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ORIGINAL RESEARCH ARTICLE

DEVELOPMENT OF A LABORATORY AIRBAG MODEL TO CUSHION THE EFFECT OF VEHICLE TYRE BURST WHILE IN MOTION

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ABSTRACT
The incessant rate of traffic accident as a result of tyre burst on our roads from the motor vehicle necessitated the development of this airbag to cushion the effect of tyre burst. The development of this laboratory airbag model is such that the airbag is incorporated into the rim (i.e. on the rim, inside the tyre). This allows the vehicle balance for some time until the driver is able to maneuver and park the vehicle safely. The frame of the airbag model was made of 0.5 mm ply wood cut into six (6) pieces and to form the box. A hole was drilled at the front to give space for motor to be used as a prime mover. The shaft produced from a 30 mm diameter mild steel rod was machined on a lathe machine to 25 mm diameter and cut to length of 10 mm. The calculated resultant stress upon impact was 83.96 MPa. The contact area and airbag thickness was 0.258 m^2 and 2.8 mm, respectively. A mini inflator was selected and actuated with the aid of an infrared sensor; it took less than six (6) seconds to actuate the shape airbag. The laboratory model was powered by a DC source and tyre burst signals were transmitted wirelessly through a control system.

1.0 Introduction

Nearly 1.3 million people die in road crashes each year, on the average 3,287 deaths are recorded a day (Anand, 2000). Nigeria is one of the worst hit countries with a human population of about 167 million, a high level of vehicular population estimated at over 7.6 million, a total road length of about 194,000 km (Vitus, 2014). Nigeria has suffered losses due to fatal car accidents. Its population density varies in rural and urban areas at about 51.7% and 48.3%, respectively and translates to a population – road ratio of 860 persons per square kilometer, indicating intense traffic pressure on the available road network, (Tyremarket, 2016). Undoubtedly, this immense pressure contributes to the high road traffic accidents in the country (Vitus, 2014). Vitus (2014) categorized the causes of fatal car accidents in Nigeria into human, mechanical, and environmental factors.

The human factor accounts for up to 90% of accidents, while the mechanical and environmental factors contribute to the other 10%. Human factors include visual acuteness, driver fatigue, poor knowledge of road signs and regulations, illiteracy, health problems, excessive speeding, drug abuse, and over-confidence while at the steering wheel. Among the mechanical factors that lead to fatal car accidents are poor vehicle maintenance, tyre bursts, poor lights, non-roadworthiness of vehicles, and broken-down vehicles on the road without adequate warning. The environmental factors include heavy rainfall, harmattan winds, reflection, heavy wind, pot holes, and un-tarred roads. These factors have independently or collectively contributed to the high rate of fatal road accidents in Nigeria.

Over-speeding and tyre burst are frequently being reported as the most common causes of road accidents around the country (Maureen, 2016). A survey by the Federal Road Safety Corps (FRSC) shows that tyre-related crashes have been responsible for the destruction of 5,288 vehicles between 2011 and 2015. A total of 224 road traffic crashes due to tyre burst have been recorded between the 1st of January and 15th May in the year 2016, (Maureen, 2016). In the present-day Nigeria, a road accident ranks the second to Boko haram as the source of violent death. About 11,363 head accidents were recorded in 2016 of which 4,796 deaths were recorded, 40% of these fatal accidents were due to tyre burst, (Maureen, 2016). These tyre bursts cannot be controlled in Nigeria with the use of new and non- expired tyres because the states of the roads are accident prone. For this reason, it has become imperative to develop airbag mechanism as a means of reducing the effect of tyre burst. Torus shape Airbag is therefore adapted in this study, because it has the same shape as a vehicle tyre; with the device consisting of shaft, motor, mini inflator, transmitter and receiver.

2. Literature Review

The airbags are spreading in use with several now being fitted to each vehicle-for driver, passenger, thorax, knee side and side curtain airbags- and it is expected that in Europe alone approaching 100 million modules will be required Gülsah, (2008). Rishikesh, (2014), designed an airbag system for 2-wheeler vehicle system. The design made use of Airbag (leather material with grip technology), Chemical cylinders for releasing the air or gas, Sensors (angle sensor and crash sensor), Fitting cage, Angle measurement instrument (angle indicator) and Battery used (bike battery). A maximum of 50 milliseconds were recorded for the airbag to be deployed through the explosion of Nitrogen gas. Yi-Jen Mon, (2013), developed a test platform for airbag controller design so as to obtain a crash data for design. The test platform was implemented using recurrent fuzzy neural network (RFNN) algorithm. The airbag ignition was verified for good effectiveness. An average of 29 ms was recorded with his taste platform.

