A New Ultrasound Pulser Technique for Wide Range Measurements

M. S. Salim[1], M. F. Abd Malek[2], N.M.Noaman[3], Naseer Sabri*, Latifah Mohamed[2], and K. M. Juni**

[1]School of Mechatronics Eng., University Malaysia,Perlis,01000, Malaysia.
[2]School of Electrical System Eng., University Malaysia,Perlis,01000, Malaysia.
*Electrical and Electronics Engineering Department, Gulf University, Bahrain Kingdom.
*School of Computer and Communication Eng.,University Malaysia Perlis, Perlis 01000, Malaysia.
**Electrical Engineering Department, Politeknik Tuanku Syed Sirajudain, Malaysia.

E-mail   muhsabri1967@yahoo.com

Abstract. The objective of this research was to design and implement a new ultrasonic pulse-power–decay technique that transmits multiple ultrasound pulses through slurry to determine the lowest concentration that can provide an accurate attenuation measurement. A wide measurement range is obtained using the pulsed-power-decay transmission technique, and regardless of the material used to construct the container. A signal in the receiver transducer provides the attenuation measurements, for each echo, a fast Fourier transform (FFT) of the appropriate signal was obtained and compared with the water signals to yield the attenuation as a function of frequency. The data show the feasibility of measuring a kaolin concentration of 5% wt. When using a commercial pulser with the same device setting, no detectable echo was observed. Therefore, new technique measurements may prove useful in detecting solid content in liquid. This study demonstrated that the proposed pulsed-power transmission technique is promising for evaluating low concentrations of solids in fluids and for measuring sedimentation in solid-liquid systems.

Index Terms — Pulse-power decay system, Attenuation, Contaminates detection, process control.

1. Introduction

Measuring the concentration of solids in liquid is desirable, as many industries use this information for quality control and to monitor their product contents. Different pulsed ultrasound power levels should be used to increase the ability to measure the solid weight percentage of low-concentration (less than 5%) slurry and also to provide an accurate measurement of the velocity of sound. The analysis of multi-echoes can be used to measure slurry density. The classic methods used depends on the power, medium, frequency, quantity of the transmitted pulses and the reflection coefficient of the material from which the container is made of. Therefore, if the power, medium, frequency and number of the transmitted pulses are constant, then the container material is an essential parameter that is directly proportional to the measurement range. M.S. Greenwood et al. [1] used a stainless steel container, which had a high reflection coefficient and increased the weight percentage measurement of the slurry

concentration. Also many researchers used a pitch-catch method to measure the liquid density and the attenuation of waves propagated through a suspension of solid particles in liquids (slurry). In such as these method, a constant train of power pulses was injected into the liquid-filled container, based on the attenuation measurement of the solid concentration. The concentration measurement was limited by the power and number of the transmitted pulses [2]. Clearly, the two methods have disadvantages related to power consumption and they depend on the type of container material is made of. Therefore, the number of echoes received depends upon the power level transmitted and the container material is made of. This means that when the container material has a low reflection coefficient or if the liquid has a low impedance value, then the number of echoes and the measurement range also decrease. However, we designed and implemented a new ultrasonic pulser technique by combining the useful features of the two methods currently used. The proposed technique is included in new ultrasound pulses transmission models and hardware designs, Firstly, the new pulser technique lack dependence on container material is made of; it changes the path measurement technique used for different concentrations and consumes less power than a commercial pulsed ultrasound uses to measure the same concentrations, And secondly, the new pulser technique is a programmable pulser , which it generates a pulsed-power decay (PPD) set that is separated by an adjustable time interval. In the remaining sections, further details are provided about the PPD device, and the performance of the new technique is evaluated and compared with the performance of a commercial pulser.
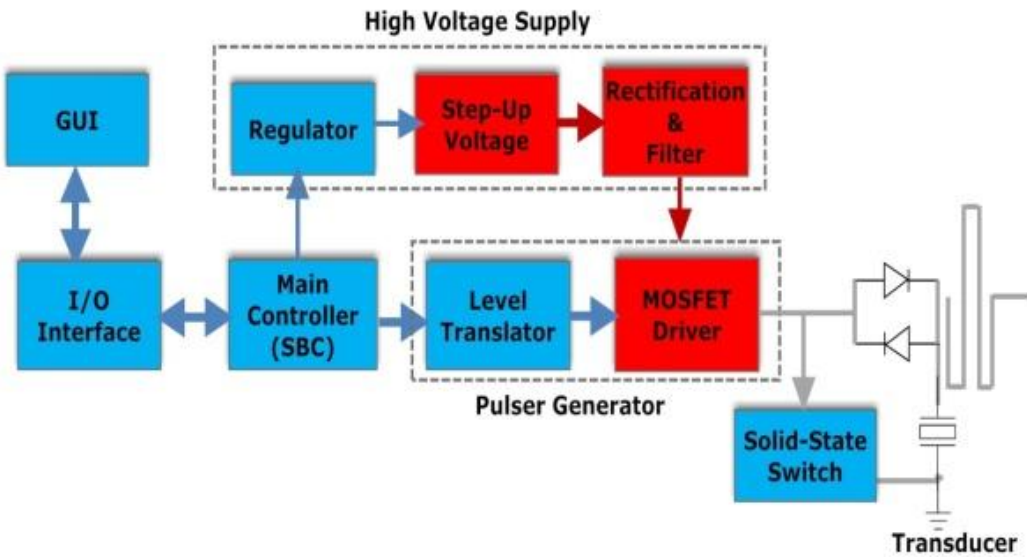

