RELIABILITY PREDICTION AND MODELING:
A Case Study of Dry Gas Seal and Buffer Gas System on Compressor for Gas Transportation

by

Wan Mohd Syazwan Bin Wan Ibrahim

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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AP Ir Dr Mohd Amin Bin Abdul Majid
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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WAN MOHD SYAZWAN BIN WAN IBRAHIM

ABSTRACT

Improvement in compressor reliability in petrochemical, chemical and gas industry services will results in higher production revenue and significant savings in maintenance related cost. Centrifugal compressors play a major role in the successful operation of transporting hydrocarbons from offshore by compressed and boosted it to the onshore refinery facilities. To reach the onshore facilities, the pipeline system required several other compression stations to help boost the gas to the shore depending on the distance covered. The compressor is interconnected with the driver which will drive the compressor. Each compressor is supported with gas seal and buffer gas seal supply to deliver the dry gas to the mechanical seal install at the both end of the shaft. For the seal to function without any failure, the dry gas and buffer gas system has to have high reliability. The study conducted is to calculate the reliability of the compressor dry gas seal and buffer gas seal system which is used in the oil and gas industry and identify weather the system is reliable or not for the operation. The Pipping and Instrumentation Diagram (P&ID) of dry gas and buffer gas system of Baram compressor was converted to Reliability Block Diagram (RBD) which simplified and derived the mathematical model of both systems. Using Offshore Reliability Data Handbook 2002 (OREDA 2002), data on failure rate and reliability of each equipment was obtained. Finally, the mathematical model was simulated using the failure rate value and the overall gas seal system reliability is obtained.

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CHAPTER 1

INTRODUCTION

1.0 Background of Study

One of the concerns for users of centrifugal compressors is to increase the reliability of centrifugal compressor which could lead to reducing operating and maintenance cost and improve profit margins exist. The reliability of the compressor is affected by its critical components; among which is the dry gas seal and buffer gas system. It is important to predict and identify the reliability of this system. The reliability number of equipments in the dry gas and buffer gas systems is used in order to calculate the reliability of the system reliability. This helps the engineers to predict the failure of the dry gas seal and generate the necessary preventive maintenance measures to keep the system output at optimum capacity at all time.

1.1 Problem Statement

There always been a problem with the compressor which runs for 2 to 3 years non-stop in the offshore environment. One of the problems is the gas seal failure due to the gas supply. Hence, it is important to know the reliability of the dry gas and buffer gas system to reduce unscheduled shutdown. This project aim to address this issue where the failure of the dry gas seal which is caused by contamination of the supply gas and leads to gas seal degradation and reduced the overall compressor reliability. The contamination of the dry gas seal supply occurs when the sealing gas is not properly treated upstream of the dry gas seal [1]. The unscheduled shutdown causes by failure of the dry gas seal and its components will results in lost of production to the offshore and onshore refinery since the hydrocarbon cannot be delivered.

1.2 Objective and Scope of Study

The objective of this project is to analyse the reliability of the gas seal and buffer gas seal compressor for gas transportation from Baram field. The result from the analysis has been further study to see the overall reliability of the system. The scope of the project covers analysis, model development and simulations of the system reliability program.

CHAPTER 2

LITERATURE REVIEW / THEORY

2.0 Compressor in Offshore Hydrocarbon Transportation

Transportation of hydrocarbon from offshore to the onshore facilities usually refinery is using pipeline system. The pipeline system is supported by compressors to boost the hydrocarbon to the onshore facilities. The compressor cannot function by itself but it need to be driven by the turbine as the driver as per Figure 2.1. The hydrocarbon which is extracted from the well will first be separated to oil and gas. Oil will be send directly onshore without any pre-treatment while gas will undergo a process to remove water content in the gas using the glycol dehydration system. The process is necessary and very critical for the compressor because the present of water can cause catastrophic failure to the compressors.

In onshore refinery, almost every refinery is equipped with a reforming plant, requiring compressors for circulating hydrogen rich gases. The compressors used are of the barrel type. Refinery processes also make extensive use of refrigeration compressors for a variety of low temperature distillation, alkylation and de-waxing processes.

There are two types of compressor which is commonly used in transporting the hydrocarbon which is centrifugal and reciprocating compressors. Usually, in the transportation process, centrifugal compressors has always been used to compressed and boost up the hydrocarbon to the onshore facilities because of its low maintenance cost.

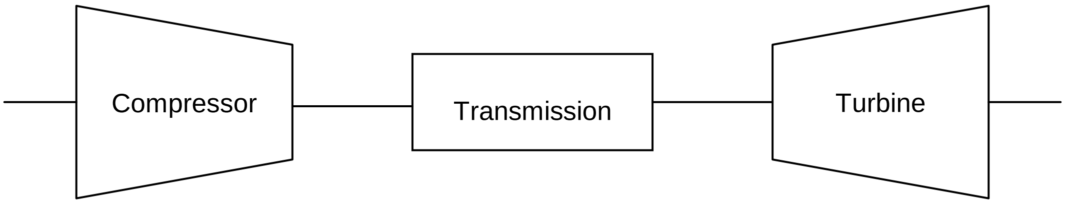

Figure 2.1: Turbine Driven Compressor

2.1 Reliability

Reliability is a characteristic of an item, expressed by the probability that the item will perform its required function under given conditions for a stated time interval [2]. From qualitative point of view, reliability can be defined as the ability of an item to remain functional. Quantitatively, reliability specifies the probability that no operational interruptions will occur during a stated time interval. The main concept used to calculate the reliability of equipment is the probability concept. In order to identify the reliability of the equipment, engineers are concerned with the probability that an item will survive for a stated interval.

2.1.1 Reason of Equipment Failures

It is important to know how the failures happened in order to prevent it from happening. But, it is unlikely to anticipate all the causes, so it is necessary to take into account of the uncertainty involved. Reliability engineering effort, during design, development and in manufacture and service should address all the anticipated and possibly unanticipated causes of failure to ensure that their occurrence is prevented or minimized.

After doing some reading, there are five common reasons why failures occur and listed down below [3]:

1) Design failure

   The material use for the design is not capable of withstanding the load given; the item suffers from resonance at the wrong frequency.

2) Item is overstressed

   When the stress applied to the item exceeded the strength of the material then the failure will occur. Normally, there will be the margin of safety during the designing stage. The designer should know the properties of the material they are using and they ensure that there is an adequate margin between the strength of the component and the maximum applied stress. However, it might not be possible to provide protection against every possible stress application hence overstressed still occur.

3) Failure by variation

   When the strength of the material exceeded the load applied, the failure will not occur. In most cases, there will be some uncertainty about both. The actual strength value of any population of component will vary: most of the items will have average strength but some will slightly stronger or weaker. Apart from that, load applied may be variable as well due to the human error or equipment malfunction.

4) Failure by wear out

   Wear out happened when any mechanism or process that causes an item that is sufficiently strong at the start of its life to become weaker with age.

5) Failure by error

   Incorrect specifications, designs or instrumentation by fault assembly or test, by inadequate or incorrect maintenance or by incorrect use can also cause equipments/machines to fail.

2.2 Failure Pattern from Bathtub Curve

The reliability of every component is represented by the failure rate curve or known as bathtub curve as per Figure 2.2. The curve can be divided into the three following regions. The first region is infant mortality failures which occur within a relatively short time after a device starts to be used. The second region is known as useful life which occurs over a long period of time. Lastly the third region called wear-out failures, which increase as the device nears the end of its life.