3. Materials and Method

3.1 Materials

The materials used in this study and their specifications are presented in Table 1

Table 1: Materials Used for the development of Airbag.

S/N	Material	Specification
1	Casing	12.5 m plywood
2	Plexiglas: light weight used to hold receiver	2 mm thick
3	Airbag	Torus shape
4	Inflator	Model AP 101
5	Power switch	Two way
6	Hose	Ø30 mm× 150 mm

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3.2 Method

The process followed in the development of the airbag model are presented as follows:.

3.2.1 Design considerations

According to Khurmi and Gupta (2008), the design considerations are characteristics that influence the design of the elements on the entire system, therefore, the design considerations that are important to this design are:

Strength of the airbag: The ability to withstand the internal stress and impact upon tyre burst.

Inflation time (in seconds): The inflator will be required to pump air into the airbag in< 5 ms.

Fatigue resistances: The resistance to fatigue load due to tyre roll.

Shape: An airbag to cushion the effect of tyre burst must be able to roll like tyre.

Airbag pressure is assumed to be distributed uniformly.

3.2.2 Working Principles

The sensor is connected to the controller and the controller is connected to the transmitter. As a result, when the distance to the ground is shortened the controller sends a message to the radio transmitter. On the other hand, the radio receives the message and activates the relays which operate the inflator. A torus tube was used as an airbag (as shown in Figure 1). Because a torus like airbag can easily be fitted into wheel tire assembly. An ultrasonic (UTS) proximity sensor was used to monitor the position of the tyre while in active position that is fully inflated and if there is a tyre burst, the UTS will activate the mini tyre inflator which in turn pumps air into the torus like airbag. The inflator, the sensors and other electronic components are beef powered by a 12V battery. The UTS installed on the transmitter located around the tyre send a signal to the receiver. The detail CAD drawings are show in Figure 2 and 3.

