Ultrasonic Device for Non-Contact Studying of Materials

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Abstract: *In this paper is described the design and implementation of a device for non-contact ultrasonic studying of materials. Presented is a scheme solution of the device, into which are provided several key features for work with purpose for greater versatility. There are presented block diagrams of algorithms of the software necessary for some modes of work of the device with microcontroller PIC16F84A. These modes are related to the way for excitation of the ultrasonic transmitter and the synchronization of measurement. Principle of work of the system is described in detail.*
Key words*: Ultrasonic, Ultrasonic sensors, Non-contact method, PIC16F84A.*

INTRODUCTION

In the automation systems increasingly is required total integration into automation (Totally Integrated Automation) [1]. Some of these tasks are related to studying (research) of materials for their identification. They are equally applicable to both light and in heavy industry. For example, in industries of food industry, foundry, machine construction (engineering), and etc. Solving these problems is related to the collection and processing of data on the course of the related technological process. Different methods are used - contact and non-contact. The last are have precedence when used. From the famous modern methods for studying of materials of interest for many technological applications is a non-contact ultrasonic method, which uses acoustic echo sounding principle. It is based on the use of acoustic waves with ultrasonic frequency range located between 20 kHz and 10 MHz. It is based on the effect of reflection. The measuring converter is not in direct contact with the object of measurement and control. In determining of the distinctive characteristics of different physical mediums and materials with purpose for their recognition (identification) the echo signal is analyzed, which is in the result of reflection of the ultrasound waves. This analysis includes discretization of the returned signal, mathematical processing for extracting of distinctive characteristics and its recognition on selected criteria [2]. The actual process of recognition is multiaspect process according the specific technological application. For example, the presence of an object, distance to the object, classification of materials by specific characteristics, identification, and etc.

The development aims at designing and implementing of a device for non-contact ultrasonic studying of materials.

Base stages in the development are:

- Synthesis of principal electrical scheme of the device for non-contact ultrasonic studying of materials;
- Development of algorithm for work and software support for the measuring device;
- Analysis of the results of measurements made with different ultrasonic sensors.

REALISATION

In order for greater flexibility and convenience are formulated the following features of the device:

- Working with different ultrasonic sensors;
- Work with internal excitation of the ultrasound transmitter with programmable circuit;
- Choice of operating frequency for internal excitation of the ultrasound transmitter with programmable circuit;

- Working with external excitation of ultrasonic transmitter;
- Feature for manually starting of the excitation of the ultrasonic transmitter with a programmable circuit;
- Feature for externally starting of the excitation of the ultrasonic transmitter with a programmable circuit.

In Fig. 1 is shown the functional block scheme for ultrasonic studying of materials. The main blocks in the scheme are three:

- Ultrasonic device - the main function of this unit is to transmit and receive signals from the ultrasound range, according to the set mode of work and to produce output signals (analogue and digital) with appropriate parameters for further processing;

- Multifunctional module - built on the basis of module USB-6251 M Series, made by company National Instruments. Serves to control the measurement process and the storing of the information. The transfer of data and its control is by USB interface with PC;

- Personal computer (PC) – there is realized virtual instrument built in an environment of LabView, and with the help of which is controlled the work of the multifunction module. The data obtained from the measurement process are processed, demodulated and evaluated by specialized software (eg. MATLAB).

The ultrasonic device consists of several main functional blocks:

- Transmitter and receiver – they are matched on parameters couple ultrasonic transducers with the same resonance work frequency. The piezoceramic elements of the sensors are shaped as disk;

- Pulse former - used to form the excitation signal for the transmitter;

- Amplifier - serving for amplifying of the reflected echo signal from the studying material to the necessary for its further processing level;

- Elements for control and adjustments – jumpers, through which is set the desired mode of operation of the device, buttons for manually starting of the measurement and to restart the microcontroller. The choice of the frequency of pulses for excitation, the time delay after the receiving of the start signal;

