RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING
e-ISSN: 2773-4765

RPMME

Vol. 5 No. 1 (2024) 492-496
https://publisher.uthm.edu.my/periodicals/index.php/rpmme

Failure Mode and Effect Analysis of Butterfly Valve in UTHM Biodiesel Plant

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DOI: https://doi.org/10.30880/rpmme.2024.05.01.056

Article Info

Received: 15 January 2024
Accepted: 15 July 2024
Available online: 15 Sept. 2024

Keywords

FMEA, Butterfly Valve, Risk Priority Number

Abstract

This study presents a Failure Mode and Effect Analysis (FMEA) conducted on butterfly valves in the UTHM biodiesel plant. This research aims to assess the risks associated with butterfly valves and develop targeted risk mitigation strategies to enhance plant safety, reliability, and performance. The introduction explores the existing knowledge of butterfly valve failures, FMEA methodologies, and previous oil and gas industry studies. The methodology section outlines the research design, data collection procedures, and the FMEA process, including severity, occurrence, and detection assessments. The study aims to identify critical failure modes, assign risk priority numbers, and propose effective risk control measures. The expected results include a comprehensive understanding of failure modes specific to butterfly valves in the UTHM biodiesel plant, prioritized risk areas, and targeted risk mitigation strategies. The significance of this research lies in its potential to minimize failures, reduce downtime, optimize resources, and contribute to the existing knowledge in butterfly valve failure analysis. The findings of this study can be used to enhance the safety and reliability of butterfly valves in the UTHM biodiesel plant and potentially benefit other similar industrial applications.

1. Introduction

The valve failure might be due to a physical failure of the valve, such as exterior leaking from the valve body or improper valve sizing, or it can be due to the valve not operating or functioning properly [1]. Although there may have been a problem with the hydraulic power source or the control system, this is still seen as a valve failure. At the UTHM Biodiesel Plant, valve leakage and poor maintenance are the main causes of BVs. Determine whether the valve has a locking device after performing a strength test on the failed component [2]. Additionally, component deterioration may potentially contribute to failure.

The expected outcomes of the FMEA study on BV in the UTHM biodiesel facility include a thorough understanding of the probable FMs and risks associated with these valves. The study's goal is to provide insights into the severity, likelihood of occurrence, and detection capabilities of each FM, allowing for the prioritization of high-risk locations. The desired outcome is the identification of major FMs that must be addressed immediately, as well as the development of focused risk mitigation solutions.

The FMEA research on BV at the UTHM biodiesel plant is critical to improving the plant's overall safety, dependability, and performance. The analysis identifies crucial areas that demand attention and action by methodically analyzing potential failure mechanisms and their associated risks. It provides proactive risk management through the implementation of specific risk reduction methods such as design enhancements, maintenance procedures, and operational adjustments.

2. Equipment and Methods

Failure Mode and Effect Analysis (FMEA) is an engineering technique used to define, identify, and eliminate known and potential problems, errors, and so on from the system, design, process, and service before they reach the customer [3]. The history of FMEA can be traced back to the early 1950s when it was used for the design of flight control systems [4]. FMEA is one of the best candidates for reliability analysis at the design stage, is well-defined and has been used for many power generation engineering systems [5]. The main objective of this paper is to carry out a comprehensive FMEA on a manually operated and electrically operated BV and provide various inputs to designers to improve design configurations [6].

The FMEA is a formalized but subjective analysis for systematically identifying possible root causes and FMs and estimating their relative risks [7]. FMEA is usually carried out by a team consisting of design and maintenance personnel whose experience includes all the factors to be considered in the analysis [8, 9]. This entails assessing the effects on safety, dependability, efficiency, environmental aspects, production continuity, and other pertinent elements. Understanding the probable consequences of failure aids in prioritising and allocating risk mitigation resources [10].

This research involved laboratory and biodiesel plant investigations supervised by laboratory assistants. The initial step in the laboratory involved disassembling the butterfly valve (BV) display, following safety protocols by wearing protective gear. To prevent fluid or gas flow, upstream and downstream valves were closed, and if the valve was pressurized, proper depressurization measures were taken. Disassembly started by disconnecting the actuator valve from the BV (Fig. 1) and then separating the BV components (Table 1). For universal BV sub-components like body, disc, stem, seat, and seal, the following general steps were taken:

a) Safety First: Wear suitable personal protective equipment (PPE), gloves, and safety glasses.
b) Disassemble the Valve Body: Identify and remove bolts or screws holding body parts together. Replace gaskets or O-rings if present.
c) Disassemble the Disc and Stem: Examine the connection and remove any retention clips, pins, or fasteners. If the disc and stem are one piece, no separation is needed.
d) Handle Seat and Seal: Look for retention clips, nuts, or screws securing the seat and seal. Remove these fasteners to separate them from the valve body.
e) Inspect and Clean: After disassembly, inspect for damage or wear, and clean the components thoroughly, removing any debris.

