Investigation of Natural Frequencies through Modal Analysis in Kart Cross Off-Road Vehicle chassis

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Abstract- *Kart cross off road vehicle chassis the preferred choice of chassis design due to its high strength, lightweight and safe qualities which made it suitable for a single-seat car application and an important aspect in the construction of the off-road vehicle chassis. The functions of main section in the chassis is vital for the driver's safety under high impact collision and high frequency operating conditions. There occurs some damage to the upper part of driver's body due to collision. To avoid this Side Impact Protection sub-frame can be added. In this work existing frame was designed using Solid works modelling software. Then to increase driver's safety additional sub-frames were added. Then the first six natural frequencies. Then mode shapes were obtained using ANSYS. From analysis, the natural frequencies extracted using ANSYS produced 6 mode shapes within 0-100 Hz frequency range. All mode shapes produced natural frequencies above 32 Hz. The maximum deflection occurred in the chassis structure is 8.17 mm due to vibration. It is located at the side impact protection sub-frame. Improvement can be made by installing cross member frame on both side of the sub-frame. In this study, the amount of displacement is considered small.*

Keywords- Kart Cross, off-road vehicle chassis, Solid works, Natural Frequencies, ANSYS.

I. INTRODUCTION

Nowadays, there are various formula-style racing competitions for universities students around the world to compete. Among the notable student-based competition are the Formula SAE (FSAE) and Formula Student. Normally, the formula-style design and race based competition require the participant to design, fabricate and finally race against each other in a highly competitive tournament. The competition imposes some limitations on the chassis design and engine capability requires the student to use their knowledge and creativity to overcome the limitation. Space frame is one of the compulsory requirements in designing the chassis. The use of space frame provides notable advantages is the mass of the chassis structure is lower and cost effective compared with other type of chassis, however complicated manufacturing process, limits its usage only to performance and niche market cars. The construction of the chassis structure is divided into several sections namely, Main Hoop, Front Hoop, Side Impact Protection and the Crush Zone. The functions of the main sections in the chassis structure is vital for the safety of the driver, in which, both Main Hoop and Front Hoop will protect the driver in case of rollover and to ensure upper part of the driver's body is sufficiently covered. The Side Impact Protection sub frame is constructed to protect the driver from any collision on the either side of the car. As part of the main chassis structure, the Crush Zone is located on the front section of the chassis. It is specifically designed to absorb energy during head on collision.

Different chassis structure produces different dynamic characteristic, therefore it is important to study dynamic characteristic to ensure the structure and vibration failures do not occur during the chassis operating life. There are various ways to analyze dynamic characteristic of a structure, among the well-known method of extracting dynamic behavior in a structure is Modal Analysis, from which natural frequencies, mode shape and resonance frequency of a structure can be ascertained. Vehicle chassis structure usually dynamically excited from uneven or rough road profile, engine and transmission vibration and etc. Under the dynamic excitation experienced by the chassis, the chassis structure will vibrates. If the vibration caused from the external excitation is the same as the natural frequency it will cause a phenomenon called resonance, which can lead to excessive deflection and failure as explained by Rao. First natural frequency or resonance is one of the contributing factors for vibration and noise related problems that occur in structures and machineries. The dynamic characteristic can be analyzed through experimentation and simulation. With advancement in hardware computing power finite element analysis simulation has made possible and gained it place in complement with experiment based analyses.

