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The High Precision Vibration Signal Data Acquisition System Based on the STM32

[1] Zhu Hui-Ling, [2] Zhu Xin-Yin

[1] School of mechanical engineering, University of South China, Hengyang, Hunan, 421001, China
[2] Affiliated Nanhua Hospital, University of South China, Hengyang, Hunan, 421002, China
E-mail: dianli981@sina.com

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Abstract: Vibrating wire sensors are a class of sensors that are very popular used for strain measurements of structures in buildings and civil infrastructures. The use of frequency, rather than amplitude, to convey the signal means that vibrating wire sensors are relatively resistant signal degradation from electrical noise, long cable runs, and other changes in cable resistance. This paper proposed a high precision vibration signal acquisition with storage function based on STM32 microcontroller in order to promote safety in engineering construction. The instrument designed in this paper not only can directly collect vibrating signals, but also store data into SD card and communicate with computer so as to realize the real-time monitoring from point to point.

Keywords: STM32, Data acquisition, Data storage, Vibrating wire sensors.

1. Introduction

Vibrating wire sensors (VWS) are a class of sensors that are very popular used for strain measurements of structures in buildings and civil infrastructures. The operating principle of vibrating wire sensors is based on the measurement of the change in the frequency of a vibrating wire, which is stretched on a support, depending on the physical parameters of the wire and environment in which oscillations take place [9]. Nowadays, VWS have been implemented in numerous areas, such as monitoring structural responses, structural health monitoring, civil engineering, water pressure, density and viscosity of fluids, dams and excavation walls, strain inside structures etc., due to the advantage of long transmission length, lower exterior electromagnetic effect, ease and cost of installation compared with other electrical resistance strain gauges [1-8], especially for building under construction. In [1, 3, 4, 6, 8], authors used VWS to monitor the structural health based on wireless sensor network system for a building under construction. In [2], VWS was selected to measure beam halo at Linac-3GeV Beam Transport line in Japan in order to determine more detail of halo formation. The results showed that the VWS was insusceptible secondary electrons which are one of major noise source for beam monitoring. In [5], the researchers used vibrating wire strain gauges to monitor corrosion-induced cover concrete stress development, crack initiation and propagation process along with the procedure of reinforcement corrosion. An interesting vibrating wire field-measuring technique has been developed for determination of magnetic center of units in accelerators [13].

Moreover, the physical size of the data logger for VWSs is relatively smaller than that of fiber optic sensors since the measurement principle of VWSs is very simple. The sensor proves scalable and much less obtrusive when fully embedded, since it can be made flat and very flexible. They are appropriate for long-term monitoring because vibrating wires exhibit minimal deterioration over time [10-12]. It is very important that in each of mentioned areas, due to its extreme sensitivity, VWS can perform measurements that are impossible using any other existing technologies.

In order to promote safety and convenience for application of VWS, this paper presents a high precision vibration signal acquisition with storage function based on STM32 microcontroller. The instrument designed in this paper not only can directly collect vibrating signals, but also store data into SD card and communicate with computer so as to realize the real-time monitoring from point to point. The rest of this paper is organized as follows. In Section 2, vibrating wire sensors mathematical model is introduced and the principle of measurement is also given. Section 3 presents the detail hardware and software design of collection system. Results using real measurement data are provided in Section 4. Section 5 concludes the paper.

2. Methodology

2.1. VWS Mathematical Model

Fig. 1 presents the basic components of a vibrating wire sensor, which consist of a vibrating wire whose frequency changes according to tension and compression, and the plucking and pickup coil, which excites the wire and measures its resonance frequencies.

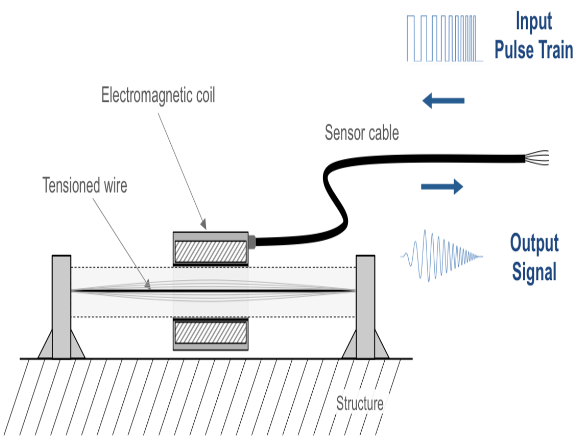

Fig. 1. Structure of vibrating wire sensors.