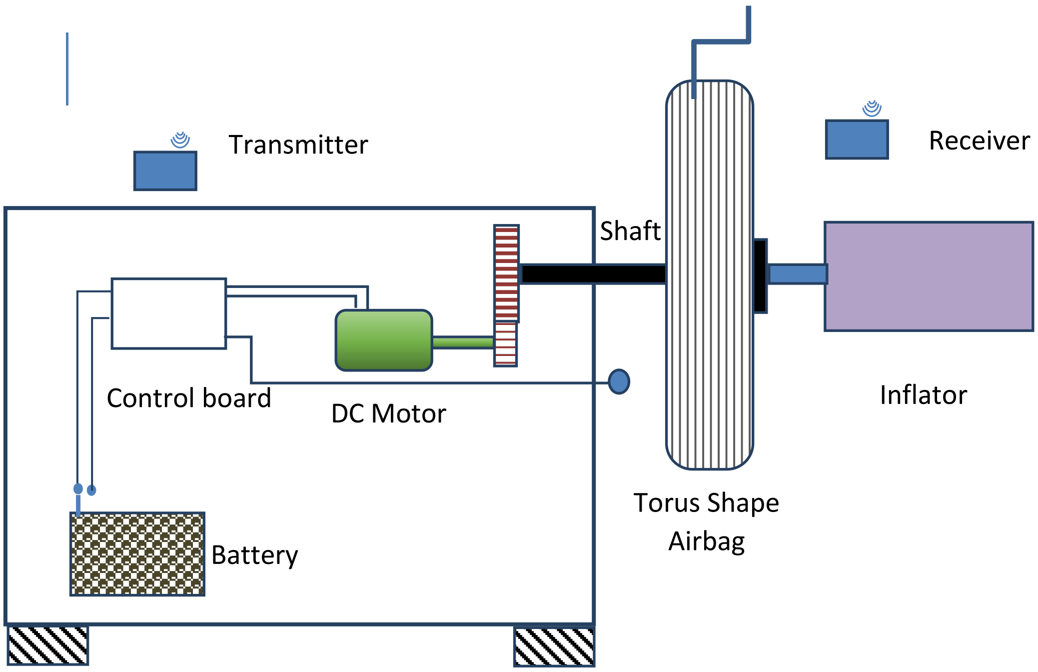

Figure 1: Schematic Diagram of Airbag Mechanism

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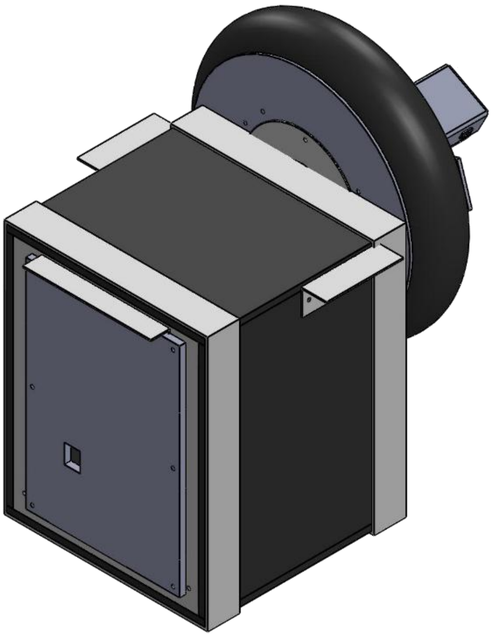

Figure 2: Isometric Drawing Airbag Mechanism.

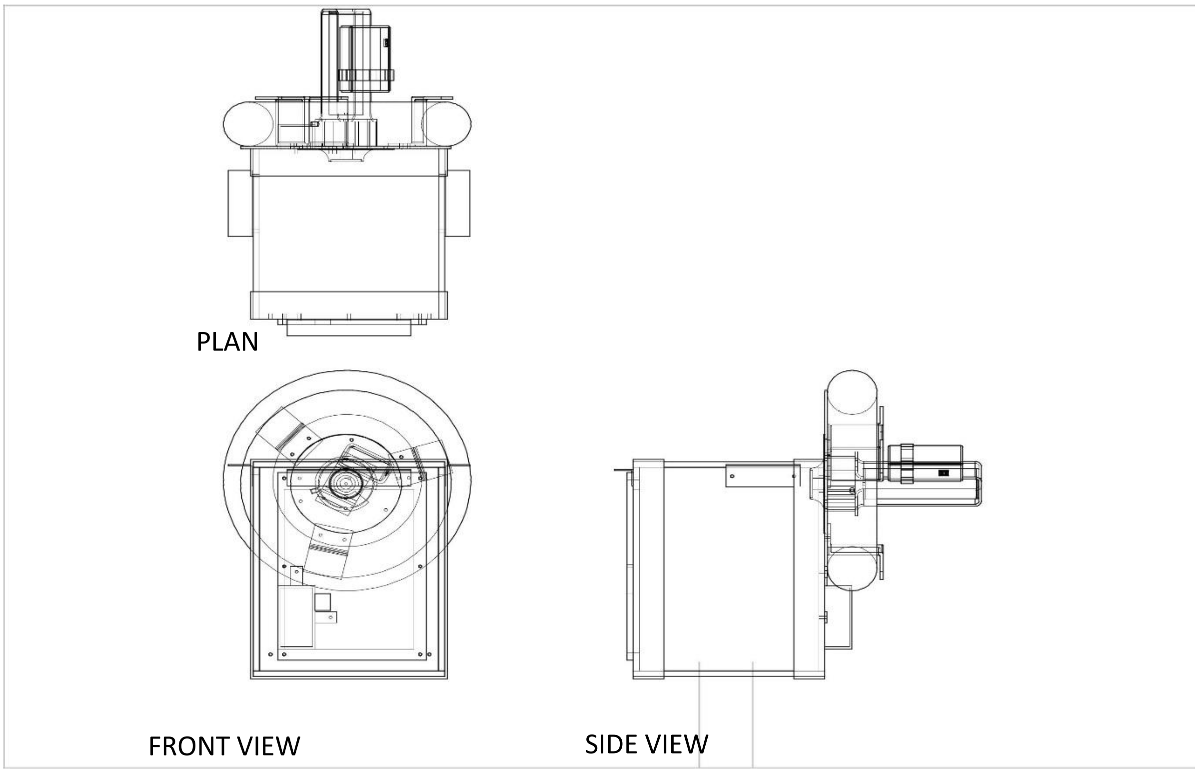

Figure 3: Orthographic Projection of Airbag Mechanism

3.3.3 Design Requirements

The weight of a Toyota Camry (2012 model) with four passengers were used as the design weight for the airbag about the weight is about 144.959 k_g according to Miller-Wilson, (2017), while the average adult weight (w_a) is 81.64k_g Halls (2017).

