Measurement 63 (2015) 282–286

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Development of a capacitive angular velocity sensor for the alarm and trip applications

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ARTICLE INFO

Article history:
Received 15 July 2014
Received in revised form 1 December 2014
Accepted 11 December 2014
Available online 23 December 2014

Keywords:
Capacitive
Angular velocity sensor
Trip applications
Pull-in instability

ABSTRACT

This paper reports a capacitive angular velocity trip sensor designed for protection of sensitive and accurate spinning equipment by utilizing alarm and trip. The recommended sensor can be able to measure rotating machinery angular speed and subsequently it sends alarm messages using LEDs and buzzers in the domain of an angular velocity that it can be programmable with micro-processer packages. Of course in the critical angular speed the sensor can trip the system. Moreover, the resolution of the trip sensor is determined and it is shown that with increasing of the width of the micro-beam high trip resolution is observed.

1. Introduction

With the progress of micro fabrication technology and explosive development of micro-machined sensors, the capacitive sensors [1] are becoming more and more popular. Electrostatic transductions are major roles in the actuation and sensing methods in MEMS devices because of its simplicity, favorable scaling property, and better performance than other excitations. First time Nathanson et al. [2] observed pull-in phenomenon – when the applied voltage to the electro-statically actuated micro-beam reaches a critical value pull-in instability is occurred experimentally and also they analyzed a mass-spring model of electrostatic actuation and provided the first theoretical description of pull-in instability. Zhang and Zhao [3] described the pull-in instability of an electro-statically actuated MEMS switch. Kacem et al. [4,5] investigated a comprehensive nonlinear multi-physics model and the pull-in instability of doubly clamped nano-beam and NEMS cantilevers for gas/mass sensors which applied to both mechanical and electrostatic nonlinearities. Rezazadeh and coworkers [6] developed a micro-capacitive wall shear stress sensor for the measurement of skin friction. They studied the static response, mechanical behavior and pull-in phenomenon in proposed sensor. Guo and Zhao [7] analyzed the influence of vdW and Casimir force on the stability of electrostatic torsional nano-electro-mechanical systems (NEMS) actuators. Lin and Zhao [8] studied the dynamic behavior of nano-scale electrostatic parallel-plate RF switches with the consideration of the van der Waals (vdW) effects. In another work they [9] studied the Casimir effect on the pull-in parameters of nanometer switches.

In the manufacture of many accurate industrial types of equipment, design and modeling interfere with based on principles human knowledge and usually some errors are inevitable in the designed machines. Thus, experience has shown that alarm and emergence shutdown systems are essential in safe operation of industrial tools. An alarm system is provided useful information and functionality to support the operator's tasks; and can be management of abnormal situations with activation of buzzers, light emitting diodes (LED), light dependent resistors (LDR), piezo sounders, liquid crystal display (LCD), etc. While limitation, the alarm trips are best known as a reliable method to

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http://dx.doi.org/10.1016/j.measurement.2014.12.026
0263-2241/

activate a warning when the processes of problems are occurred. In fact, today's highly flexible and versatile alarm trips can be found that working in a wide range of applications for example: smoke and fire sensors [10], trip temperature sensors [11], collision alarm system for automotive vehicle [12], etc.

Many attempts have been made to model of the capacitive sensors. To the best of the author's knowledge, no previous work has been done on the study of the trip angular velocity sensor. Therefore, in this paper, a novel method to protect sensitive spinning equipment using an alarm and a trip application is presented. The proposed sensor is designed based on micro-beam deflection measuring and emergency shutdown rotary machines by using the pull-in phenomena. By using electric smart interfacing circuits, the change in the capacitances is measured. With considering the 10^{-16} F [13] for the minimum measurement range of the circuit that can be detected, the resolution of the angular speed sensor for different values of micro-beam's width are presented.

