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Optimal placement of a piezoelectric ring in an ultrasonic powder transport system

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Abstract

The transport of powder materials is an important aspect of process engineering. Various industries such as the food, chemical, pharmaceutical, coating, information and telecommunication industries have set a high demand on the performances of existing plants, which are mainly for bulk powder transfer. Modern systems demand powder transport systems which have a high quantitative accuracy. Therefore, the ultrasonic material transport process technology has in the last few years developed into an attractive alternative compared to the classical technologies. This technology involves transfer of powder through a pipe in which the ultrasonic waves are transmitted. However, this technology is not refined. In this paper, the optimal placement of the piezoelectric transducer on the pipe in order to produce traveling ultrasonic waves is investigated. A given length of the pipe is considered for transmission of the ultrasonic waves.

Keywords: Acrylic, piezoelectric, ultrasonic, vibration.

1. Introduction

In the recent past, powder transportation using ultrasonic vibrations has generated a lot of interest. This has applications in several industrial fields requiring powder handling capability with very accurate mixing processes demanding for an exact control of powder feeding (Loh and Ro, 2000). (Mracek and Wallaschek, 2005) developed a trial device for transporting small amounts of powder using a lossy transmission material (acrylic pipe) and only one transducer as shown in Figure 1. The device was used to move powder placed inside the pipe forward. During interference of the incident and the reflected waves, the incident waves became dominant producing a traveling wave. This resulted in the particles placed inside the pipe moved forward through the resulting elliptical movement of the surface area points.

1.1 Generation of ultrasonic waves

The most widely used methods for the generation of ultrasonic waves are the magnetostriction and piezoelectric methods. If a magnetic field is applied along the axis of a ferromagnetic material such as iron, cobalt and nickel in the form of a rectangular box, then a change in the length of the bar occurs. In a direct field, this change is small. If, however, the field oscillates, then the effect becomes much more pronounced because the internal elastic forces of the bar no longer oppose the change, and the only forces to be overcome are from the viscosity of the material. Further, if the oscillating field is resonant with the natural frequency of the bar, this effect becomes much more pronounced (Sen, 1990). Electromagnetic transducers, also called electrodynamic transducers are also used as ultrasonic transducers. They are used at audio frequencies (kilohertz frequencies) as loudspeakers and microphones. Electromagnetic acoustic transducers (EMATs) are used in electromagnetic propagation and reception of ultrasound at megahertz frequencies. The main restriction for these transducers is the relatively high mass needed for the moving material and the consequent drop in sensitivity with frequency (Blitz and Simpson, 1996). Laser pulses are also used to generate ultrasonic waves in metals. Common lasers used for ultrasound generation are solid state Q-Switched Nd:YAG and gas lasers (CO2 or Excimers). The principles used are thermal expansion (also called thermoelastic regime) and ablation. In the thermoelastic regime the ultrasound is generated by the sudden thermal expansion due to the heating of a tiny surface of the material by the laser pulse. If the laser power is sufficient to heat the surface above the material boiling point, some material is evaporated and ultrasound is generated by the recoil effect of the expanding material evaporated. In the ablation regime, plasma is often formed above the material surface and its expansion makes a substantial contribution to the ultrasonic generation (Huber et al., 2005). The advantage of using lasers in ultrasonic waves generation is the large frequency spectrum of the excited vibrations. However, the technique requires the complete knowledge of the structure of the laser-excited acoustic field in thin metal plates and the energy parameter of the laser radiation (Gurevich et al., 2009).

If direct voltages are externally applied to a piezoelectric ring, it responds with a mechanical deformation. Similarly, an alternating current field will cause the ceramic to alternate in size. In particular, the piezoelectric will have its own resonant frequencies at which it vibrates most easily, the value of which is determined by its composition, size and shape. If the ceramic is stimulated by an alternating current field at this frequency, it will oscillate with greater efficiency, converting electrical energy into mechanical (acoustical) energy (Kocbach, 2000). At high frequencies of the alternating current field, the mechanical vibrations produced can be in the ultrasonic range.

1.2 Traveling ultrasonic waves

Acrylic material has elastic properties similar to those of a metallic spring and has energy absorbing properties like those of a viscous liquid. These viscoelastic properties allow it to maintain a constant shape after deformation, while simultaneously absorbing mechanical energy. The viscosity follows Newtons law, increases with reduced temperature and increases with increased strain rate whereas the elasticity follows Hooke’s law and increases with increased strain (Harris and Piersol, 2010). (Kirekawa, Ito and Asano, 1992) researched on the feasibility of acrylic material as a vibration energy absorbing device and found out that although the mechanical characteristics considerably varied with the ambient temperature and excitation frequency, the acrylic material had great vibration energy absorbing capacity. An ultrasonic lossy transmission line can be used for generation of traveling ultrasonic waves whereby the reflected waves reduce in magnitude and the waves transmitted from the driving transducer become dominant in the line. That is, the traveling wave is generated practically without attention to the acoustical matching at the receiving end (Takano and Tomikawa, 1998). The acrylic pipe has specific damping properties which allow the excitation of a traveling flexural radial wave in a pipe, using only a single piezoelectric actuator. By this, a wave front is sent along the pipe which causes compressions and dilatations at the inside of the pipe (Zhizhi, 2010). It is the ability of the pipe to produce the progressive waves that makes it superior to other materials like steel, which would need a mechanism to counter the reflected waves (Takano and Tomikawa, 1998).