A tensioned steel wire, hermetically sealed, is coupled with an electromagnetic coil. The wire will settle to its resonant vibrating frequency, and these vibrations in turn induce current back onto the signal wires. This signal can then be measured and used to determine the tension in the wire, and therefore also the strain in the structure to which the vibrating wire gage is attached. For a given pretension of the wire at the initial set-up, the relationship between the natural frequency of a vibrating wire and the strain of the wire is expressed as in Equation (1) [8].

$$f_0 = \frac{1}{2L}\sqrt{\frac{\sigma}{\rho}} = \frac{1}{2L}\sqrt{\frac{E\varepsilon_0 g}{\rho}}, \quad (1)$$

where g is the gravitational acceleration, m/s^2, f_0 is the natural frequency, Hz, L is the length, m, σ is stress, Pa, ρ is the mass density, kg/m^3, E is the modulus of elasticity, and ε_0 is the strain of a wire at the initial set-up in the VWS.

Since the tension of the vibrating wire is directly proportional to the strain in the wire, and to the strain in the attached structure, the measured strain can be calculated as in terms of the change in the natural frequency of the wire:

$$\varepsilon = \varepsilon_i - \varepsilon_0 = k\left(f_i^2 - f_0^2\right), \quad (2)$$

where ε_i is the strain of a wire at the i^{th} reading, f_i is the measured frequency, while, f_0 is the initial frequency, k is the gage factor, which is determined from the physical properties and length of the wire [9, 11].

2.2. Principle of Measurement

In this paper, we designed an instrument for collecting VWS signal, the architecture of design is shown as in Fig. 2. The system is consists of STM32 microcontroller module, which is used to control all the other modules. The microcontroller used in this study is STM32F103RET6, which is a 32-bit microprocessor based on ARM Cortex-M3 core. The STM32 contains 512 kB Flash, 64 kB SRAM, 8 timers, and multi-interfaces, such as CAN interface, SPI interface, and USART serial communication interface [14].

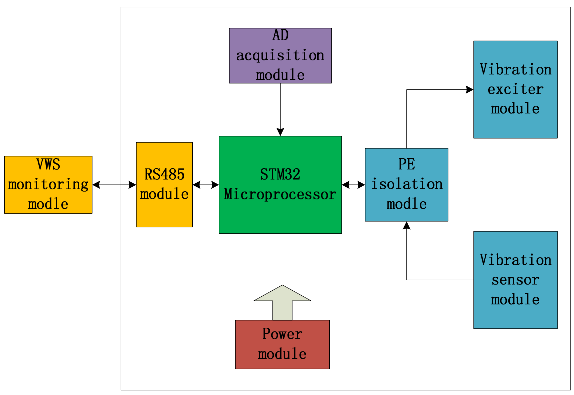

Fig. 2. Architecture of design instrument.

There is an AD acquisition module in this system, AD7705, which is a 16-bit resolution analog to digital chip. RS485 communication module is also included so as to communicate with VWS monitoring module. Finally, there are still vibration sensor module, vibration exciter module and power module, with the function for supply power for the whole system.

3. System Design and Implementation

3.1. Power Module

The voltages supplied by power module are 8.8 V, 5 V and 3.3 V, 5 V and 3.3 V are used for microcontroller, SD card circuit and AD module, which could be produced by constant voltage chip, 1117-5 and 1117-3.3. However, the 8.8 V voltage can't be generated by constant voltage chip directly, and we design it through LM2596-ADJ, with the output voltage adjustable. The schematic diagram of 8.8 V power circuit is shown as in Fig. 3, and the output V_0 is calculated as in Equation (3), by selecting suitable values of R_{48} and R_{49}. In this system design, the values of R_{48} and R_{49} are 6.2 kΩ and 1 kΩ, respectively, and the theoretical output voltage of circuit is 8.856 V, and we could get the 8.8 V voltage for VWS.

$$V_0 = 1.23\left(1 + \frac{R_{48}}{R_{49}}\right) \tag{3}$$

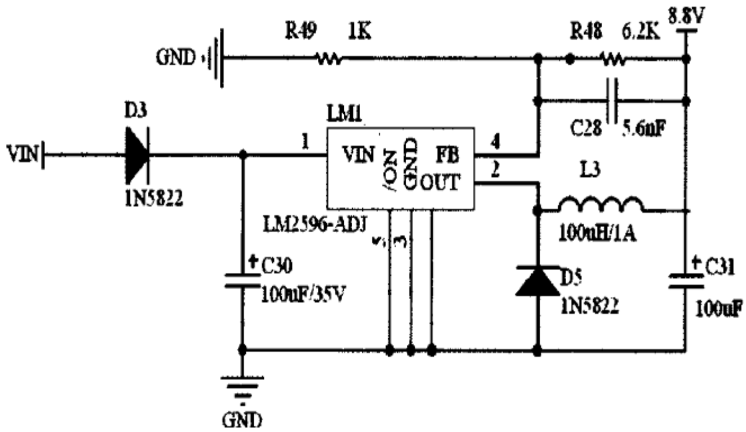

Fig. 3. Schematic diagram of power circuit.