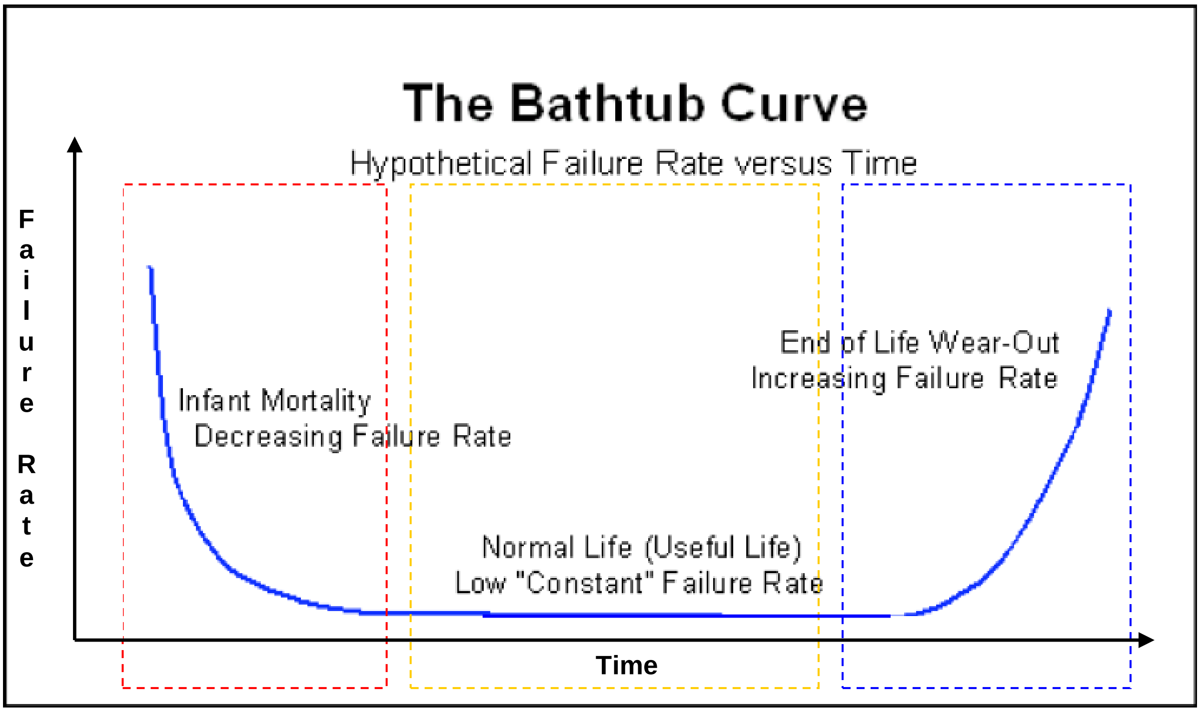

Figure 2.2: The Bathtub Curve

During the infant mortality failure, the failures caused by initial weaknesses or defects in material, defective design, substandard materials, poor quality control, poor workmanship, and damage or missing parts in assembly. Early failures show up early in the life of a unit and are characterized by a high failure rate in the beginning which keeps decreasing as time elapses.

During the second period of time, as represented by the middle section of the bathtub curve of Figure 2.2, the failure rate is approximately constant. This period of life is also known as the useful life during which only random failures occur. These unexpected failures are caused by a sudden and step increases in the stress level beyond the design strength such as power surges, temperature fluctuations, overloading and others, and they cannot be eliminated by debugging techniques or maintenance practices.

Beyond the useful life is the increasing failure rate period or the wear out period of a product. During this time period, products fail due to fatigue at an increasing rate. The point at which wear out begins can be dramatically reduced as emerging and replacement technologies are introduced due to obsolescence [4].

The bathtub curve as per Figure 2.2 was based on the Weibull Probability Density Function (pdf). Each graph shape in each region were depends on the β value of the Weibull pdf represent the shape parameter.

2.3 Reliability Prediction and Modelling

Reliability prediction is the concept of deriving mathematical models which could be used to predict reliability, in the same way as models are developed and used in other scientific and engineering fields. Depending upon the equipment, advance knowledge of reliability would allow accurate forecasts to be made of support costs, spares equipment, warranty costs and etc. the accuracy of reliability prediction is always a hot topic to be debated by engineers. In actual fact, a reliability prediction can rarely be made with high level of accuracy. Nevertheless, it can often provide good basis for forecasting the performance of equipments as well as it dependent factors such as life cycle costs. Reliability predictions can also be as important as part of the study and design processes, for comparing options and for highlighting critical reliability feature of design.

The failure logic of a system can be shown as a reliability block diagram (RBD). Establishing RBD help to identify which item under consideration are necessary for the fulfilment of the required function and which can fail without affecting it. RBD is not the same as a block schematic diagram of the system’s functional layout. Block diagram analysis consists of reducing the overall RBD to a simple system which can then be analysed using the formulae for series and parallel arrangement.

2.3.1 System Reliability Models

Series Reliability Model

The system is considered to be in series when all elements must work in order to fulfil the required function. It is also known as no redundancy model. The reliability block diagram consists in this case of the series connection of all elements as shown in Figure 2.3. In order for the system to function, all of the components below need to function properly [5].

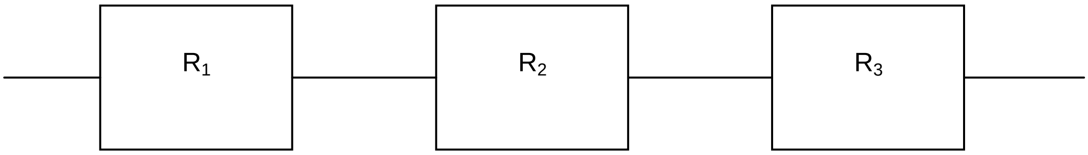

Figure 2.3: Series Reliability Model

The series reliability is calculated using the product rule. For example, if the system has three components Figure 2.3 which $R_1 = 0.92$, $R_2 = 0.95$ and $R_3 = 0.96$, the reliability of the system is calculated using the formula (2.1) below:

$$R_s = R_1 \text{ x } R_2 \text{ x } R_3 \text{ x } \dots \text{ x } R_n \qquad (2.1)$$

$$R_s = 0.92 \text{ x } 0.95 \text{ x } 0.96 = 0.839$$

If all the components in the series system have the same reliability value, then the formula can be simplified to:

$$R_s(t) = R(t)^n \qquad (2.2)$$

Reliability can be also calculated using the failure rates data in series system. At this time, the individual component reliability is not needed. Instead the failure rate is being use and substitute into the basic reliability formula to compute the overall system reliability. The formula is stated below:

$$Rs = e^{-\lambda_1 T} \text{ x } e^{-\lambda_2 T} \text{ x } \dots \text{ x } e^{-\lambda n T} \qquad (2.3)$$

Parallel Reliability Model

A parallel system is defined as complex set of interrelated components connected in such way that a redundant or standby part can take over the function of a failed part to save the system. Parallel system is also known as redundant system or active redundancy as shown in Figure 2.4.

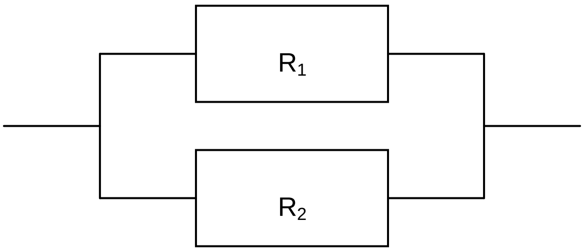

Figure 2.4: Parallel Reliability Model

The calculation of parallel reliability or active redundancy is more complex than the series reliability and includes the use of unreliability concept. The formula is listed below:

$$R_s = R_1 + R_2 – R_1 R_2 \tag{2.4}$$

$$R_s = R_1 + R_2 \text{ x } (1 – R_2) \tag{2.5}$$

2.3.2 Fault Trees Analysis

Fault tree analysis is a deductive methodology for determining the potential cause of accidents or for system failures more generally and for estimating the failure probabilities. Fault-tree analysis is focusing about determining the cause of an undesired event referred to as the top event since fault trees are drawn with it at the top of the tree. Then we worked downward, break down the system in increasing detail to determine the root causes or combinations of causes of the top event. Top events are usually failures of major consequence, causing serious safety hazards or the potential for significant economic loss [6]. The analysis yield both qualitative and quantitative information about the system at hand. The construction of the fault tree in itself provides the analyst with a better understanding of the potential sources of failure and thereby a means to rethink the design and operation of a system in order to eliminate many potential hazards. Once completed the fault tree can be analyse to determine what combinations of component failures, operational errors or other faults may cause the top event. Fault trees are used together with reliability data for the basic events to make estimates of system reliability which is further develop in chapter 4 [7].

