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A novel optimal sensitivity design scheme for yarn tension sensor using surface acoustic wave device

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ABSTRACT

In this paper, we propose a novel optimal sensitivity design scheme for the yarn tension sensor using surface acoustic wave (SAW) device. In order to obtain the best sensitivity, the regression model between the size of the SAW yarn tension sensor substrate and the sensitivity of the SAW yarn tension sensor was established using the least square method. The model was validated too. Through analyzing the correspondence between the regression function monotonicity and its partial derivative sign, the effect of the SAW yarn tension sensor substrate size on the sensitivity of the SAW yarn tension sensor was investigated. Based on the regression model, a linear programming model was established to gain the optimal sensitivity of the SAW yarn tension sensor. The linear programming result shows that the maximum sensitivity will be achieved when the SAW yarn tension sensor substrate length is equal to 15 mm and its width is equal to 3 mm within a fixed interval of the substrate size. An experiment of SAW yarn tension sensor about 15 mm long and 3 mm wide was presented. Experimental results show that the maximum sensitivity 1982.39 Hz/g was accomplished, which confirms that the optimal sensitivity design scheme is useful and effective.

1. Introduction

Regarding the rapid development of acoustic wave technology in the last decade, surface acoustic wave devices have been widely used in sensor applications for detection of both physical [1–4] and chemical [5–10] quantities due to their great sensitivity to wide variety of parameters such as temperature [11], pressure [12,13], humidity [14,15], mass loading [16], torque [17], and conductivity [18], and benefit from the excellent properties of the surface acoustic wave devices, small size, high reliability and reproducibility, excellent stability, high sensitivity, low cost, and fast response time. When these physical effects are subjected to the substrate, it will induce variations in the electrical and mechanical properties of the substrate, and these variations modify the propagation velocity and shift the oscillation frequency consequently [19,20]. Meanwhile, the oscillation frequency of the surface acoustic wave device is a sensitive function of those physical quantities applied on the diaphragm.

Normally, in each process of yarn and fabrics production, yarn tension is one of the most important factors, which directly determines the production and quality of yarn and fabrics products [21]. The force applied to the yarn during feeding process must be maintained accurately [22]. If the force is exceeding, the yarn will be damaged and end-down, and if not enough, the yarn will become loose and curled. These problems will cause a drop in productivity. Moreover, yarn tension is subject to be affected by many elements (e.g., yarn feeding speed, yarn feeding angle, and yarn hairiness and thickness, and so on) of the machine and process parameters [23,24], so the monitoring of yarn tension becomes a complicated task due to the irregularly fluctuation of yarn tension caused by those elements. It means that the yarn tension sensor should have high sensitivity, high stability and fast response time, so that the magnitude and variation of yarn tension could be measured very well.

The yarn tension sensor using SAW oscillator has been developed [25]. Due to output frequency signal, the new sensor has stronger anti-interference capability compared with output analog signal of the traditional yarn tension sensors.

It is well known that the higher the sensitivity of the yarn tension sensor is, the better the quality of yarn and fabrics products is and the higher the production of yarn and fabrics products is. So in this paper, the effect of the SAW yarn tension sensor substrate size on the sensitivity of the SAW yarn tension sensor was investigated

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and their regression model was established for the first time, which can be used to present a novel optimum design scheme that can help to obtain the optimal sensitivity of the SAW yarn tension sensor.

2. Sensor principle and design

2.1. Principles of SAW yarn tension sensor

In Fig. 1, when the yarn tension F is subjected to the piezoelectric substrate, it induces variations in the electrical and mechanical properties of the piezoelectric substrate, and these variations modify the SAW propagation velocity and shift the output frequency of SAW oscillator 1 consequently. In addition, the output frequency shift of SAW oscillator 1 is a sensitive function of the yarn tension F applied on the diaphragm. So the yarn tension can be achieved by measuring the output frequency shift of SAW oscillator 1, and the output frequency of SAW oscillator 1 can be defined as

$$f = f_0 + \Delta f \tag{1}$$

where f_0 is the output frequency of SAW oscillator 1 when the yarn tension F is equal to 0, Δf is the output frequency shift of SAW oscillator 1 when the yarn tension F is not equal to 0.

2.2. Designs of SAW yarn tension sensor

The sensor is designed as an oscillator fabricated on a 42° Y–X quartz substrate by the conventional contact ultraviolet photolithography, using 3000 Å aluminum metallization. The thickness of the quartz substrate is 0.5 mm. The pair number of input interdigital transducer is 187.5, the pair number of output interdigital transducer is 160, the width of the interdigital transducer is 4.66 μm, the aperture is 1.8 mm, the metallization ratio is 0.5, and the distance between input interdigital transducer and output interdigital transducer is 0.3 mm. The propagation velocity of the SAW in 42° Y–X quartz substrate is 3157 m/s and therefore the operating frequency of the oscillator is 169.4 MHz. The characteristics of the SAW oscillator were measured by a network analyzer (E5061A, Agilent, USA) at room temperature (25 °C).

