DESIGN AND DEVELOPMENT OF ROTATING-SLEEVE REFRIGERANT COMPRESSOR

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"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 (*Mechanical*)"

Signature	: …………………………………………..
Name of Supervisor	: PROFESOR DR. MD NOR BIN MUSA
Date	: ………………………………...………

To my parents,
My wife and
Lovely daughter

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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 penyamanan 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 posotif. 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 komisial 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].

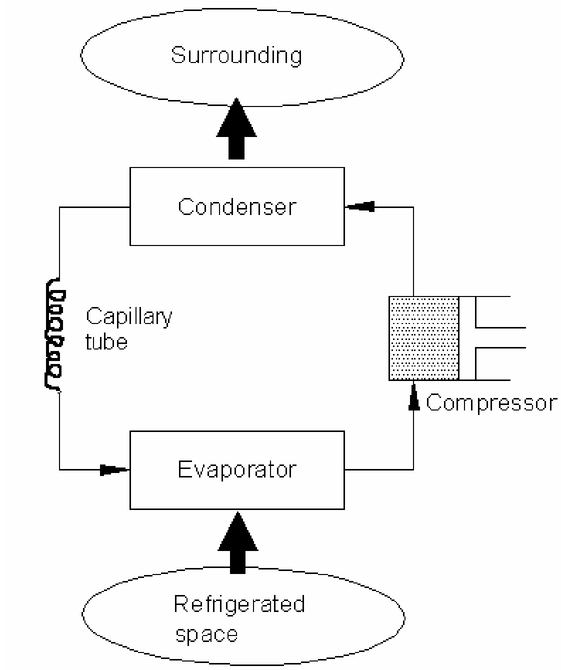


Figure 1.1: Schematic diagram of refrigeration system

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].

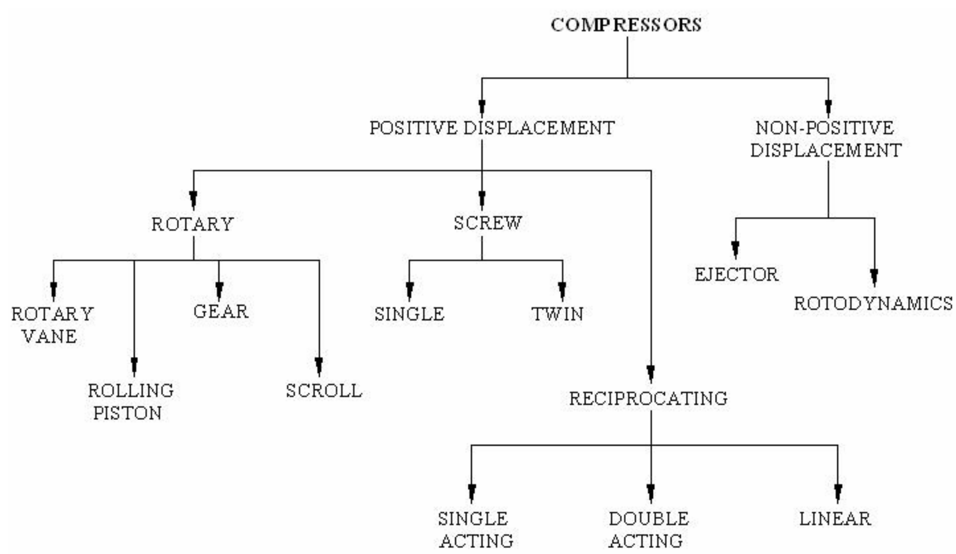


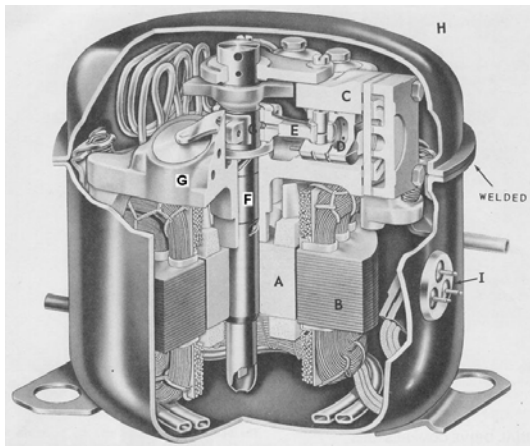
Figure 1.2: Classification of compressor

