

# Design Optimization and Validation of Hybrid Upper H-Arm Suspension link of a BAJA All Terrain Vehicle using Finite Element Analysis and Accelerometer Validation Setup

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**Abstract** - Suspension links are critical to not only vehicle performance but also to their safety. Suspension members have different shapes and mechanisms based on their requirements. Conventionally, these links were made of steels, but with time the consumer and performance demands grew and this resulted in a need of high performance low weight components which enhance the suspension response. In this paper, the design and optimization of an Upper H-Arm suspension link is discussed. The optimization was aided by the acquisition of data by an ADXL 345 accelerometer. The data obtained was processed and filtered using Power Spectral Density for obtaining accurate data devoid of noise. Understanding the shortcomings of the initial design in experimental testing in combination with the data obtained during the test helped improve the existing idea of the loads acting. ANSYS workbench has been utilized to perform complex CAE static structural simulations to match the real-life operational conditions.

**Key Words:** MATLAB, FEA, Power Spectral Density, Design optimization, Data Acquisition, Suspension geometry.

## 1. INTRODUCTION

Suspension geometries of BAJA SAE ATVs are expected to be tough, sturdy and light weight. The performance of the vehicle is highly dependent on the suspension's reliability, as in many scenarios failure of the suspension system will greatly reduce track time. So, it is important to have durable suspension mechanisms which are essential for optimal performance. Optimizing the strength to weight of a

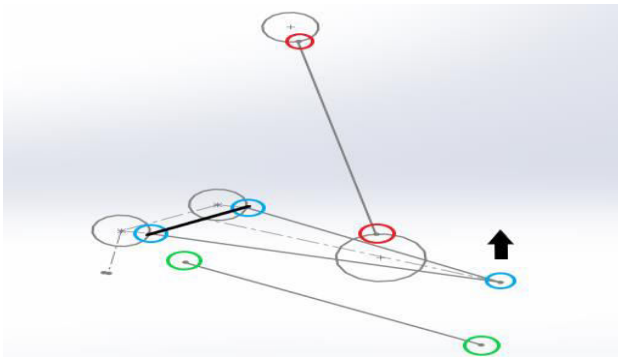
suspension system is key to obtaining the aforementioned outcomes.

This paper addresses some of many problems faced by suspension engineers while designing the suspension links i.e., deformation of the links, heavy stress concentration, high unsprung mass due to over designed components. Suspension components are assumed to be physically rigid links that maintain a specific form and function, but deformation due to unforeseen operational scenarios will affect the predetermined behaviour of the suspension. In order to achieve this we have utilized Data Acquisition (DAQ) Systems which transduce physical input to digital signals that can be calibrated based on knowledge models from a known scenario. An accelerometer setup has been employed to meet this requirement by sensing and converting the inputs to a digital form. Accelerometer has high sensitivity and better frequency response, which makes it a reliable DAQ option. MMA7260QT and ADXL-345 accelerometers were considered for the setup. From the stationary point of view, the ADXL345 shows better response than the MMA7260QT based on its consistency values[2]. 'ADXL-345' is an accelerometer which has high resolution and range of -16g to 16g. ADXL-345 is also deemed to be more suitable for harsh dynamic operations due to its durability. This data thus logged has helped understand the loads acting on the suspension links and following proper engineering principles would help optimize the design.

## 2. EXPERIMENTAL SETUP & DEVELOPMENT

### 2.1 Introduction to suspension geometry

An H - arm and single control link suspension geometry is generally used on BAJA SAE ATV. The H-arm and control link suspension is used on the rear of the vehicle where there is no necessity of toe misalignment. An H- arm and control link suspension dampens the road shocks by traversing about an axis parallel to the direction of motion of the vehicle. A Hybrid H - arm and control link suspension is a type of suspension geometry which has the features of a Trailing Arm suspension geometry which is a suspension geometry where the suspension link responds to road shocks by traversing about an axis perpendicular to the motion of the vehicle. The hybrid H-arm suspension geometry has suspension properties similar to that of both H-arm and Trailing arm suspension.



**Fig -1:** Line diagram representing Hybrid H-arm and single control link suspension geometry.

Hybrid H-arm and control link is a suspension geometry with 5 control points and 2 Shock points. In the Fig 1. the red circles mark the points where the shock absorber is connected the suspension and the chassis of the vehicle, the blue circles define the H- arm; here, we can notice that the shock absorber is connected to the H-arm which is above the drive-axle. The green circles mark the single control link. The black arrow shows the direction of traverse of the H-arm outboard point by rotating about an axis that other two points define (denoted as a black line). The H-arm bears most of the road shocks in this suspension geometry.

