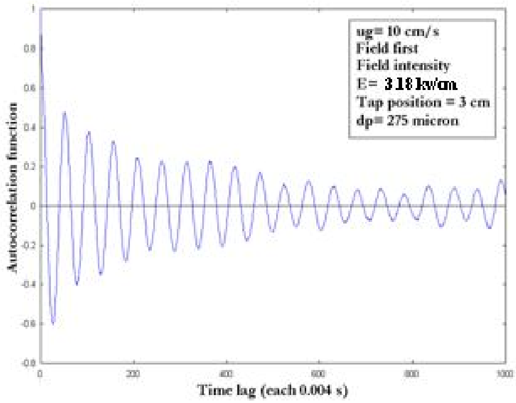


Figure 5

Autocorrelation function (ACF) against time delay at varying electric field intensity (E) with field first mode. (Tap position=3 cm).
Field First Fluidization Last mode (tap position=24 cm)

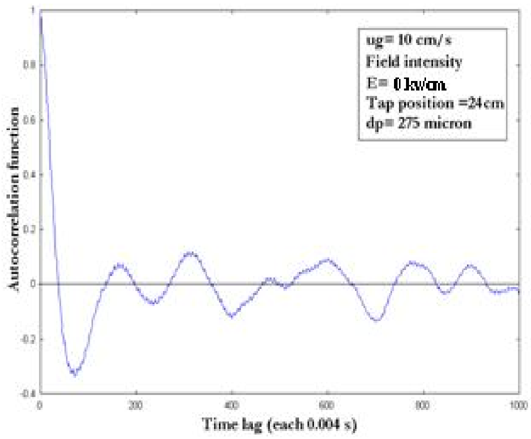


Figure 6

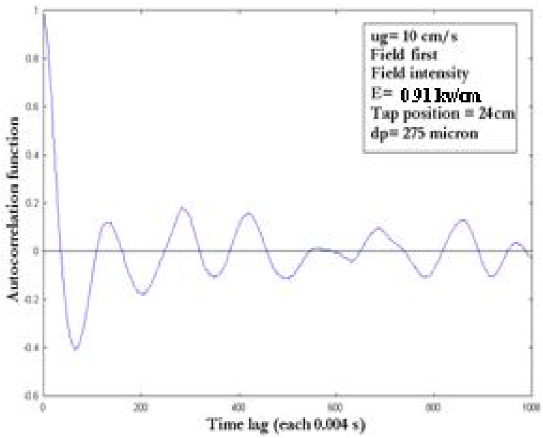


Figure 7

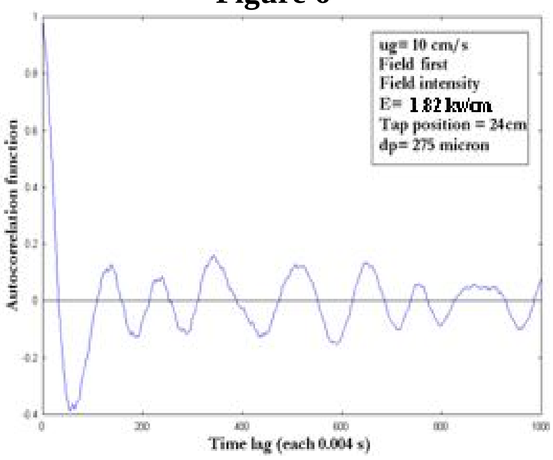


Figure 8

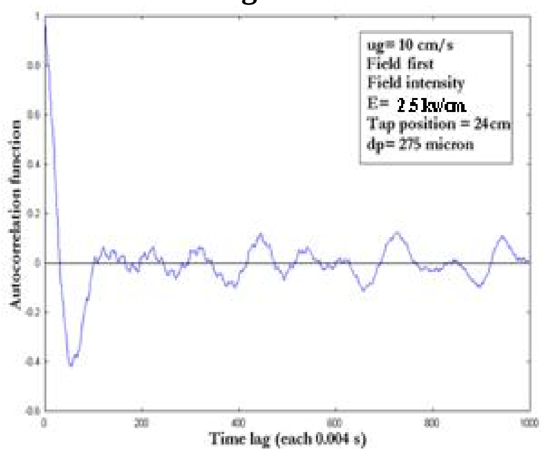


Figure 9

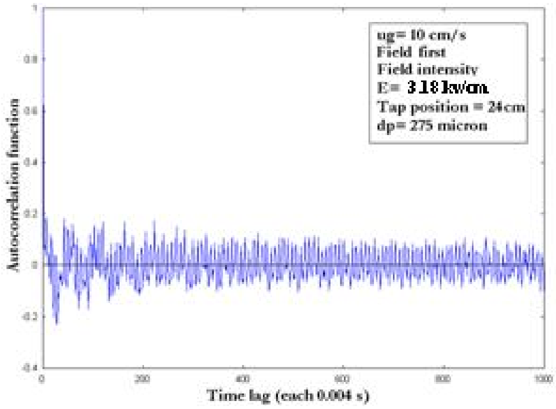


Figure 10

Autocorrelation function (ACF) against time delay at varying electric field intensity (E) with field first mode. (Tap position=24 cm)

