

DESIGN AND DEVELOPMENT OF ROTATING-SLEEVE REFRIGERANT
COMPRESSOR

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

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APRIL 2005

“I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Master of Engineering
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Date :

To my parents,
My wife and
Lovely daughter

ACKNOWLEDGEMENT

First of all, thanks to Allah SWT for giving me the strength and the chances in completing this project.

Secondly, I wish to express my sincere gratitude to my supervisor, Professor Dr. Md. Nor Musa for his guidance and encouragement during this master project. I greatly appreciate his care and dedication in constructively criticizing my work, including my thesis. I have truly enjoyed working with him.

Millions of gratitude to other members of research group for their supports and advices especially to En. Mohd Faizal Mohideen for his dedication in checking all the engineering drawings produced in this project. Also, I wish to thank the Ministry of Science, Technology and Innovation for supporting me via NSF scholarship during this master project and supporting this research via IRPA Grant: 74522.

Finally, I would like to thank my family especially my wife for their constant support, encouragement and understanding during my struggle away from home.

ABSTRACT

A Single Vane Rotating Sleeve compression concept is the main focus of this study. Research and development on the concept was carried out to investigate its feasibility on a refrigeration system. The prototype was designed based on the specifications of the existing reciprocating compressor factory installed in a refrigerator which is used as the experimental rig of the present work. In order to design a functional prototype, the author has conducted literature study on existing rotary compressor models such as rolling piston and sliding vane types that are used in room and car air conditioning systems respectively. The literature study is crucial in areas such as the geometrical optimization, material selection, tolerance and surface finishing in designing the prototype. Three prototypes were fabricated and tested. The first two units were not functioning well, but the third prototype showed some positive result. Using a refrigerator mentioned above, a test rig was developed according to the international standard requirement for tropical climate such as ASHRAE, AHAM and ARI, to generate the base data and set as a benchmark in evaluating the performance of the new rotary compressor. The experimental rig was tested and commissioned and produced a refrigeration capacity at 233 W with COP of 2.94. The third prototype was tested and has achieved a volumetric efficiency of 31.3 % with mass flow rate at 0.8 g/s. The indicated power was 26.6 W, with refrigeration capacity of 124.7 W and COP of 4.67. Hence, it is proven that the new concept in principle is successful. However further research and development is needed to improve the compressor performance up to a commercially acceptable level.

ABSTRAK

Konsep pemampatan *Single Vane Rotating Sleeve* merupakan fokus utama kajian ini. Kajian dan pembangunan telah dilaksanakan ke atas konsep berkenaan untuk mengenalpasti kebolehfungsiannya di dalam sistem pendinginan. Prototaip yang telah direkabentuk adalah berdasarkan spesifikasi asal pemampat salingan yang dipasang oleh kilang di dalam peti sejuk yang mana digunakan sebagai pelantar ujikaji di dalam penyelidikan ini. Untuk menghasilkan satu prototaip yang baik, penulis telah mengkaji beberapa model pemampat berputar yang sedia ada seperti jenis *rolling piston* dan *sliding vane* yang masing-masingnya digunakan dalam sistem penyaman udara bilik dan kereta. Kajian ilmiah amat penting terutama dalam aspek geometri, pemilihan bahan, kelegaan dan kelicinan permukaan dalam merekabentuk prototaip. Hasilnya, tiga unit pototaip telah difabrikasi dan diuji. Dua unit prototaip yang pertama tidak berfungsi dengan baik, tetapi prototaip yang ketiga telah menunjukkan satu keputusan yang positif. Dengan menggunakan peti sejuk yang disebutkan di atas, satu pelantar ujikaji telah dibangunkan bersesuaian dengan kehendak piawai antarabangsa untuk iklim tropikal seperti ASHRAE, AHAM dan ARI bertujuan untuk menghasilkan satu data asas dan sebagai tanda aras untuk menilai prestasi pemampat berputar yang baru. Pelantar ujikaji ini telah diuji dan disahkan dan telah menghasilkan kapasiti penyejukan pada 233 W dengan pekali prestasi (COP) pada 2.94. Prototaip ketiga telah diuji dan mencapai kecekapan isipadu pada 31.3 % dengan kadar aliran jisim pada 0.8 g/s. Kuasa tertunjuk yang dihasilkan sebanyak 26.6 W, kapasiti penyejukan sebanyak 124.7 W dan kecekapan prestasi (COP) sebanyak 4.67. Dengan itu, konsep pemampat yang baru ini telah terbukti secara prinsipalnya berfungsi dengan baik. Walaubagaimanapun, penyelidikan dan pembangunan lanjutan diperlukan untuk meningkatkan prestasi pemampat sehingga ke tahap komersial yang boleh diterima.

