PAPER • **OPEN ACCESS**

Research of influence of technological admissions on characteristics of a solid-state wave gyroscope

To cite this article: E Ph Pevtsov *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **498** 012010

View the article online for updates and enhancements.



IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

This content was downloaded from IP address 223.68.190.130 on 20/09/2019 at 05:16

Research of influence of technological admissions on characteristics of a solid-state wave gyroscope

E Ph Pevtsov[*], T A Demenkova and K A Grishunin

Moscow Technological University MIREA (Moscow State Institute of Radio-engineering Electronics and Automation), Prospekt Vernadskogo 78, 119454 Moscow, Russian Federation

[*]Corresponding author's e-mail address: pevtsov@mirea.ru

Abstract. The route of design and technique of simulation of a wave solid-state gyroscope with the ring resonator are developed. Simulation of dependences of gyroscope characteristics on design data and their optimization for the job of the necessary mode of movement, in particular, of resonance frequency of excitation of the second mode are executed. The technique of compensation of the mass defects resulting from admissions on technological operations of production of a wave solid-state gyroscope (technological defects) and leading to the shift of initial provision of nodal points is presented.

1. Introduction

The wave solid-state gyroscopes (WSSG) executed in design as microelectromechanical systems (MEMS) [1] possess rather high characteristics on the accuracy and working range. In combination with the low cost, considerable stability to vibrations and shock influences it does them perspective sensors for measurement of angular speed of an object in many scopes.

The effect of origin of standing waves of elastic deformations in the ring plane is the cornerstone of operation of a wave solid-state gyroscope. In the movement mode on resonance frequency in a ring there are oscillations of the second mode so that the nodal points located in two mutually perpendicular directions remain fixed. In case of rotation of the resonator with angular speed Ω, the ring on tangents are affected by Coriolis forces, the deviation of nodal points from initial situation results. Information on these movements is registered by capacitor sensors and is transferred for further processing. Theoretical bases of wave solid-state gyroscopes are stated in works [2-5].

2. Formulation of the problem

The understanding of the influence of the defects connected with the imperfection of their production is important for practical applications. Classification of defects is given in work [3] and the mathematical apparatus for calculations of their influence on characteristics of a gyroscope is offered. This work considers the problem from positions of simulation of similar effects by tools of a modern CAD.

Research problems:

-development of a route of design and techniques of modeling of WSSG with the ring resonator;

-research of the free and forced oscillations under the influence of the given forces and determination of resonance frequencies and optimization of design data of WSSG for the job of

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

the necessary mode of movement, in particular, the resonance frequency of excitation of the second mode;

-development of techniques of compensation of the mass defects resulting from admissions on technological operations of production of WSSG (technological defects) and leading to the shift of initial provision of nodal points.

The design of WSSG is schematically presented in Figure 1. The resonator represents a thin ring which is connected to the massive basis by means of eight elastic elements.

