UNIVERSITI PUTRA MALAYSIA

ERGONOMIC CONSIDERATIONS FOR ASSEMBLY AND DISASSEMBALY OF CNG TANKS ON A VEHICLE

LO WOON CHEK.

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LO WOON CHEK

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Chairman: Associate Professor Rosnah Mohd. Yusuff, PhD

Faculty: Engineering

The use of natural gas as an automotive fuel is expanding worldwide, particularly so with the increasing price of petrol and diesel. Natural gas vehicle (NGV) is a relatively new and rapidly evolving technology in Malaysia. As of 2005, there were more than 12,000 NGVs and 38 refuelling stations available in the country. However, the use of natural gas as a vehicle fuel creates challenges in vehicle design. The installation of compressed natural gas (CNG) cylinders into the vehicle requires an analysis of the space availability, mounting system, design to assembly, disassembly and maintenance, fasteners operations, visibility and labelling issues, therefore creating a new impact on the vehicle design. In this study, a petrol fuelled sedan type passenger car has been chosen as a case study by its conversion to bi-fuelled and mono-fuelled NGV. A total of four designs have been introduced: locating the CNG

cylinders in the (i) luggage compartment and (ii) beneath the vehicle floor pan while retaining the original platform, also (iii) placing the cylinder under the backbone and (iv) rear platform by raising the floor. Ergonomics design guidelines and industrial NGV standards have played an important role in the design and design assessment. Many characteristics have been considered and studied to integrate the human into the system. These included equipment accessibility, workspace and operations, and physical accommodation. Virtual reality (VR), which enables the modelling of systems and components, was used for the simulation of assembly, disassembly, maintenance, reachability and visibility operations, and subsequently to evaluate and improve the designs. Concurrently, postural analyses were conducted using Rapid Upper Limb Assessment (RULA) technique. The virtual human contained within the VR software was used to perform the physical work, in an effort to reduce the risk of musculoskeletal disorder.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

PERTIMBANGAN ERGONOMI DALAM PEMASANGAN DAN PEMBUKAAN SILINDER CNG DALAM KERETA

Oleh

LO WOON CHEK

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Pengerusi: Profesor Madya Rosnah Mohd. Yusuff, PhD

Fakulti: Kejuruteraan

Penggunaan gas asli sebagai bahan bakar kenderaan telah berkembang di serata dunia, terutamanya dengan peningkatan harga petrol dan minyak diesel. Kenderaan gas asli (NGV) merupakan satu teknologi baru yang sedang membangun di Malaysia. Pada tahun 2005, terdapat lebih daripada 12,000 NGV dan 38 stesen pengisian di negara ini. Akan tetapi, penggunaan gas asli telah mendatangkan cabaran kepada rekabentuk kenderaan. Pemasangan silinder gas asli termampat (CNG) pada kederaan memerlukan analisis ruang, sistem pemasangan, rekabentuk untuk pemasangan, pembukaan dan penyenggaraan, operasi pengancingan, kebolehlihatan serta isu pelabelan, justeru memberikan kesan baru kepada rekabentuk kenderaan. Dalam kajian ini, sebuah kereta sedan yang mengguna petrol sebagai bahan api pada asalnya telah dipilih sebagai kes kajian dalam pengubahsuaian kepada NGV

menggunakan dua dan satu bahan api. Sebanyak empat rekabentuk telah diperkenalkan: pemasangan silinder di (i) tempat bagasi dan (ii) di bawah lantai kenderaan sementaran mengekalkan badan asal, serta (iii) bawah backbone and (iv) lantai belakang dengan menaikkan badan kereta. Panduan rekabentuk ergonomi dan piawai NGV perindustrian telah memainkan peranan yang penting dalam rekabentuk dan taksiran rekabentuk. Banyak ciri-ciri telah dipertimbangkan dan dikaji untuk mengintegrasikan manusia ke dalam sistem. Ini termasuklah kebolehsampaian peralatan, ruang kerja serta operasi, dan penempatan fizikal. Realiti maya (VR) yang membolehkan pemodelan sistem dan komponen telah digunakan untuk mengsimulasikan operasi pemasangan, pembukaan, penyenggaraan, kebolehcapaian serta kebolehlihatan, dan seterusnya menilai dan memperbaiki rekabentuk. Pada masa yang sama, postur analisis telah dijalankan dengan menggunakan teknik *Rapid Upper Limb Assessment* (RULA). Manusia maya yang terkandung dalam perisian VR telah digunakan untuk melaksanakan kerja fizikal, dalam usaha mengurangkan risiko gangguan kerangka otot.