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)

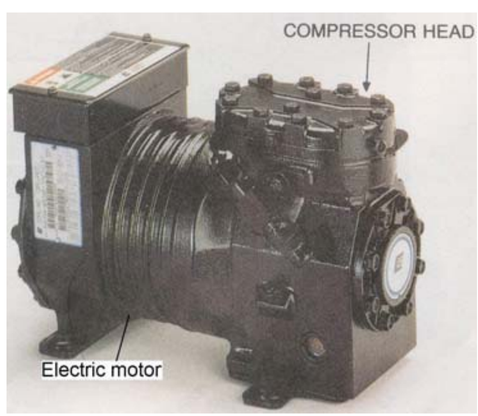
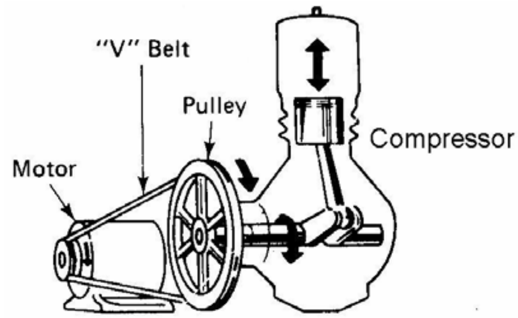
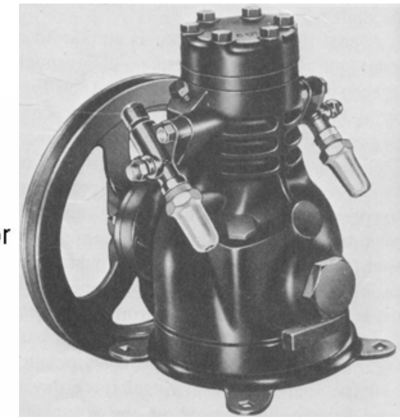


Figure 1.4: Photograph of semi-hermetic compressor (Whitman and Johnson, 1995)





(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 Technologi 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.

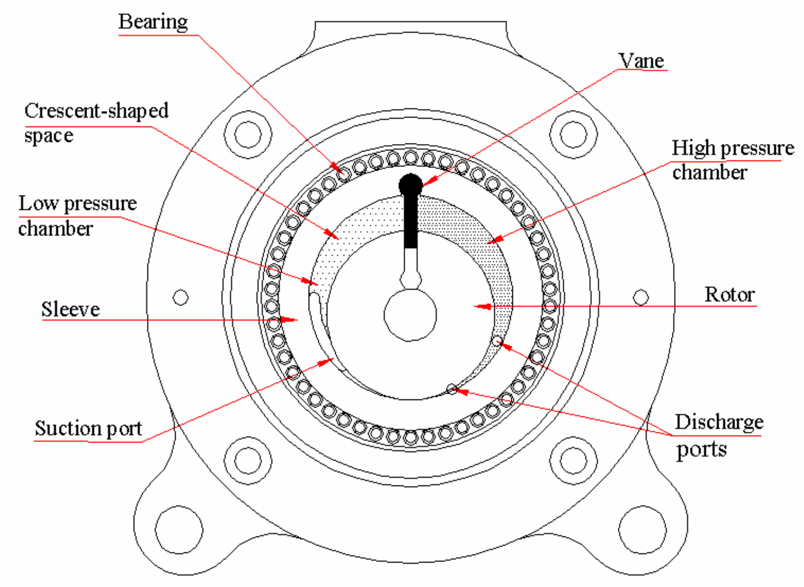


Figure 1.6: Concept of single vane rotating sleeve rotary compressor

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 0º with the compression chamber fully filled by gas and the high-pressure gas is completely delivered at 360º. The rounded vane tip allows it to swing so that kinematically the rotating mechanism works successfully inspire 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].