## 2.2 Initial Design Overview

The initial upper H-arm suspension link was designed to be fabricated with laser cut Mild Steel plates of 1.5mm thickness that were be TIG welded together with a Square cross-section of 1.2 in side along the lines that define the H-arm. The plates have engineered trusses for ideal stress flow and distribution. FEA of this component was conducted on ANSYS19.2 with assumed loads. It had significant deformation near the shock loaded region. Then in-order to accurately determine the actual loads on the suspension link we have used ADXL-345 Accelerometer. This data was used to assess and understand the loads acting on the H-arm due to the suspension geometry.



**Fig -2:** Laser-cut Upper H-Arm Design

## 2.3 Data Acquisition Methodology and Components

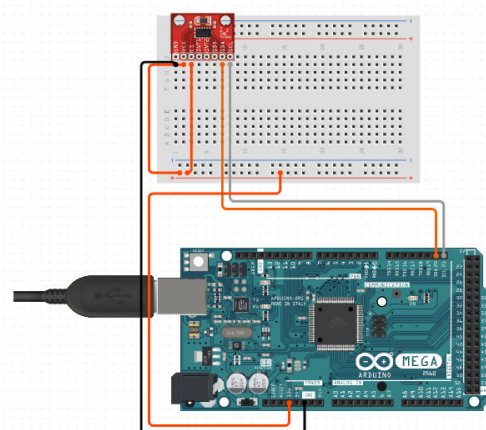
‘Data acquisition’ is converting real-time data into a digital form. The accelerometer was mounted on the H-arm to determine the acceleration in the desire direction with the help of micro-controller and sensor. In the experiment, we observed additional vibrations which adulterate the data in the form of Noise. This raw data which is collected is further processed on MATLAB.

### Components used-

**Arduino Mega 2560:-** This micro-controller is based on Atmega2560 and has 54 digital input/output pins in which 15 pins are used for PWM(Pulse Width Modulation) and has 16 analog pins with 5 volt operating voltage and 7-12 V input voltage is recommended with a clock speed of 16MHz and also has USB connection. It is compatible with different shields.

**Accelerometer:-** Accelerometer used for the force analysis is ADXL 345; it has 3 axes (X, Y, Z) with a high resolution of 13 bit which measures from -16g to +16g. It has both SPI and I2C communication interface with a supply voltage range of 2.0 V to 3.6 V. It measures the acceleration components in dynamic condition with the help of motion and shocks sensed by it.

**Data Logger shield:-** This Arduino data logger shield is used to collect the data in dynamic condition so in this the data is stored in the form of ‘.csv’ file. In this we can store multiple files simultaneously.



**Fig -3:** Circuit Diagram

We have powered the sensor with micro-controller’s 3.3 V pin and grounded it with pin GND and we have connected SDA pin and SCL pin for using I2C communication interface for retrieving the data from the sensor. The micro-controller is powered with the help of a mobile-power bank for dynamic testing.



Fig -4: Setup mounted for Experimental Test

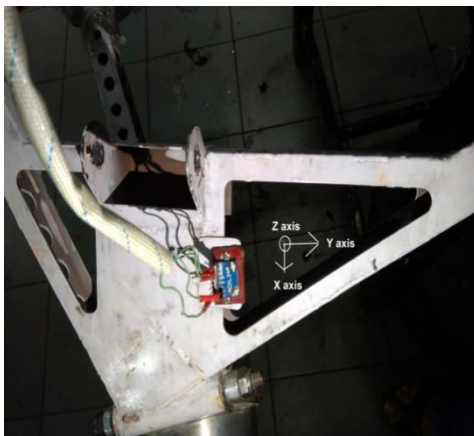


Fig -5: Accelerometer mounted on Suspension Link

Firstly, a mild steel plate with holes for bolting is welded on the H-arm to mount the sensor. A polyurethane slab was used as a base for the sensor to damp the additional noise by cancelling out the vibrations. So, the data from the 3 axes accelerometer ADXL345 using I2C communication interface was used to determine acceleration components it experiences. As this sensor senses motion in terms of acceleration components based on calibrated capacitive responses it has been mount on points with maximum possible dynamic change.

#### Filtering Data

I2C supports multiple masters and can communicate to different slave devices. The raw data is imported into MATLAB environment to filter the noise using a *band pass filter*. The program reads data logged from the .csv file and uses *Periodogram function* which returns the power spectral density (PSD) estimate of the input signal. After parsing that through the *Power function* we obtain the cutoff frequency which then is used as the frequency bounds for the pass band of the filter. This obtained data has time and frequency domains in filtered form which gave precise values of the acceleration components that helped optimize the H-Arm design.