Figure 1. A block diagram of the pulse-power decay ultrasonic pulser system.
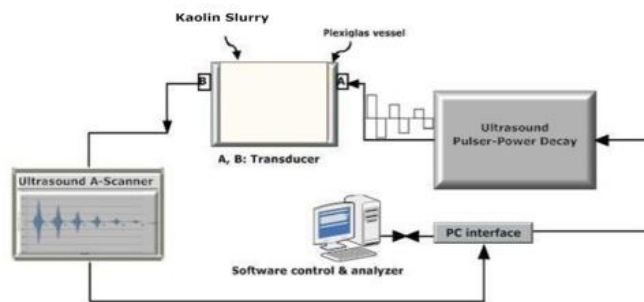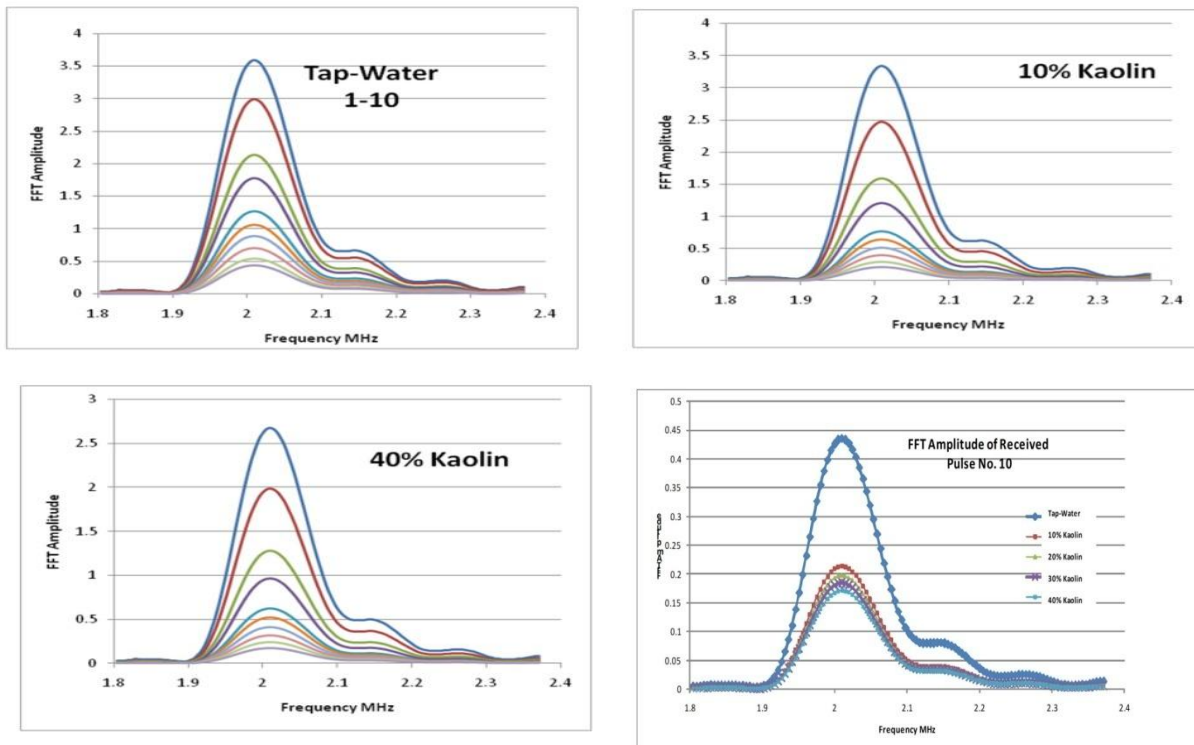
Figure 2. Sketch experimental setup.

