ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Wireless Sensor for Injection Molding Cavity Pressure Measurement

Lavanya Yandrapu
M.Tech Student(Embedded System),
Department of ECE,
Miracle Educational Group of Society.

P.Suvarnaraju
Associate Professor,
Department of ECE,
Miracle Educational Group of Society.

ABSTRACT:

The concept of a wireless sensor for injection molding machine cavity pressure measurement is proposed. The pressure information inside the cavity can be sensed by means of a series of ultrasonic pulses. The current pressure is obtained simply multiplying the number of pulses with a preset threshold value. Instead of using any external power supply, the sensor is self-powered by a piezoelectric stack that extracts energy from the melt pressure changes and converts it into electrical energy. Theoretical background of ultrasonic pulses and micromechanical switches are introduced, in view of their applications in the proposed design. Preliminary experiments have shown that pressure change of 20 MPa within 1 s could be detected wirelessly by a single ultrasonic pulse. Further work will be done to validate the proposed design.

1. INTRODUCTION:

Injection molding is capable of producing very complex components to tight specifications. The process consists of several stages: plastication, injection, packing, cooling, and ejection. In injection molding and its variants (coinjection, injection compression, gas assist molding, etc.), thermoplastic pellets are fed into a rotating screw and melted. With a homogeneous melt collected in front of the screw, the screw is moved forward axially at a controlled, time-varying velocity to drive the melt into an evacuated cavity. Once the melt is solidified and the molded component is sufficiently rigid to be removed, the mold is opened and the part is ejected while the next cycle's thermoplastic melt is plasticized by the screw.Cycle times range from less than four seconds for compact discs to more than three minutes for automotive components.

For injection molding high quality products with low rejection rates, on-line process control of temperature and pressure is necessary. In the case of pressure measurements, there are three basic sensor locations: within the mold cavity, in the nozzle, and in the hydraulic cylinder. Pressure measured in the hydraulic system or in the nozzle only reflects the setpoints of the injection-molding machine. Cavity pressure is a process state internal to the mold cavity and directly relates to the part quality. Therefore, measuring the mold cavity pressure is critical to achieving better control of the molding process and improving part quality. Traditionally, cavity pressure sensors are mounted in the mold and connected to the data processing devices outside of the mold by cables, as shown in Fig. 1a. Holes and channels need to be machined on the mold to house the cables for sensor installation. Because of the structural modification it has been estimated that the installation cost may far exceed the purchase cost of the sensors. Also the number of sensors that can be installed in one mold is highly restricted due to economic and location constraints. In comparison, a wireless sensor arrangement, as shown in Fig. 1b, has the inherent advantage of lower installation cost and less mold structure modification.

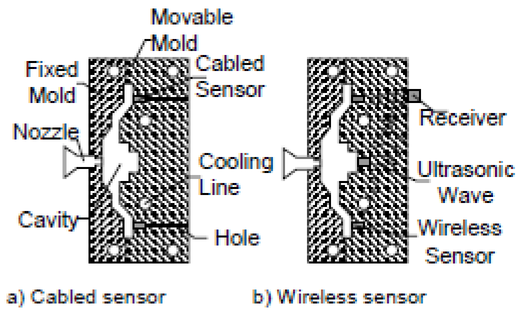

Fig. 1. Schematics of cabled sensor and wireless sensor installed in a mold

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Wireless temperature or pressure sensing using passive thin film sensors based on surface acoustic wave (SAW) technology has improved significantly in recent years [2-3]. A sensor of this type generally has two interdigital transducers (IDT) on the surface of a piezoelectric substrate. The principle for the measurement is that the mechanical resonance frequency of the IDT is highly sensitive to changes in temperature or pressure.Radio frequency (RF) electromagnetic (EM) signals from an inquiring unit trigger an interdigital transducer, which is excited to vibrate, sending out surface acoustic waves on the surface of the substrate. The waves propagate to an adjacent IDT, and are then reflected to the first IDT. The first IDT reconverts the reflected waves into electromagnetic signals and sent them back to the inquiring unit (Fig. 2). These signals contain the temperature and pressure information to be measured and can be evaluated by comparing them to an unaffected signal. However, for the present study on injection molding process monitoring, mold steel acts as an electromagnetic shield and prevents the EM signal from transmitting out of the mold successfully. Accordingly, the surface acoustic wave sensor is not considered for measuring the mold cavity pressure.