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LIST OF SYMBOLS

A	-	Area
COP	-	Coefficient of performance
D	-	Inner sleeve diameter
d	-	Rotor diameter
e	-	Eccentric distance
h	-	Enthalpy
l	-	Length
m	-	Mass
\dot{m}	-	Mass flowrate
N	-	Speed
n	-	Polytropic compression index
p	-	Compressor power
p_1	-	Suction Pressure
p_2	-	Discharge Pressure
Q	-	Refrigeration effect
\dot{Q}	-	Refrigeration capacity
R	-	Gas constant
R	-	Inner sleeve radius
r	-	Rotor radius
s	-	Entropy
T	-	Temperature
T_1	-	Suction Temperature
T_2	-	Discharge Temperature
t	-	Height
V	-	Volume
V_1	-	Total volume
V_2	-	Discharge volume

V_3	-	Clearance volume
V_s	-	Swept volume
v	-	Velocity
W	-	Compressor work
W_{12}	-	Compression work
w	-	Width of vane
β	-	Sleeve rotation angle
θ	-	Rotor rotation angle
ρ	-	Density
π	-	Pi
η_{com}	-	Compressor efficiency
η_{cp}	-	Compression efficiency
η_{mec}	-	Mechanical efficiency
η_{motor}	-	Motor efficiency
η_v	-	Volumetric efficiency
Δ	-	Area
Φ	-	Diameter

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CHAPTER 1

INTRODUCTION

1.1 Fundamental of Refrigeration

Refrigeration is the process of removing heat from a space or substance and transfer that heat to another space or substance. The term refrigeration is used here to include both the cooling process to preserve food and comfort cooling (air conditioning). In any refrigerating process, the substance employed as the heat absorber or cooling agent is called the refrigerant. The refrigerant absorbs heat by evaporating at low temperature and pressure and remove heat by condensing at a higher temperature and pressure. As the heat is removed from the space, the area appears to become cooler. The process of refrigeration occurs in a system which comprises of a compressor, a condenser, a capillary and an evaporator arranged as depicted schematically in Figure 1.1.

Compressor is a mechanical device to compress and pump the refrigerant vapour from a low-pressure region (the evaporator) to a high-pressure region (the condenser). The condenser is a device for removing heat from the refrigeration system. In the condenser, the high temperature and high-pressure refrigerant vapour transfers heat through the condenser tube wall to the surrounding. When the temperature of the refrigerant vapour reaches the saturation level, the latent heat is released causes condensation process and the refrigerant vapour changes phase to a liquid form. The metering device (throttle valve or capillary tube) controls the refrigerant flow from the condenser to the evaporator and separates the system to high pressure and low-pressure sides. The evaporator is a device for absorbing heat

from the refrigerated space into the refrigeration system by evaporating the refrigerant [1, 2].