#### Graphs Obtained

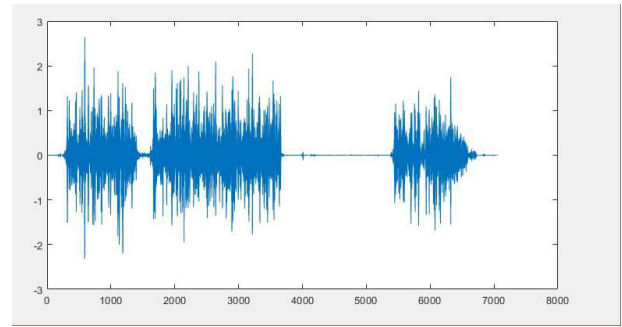


Fig -6: Laser cut H-Arm: Time domain filtered Graph

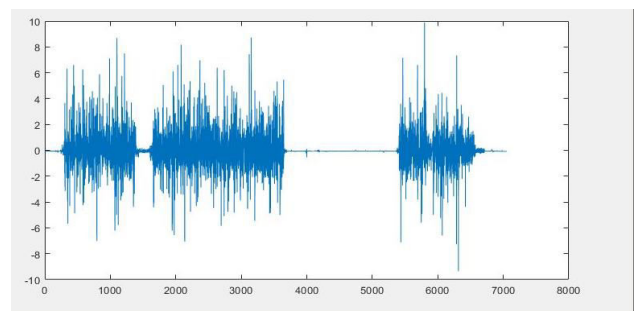


Fig -7: Laser cut H-Arm: Time domain Unfiltered graph

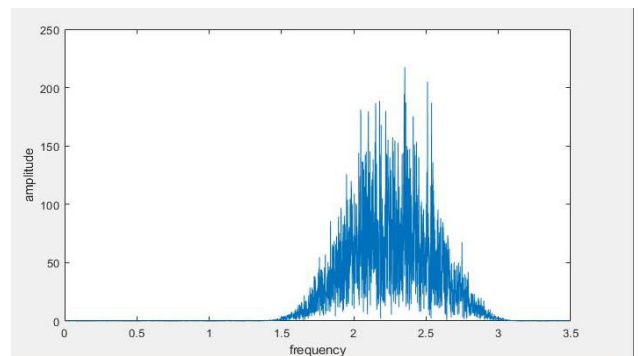


Fig -8: Laser cut H-Arm: Frequency domain graph

#### 2.4 Force Calculation from filtered data

After obtaining the filtered data, the Force acting on the H-arm was determined as follows

$$Force(N) = CornerSprungWeight(Kgs) \times g_{force}$$

Where,

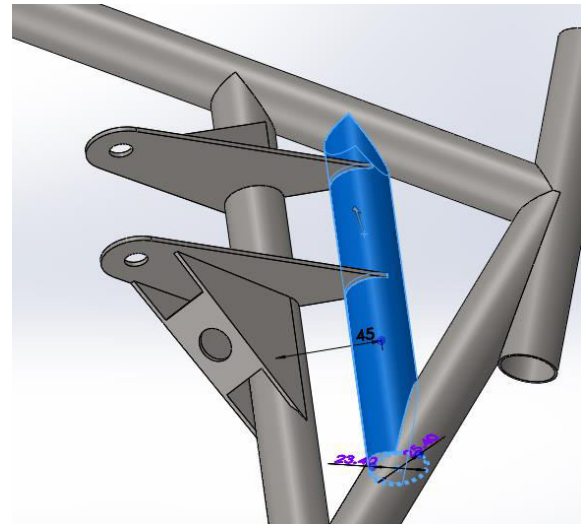
$$g_{force} = \text{filtered accelerometer peak magnitude} \times 9.81$$

The Corner Sprung Weight(CSW) with the laser-cut Upper H-Arms installed was measure by placing each tyre of the ATV on identical scales. The reading showed 50.455 Kg, as shown in Fig. . For the sake of safety we approximated this value to 50.5 Kg.