Figure 3. FFT amplitude for one transmitted set size 10, propagated through water, 10% kaolin, and 40% kaolin (a). FFT amplitude comparison of 10th interest signal received for water, 10%, 20%, 30%, and 40% (b).

Table I. One set size 10, FFT amplitude of IS for tap-water and 10% kaolin at 2MHz

Pulse No.	Tape-Water,FFT amplitude at 2MHz	10% Kaolin, FFT amplitude at 2MHz
1	3.51	3.262
3	2.089	1.558
5	1.243	0.758
7	0.863	0.505
10	0.425	0.208

Table II. The detection comprise between commercial and proposed technique for 1% kaolin.

Set Pulse No.	Amplitude of Commercial Pulser (Volt)	Amplitude of PPD Pulser (Volt)	Tap water FFT Amplitude of		1% Kaolin FFT amplitude of	
			Commercial Pulses	PPD Pulses	Commercial Pulses	PPD Pulses
1	75	75	3.51	3.51	3.496	3.494
5	75	55	3.51	1.243	3.496	1.05
10	75	30	3.51	0.425	3.496	0.281

2. PPD Ultrasound System Design

The pulse-power decay device (PPD) ultrasound has a new technique that generates multi-pulse transmissions. The PPD starts with constant amplitude train pulses (commercial pulsed ultrasound) until the set size and time interval of the decay-power pulses are set. A block diagram of the proposed ultrasonic pulser system is shown in figure 1. The PPD device consists of six hardware parts, panel control software, an I/O serial interface, the main controller (single board computer [SBC]), a high voltage power supply, a bipolar pulses generator, and a solid-state switch. The transducer is driven by pulses from a decay power generator, which delivers sets of high-voltage bipolar pulses. The advantage of using bipolar pulses is that the peak-to-peak pulse voltage can measure twice the voltage rating of the coaxial cable connecting the pulser and the transducer. The pulse frequency, decay power factor, set size, time interval, set mode and start amplitude are programmed

$$P_n = P_p - P_{df} \qquad (1)$$

Where P_n *is* the next pulse amplitude, P_p is the previous pulse amplitude, and P_{df} is the decay power factor. The pulse transmission style can be easily modified via the control panel software. The PPD technique can follow the commercial pulsed ultrasound by setting both the time interval and decay power factor values to zero; therefore, the PPD device generates a sequential set of constant amplitude pulses.

3. Experimental Setup

The new PPD technique can be adaptive with wide application fields. In this research, the objective of the experiments was to evaluate the performance of PPD technique to gather ultrasound measurements for different percentages of solid concentrations in liquid. Invasive measurement is the most direct method of achieving an accurate measurement. Hence, this method was used for all the experiments carried out for this paper. Using the assumption that 1 ml of tap water equals 1gram in weight, kaolin was mixed with tap water in concentrations of 10%, 20%, 30% and 40% to create the different sets of slurries. These concentrations were measured by the weight of kaolin and tap water.