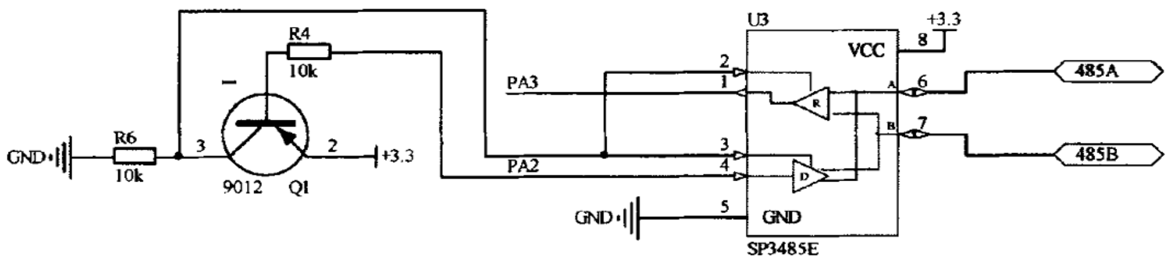

Fig. 4. Schematic diagram of RS485 circuit.

3.2. RS485 Module

As we all know, RS485 is half-duplex communication, in order to enhance the stable communication for RS485 module and simplify the hardware and software design, we present a novel circuit, which could send and receive by itself. Default, PA2 is high, and Q1 is in cut-off state, then RS485 could receive data. On the other hand, if we want to send data, when send '0', PA2 is low, and Q1 is on, then RS485 output '0', when send '1', RS485 return receive state and the A, B bus appear high level to the other slavers. The schematic diagram of RS485 circuit is shown in Fig.4.

3.3. SD Store Module

SD card is a non-volatile memory card format for use in portable devices, which is usually used for storage in the embedded system. There are two modes to communicate to the SD card, namely, SPI mode and SD mode. SD mode is selected because its transfer rate is larger than SPI mode in this paper [15]. There are two kinds of application in SD mode, one is the 1-bit transfer mode, which is consist of only one bit data cable, and the other is 4-bits transfer mode, which is consists of four data cables. It is definitely the transfer speed of 4-bits is faster than 1-bit. Therefore, we adopted the 4-bits mode, and the schematic diagram of is described as in Fig. 5.

The transfer speed between STM32 and SD card is 4 Mb/s in this study, which can satisfy the requirements of the system.

3.4. AD Acquirement Module

In order to satisfy the temperature measuring range of system and accuracy requirements, we used AD7705 digital analog converter, which has two 16-bit no-missing code Σ-Δ channels. AD7705 adopts differential inputs, with a complete analog built-in programmable gain amplifier and programmable digital filter. The channels can be calibrated by AD7705 itself or by the microprocessor system [16, 17]. The schematic diagram circuit of AD7705 is shown as in Fig. 6, we only used one channel in this system. The reference voltage of AD7705 is from TL431 on the right side of Fig. 6. R_{45}, R_{48} and R_{49} consist of voltage division circuit.

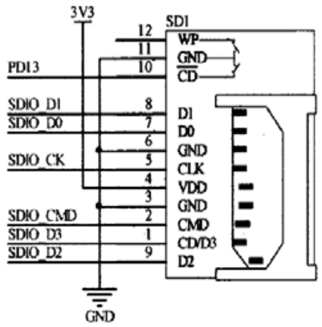

Fig. 5. Schematic diagram of SD card circuit.

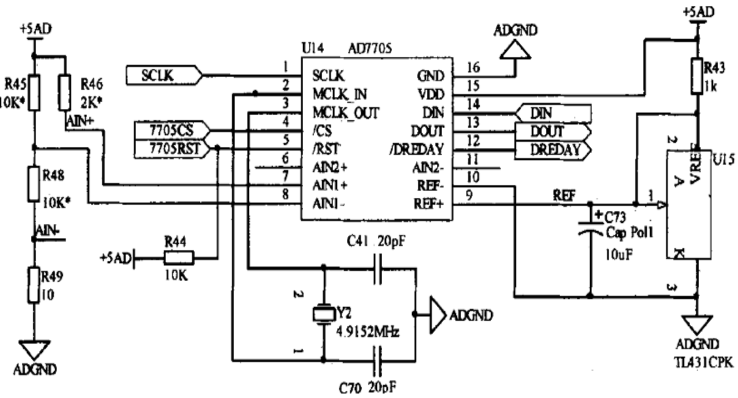

Fig. 6. Schematic diagram of AD7705 circuit.