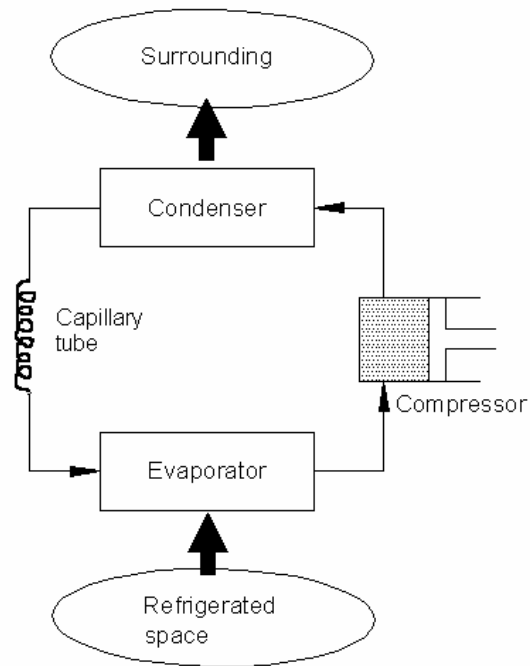


Figure 1.1: Schematic diagram of refrigeration system

1.2 Refrigerating Compressor

Refrigerating compressor is a heart of a refrigeration system. It raises the pressure of the refrigerant so that it can be condensed into liquid, throttled to a lower pressure, and evaporated into vapour to produce the refrigeration effect. It also provides the primary force to circulate the refrigerant through the cycle [3]. According to the compression process, the refrigerating compressor can be divided into two main classifications and each classification can be further sub-divided into several groups, as illustrated in Figure 1.2. The positive displacement compressor is a type that increases the gas pressure by reducing the internal volume of the compression chamber through the mechanical force that is applied to the compressor. Whereas, a non-positive displacement compressor is where the compression of the gas depends mainly on the conversion of dynamic pressure into static pressure [4].

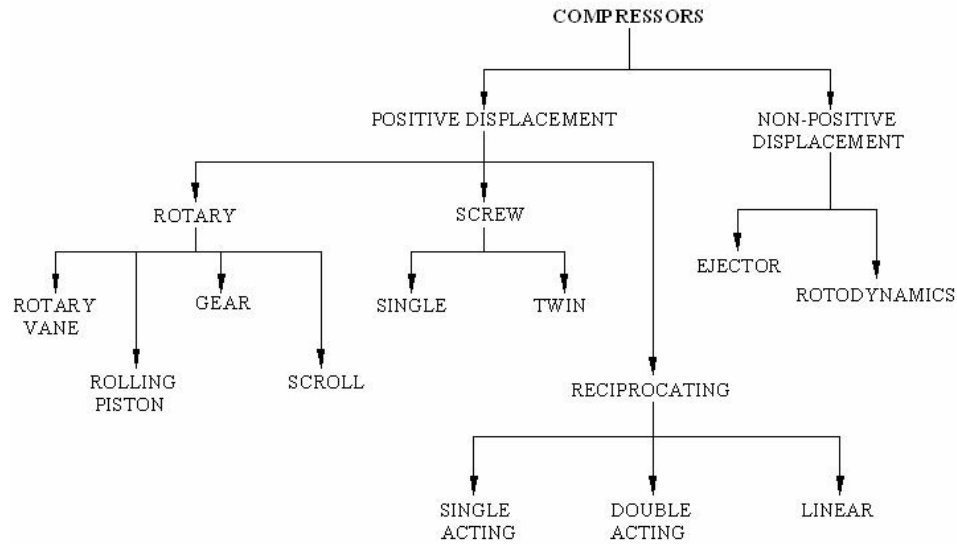
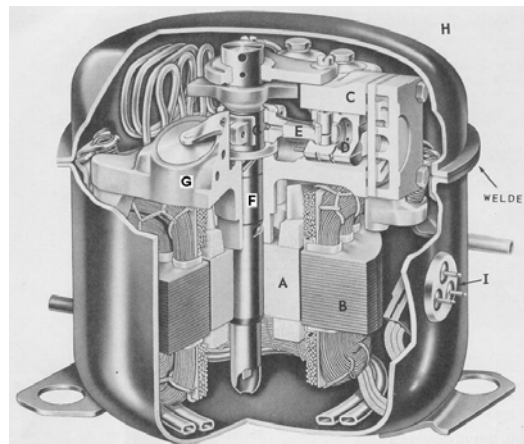


Figure 1.2: Classification of compressor

The positive displacement compressors can be further classified into rotary, screw and reciprocating types. Only rotary and reciprocating types are discussed in this report. These two types of compressors are packaged into three different assemblies as described in the following discussion:

- i. **Hermetic compressor.** In the assembly the motor and the compressor are sealed or welded in the same housing as shown in Figure 1.3. Hermetic compressor has two advantages that it minimizes leakage of refrigerant and has mechanism to cool the motor by using the suction vapour flowing through the motor windings. Motor windings in hermetic compressors must be compatible with the refrigerant and lubricating oil, resist the abrasive effect of the suction vapour, and have high dielectric strength.
- ii. **Semi-hermetic compressor.** This compressor is also known as accessible hermetic compressor or serviceable hermetic compressor. The unit is as shown in Figure 1.4. The main advantage of this compressor over the hermetic type is that its accessibility for repair during a compressor failure or for regular maintenance.

- iii. **Open compressor.** In an open compressor, the compressor and the motor are enclosed in two separate housing as shown in Figure 1.5. This compressor needs the shaft seals to prevent refrigerant leakage. In most cases, an enclosed fan is used to cool the motor windings using ambient air. Notice that, there are two driving concept of the open compressor; belting drive and direct drive. An open compressor may be disassembled for service and preventive maintenance to the internal parts [3, 4, 5, 6].



- A- Motor rotor
- B- Motor stator
- C- Cylinder
- D- Piston
- E- Connecting rod
- F- Crankshaft
- G- Crankcase
- H- Shell
- I- Electrical connection

Figure 1.3: Photograph of hermetic reciprocating compressor (Whitman and Johnson, 1991)

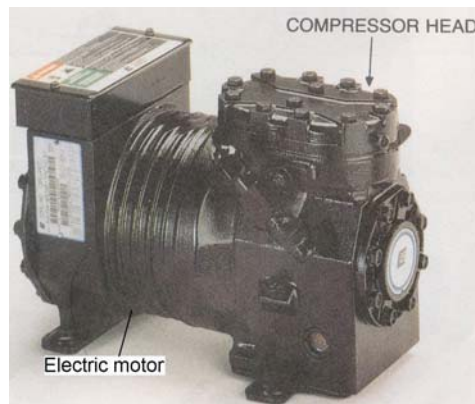
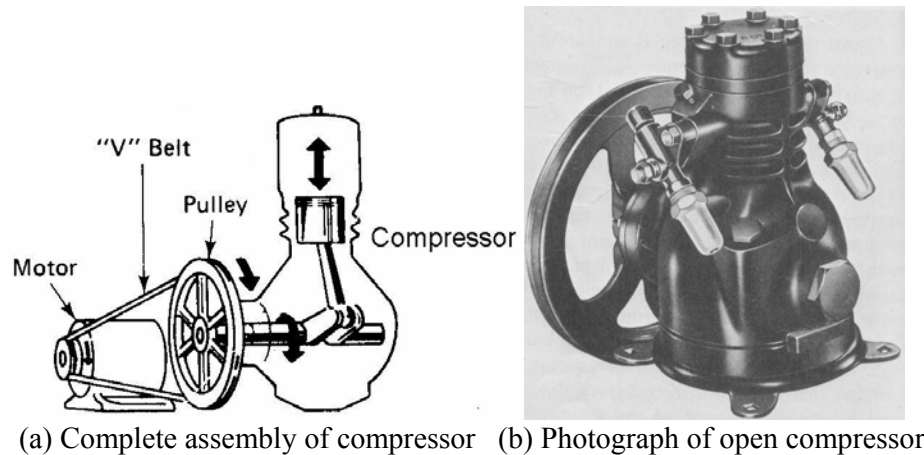


Figure 1.4: Photograph of semi-hermetic compressor (Whitman and Johnson, 1995)



(a) Complete assembly of compressor (b) Photograph of open compressor

Figure 1.5: Open compressor assembly type (Langley, 1982)

1.3 Research Overview

The application of reciprocating compressor in a refrigerator and an air-conditioner is already established. Chillers for some big building air-conditioning system are using screw compressors, but the researches are still on-going to improve the performance. Whereas automotive air-conditioning system are using both rotary and reciprocating types and again research in this area is actively pursued. Domestic refrigerator has been known to use reciprocating compressor until lately when rotary compressor has been introduced and appears to be successful. This success is as a result of continuous research carried out by the industry to improve the efficiency and reliability of rotary compressors. As described later this compressor can be of static or rotating vane types.

