

**DESIGN AND DEVELOPMENT OF A MULTISTAGE SYMMETRICAL
WOBBLE COMPRESSOR**

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DESIGN AND DEVELOPMENT OF MULTISTAGE SYMMETRICAL
WOBBLE COMPRESSOR


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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering

Faculty of Mechanical Engineering
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DECEMBER 2006

I declare that this thesis entitled, "*The Design and Development of Multistage Symmetrical Wobble Plate Compressor*" is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



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Specially Dedicated to My Beloved :

**Wife (Harisaweni. ST),
Daughter (Nanila Salwa Ardiyansyah),
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Parent-in-law (M. Nasir) and (Dra. Hernita Rais),
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ABSTRACT

There are many types of compressor design based on variation applications from the low pressure to the high pressure compression. For the high pressure application, the horizontal opposed reciprocating compressor is the most popular. However, for the smaller flow-rate natural gas refueling appliance compressors, scotch-yoke type has just been introduced into the market. Judging from the advantages and disadvantages from these compressor types, the wobble-plate and swash-plate compressor were chosen to be the combined concept for development of the new compressor. Both compressor concepts are currently used only for low pressure application with single stage compression. For this new compressor design development, both compressor types were combined to develop into a new symmetrical multi-stage wobble-plate compressor. The new compressor design operates with the suction pressure of 3 bar and discharge pressure of 206 bar. This new compressor design inherits the advantages of the wobble-plate and the swash-plate compressor which are compact and able to operate at high operating speed. Main improvement in this new compressor design is the introduction of the symmetrical wobble-plate configuration which allows for higher compressor capacity and balanced horizontal forces. The rotor concept from the swash-plate compressor has also been adopted in this new design. The normal connecting rod with the two ended ball joints has been replaced by the connecting rod with standard end-joints at both ends. This has eased the manufacturing process as the end-joints are available on the shelves. However, this standard universal end joint has limit the tilting angle of the wobble plate to a maximum of 16°.

Against this limitation and for the compressor to operate with minimum possible operating torque and optimum pressure ratio, analysis conducted concludes that the optimum number of stages is five. Flow analysis was conducted to simulate pressure and gas velocity distributions. This has helped in the conceptual development and this design of the suction and discharge port, the value and the cylinder of each stage. Heat transfer analysis was also conducted to simulate the temperature distribution on the cylinder block. The predicted temperature is about 302°C at the first stage. Temperature rise due to compression of the air for both prototypes was found to be insignificant. As such the inter-cooler and after-cooler provided were found unnecessary and were not used. Both prototypes operated with good stability at all speeds and noise generated was acceptably low. The 1.00 m³/hr prototype compressor was run at 1100 rpm producing a discharge pressure of 260 bar and for flow rates of 10 m³/hr was run at 400 rpm producing a discharge pressure of 180 bar.

ABSTRAK

Kebanyakan pemampat direkabentuk berdasarkan aplikasi bermula dari pemampat bertekanan rendah hinggalah ke pemampat bertekanan tinggi. Bagi aplikasi bertekanan tinggi, pemampat salingan berkedudukan mendatar adalah yang paling popular. Walaubagaimanapun, untuk kadaralir yang kecil pemampat jenis *scotch-yoke* lebih sesuai dan telah berada di pasaran. Setelah semua kebaikan dan keburukan bagi semua pemampat diambil kira, konsep pemampat jenis plat wobal dan plat *swash* telah digabungkan dan dipilih sebagai pemampat baru yang akan dibangunkan. Pada masa kini, kedua-dua konsep pemampat digunakan untuk aplikasi satu peringkat dan bertekanan rendah. Kedua-dua konsep pemampat ini digabungkan untuk membentuk satu konsep pemampat baru iaitu pemampat salingan plat wobal simetri berbilang peringkat. Pemampat baru ini direkabentuk untuk beroperasi dalam keadaan tekanan masukan 3 bar dan tekanan keluaran 206 bar. Pemampat baru ini lebih kecil dan boleh beroperasi dalam kelajuan tinggi. Penambahbaikan utama pemampat baru ini ialah dengan pengenalan ciri plat wobal simetri yang mana akan dapat menambahkan kapasiti pemampat dan mengimbangkan daya mendatar yang terhasil. Konsep rotor bagi pemampat jenis plat *swash* juga telah diadaptasi di dalam rekabentuk baru ini. Rod penyambung asal yang berbentuk bebola di kedua-dua hujung telah ditukar dengan dua *end-joint* piawai di kedua-dua hujung. Penggunaan komponen piawai ini akan memudahkan lagi proses pembuatan. Namun demikian komponen piawai ini mempunyai had sudut kemiringan maksimum tersendiri iaitu 16 darjah.