There are several software that can be used to analyze dynamic behavior, computer-based finite element analyses ANSYS, dynamic characteristic can be obtained using variety of vibration and structural design analyses packaged in the software as described by (Lin *et al*., 2012; Wang and Sun, 2010). Earlier study by Suhir and Burke (1994) concurred that, finite element analysis using finite element method is a practical tool to identify structural dynamic behavior such as mode shape and natural frequencies. As explained previously by Rao (2004), forced external excitation from engine's imbalance cycle and uneven road condition could lead to failure. Further studies conducted by Ferreira and Lopez-Pita (2012) and analyzed by (Gou-Lin and Dai-Sheng, 2008; Yang *et al*., 2012) in which they conclude that if excitation signal frequency and the response frequency of the skin structure is similar, the mechanical structure will produce resonance and deflection. Naveen and Venkatesh (2014) presented from the mode shape generated from two wheeler chassis derived from Operation Deflection Shape (ODS) analysis produced six experimental mode shape, includes torsion, lateral bending and vertical bending in different modes. Computational method is a modern technique to find mode shapes of a structure where the rigidity of the structure can be analysed and the resonance vibration could be avoided. Madhu and Venugopal (2014) study shows that 14 mode shapes is extracted from the modal analysis and actual vibration characteristic under varied frequency range can be predicted. The result from Madhu and Venugopal (2014) can be used a reference value for other analysis related to dynamic behavior i.e., random analysis, harmonic analysis based on similar structure configuration of the study.

A harmonic analysis is used to calculate the response of the chassis structure to a cyclic load over a frequency range and the result is plotted on amplitude vs. frequency graph to provide valuable dynamic characteristic information concerning the chassis structure. ANSYS's Harmonic Analysis module can simulate a structural response under forced vibration from imbalance engine cycle drive and the module efficiently extract the forced excitation amplitude deflection of the structure, which later can be used to predict and prevent damage and large deflection to the structure as explained in studies by (Zhang and Kang, 2013; Luo *et al*., 2012). Ahmad and Brahmananda (2003) presented a result from motorcycle chassis mode shape analysis showed that large displacement at handlebar position could cause the rider discomfort and the first two frequencies obtained lies in the human discomfort region (0-100 Hz). Thus, further study and modification is needed to bring the motorcycle chassis vibration within the human comfort zone. As stated earlier, vibration analysis can be done experimentally, but the cost of conducting using this method is expensive compared to simulation based analysis. However, the result from the analysis will be more precise compared with the simulation based counterpart. This is due to over simplification of the physical model in the simulation, apart from selecting unsuitable element and coarse element meshing which can lead to producing in accurate result. There are several studies related to experimental vibration analysis, for instance in reference to work performed by (He and Fu, 2001). In this study the chassis is tested experimentally by suspending the chassis structure with springs to simulate free-free boundary condition and the chassis is excited using a shaker so that the mode shape of the chassis can be derived. Another notable study on experimental harmonic analysis on full sized vehicle chassis is performed by Wenlin *et al*. (2010). The study utilized Land-Wind X6 chassis, data acquisition system and an input hammer, which produced eleven mode shapes with the frequency below 150Hz are then verified with Modal Assurance Criteria (MAC) method for validation.

Although there are several of research on car chassis structure vibration analysis both experimentally and simulation, but most of the research are not fully address modal analysis specifically on kart cross race car chassis. The goal of the study is to analyze the mode shape of the kart cross race car chassis structure under vibrational excitation through modal analysis using Finite Element (FE) method. This study acts as an initial step to perform vibration analysis experimentally.

II. THEORY OF VIBRATION ANALYSIS

Frequency Response Function utilizes measurement techniques of Fast Fourier Transform(FFT), which is widely used in analyzing structural dynamic especially in automotive industries to establish vibration characteristic i.e., mode shape, natural frequencies of vehicle model. The equation of motion for undamped system is formulated from:

$$[m]\{\ddot{q}\} + [k]\{q\} = \{0\} \quad (1)$$

where, m, q and k is the constant which describe the mass, displacement and stiffness of the system and Equation (1) equal to zero if there is no force applied to the system. q Is displacement for a linear system, which in harmonic form will be Equation 2:

$$\{q\}_i = \{Q\}_i \sin(\omega t) \quad (2)$$

Where, Q_i is the amplitude of mode shape of the *ith* natural frequency ω_i, therefore:

$$\left(-\omega^2 [m] + [k]\right)\{Q\} = 0 \quad (3)$$

The solution from Equation (3) gives Eigen values, which is the square root of the natural frequencies and the Eigen vectors are the amplitude of the corresponding natural frequencies. The natural frequencies gathered from the modal analysis can be used to provide information on critical mounting points for vibration sourced component i.e., engine, transmission, suspension system, electric motors and etc.

