DESIGN OF MICROCONTROLLER-BASED PORTABLE INSTRUMENT FOR MEASURING P-WAVE SPEED IN IMPACT-ECHO METHOD

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ABSTRACT

Impact-echo method is widely used for non-destructive testing on concrete evaluation. One of the procedures of this method is determining P-wave speed by measuring travel time of P-wave (Δt) between two transducers. For this purpose, a microcontroller-based portable instrument is developed. This research proposes a PIC microcontroller routine using interrupt-on-change and timer0 features. On concrete, impact waves reach the first accelerometer and will interrupt the main routine and start the timer0. When the waves reach the second accelerometer, the timer0 will be stopped. The value of the timer represents the travel time of P-wave. Therefore, the P-wave speed can be calculated. The routine is verified using controlled signal generated by internal PIC. The accurate result of the travel time measurements is presented.

***Keywords**: impact-echo, P-wave speed, PIC microcontroller, interrupt-on-change, timer0*

1. INTRODUCTION

One of the purposes of a concrete evaluation is identifying and quantifying suspected problems within a structure, in quality control applications, such as measuring the thickness of new highway pavements, and in preventive maintenance programs, such as routine evaluation of bridge decks to detect delaminating. There are two groups of test methods for concrete: destructive test, such as coring and drilling, and nondestructive test, such X-rays, gamma rays, radar, infra-red and echo method. While destructive methods are highly reliable, they are also time consuming and expensive and the defects they leave behind often become focal points for deterioration [Sansalone, 1997]. Nondestructive tests have become widely used for concrete evaluation.

Impact-echo is one of non destructive test which has proven to be a powerful technique for flaw detection in concrete structures [Carino, 2001]. Equipment for impact-echo test was developed in 1990 and always re-developed to get an easy-use system. The development of a simple instrument based on impact-echo method is still doing. This paper presents a part of this work, microcontroller programming application using PIC-C Compiler for measuring P-wave speed, one of the procedures of impact-echo test.

2. IMPACT-ECHO METHOD

Impact-echo method is a technique based on the use of transient stress waves generated by elastic impact [Sansalone and Carino, 1986]. In 1998, American Society of Testing Materials (ASTM) adopted a test method on the use of the impact-echo method to measure the thickness of concrete members [ASTM C 1383]. The method includes two procedures. Procedure A, which is shown in Fig. 1.a, is used to measure the P-wave speed (c_P) in the concrete using equation

$$c_P = \frac{L}{\Delta t} \quad (1)$$

This measurement is based on measuring the travel time of the P-wave (Δt) between two transducers a known distance apart (L) [Sansalone et al. 1997a, 1997b]. Procedure B (Fig. 1.b) is measuring the thickness frequency (f_T) using the impact-echo method from which the plate thickness (T) is calculated using the measured P-wave speed and equation

$$T = \frac{0.96 c_P}{2 f_T} \quad (2)$$

3. PIC 16F877A

PIC 16F877A is microcontroller unit (MCU) from Microchip. It has 40 pins microcontroller, 8 Kbytes program memory and operating frequency at 20 MHz. Some features related to this project will be described.

Four of the PORTB pins, RB7:RB4, have an interrupt-on-change feature. Only pins configured as inputs can cause this interrupt to occur (i.e., any RB7:RB4 pin configured as an output is excluded from the interrupt-on-change comparison). The input pins (of RB7:RB4) are compared with the old value latched on the last read of PORTB [Microchip, 2003]. The compiler will generate code to jump to the interrupt service routine (ISR) when the interrupt is detected. It will generate code to save and restore the machine state, and will clear the interrupt flag. The interrupt-on-change feature is recommended for wake-up on key depression operation and operations where PORTB is only used for the interrupt-on-change feature.

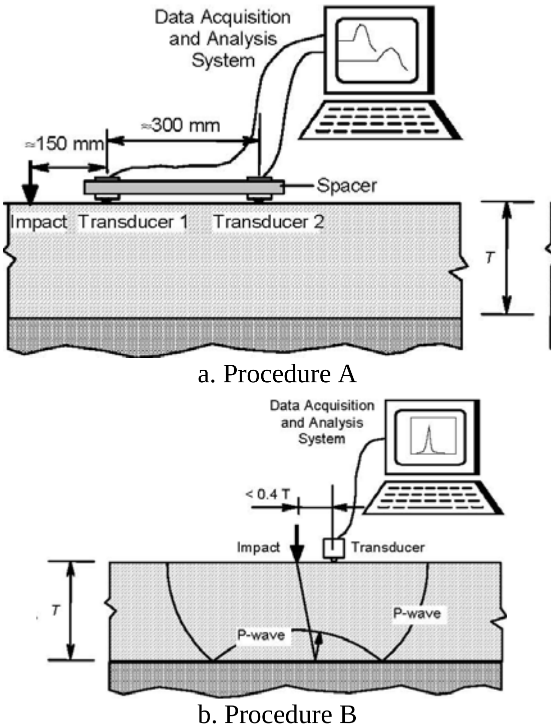

Fig. 1. Two-step procedure for measuring plate thickness according to ASTM C 1383: (a) Procedure A is used to determine the c_P and (b) Procedure B is used to determine f_T.