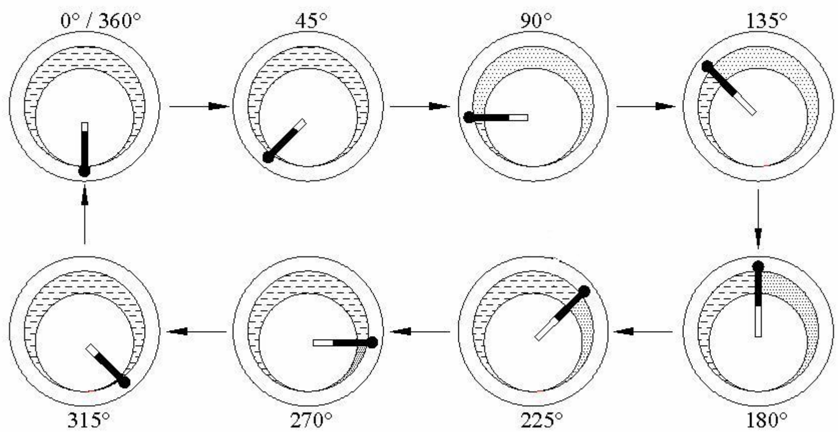


Figure 1.7: Operation of single vane rotating sleeve rotary compressor concept

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.