The literature study has been done on the rotary and reciprocating compressors and findings showed that the performance of rotary compressor is better than reciprocating compressor. Recently, Universiti Teknologi Malaysia (UTM) has developed a new compression concept comprises of a rotating vane, a rotating sleeve and a rotor. This is a simple concept compared to the other rotary compressors available in the market today. Details of the new rotary compressor concept are shown in Figure 1.6.

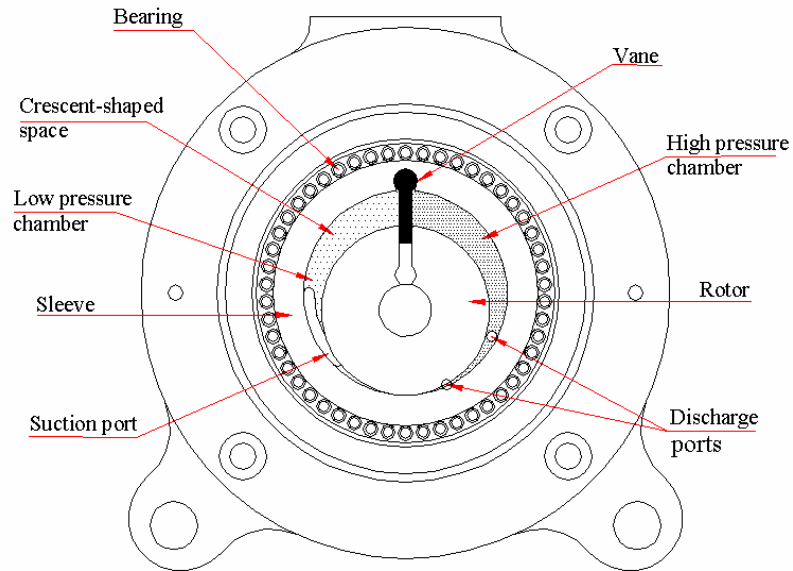


Figure 1.6: Concept of single vane rotating sleeve rotary compressor

The concept is equipped with main components such as a vane, a sleeve, a rotor, a shaft and a cylinder block. The sleeve as well as the cylinder block are assembled eccentrically to the rotor to produce the compression chamber with a crescent-shaped area formation. Then, the head or tip of the vane is assembled permanently into the slot on the inner part of the sleeve, and the vane hub is put inside the rotor slot. There is a contact point between rotor and sleeve to prevent the gas from leaking to the adjacent area. Therefore, the center points of sleeve rotation and rotor are different, and when the rotor starts to rotate, the vane will start to compress the gas. During first half of rotation, the sleeve pulls the vane out of the slot and during the second half the vane is pushed back into the slot, in the rotor. This concept is expected to reduce leakage through the vane tip which occurs in existing rotary compressor.

Figure 1.7 describes the operation sequence of this concept. The sequence starts at 0° with the compression chamber fully filled by gas and the high-pressure gas is completely delivered at 360° . The rounded vane tip allows it to swing so that kinematically the rotating mechanism works successfully in spite of eccentricity. The designed compressor will be installed to the household refrigerator-freezer. Generally there are three types of household refrigeration system, which are

refrigerator unit, freezer unit and combination of refrigerator and freezer. This research is focused on combination of refrigerator and freezer unit. The combined unit is normally known as refrigerator [7].

