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A Study on the Strength of CNG Cylinders Frame in a New Energy Coach

Zhengyang GENG[1],Yong HAN[1],Jinping XIE[1], Hongwu HUANG[1]

[1] *School of Mechanical and Automotive Engineering, Xiamen University of Technology, Fujian Xiamen 361024, China.Email*:yonghan@xmut.edu.cn

Abstract:

***Background*:**Recently, the global energy and environmental situations have promoted the development of new energy coaches. The compressed natural gas (CNG) coaches with the advantages of low pollution, low energy consumption have become the main tools of residents' travels, which is also bringing about an urgent problem to solve for vehicle safety.

***Objective*:** This paper is aimed to study the influence of dynamicload for CNG cylinder frame in a new energy coach.

***Method and Material*:** The finite element model of CNG cylinders and frame was developed with 3D reverse engineering and the finite element method. The strength analysis was performed by loading 6.6g acceleration in the forward direction and 5gacceleration in horizontal direction according to ECE R110 regulations requirements.

***Results*:**After the displacement of frame reached to the dynamic balance, the von Misesstress distribution was analyzed. The results indicatedthat the maximum valueswere less than the permissible stress.

Conclusions:The finite element method was adopted to analysis of the strength ofCNG cylinders frame,reduce the cost of the development ina new energy coach, and provide an important reference of the research and design in a new energy coach.

Keywords: New energy coach, Dynamic loadings, CNG cylinder frame, Finite element method

1 Introduction

Recently, the global energy and environmental situations have promoted the development of new energy coaches [1]. The compressed natural gas (CNG) coaches with the advantages of low pollution, low energy consumptionhavebecome the main tools of residents' travels[2]. Compared with regular passenger cars, the natural gas coacheshave been increased the CNG cylinders and frame. In the regulation of the ECE R110[3] and ISO/DIS 11439[4],the compressed natural gas (CNG) cylinders frame must have the ability of maintaining the CNG cylinders salability front the shock of the impact force of 6.6g acceleration in the forward direction and 5gacceleration in horizontal direction. Therefore, based on ECE R110 requirements, the finite element model of CNG cylinders and frame was developed in HyperMesh and LS_DYNA Solver code was selected to study the influence of dynamicload for CNG cylinder frame in a new energy coach.

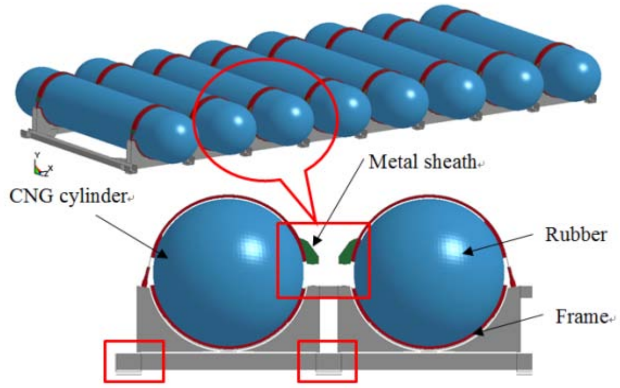
2 Model development

2.1 Finite Element Model

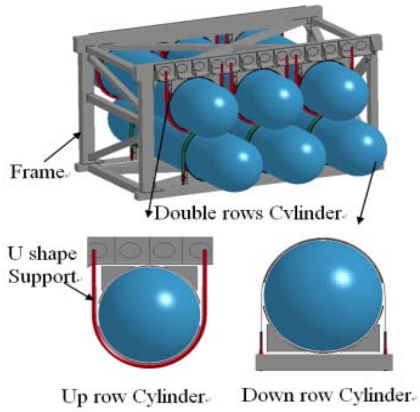
Usually, the CNG cylinder frame of a new energy coach is fixed on the body frame by the embedded bolt, and the cylinders are connected to the fixed frame by metal sheath [5]. In this paper, the CNG cylinder frame consists of two parts, respectively is the single row cylinders located on the top and double rowscylinder located in the bottom of the new coach. In order to reduce the calculation time, the model was simplified as follows:

1) Most of the body frame was cut out expect the partsconnected to the CNG cylinder frame.
2) The adjacent nodes were merged according to the principle of node merging processing
3) The nodes of CNG cylinders were added the weight by means of uniform quality.
4) The weld and bolts was simulated by the beam elements.

The FE models consist of CNG cylinders, frame, rubber ring, metal sheath and some bolts, which are shown in Figure 1.