3.5. System Software Design

Configuration for STM32F103VET6 is the first step of software design, in this step we must open the relevant system clock for other modules, such as external clock is 8 MHz, and PLL working clock is setting 72 MHz. Besides that, the clocks of RTC, USART, SDIO are should be configuration too. After system configuration for STM32, it begins to collect tasks.

Fig. 7 shows the flow chart of system collecting process, which has three working modes: namely numbered sampling, timing sampling and continuous sampling. In the numbered sampling mode, the sampling times is set from 1~99. In the timing sampling mode, the measure frequency could be configured by user. While, in the continuous timing sampling mode, the sample process will not stop unless the stop key is down. The working sequence of system is as following:

1) First is initialization, setting time calibration according the time information from RTC module, which is useful for recording the timeslot of storing data into SD card.

2) Open the specified acquisition channel and prepared to collect data.

3) Set sampling mode, numbered sampling, timing sampling or continuous sampling

4) Execute data acquisition process according sampling mode set by user.

5) Store data into SD card in order, and record the timeslot too.

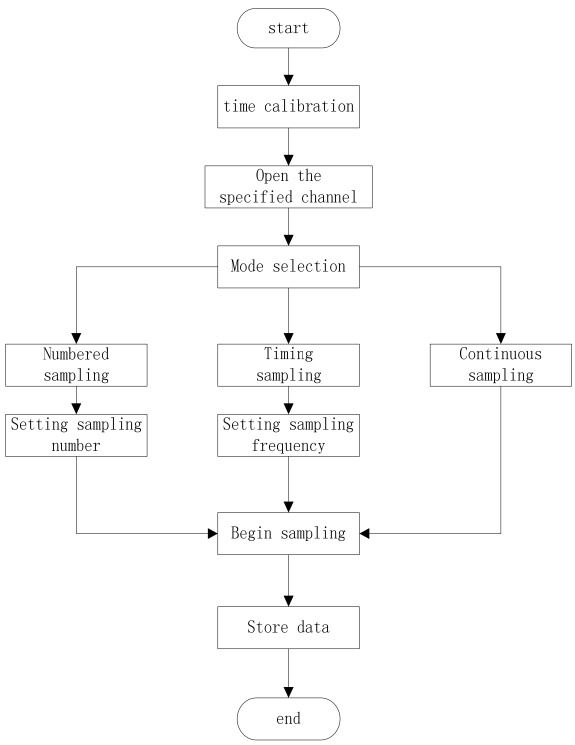

Fig. 7. Flow chart of system collecting.

4. Experiment and Analysis

We select a vibrating wire osmometer to test the accuracy of the instrument we proposed in this paper, with the product model is 4500SR. The pressing measurement formula of osmometer is shown in Equation (4), while the water depth is calculated by Equation (5).

$$P = G(R_1 - R_0) + K(T_1 - T_0), \quad (4)$$

$$h = P * 101.972, \quad (5)$$

where G is the coefficient of line, with the value is G=-0.172, and K is the correction factor, with the value is K=-0.003, R_1 and R_0 are the measured modulus and initial modulus, respectively, T_1 and T_0 are measured and initial temperature, respectively. The modulus of osmometer could be calculated according to the frequency, as Equation (6).

$$R = \frac{f^2}{1000} \quad (6)$$

Standard deviation is used to check the accuracy of collector, the smaller standard deviation, shows that the measured results closer to the true value, and the higher accuracy of measurement.

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + \cdots + d_n^2}{n-1}}, \quad (7)$$

where *d* is the difference between measured value x_i and average value of all the sampling points, x_a, *n* is the number of samples.

First, we do an experiment to test the frequency response of system under laboratory conditions, with the environmental temperature is 25.5°C, and the depth of osmometer insert water is 30 cm. The experiment is conducted 20 times, and the results are shown as in Table 1. The standard deviation calculated is σ =0.02, which could meet the requirements of engineering.

Next, we do experiment in real environment. The insert depth of sensor in the water is up to 5 m, with step is 0.5 m, and the measurements are shown as in Fig. 8~Fig. 11.