2.4 CASE STUDY

Compressor in transporting gas is often driven by gas turbine or electric motor. Without the driver, the compressor will not function by itself. If we were to describe the compressor and the driver in RBD, it will be in series system as shown in Figure 2.5.

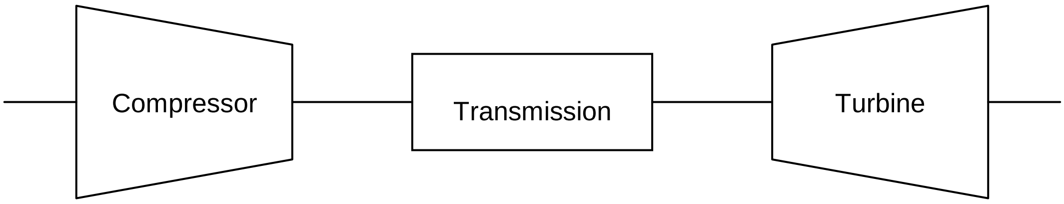

Figure 2.5: Reliability Block Diagram for Compressor System Consisting of Compressor, Transmission and Turbine

So, in order for the system above to have high reliability, the system cannot afford to have failure on compressor or driver.

2.4.1 Compressor seals

Most of the compressor shaft passes out through the casing. It is then necessary to have a seal to prevent the outward leakage of the gas being compressed or in the case of vacuum duties, inward leakage of air. The seal is needed to prevent the process gas from escaping the compressor case uncontrolled into the atmosphere. Over 80% of centrifugal compressors manufactured today are equipped with dry gas seal [1]. Where the compressor is handling an innocuous gas such as air, the sealing function can be achieved by simple labyrinth seal or close clearance devices such as segmental carbon rings, because the small continuous leakage from such devices can be tolerated. Basically, there are two types of seals which are conventional seals and dry gas seal [8]. Conventional seals were used before dry gas seal is become available. In this project, we are going to focus on the dry gas seal since we are interested on its gas seal system.

2.4.2 The Gas Seal System design

The gas seal system explains how the gas seal will be operated and controlled and therefore significantly affects reliability of the seals. The main concern of the gas seal system is the source of the seal gas supply. It is essential for the gas seal source be available at sufficient in order to cover entire operating range of compressor. The source of the gas seal can come from the compressor discharge or separate system from the compressor. When the source is from the compressor discharge system, there will be an effect on the seal during transient condition (start-up, shutdown and idling) of the compressor. The effect is it will be an insufficient pressure rise across the compressor to allow continuous flow of seal gas into the seal.

In order for the gas seal have sufficient amount of pressure, a minimum pressure of 50 Psi needed. The minimum pressure will also allow for pressure drops throughout the seal gas system. This condition usually did not happened in the real case of transient condition.

For example, a gas plant in Asia where several gas turbine driven compressor trains operating in parallel experienced multiple gas seal failure. The gas plant uses compressor discharged gas as the source of the seal gas for each compressor. A study on their operating history has showed that when one of the compressor is not needed in the process, it is not put into shutdown instead it was put on hot standby where the compressor still running. During the hot standby, a very low pressure rise existed across the compressor which causes insufficient seal gas pressure resulting process gas to come into direct contact with gas seal which later causes contamination of the primary gas seal and seal failure [1].

Another concern in gas seal system design is the quality and composition of the seal gas. In most cases, the seal gas filtration system for a compressor dry gas seal must perform two functions. The first is to remove debris and small particles that can cause excessive wear of the seal faces and silt up the seal cartridge. The second is to prevent liquids from entering the seal and causing sudden failure of the seal. Typically, the sealing gas must be dry and filtered of particles 3 micron and larger [9]. Filters are normally provided in the gas seal system to meet this requirement, but pre-filtering may be needed in order to increase the reliability.

2.4.3 Failure of the Dry Gas Seal

Worn out is the usual problem which is faced by the dry gas seal. When the dry gas seal worn out, it will cause the degradation of seal performance and failure of the seal. When this happened, the process gas will escape to the atmosphere which will result in decrease efficiency of the compressor. So, a clean gas which are free from any solid particles and dry are needed for the gas seal to last longer and resulted in increase reliability of the compressor.

Before gas seal is used in the compressor, the function of sealing is done by oil seal. The reason of replacing oil seal with dry gas seal is because it can provide better sealing qualities and most importantly minimize the contamination of bearing lubricating oil. The problem with dry gas seals is that they are passive in the sense that they do not provide any contribution to the rotor dynamic coefficient. Thus, it removes damping and stiffness from the system [8].

Dry gas seal can suffer from aerodynamic instability. When the compressor is used at very high pressure, particularly with high molar gases, the forces generated in these gas seal can be sufficient to destabilise the shaft. Vibration of the shaft will occur when this problem takes place. Hence, this will also reduce the efficiency and reliability of the compressor.

2.4.4 Temperature Effect on the Gas Seal and the System

Components of the gas seal system such as filters, valves, orifices and the seal faces will cause seal gas pressure to drops during operation. As the seal gas expands across these components, the Joule-Thompson effect will result in a corresponding decrease in the gas temperature. The pressure-temperature relationship of the seal gas must be considered. This can be done by simulating the seal gas pressure and temperature drops expected across the various components within the gas seal system. If the seal gas supply contains water, it will slowly effect and damaging the seal gas which later disturb the compressor operation and reduce the reliability of the compressor [1]. This is the common factor that always been overlooked. It has happened at one of the Malaysian Petroleum Facilities where when inspection was done, the seal failure is caused by buffer fluid forming condensation across the pressure regulator valve, which was located downstream of the filters [10].

CHAPTER 3

METHODOLOGY / PROJECT WORK

3.0 Procedure Identification

3.1.1 Procedure for the project

Understand and analysing the problem requirements

- Background studies
- Defining the problem statement and the objectives of the project
- Clarifying the problems and the objectives of the project

Literature Review

- Gathering information regarding the topic from reliable sources such as the internet, books, journals and experts of the given topics.

Analysing the Research Findings

- Extracting the results obtained in accordance with the topic
- Listing down the important information
- Narrowing down the scope of findings
- Analyzing the compressor dry gas system

Reliability Block Diagram

- Develop reliability block diagram for the dry gas system

Mathematical Model Development

- Develop mathematical model for the dry gas system

Refine the Model

- Refine the model from time to time base on the data available.

3.1 Tools / Equipment Required

- Windows based PC
- Microsoft Excel

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Gas Seal System Types

The dry gas seal system is important to supply a ‘clean gas’ for the dry gas seals to last long which increases the reliability of the compressor. Clean gas means the gas is free from solid particles and dry. If the gas seal supplied is not clean, it will cause degradation and wear out of the seal. There are two types of gas seal systems – differential pressure (DP) control and flow control.

DP systems control the supply of seal gas to the seal by regulating the seal gas pressure to a predetermined value typically 10 Psi above the sealing pressure. This is accomplished through the use of a differential pressure control valve [8].

Flow control system controls the supply of seal gas to the seal by regulating the seal gas flow through an orifice upstream of the seal. This can be accomplished with a simple needle valve or through the use of a differential pressure control valve monitoring pressures on either side of the orifice [1].

This project is focused only on one gas seal system which is DP systems that is illustrated in Figure 4.1.