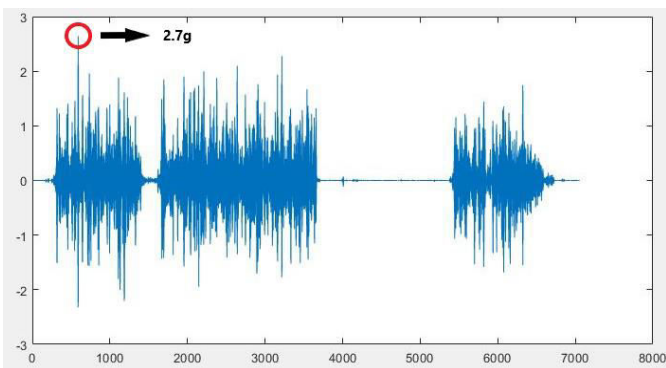
**Fig -9:** Corner Sprung Weight



**Fig -11:** Additional structural truss for preventing twist of the mount.

One more reason this occurred is due to the low torsional rigidity of the square cross section. Since tubular structures have higher torsional rigidity, our new design was designed using tubes instead of plates with the aforementioned structural geometry.

Selection of material for the hypothesized design was approached by comparing their mechanical properties involving different materials. AISI 4130 has a wide range of hardenability which enhances its strength in trade for elongation and softness. Also, the weld-ability of AISI4130 with ER70S fillers is much better compared to AISI1020, which in turn develops into stronger welded joints.



**Fig -10:** Acceleration in terms of g under dynamic condition as obtained from the accelerometer

For the Laser-cut H-Arm this acceleration was 2.7 g

Force for the Laser-cut Upper H-Arm,

$$F_{\text{Laser-cut}} = 50.5 \times 2.7 \times 9.81 = 1337.593 \text{ N}$$

To the force value obtained theoretically, we have applied a multiplication factor of 3 to enhance the safety of the component for unseen circumstances on the terrain.

The final magnitude of force for CAE becomes,

$$F = 1337.593 \times 3 = \underline{4012.779 \text{ N}}$$

This magnitude of the force was further split into X-Y-Z components to accurately define the direction of application of force.

### 2.5 New Design Hypothesis

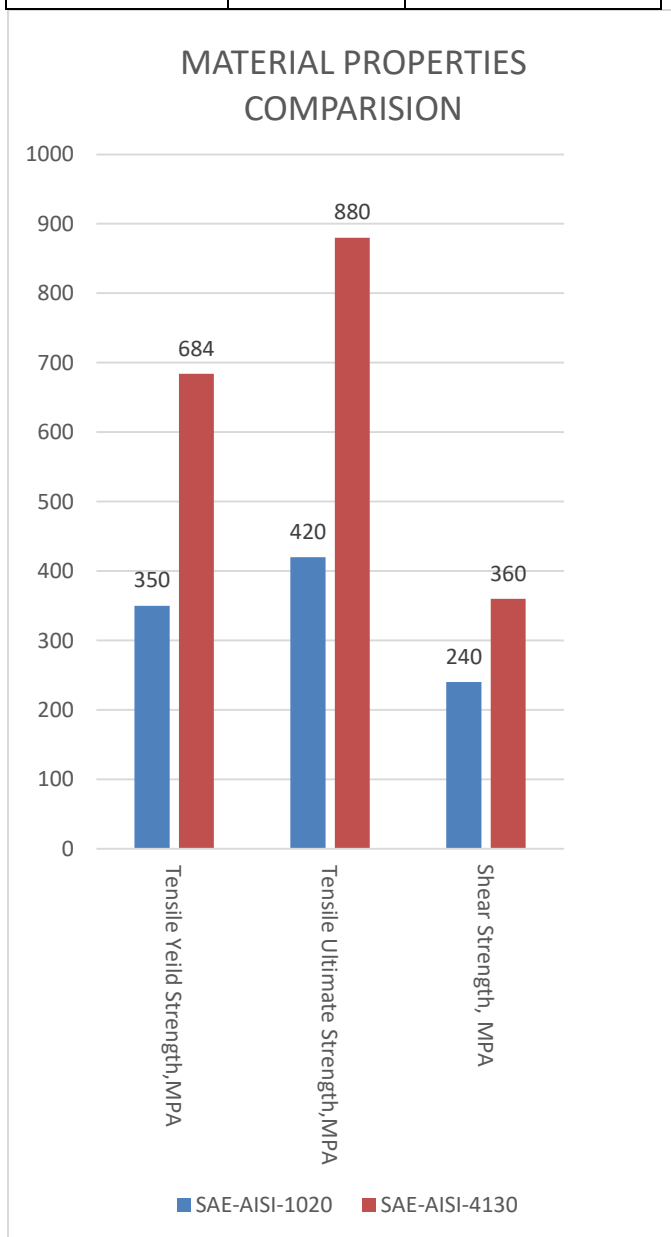
The initial design experienced deflection as predicted from the Ansys analysis when it was tested on the vehicle. The deformation arised due twisting of the Upper H-Arm in the region of the shock mount towards the out-board control point. To mitigate this an additional structural truss was added to the design.