1.3 Traveling ultrasonic waves in an acrylic pipe

There are three possible fundamental modes of vibrations in a piezoelectric ring when an electric field parallel to the poling direction is applied (Hueter and Bolt, 1955).

1. The thickness (axial) mode vibration occurs when the applied frequency is coincident with the thickness resonant frequency which induces a change in thickness,
2. The radial mode vibration occurs when the applied frequency is coincident with the radial resonant frequency, which induces a change in the mean diameter. The radial mode always appears as the lowest frequency as the diameter is the largest dimension.
3. The wall thickness mode occurs when the frequency is coincident with the resonant frequency along the wall thickness direction, causing a change in the wall thickness (Cheng and Chan, 1998).

The three modes of vibrations in radial direction mentioned in were used to excite flexural traveling waves in an acrylic pipe (Takano and Tomikawa, 1998) with the waves formed shown in Figure 2. Three kinds of flexural waves were excited corresponding to the vibration modes of the piezoelectric ring. Figures 2a, 2b, and 2c show the symmetrical flexural mode excited by the (R,1) mode, the asymmetrical mode excited by (1,1) mode and the rotating flexural mode excited by degenerated (1,1)-(1,1)’ mode respectively. The flexural progressive wave with rotation was excited into the pipe because two orthogonal flexural waves were driven by two electric signals with a phase difference of 90^o (Takano and Tomikawa, 1998). From experiments on the vibration modes in acrylic pipes (Takano, Suzuki and Adachi, 1991), the symmetric mode transported more powder than the asymmetric mode, that is, the powder sending speed by the symmetric was about $15 - 20$ times faster than the asymmetric mode as shown in Figure 3. This is because the elliptic motion of the displacement of sending force by the symmetry mode occurred in the same direction on the entire inner side of the pipe as shown in Figure 4a. Conversely, in the asymmetric mode, the elliptic motion of displacement is not uniform; that is, it was maximum at the top and bottom of the pipe, but non-existent in the middle area depicted in Figure 4b.

2. Modeling

The design of the powder transport system is shown in Figure 5. Finite Element Analysis was used to obtain the optimal position and the acrylic pipe considered had a length of 900mm. In this analysis, the piezoelectric ring and the acrylic pipe were bonded together. The model was meshed automatically and later refined as shown in Figures 6a and 6b respectively. Thereafter, the piezooceramic ring was loaded with 10V alternating current at frequencies varying from 20 kHz to 70 kHz. Frequency deformation of the amplitude was obtained at different offset positions along the length of the pipe. This was varied from the edge of the pipe to halfway along the pipe to take advantage of the symmetry.

3. Results and Discussion

The optimum position of placing the transducer was obtained as the highest value of the amplitude in the particular length of the acrylic pipe and the results are shown in Figure 7. It was also observed that there was erratic deformation in the first 20% of the pipe which then decayed to an almost constant minimal value and the amplitude was affected by the length and the offset position of the transducer. At this position, a traveling ultrasonic wave was produced inside the acrylic pipe, which was attenuated along the length.

4. Conclusion

In this ultrasonic powder transportation device, the optimum position of placing the piezoelectric transducer was obtained through modeling. The optimum position was found as 11mm from the edge of the pipe which led to the biggest amplitude of the wave being produced. It was found that at resonant frequency, the highest wave was being produced.