Therefore, the total design weight, w_d were computed using equation 1;

$$w_d = (w_c + 4w_a) \times 9.81 \tag{1}$$

Therefore, the weight of the vehicle on one tire is given by:

$$w_w = \frac{w_d}{4} \tag{2}$$

From the Equation 2, the design load is $w_w = 5\text{kN}$, and a nylon fabric rubber material can withstand an impact load of up to 11.9kN Miller-Wilson, (2017).

3.3.4 Determination of Airbag Internal Pressure Required to Sustain The Weight of The Car

The airbag governing equations as presented by Anand (2000) is used and presented in equation 3.

$$\frac{e_1}{e_2} = \left(\frac{v_1}{v_2}\right)^{\gamma} = \left(\frac{e_2}{e_1}\right)^{\gamma} \tag{3}$$

where:

$\gamma = \frac{C_p}{C_v}$

C_P = heat capacity at constant pressure

C_v = heat capacity at constant volume.

v = volume

Also $e = \frac{E}{\rho_o}$

Then the airbag internal pressure Pi is given by

$$P_I = (\gamma - 1)\rho_e \tag{4}$$

And the airbag internal energy depends on the gas entering and leaving the airbag. (See equation 5)

$$E_{in} = C_p(m_{in}T_{in} + m_{out}T_{out}) - PV \tag{5}$$

3.3.4 Determination of stresses acting on the torus airbag

The hoop stress is the force exerted circumferentially (perpendicular both to the axis and to the radius of the object). In the directions on every particle in the cylinder wall David, (2000) stated that the hoop stress of a torus shaped object can be obtained using equation 6

$$\sigma_{r_I t} = \frac{r_I^2 P_I - r_0^2 P_0}{r_0^2 - r_I^2} \mp \frac{r_I^2 r_0^2 (P_I - P_o)}{\left(r_0^2 - r_I^2\right) r^2} \tag{6}$$

where:

σ_r- Radial stress

σ_t- Tangential stress

σ_i – Internal radius

σ_o –External radius

r – Radius

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3.3.5 Device shaft design

The shaft is subject to bending load from the weight of the airbag tube, and twist load from the motor, therefore equation 7 is used for the shaft design (Kost, 2014).

$$T_e = \sqrt{M^2 + T^2} \tag{7}$$

where: Te is the equivalent twisting moment, M is bending moment and T is the twisting moment.

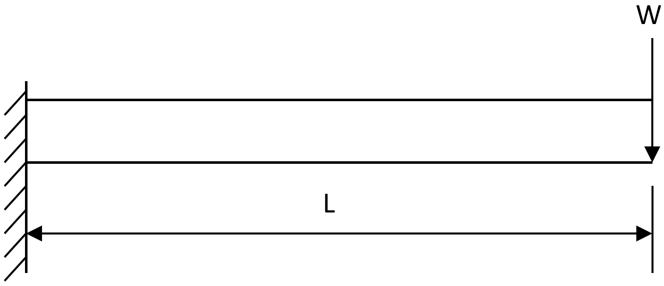

Figure 2: The Shaft with a pointed load.

The bending moment is obtained using equation 8

$$M = W \times L = m.g.l \tag{8}$$

where:

W- Load on shaft (N).

l - Shaft length (220 mm, constrained by space.).

m - Mass of air in the airbag (0.0299kg)

g - 9.81 m/s^2

The torque or twisting moment was obtained using equation 9

$$\tau = \frac{60P}{2\pi N} \text{(Khurmi and Gupta, 2008)} \tag{9}$$

A 12V motor was used for this design with 50 rpm and 350 W power rating.

3.3.5 The Power Supply

The power supply for the DC motor, the drives the airbag is 12V, 7Ah battery. This was used instead of the car battery to save cost. However, in the car, the car battery is the kind of battery needed. Another 9V battery was used to power the transmitter which is regulated to 5V via a regulator 7805. This regulator converts 9V to 5V. The essence of having a 5V supply is to ensure the powering of the controller which is usually not more than 5V any attempt to do that will damage the chip.