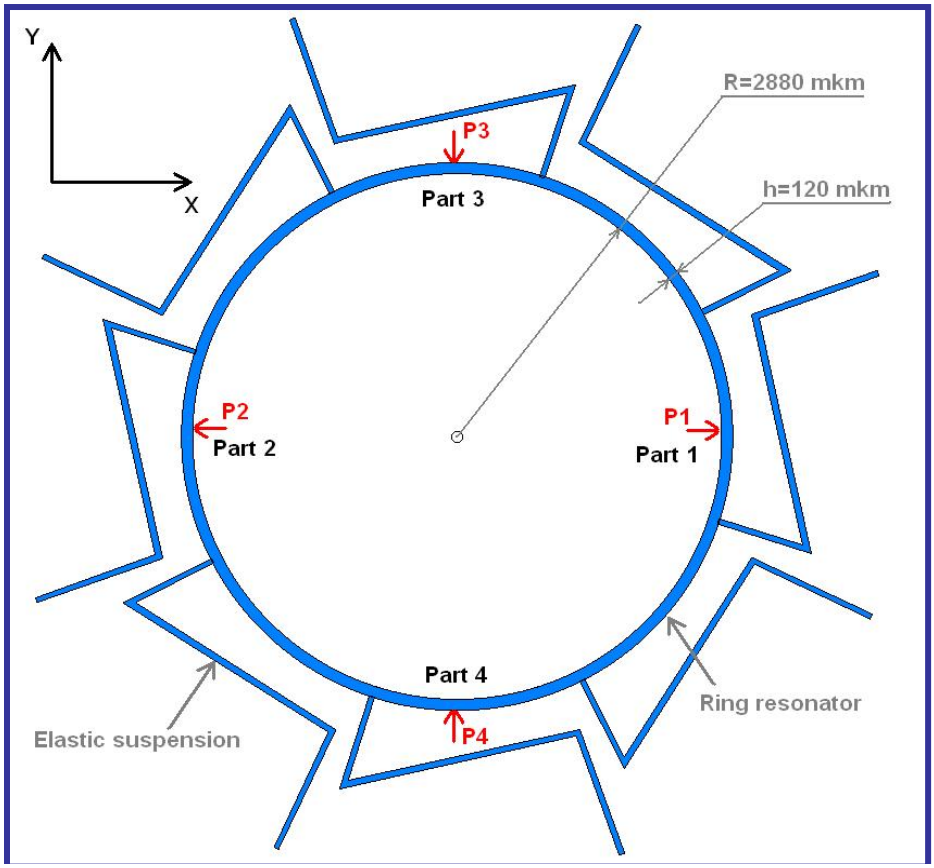


Figure 1. Design of wave solid-state gyroscope and parts of application of forces.

3. Route of design and setting simulation conditions

The work was performed on basis of tools of a package of the computer-aided design system (CAD) CoventorWare® [6], which is specially intended for design of MEMS. Reliability of the received results of simulation was controlled by their comparison to the analytical decisions received for special cases of boundary conditions and the simplified models.

The main design procedure of the design route with CAD CoventorWare is the development of the drawing of device design and a set of drawings of masks for its production on the basis of standard operations of MEMS technologies. For obtaining the relevant design decisions the plotter of the two-dimensional model (the editor of masks) Layout Editor®, the editor of properties of the constructional materials Materials Properties Data Base ® and the library of standard technological processes Process Editor ® are used.

Main operations of formation of the volume design:

- setting substrate from silicon;
- sedimentation of a layer from silicon of the set thickness on a substrate;

- etching of this layer for formation of external and internal perimeters of a ring, using masks with positive and negative photoresist;
- removal of a silicon substrate.

The result of design procedures of the description of a design is the synthesis of three-dimensional model of a gyroscope executed by tools of the Designer ® module (see Figure 2).