Bagi membolehkan pemampat beroperasi dengan daya kilas yang minimum dan nisbah tekanan yang optimum, analisis telah dijalankan dan didapati bilangan peringkat yang sesuai ialah pada 5 peringkat. Selain itu, analisa aliran juga dibuat untuk mensimulasikan tekanan dan pengagihan halaju gas. Ini telah membantu dalam membangunkan konsep yang baik terutamanya dalam merekabentuk bahagian masukan dan keluaran pada setiap blok silinder. Analisis pemindahan haba juga dijalankan untuk mensimulasi taburan suhu pada blok silinder. Suhu anggaran pada blok silinder pertama adalah setinggi 302 darjah Celsius. Bagi kedua-dua prototaip, didapati peningkatan suhu tidak disebabkan oleh tekanan. Oleh itu penggunaan penyejuk (*inter-cooler/after-cooler*) tidak diperlukan. Kedua-dua prototaip beroperasi dengan stabil dan pada kebisingan yang rendah. Prototaip pemampat bagi 1.00 m³/jam beroperasi pada kelajuan 1100 ppm dan menghasilkan tekanan keluaran 260 bar dan bagi prototaip pemampat 10m³/jam pula yang beroperasi pada 400 ppm telah menghasilkan tekanan keluaran setinggi 180 bar.

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CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia has a huge reserve of natural gas as compared to that of oil. Most of the natural gas is exported to Japan and Korea, while the remaining substantial amount is consumed by local industries. A pipeline network has been installed by Gas Malaysia a subsidiary of national petroleum agency, PETRONAS, throughout the peninsular running through major industrial areas. This infrastructure is put in place to encourage industries to use natural gas as an alternative fuel.

To encourage automotive vehicles to use natural gas, PETRONAS has been instructed to build NGV refueling stations throughout the country. So far, 24 stations have been built in Klang Valley, 1 station in Negeri Sembilan and 4 stations in Johor.

Petronas is also embarking into developing domestic natural gas refueling facilities. The concept is that of slow refueling over a fairly long period of time. Petronas has drawn up a set of specifications where by the design is relatively small, light and produces low levels of noise and vibration. This challenge is now partly translated into a scope of the present work. A symmetrical swash wobble plate multistage reciprocating compressor is found to fulfil the specification and will be the subject of the research.

1.2 Research Scopes

The scope of this research which can be summarized as follows:

- i. Review on literature, patents and existing models of wobble plate reciprocating gas compressor.
- ii. Develop the new concept of a wobble plate compressor.
- iii. Set the operating specification and conduct thermodynamic, heat transfer and flow analyses on wobble plate compressor.
- iv. Design compressor and conduct design analysis
- v. Analytical Simulation.
- vi. Fabrication and testing
- vii. Write report (thesis).

1.3 Objectives

The objectives of this study are as follows:

- i. To develop a new concept of “Symmetrical Wobble Plate Multistage Reciprocating Compressor”.
- ii. To design a Symmetrical wobble plate multistage reciprocating compressor for compression natural gas from pressure 3 bar to 206 bar.
- iii. To design a reciprocating compressor that is effective and efficient to the application of home Refueling.

1.4 Importance of Research

- i. Malaysia has to fully utilize compressed natural gas.
- ii. Universiti Teknologi Malaysia (UTM) together with Petronas Research & Scientific Services (PRSS) and Universiti Teknologi Petronas (UTP) are to

develop domestic natural gas refueling facilities. UTM is to develop the compression system.

- iii. The compression system has to be small, compact, light and of low noise and vibration levels.

1.5 Research Problem

The problems of energy supply shortage, polluted and poor air quality and high energy costs have contributed to the importance of natural gas as an alternative to fossil oil based fuels. As a transportation fuel, the gas must be compressed to increase its storage capacity in order for the vehicle to travel a much longer distance but still using the standard size tank. The compressor therefore becomes important primary equipment to the natural gas (CNG) refueling station.

The present design of reciprocating compressor that is used in the NGV refueling station is relatively huge, heavy, and occupies a lot of space^[22]. Alternative to this is a smaller, compact and low noise vibration levels compressors when installed in a modular arrangement which can also meet the specification of the present model large compressor. If a concept of home refueling is to be implemented a single module of this small compressor may be sufficient to meet the requirement of a slow refueling rate.

After exhaustive review of the open literature which includes journal, conference proceedings and patent it is concluded that more research should be carried out to develop a compressor which is small in size, compact in the assembly and stable in the operation. A scotch-yoke concept has already been developed but the compressors are still not available in the market probably because of the problem of stability.