The current supply by the battery to the motor were determined from equation 10;

$$V = IR \tag{10}$$

where:

V = Voltage (V)

I = Current (A)

R = Resistance (Ω)

3.3.6 Rating of Battery

Capacities of battery are rated in terms of output ampere-hour. Figure 3, presets the powered circuit while, equation 11 represents the battery power required.

$$\text{Power} = VI \tag{11}$$

Watt Hour = Voltage (V) × Current (A) × Time (Hour)

A12V, 7Ah lead acid battery is selected.

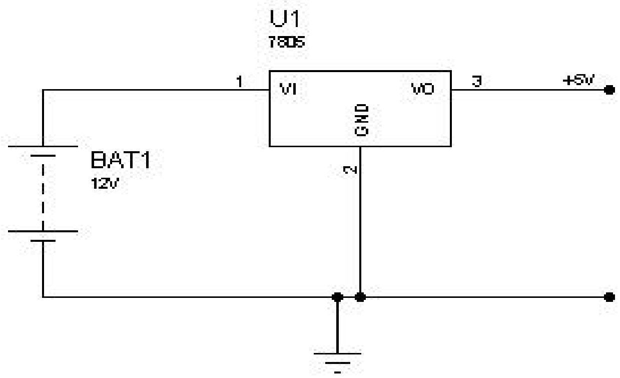

Figure 3: circuit diagram of the power.

3.3.7 Proximity Sensor

The sensor used is an infrared barrier detector. The sensor was bought in an open market in Minna, Niger State of Nigeria, as a module. It consists of three pins Vcc, ground and output. The module which has an infrared transmitter and receiver can sense distance. When the distance is at a particular level, the output goes high.

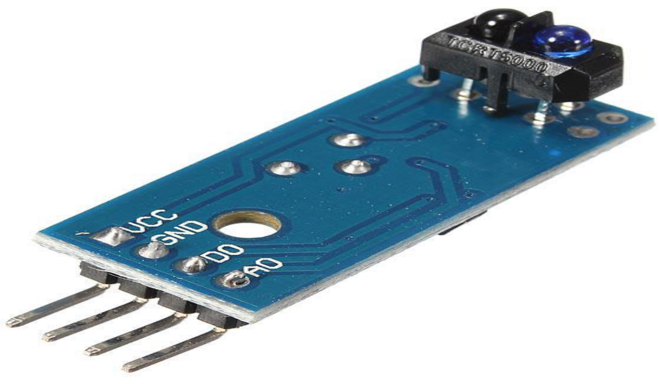

Figure 4: Pictorial View of the Sensor.

Controller: the controller used is PIC16f628A. The reason for the selection of the chip is because it is small in size so it will ensure compactness. The 5V system has a serial port which is connected to the radio transmitter at the transmitter unit to send message which is a string "AAAx". At the receiver, the controller receives this message among other radio messages in the air, however it is programmed to discard every other message except this particular one sent by the transmitter. The circuit diagram of the controller is shown below in Figure 5.

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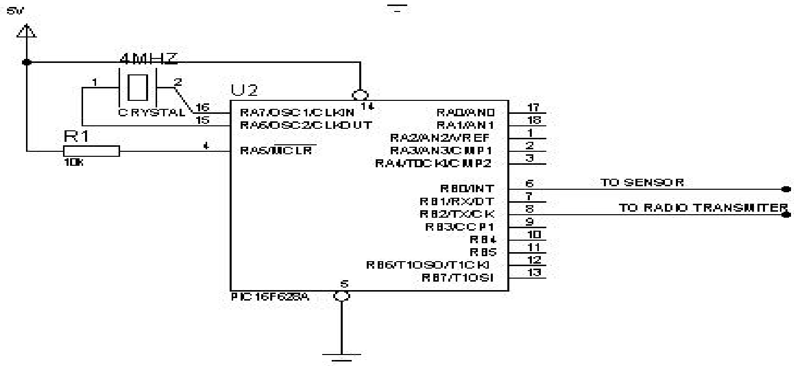

Figure 5: Circuit Diagram of Controller Unit.