III. FINITE ELEMENT MODEL GEOMETRY

Most of the racecar design regulations are loosely based on the Formula SAE design criteria (Formula SAE® Rules). There are three main sections used in the construction of the kart cross chassis, with all the different section are intended for the specific purposes of the chassis structure. A 20 mm diameter tube with wall thickness of 3 mm is used for both front and main hoops construction. Other tube frame construction such as the side beam and front beam is constructed by using a 25 mm with 2 mm wall thickness tube. The wish bone section of the chassis is constructed with 18 mm tube with 1.8 mm wall thickness. The thicker tube is selected for both front and main hoops section since it can withstand any rolling impact in case the car rolls over. The wish bone is assumed as not a part of the chassis structure because it is not permanently fixed to the main structure. The entire tube specifications and thicknesses are entered to the section geometry option in the ANSYS software. The chassis structure modelling is done entirely on ANSYS Workbench.

Fig. 1. The actual space frame race car chassis in solid works

The actual race car model is shown in Fig. 1. Chassis structure carries the engine and fuel tank located at rear, single seat passenger and electrical equipment at mid chassis and braking and steering system component is placed at the front section. All equipment's and components as well as the passenger are excluded from the analysis to ensure the accuracy in the result.

IV. GEOMETRY MESHING

The model in ANSYS is assumed to be made from tube frame in which PIPE288 element is selected to simulate the car chassis. PIPE288 element is chosen because the element is suitable for analyzing short pipe structures which based on the Timoshenko beam theory with shear deformation effect are included (ANSYS, 20174). PIPE288 is a 3-D linear, quadratic two-noded pipe element which has six degrees of freedom, making the element suited for linear, large rotation and strain nonlinear application (ANSYS, 2017). Key point is created by using the dimension according to the actual chassis construction and then the key points created are connected using lines option and the lines are meshed using mesh tool in ANSYS. The model is meshed using mapped element with equivalent size on every line. A total of 5875 nodes and 5900 elements are created. The total number of nodes and elements created are sufficient to produce an acceptable result.

V. MATERIAL PROPERTIES

All of the tube is made from steel. The selection of steels as the material from chassis construction is based on the rules and regulation set by FSAE. In the rules, there are only two type of materials can be used for constructing the car chassis which are aluminum and steels and for the analysis purposes, steels is selected. Steels have a material density of 7860 kg/m2, a Poisson's Ratio of 0.3, Young's Modulus of 200 GPa and yield strength of 355MPa.

VI. BOUNDARY CONDITION

Since no weight is carried by the chassis, therefore there are no loads are applied in vibration analysis with all degree of freedom are free to evaluate the natural response of the chassis structure. For analysis purposes, damping coefficient is ignored for modal analysis.

VII. FINITE ELEMENT RESULT MODAL ANALYSIS

This study utilize modal analysis to generate the natural frequencies and mode shapes of the kart cross chassis structure. Result from Modal Analysis is important as it can predict the response of structural parameters under dynamic loading condition. Mode shapes simulated from Modal Analysis can provide the information of how the chassis structure will naturally displace. ANSYS Workbench is used for the modal analysis. The mode shapes are extracted using Block Lanczos method. From the result, 6 modal analysis results are obtained between 0-100 Hz range; Fig. 2 to 13 illustrate the first six natural frequencies for the corresponding mode shape which are important to the study. Mode shapes frequencies and characteristic are tabulated in Table 1 and Table 2. Table 1 and Table outlines the first natural frequency for the chassis is at approximately 32.768 Hz. The mode shape of the race car structure is critical because resonance usually occurs in these frequencies. The second modal frequency is vibrated at 44.785 Hz, the third modal frequency vibrated at 64.756 Hz, fourth modal frequency at 71.648 Hz, fifth modal frequency at 82.017 Hz and the last modal frequency within 0-100 Hz range vibrated at 89.793 Hz. The 6 mode shapes are produced by ANSYS illustrates different modal frequency characteristic. The first mode shape generated a bending behavior, occurred at the rear section of the chassis. If the bending behavior is animated in ANSYS, it produced a flapping-like animation resembling a bird flapping its wing, as called by Wenlin et al. (2010).