Many wobble or swash plate compressors are used in the automotive sector especially for air conditioners, where the maximum operating pressure is relatively

low at about 14 bar. The normal wobble plate or swash plate compressor models are designed with only one side compression mechanism which creates instability especially running at high speed. The design of the compressor is to achieve smaller size, compact and stable. Instability problem at the existing compressor can be solved by developing the same system on the opposite side. The symmetrical wobble plate piston-cylinder assembly is thought to produce a dynamically balance compression machine and further development work on the piston, piston rings and cylinder liner should be able to produce a system that can compress and discharge a natural gas up to a very high pressure of 206 bar.

However, it was expected that there would be a number of parameters needed to be investigated during the development of this new concept. These parameters are interdependent on each other that finding an optimum design will be a problematical but challenging task.

1.6 Research Design and Methodology

The work involved design and development new concept high pressure compressor, analysis and simulation, and experimental. The methodology of research showed Figure 1.1.

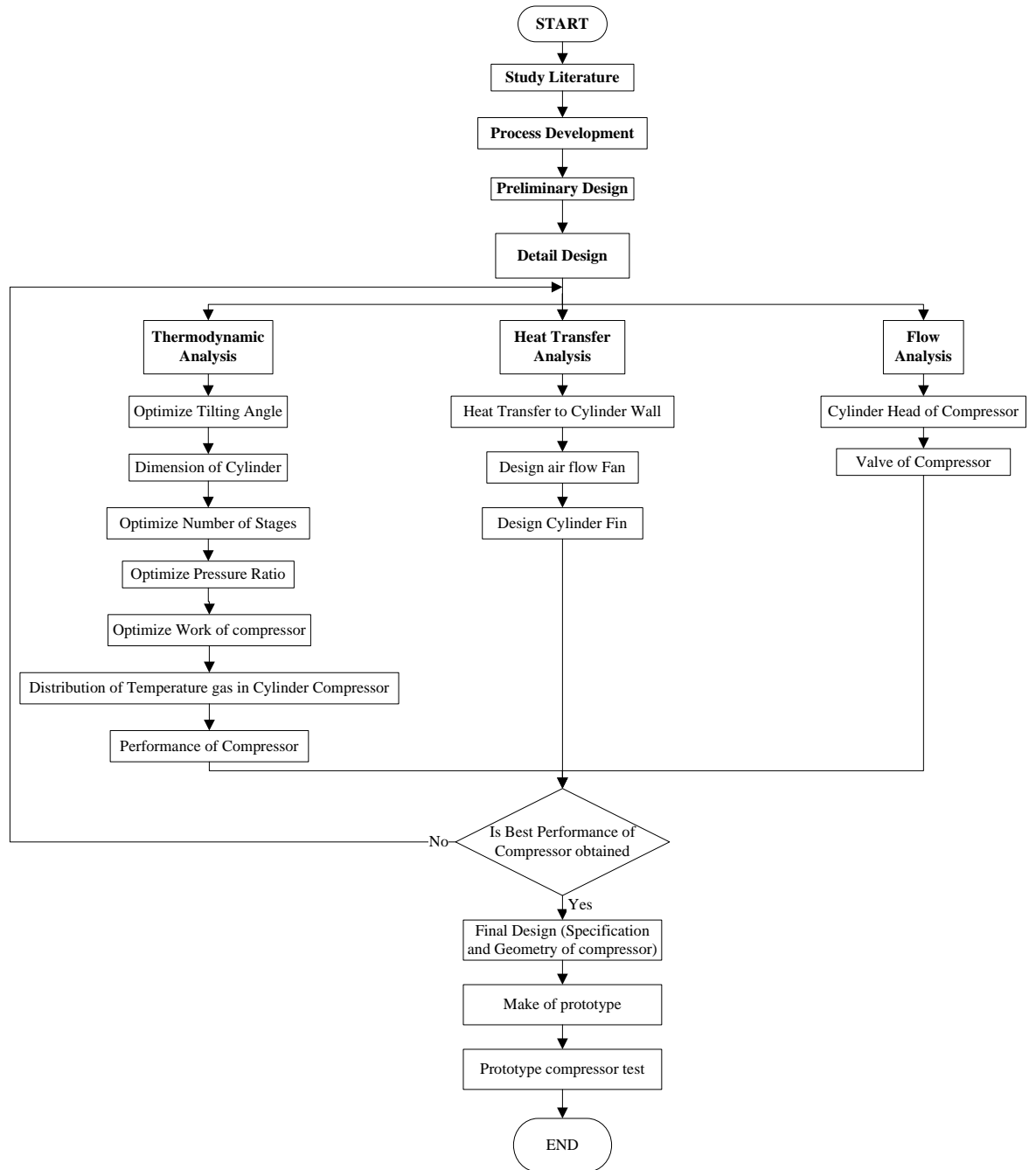


Figure 1.1 Methodology of research

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