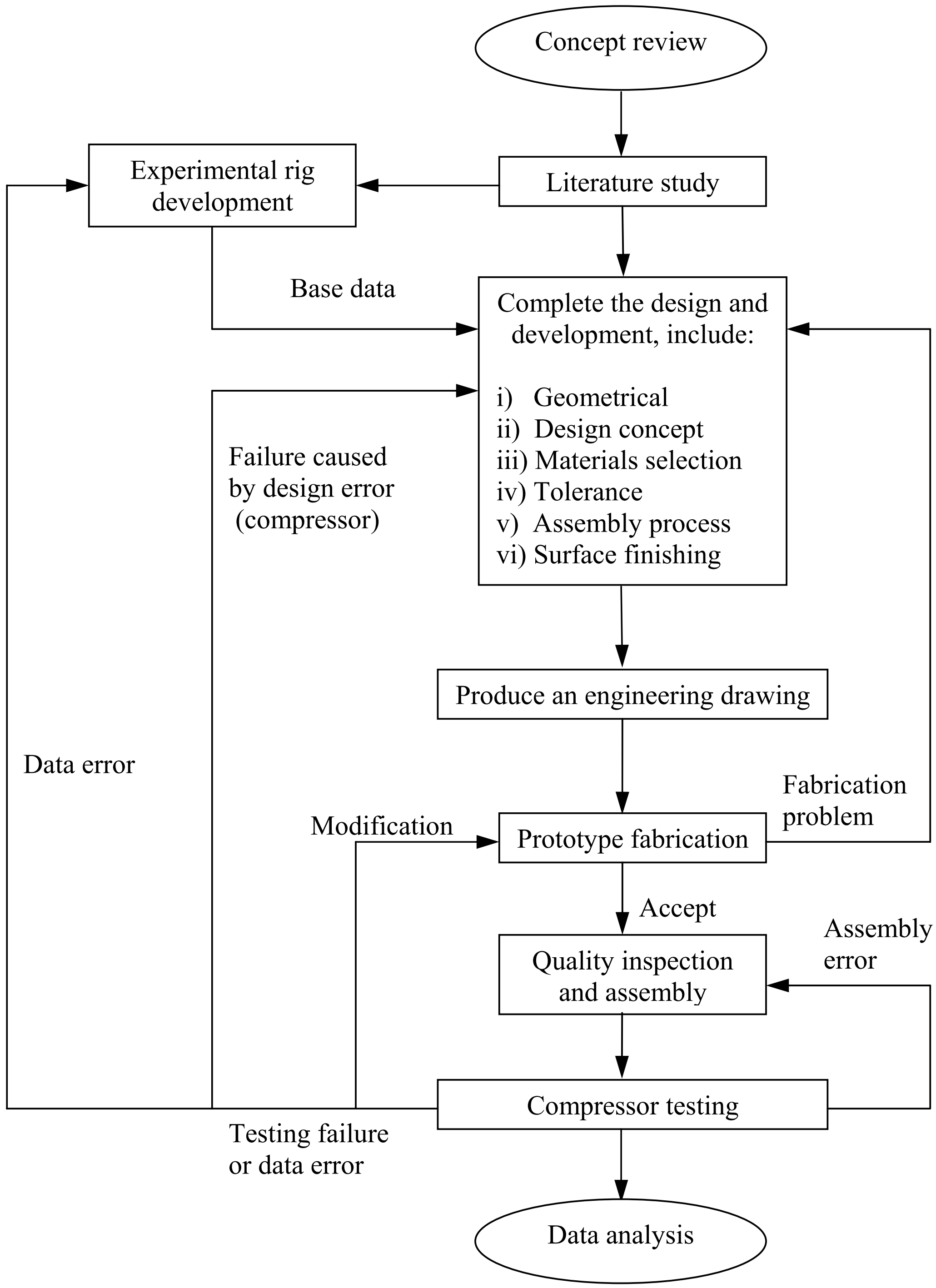


Figure 1.8: Research methodology flow chart

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.

References

1. Jordan, R. C. and Priester, G. B. (1985). "*Refrigeration and Air Conditioning System*." 2nd edition. Prentice-Hall of India Private Limited, New Delhi. 3 – 15.
2. Whitman, C. W., Johnson, W. M and Tanczyk, J. A. (2000). "*Refrigeration and Air Conditioning Technology*." 4th edition. Delmar Thomson Learning, USA. 22 – 25.
3. Shan, K. Wang, Zalman Lavan and Norton, P. (2000). "*Air Conditioning and Refrigeration Engineering*". CRC Press, New York. 83 – 84.
4. Shan, K. Wang. (1993). "*Handbook of Air Conditioning and Refrigeration*." Mc Graw-Hill Inc., New York. 10.22 – 10.23.
5. Whitman, C. W. and Johnson, W. M. (1995). "*Refrigeration and Air Conditioning Technology.*" 3th edition. Delmar Thomson Learning, USA. 363 – 366.
6. Langley, B. C. (1978). "*Refrigeration and Air Conditioning*." Prentice-Hall Company, Reston Virginia. 74 – 77.
7. Air Conditioning and Refrigeration Institute (ARI) (1998). "*Refrigeration and Air Conditioning*." 3rd edition. Prentice Hall, USA. Pg. 416 - 437.
8. Vladimir Chlumsky (1966). "*Reciprocating and Rotary Compressor*". SNTL Publisher of Technical Literature, Prague-Checkoslovakia. 275 – 278.
9. Dossat, R. J. (1978). "*Principles of Refrigeration*." John Wiley & Sons, New York. 462 – 465.
10. ASHRAE (2000). "*ASHRAE Handbook CD: HVAC Systems and Equipment*". CD edition. ASHRAE, USA. 34.9 – 34.11.
11. Chlumsky, V (1966). "*Reciprocating and Rotary Compressor*". SNTL Publisher of Technical Literature, Prague-Checkoslovakia. 286.
12. Shan, K. Wang. (1993). "*Handbook of Air Conditioning and Refrigeration*." Mc Graw-Hill Inc., New York. 10.29
13. Shan, K. Wang, Zalman Lavan and Norton, P. (2000). "*Air Conditioning and Refrigeration Engineering*". CRC Press, New York. 83.

14. Langley, B. C. (1978). "*Refrigeration and Air Conditioning*." Reston Publishing Company Inc, Reston Virginia. 65.

15. Joel, R. (1996). "*Basic Engineering Thermodynamic*." 5th edition. Addison Wesley Longman Limited, England. 392 – 394.

16. Dossat, R. J. (1978). "*Principles of Refrigeration*." 2nd edition. John Wiley & Sons, New York. 271.

17. Kinney, J. R. (1911). "*Rotary Pump*." (U.S. Patent 993, 530).

18. Buchanan, J. C. and Hubacker, E. F. (1933). "*Discharge Valve*." (U.S. Patent 1, 931, 017).

19. Warrick, L. K., Muskegen Heights and LaFlame, F. E. (1952). "*Compressor-Motor Assembly*." (U.S. Patent 2, 612, 311)

20. Dreiman, N. I. (1998). "*Suction Inlet For Rotary Compressor*." (U.S. Patent 5, 829, 960).

21. Caio, M. F. N. and Costa, D (1991). "*Discharge System For Rotary Rolling Piston Compressor*." (U.S. Patent 5, 004, 408).