	SAE-AISI-1020	SAE-AISI-4130
Youngs Modulus,GPA	205	205
Tensile Yeild Strength,MPA	350	684
Tensile Ultimate Strength,MPA	420	880
Shear Strength, MPA	240	360
Elongation at break, %	15	21.5

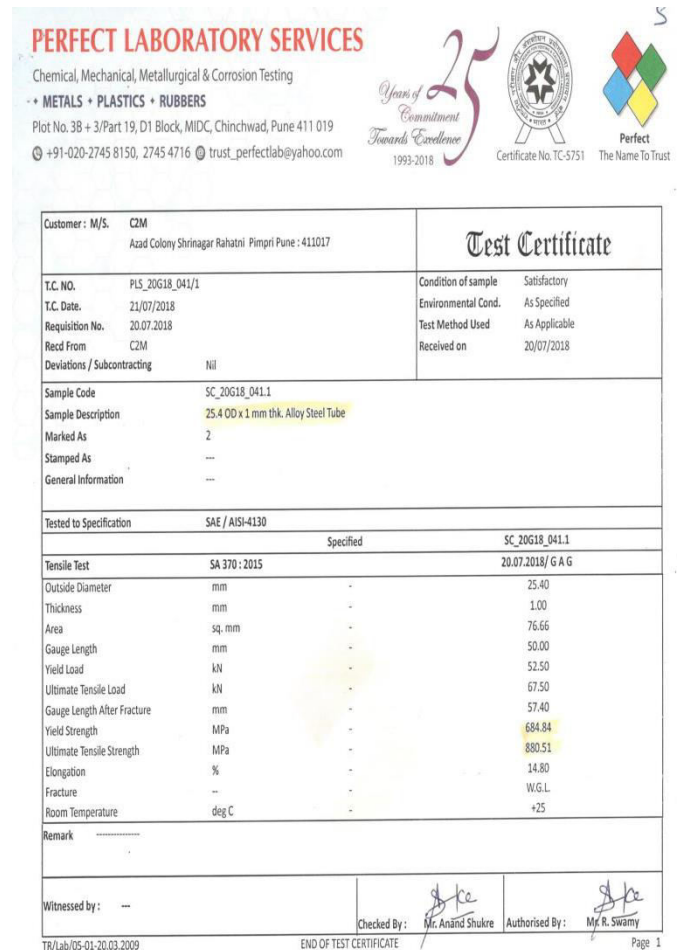
The Strength comparison is shown in the chart above from which we can conclude the superior strength of AISI 4130 compared to AISI1020.

**Table -1:** Statistics comparing AISI 1020 and AISI 4130[1]

Tensile test of the hypothesized design’s tube dimensions was conducted and the test report is shown below:



**Fig -12:** Comparison base on strength of AISI 1020 & AISI 4130



Customer: M/S. C2M		Test Certificate	
Azad Colony Shrinagar Rahatni Pimpri Pune : 411017			
T.C. NO.	PLS_20G18_041/1	Condition of sample	Satisfactory
T.C. Date.	21/07/2018	Environmental Cond.	As Specified
Requisition No.	20.07.2018	Test Method Used	As Applicable
Recd From	C2M	Received on	20/07/2018
Deviations / Subcontracting	Nil		
Sample Code	SC_20G18_041.1		
Sample Description	25.4 OD x 1 mm thk. Alloy Steel Tube		
Marked As	2		
Stamped As	---		
General Information	---		
Tested to Specification	SAE / AISI-4130	Specified	SC_20G18_041.1
Tensile Test	SA 370 : 2015		20.07.2018/ G A G
Outside Diameter	mm	-	25.40
Thickness	mm	-	1.00
Area	sq. mm	-	76.66
Gauge Length	mm	-	50.00
Yield Load	kN	-	52.50
Ultimate Tensile Load	kN	-	67.50
Gauge Length After Fracture	mm	-	57.40
Yield Strength	MPa	-	684.84
Ultimate Tensile Strength	MPa	-	880.51
Elongation	%	-	14.80
Fracture	--	-	W.G.L.
Room Temperature	deg C	-	+25
Remark			
Witnessed by:	---	Checked by: Mr. Anand Shukre	Authorised By: Mr. R. Swamy
TR/Lab/05-01-20.03.2009	END OF TEST CERTIFICATE		Page 1

**Fig -13:** Outsourced Tensile Test report for AISI 4130 tubes

Hence, AISI4130 tubes have been selected for the hypothesized design.