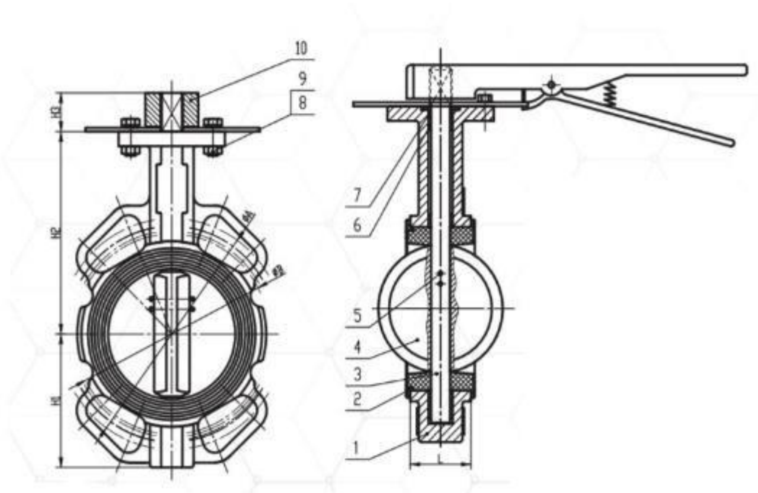

Fig. 1 - 2D Drawing (Part's Label)

Table 1 - BV Parts

Parts No.	Sub-Component
1	Body
2	Seat
3	Stem
4	Disc
5	Pin
6	Bushing
7	Packing Ring
8	Nut
9	Bolt
10	Handle

The Risk Priority Number (RPN) is a numerical value determined by multiplying a certain FM or risk's severity, occurrence, and detection ratings. It is used to prioritize risks in risk assessment and analysis. By assessing the potential severity of the effects, the chance of occurrence, and the efficacy of detection mechanisms, the RPN assists in identifying and prioritizing high-risk areas.A higher RPN signifies a higher level of danger, necessitating more rapid attention and action.

Risk Ranking Logic is a systematic way to assess and prioritize risks associated with distinct failure modes within a system, which is frequently applied through the Risk Priority Number (RPN) in Failure Mode and Effect Analysis (FMEA). The RPN is determined by multiplying the Severity, Occurrence, and Detection values assigned to each failure mode by the number of failure modes. This numerical value offers a quantitative indication of the risk associated with a particular failure mode, allowing for prioritization.

$$Risk\ Priority\ Number = Severity \times Occurrence \times Detection \quad (1)$$

$$Cost\ of\ difference = Current\ Cost - New\ Cost$$

$$Cost\ Saving = \frac{Cost\ of\ Difference}{New\ Cost} \times 100\% \quad (2)$$

3. Result and Discussion

Drawing insights from prior studies, this checklist was meticulously populated with exhaustive details encompassing the identification of functions, materials employed, potential failure modes, effects of failure, causes of failure, existing controls, and prescribed maintenance periods for each sub-component. By leveraging the plant assistant's expertise and insights, the severity, occurrence, and detection ratings were populated, contributing to the holistic evaluation of the risk landscape associated with each part of the butterfly valve. This collaborative approach aimed to ensure the accuracy and relevance of the RPN values assigned to each sub-component, laying a robust foundation for subsequent phases of the Failure Mode and Effect Analysis (FMEA) study.

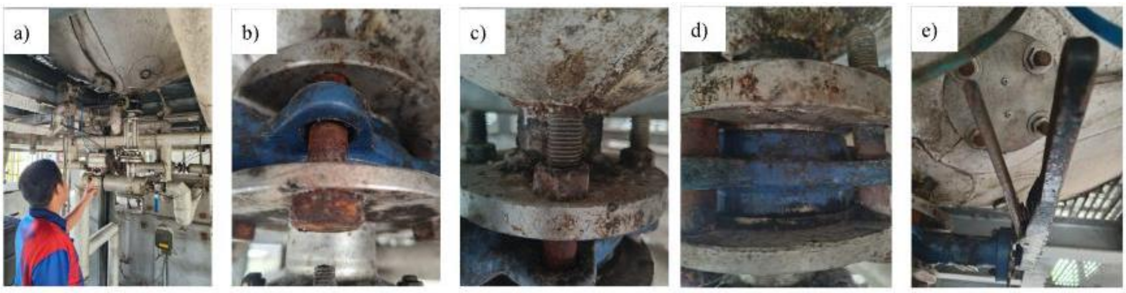

Fig. 2 - Outer visual inspection of (a) full outer body (b) bolt (c) nut (d) body (e) handle

Penerbit UTHM

In this dedicated section, a comprehensive analysis and commentary on the comparison between the current and new results take centre stage. The primary goal is to discern the project's overall achievement. The focal point of this assessment lies in the examination of the disparity between the Current Risk Priority Number (RPN) and the New RPN for each sub-component (Fig. 2). This divergence is a direct consequence of the profound impact of the risk mitigation strategy derived from the new maintenance approach. The crux of the matter becomes evident as we observe a substantial decrease in RPN values when the maintenance methodology is correctly implemented. This insightful observation serves as a tangible indicator of the project's success in aligning with its objectives.