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LIST OF ABBREVIATIONS

3D	Three Dimensional
ANSI	American National Standards Institute
CAD	Computer Aided Design
CNG	Compressed Natural Gas
CNG-DI	Compressed Natural Gas Direct Injection
CTD	Cumulative Trauma Disorder
DFA	Design for Assembly
GLE	Gasoline Litre Equivalent
ISO	International Organization for Standardization
MSD	Musculoskeletal Disorder
NASA	National Aeronautics and Space Administration
NFPA	National Fire Protection Association
NGV	Natural Gas Vehicle
NIOSH	National Institute of Occupational Safety and Health
OEM	Original Equipment Manufacturer
OWAS	Ovako Working Posture Analyzing System
PNGV	PETRONAS NGV Sdn. Bhd.

PROTON	Perusahaan Otomobil Nasional Sendirian Berhad
REBA	Rapid Entire Body Assessment
RULA	Rapid Upper Limb Assessment
VR	Virtual Reality

CHAPTER 1

INTRODUCTION

Natural gas vehicle (NGV) technology has a long but sporadic history. Environmental and energy supply concerns have received increasing attention in the past several decades, natural gas has been promoted as an alternative to petrol and diesel vehicles. The technology, marketing and political activities to support NGV commercialisation have grown substantially, particularly in the period of 1980 - 2000 (IANGV, 1998). Balancing the strengths and weaknesses of the fuel and vehicle technology, the fledgling NGV industry has an opportunity to change from an alternative fuel to a true fuel alternative.

NGV is a relatively new and rapidly evolving technology in Malaysia. As of 2005, there are more than 12,000 NGVs and 38 refuelling stations available in the country, compared to 975 converted NGVs and 8 refuelling stations in February 2000 (IANGV, 2004). These natural gas vehicles are mainly located in Klang Valley and Johor Bahru. Of this, retrofitted bi-fuel vehicles dominate the natural gas vehicle population in Malaysia with majority of the users being city taxis, while others

remain as airport tractors and forklifts. There is a drive to increase the share of natural gas in transportation energy. For this, there are two principal reasons, namely (a) reduction of emissions and (b) diversification of energy sources (Kojima, 2001).

Natural gas, as a cleaner burning fuel, significantly reduced exhaust emissions of other pollutants over all existing petroleum fuels and offers up to 100% reduction in particulate matter. The increase use of NGV can contribute to a reduction in urban air pollution and an improvement in air quality. Besides that, Malaysia has a large indigenous natural gas reserves but limited diversity. At 2.336×10^{9} m^3 (82.5 trillion cubic feet), these reserves are two times the amount of oil. Before the introduction of NGV, natural gas is focused on heating, furnaces, cooking and electricity generation only. Because of these, the government is looking to diversity it supply alternatives for energy generation by attempt its use through NGV.

The development of NGV industry in Malaysia is led by PETRONAS NGV Sdn. Bhd, a wholly owned subsidiary of PETRONAS. In order to promote the use of natural gas in the transportation sector, PETRONAS launched the Natural Gas Vehicles program in 1991. During May 1992, 450 NGVs were introduced in Malaysia. Various incentives are provided to encourage the motoring public to use

NGV, while ongoing efforts are being undertaken to expand the NGV refuelling facilities in the country as well as to enhance public awareness on NGV and its benefits. PETRONAS arranges cheap loans for the conversion of vehicles at about RM 2,300.00, and organizes training program for mechanics. The government, through exemptions from import and excise duties, subsidizes the program. The retail price of fuel for natural gas vehicles has been set at half the price of premium petrol. PETRONAS also introduced the *Enviro 2000* NGV taxi in 1996 to further promote the use of NGV. The government is currently targeting buses as the next public transport to convert to NGV.

1.1 Problem Statement

On-board compressed natural gas (CNG) fuel storage presents unique challenges for the commercialization of natural gas vehicles. Vehicle range, storage system, durability, weight and compatibility of component material are all key issues (Haaland and Kunz, 2000). Natural gas has a low volumetric energy density compared to petrol. On average, it takes 0.921 cubic meters (m^3) of natural gas to equal the same energy content as one litre (l) of gasoline (Boykiw, 1999; Kojima, 2001).

As of Malaysia, due to the small size of CNG cylinder mounted in the luggage compartment of the converted NGV and lack of refuelling stations, it has resulted in long queues at the refuelling stations. The low CNG cylinder capacity also contributes to low travel distance and hence require constant refuelling. In order to store sufficient natural gas on board, increase the travel range and reduce the refuelling rate, a higher CNG cylinder capacity that can be mounted on the vehicle should be considered. The cheaper price of natural gas compared to the ever increasing price of petrol, also drive the use of higher cylinder capacity. As the more fuel a vehicle can carry, the better the economic payback will be.

Currently, the selections of cylinders to be mounted during conversion for various types of vehicles are based on the range of CNG cylinder sizes available in the market. The cylinders were mostly fitted in the luggage compartment irrespective to the space available in the various car models. These can be clearly seen on the converted saloon type vehicles available in Malaysia. For example, even though the luggage space accessible in *Proton Waja* vehicle is more compared to the *Proton Iswara* vehicle, the size of the CNG cylinders mounted in the luggage compartment are the same, as only one size of cylinder is available for the saloon type vehicle from the conversion company.