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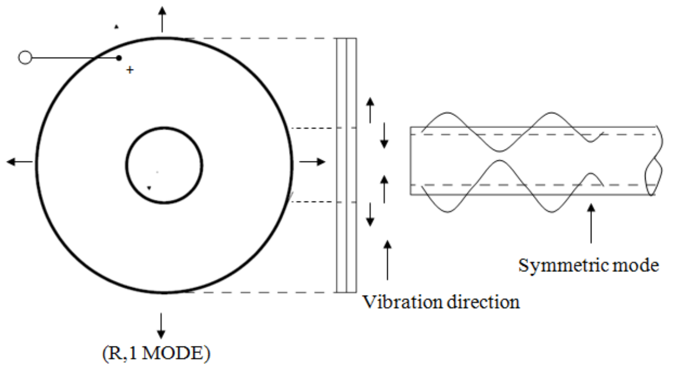
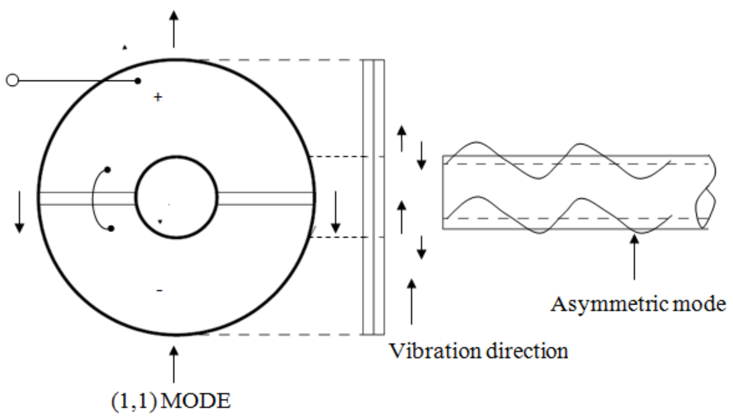


(a) Symmetric flexural mode.



(b) Asymmetric flexural mode.

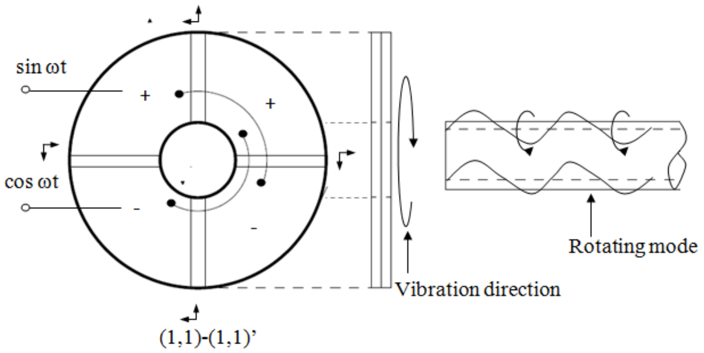


Figure 1: Traveling waves excited by the vibration modes of a piezoelectric ring

(c) Rotating flexural mode.