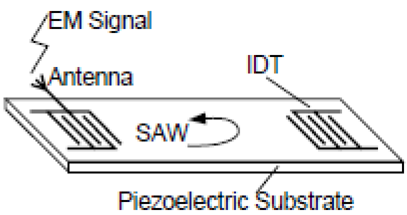

Fig. 2. Schematic of a passive SAW sensor

Being mechanical wave in nature, ultrasounds can propagate through the steel without much attenuation. Ultrasonic technology has long been used in non-destructive testing (NDT) of material properties. In this area, piezoelectric elements (PE) play an important role [4-5]. By means of the inverse piezoelectric effect, a piezoelectric element under electrical excitation can vibrate and generate ultrasound. Another useful property of piezoelectric elements is that they can convert mechanical energy to electrical energy. This property, called piezoelectric effect, makes piezoelectric elements widely used for measurement of mechanical quantities, such as pressure, vibration and displacement. The proposed research utilizes these two effects in an integrated fashion. The overall design is to convert mechanical energy from the melt pressure being measured into electrical energy, and then use it to generate an ultrasonic signal. A schematic illustration of this concept is shown in Fig. 1b.

In this paper, considerations on the design of a piezoelectric stack for energy extraction from melt pressure are discussed and the theoretical background of signal generation and transmission using ultrasound is presented. To reduce energy consumption, a micromechanical switch based on the microelectromechanical system (MEMS) technology is proposed to replace traditional TTL or MOSFET electronic switches. The experimental validation of a wireless sensor prototype for rapid pressure change measurement is demonstrated.

2. SENSOR DESIGN:

The term “wireless sensor” implies that there are no cable connections between the in-mold pressure measuring sensors and the data receiver outside the mold. Consequently two design constraints must be considered. First, the sensor itself must supply the energy required for signal generation and transmission. Secondly, the signal must transmit wirelessly through the mold to the data receiver. During the molding cycles, the change in melt pressure inside the cavity is typically 100-200 MPa. This pressure differential, if converted appropriately, is sufficient for the sensor energization.

The energy conversion can be achieved using a piezoelectric element. Traditionally, pressure measurement using piezoelectric sensor requires a cable connection to charge amplifier, which amplifies the electrical charge generated by the sensor subjected to pressure differential. The charge amplifier is a high gain amplifier with high input impedance that ensures the charge alterations on the sensor are measured without leakage. The output is an easily evaluated voltage proportional to the pressure differential. The energy needed for this measuring and charge conversion process is supplied by an external power supply.

For the proposed design where the sensor extracts its own energy, the use of a charge amplifier is not appropriate because the extracted energy from the melt pressure is not sufficient to power the charge amplifier. To minimize energy consumption, a different measuring concept is introduced.

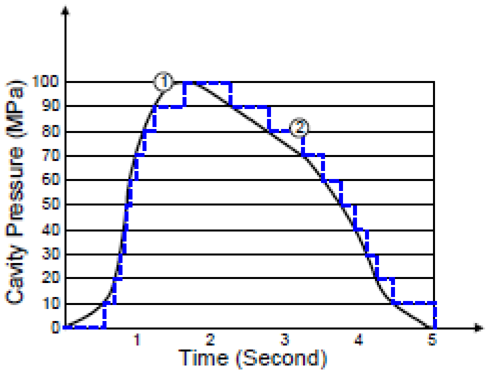

Fig. 3. The concept of digitized pressure measurement
1) Typical cavity pressure
2) Measured cavity pressure

A typical cavity pressure curve has two basic segments, as illustrated in Fig. 3. The curve is monotonically increasing before it reaches the peak point, and monotonically decreasing afterwards. The monotonic characteristics of cavity pressure make it possible to measure the change of pressure. The measurement starts when the melt front reaches the sensor. At this stage the cavity pressure is increasing, together with the converted energy. Each time the pressure rises and the energy exceeds a preset value, the energy will be released and a signal generated. The total number of generated signals is a measure of the pressure change.

During the pressure falling phase, every time a signal is generated, the total signal number count will be subtracted by one. As a result, the continuous current cavity pressure is digitized and measured by multiplying the number of signals with the preset pressure value. This concept is illustrated in Fig. 3. A signal is generated each time the pressure increases by 10 MPa from the previous value and the current pressure value is obtained by multiplying the number of signals by 10 Mpa.

EXPERIMENTS:

To validate the proposed design, a step function voltage has been used in the experiment to simulate the electrical pulse that is applied to the ultrasonic transducer. A piezoelectric element was excited by the rising edge of a 5 V step function. Waveforms of step function voltage and received ultrasonic pulse are shown in Fig.