NATURAL FREQUENCIES FOR EXISTING MODEL
FIXED FREE BOUNDARY CONDITION

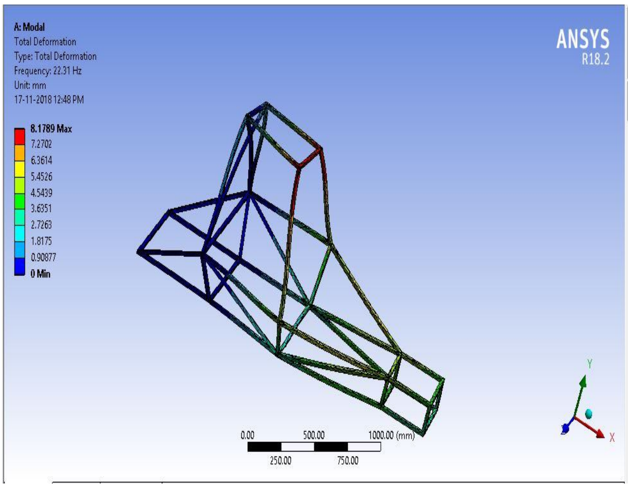

Fig No: 2 First mode shape

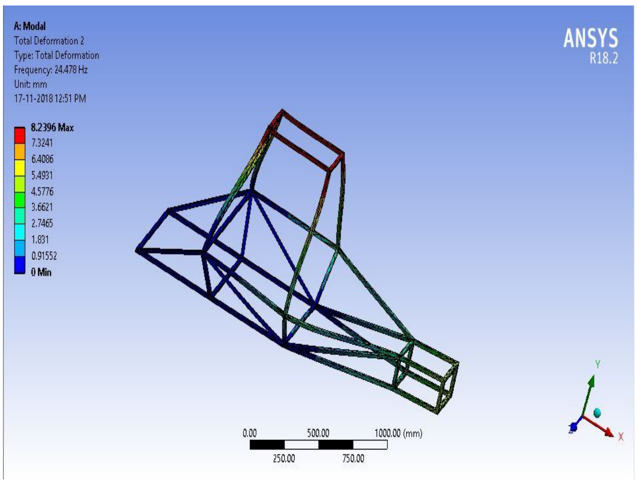

Fig No: 3 Second mode shape

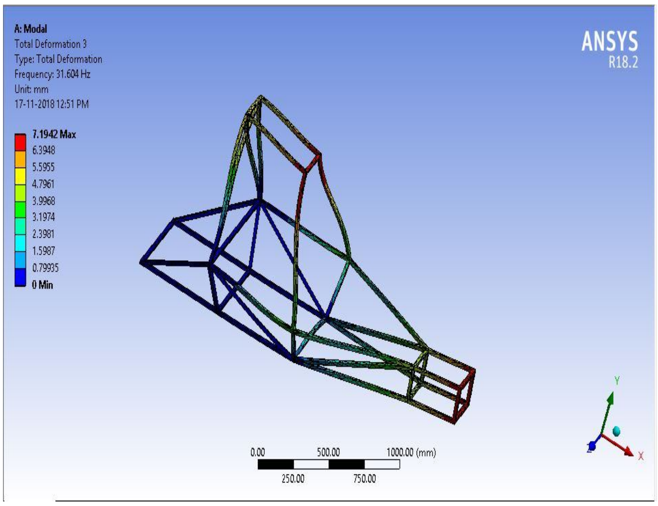

Fig No: 4 third mode shape

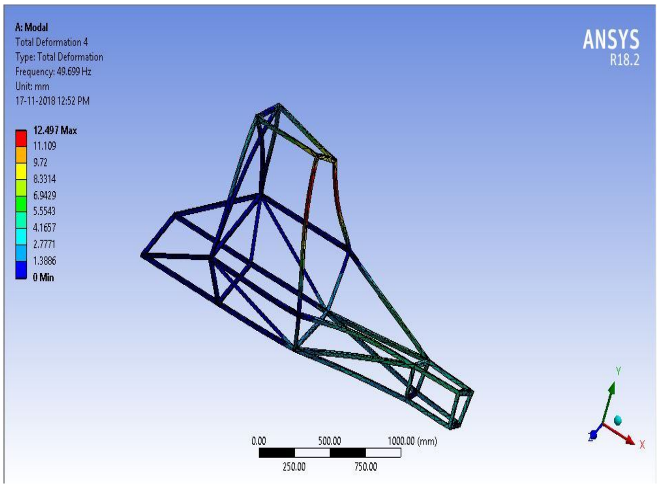

Fig No: 5 Fourth mode shape

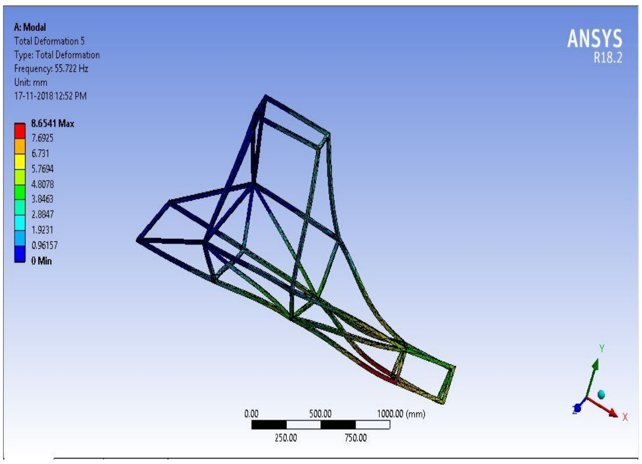

Fig No: 6 Fifth mode shape

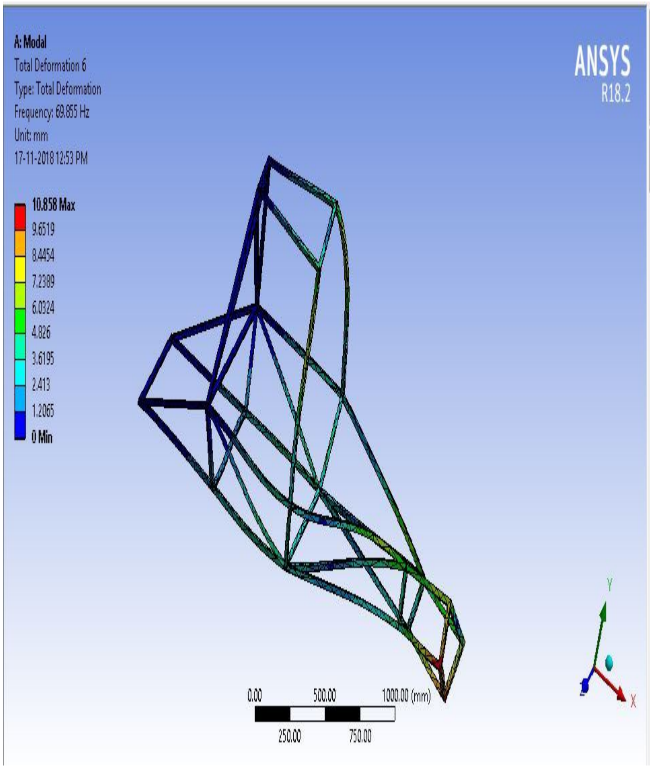

Fig No: 7 Sixth mode shape

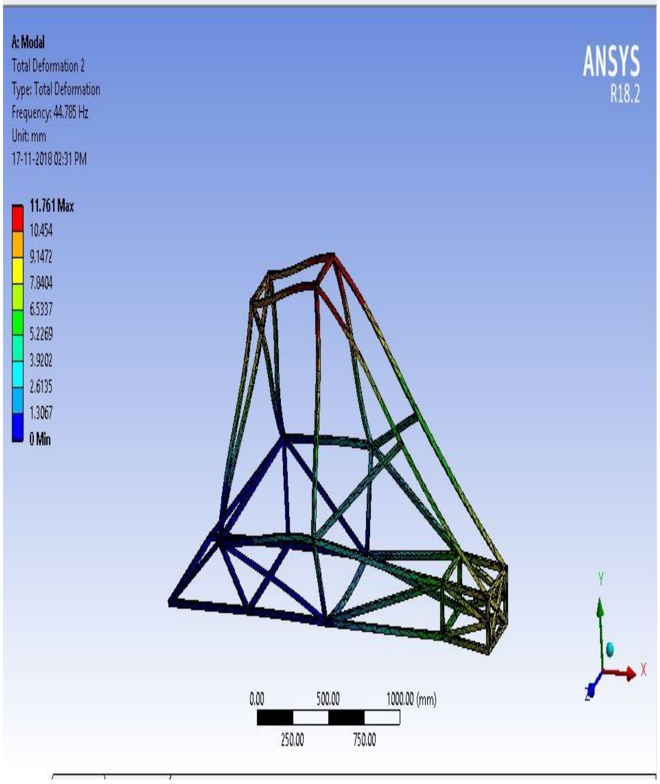

Fig No: 9 Second mode shape

NATURAL FREQUENCIES FOR MODIFIED MODEL