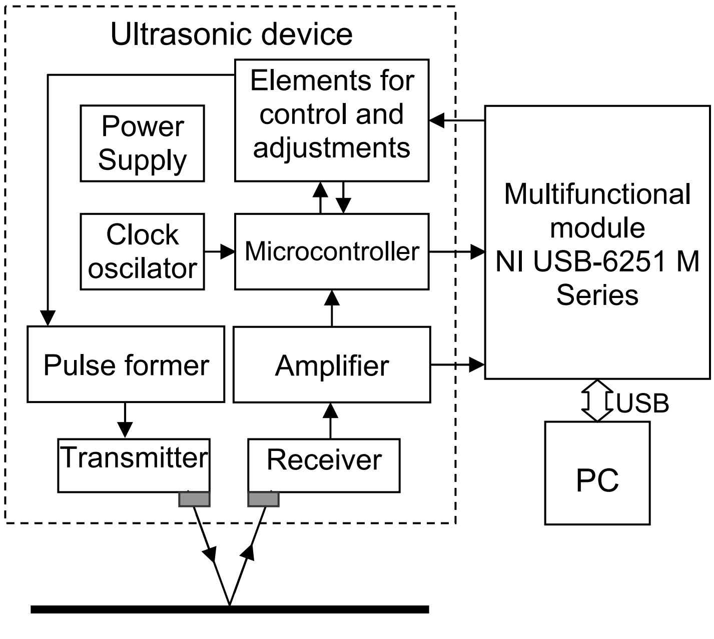

Fig. 1. Functional block scheme of the device for non-contact ultrasonic study

- Power Supply - provides voltages to all blocks of the scheme;

- Clock oscillator - provides a stabilized clock frequency for operation of the microcontroller;

- Microcontroller - serve to generate a packet of pulses to block Pulse former for excitation of the transmitter. It works according the set mode from block Elements for control and adjustments.

In Fig. 2 is presented principal electrical scheme of the developed device.

For the excitation of the ultrasound transmitter based on reverse piezoeffect are used CMOS inverters 4069. The last are connected in parallel by two to increase the power and amplitude of the transmitted signal. The voltages applied to the leads of the ultrasound transmitter are with phases at 180 degrees. For the purpose on the couples of inverters (the leads of the transmitter BQ2), the signal from the collector of the transistor VT2 is inverted by the element IC3E. Because of the C5 the voltage over the leads of the transmitter is higher than the supply voltage.