### 2.6 Design goals for new design

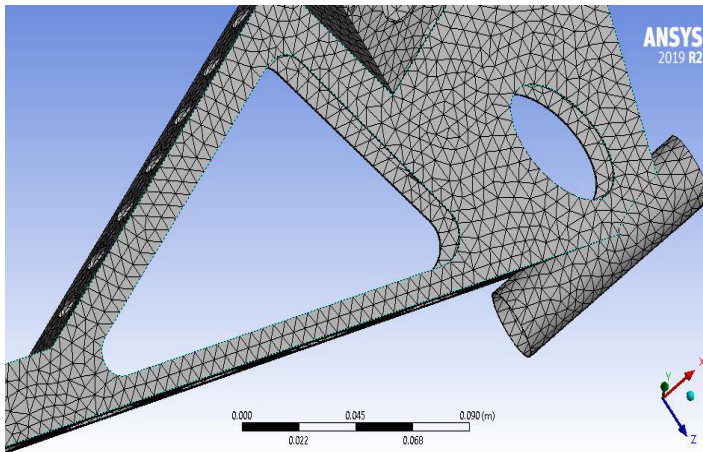
The goals for the new design were listed based on shortcomings of the previous design, which are:

- Enhance Stress distribution
- Weight reduction
- Reduction of deformation

### 2.7 Simulation Results

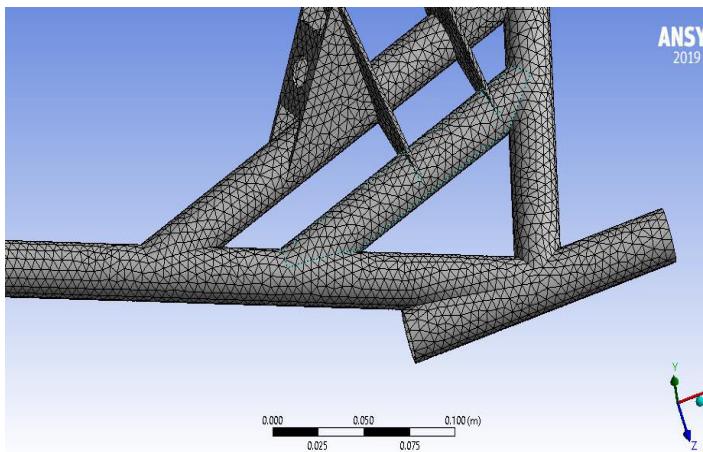
A CAD model of the hypothesized design was built on the same suspension geometry and structural Finite Element Analysis was conducted in ANSYS19.2 workbench

environment. Uniform Homogeneous Tetrahedral mesh was generated for both Laser-cut and Tubular H-arms.



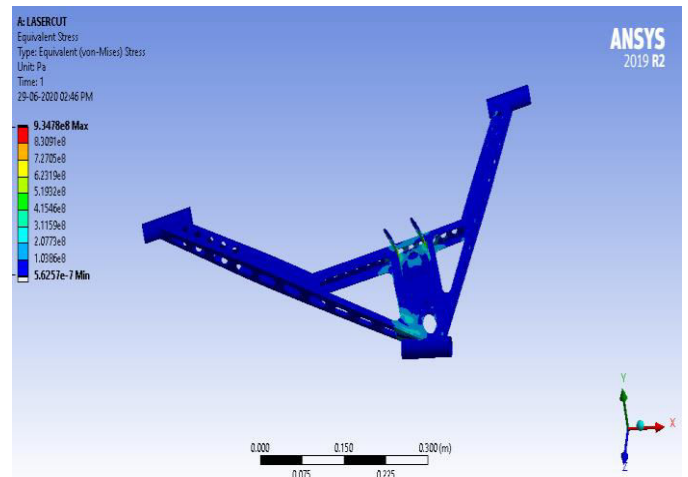
**Fig-14:** Mesh of Laser-cut H-arm.