22. Kang, Heui-Jong (1998). "*Rotary Compressor Having A Roller Mounted Eccentrically In A Cylindrical Chamber of A Rotatable Cylinder*." (U.S. Patent 5, 733, 112).

23. Gillespie, J. E. (1873). "*Improvement In Rotary Pump*." (U.S. Patent 141, 000).

24. Walter, J. P. (1923). "*Rotary Pump*." (U.S. Patent 1, 444, 269).

25. Camilo, V. N. (1954). "*Rotary Vacuum And Compressor Pump*." (U.S. Patent 2, 672, 282).

26. Adalberd, G., Jurgen Hess and Linder, E (1974). "*Pressure-Sealed Compressor*." (U.S. Patent 3, 852, 003).

27. Adalbert, G. and Vysiotis, T. (1985). "*Vane Compressor, Particularly A Cooling Medium Compressor For Use In Air-Conditioning Equipment of A Vehicle*." (U.S. Patent 4, 505, 656).

28. Cavalleri, R. J. (1994). "*High Performance Dual Chamber Rotary Vane* Compressor." (U.S. Patent 5, 302, 096).

29. Meece, W. (1974). "Design of Oil-Less Compressor and Pumps." *Proc. of the 1974 Purdue Compressor Technology Conference*. Indiana, USA. 250 – 257.

30. Pendeya, P. and Soedel, W. (1978). "Rolling Piston Type Rotary Compressors with Special Attention to Friction and Leakage." *Proc. of the 1978 Purdue Compressor Technology Conference.* Indiana, USA. 209 – 217.

31. . Matsuzaka, T. and Nagatomo, S. (1982). "Rolling Piston Type Rotary Compressors Performance Analysis." *Proc. of the 1982 Purdue Compressor Technology Conference*. Indiana, USA. 149 – 158.

32. Kawai, H. (1984). "Efficiency Improvement in Rolling Piston Type Rotary Compressors." *Proc. of the 1984 International Compressor Engineering Conference at Purdue*. Indiana, USA. 299 – 306.

33. Nagatomo, S., Sakata, H., Tago, M. and Hattori, H. (1984). "Performance Analysis of Rolling Piston Type Rotary Compressors for Household Refrigerators." *Proc. of the 1984 International Compressor Engineering Conference at Purdue*. Indiana, USA. 291 – 298.

34. Nomura,T., Ohta, M., Takeshita, K. and. Ozawa Y. (1984). "Efficiency Improvement in Rotary Compressors." *Proc. of the 1984 International Compressor Engineering Conference at Purdue*. Indiana, USA. 307 – 314.

35. Shintaku, H., Ikoma M., Hasegawa, H., Nishiwaki, F., Harada, T., Nakata, H. and Kurimoto, M. (2000). "Experimental and Theoretical Study of an Advanced Rotary Compressors." *Proc. of the 2000 International Compressor Engineering Conference at Purdue, Vol. (1)*. West Lafayette, Indiana. Purdue University, 753 – 760.

36. Huang, Y., Harte, S., Sud, L., Kheterpal, V. and Strikes, G. (2000). "A Novel Automotive Two-Stage Air Conditioning Compressor." *Proc. of the 2000 International Compressor Engineering Conference at Purdue, Vol. (1)*. West Lafayette, Indiana. Purdue University, 403 – 408.

37. Huang, Y., Harte, S. and Sud, L. (1998). "Dynamic Parameter Optimization of an Automobile Air Conditioning Compressor Using Taguchi Method." *Proc. of the 1998 International Compressor Engineering Conference at Purdue, Vol. (1)*. West Lafayette, Indiana. Purdue University, 260 – 266.

38. Sud, L., Dalal, H., Harte, S. and Yong, Huang (2000). "Development of Rotary Compressor for Semi / Trailer Truck Applications." *Proc. of the 2000 International Compressor Engineering Conference at Purdue. Vol. (1)*. West Lafayette, Indiana. Perdue University, 397 – 401.