The single row cylinder FE model



Double row CNG cylinders FE model
Figure 1 The CNG cylinder FE models

Table 1 shows the information of the two types of the FE models of the cylinder

Table 1 CNG cylinder FE model

Model	Mass(Kg)	No. of Elements	Cylinder full gas（kg）	Nodes	Trias	# of Trias （%）
Single row	930	439,343	100	258,547	6,662	1.5
Double row	771.3	506,011	100	366,319	21,568	5.8

2.2 Material Test

The CNG cylinder frame is main supported by the components of the rubber ring, metal sheath and bolt. In which, the material tensile test has been performed based on the regulation of Chinese standard GB/T228-2002 [6]. The true stress-strain curve has been shown in figure 2.The parameters of the metal sheath are: Steel's density is 0.78g/cm^3, its yield stress is 268 MPa, its Elasticity Modulus is 250Gpa, and its Poisson Ratio is 0.3.

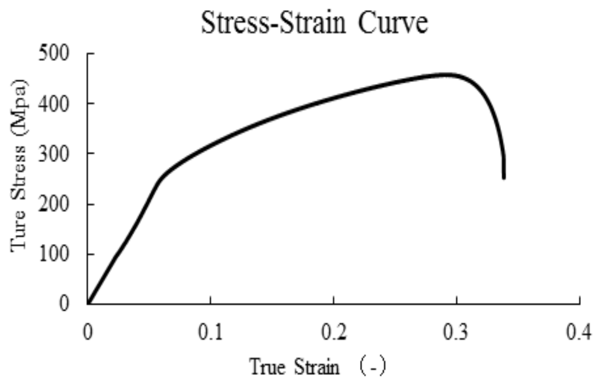


Figure 2the Material TensileTest

In addition, the tensile experiment conjunction of the metal sheath and bolt was performed to examine the strength of the welding rod. Figure 3 shows the tensile test of the conjunction. The failure location was observed at the metal sheath part, no failure was observed at the screw bolt and welding rod. Figure 4 shows the tensile stress. The failure stress of the metal sheath was 460 MPa.

Figure 3 Tensile test of the conjunction

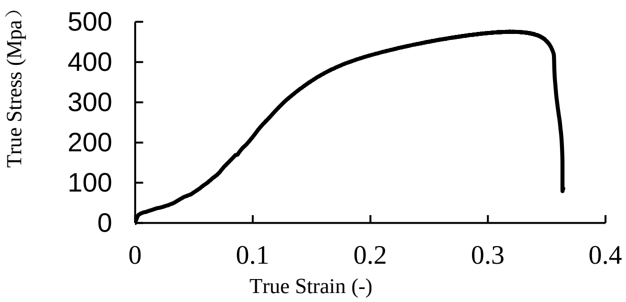


Figure 4 Stress-Strain Curve of the conjunction structure

2.3 Boundary condition

In the simulations, the boundary conditions were defined based on the requirement of ECE R110 section 17.4. Two type of the conditions has been defined in simulation models.

1) Load a 6.6gforward direction acceleration while taking the gravity into account;

2) Load a5g horizontal direction acceleration while taking the gravity into account.

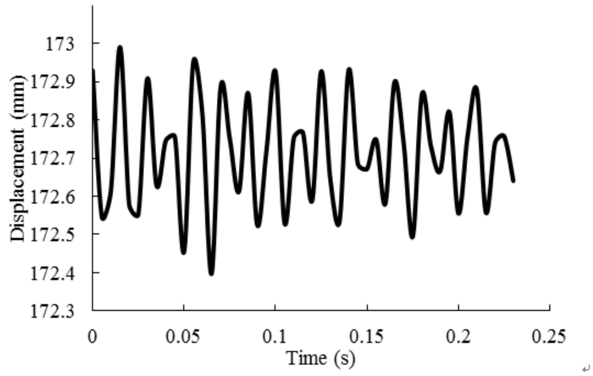
In addition, the frames in both models were fixed with 6-degrees to simulate the frame fixed to the vehicle body.