4.1.1 Dry Gas Seal and Buffer Gas Seal System Process Drawing

There are two type of gas supply system which supply seal gas and buffer gas to the compressor while it is running. The seal gas system is supplying the clean gas to the dry gas seal to prevent the process gas from escaping the compressor into the atmosphere while the buffer gas (normally uses instrument gas) injected between the primary and a secondary seal to ensure that gas leaking through the secondary seal does not contain any process gas. The dry gas seal system process flow is shown on Figure 4.1. The green line indicates the flow path of the dry gas to the seal which is labelled as J and K in Figure 4.1.

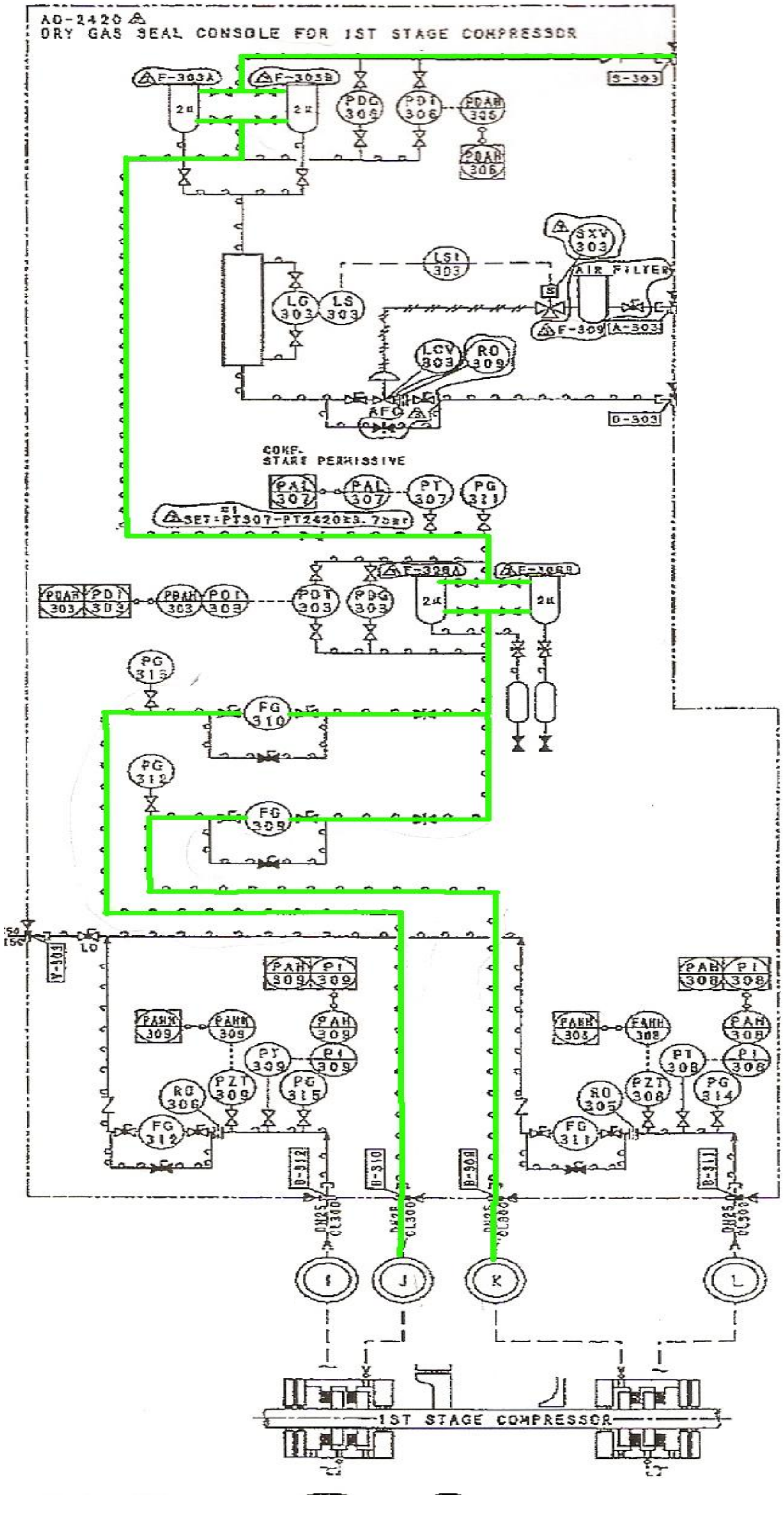

Figure 4.1: Dry Gas Supply System P&ID

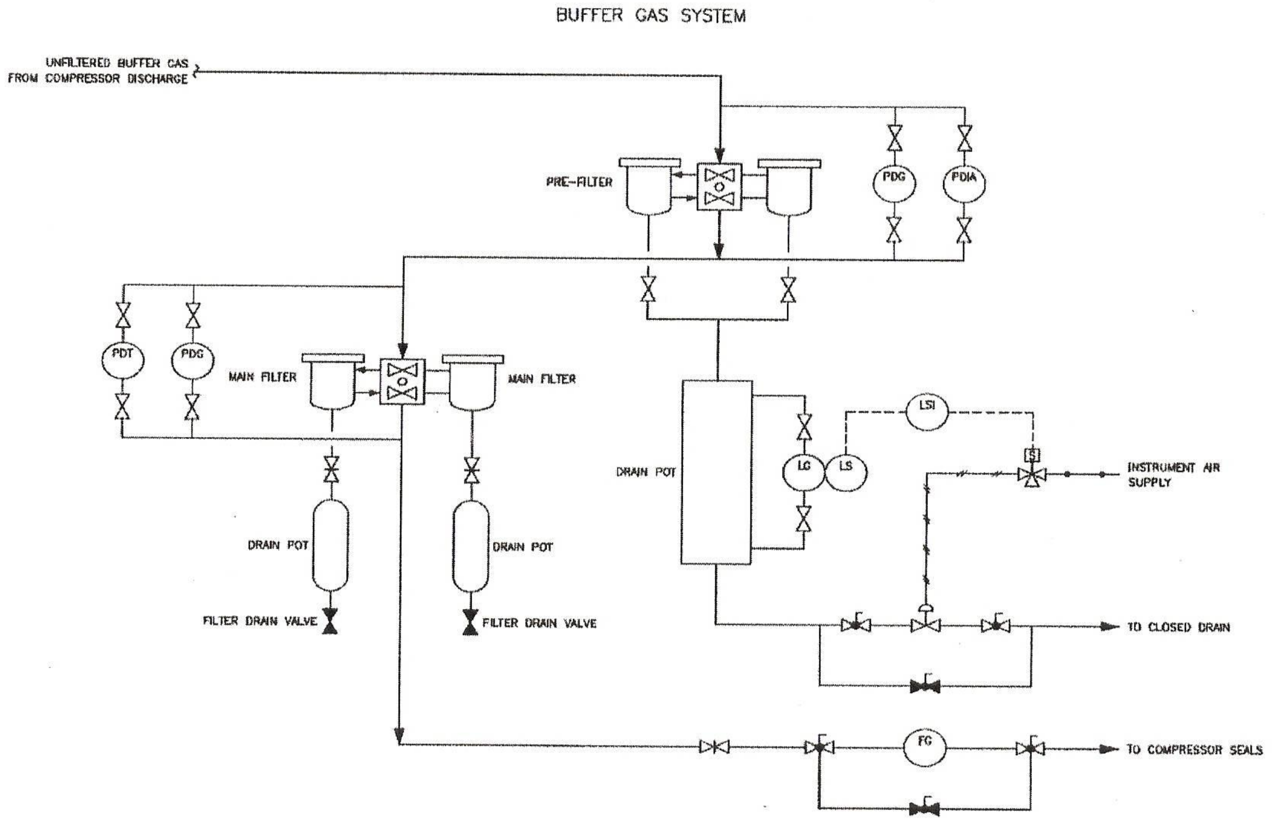

Figure 4.2: Buffer Gas Supply System P&ID

In the event of dry gas seal failure, buffer gas seal take place to prevent the outward and inward leak of the atmospheric or process gas. The buffer gas system as shown in Figure 4.2 is quite similar configuration as the dry gas system. At the start of the both systems, both of the systems have the same arrangement accept when entering the compressor. In order to calculate the system reliability of both systems, Figure 4.1 and Figure 4.2 was simplified into Reliability Block Diagram (RBD) which is describe in Figure 4.4 and Figure 4.5.