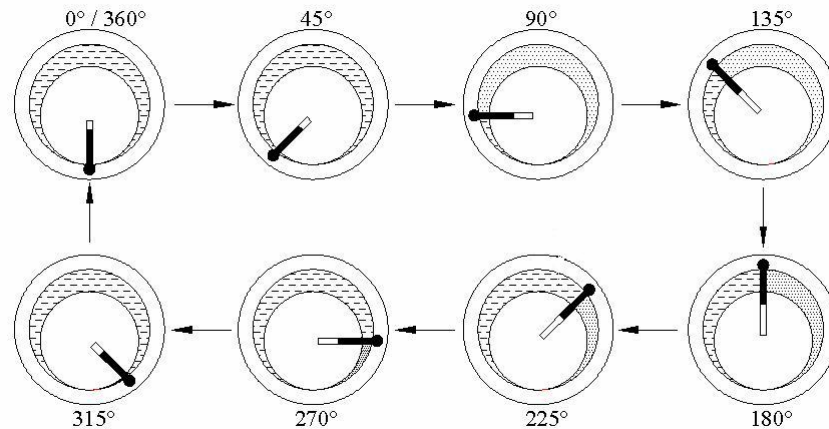


Figure 1.7: Operation of single vane rotating sleeve rotary compressor concept

1.4 Problem Statement

In Malaysia, the main refrigerator-freezer manufacturer is Matsushita Group of Companies with their products of National and Panasonic brands. Beside that, these companies also produce the compressor to be supplied to other refrigerator-freezer manufacturers such as Sanyo, Hitachi and Pensonic. Most of the refrigerator-freezers use reciprocating type compressor. However, there is also rotary type used in refrigerator-freezer such as for three doors refrigerator-freezer model. The presence of these companies in Malaysia gives us the opportunity to learn the technology and the manufacturing processes involved. This will gradually increase our capability in this industry and ensures that Malaysia remains the world biggest supplier of domestic refrigerators and split-unit air-conditioners. In this respect compressor is the most important component. Therefore, the main objective of this research is to develop our own technology of compressor. The research work is focus on the weaknesses of the two existing compressor models; rolling piston and sliding vane rotary compressor. As a result, a superior version of compressor will come out. The weaknesses on the existing compressors are leakage and friction problem

through the vanes tip and cylinder block or rolling piston during compression process which will be discussed later.

1.5 Significant of Research

The sliding vane rotary compressor has a fairly high volumetric efficiency. The rolling piston rotary compressor has even higher efficiency. However from the literature review and theoretical analysis conducted the performance of rotary compressor can be further improved and manufacturing cost reduced. This is indeed a good starting and to proceed to a more interesting and useful R&D work in the effort to fully acquire this very important technology.

1.6 Objective of Research

The main objective of this study is to design and develop a rotary compressor based on a new concept, which is a single vane rotating sleeve rotary compressor for refrigerator application.

1.7 Scope of Research

The scopes of this research are described as follow:

1) Literature study

This involves patent study, technical review and reverse engineering work. The outcome from this study will be adopted into the new compressor design.

2) Thermodynamic analysis

Analyze thermodynamic aspect of existing system so that the main parameters of new rotary compressor are similar with the existing compressor.

3) Concept and design development

Design a new rotary compressor based on the rotating vane and sleeve concept. Concept is finalized and design is completed with the detail technical drawing and material selection.

4) Fabrication of prototype

To fabricate compressor prototype based on the technical drawing that is produced.

5) Test rig development

Testing rig will be developed utilising existing refrigerator to generate base data and adopted into the new design rotary compressor. The new rotary compressor also will be tested on the same testing rig. It is to be installed in parallel with the existing compressor.

6) Performance testing

Performance testing of new rotary compressor is focused on the thermodynamic aspect. The performance of the new rotary compressor will be compared to that of the existing reciprocating model.

1.8 Research Methodology

The research is carried out according to the methodology flow chart drawn up as shown in Figure 1.8.