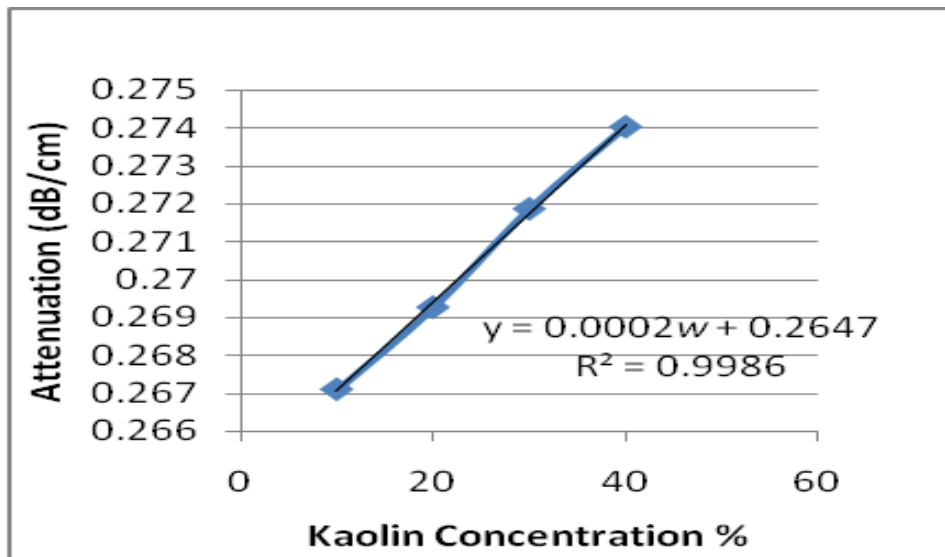The vessel, shown schematically in figure 2, consists of a Plexiglas container and two transducers with

Figure 4. Relationship between attenuation measurement (dB/cm) and solid concentration wt%.

a centre frequency of 2 MHz affixed to the outside of the container on opposite sides, using a pitch-catch method. The vessel walls have a thickness w of 3.2 mm and the inside walls are separated by a distance D of 4 cm. The temperature, measured by temperature sensor (LM35), is recorded. For simplicity, the temperatures for all the experiments were kept at room temperature (20ºC), between ±1°C [3]. When the vessel is filled with water, less than 10% of the ultrasound is reflected at the Plexiglas-water interface and the rest is transmitted into the water. At the opposite wall, 91% is

reflected at the water-Plexiglas interface. With the pitch-catch mode operating, the receive transducer records only the first individual signal, as it corresponds to travelling through the slurry. The ''signal of interest'' (IS) occurs at the shortest time and the path length for the Nth IS (for example the interest received signal of the fifth pulse of set) in the pitch-catch mode is ($2w+D+v\times T$), where v is the speed of sound through material and T is the total time delay of Nth pulse; and calculated using the equation (2):

$$T = (N-1)(t_S + t) \qquad (2),$$

Where the t_S is the pulse spacing time and t is the bipolar pulse width.

To obtain attenuation measurements as a function of frequency, the fast Fourier transform (FFT) of the peak of data were corrected for the receiver gain. The results of the FFT analysis of the ''peak of interest'' are shown for water, 10%, and 40% kaolin (figure 3 (a)). The effects of attenuation for water are clearly observed as the peak amplitude shifts to a smaller frequency as the IS number increases.

