www.ijecs.in
International Journal Of Engineering And Computer Science ISSN: 2319-7242
Volume 5 Issue 10 Oct. 2016, Page No. 18384-18388

Modelling and Design Analysis for Nonlinear 3D Dynamic Simulation of Triangular Microspring for MEMS based SAM

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Abstract: ***This paper reports the design and modelling of triangular shaped microspring which is proposed to be used for munition purpose. The simulation results are obtained for Safe and Arm mechanism for different 'g' for MEMS based Rocket SAM. Design for MEMS based technology for Rocket SAM chip is structured in such a way that it has both movable and non-movable parts which utilizes mechanical properties, structural properties and material properties that may be and may not be electronically controlled. The design proposed for Rocket SAM in this research is aimed to achieve reliability, safety and cost effectiveness for mass-production. Our motive is to design, simulate and derive its results using metal alloy MEMS based Rocket SAM using SOLIDWORKS Multiphysics software is used which propounds a prodigious environs to solve this problem. Thus, this research presents the design analysis, modelling and nonlinear 3D dynamic simulation of MEMS based metal alloy for Rocket SAM using SOLIDWORKS Multiphysics GUI tool.***

Keywords: MEMS, MEMS based SAM, Nonlinear dynamic simulation, Rocket SAM, SOLIDWORKS Multiphysics tool

1. Introduction

This research has considered multidisciplinary technology which integrates most of the essentials from wide section of science and engineering. Main aim of this research paper is to design, simulate and derive the results using metal alloy MEMS based Rocket SAM, using SOLIDWORKS Multiphysics software which propounds a prodigious environs to solve this problem. Thus, this research presents the design analysis, modelling and nonlinear 3D dynamic simulation of MEMS based metal alloy for Rocket SAM using SOLIDWORKS Multiphysics GUI tool. Mems technology has immense scope in present as well as in future. This paper fulfills the goal to represent the nonlinear dynamic 3D simulation and results, its model and design analysis of MEMS based Rocket SAM. The proposed design basically works as S&A device and its work has been started with two aims:

1. Modelling, Design Analysis and Simulation of MEMS based Rocket SAM for safety and armed purpose.
2. Simulation of safe and arm mechanism for different "g"

1.1 Brief History and Background

The possibility of manufacturing of micro-miniaturized to ultra-miniaturized systems was proposed by Feynman in 1959. Feynman not only anticipated this kind of system but he also thought to taking this technology to the level that may involve a multiscale formulation method. As is implied, MEMS and NEMS are the small miniaturized integrated devices, that combines electrical, electronic as well as mechanical elements as shown in flowchart in figure 1. From the flowchart it is elucidated that MEMS are the militarized systems that comprises of electrical components, electronics components as well as mechanical components and we can state that these can be considered as a level of microscale and nanoscale with more functionalities and capabilities that are easily realized.

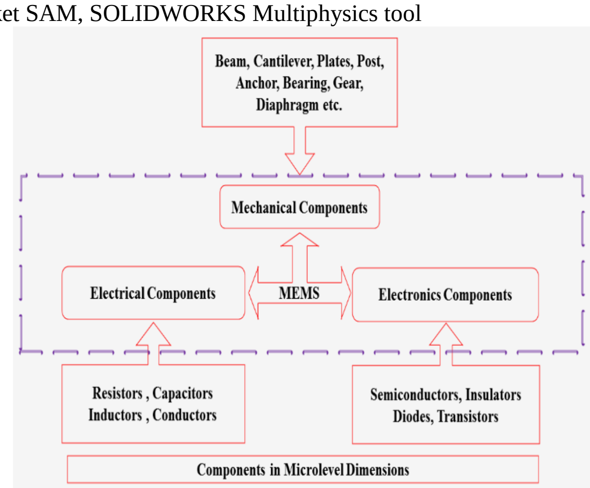

Figure 1: MEMS flowchart

The density of MEMS chip is measured in terms of number of components thus, the number of components present in the chip defines the scale of integration. It is a technology that combines computers with micro-miniaturized devices such as gears, actuators etc. embedded in semiconductor chips.

1.2 Outlines of the paper and function

This paper outlines the designing, modelling and 3D nonlinear dynamic simulation of MEMS based Rocket SAM in perilous progression, manufacturability and simulation using SolidWorks GUI software for MEMS S&A as applied for 25mm x 25mm x 10mm of device. In this paper, MEMS based Rocket SAM architecture, its designing, the device requirements and specifications, device's working environment and constraints of MEMS based Rocket SAM is discussed in section 2. Section 3 of this paper explains the modelling and design analysis. This section will introduce SolidWorks Multiphysics Software in which the proposed design is modelled and assembled.