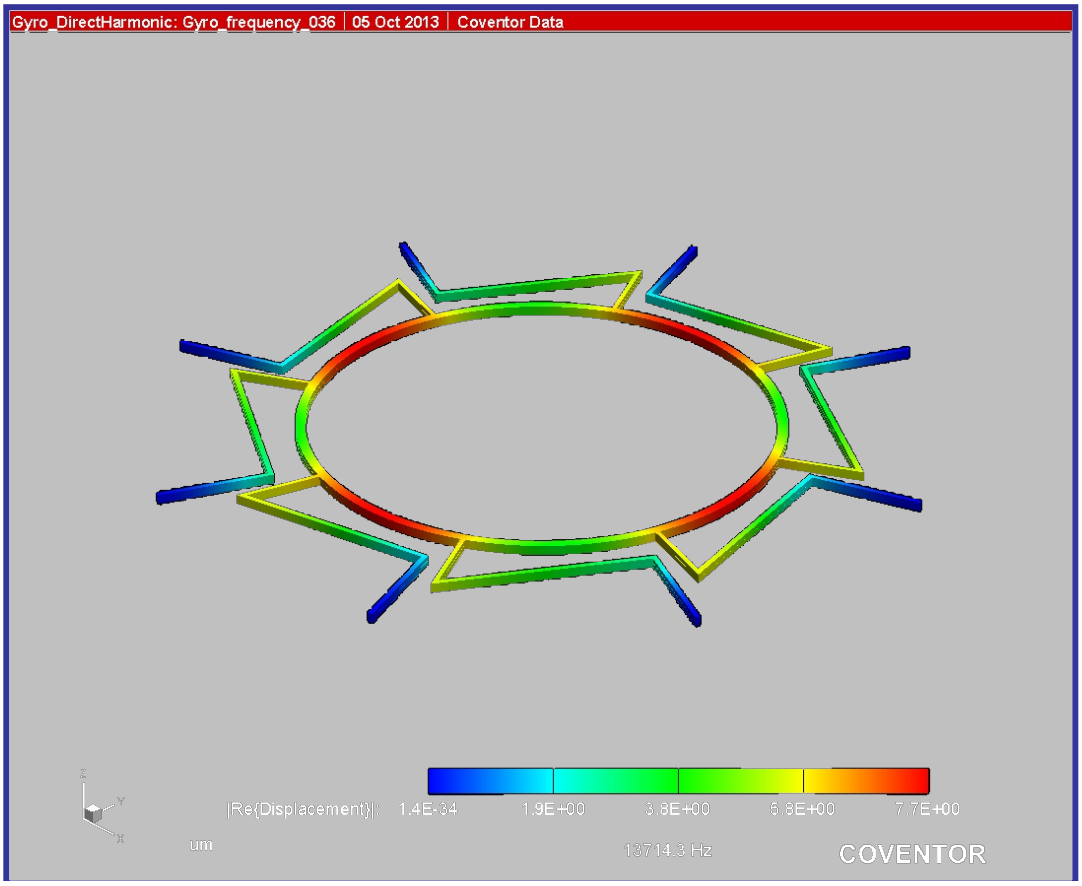


Figure 2. WSSG 3D model in the mode of oscillations excitation.

The important step preceding calculations is setting the grid for application of a method of final elements and a step of splitting. When performing this work it is experimentally shown that in the task for calculations the type of the grid "Extruded bricks" is optimum, and the step of splitting which was chosen by standard criterion of double reduction till the moment when results of calculations in the subsequent iteration differed from previous no more, than for 5%.

For simulation of the mode of movement of WSSG and excitation of oscillations of standing waves on a sensitive element of gyroscope influence of four harmonic forces P1 … P4 (see Figure 1) deforming a ring in mutually perpendicular directions was set. Value of amplitude of forces P1...P4 made $3{,}53 \cdot 10^{5}$ N, and the corresponding pressure upon sectors, exciting oscillations - $1{,}23 \cdot 10^{4}$ MPa.

4. The received results and their discussion

First, the excitement of the mode of the movement WSSG at a variation of parameters of design was simulated. The emergence of a standing wave in the ring resonator clearly demonstrates Figure 3 (counting of an angle is conducted from the positive direction of the axis OY counterclockwise, in the initial rest position the axis of symmetry of a gyroscope is turned concerning OY axis on $4{,}7^{\circ}$).

In the same figure provisions of the nodal points symmetrized on the middle of four sectors of a ring are designated.