4.1.2 Fault Tree Analysis for Dry Gas Seal and Buffer gas Seal Supply

With the system reliability number gathered, fault-tree analysis is prepared to determine the causes which affected the system reliability. With this analysis, engineer will have a guide to plan and conduct maintenance for both systems. The fault-tree analysis describe in Figure 4.3 on the next page is can be applied for both system since both system is practically similar. The failure of the seal is caused by two main factors as describe in Figure 4.3.

- Contamination of the gas seal
- Gas contained liquid due to condensation

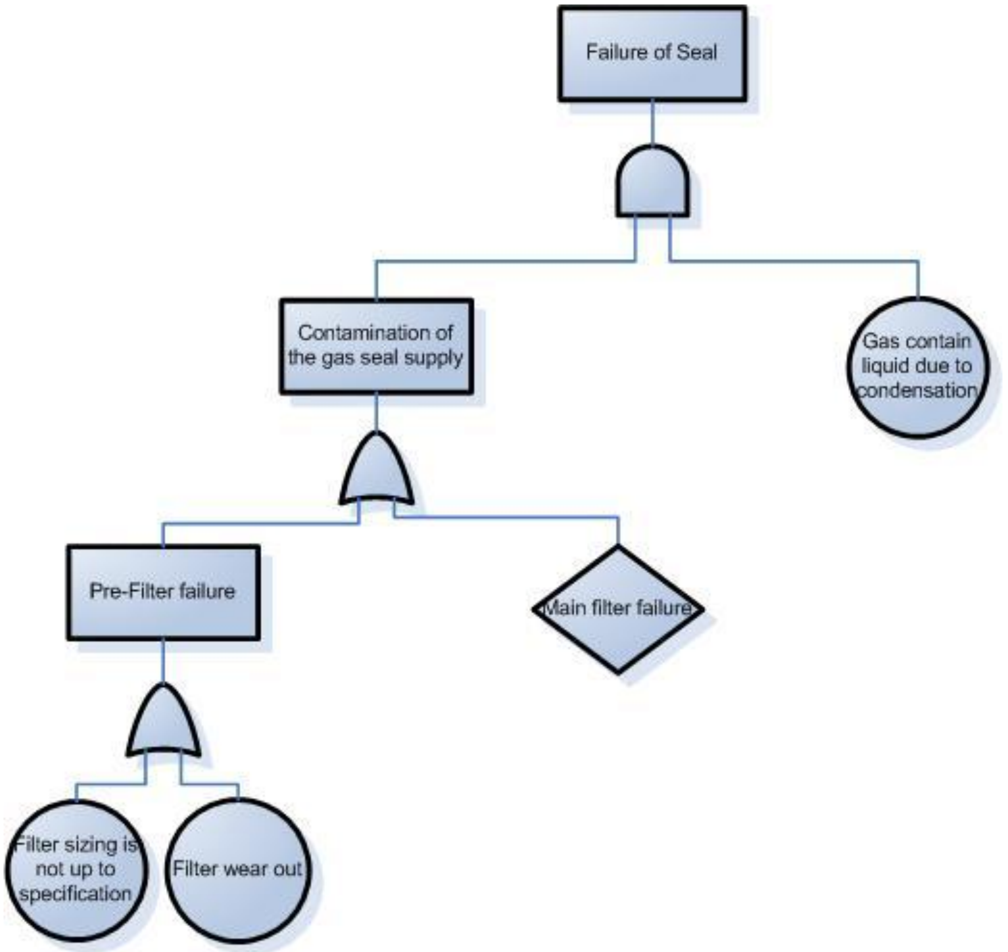

Figure 4.3: Fault-Tree Analysis of Seal Failure

The pre-filter purpose is to remove the liquid from the gas seal while the main filter purpose is to remove particle from the gas seal supply. The filter sizing used in this system is 2 microns for the pre-filter and main filter. The running gap between the primary and mating gas seal rings is typically around 3 to 4 microns. When the contaminant gas which can contain solid or liquid reach this narrow seal running gap, it can cause degradation of seal performance which will lead to failure of the seal gas and resulting to the failure of the compressor.

In order for the seal gas to operate in high efficiency, dry gas needs to be free of any liquid. In the operation, the supply dry gas will go through equipment such as filters, valves and seal faces which can cause the gas seal pressure to drop and can result condensation of the gas. When condensation takes place, the water vapor exist is the seal gas and effect the seal performance.

4.1.3 Reliability Block Diagram of each System

The seal gas system which supplies the seal gas to the dry gas seal is quite a complex system. The reliability block diagram of the dry gas seal system was divided into three subsystems shown in Figure 4.4. The seal gas first flow through check valve and diverts in 2 different paths which then enters the gate valve before it run to pre-filters. The pre-filter is used to filter the gas from any liquid contain in the system before entering the dry gas seal. Next, the gas will flow through gate valve and again to check valve. This process takes place in subsystem A before proceeding to subsystem B. Before the gas pass through the main filter to remove particles which contains in the gas and exiting through another gate valve in subsystem B, first it flows into the gate valve. Finally in subsystem C, the gas enters the needle valve, two ball valves and a flow meter before reaching the seals. There are an active redundancy system provided in subsystem A and B as a standby in case of the main line fail.

Buffer gas system operates in the same way as the dry gas system except that the system is simpler. The system is divided into three subsystems which is subsystem A, Subsystem B and Subsystem C to make the analysis easier as described in Figure 4.5. First, the gas flows through the subsystem A containing gate valve, pre-filter and exited through another gate valve. Next, the gas will under go the subsystem B the main filter which removed the particles which contain within the gas. Both systems have active redundancy system that will function if the main line fails. Lastly, the gas flows through subsystem C contain needle valve, ball valve, flow meter and ball valve before entering the seal. Referring to Figure 4.5, R_{16} which is the ball valve (normally close) are in parallel with the flow meter. The reason is if the flow meter fail, the flow will divert to R_{16} so the system will function as usual.