3.3.8 Transmitter/Receiver Unit

The module in figure 6 were used to transmit the signal from the proximity sensor to the control board, which in turns actuate the inflator. This is made up of radio module 433 MHz The radio module has the ability to send message for a distance of 25 meters. It has three pins Vcc which is connected to 5V, ground pin and data line. For efficiency it is important for the module to have an antenna (Cai and Duan, 2015). This unit is made up of 433 MHz radio receiver. The receiver receives many messages from the air. The four pin device has Vcc, ground, and two data lines.

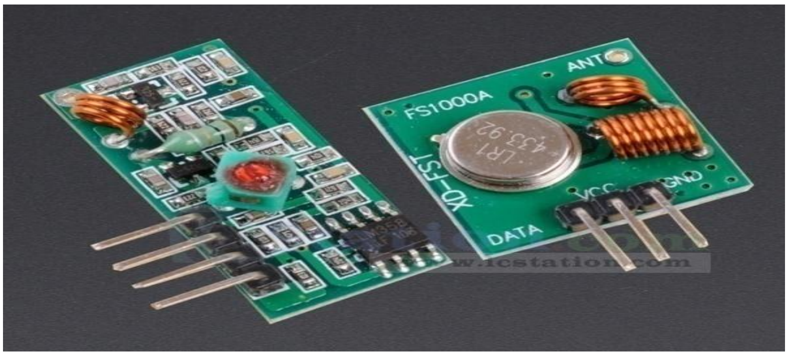

Figure 6: The Pictorial View of RfTx and Rx.

3.3.9 Relay unit

The relay unit for which the circuit is shown in figure 7 were used to control (ie switching on/off) the inflator. This is achieved via the use of electromagnetic switch as shown in figure 7. The relay cannot operate on its own since the controller cannot supply all the current it needs. Therefore, a transistor is used as a driver.

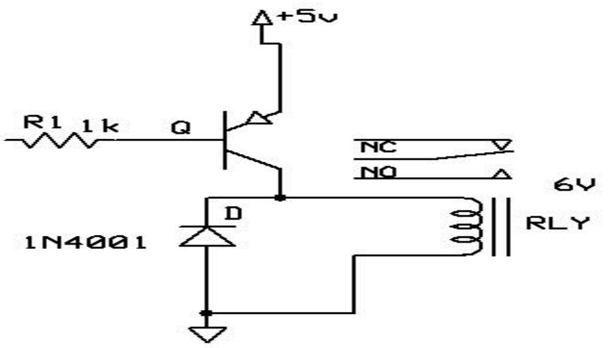

Figure 7: Circuit of Transistor

The transistor used is A1015 biased with a 1k ohms resistor. This is used to drive a relay.

3.3.10 Test Procedure

The model Airbag mechanism in figure 7 were tested with a lead acid battery (with 12V 7.2Ah) connected via terminals switch. The system was switch on as the time was working that is simulating vehicle movement. A object placed in front of the sensor signifying a tyre burst, this activate the transmitter and receiver led circuit which in turn inflate the airbag. The time, Airbag pressure and volume were recorded.

4. Results and Discussion

4.1 Design Analysis Results

The design analysis was carried out to satisfy the design consideration earlier mentioned. That is to establish minimum safe dimensions and to ensure its functionality. The mechanical design results obtained from Equations 1 – 13 are presented in Table 2.

Table 2: Mechanical Design Result

S/No	Item	Value Obtained
1	Design load	5Kn
2	Tyre contact area	0.0258 m^2
3	Stress upon impact	195.93 MPa
4	Airbag strain energy	73.8J.
5	Airbag internal pressure (max)	0.369 MPa (53.33Psi)
6	Airbag max radial/stress	52.16 MPa
7	Airbag max tangential stress	65.52 MPa
8	Resultant stress/airbag	83.96 MPa
9	Airbag min Thickness	2.8 mm

According to Anand, (2000), Nylon fabric rubber has a yield stress of 450 MPa and can take up to 11,000kN. The resultant stress calculated for the airbag is less than the yield stress of the airbag materials, the thickness of the airbag material is close to what has been used in the works of Anand (2000) and Bells (2016).

The results of stress analysis of the torus airbag are shown in Figure 8 and 9 This shows that the maximum stress the nylon fabric rubber is been subjected to is less than its yield stress.