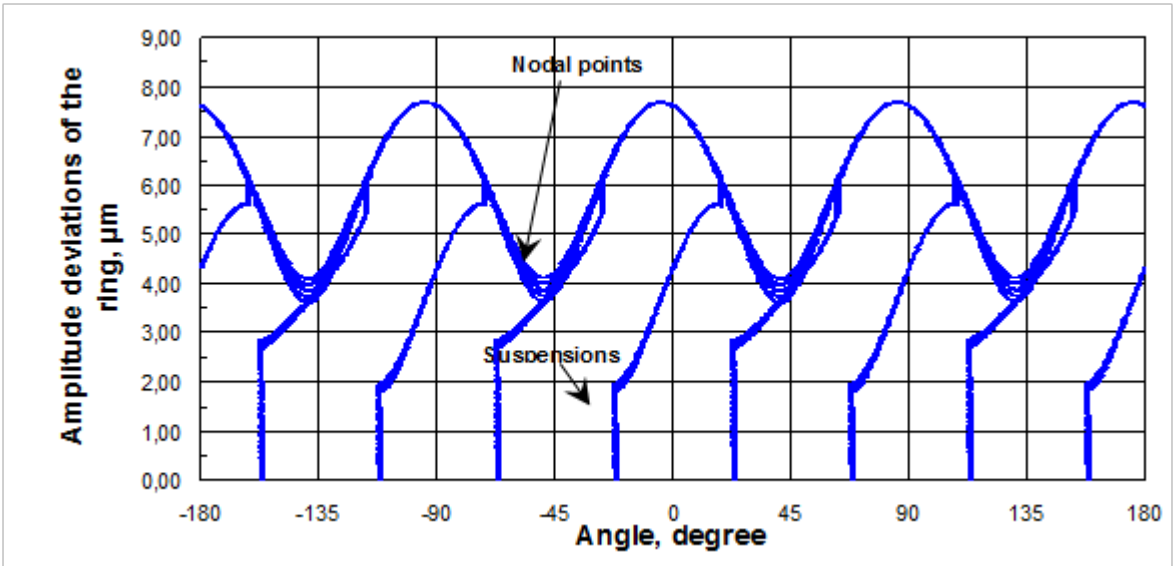


Figure 3. Deviations of points of the ring and suspensions of the WSSG resonator from initial situation in the movement mode on resonance frequency 13,6 kHz.

Examples of amplitude-frequency characteristics of gyroscope are given in Figure 4.