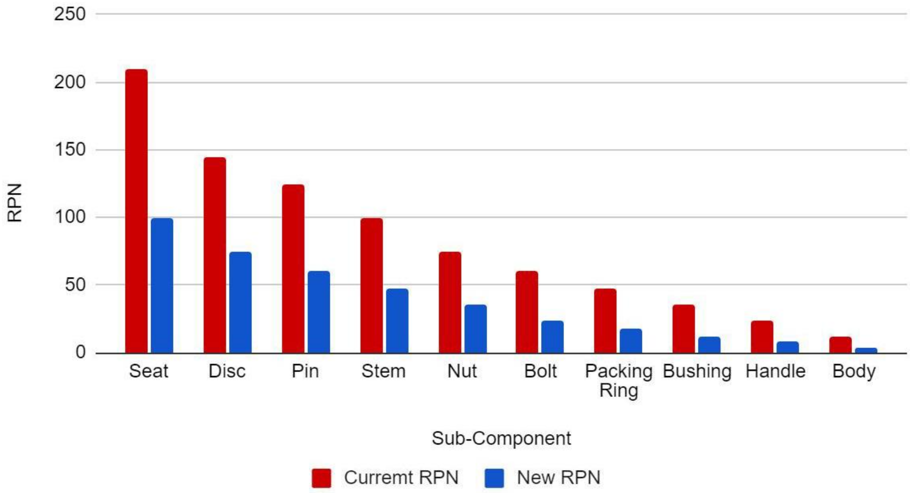

Fig. 3 -*Pareto Chart of Current RPN and New RPN*

The summarized results inTable 2 underscore notable shifts in the risk thresholds, illuminating the impact of strategic adjustments in the maintenance approach. Notably, the seat and disc have transitioned from the red zone, signalling a need for corrective action, to a more favourable yellow zone, denoting consideration. This positive shift can be attributed to the implementation of a maintenance strategy focused on establishing on-site seat replacement capability and instituting a seat replacement program.

Table 2 *Risk Ranking Logic of Current RPN and New RPN*

Sub-Component	**Risk Ranking Logic**	
	Current	**New**
Seat	Need Corrective Action	Consideration
Disc	Need Corrective Action	Consideration
Pin	Need Corrective Action	Acceptable
Stem	Consideration	Acceptable
Nut	Consideration	Acceptable
Bolt	Consideration	Acceptable
Packing Ring	Consideration	Acceptable
Bushing	Acceptable	Acceptable
Handle	Acceptable	Acceptable
Body	Acceptable	Acceptable

An analysis of the cost difference between new and existing spare parts for various sub-components in maintenance reveals key insights. Notably, the use of EPDM for seat and bushing maintenance, along with a strategic plan, reduces spare components from three to two over three years. EPDM is chosen for its resilience and sealing capabilities. Stainless steel is chosen for disc and pin maintenance, reducing spare parts and emphasizing durability. Substituting stainless steel for the original carbon steel nut and bolt enhances corrosion resistance and durability, reducing spare parts needed from three to two. Stem maintenance requirements decrease from two to one, showcasing a more efficient plan. Silicone rubber replaces mild steel in the packing ring, leading to less frequent maintenance and cost savings. For handle and body maintenance, stainless steel remains constant, requiring only one spare part over three years, highlighting the reliability of the current maintenance strategy. Overall, strategic material choices and maintenance plans contribute to efficiency, cost savings, and component reliability.

TOTAL	873.85	648.12

$$Cost\,of\,difference = 873.85 - 648.12 = 225.73$$

$$Cost\,Saving = \frac{Cost\,of\,Difference}{New\,Cost} \times 100\%$$

$$= \frac{225.73}{873.85} \times 100\%$$

$$= 25.832\%$$

Fig. 4 *Cost of saving calculation*

4. Conclusion

The Failure Mode and Effect Analysis (FMEA) on butterfly valve sub-components in the UTHM Biodiesel Plant's VE203 to T209 pipeline, overseen by plant assistants, revealed key insights and prompted strategic changes. Identified high-risk components like the seat, disc, and pin underwent improved maintenance approaches, leading to a significant decrease in Risk Priority Numbers (RPNs) from the red to yellow or green zones. Material choices, such as EPDM for seats, stainless steel for various parts, and silicone rubber for packing rings, demonstrated a focus on durability, reliability, and cost-effectiveness. Optimizations, like substituting stainless steel for carbon steel and reducing stem spare parts, aimed at enhancing corrosion resistance and long-term reliability. The calculated cost savings of RM225.73 (25.832%) validate the effectiveness of the revised maintenance, emphasizing potential long-term cost reduction and operational efficiency.

Acknowledgement

The authors would like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, for giving the opportunity to conduct this study.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

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