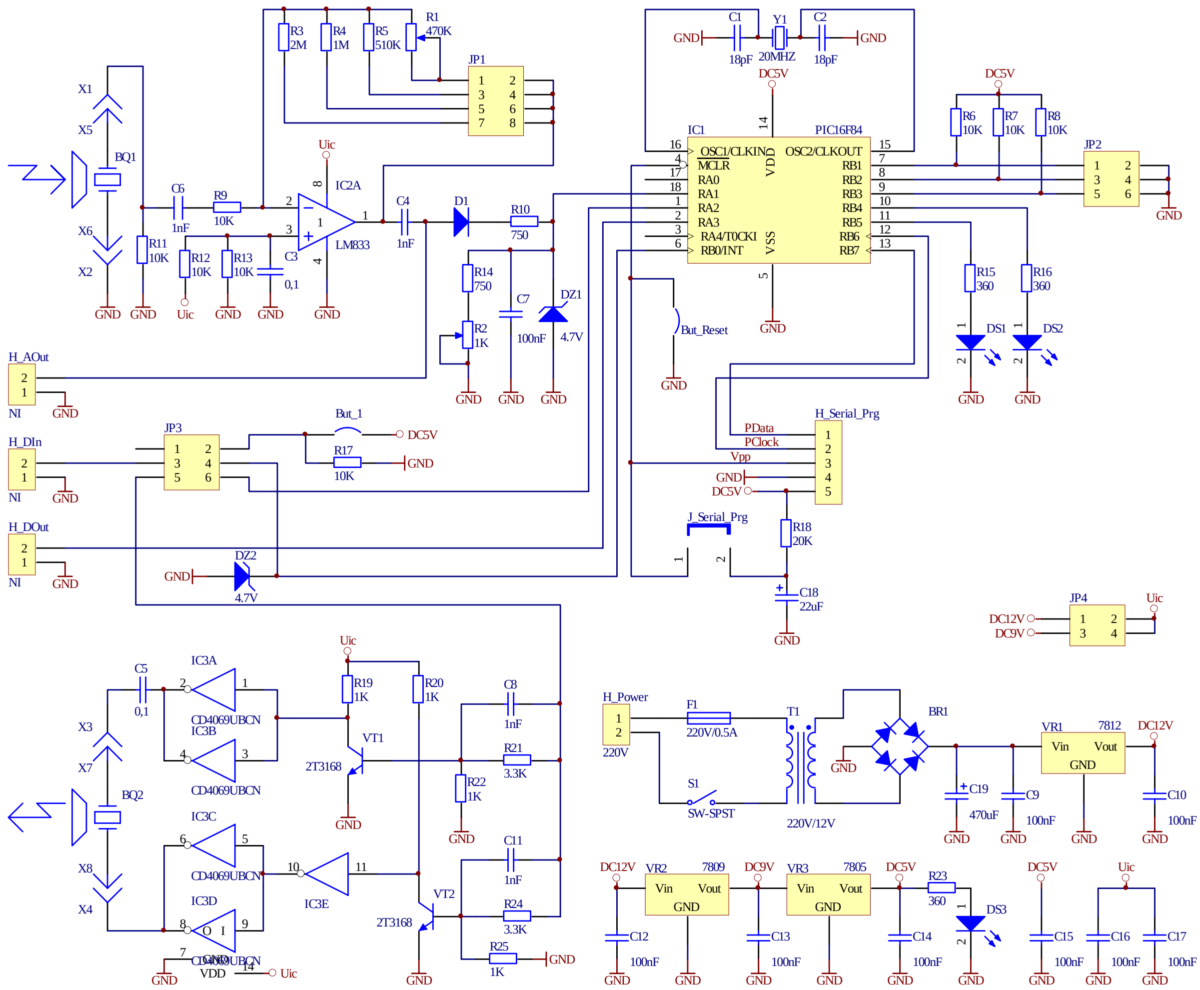

Fig. 2. Principle electrical scheme of the ultrasonic device

The piezoceramic elements (transmitter and receiver) according to the set mode of work of the device can be for 40 kHz (UST40T and UST40R) [3] or 125 kHz (125SR250B) [4].

The excitation signal for the ultrasound transmitter is a packet of pulses with rectangular form with its resonant frequency. According the recommendation of the company manufacturer of ultrasonic transmitters, for the full excitation of the piezoelements it is necessary to provide a packet of six pulses with specified parameters.

The transistors VT1 and VT2 are controlled by the same excitation signal, which according to the position of jumpers in JP3, may be either from the output RA2 from the microcontroller PIC16F84A or to be obtained externally from the output of the multifunctional module NI USB-6251 M Series. To obtain more rapid fronts at switching of the transistors, there are placed forcing circuits realized by C8, R21 and R22 for VT1 and C11, R24 and R25 for VT2. VT1 and VT2 are used to coordinate the PIC16F84A levels to those of CMOS inverters 4069.

The reflected from the studied material ultrasound wave acoustically influence over the receiver. Because of the straight piezoeffect from the ultrasound receiver is obtained an electrical signal which through the C6 is supplied to the input of operational amplifier IC2A (LM833N). The amplification can be adjusted by jumper from JP1. Depending on its place the amplification coefficients are set - 200, 100, 51 or through potentiometer R1 can smoothly varying from 1 to 47. It is also possible to obtain a different gain than those by the parallel connection of resistors selected in the feedback of the operational amplifier, by placing additional jumpers at JP1. In the scheme is used single-stage amplifier because of the gain coefficients provided to achieve adequate output level of the signal for its further processing.