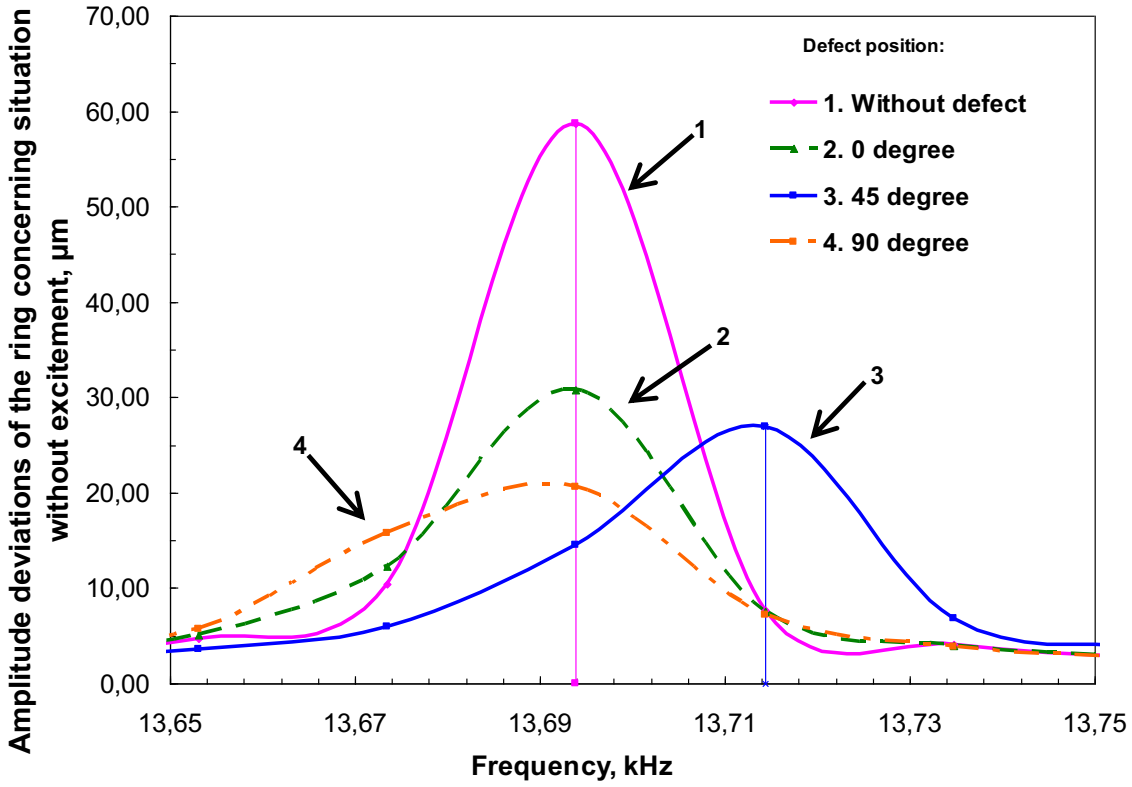


Figure 4. Amplitude-frequency characteristic of WSSG resonator ring and influence of technological defects: 1 – without defect, 2 – technological defect is located at the angle 0°, 3 – 45°, 4 – 90°.

During simulating the technique of determination of natural frequencies of the resonator depending on design data is developed. In particular value of resonance frequency for this construction free of defects of weight made 13694 Hz that with an accuracy of ten hertz matches results of the experimental studies received on a prototype of WSSG made in FTIAN [7].

For simulation of the influence of tolerances of topology masks and parameters of construction, and also the modes of technological processes of manufacture in case of simulation of construction in a ring of the resonator the defects of weight representing hollow dredging with sizes of 432x92x61 mkm^3 and mass 6,1 nkg, placed in different sectors of a ring were artificially created.

Figures 4 and 5 illustrate the influence of defect of mass. Dependence of resonance frequency of the second mode of oscillations on the mass of defect is practically linear in the range of masses from 0 to 30 ng. It is shown that existence of the defects of mass located at an angle 0 and 90 degrees to OY axis doesn't influence resonance frequency of oscillations, but offsets the provision of nodal points while the defects of mass located at the angle 45 degrees in addition lead to shift of resonance frequency that can be explained by changes in elastic properties of construction.

Existence of mass defects is the negative factor reducing characteristics of WSSG because of errors of initial position of an arrangement of nodal points in the mode of the movement. For simulating of compensation of the arising distortions it is offered to enter the additional compensating mass defects. It can be done, for example, by means of laser adjustment by selective evaporation of a part of ring segment of the resonator. The purpose of such technological operation is return of points of 1-4 (fig. 2) to situation, the maximally close to initial. Results of simulation of introduction of the compensating mass defects are illustrated in Figure 5.