As soon the modeling, designing and necessary features are added, MEMS based Rocket SAM is simulated. Simulation requirements, various physics used for acceleration during simulation along with calculations are discussed in section 4 of this paper. Section 5 of this paper shows various nonlinear dynamically simulated results and conclusion of MEMS based Rocket SAM.

2. Discussion

2.1 MEMS based Rocket SAM Design Architecture

The device anticipated in this paper is basically a four layered assembly. All the four layer plays a significant role for this device. The assembly of Rocket SAM S&A consist of the interlock system, microspring system and spring sliders for their interaction in response to set back acceleration and centrifugal force. The MEMS based SAM embodiment is shown in figure 2.

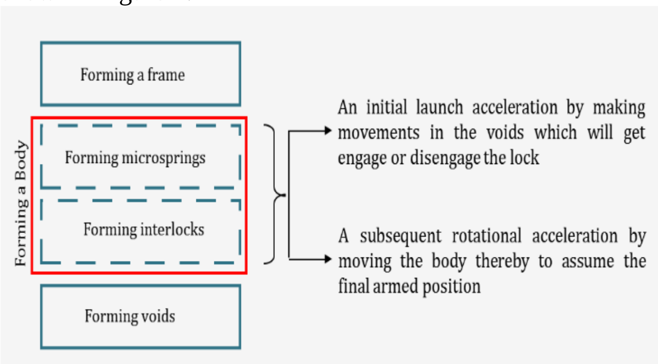

Figure 2: Flowchart for embodiment of the proposed Rocket SAM

The complete architecture of MEMS based Rocket SAM is first initiated by designing the outer frame and the inner frame which includes all the four layers. With initialization of frames, voids are mapped on different layers for various movable and non-movable body parts. Acceleration microspring is designed such that it can make movements in the voids in order to engage and disengage themselves. Microspring is provided with the interlock system and the complete design is now assembled into the voids of the frame.

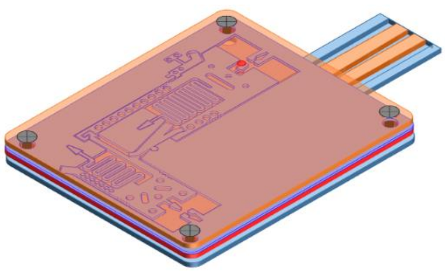

Figure 3: Complete assembly of Rocket SAM S&A

Figure 3 shows the complete assembly of proposed design for MEMS based Rocket SAM. The design is now ready for the nonlinear 3D simulation.

2.2 Requirements and Specifications

Design for MEMS based technology [1], [2] Rocket SAM chip is structured in such a way that it has both movable and non-movable parts which utilizes mechanical properties, structural properties and material properties that may be and may not be electronically controlled. The device specification is tabulated below for MEMS based Rocket SAM. Table 1 caters the requirement and the specification at which device is to operate. It shows the size of the device, the operational environments, operating temperatures along with acceleration requirement and spin requirements.

Table 1: Specification for MEMS based rocket SAM

Size	25*25*10
First Environment	Acceleration: 15 'g'
Second Environment	Spin: 400 rpm
Acceleration environment (Max)	1400 g
Temperature Operational	-40^0 C to $+63^0$ C
Temperature Storage	-40^0 C to $+70^0$ C

2.3 Environment and Design Constraints

Two objectives are paramount in the context of explosive weapons in general:

1. The device should explode when it is supposed to
2. and it should not accelerate before or after the target

Practically it means that the device or the microchip should reliably get armed during the launch or after the launch and not before it i.e. it should respond the true conditions. At false condition it should not produce the similar results. Thus, two types of environment are formed to prevent the false condition (i) Environment 1: Valid launch huge acceleration and (ii) Environment 2: Valid launch rotation

The MEMS based metal alloy SAM which can be used as a function to ensure the weapon safety and allow detonation only when certain deployment criteria are satisfied [3]. The four leading edge technology [5] which will not only reduce cost and volume of S&A's for projectile munitions but will also improve the lethality of superior payload and its affordability. Compared with traditional electromechanical system, various advantages like low cost, high reliability, less volume, multi-functionality etc. Weapon equipment in military application based on MEMS has high significance [6]. The paper outlines the designing of MEMS based SAM in critical advancement, manufacturability and simulation using SOLIDWORKS GUI Software for MEMS S&A as applied for various SAM devices.

3. Modelling & design analysis of SAM

3.1 Introduction to SOLIDWORKS GUI Multiphysics

"SolidWorks (stylized as SOLIDWORKS), is a solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) computer program that runs on Microsoft Windows. SolidWorks is published by Dassault Systems". Numerous explanations and results have been provided by SOLIDWORKS Multiphysics GUI to various types of simulation problems like some of which includes partial differential equations: time dependent form and stationary form using numerical techniques [8].