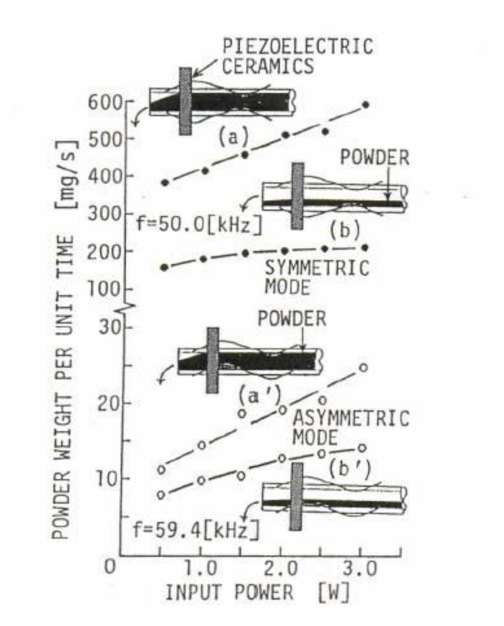


Figure 2: Sending characteristics of the device

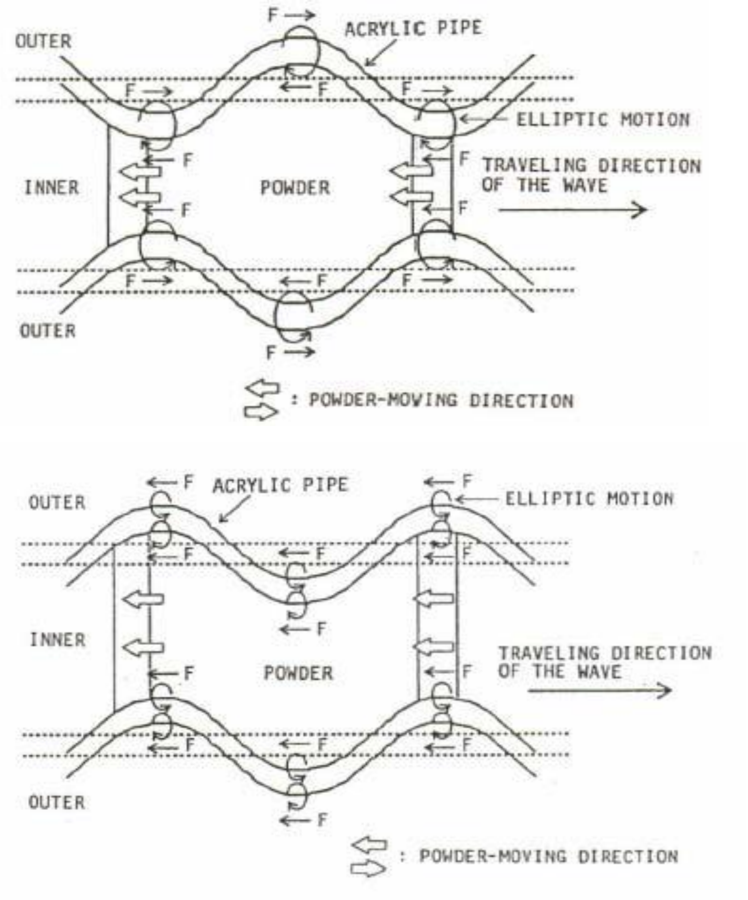


Figure 3: Elliptic motions of displacement and powder moving directions

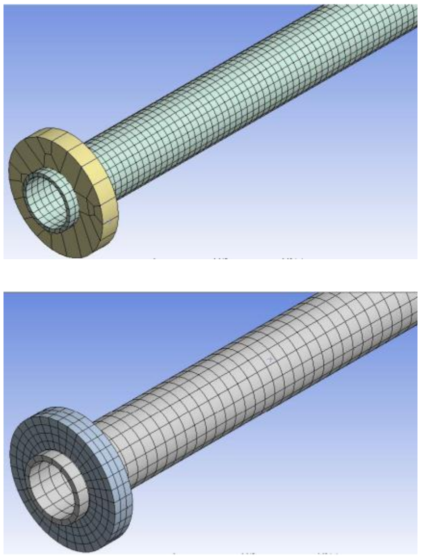


Figure 4: Meshing the model

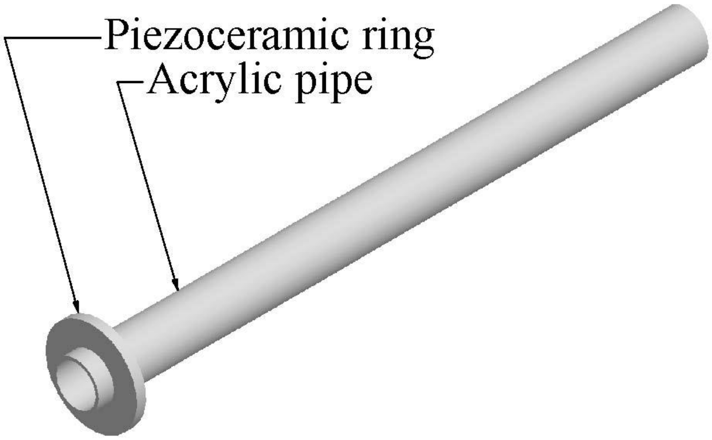


Figure 5: The design of the powder transport system prototype

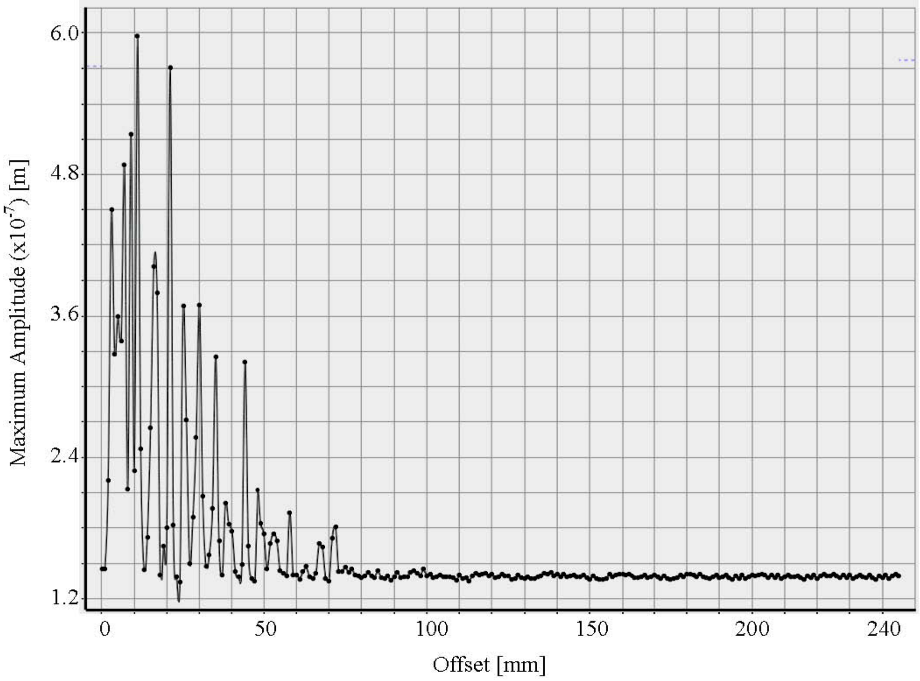


Figure 6: Plot of amplitudes along various points along the pipe

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