3 Dynamic simulation and results

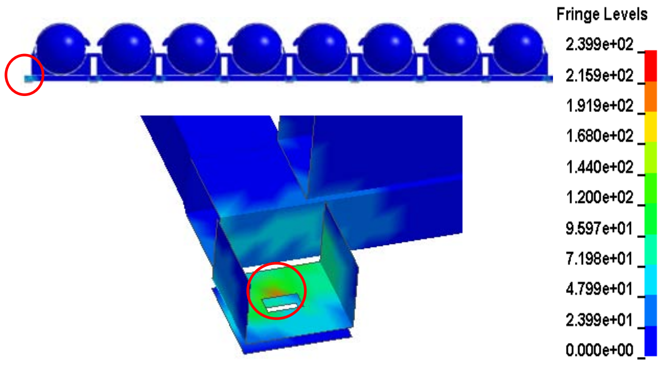
In the FE simulations, LS-DYNA solve soft was used to analyze the von Mises stress distribution.

3.1 Single CNG Cylinder FE model

Figure 5 and figure 6 show the results of the single row CNG cylinder. Figure 5(a) shows the movement displacement of the cylinder in forward moving direction; figure 6(a)showsthe vehicle horizontal direction.The vibrations of the maximum displacement of cylinder were all less than 1 mm, which demonstrated that the movement of the CNG cylinderreached the dynamic equilibrium and relatively stability without movement at time of 230ms. The von Mises stress can be as the maximum value.Figure 5(b)shows the maximum value in forward direction was 239.9MPa and local at the screw bolt (red ring); figure 6(b) shows the maximum value inhorizontal direction was 241.1 MPa and also local at the screw bolt. When the SF is 1.1, the maximum values in forward moving direction and in forward moving direction were lower than the permissible stress (243.6 MPa) depending on Mises yield criterio. Therefore, the cylinder fixed frame can withstand dynamic load produced by the CNG cylinders and prevent the CNG cylinders from being destroyed and the cylinder was protected well.