Fig. 8 shows the measured depth compared with real depth of water, which is calculated by Equation (5), it can be seen that the measurement responses the changing of water, with the measurement error is very small. Fig. 9 presents the frequency varies along with water depth, the measurement frequency is decreasing as the increase of water.

Fig. 10 describes the temperature changes along with water depth, it can be seen that temperature varies little with the increasing of water depth. Fig. 11 reflects the accuracy of this experiment, it can be seen that the relative error of most of the sampling points are less 3 %, which indicates the high precision of the system.

Table 1. Frequency measurement table.

n	Frequency /Hz	*d*
1	2909.62	-0.027
2	2909.65	0.003
3	2909.64	-0.007
4	2909.67	0.023
5	2909.65	0.003
6	2909.65	0.003
7	2909.68	0.033
8	2909.66	0.013
9	2909.64	-0.007
10	2909.64	-0.007
11	2909.63	-0.017
12	2909.65	0.003
13	2909.62	-0.027
14	2909.68	0.033
15	2909.62	-0.027
16	2909.63	-0.017
17	2909.65	0.003
18	2909.68	0.033
19	2909.65	0.003
20	2909.62	-0.027
21	2909.69	0.043
22	2909.58	-0.067
23	2909.72	0.073
24	2909.66	0.013
25	2909.63	-0.017

5. Conclusions

This paper presents a data acquisition system for measuring vibrating wire sensors, which could collect vibrating signals from point to point and store the data into SD card, which will not loss information if power down. The power module, RS485 communication circuit, SD storage module and AD acquisition module are detailed introduced in this research. Finally, we used the vibrating wire ohmmeter to test the accuracy of the instrument. The real environment measurement experiment shows that, the standard deviation is σ =0.02 and the high precision, 3 %, which could satisfy most of engineering requirements. In the future, we will add GPRS communication module to this system so as to realize the remote acquisition.

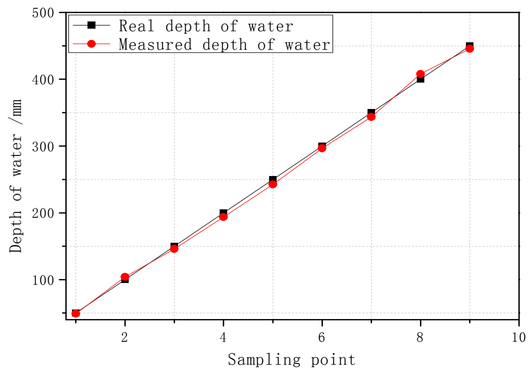

Fig. 8. Sensor depth in water measurement.

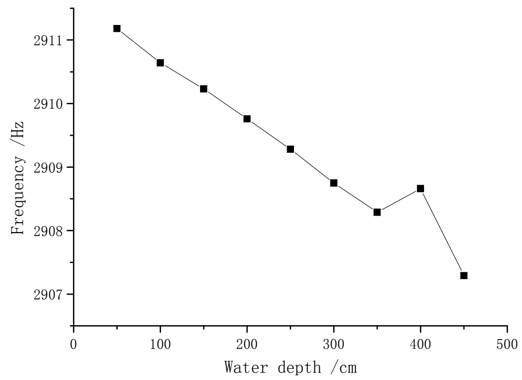

Fig. 9. Frequency changing with the depth of water.

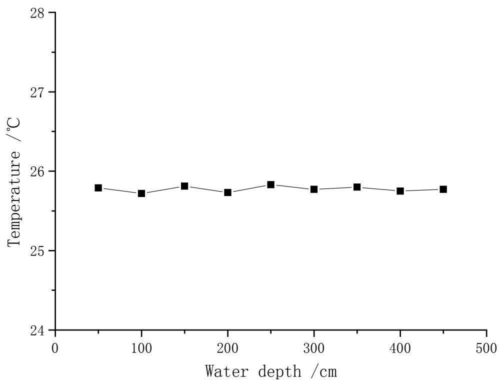

Fig. 10. Tempereature changing with the depth of water.

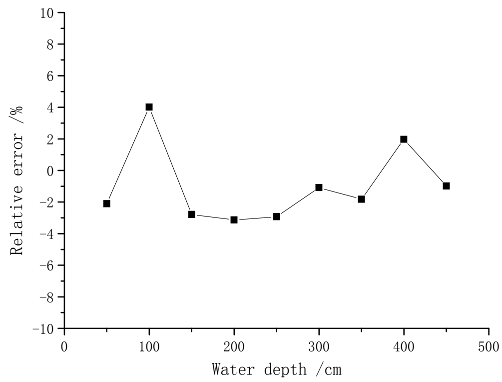

Fig. 11. Relative error of measurement.

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