39. Reed, W. A. and Hamilton, J. F. (1980). "Internal Leakage Effects in Sliding Vane Rotary Compressor." *Proc. of the 1980 Purdue Compressor Technology Conference.* Indiana, USA. 112 – 117.

40. Rodgers, R. J. and Nieter, J. J. (1996). "Comprehensive Analysis of Leakage in Rotary Compressors." *Proc. of the 1996 International Compressor Engineering Conference at Purdue*. Indiana, USA. Vol. 1. 287 – 293.

41. Gasche, J. L., Ferreira, R. T. S. and Prata, A. T. (1998). "Transient Flow of the Lubricant Oil through the Radial Clearance in Rolling Piston Compressors." *Proc. of the 1998 International Compressor Engineering Conference at Purdue*. *Vol. (1)*. West Lafayette, Indiana. Purdue University, 25 – 30.

42. Komatsubara, T., Okajimi, M., Hoshino, H. and Obokata, Y. (1990). "Fiber Reinforced Aluminium Alloy for the Moving Parts of Rotary Compressor." *Proc. of the 1990 International Compressor Engineering Conference at Purdue, Vol. (1)*. West Lafayette, Indiana: Purdue University, 105 – 112.

43. Matsumoto, K., Sunaga, T., Matsuura, D. and. Takabashi, Y (2003). "*Rotary Compressor*." (U.S. Patent 6, 592, 347).

44. Jordan, R. C and Priester, G. B. (1985). "*Refrigeration and Air Conditioning*." 2nd edition. Prentice-Hall of India Private Limited, New Delhi. 68.

45. Arora, C. P. (2000). "*Refrigeration and Air Conditioning*." 2 nd edition. McGraw- Hill, Boston. 274 – 275.

46. Arora, C. P. (1981). "*Refrigeration and Air Conditioning (SI units)*." Tata McGraw-Hill Publishing Company Limited. 181 – 185.

47. Jones, W. P. (2001). "*Air Conditioning Engineering*." 5th edition. Butterworth Heinemann, Britain. 266 – 267.

48. Shan, K. Wang. (1993). "*Handbook of Air Conditioning and Refrigeration*." Mc Graw-Hill Inc., New York. 10.23 – 10.27.

49. Changel, Y. A. and Boles, M. A. (1998). “*Thermodynamics: An Engineering Approach*.” 3rd edition. McGraw-Hill Inc., Singapore. 619 – 625.

50. Dossat, R. J. (1978). “*Principles of Refrigeration*.” John Wiley & Sons, New York. 143.

51. Anderson, E. P. (1966). “*Refrigeration and Air Conditioning Guide – 1: Home Refrigeration and Air Conditioning*.”D. B. Taraporevala Sons & Co. Private Ltd, Bombay. 88 – 100.

52. Dincer, I. (2003). “*Refrigeration System and Application*.” John Wiley & Sons Ltd, England. 109 – 120.

53. Jones, W. P. (2001). “*Air Conditioning Engineering*.” 5th edition. Butterworth Heinemann, Britain. 249 – 257.

54. SKF (1991). “*General Catalogue*.” Carl Gerber GmbH, Germany. 415 – 457.

55. Air Conditioning and Refrigeration Institute (ARI) (1998). “*Refrigeration and Air Conditioning*.” 3rd edition. Prentice Hall, USA. 289 – 310.

56. Althouse, A. D., Turnquist, C. H. and Bracciano, A. F. (1988). “*Modern Refrigeration and Air Conditioning*.” The Goodheart-Willcox Company, Holland. 39 – 71.

57. Ballaney, P. L (1985). “*Refrigeration and Air Conditioning*”. Khanna Publisher, Delhi. 526.

58. Langley, B. C. (1990). “*Heating, Ventilating, Air Conditioning and Refrigeration*.” Prentice-Hall, New Jersey. 62 – 88.