Nodes:70759 ; Elements: 33803

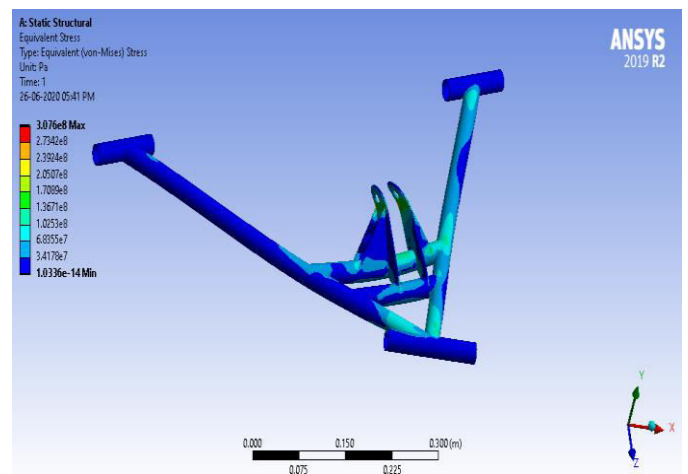


**Fig-15:** Mesh of Tubular H-arm

Nodes: 77290 ; Elements: 38774



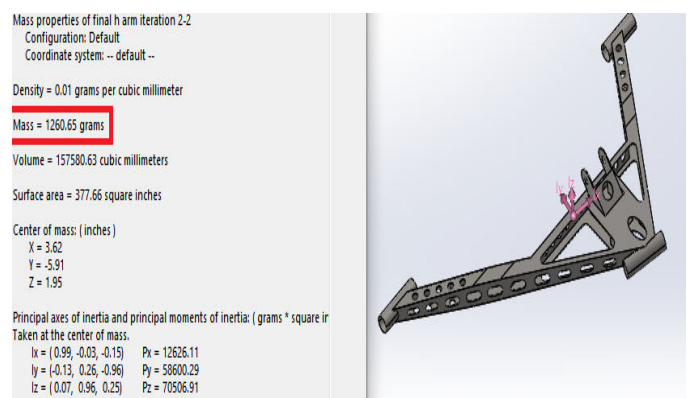
**Fig -16:** Stress distribution in Laser-cut H-arm



**Fig -17:** Stress distribution in Tubular H-arm

Here, it can be observed that the tubular structure has better stress distribution as compared to the laser-cut H-arm on the same suspension geometry.

The results of the simulations are discussed below-



**Fig -18:** Laser-cut H-arm; weight 1260.65g



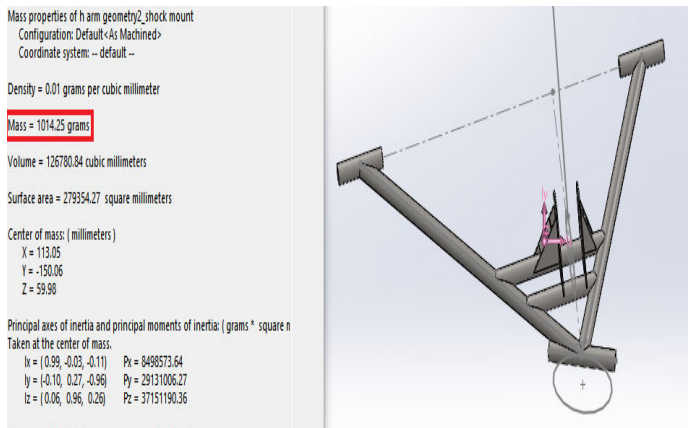


Fig -19: Tubular H-arm; weight 1014.25g

The observed weights of the laser-cut and tubular H- arms are as shown above and were found to be 1.26Kgs for the laser-cut H-arm and 1.01Kgs for the tubular H-arm, which shows a significant weight reduction.