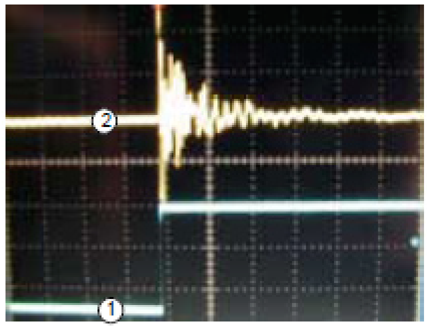

Fig. 9. A transducer driven by a step function voltage, with the time base 100 µs/div. 1) An electrical step function, 2 V/div. 2) Received ultrasonic pulse, 20 mV/div.

Figure shows a stack of ten piezoelectric rings (APC850) electrically connected in parallel. Each individual ring is 1mm (0.04 inches) thick. The outer diameter is 12.7mm (0.5 inches) and the inner diameter 6.35mm (0.25 inches). A copper foil electrode is sandwiched between each two adjacent rings. To ensure rigidity and contact, the stack is clamped by two steel bushings and preloaded by a central bolt. The equivalent capacitance of this stack is measured to be 14 nF. Under a pressure of 100 MPa, the stack was able to generate a charge of 38 C and an open circuit voltage of 2700 V. Accordingly, the potential energy stored in the stack is 52 mJ.

Fig. 10. A ten-piezoelectric ring stack

A test rig (Fig.) has been designed and fabricated to generate a pressure differential on the piezoelectric stack. The steel mass is dropped and slowed down by the spring. While the spring compresses, the force on the free end of the lever rises sinusoidally. The piezoelectric element stack is electrically connected in parallel to an ultrasonic transmitter (PAC S-1000BM). The transmitter is coupled to one side of a steel bar about 5mm thick, which simulates the wall of an injection mold. An acoustic emission sensor (PAC D9203B) is coupled to the other side to "listen" to the ultrasonic signal. The output of the acoustic emission sensor is connected to an oscilloscope (Tektronix TDS3012) which can display and record the received ultrasonic signal.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

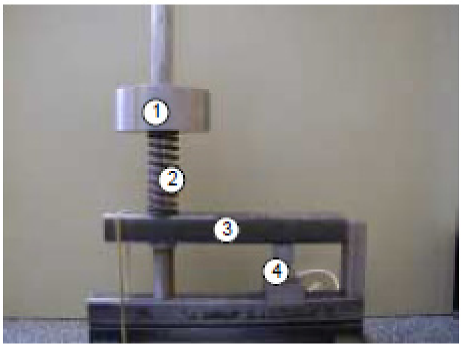

Fig. 11. Test rig for experiment 1) Mass 2) Spring 3) Lever 4) Piezoelectric Stack

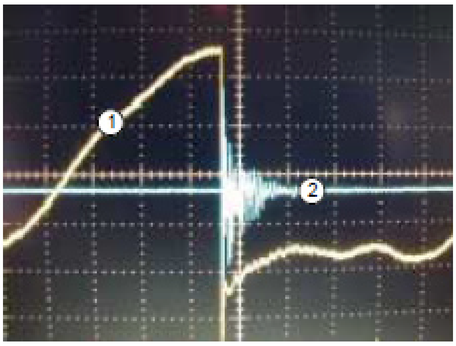

Fig. 12. Ultrasonic transmitter excited by the step voltage, with time base 20 µs/div. 1) The voltage measured between the two faces of the stack, 100 V/div. 2) The voltage measured at the output of AE sensor, 2 V/div.

The stack is placed near the fixed end of the lever, which amplifies the force from the mass. With this arrangement the piezoelectric stack is subjected to a rapid pressure. The voltage measured across the two poles of the stack is about 500 V (Fig. 12), which corresponds to a pressure of 20 MPa. With the spring compresses to its solid length, the steel mass bounces back from the stack and the load on the stack is released instantly. The release time was measured to be 1 s, which is much shorter than the load rise time. The ultrasonic transmitter is excited by this step voltage and sends out an ultrasonic pulse (Fig.). The maximum peak-peak voltage of the sensed pulse is about 8 V and decays within 40 s.

CONCLUSIONS AND FUTURE WORK:

A new wireless sensor for injection molding machine cavity pressure measurement is proposed. Determined by the characteristics of the cavity pressure curve, the pressure information is digitized by a series of ultrasonic pulses. Each single ultrasonic pulse represents the pressure rise/fall across a threshold value, and the current pressure is obtained by multiplying the number of pulses with the threshold value. To enable wireless sensing, a piezoelectric element is used to draw energy from the cavity pressure change and convert it to electrical energy. A stacked piezoelectric element design consisting of ten 1mm thickness piezoelectric rings (APC850)is proposed which increases the equivalent capacitance and charge generation efficiency. The capacitance is about 14 nF which is 100 times greater than that of one single 10 mm thick ring design. A pulse generation mode is proposed, which consumes less energy than the continuous wave mode. To further reduce energy consumption, a micromechanical switch based on the MEMS technology is proposed to replace the commonly used electronic switches.