SOLIDWORKS Multiphysics has emerged as one of the excellent software for simulation for challenging designs. This explores the reproducibility of software to work in an effective environ. In this paper, nonlinear 3D dynamic simulation has been done to find the result for MEMS based metal alloy Rocket SAM for S&A device for ammunition. Simulation and results are discussed later in this paper.

3.2 Modelling with SOLIDWORKS GUI Multiphysics

Modelling of the MEMS based Rocket SAM is done by parts in 4 layers.

1. Energetic Layer with View port
2. MEMS Safe and Arm layer

DOI: 10.18535/ijecs/v5i10.27

3. Explosive Layer
4. Ignitor Layer

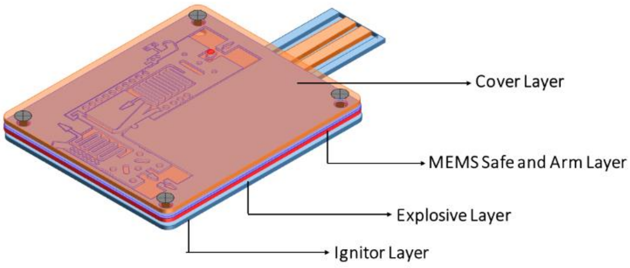

Figure 4: Modelling of Rocket SAM

3.3 Working of the SAM device

Immense researches have been done on developing highly reliable MEMS S&A devices and many of them are currently going on. The proposed design mapped in this paper is inspired from [5] and the ultimate motive for designing and modelling of MEMS S&A device is to reduce weight, cut cost and reduce volume [4] of the munition as well. Reduced weight and volume of the munition S&A will not only help our soldiers to carry it easily but it will also help in providing more space for warheads. Such kind of light weighted, miniaturized MEMS S&A munition device is made possible when complete advantage of MEMS technology is incorporated [4].

The proposed MEMS based Rocket SAM chip is dimensionally 25x25x10 (parameters in mm) and it is demonstrated in two types of environments. The four layered device weighs around 2gms. It is spinning at 400rpm with varying acceleration from 15g to 1400g. To get started in order to solve and verify the displacement analysis and acceleration analysis: graphical user interface SOLIDWORKS software is used.

This paper outlines the technical progress on the way of realization of miniaturization, less expensive and mass-producible MEMS based Safety and Armed (S&A) devices. It also reports metal alloy based SAM and its waveform in accordance with time vs displacement for acceleration microspring. Due to spin starting from 400 rpm with gravitational force being 15g to 1400g, the setback slider moves linearly and the latch is opened to operate the arming slider which is too under the influence of centrifugal force of the device.

Hence, the acceleration of the projected munition and displacement due to spinning sets the setback slider and arming slider into its final position. Only when the latches are correctly operated the sliders are disengaged to their final position and the ignitor is operated and detonation occurs. A typical arming device is in microns' size and all the parts are assembled using screws, pins, springs, microspring or the tight tolerance components.

4. Simulation

4.1 Simulation Requirement and applied physics

During the launch stage, the munitions is subjected to accelerations in the munitions axial direction. The angular acceleration is approximately proportional to the linear acceleration. The centrifugal acceleration, however, is proportional to square of angular velocity.

During the launch stage, the rotation speed of the projectile is accelerated approximately linearly from 0g to peak value. Figure 5, in this section shows the modelling and designing done in SolidWorks Software. It shows the direction of acceleration along with setback slider and embedded lock.

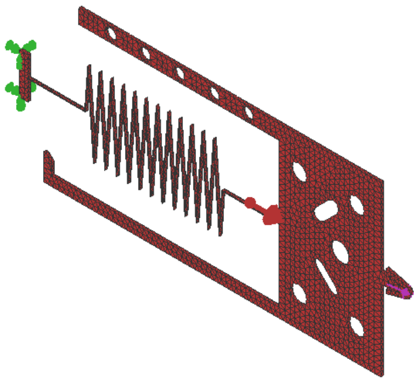

Figure 5: Acceleration Microspring

Considering a very simple spring mass system, representing equation 1.1

$$F = mu''(t) \qquad (1.1)$$

The mass (m) is subjected to a force F(t) in the u direction as, a function of time. The mass is allowed to move in the u direction only. The motion is resisted by a spring of stiffness (k) given in equation 1.2

$$mu''(t) + ku(t) = F(t) \qquad (1.2)$$

where: $u''(t)$ is the acceleration of the mass at time (t) and it is equal to the second derivative of u with respect to time and k is the stiffness of the spring.