The scheme works with single polar power supply. To achieving of uniform amplification of the positive and the negative part of the AC signal is created a virtual ground, raised with the half of the supply voltage by divider R12 and R13, which is submitted as a voltage to the positive input of operational amplifier LM833N (IC2A). The capacitor C3 is included for stabilization of the virtual ground and for filtering of signals.

In sequence to the output of the operational amplifier capacitor C4 is placed to separate the DC component from the output signal. Thus obtained analogue signal is output from the device for further processing.

In order to register the return echo signal from the microcontroller, in the scheme is placed detector-integrator composed of elements D1, R10, R14, R2 and C7. Setting of a different time constant of integration (and thus the threshold of activation) is by using the potentiometer R2. To limit the maximum voltage that is fed to the input RA1 of the microcontroller is connected a zener diode for 4.7V DZ1.

In the scheme is provided feature for selection of the signal source for starting a package of excitation pulses generated by the microcontroller. The choice is made by a jumper from JP3. The source of the start signal may be digital signal from an external unit or a signal obtained by pressing a button But_1. In both cases, the resulting signal is fed into the input RB0/INT of the microcontroller. To protect the microcontroller from a signal with a higher level from 5V, into the scheme is placed a zener diode for 4.7V DZ2.

The outlet of the digital signal from the output RA3 of the microcontroller to an external module is made by the connector H_DOut. This signal is necessary to be synchronized the work of the external module with the moment of sending of the packet with the excitation pulses to the transmitter.

For the normal operation of the device are used voltages +12 V, +9 V and +5 V. There is feature to change the supply voltages of the excitation scheme (IC3) of the transmitter BQ2, of the amplifier block IC2A and of the transistors VT1 and VT2 - from +12V to +9V and vice versa. This change is set by the jumper in JP4. If there is a +5 V supply voltage through the circuit R23, DS3 is current flow, resulting in the LED as an indicator lights.

Using elements R15, DS1, and R16, DS2 respectively connected to the outputs RB4 and RB5 of the microcontroller is provided a digital indication in operating frequency 125 kHz for excitation of the transmitter (lights the LED DS1) and mode of operation with a 10 ms delay after receiving the starting signal (lights the LED DS2).

The time-setting chain R6, C8 determine the delay of the actual start of the microcontroller. This requires the voltage over the lead $\overline{MCLR}$ to rise to the level of logical one. The slow increasing of the voltage over this input is needed to be started the program when there is already set stable power supply.

Into the scheme is provided a connector for serial programming in-place by a programmer of the microcontroller without the need to remove it from the circuit board.

Software for the microcontroller

The work of the developed device according the specified requirements is supported by the creation of corresponding software for the microcontroller in it - PIC16F84A [5].

In Fig. 3 is presented the algorithm of the main program in the microcontroller. Its work began with the switching-on the power.