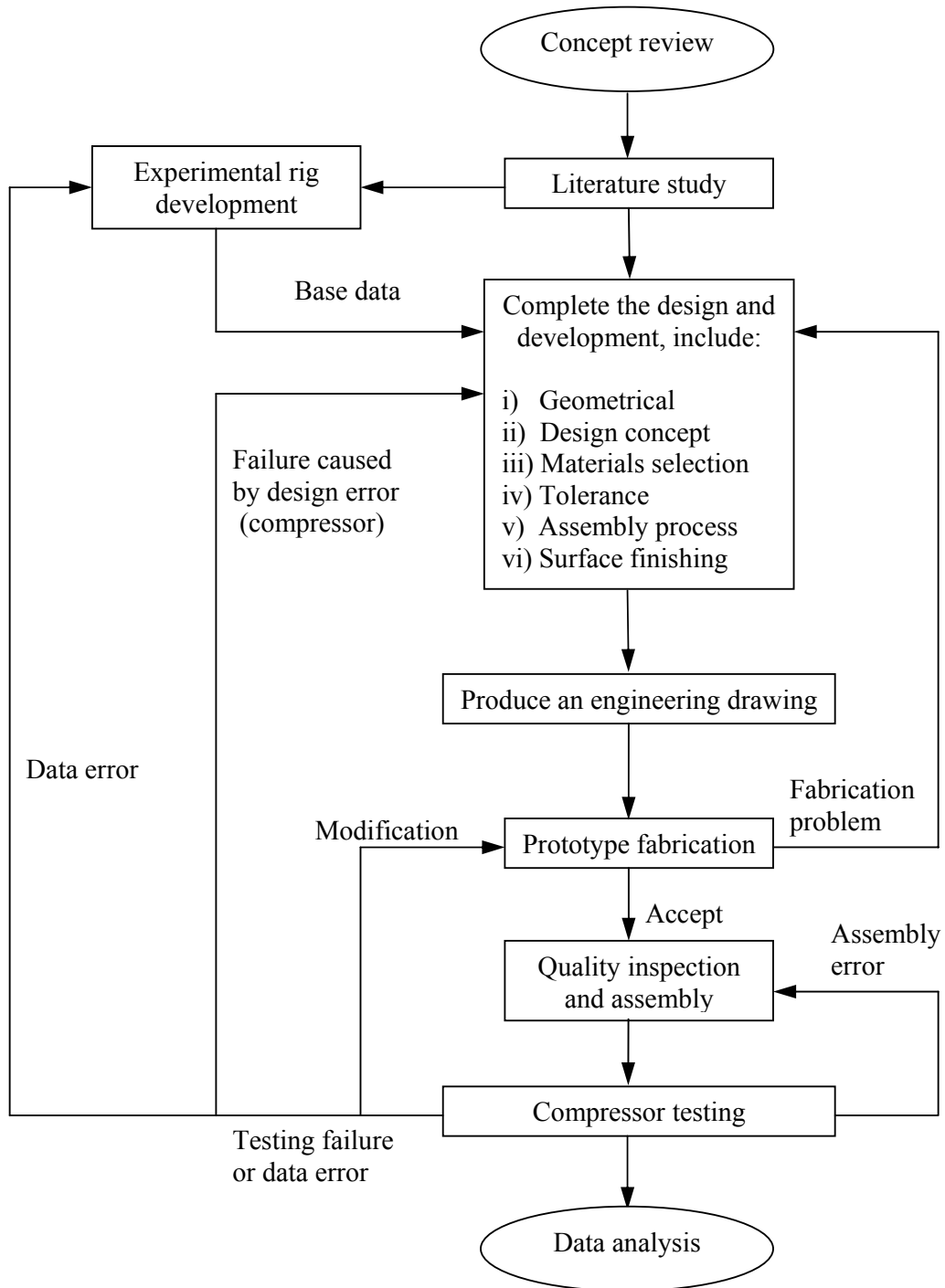


Figure 1.8: Research methodology flow chart

- 4) A study should be conducted to investigate the effect of various tolerances, ranging between 5 to 50 μm on to the performance (volumetric efficiency) of the new compressor.
- 5) Prototype development should involve comprehensive study on vibration and noise kinematics that affect the compressor efficiency.
- 6) Modification can be made to further improve the compressor such as adding several sliding vanes to increase the capacity and efficiency. The idea is one of the vane is fixed to the sleeve while the rest of vanes slide freely with the vanes tip touching the sleeve inner wall.
- 7) Finally, the compressor can be designed as a hermetically sealed assembly to minimize leakage during operation.

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