FIXED FREE BOUNDARY CONDITION

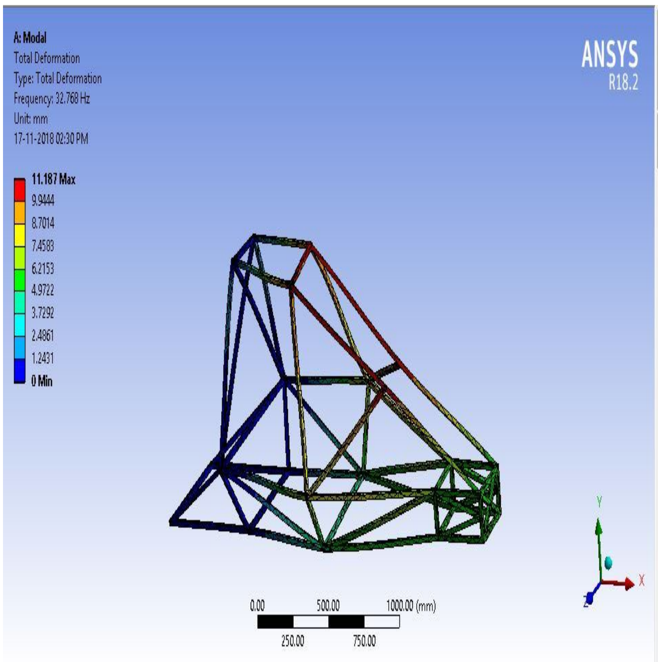

Fig No: 8 First mode shape

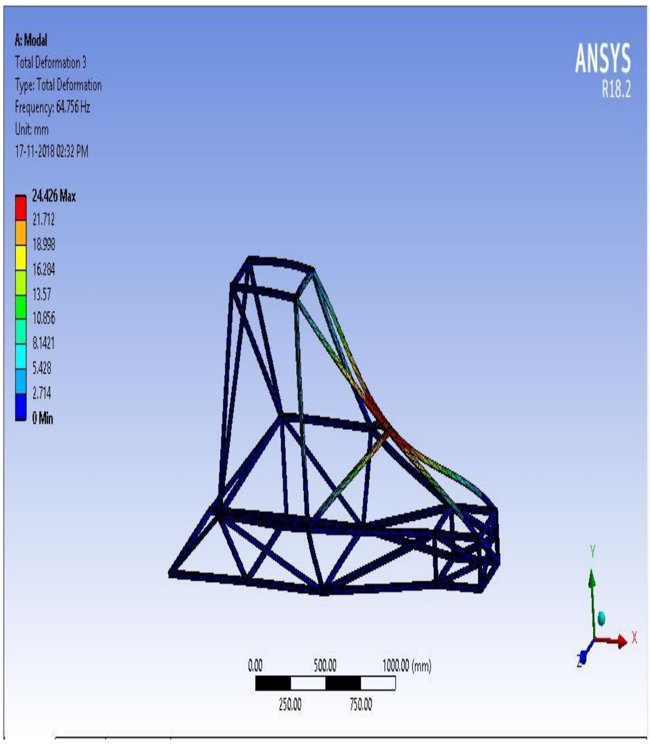

Fig No: 10 Third mode shape

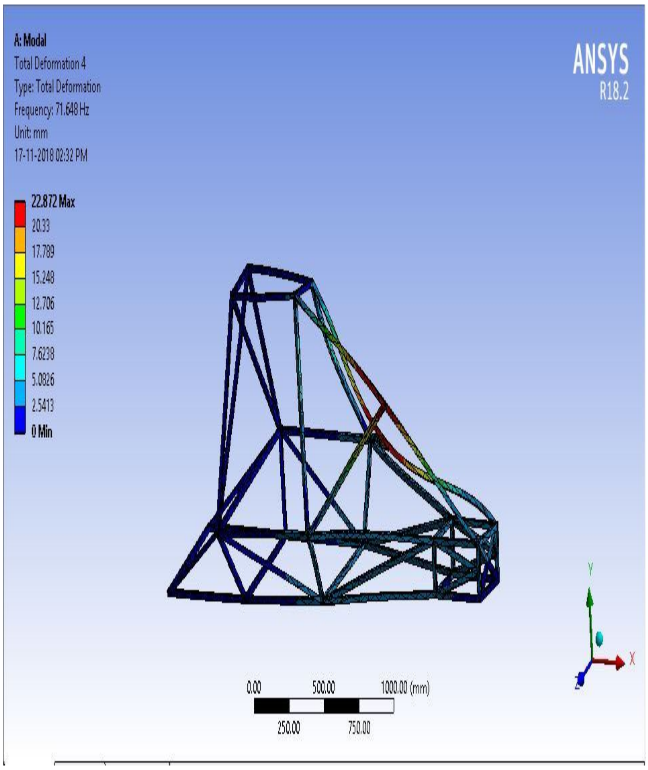

Fig No: 11 Fourth mode shape

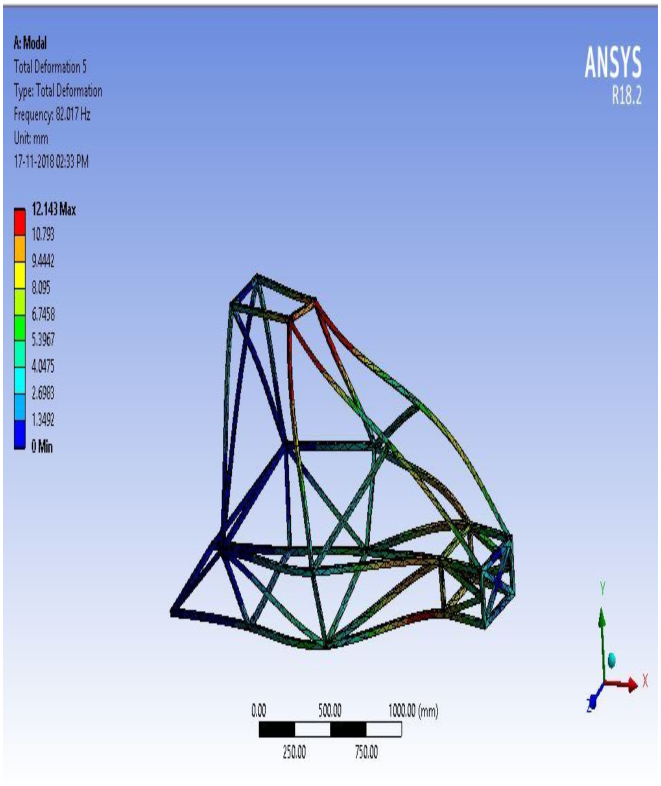

Fig No: 12 Fifth mode shape

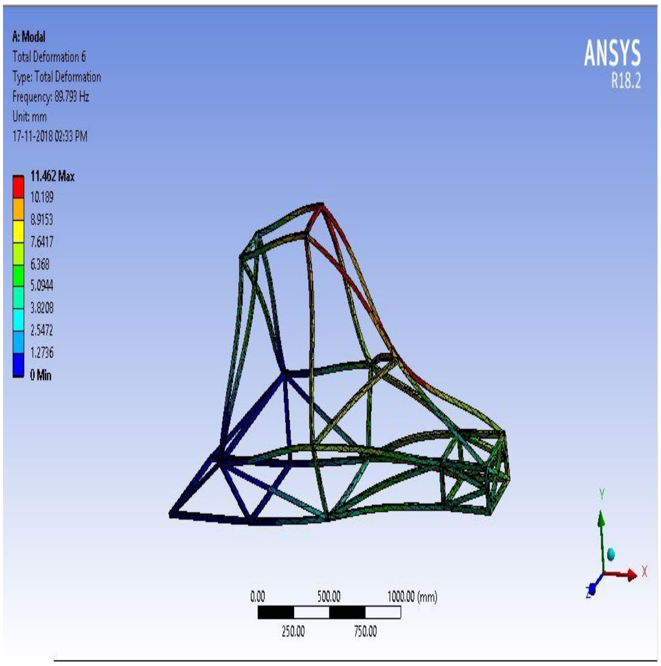

Fig No: 13 Sixth mode shape

BOUNDARY CONDITION FOR FIXED FREE SUPPORT

Table: 1 Frequencies and Deformation of the New Model

MODE	FREQUENCIES (HZ)	DEFORMATION (mm)
1	32.768	8.1789
2	44.785	8.2396
3	64.756	7.1942
4	71.648	12.497
5	82.017	8.6541
6	89.793	10.858