2. Sensor model description and assumptions

As shown from Fig. 1 the proposed angular velocity sensor is consisted of a clamped–clamped micro-beam suspended between two stationary electrodes and subjected to an electrostatic and a centrifugal force. The micro sensor is mounted on a rotating machine and the beam has length of L width of b, thickness of h, and the radius of the rotating machine of r.

The proposed speed sensor is designed with a two electrode, allows an electronic compensation of mechanical imbalance in order to reduce the sensor offset and offset drift. For keep away from to be affected by the environment's physical situations, the entire sensor is covered with an insulated package. with the aim of avoid unbalancing in the very sensitive rotating machines, twin sensor packages can be mounted on the rotating shaft surface in symmetric positions, and the average of the measured angular velocities can be considered as the machines angular speeds.

The proposed sensor can be optimally designed by fabrication process as there are two substrates in the introduced microstructure two wafers is used; first wafer: 1 – oxidation, 2 – Al evaporation, 3 – lithography & Al pattern, 4 – spin thick photo-resist as sacrificial layer for 4.6 μm, 5 – lithography, 6 – ploy silicon deposition (LPCVD), 7 – lithography & poly silicon pattern, 8 – releasing the structure; second wafer: 1 – silicon dry etching 2 – wafer bonding.

In order to description and completion of the sensing process via capacitive sensor, was required to a simple electric circuit. Electric circuit was converted the mechanical displacement into electrical signal and measured the capacitance. Capacitive divider or fully differential circuits can be sensing capacitance changes [13]. The sense voltage in the output of the circuit that is indicated capacitance changes can be to calibrated whit the angular speed change which as a result of the angular speed sensors.

The block diagram of an isolated sensing and trip package that can measure the angular speed and operate in alarm and trip applications is shown in Fig. 2. A range of the alarm trip monitors can be written with a specific control programs on a microcontroller chip. If the process signal moves to an undesirable high or low condition, the alarm activates to warn of difficulties using buzzers and LEDs, so when control systems or operators are unable to adjust the system to the safe area and process signal exceeds critical situations, the rotary machine emergency shutdown with utilized the pull-in phenomena in the sensor.

The electrostatic forces in the proposed sensor, for a micro-beam is under an applied bias voltage through the both substrates electrostatic pressure, can be computed using a non-dimensional governing equation takes the following form [14]:

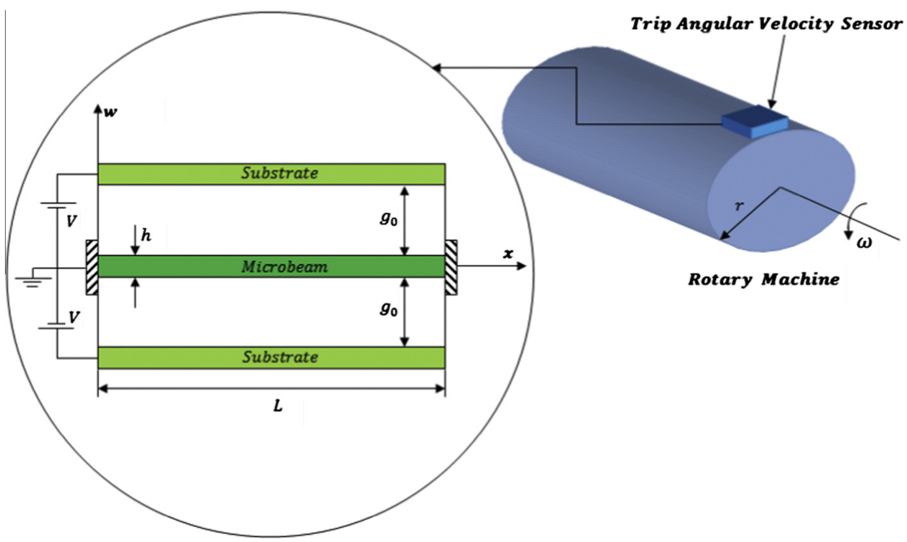

Fig. 1. Schematic view of a angular velocity trip sensor.