Theoretically, if the mass is displaced and released, phenomenon called damping occurs and it is caused by loss of energy through friction and other effects. For the purpose of this discussion, assume that the damping force is proportional to the velocity. Considering damping, the above equation becomes [7]:

$$mu''(t) + cu'(t) + ku(t) = F(t) \qquad (1.3)$$

4.2 Calculation of Inertial Force

Considering a simple spring mass equation

$$F_{IF} = m_{device} a \qquad (1.4)$$

Table 2 shows the inertial force calculations. After the calculations are made, logarithmic graph is plotted as in figure 6.

Table 2: Calculated Inertial force & its equivalent weight

Acceleration	Force (N)	Weight (Kg)
1g	0.000038393264	3.91502E-6
5g	0.00019196632	1.95751E-5
10g	0.00038393264	3.91502E-5

15g	0.00057589896	5.87254E-5
20g	0.00076786528	7.83005E-5
50g	0.0019196632	1.95751E-4
100g	0.0038393264	3.91502E-4
500g	0.019196632	0.00196
1000g	0.038393264	0.00392
1400g	0.05484752	0.00559

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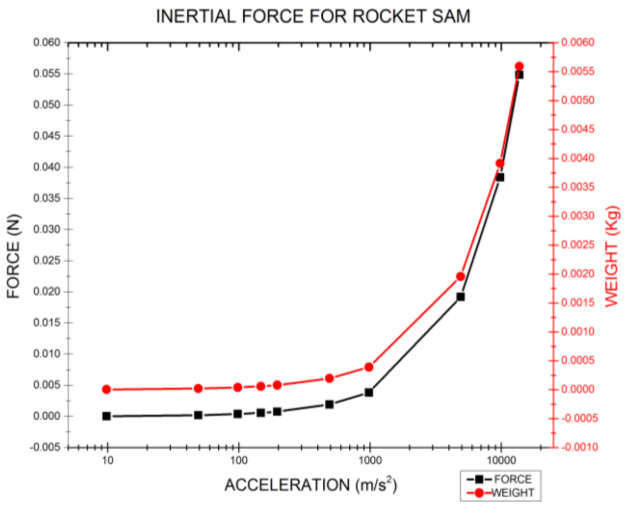

Figure 6: Logarithmic graphical representation of inertial force vs acceleration

5. Results

The goal of this study is completed when the acceleration microspring makes 1.19mm of displacement and can engage itself within 500ms with nonlinear 3D dynamic simulation in SolidWorks. The displacement study plot is observed for acceleration microspring in figure 7. While figure 8 displays the graphical representation of time history plot. With graph it is concluded that the acceleration microspring is able to engage itself in approximately 140ms. Below 140ms, SAM device is in safe mode after it has achieved the peak value i.e. device has covered its path, it will be in armed mode.

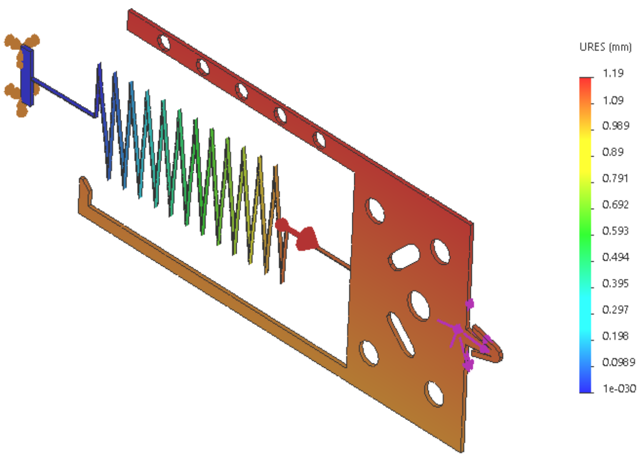

Figure 7: Simulated Displacement Plot

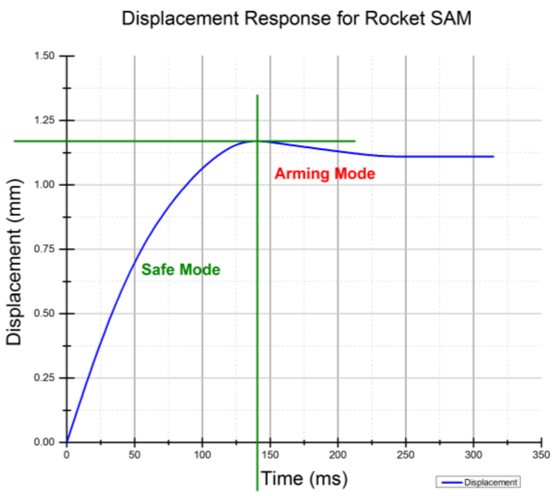

Figure 8: Time History Plot

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