Table: 2 Frequencies and Deformation of the Existing Model

MODE	FREQUENCIES (HZ)	DEFORMATION (mm)
1	22.31	11.187
2	24.478	11.761
3	31.604	24.426
4	49.699	22.872
5	55.722	12.143
6	69.855	11.462

The result from ANSYS solver shows large deformation caused by the modal frequencies and can be magnified, that in so doing, any small or large deformation can be seen in the result.

VIII. CONCLUSION

The analysis found that the natural frequencies extracted using ANSYS produced 6 mode shapes within 0-100 Hz frequency range. All mode shapes produced natural frequencies above 32 Hz which is safe and comfortable for human usage, which is similar result produced from the study by Mohammad Al Bukhari Marzuki (2011). The lowest natural frequency produced from the chassis is at approximately 32 Hz, far-off from external excitation frequency.

Mode shapes generated from modal analysis shown that different frequency produced different characteristic which include bending. It is an important fact that if external excitation similar to that of the natural frequencies, this will consequently result in deflection in the chassis structure. The highest displacement caused by vibration in the chassis structure is 8.17 mm located at the side impact protection sub-frame. Improvement can be made by installing cross member frame on both side of the sub-frame, although in this study, the amount of displacement is considered small. Based on the Modal Analysis, the resonance frequency for the chassis structure is marked on the sixth natural frequency of 93.14 Hz with recorded maximum deflection of 8.17 mm at this frequency. Overall, the results produced from modal analysis are an important in finding of analyzing dynamic response of a kart cross off road vehicle chassis structure.

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