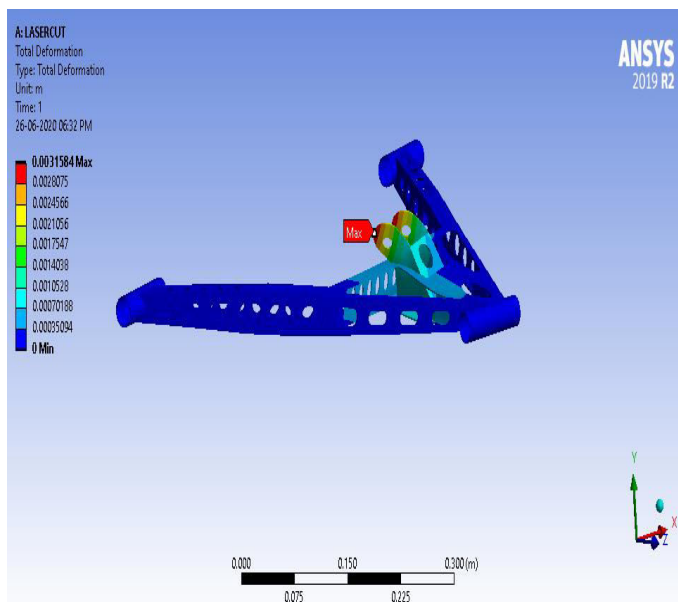


Fig -20: Deformation of the Laser-cut H- arm

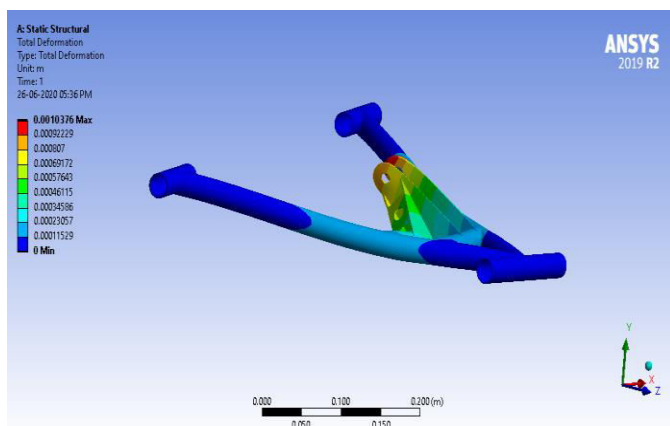


Fig -21: Deformation of the Tubular H- arm

The results for all the above aspects as generate by the simulation are as shown -

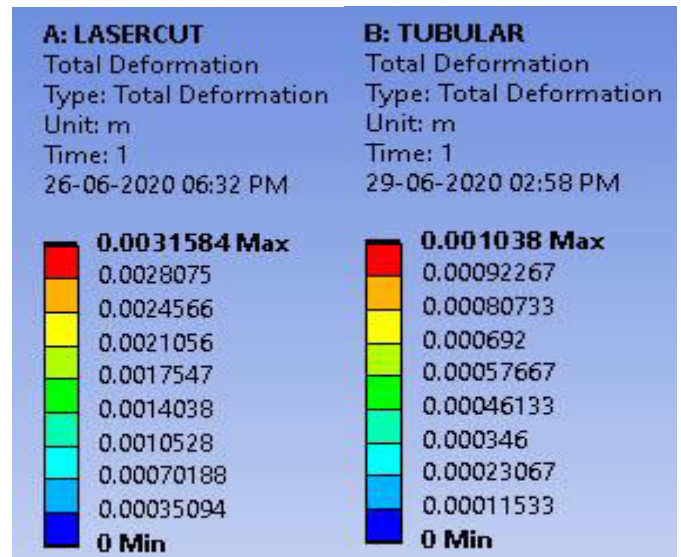


Fig -22: Results of Deformation of the Laser-cut and the Tubular H-arms

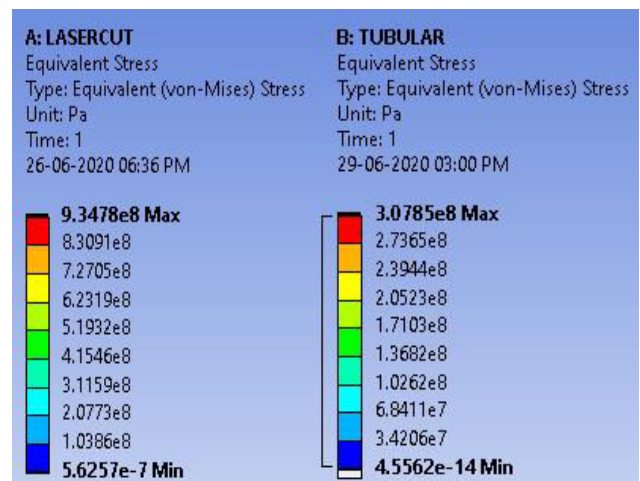


Fig -23: Results of Stress concentration of the Laser-cut and the Tubular H-arms

Here, from the results it can be inferred that there is a significant reduction of deformation in the compared designs; from 3.15mm to 1.03 mm, and tubular has lesser deformation. Also, it can be observed from the results that there is reduction in stress concentration; from 9.34 pa to 3.07 pa, which is a consequence of enhanced stress distribution.

### 3. CONCLUSIONS

The data acquired from the ADXL-345 accelerometer was used to conduct a more accurate CAE analysis on the new suspension link. The observations from dynamic testing, was used to make design improvements. The shift from a square cross section to a tubular structure gave the link a more rigid structure in terms of torsional rigidity. The additional member for the shock mount also reduced the cantilever effect due to the shock mount. The ANSYS results showed 66% less

deformation in the Tubular H Arm as compared to the laser cut one. The Stress Distribution has been improved by the tubular structure. We also met the design target of weight reduction with the new design, seeing a 200g drop on the new design. The transition from AISI 1020 to AISI 4130 also improved fabrication quality owing to its better weldability and higher strength to weight ratio. In conclusion, the data acquisition in combination with the appropriate design changes developed a lighter and more reliable suspension link, without compromising on performance.

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