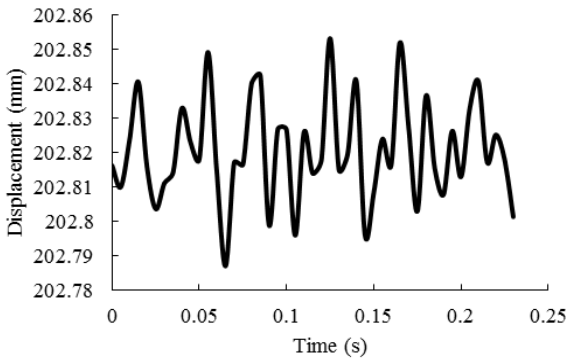


(a) **CNG cylinder movement displacement**

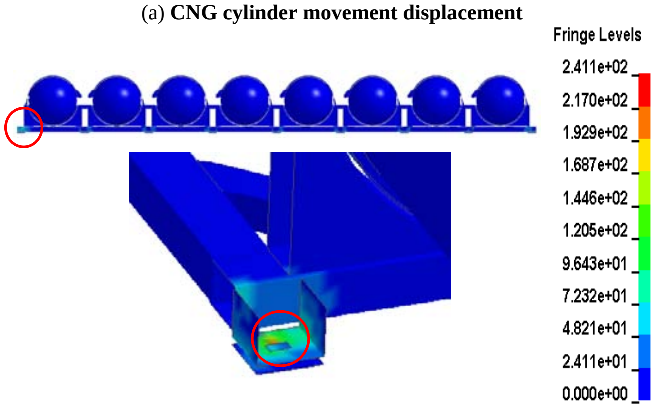


(b) **von Mises stress distribution of the FE model**

Figure 5 single row CNG cylinders analysis results in forward moving direction



(a) **CNG cylinder movement displacement**

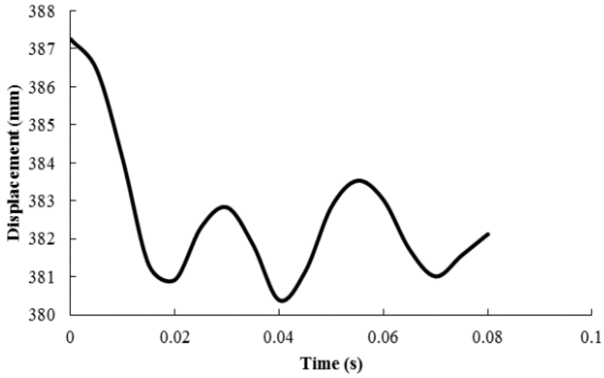


(b) **von Mises stress distribution of the FE model**

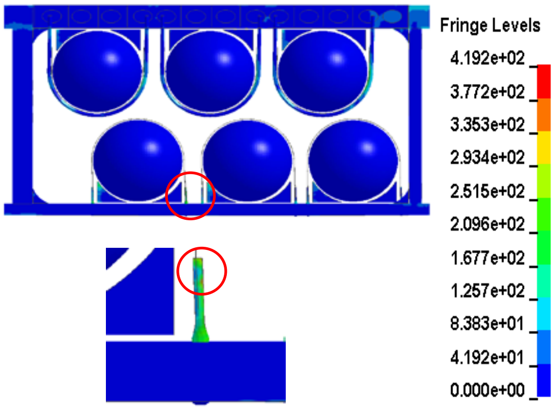
Figure 6 Single row CNG cylinders analysis results in vehicle horizontal direction

3.2 Multi-CNG Cylinder FE model

In the double row CNG cylinder FE simulations,the accelerations were loaded in the forward moving direction and vehicle horizontal direction.Figure 7 and figure 8 show the analysis results. Figure 7(a) and figure 8(a)show the relative node's displacement in cylinder and frame respectively. The vibrations of the displacement were small and reached dynamic equilibrium from 20 ms, which demonstrated that the loading force reached the maximum.Then, the von Mises stress reached up to the Max. Value.The Max. Stress distribution in forward directionwas 419.2 MPa and located at the rubber ring area and boltarea(figure 7(b)); the maximum von Mises stress in horizontal direction was 266.2MPa and located at the bolt (figure 8(b)). When the SF is 1.5, the maximum valueswere lower than the permissible stress (426.6 MPa).The stress distribution of other placewas homogeneous. The Max.value of the cylinder was 220 MPa. Therefore, the cylinder was protected well.

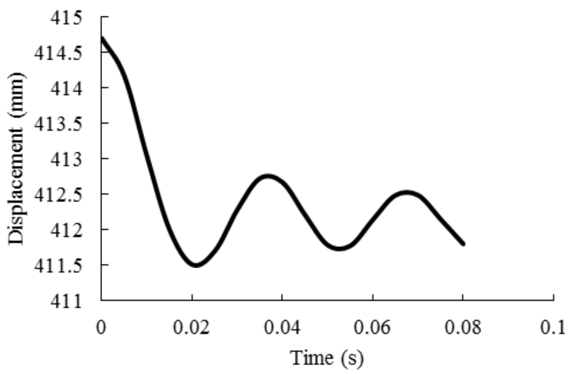


(a) **CNG cylinder movement displacement**

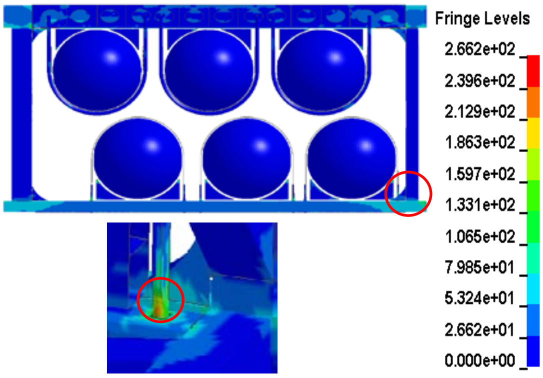


(b) **von Mises stress distribution of the FE model**

Figure 7 Double row CNG cylinders analysis results in forward moving direction



(a) CNG cylinder movement displacement



(b) von Mises stress distribution of the FE model

Figure 8 Double row CNG cylinders analysis results in vehicle horizontal direction

4 Conclusions

Application of CNG as a new fuel is an effective and realistic method to resolve the current problems of environmental protections and preservation of oil reserves. This paper put the method of 3D reverse engineering and the finite element to study the influence of dynamicload for CNG cylinders frame in a new energy coach. The conclusions are as follows:

The maximum value in the single row cylinder was 239.9 MPa and 241.1 MPa, located at the screw bolt and less than the permissible stress of 243.6 MPa. The maximum value in double row CNG cylinders was 419.2 MPa and 266 MPa, located at the bolt and less than the permissible stress of 426.6 MPa. So the cylinder fixed frame can withstand dynamic load produced by the CNG cylinders and prevent the CNG cylinders from being destroyed, which meets the requirements of the ECE R110.

The method of 3D reverse engineering and the finite element can be used to identify whether the strength of the CNG cylinder frame meets the repairmen of the ECE R110, which reduces the number of experiments and the new energy coach design and development costs.

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