59. Pannock, J., Liu, Z., Radermacher, R. and Yu, K. (1994). “Evaluation of R-134a And R-152a as Working Fluids in a Domestic Refrigerator / Freezer.” *ASHRAE Transaction: Symposia, Volume 100, Part 1*. ASHRAE Inc. 1344 – 1350.

60. Philipp, J., Kraus, E. and Meyer, A. (1996). “Presentation of a Test Rig To Record Mass Flow Rate, Pressures and Temperatures of a Household Refriherator During On/Off Cycling Mode.” *Proc. of the 1996 International Refrigeration Conference at Purdue.* West Lafayette, Indiana: IIR, 1996. 477 – 482.

61. McKellar, M. G. and Tree, D. R. (1988). "Steady State Characteristics of Failures of a Household Refrigerator." *Preprints of the 1988 Purdue – International Refrigeration (IIR) Conference*. West Lafayette, Indiana: IIR, 1988. 257 – 265.

62. Melo, C. and Pereira R. H. (1988). "Steady State Characteristics of Failures of a Household Refrigerator." *Preprints of the 1988 Purdue - International Refrigeration (IIR) Conference*. West Lafayette, Indiana: IIR, 1988. 98 – 106.

63. ANSI / ASHRAE Standard (1986). "*Standard Method for Temperature Measurement*." Atlanta: (ANSI / ASHRAE 41.1-1986 (RA 2001).

64. Langley, B. C. (1982). "*Refrigeration and Air Conditioning*." 2nd edition. Prentice-Hall Company, Reston Virginia. 53 – 59.

65. Changel, Y. A. and Bolos, M. A. (1998). "*Thermodynamics: An Engineering Approach*." 3rd edition. Mc Graw-Hill, New York. 623 – 625.

66. Jones, W. P. (2001). "*Air Conditioning Engineering*." 5th edition. Butterworth Heinemann, Britain. 258 – 261.

67. American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). "*2001 ASHRAE Handbook CD*." 1.12.

68. King, G. R. (1971). "*Basic Refrigeration: Principles, Practice and Operation*." Nickerson & Collins Co., USA. 336 – 342.

69. ANSI/ASHRAE Standard (1989). "*Standard Method for Pressure Measurement*." Atlanta: (ANSI / ASHRAE 41.1-1986 (RA 2001).

70. Air Conditioning and Refrigeration Institute (ARI) (1998). "*Refrigeration and Air Conditioning*." 3rd edition. Prentice Hall, USA. 319 – 321.

71. Eugene, Silberstian (2002). "*Heat Pump*." Thomson Delmar Learning, United State. 48 – 49.

72. Dossat, R. J. (1978). "*Principles of Refrigeration*." John Wiley & Sons, New York. 510.

73. Jones, W. P. (2001). "*Air Conditioning Engineering*." 5th edition. Butterworth Heinemann, Britain. 360.

74. Althouse, Turnquist and Bracciano (1988). "*Modern Refrigeration and Air Conditioning*." The Goodheart-Willcox Company, Holland. 252.

75. Air Conditioning and Refrigeration Institute (ARI) (1998). "*Refrigeration and Air Conditioning*." 3rd edition. Prentice Hall, USA. 336.
76. Eugene, Silberstian (2002). "Heat Pump." Thomson Delmar Learning, United State. 96 – 98.
77. Jordan, R. C. (1956). "*Refrigeration and Air Conditioning*." Prentice-Hall Inc., USA. 280.
78. Jordan, R. C. (1956). "*Refrigeration and Air Conditioning*." Prentice-Hall Inc., USA. 318-319.
79. Ballaney, P. L (1985). "*Refrigeration and Air Conditioning*". Khanna Publisher, Delhi. 527 - 529.
80. Air Conditioning and Refrigeration Institute (ARI) (1998). "*Refrigeration and Air Conditioning*." 3rd edition. Prentice Hall, USA. 336 - 339.
81. Althouse, Turnquist and Bracciano (1988). "*Modern Refrigeration and Air Conditioning*." The Goodheart-Willcox Company, Holland. 366 – 372.
82. Air Conditioning and Refrigeration Institute (ARI) (1998). "*Refrigeration and Air Conditioning*." 3rd edition. Prentice Hall, USA. 339 - 344.