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A Novel Rotation Speed Measurement Method Based on Surface Acoustic Wave[1]

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Abstract—This paper presents an original passive wireless rotation speed measurement method based on surface acoustic wave (SAW) technology. A theoretical analysis was conducted on the principle of SAW rotation speed measurement and a numerical analysis on the SAW response energy pulses with different rotation angles and resonance frequencies was performed. Numerical calculation results showed that when the distance and the effective length of the antenna connected to SAWR vary with the rotation angle, the energy of acquired SAW response varies periodically. The rotation speed was estimated by searching the crossing points of the SAW response energy pulses and its mean value line. The SAW rotation speed measurement system was set up and the high performance SAW resonators were fabricated on a quartz substrate. The proposed measurement system was tested with a maximum error of 0.6 rpm, indicating that the system is capable of measuring rotation speeds from 10 to 100 rpm. Experimental results verified the validity and feasibility of presented rotation speed measurement method.

Keywords: SAW, rotation speed, SAW response

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1. INTRODUCTION

In order to monitor the operating status of a rotational shaft, not only the applied torque but also the rotation speed should be accurately measured [1, 2]. The passive wireless surface acoustic wave (SAW) sensor provides unique advantages only in the measurement of transmission shaft torque [3, 4]. It is necessary to adopt an extra rotation speed measurement system besides the implemented SAW torque measurement system. At present, different types of rotation speed measurement methods have been reported, such as magnetic encoder [5], image sensor [6], photo-electricity coder, eddy current transducer, Hall sensor, all of which have a number of potential advantages of high accuracy, wide measurement range. However, those traditional speed measurement systems are complex and require a uniform coding structure which involves high precision technology. Moreover, it is hard to integrate them into the designed SAW torque measurement scheme. There is an orientation to develop an integrated portable (non-contact) torque and rotation speed measurement system. So far the SAW technology which can measure both the applied torque and the shaft rotation speed simultaneously has not been found yet. Due to the fast response ability of SAW device, it is very suitable for identifying the moving and rotating objects and also can be utilized to measure the rotation speed.

A passive wireless SAW sensor system is only powered by an external radio frequency (RF) module and has a large readout distance [7]. During interrogation, the SAW interrogator transmits a RF signal to excite the SAW resonator (SAWR), and then an excited SAW response is re-transmitted to the SAW interrogator via an antenna [8]. Both the exciting signal and SAW response are RF signals. Thus, the energy of acquired signal has to do with the interrogation distance. And also, the surface of the shaft in the wireless channel between the interrogator and the SAWR has an impact on the received RF energy. According to the fact that the radio signal strength drop-off roughly obeys an inverse square drop-off as distance from the base station increases, a group in Michigan state university implemented an indoor 3D location sensing prototype system by using the Radio Frequency Identification (RFID) technology for locating objects inside buildings in 2003 [9]. In the same way, when the mounted SAWR rotates with the shaft, not only the resonant frequency of SAWR will vary due to the applied torque, but also the energy of SAW response will vary periodically due to the variations of the interrogation distance and the reflective area. Thus, we can make

[1]The article is published in the original.