4. Data analysis

Data similar to were obtained for the kaolin slurries of 10%, 20%, 30%, and 40% kaolin by weight. The attenuation due to the 10% kaolin slurry can be observed in Table 1 by the increasing separation between the FFT amplitudes for water and the slurry. The data for kaolin slurry wt10% concentration were compared with that for water by evaluating the natural logarithm of the ratio (FFT amplitude slurry/ FFT amplitude water) for a specified frequency (2 MHz). The data exhibit straight lines and the interest signal (IS) for each set pulse was obtained for water and for the slurry. The data were obtained in ten steps, using ap appropriate decay factor for the transmitted pulses and the receiver gains. Overlapping interest signals (IS) were used to determine the effect of changing the pulser voltage travelling through slurry, and the data were normalized to a pulser voltage of ±75 V. Additionally, the slopes (S) were obtained. The lower pulses-power such as 40, 35, 30 volts greatly affected by low concentrations of slurry than the higher pulse power for one transmitted set as shown in figure 3(b).for example, the received pulse number 10 has 0.425 volt while the amplitude of same pulse travelled through 10% kaolin was 0.208 volt (table 1); therefore, to detect low concentrations with a long range of measurement, the set size should be increased (i.e., decreasing the decay factor leads to incremental increases in the amount of pulsed-power decay). Decreasing the decay factor leads to an increase in the number of pulses in one transmitted set and causes more generated lower-power pulses; this increase is limited by the high voltage supply. Due to the attenuation of the ultrasound waves propagated through slurry, the relationship between kaolin concentration and the attenuation was determined. The attenuation (α) was calculated using equation 3, [4].

$$\alpha = \frac{-20}{D}\log_{10} e^S \qquad (3)$$

For a given frequency, a plot of the attenuation (α) versus the kaolin weight percentage (w) displays a straight line (figure 4), as expected. For example, when the values of the attenuation at 2 MHz are extracted from figure18, such a plot shows the following linear relationship: α = 0.0002w + 0.2647, where the slope has units of dB/cm wt%. Table 2 illustrates the differences between a commercial pulser and the PPD technique.

5. Discussion

In this study, we developed a self-contained prototype of ultrasonic decay pulser system with computer control for solid concentration content in fluid detection. Incorporating the new pulser technique and pitch-catch method, we demonstrated that the system could be used to distinguish the

presence of lower than 5% concentration in fluid, while the current method cannot detect with the same device settings. The PPD ultrasound system, built in-house, generates a multi-pulsed powered decay train for transducer excitation instead of a single negative pulse, which is used in traditional pulsers. It also delivers variable transmitted ultrasound energy that would increase the received interest signal level for SNR improvement, and the concentration accuracy measurement was increased. The number of pulses per transmitted set is determined by the user based on the concentration detection level required. Our comparison results reveal that PPD ultrasound transmission through the fluid conversion for solid concentration detection is more efficient, especially for very low concentration (5%) of solid content in fluid than the currently pulsed ultrasound. Although the attenuation coefficient of the last numbered pulses of the transmitted set is higher than that of the first numbered pulses due to the decay power technique used (from the A-Scanner device) the concentration is very clearly effects by high coefficient container wall. This technique can be used to detect different concentration in fluid and can use in control process.

Conclusion

A PPD ultrasound system incorporating a pitch-catch technique was proposed and successfully demonstrated solid detection of 5% concentration in water. The presence of 5% concentration in fluid kaolin slurry was clearly distinguished with using decay waves propagation through water, but the currently pulsed ultrasound method failed to detect the same concentration with same device setting. The PPD technique is adaptive with all types of container material is made of, wide range of transducer frequency operation, and concentration measuring.

References

[1] M.S. Greenwood, J.D. Adamson, J.A. Bamberger. Long-path measurements of ultrasonic attenuation and velocity for very dilute slurries and liquids and detection of contaminates. Ultrasonic 44 (2006) e461–e466.

[2] Chen Q., S. Freear, D. M. J. Cowell. Measurement of Solid in Liquid Content Using Ultrasound Attenuation. 5th World Congress on Industrial Process Tomography, Bergen, Norway.

[3] Parker D., LEC R.M., PENDSE H.P., VETELINO J.F. (1990), Ultrasonic Sensor for the Characterisation of Colloidal Slurries, IEEE Ultrasonics Symposium, pp.295-2981.

[4] M. S. Salim, M. F. Abd Malek, R. B. W. Heng, Naseer Sabri Salim and K. M. Juni4. A new measurement me-thod of separation percentage for human blood plasma based on ultrasound Attenuation. International Journal of the Physical Sciences Vol. 6(30), pp. 6891 - 6898, 23 November, 2011.