Fluidization First Field Last mode (tap position=3 cm)

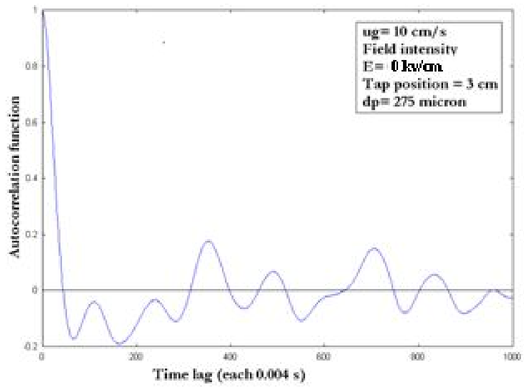


Figure 11

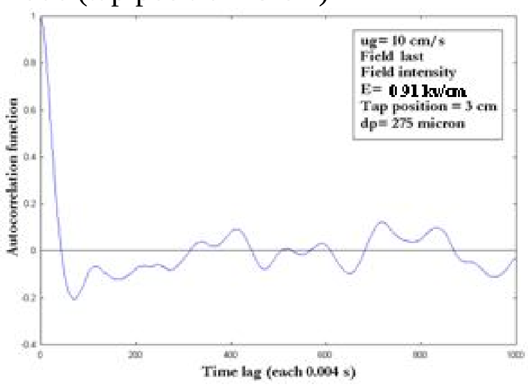


Figure 12

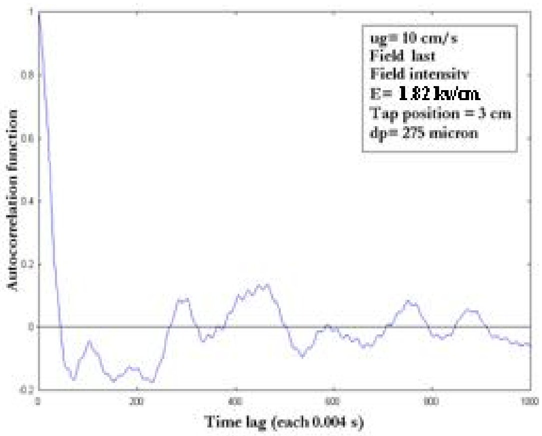


Figure 13

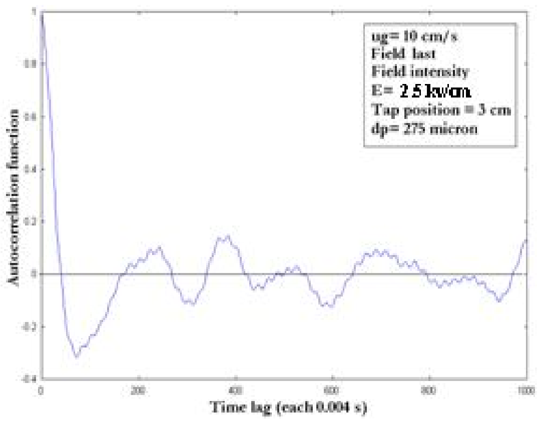


Figure 14

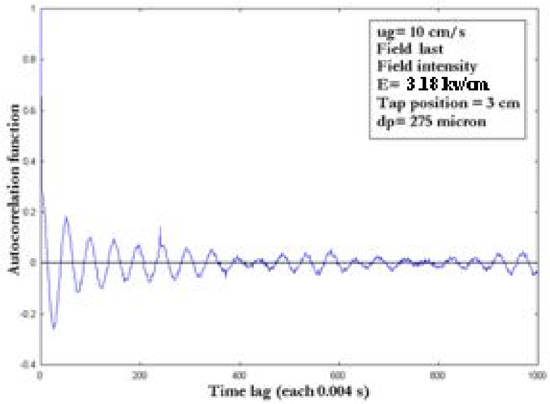


Figure 15

Autocorrelation function (ACF) against time delay at varying electric field intensity (E) with field last mode. (Tap position=3 cm)

Fluidization First Field Last mode (tap position=24 cm)