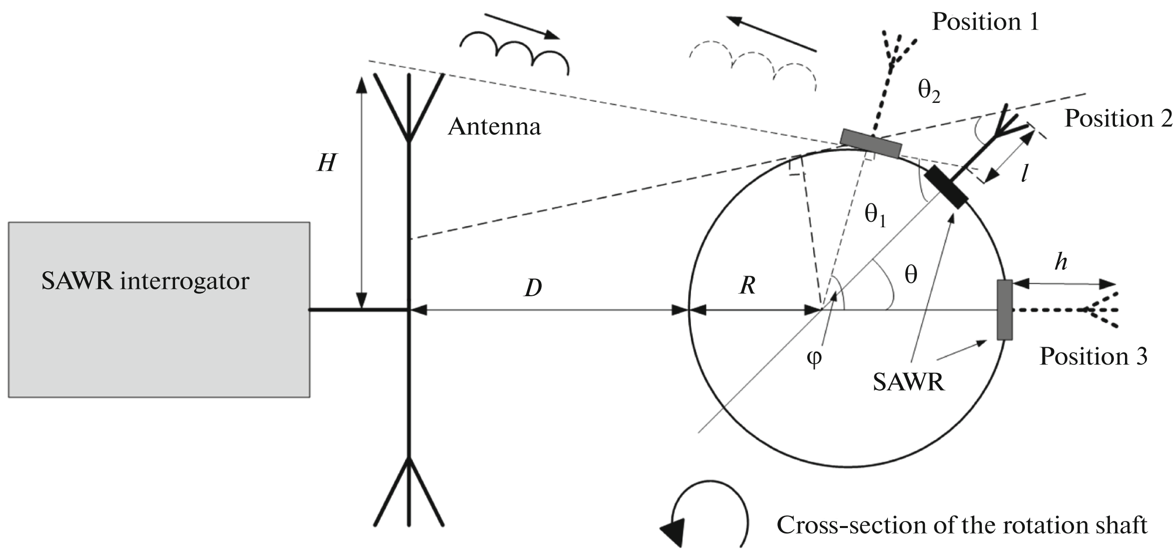

Fig. 1. The illustration of SAW rotation speed measurement system.

use of the variation of the acquired signal energy to develop a rotation speed measurement system. The present study tentatively demonstrates the utilization of SAW devices for rotation speed measurement. The theoretical analysis and the experimental verification were presented.

2. THEORETICAL ANALYSIS ON THE PRINCIPLE OF SAW ROTATION SPEED MEASUREMENT

In order to study the rotation speed measurement method based on the SAW technology [10], the relationship between stimulus signal and excited SAW response should be analyzed from the start. A passive wireless SAW rotation speed sensor consists of a SAW interrogator, SAWR, rotational shaft, and antennas, which are connected to the interrogator and the resonator respectively, as shown in Fig. 1. The SAWR is bonded on the shaft using standard adhesives. The energy of SAW response is mainly determined by the distance between SAWR and the interrogator, the bandwidth of the excitation signal, the quality factor of SAWR, and environmental obstacles in the wireless channel. Suppose the power of the RF signal emitted from the antenna connected to the interrogator is $P_{\mathrm{A,Tx}}$, the transmission loss between the interrogator and the resonator is α_1, which is mainly composed of two parts. The first part is the loss caused by the propagation of the signal in the wireless channel, which can be approximated by the following formula [11]:

$$\alpha_{11} = \left(\frac{\lambda}{4\pi d}\right)^2, \tag{1}$$

where λ is the wavelength of the RF signal, d is the distance from the antenna connected to the interrogator to the antenna connected to the SAW resonator, approximately expressed as

$$d = \sqrt{(D + R + (R + h/2)\cos\theta)^2 + ((R + h/2)\sin\theta)^2}, \quad -\pi \le \theta \le \pi, \tag{2}$$

where D is the distance between the antenna of interrogator and the shaft, R is the radius of the shaft, θ represents the position of SAWR on the shaft, h represents the length of the antenna connected to SAWR, shown in Fig. 1.

The other part is the loss caused by the RF signal reflected from the surface of the shaft in the wireless channel. When the mounted SAWR rotates with of the shaft, due to the reflection of the shaft, the effective length l of the SAWR antenna that can receive RF signals from the interrogator shown in Fig. 1 will vary periodically. For simplicity, suppose the antenna is an isotropic antenna that radiates equal signal power in all directions and the radiated power is proportional to the length of the antenna. The ratio γ of the antenna length h to the effective length l can be expressed as:

$$\gamma = \frac{l}{h} = \begin{cases} (R + h - R/\cos((\varphi - |\theta|))/h, & |\theta| \le \varphi, \\ 1, -\pi < \theta < -\varphi \quad \text{or} \quad \varphi < \theta \le \pi, \end{cases} \tag{3}$$

where φ can be represented as:

$$\varphi = \pi - \arctan(H/(D + R)) - \arccos\left(R\Big/\sqrt{H^2 + (D + R)^2}\right). \tag{4}$$

To make sure that the antenna at position 3 shown in Fig. 1 can receive the radio transmitted from the