The most common feature used in many applications is timer. Timer counts the value of a real time clock/counter. All timers count up. When a timer reaches the maximum value it will flip over to 0 and continue counting (for example 8 bit timer: 254, 255, 0, 1, 2...) [CCS, 2003]. PIC 16F877A has 3 timer, i.e. two 8 bit timer and one 16 bit timer.

The basic language of microcontroller is assembly language. Whatever, many compilers are developed to make easier programming. PIC-C compiler from Custom Computer Service (CCS) is specially designed to meet the special needs of the PIC based on C programming language. These tools allow developers to quickly design application software for these controllers in a highly readable, high-level language. The compiler has some limitations when compared to a more traditional C compiler because of the hardware limitations [CCS, 2003].

4. SYSTEM DESIGN

The system is designed for measuring the travel time of the P-wave (Δt) between two transducers a known distance apart (*L*) and calculate the P-wave speed measurement using Equation 1. The hardware system consist PIC 16F877A, clock generator using 20 MHz crystal oscillator, liquid crystal display (LCD) module and two piezoelectric accelerometers from DJB Instruments as shown at Fig. 2.

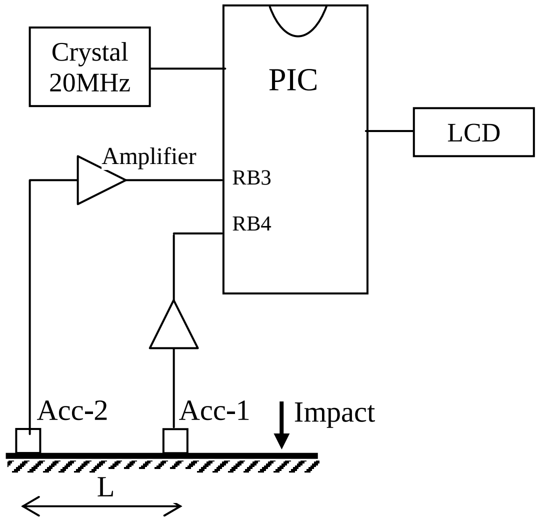

Fig. 2. Design of hardware system

PIN B4 in PIC is set as input pin of interrupt-on-change. This pin is connected to Acc-1 (Fig. 2). PIN B3 is connected to Acc-2. Because the output voltage of accelerometer is very small (below 500 mV), an amplifier is used to amplify the signal with gain 50. By this amplifying, the accelerometer signal is sufficient to activate the digital level of PIC.

The software design for the system uses 2 PIC's features: interrupt on change (INT_RB) and *timer0*. The 8 bit *timer0* starts counting at 0, 1, 2, …, 255 and continue counting 0, 1, 2, … until timer stop. The *prescaler* of *timer0* must be defined to determine the increment time of timer. The *timer0* is sufficiently used to measure the 50–150 microseconds travel time of P-wave.

When elastic impact generates transient stress wave, the wave will propagate reached the first accelerometer (Acc-1) and then the second accelerometer (Acc-2). Acc-1 will capture the signals and sends it to PIC as interrupt signals. When interrupt is occurred, the ISR will be executed. The ISR contains functions to start *timer0* and get the value. When the wave reached Acc-2, the ISR will execute the function to get the *timer0* value. The difference between the *timer0* values is the travel time (Δt) of the waves. Fig. 3 shows the flowchart of ISR.

Because the distance between the two accelerometers has been defined (L=300 mm), the P-wave speed can be easily calculated by PIC using Equation 1. The result will be displayed on 16x2 LCD Module.

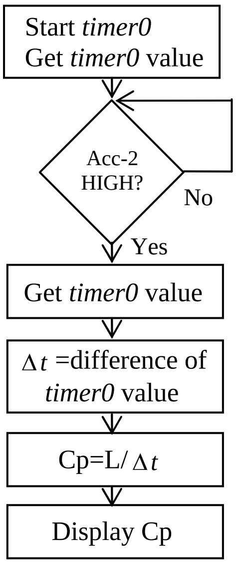

Fig. 3. ISR flowchart

5. RESULT AND DISCUSSION

For verifying the routine, a high speed external signal is needed. For this paper, controlled signal generated from internal PIC (RB1 and RB2) is used. RB1 is connected to RB4 and RB2 to RB3. Signal from RB1 represents signal from Acc-1 and signal from RB2 represents signal from Acc-2. By defining the delay time between output-high of RB1 and RB2, the travel time represented by the value of *timer0* can be determined. Table 1 shows the result of travel time (Δt) with controlled signal. The result is very satisfied and accurate.

Table 1. Travel time (Δt) with controlled signal

Delay time between output-high of RB1 and RB2 (μs)	***Travel time (Δt) measured by PIC (μs)***
50	49.9
68	67.9
100	99.99
143	142.9

Interrupt on change PORTB will be activated if the interrupt signal voltage is more than 1.5 volt. It is important to make sure that the interrupt port must be cleared before enable the INT_RB. Otherwise, the PIC will be confused by the condition of the interrupt pin.

6. CONCLUSION

A microcontroller-based portable instrument for determining P-wave speed has been designed. The microcontroller routine is used to measure the travel time of P-wave between two accelerometers. The routines apply interrupt-on-change PORT_B and *timer0* features of PIC. A verification using internal controlled signal shows an accurate result.

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