The threshold voltage required to close the switch can be varied by changing the geometry of the switch. Experimental validation has shown that a force actuator created a pressure drop of about 20 MPa within 1 s on the stack. The stack then generated a 500 V step voltage to excite an ultrasonic transmitter. The transmitter propagated an ultrasonic pulse in a 5mm thickness steel bar. The pulse was successfully detected on the other side of the steel bar by an AE sensor. The experiment shows that a rapid pressure change can be sensed wirelessly by means of one single ultrasonic pulse. The first wireless sensor with a micromechanical switch will be modeled, fabricated, and tested. This sensor is able to generated one single ultrasonic pulse when the melt pressure reaches 100 Mpa and can be used to detect the arrival of the melt front.

REFERENCES:

[1] Orzechowski, S., Paris, A., and Dobbin, C., 1998, "A Process Monitoring and Control System for Injection-Molding using Nozzle-based Pressure and Temperature Sensors", Proceedings of the 1998 56th ANTEC, 1, pp. 424-428.

[2] Bulst, W.-E., Fischerauer, G., and Reindl, L., 1998, "State of the Art in Wireless Sensing with Surface Acoustic Waves", Proceedings of the 1998 24th Annual Conference of the IEEE Industrial Electronics Society, 4, pp. 2391-2396.

[3] Buff, W., Klett, S., Rusko, M., Ehrenpfordt, J., and Goroll, M., 1998, "Passive Remote Sensing forTemperature and Pressure Using SAW Resonator Devices", IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 45, pp. 1388- 1392.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

[4] Randeraat, J. V. and Setterington R. E., 1974, Piezoelectric Ceramics, Mullard limited, London.

[5] Asher A. C., 1997, Ultrasonic Sensors for Chemical and Process Plant, Institute of Physics, London.

[6] Matthys, R. J., 1983, Crystal Oscillator Circuits, John Wiley & Sons, New York.

[7] Frederick, J. R., 1965, Ultrasonic Engineering, John Wiley & Sons, New York.

[8] Yao, Z. J., Chen S., Eshelman, S., Denniston, D., and Goldsmith, C., 1999, "Micromachined Low-Loss Microwave Switches", IEEE Journal of Microelectromechanical Systems, 8, pp. 129-134.

[9] Shikida, M., Sato, K., Tanaka, S., Kawamura, Y., and Fujisaki, Y., 1994, "Electrostatically Driven Gas Valve With High Conductance", IEEE Journal of Microelectromechanical Systems, 3, pp. 76-80.

[10] Petersen, K. E., 1979, "Micromechanical Membrane Switches on Silicon", IBM J. Res. Develop, 23, pp. 376-385.

[11] Legtenberg, R., Gilbert, J., Senturia, S. D., and Elwenspoek, M., 1997, "Electrostatic Curved Electrode Actuators", IEEE Journal of Microelectromechanical Systems, 6, pp. 257-265.

[12] Taylor, W. P., Brand, O., and Allen, M. G., 1998, "Fully Integrated Magnetically Actuated Micromachined Relays" IEEE Journal of Microelectromechanical Systems, 7, pp. 181-191.

[13] Zavracky, P. M., Majumder, S., and McGruer, N. E., 1997, "Micromechanical Switches Fabricated Using Nickel Surface Micromachining", IEEE Journal of Microelectromechanical Systems, 6, pp. 3-9.

[14] Nathanson, H. C., Newell, W. E., Wickstrom, R. A., and Davis, J. R., 1967, "The Resonant Gate Transistor", IEEE Transactions on Electron Devices, ED14, pp. 117-133.

[15] Kruglick, E. J. J. and Pister, K. S. J., 1999, "Lateral MEMS Microcontact Considerations", IEEE Journal of Microelectromechanical Systems, 8, pp. 264-271.

[16] Fedder, G. K. and Howe, R. T., 1996, "Multimode Digital control of a Suspended Polysilicon Microstructure", IEEE Journal of Microelectromechanical Systems, 5, pp. 283-297.

[17] Carlin, B., 1960, Ultrasonics, McGraw-Hill, New York.

[18] Beyer, R. T. and Letcher, S. V., 1969, Physical Ultrasonics, Academic Press, New York.

[19] Kino, G. S., 1987, Acoustic Waves, Devices, Imaging & Analog Signal Processing, Prentice-Hall, Englewood Cliffs, New Jersey.