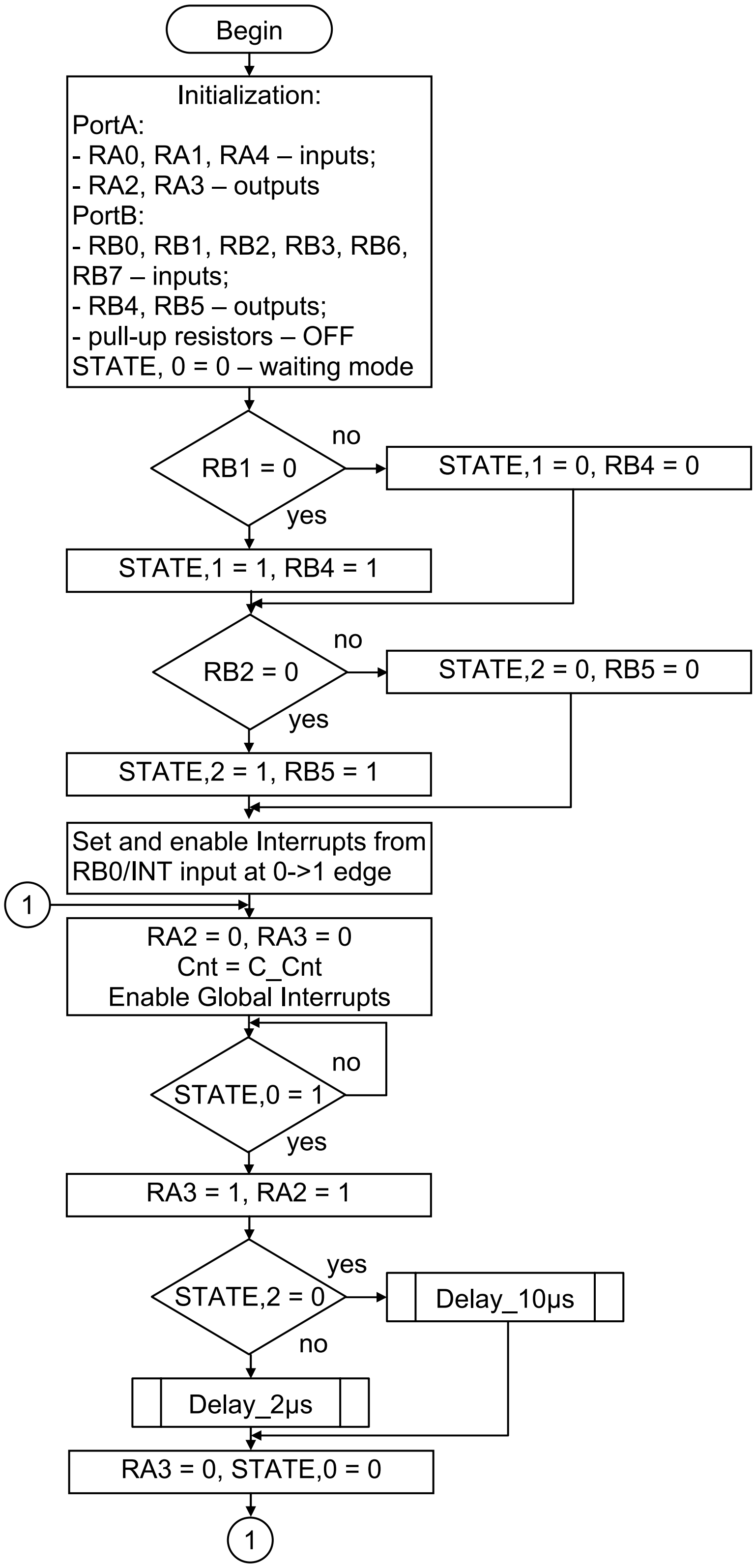

Fig. 3. Block diagram of the main program

At first there is executed an initialisation: the type of the leads for port A and port B are set, the pull-up resistors of port B are switched off, and in the variable STATE is set, that in the moment the mode of work of the microcontroller is “waiting”. The next are readings of the current state of the inputs RA1 and RA2, to which are connected the jumpers from JP2 and setting of the values of the bits in the variable STATE.

Log. 1 RB1 set to not delay, and a log. 0 - to have delay around 10ms after receiving the synchronization pulse on input RA3. Since synchronizing (starting) pulse can be set by the button But_1 in the scheme, in which case it is necessary to be waited until his contacts are settle. When it is set to have such delay, this is indicated by LED DS2, which is connected to lead RB4.

Log. 1 on RB2 set the frequency of the pulses in the packet to 40kHz, and log. 0 - 125kHz. When working with 125kHz this is indicated by LED DS1, which is connected to lead RB5.

At the end of initialization are set and enabled the interrupts at transition from 0 to 1 of the input RB0/INT.