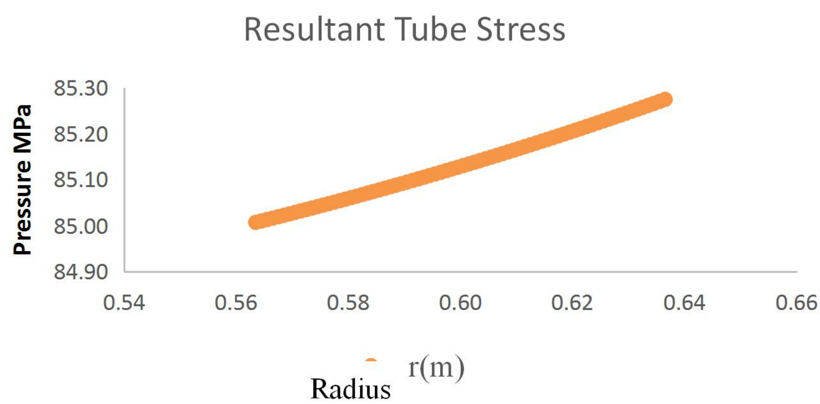

Figure 8: Airbag Resultant Stress

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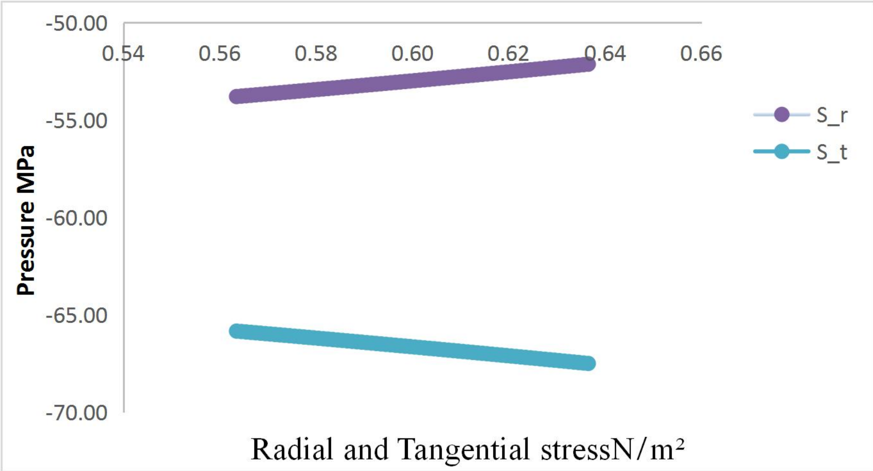

Figure 9: Airbag radial (σ_r) and tangential (σ_t) stress

4.2 Test Results

After the design and fabrication, the laboratory model of the torus airbag system was tested and the result obtained are shown in Table 3. The pressure in the airbag and its corresponding weight was recorded as shown over time in seconds.

Table 3: Experimental Data Recorded of Pressure in the Airbag and its corresponding Weight.

Time(s)	Pressure MPa	Volume (m^3)	Gram
0	120.3	407111.9	4.912334
3	121.6	422037.1	5.092426
5	123.1	439699	5.30554
7	125.6	470200.7	5.673583
9	127.8	498163.6	6.010991
10	129.5	520503.3	6.280548
12	131.1	542120.8	6.541392
15	134	582790.6	7.032126
20	137.1	628429.6	7.58282

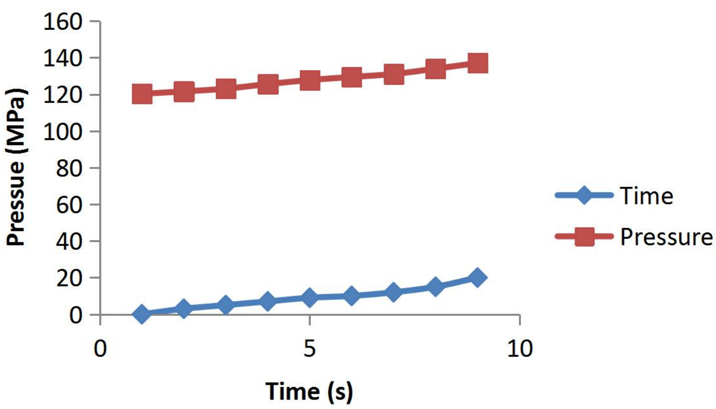

Figure 10: Experimental Data on Time (s) against Pressure (MPa)