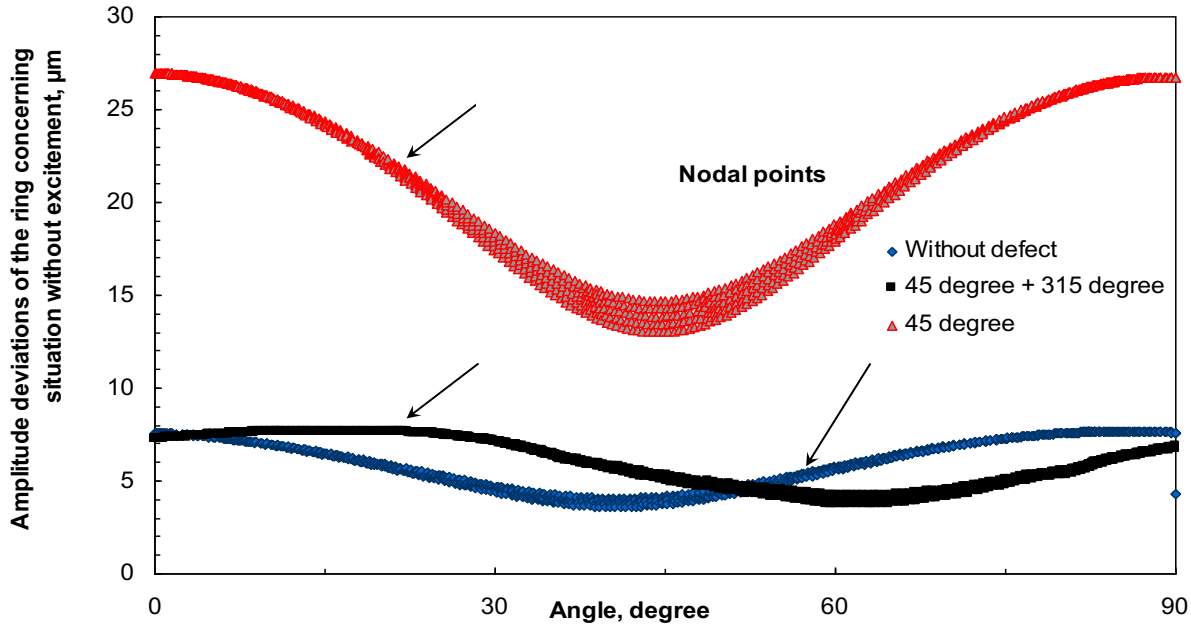


Figure 5. Influence of the compensating defects on amplitude deviations of a ring concerning situation without excitement. Arrangement of defects: 1 - without defect, 2 - 45°, 3 – the main: 45°, compensating: 315°.

From Figure 5 it is visible that distortions of a trajectory, arising in case of an arrangement of technological rectangular defect of mass in 6 ng with the center located at an angle 45° to a vertical axis can be compensated with an accuracy of 98% by introduction of the compensating defect of the same mass with the center located at the angle 315°. The developed technique of compensation can be applied to recovery of the zero provision of nodal points at other parameters of technological defects.

5. Conclusions

As a result of the simulation the decisions having essential value for increase in technical and utilization properties of a solid-state wave gyroscope with the ring resonator were received.

1. A route of design of WSSG by the CAD tools which finite project solution is the mask set for manufacture with use of standard operations of MEMS technology.

2. Technique of determination of resonance frequency of a wave gyroscope. It is shown that in case of the given parameters of construction (Rint.=2880 mkm, Rext.=3000 mkm, P=123 Pa) the value of resonance frequency received by results of simulation makes 13694 Hz that will be coordinated with the data of experimental studies of WSSG prototypes.

3. The technique of simulation of influence of mass defects on characteristics of sensitivity of WSSG and a method of optimum compensating of mass defects on the basis of deleting the compensating volumes of the fluctuating frame are offered. Results of simulation of position of the compensating defects and their masses showed that zero drift of a gyroscope can be compensated to 98,5%.

Acknowledgments

This work was supported by Ministry of Education and Science of Russian Federation, (project 8.5098.2017).

References

[1] Vasiliev A A, Sokolov A V, Pisliakov A V, Oblov K Yu, Samotaev N N, Kim V P, Tkachev S V, Gubin S P, Potapov G N, Kokhtina Yu V and Nisan A V 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **151,** 012024

[2] Gankevych Z, Kucher S and Bondar P 2010 *Gyroscope XXIV Symposium Vibrations in Physical Systems*. (Poznan – Bedlewo)

[3] Yilmaz E and Bindel D 2013 *Conference: Sensors, IEEE.*

[4] Dzhashitov V E and Pankratov V M 2010 *J. Mach. Manuf. Reliab.* **39** p 248

[5] Matveev V L, Lipatnikov V I and Alehin A V 1998 *Designing of the wave solid-state gyroscope* (M.: MSTU) p 168

[6] COVENTOR 2017. Available at: http://www.coventor.com

[7] Morozov O V, Postnikov A V, Amirov I I and Kal'nov V A 2012 *Nano- and the microsystem equipment* (Russia) **7** pp 15-19