The rest of the main program is an infinite loop, where consequently are performed the following actions:

- the signals to the leads RA2 (signal for excitation of the transmitter) and RA3 (signal for synchronization of the external unit);
- the Cnt is set to be equal to the doubled number of pulses in the packet - 12;
- the global interruptions are enabled;
- begins a cycle, which will not end until the bit 0 of the STATE variable becomes 1 - this occurs when the interrupt is caused in receipt of a start pulse on the input RB0;
- the outputs RA2 and RA3 are set to log. 1 - this is the beginning of the packet of pulses;

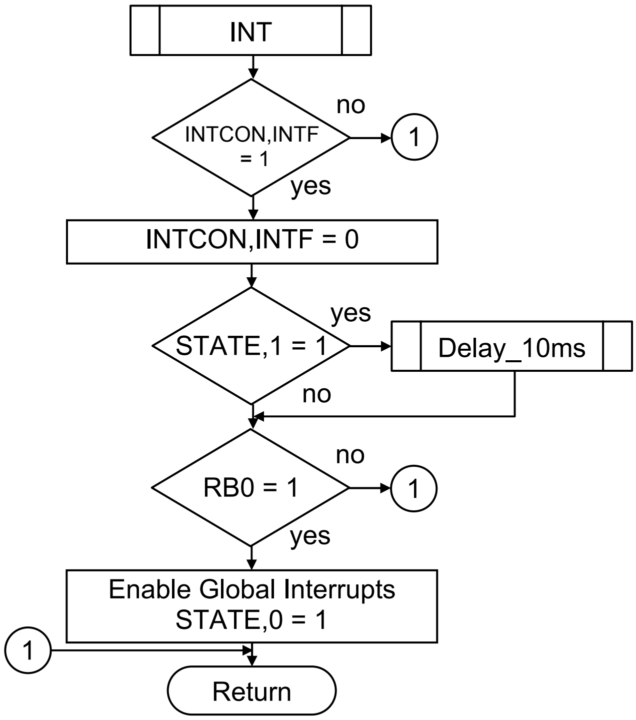

Fig. 4. Block diagram of the procedure for interrupts

- depending on the chosen frequency of the ultrasonic transmitter (bit 2 from STATE) procedure is called with the corresponding delay, where it produced a series of 6 pulses (Fig. 5 and Fig. 6);

- after returning from the procedure RA3 is set to zero and bit 0 of STATE is set to 0 (goes to standby mode waiting for the next start pulse), then the cycle continues with the first step.

In Fig. 4 is presented a block diagram of the procedure for handling of interrupts. In the main program of the microcontroller is set to generate an interrupt at the transition from 0 to 1 on input RB0/INT. The procedure proceed as follows:

- the interrupt flag for RB0/INT in register INTCON (INTF) is checked – if it is 0 it is the return from the procedure, if it is 1 – the execution continues;

- the interrupt flag INTF is set to 0;

- the bit 1 of variable STATE is checked – if it is 1 is called a procedure for time-delay of 10ms, and if 0 - continues with the next step;

- reading of the current state of RB0 – if it is 0 means that it was a false activation of the input and returns from the interrupt procedure, if it is 1 is passed to the next step;

- the global interrupts are disabled;

- bit 0 of STATE is set to 1, which indicates that the microcontroller is in the mode of transmission of pulses;

- end of the procedure for handling of interrupts.

In the next moment the execution of the main program will start sending pulses and will output a synchronizing pulse to the external module.

The time delays in the program of the microcontroller can be implemented in three ways, since it is known that the internal clock frequency of execution of instructions is 5MHz (external clock frequency is 20MHz), i.e. execution time of one instruction is 200ns:

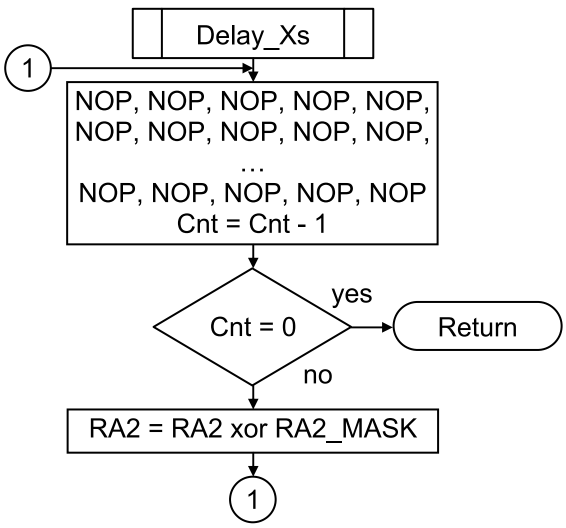

Fig. 5. Block diagram of the procedure for X time delay

- Using the built-in timer module TMR0 overflow and interrupts from it and having set a corresponding value in the timer before started;

- Time delay generated by software using a series of NOP (No OPeration) instructions;

- Time delay generated by software using a series of instructions that are repeated a specified number of times in a cycle.

In the software is used the second approach, because the times for delay must be set with high accuracy (by this approach the time can be adjusted by increments of 200ns) and because in the time interval for transmitting of pulses the microcontroller is not necessary to carry out other actions.

In Fig. 5 and Fig. 6 are presented block diagrams of algorithms for software generation of time delay - respectively by NOP instructions and by using of a cycle.

One exemplary implementation of the algorithm from Fig. 6 with assembler is presented in Fig. 7. Every instruction when executed takes one clock or time 200ns. Exceptions are instructions for transition that take 2 clocks (400ns) and the instructions for conditional jumps in which when condition is false it takes 1 clock, and when the condition is true - 2 clocks.

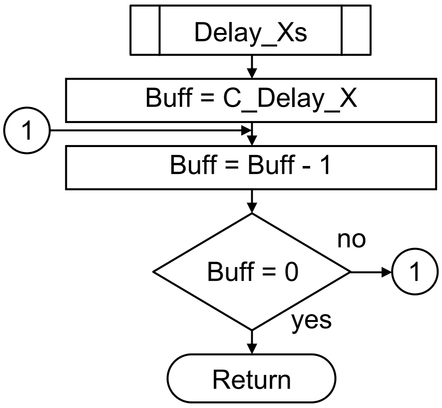

Fig. 6. Block diagram of the alternative procedure for X time delay

If we calculate the time delay for the execution of the source code of Fig. 7 we can obtain the following:

$$Delay = 200ns*(2+1+1+C\_Delay\_X*(1+2)-2+1+2) =$$
$$= 200ns*(5+3*C\_Delay\_X) = 1\mu s + 600ns*C\_Delay\_X,$$

where C_Delay_X sets the number of repeats of the cycle.

To calculate the value of C_Delay_X for the specified time delay (Delay) should be used the above depending in reverse:

$$C\_Delay\_X = (Delay - 1\mu s)/ 600ns$$

We see that in this method the step of modifying of the set time delay is 600ns, which makes it inapplicable to this case.

The pause of about 10ms for manual generating of starting pulse by the button But_1 is implemented in the procedure Delay_10ms, where are organized two nested cycles of instructions, each of which is repeated defined number of times.

```
D_Xs                        ;2 clk when called
        movlw   C_Delay_X   ;1 clk
        movwf   Buff        ;1 clk
Loop    decfsz  Buff, f     ;1(2) clk
        goto    Loop        ;2 clk
        return              ;2clk to return
```

Fig. 7. Source code of the alternative procedure for time delay

CONCLUSIONS AND FUTURE WORK

The developed hardware-software environment allows for non-contact non-destructive analysis of materials. Under development is a mobile device intended for embedding into automated manufacturing systems, which is based on the described in this paper ultrasonic device.

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ACKNOWLEDGEMENTS

This study was carried out in the framework of the DRNF 02/9 project titled "Design and development of a device for non-contact ultrasonic investigation of materials aimed at embedding in automated manufacture systems ", financed by the National Science Fund of the Bulgarian Ministry of Education, Youth and Science.

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