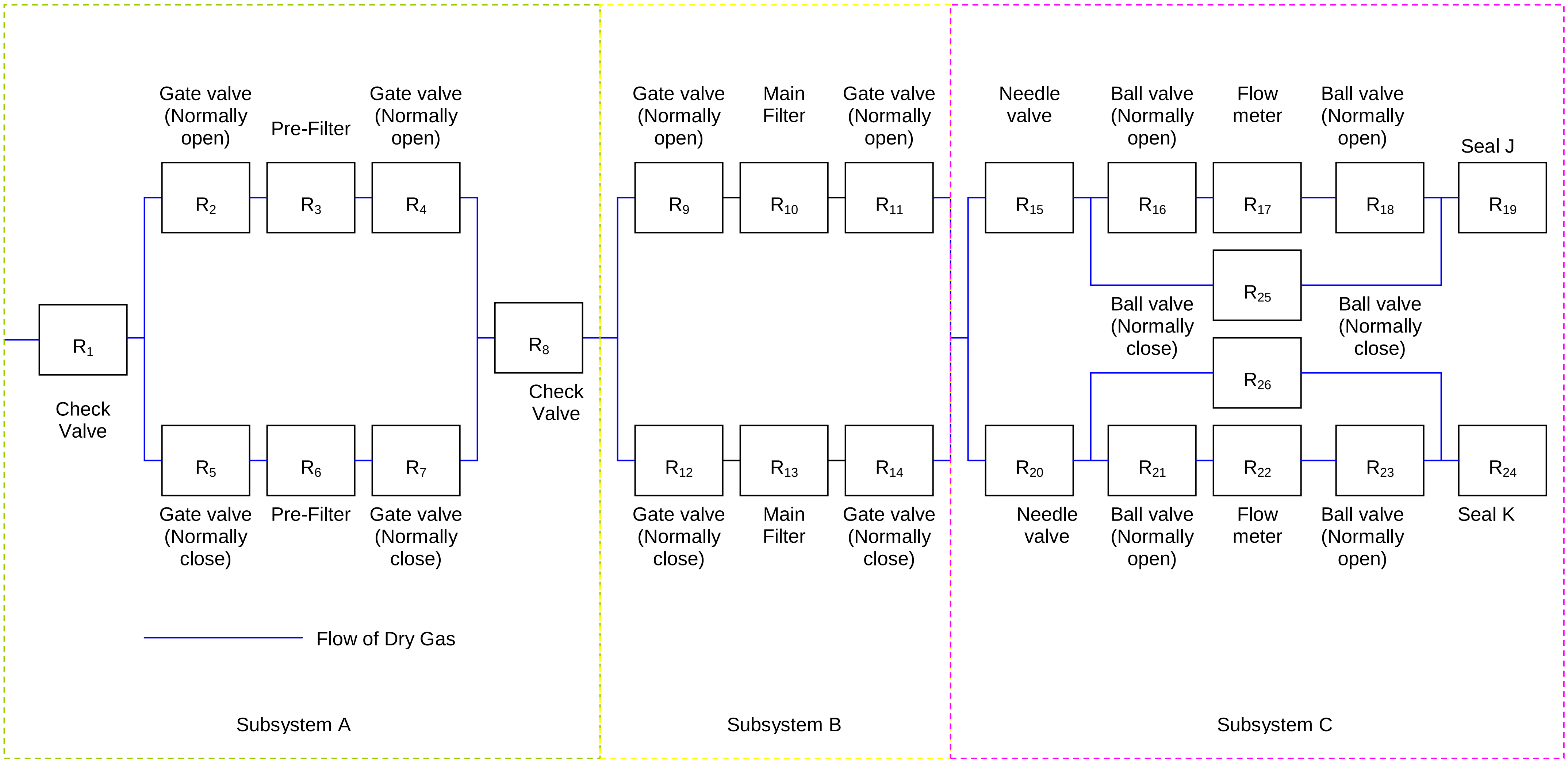

Figure 4.4: Seal Gas Supply System RBD

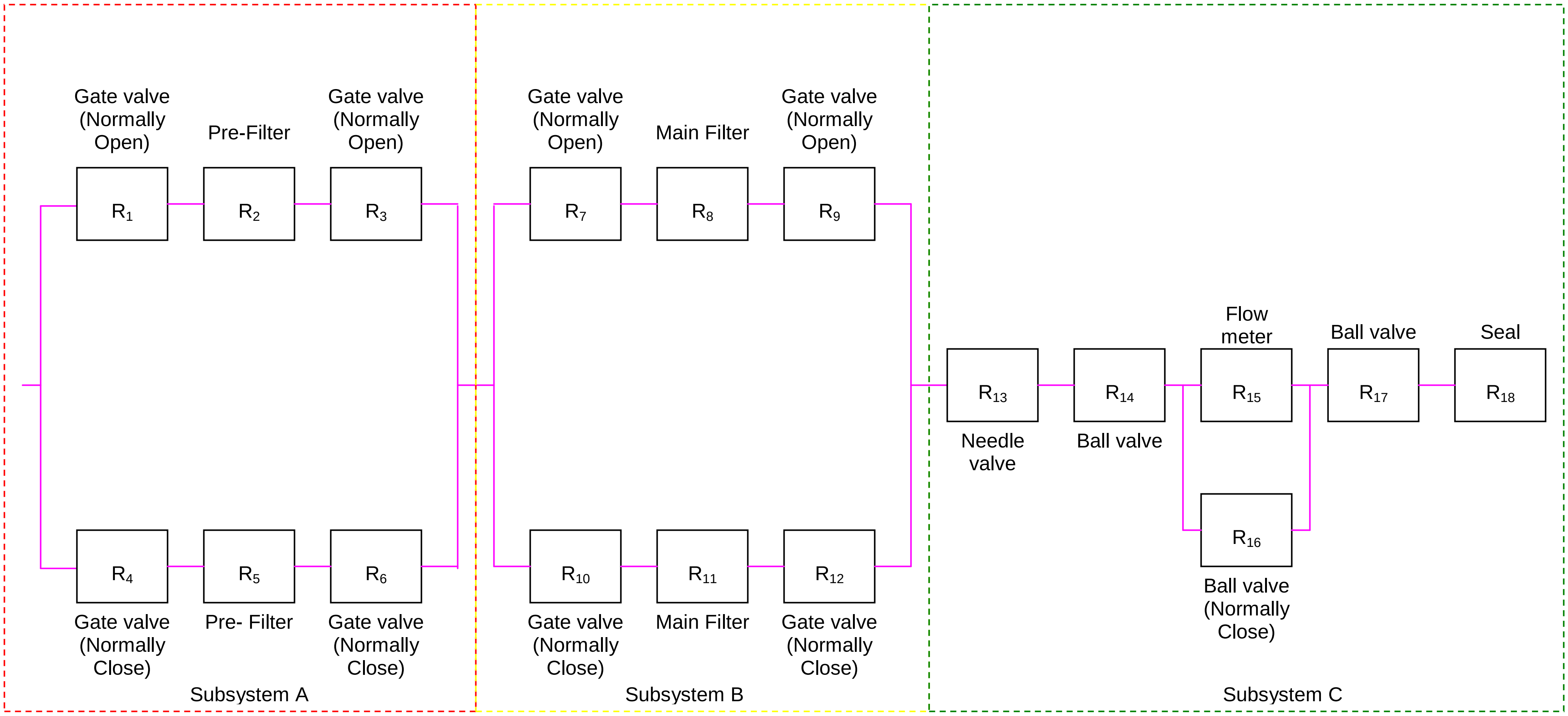

Figure 4.5: Buffer Gas Supply System RBD

4.1.4 Calculation for the system

Mathematical Model for the Seal Gas Supply System

The whole system was divided into 3 subsystems namely subsystem A, subsystem B and subsystem C:

- Subsystem A

Referring to subsystem A in Figure 4.4, the parallel system is simplified before combining it with the series system.

$R_{a1} = R_2 \text{ x } R_3 \text{ x } R_4$

$R_{a2} = R_5 \text{ x } R_6 \text{ x } R_7$

$R_{a3} = R_{a1} + R_{a2} \text{ x } (1 - R_{a2})$

$R_{sysA} = R_1 \text{ x } R_{a3} \text{ x } R_8$

- Subsystem B

Similar to subsystem A, the parallel system was simplified in subsystem B as shown in Figure 12.

$R_{b1} = R_9 \text{ x } R_{16} \text{ x } R_{11}$

$R_{b2} = R_{12} \text{ x } R_{13} \text{ x } R_{14}$

$R_{sysB} = R_{b1} + R_{b2} \text{ x } (1 - R_{b2})$

- Subsystem C

In this subsystem, there are three parallel systems which was simplified as describe in Figure 12. In this subsystem, there are two system reliability:

$R_{c1} = R_{16} \text{ x } R_{17} \text{ x } R_{18}$

$R_{c2} = R_{c1} + R_{25} – R_{c1}R_{25}$

$R_{c3} = R_{21} \text{ x } R_{22} \text{ x } R_{23}$

$R_{c4} = R_{c3} + R_{26} – R_{c3}R_{26}$

$R_{c5} = R_{15} \text{ x } R_{c2} \text{ x } R_{19}$

$R_{c6} = R_{20} \text{ x } R_{c4} \text{ x } R_{24}$

After simplifying all the subsystems, the overall reliability for the dry gas seal system as describe below. $R_{overallA}$ is formulate to calculate the seal J while $R_{overallB}$ for seal K.