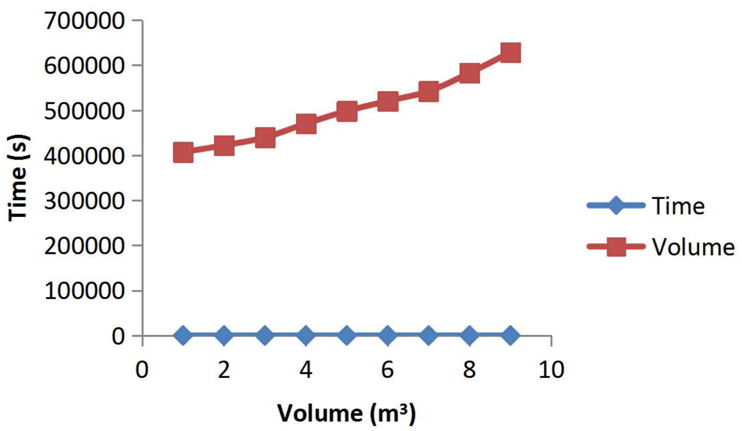

Figure 11: Experimental Data on Time(s) against Volume (m^3)

Figure 10 shows the results of the test conducted as recorded in Table 3. These were plotted in Figure 10 and 11. It was observed that during the test it took about 6 seconds for this airbag pressure to reach 45 MPa required to sustain the impact from the crash. Note: the capacity of the mini inflator use is small in size as compared with what is required in real life situation. According to Bells (2016), the response time and inflating time is always less than 1.6 milliseconds.

5. Conclusion

The laboratory test model for this mechanism were developed. The design analysis of the model components was carried out. Also a control system was built for the mechanism. A transmitter and receiver module was to authenticate control of mini inflator. The dimension obtained from design analysis was used in the fabrication of the airbag mechanism. After fabrication a performance test was conducted. It was found that the mini inflator used was able to pump the torus airbag up to 45 MPa in less than six (6) seconds. The design load obtained is 5 kN, with a tyre contact area of 0.0258 m^2 and Stress upon impact determined

References

Anand, N. 2000. Dynamic Testing of Airbag Fabric Permeability and Extensibility for Depowered Airbags. Retrieved From Https://Ttu-Ir.Tdl.Org/Ttu-Ir/Bitstream/Handle/2346/10246/31295013710842.Pdf?Sequence=1.

Bells, M. 2016. "The History of Airbags". About.com- New York Times Company. Retrieved 16 March 2017.

Cai, Y., Zang, M., and Duan, E. 2015. Modeling and Simulation of Vehicle Responses to Tire Blowout. Tire Science and Technology, 43(3): 242-258.

David, F. 2000. Metallurgical Failures in Fossil Fired Boilers. 2nd Edition. USA. John Wiley and Sons, New York.

Halls, SB. 2017. Feeling Fine Chart. Retrieved from http://halls.md/average-weight-men/ 19 March, 2017

Khurmi, RS. and Gupta, JK. 2008. A Textbook of Machine Design (Multicolour edition), New Delhi, Eurasis Publishing House, India.

Corresponding author's e-mail address: abhassan@futminna.edu.ng

Kost, F. 2014. Basic principles of vehicle dynamics. In: Reif K. (eds) Fundamentals of Automotive and Engine Technology. Bosch Professional Automotive Information. Springer Vieweg, Wiesbaden. Retrieved from https://link.springer.com/chapter/10.1007%2F978-3-658-03972-1_10#citeas

Maureen, O. 2016. Curbing tyre-related accidents on Nigerian roads. Http://www.dailytrust.com.ng/news/feature/curbing-tyre-related-accidents-on-nigerian-roads/150811.html#f7tqrw3m5qvavzy6.99

Miller-Wilson, K. 2017. List of car weights. Retrieved from http://cars.lovetoknow.com /List_of_Car_Weights. 18 March, 2017

Vitus, NU. 2014. Trends and Patterns of Fatal Road Accidents In Nigeria. Institut français de recherche en Afrique. Http://www.nigeriawatch.org/media/html/ WP6VitusV6Final.pdf

Xiaoguang, Y. 2011. Finite element analysis and experimental Investigation of tyre characteristics for developing strain-based intelligent tyre system, (Doctorate Thesis). University of Birmingham. Retrieved from http://etheses.bham.ac.uk/3072/1/Yang11PhD.pdf