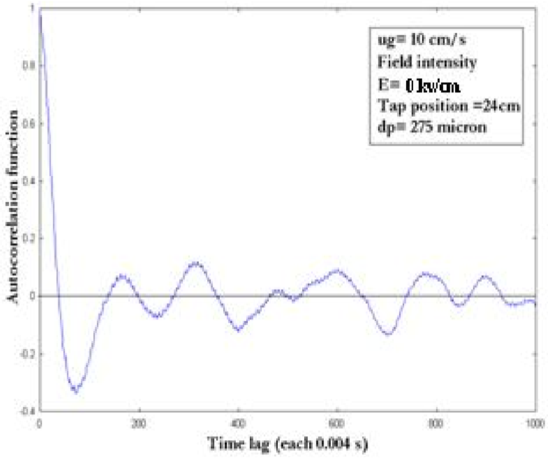


Figure 16

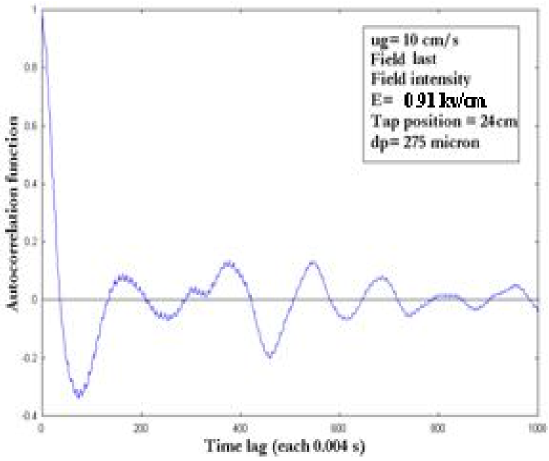


Figure 17

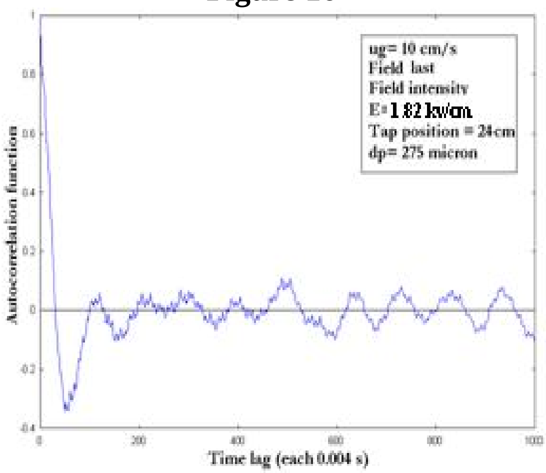


Figure 18

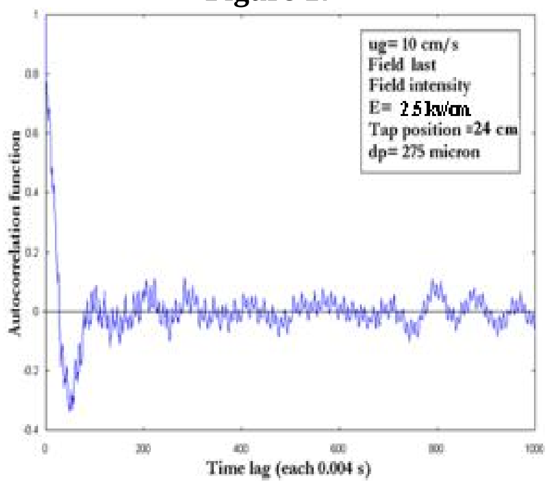


Figure 19

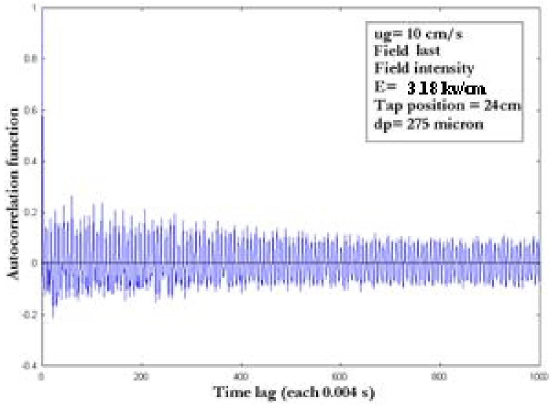


Figure 20

Autocorrelation function (ACF) against time delay at varying electric field intensity (E) with field last mode. (Tap position=24 cm)

Conclusion

1) The tap position at 3 cm and 24 cm shows a reduction in time delay from 0.176 to 0.146 absence of field.
2) At high field intensity in field first mode of E=70 kv time delay reduces from 0.054 (at tap position 3 cm) to 0.048 (tap position 24 cm)
3) For the field last mode of operation the magnitude of time delay at E=70kv changes from 0.054 (at tap position 3 cm) to 0.0094 (tap position 24 cm)
4) Figure 5 and Figure 15 shows the same time delay at 3 cm. For field first and field last mode but for these modes at 24 cm the time delay reduces the value to 1/5.

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