$R_{overallA} = R_{sysA} \text{ x } R_{sysB} \text{ X } R_{c5}$

$R_{overallB} = R_{sysA} \text{ x } R_{sysB} \text{ X } R_{c6}$

<u>Mathematical Model for Buffer Gas Supply System</u>

The method used to solve the reliability of buffer gas supply system is same as used for dry gas supply system. First, all the parallel system was simplified.

- Subsystem A

$R_{a1} = R_1 \text{ x } R_2 \text{ x } R_3$

$R_{a2} = R_4 \text{ x } R_5 \text{ x } R_6$

$R_{sysA} = R_{a1} + R_{a2} \text{ x } (1 - R_{a2})$

- Subsystem B

$R_{b1} = R_7 \text{ x } R_8 \text{ x } R_9$

$R_{b2} = R_{10} \text{ x } R_{11} \text{ x } R_{12}$

$R_{sysB} = R_{b1} + R_{b2} \text{ x } (1 - R_{b2})$

- Subsystem C

Referring to Figure 4.5 in Subsystem C, the Flow meter is in parallel configuration with ball valve.

$R_{c1} = R_{15} + R_{16} – R_{15} R_{16}$

$R_{sysC} = R_{13} \text{ x } R_{14} \text{ x } R_{cx} \text{ x } R_{17} \text{ x } R_{18}$

So, the overall reliability for Buffer Seal System ($R_{overall}$) is:

$\mathbf{R_{overall} = R_{sysA} \text{ x } R_{sysB} \text{ x } R_{sysC}}$

4.2 Simulation of Mathematical Model

Using the mathematical model that was derived in previous section, it is then simulated using Microsoft Excel. Reliability number for each equipment was obtained using equation 2.3.

4.2.1 Dry Gas Seal Supply System

In this simulation, it is assumed that all of the equipment time to fail within the system is 1000 hours. Table 4.1 contained all the equipment in the subsystem A and failure rate which is obtained from Offshore Reliability Data 2002. Using the equation 2.3 as discussed in chapter 2, the reliability of equipment was calculated to find system reliability. Gate valve showed the lowest reliability number.

Table 4.1: Subsystem A Equipment Reliability

Equipment	Initial	Failure Rate	Time	Reliability
Check Valve	R_1	2.8000E-07	1000	0.999720039
Gate Valve (Normally Open)	R_2	1.4970E-04	1000	0.860966228
Pre-Filter	R_3	8.9500E-06	1000	0.991089932
Gate Valve (Normally Open)	R_4	1.4970E-04	1000	0.860966228
Gate Valve (Normally Close)	R_5	1.4970E-04	1000	0.860966228
Pre-Filter	R_6	8.9500E-06	1000	0.991089932
Gate Valve (Normally Close)	R_7	1.4970E-04	1000	0.860966228
Check Valve	R_8	2.8000E-07	1000	0.999720039

Table 4.2: Subsystem A System Reliability

	Reliability
$R_2xR_3xR_4 = R_{a1}$	0.734658143
$R_5xR_6xR_7 = R_{a2}$	0.734658143
R_{a3}	0.929593699
R_{sysA}	0.929073272

Table 4.2 shows the subsystem A system reliability. Calculation in R_{a1} and R_{a2} was done to calculate the series system of gate valve (R_2), pre-filter (R_3) and gate valve (R_4). Then, the value was used to calculate the active redundancy system which is R_{a3}. Finally, R_{sysA} is the system reliability for subsystem A. Although the R_{a1} is low,

the subsystem A reliability still have high reliability number. This is because of the active redundancy system R_{a2}, to backup in case of R_{a1} fail.

Table 4.3: Subsystem B Equipment Reliability

Equipment	Initial	Failure Rate	Time	Reliability
Gate Valve (Normally Open)	R_9	1.4970E-04	1000	0.860966228
Main Filter	R_{10}	8.9500E-06	1000	0.991089932
Gate Valve (Normally Open)	R_{11}	1.4970E-04	1000	0.860966228
Gate Valve (Normally Close)	R_{12}	1.4970E-04	1000	0.860966228
Main Filter	R_{13}	8.9500E-06	1000	0.991089932
Gate Valve (Normally Close)	R_{14}	1.4970E-04	1000	0.860966228

Table 4.3 contained the equipment and its reliability figure which was calculated. The failure rate is taken from OREDA 2002 and the time was assumed to be 1000 hours. As listed in Table 4.4, R_{b1} and R_{b2} was calculated value for series arrangement of gate valve (R_9), main filter (R_{10}) and gate valve (R_{11}). The value of R_{b1} and R_{b2} was used in order to get the value of R_{sysB}. In subsystem B, the system reliability obtained is high although the R_{b1} is low as shown in Table 4.4 below. The reason is similar with the subsystem A which is because the existence of active redundancy.

Table 4.4: Subsystem B System Reliability

	Reliability
R9xR10xR11 = R_{b1}	0.734658143
R12xR13xR14 = R_{b2}	0.734658143
R_{sysB}	0.929593699

Table 4.5: Subsystem C Equipment Reliability

Equipment	Initial	Failure Rate	Time	Reliability
Needle Valve	R_{15}	3.5800E-07	1000	0.999642064
Ball Valve (Normally Open)	R_{16}	4.3970E-05	1000	0.956982667
Flow Meter	R_{17}	1.5000E-06	1000	0.998501124
Ball Valve (Normally Open)	R_{18}	4.3970E-05	1000	0.956982667
Seal J	R_{19}	2.2000E-07	1000	0.999780024
Needle Valve	R_{20}	3.5800E-07	1000	0.999642064
Ball Valve (Normally Open)	R_{21}	4.3970E-05	1000	0.956982667
Flow Meter	R_{22}	1.5000E-06	1000	0.998501124
Ball Valve (Normally Open)	R_{23}	4.3970E-05	1000	0.956982667
Seal K	R_{24}	2.2000E-07	1000	0.999780024
Ball Valve (Normally Close)	R_{25}	4.3970E-05	1000	0.956982667
Ball Valve (Normally Close)	R_{26}	4.3970E-05	1000	0.956982667

Table 4.5 above listed the equipment in the subsystem C and reliability number for every equipment. The value of failure rate in subsystem C was also obtained from OREDA 2002 and the time was assumed to be 1000 hours.

Table 4.6: Subsystem C System Reliability

	Reliability
R16xR17xR18 = R_{c1}	0.91444313
R_{c2}	0.996319572
R21xR22xR23 = R_{c3}	0.91444313
R_{c4}	0.996319572
R15xRc1xR19 = R_{sysC1}	0.995743865
R20xRc2xR24 = R_{sysC2}	0.995743865

R_{c1} and R_{c3} which is listed in Table 4.6 is the reliability value for the series arrangement of ball valve (R_{16}), flow meter (R_{17}) and ball valve (R_{18}). The value was used to calculate R_{c2} and R_{c4} which is the parallel arrangement of ball valve (R_{25}). As stated in 4.1.4, there are two system reliability obtained because both seal in dry gas seal system is running at the same time which is R_{19} (seal J) and R_{24} (seal K). So, R_{sysC1} and R_{sysc2} is the system reliability of subsystem C.