Fig. 2(a) shows the fabricated physical form of the input and output transducers for the SAW oscillator. Fig. 2(b) is the structure diagram of the SAW oscillator. In Fig. 2*A* is the metal pedestal, *B* is the quartz spacer, *C* is the SAW oscillator substrate, *S* is the sound absorption material, and *Y* is the yarn guide ring. In Fig. 2A and B were adhered by epoxy resin, so do *B* and *C*, *Y* and *C*. The parameter l is the length of the SAW oscillator substrate *C*, the parameter w is the width of the SAW oscillator substrate *C*, the parameter l_s is the length of the quartz spacer B, and the parameter w_s is the width of the quartz spacer *B*. The subscripts are used to distinguish the design parameters of the different size SAW yarn tension sensors.

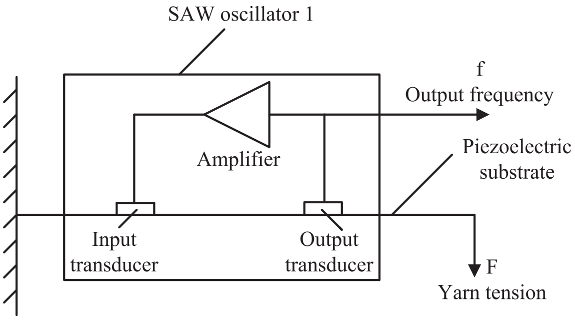

Fig. 1. Principles of the SAW yarn tension sensor.

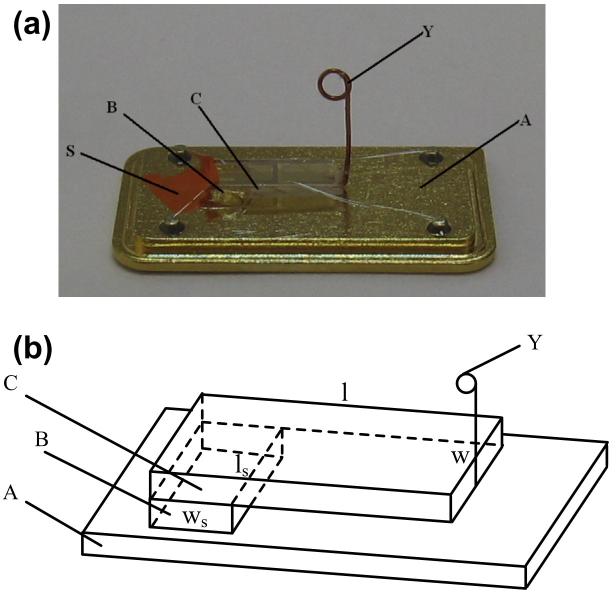

Fig. 2. The SAW oscillator. (a) Fabricated physical form of input and output transducers for the SAW oscillator. (b) Structure diagram of the SAW oscillator.

For the SAW sensor, the electrode-overlap envelope of its input IDT [26–34] is weighted, which can suppress the side lobes, while the output IDT is the uniform transducer. The dummy electrodes are used to eliminate the phase front distortion. In order to determine the location of the input and output IDT on the SAW sensor substrate, the distance from the left margin of the SAW sensor substrate to the left-most of its input and output IDT was defined as d_l, and the distance from the top of the SAW sensor substrate to the top edge of its input and output IDT was defined as d_t.

Seven different size SAW yarn tension sensors was fabricated, six of which are used to set up the regression model between the size of the SAW yarn tension sensor substrate and the sensitivity of the SAW yarn tension sensor and one is used to validate it.

In addition, the SAW yarn tension sensor should not be too larger restricted by the condition of the practical application environment; and the minimum diaphragm size of the sensor is also confined by the size of the input and output IDT. Based on the two points mentioned above, the proper substrate size designs of the SAW yarn tension sensors are shown in Table 1. The size designs of the quartz spacers and the location designs of the input and output IDT on the substrate are also listed in Table 1.

Fig. 3 is the frequency response curve for SAW_1 in Table 1, which is obtained by network analyzer. In Fig. 3, it is shown that the side lobes of the frequency response curve of the sensor SAW_1 are small.

3. Effect of SAW yarn tension sensor substrate size on SAW yarn tension sensor sensitivity

3.1. Establishment of functional relationship between output frequency shift of SAW yarn tension sensor and yarn tension

In order to research the effect of the SAW yarn tension sensor substrate size on the sensitivity of the SAW yarn tension sensor, a regression model between the two should be established. To build the regression model, we should get the sensitivities of the six different size SAW yarn tension sensors firstly. As a result, the functional relationships between the output frequency shift of the SAW yarn tension sensor and the yarn tension was established.