Based on the Table 4.2, 4.4 and 4.6, the reliability number for each subsystem which is R_{sysA}, R_{sysB}, R_{sysC1} and R_{sysC2} was obtained. The reliability number was obtained after all the parallel and series system was simplified. So, the overall reliability of the Dry Gas Seal System is:

$$\mathbf{R_{overallA} = R_{sysA} \times R_{sysB} \times R_{sysC1}}$$
$$= 0.929073272 \times 0.929593699 \times 0.999981885$$
$$= 0.859984803$$

$$\mathbf{R_{overallB} = R_{sysA} \times R_{sysB} \times R_{sysC2}}$$
$$= 0.929073272 \times 0.929593699 \times 0.999981885$$
$$= 0.859984803$$

According to the overall results, the $R_{overall}$ is greatly affected by the R_{sysA} and R_{sysB} which is lower than R_{sysC1} and $R_{sysC2.}$ If the reliability of R_{sysA} and R_{sysB} increases to the value near to R_{sysC1} and R_{sysC2}, the $R_{overallA}$ and $R_{overallB}$ will be increased. When we refer back to Table 4.1 and 4.3, the gate valves contribute for the reliability of R_{sysA} and R_{sysB} to be low.

4.2.2 Buffer Gas Supply System

In Buffer Gas Supply System, it is also assumed that time to fail for equipment is 1000 hours. Using the failure rate which is obtained from OREDA 2002 and assuming the time in table 4.7, 4.9 and 4.11, the reliability of equipment is calculated and the subsystem and overall reliability of the Buffer Gas Supply System is obtained.

Table 4.7: Subsystem A Equipment Reliability

Equipment	Initial	Failure rate	Time	Reliability
Gate Valve (Normally Open)	R_1	1.4970E-04	1000	0.8609662
Filter	R_2	8.9500E-06	1000	0.9910899
Gate Valve (Normally Open)	R_3	1.4970E-04	1000	0.8609662
Gate Valve (Normally Close)	R_4	1.4970E-04	1000	0.8609662
Filter	R_5	8.9500E-06	1000	0.9910899
Gate Valve (Normally Close)	R_6	1.4970E-04	1000	0.8609662

In Table 4.7, all of the equipment and its failure rate have been listed. From the failure rate and time given, the reliability of each equipment was obtained.

Table 4.8: Subsystem A System Reliability

	Reliability
$R_1 x R_2 x R_3 = R_{a1}$	0.734658143
$R_4 x R_5 x R_6 = R_{a2}$	0.734658143
R_{sysA}	0.929593699

Ra1 and Ra2 in Table 4.8 represent the reliability of series configuration of gate valve (R1), pre-filter (R2) and gate valve (R3). When the reliability of Ra1 and Ra2 calculated, the active redundancy system present (Figure 4.5) in subsystem A was obtained, RsysA. The existence of active redundancy has caused the subsystem A system reliability is high even though the Ra1 and Ra2 reliability value is low.

Table 4.9: Subsystem B Equipment Reliability

Equipment	Initial	Failure Rate	Time	Reliability
Gate Valve (Normally Open)	R7	1.4970E-04	1000	0.8609662
Filter	R8	8.9500E-06	1000	0.9910899
Gate Valve (Normally Open)	R9	1.4970E-04	1000	0.8609662
Gate Valve (Normally Close)	R10	1.4970E-04	1000	0.8609662
Filter	R11	8.9500E-06	1000	0.9910899
Gate Valve (Normally Close)	R12	1.4970E-04	1000	0.8609662

The equipment in the subsystem B is similar to subsystem A. Thus, the calculation and value obtained is same as previously discussed in subsystem A.

Table 4.10: Subsystem B System Reliability

	Reliability
R7xR8xR9 = R_{b1}	0.734658143
R10xR11xR12 = R_{b2}	0.734658143
R_{sysB}	0.929593699

Table 4.11: Subsystem C Equipment Reliability

Equipment	Initial	Failure Rate	Time	Reliability
Needle Valve	R13	3.5800E-07	1000	0.9996421
Ball Valve (Normally Open)	R14	4.3970E-05	1000	0.9569827
Flow Meter	R15	1.5000E-06	1000	0.9985011
Ball Valve (Normally Open)	R16	4.3970E-05	1000	0.9569827
Seal	R17	2.2000E-07	1000	0.99978
Ball Valve (Normally Close)	R18	4.3970E-05	1000	0.9569827

In subsystem C, there are one parallel configuration of flow meter (R15) and ball valve (R16). As listed in Table 4.12, Rc1 is the value obtained after the calculation was done on the parallel configuration. The RsysC is the system reliability of subsystem C when solving the needle valve (R13), ball valve (R14), the parallel configuration of flow meter and ball valve, ball valve (R17) and Seal.

Table 4.12: Subsystem C System Reliability

	Reliability
R_{c1}	0.999935522
R_{sysC}	0.91522762

So, from the tables above, the reliability for the whole Buffer Gas Supply System was obtained.

$R_{overall} = R_{sysA} \times R_{sysB} \times R_{sysC}$

$= 0.929593699 \times 0.929593699 \times 0.91522762$

$= 0.790888863$

The reliability of the Buffer Gas Supply System is lower than the Dry Gas Supply System. Based on Table 4.12, the R_{sysC} greatly affected the overall reliability. The reliability of equipment in subsystem C has high reliability. The overall reliability of Buffer Gas Supply System is low because it does not have active redundancy configuration to backup the system if it fails to function.

Finally, the overall reliability of the gas seal was obtained. As discussed before, Dry gas seal act as the primary seal while the buffer gas seal as the backup or secondary seal. Below is the overall reliability of the seal system:

Dry gas seal ($R_{overallA}$) = 0.859984803

Dry gas seal ($R_{overallB}$) = 0.859984803

Buffer gas seal ($R_{overall}$) = 0.790888863

Reliability of centrifugal compressor seal I and J

$= R_{overallA} + R_{overall} – (R_{overallA}) (R_{overall})$

$= 0.859984803 + 0.790888863 – (0.859984803) (0.790888863)$

$= 0.970721263$

Reliability of centrifugal compressor seal K and L

$= R_{overallB} + R_{overall} – (R_{overallB}) (R_{overall})$

$= 0.859984803 + 0.790888863 – (0.859984803) (0.790888863)$

$= 0.970721263$

From the result above, it can be concluded that the Baram field compressor gas seal have high reliability. Hence, the compressor gas seal is reliable on handling the operation.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The mathematical model and the simulation using Microsoft Excel was developed to calculate the overall reliability of the Dry Gas Seal Supply and Buffer Gas Supply System. The simulation was able to calculate the reliability of all subsystem when any input was changed. The overall reliability of the centrifugal compressor seal is high. The existence of active redundancy helped in maintaining the high reliability value.

From the simulation, the system reliability depends greatly on the reliability of equipment in the subsystem. The reliability of Gate Valve in subsystem A and B of both Gas Supply systems has greatly affected the system reliability. So, this equipment needs to be given high priority during maintenance. Well schedule maintenance has to be plan in order to avoid the equipment from failing during the operation.

The configuration of the system also affected the system reliability. The parallel configuration also known as active redundancy played important role on the system reliability. In R_{a3}, R_{sysB}, R_{c2}, R_{c4}, $R_{overallA}$ and $R_{overallB}$ of Dry Gas Seal Supply which is in parallel configuration, the reliability number is very high where it reaches 0.9 out of 1. However, using the active redundancy to increase the system reliability has to be done carefully since it will incur more capital cost and operation cost.

The objective of this project which is to analyse and calculate the system reliability of the dry gas system and buffer gas system in order to get the overall gas seal system has been achieved. From the analysis and calculation, the critical equipment in the system has been identified. Hence, an effective maintenance can be plan in order to reduce the compressor unscheduled shutdown which greatly effect the daily operation of transporting hydrocarbon.

5.2 Recommendation

To further enhance the model, the use of field data is recommended. In many practical cases, very few data are available on the reliability of the components of a system and the reliability prediction can then be made only on the basis of overall comparison. The following study should be included for further study:

- include Weibull distribution to predict the reliability of equipment involve in the whole system

- develop a program interface to be more informative and user friendly

- Integrate more information when analysing the system reliability such as the breakdown time.

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