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Selection of Pipeline Investigation Robot via Pugh Method

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Abstract

A pipeline network or a pipeline system is the connection of several pipes that provide a path in allowing for transportation of matter. Nonetheless, failure or deterioration may occur overtime in this pipeline system due to corrosion and/erosion. Therefore, this study was aimed at determining the optimal design for a pipeline's corrosion investigation robot via Pugh Method. An extensive research was carried out to identify the existing models and their specific mechanism for operation. Moreover, pipeline was studied to achieve a better understanding on the subject. Based on the literature, several criteria were taken into consideration in utilizing the Pugh method for the selection process. The criteria for selection were: (i) stability, (ii) mobility, (iii) adaptability, (iv) flexibility, (v) strength, and (vi) hydrodynamic. The resulting outputs were seven (7) potential designs for the corrosion investigation robot. From the Pugh Method, Design 1, Design 2, Design 3, Design 4, Design 5, Design 6, and Design 7 have earned a total of -1, +3, +2, +4, +9, +11, and +12 points respectively out of a total of +18 points. Conclusively, based on this ratings, Design 7 was selected. For future studies, it is recommended that further analysis such as finite element analysis (FEA) is conducted on Design 7.

Keywords

Corrosion, inspection robot, Pugh method, engineering design

Introduction

A pipeline network or pipeline system is the connection of several pipes that provide a path that allows for the transportation (Chala et al. 2018). Today, as a result of a huge advancement in the oil and gas industry, as well as in general urbanization and modernization; there is an increase in

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raw material, power and energy supply than ever before. This has cause pipeline to become the ultimate method of transportation in the oil and gas industry, water industry, sewage system and several other usages (Gräf, 2004; Chala et al. 2018). Nonetheless, failure or deterioration are developed overtimes in pipelines where corrosion is the main reason behind failure modes of erupting collapsing or alternative failure mechanism (Palencia, 2018). Any forms of complications that might occur within the tubing network could result in the loss of the transmitting fluid. In addition, due to the reactive and/or hazardous nature of these transported fluids, irreversible damages to the surrounding may occur which will definitely jeopardize public health. Therefore, regular inspections and tests must be carried out in order to maximize or prolonged the working life of these pipes.

The aim of this study was to design an efficient corrosion inspection robot for piping system. The proposed research work comprises of two stages where the first stage comprises of deep investigation of existing model and mechanism. The objective of this study was to determine the optimal design for a pipeline's corrosion investigation robot via Pugh Method. Based on the literature, several criteria were taken into consideration in utilizing the Pugh method for the selection process. The criteria for selection were (i) stability, (ii) mobility, (iii) adaptability, (iv) flexibility, (v) strength, and (vi) hydrodynamic. The result of this study shall facilitates the next developmental stage of the corrosion inspection robot.

Literature Review

Since pipe inspection carry a large magnitude of importance there are several models that have been developed and placed in the market to do such kind of inspections. In-Pipe Inspection Robots (IPIRs) are commonly utilized in several fields such as water supply, petrochemical and fluids transport industries. These robots can either be autonomous or remote controlled. While some are connected with cables and wires for communication purposes, others apply wireless technologies. In addition, there mechanism comes either from mimicking animal movement or from other machines such as cars and robots (inspection robot). Diverse works have been carried out on in-pipe robots by several researchers in order to improve different aspects of the robot such as sight, movement or control (Ankit Nayak, 2014). The design philosophy, competence and weakness of the various robot types has been found using the investigation of these researchers and it can be concluded that IPIRs can be divided into three primary kinds and eight sub-categories as noted by Ankit Nayak (2001).

Selection methods can be classified into two main group namely: mathematical derived principles and design alternative selection methods. Some examples of the first type are the Pugh method, house of quality, scoring method, analytic hierarchy process. The methods falling in the second group are weighted sum of product attributes, physical programming, Taguchi loss function and six-sigma (Hazelrigg, 2003). The Pugh Method also known as the Pugh concept selection or the decision-matrix selection was formulated by Stuart Pugh. It is only marginally different from QFD. This method contrasts model alternatives in a matrix structure to a range of performance-related parameters. One of the options be compared is chosen as a reference model and the other alternatives are compared to this reference on criteria or attribute at a time.

Muller et al., (2011) in their review noted that various studies such as Anders Ekholdt (2010) and Erlend Hognestad Seppola (2010) have opted to the used of Pugh matrix in their respective studies. The former was noted to applied Pugh Matrices in the sub-sea domain and concludes that that Pugh matrix was found to be effective for both as an evaluation tool and as a visual communication tool during the project by Muller et al., (2011). Muller et al., (2011) further noted that Anders Ekholdt (2010) highlighted on the benefits in the increment of focus on the core need by capturing the essential concerns from the stakeholders – similarly with Erlend Hognestad Seppola (2010). Muller et al., (2011) emphasized that the Pugh Matrix managed to captured all separate phases of the system into one system, hence, the reason it is considered as a better system.

In addition, Lønmo and Muller (2014) also underlined that if applied on the correct level, the Pugh matrix is indeed a powerful tool. The study further added that this is due to the fact that the tool has the capacity to forces reasoning to be based on explicit criteria and also serves the purpose of documenting the decision making which is beyond the norm of current practice. The study concluded that the Pugh matrix is widely used by engineers and can improve the quality of the concept selection process and facilitate a structured concept selection process. This is also agreed by Wurthmann (2020) whom noted that Pugh Matrix can maximize the potential for innovative solutions that occur at the nexus of decision-making and creativity.

Other studies that accentuated on the advantages and benefits of Pugh method are Lafleur et. al., (2008), Zuck (2014) and Villanueva et al., (2016) among others. Pugh method is consistently noted as user-friendly, possesses effective weighting process, and method treats design as a holistic activity in which professionals from different areas of knowledge interact, depending on the nature of the product to design. Hence, all of these study illustrates the positive usage of the Pugh Method. Hence, validated its usage for this study.

Methodology

Pugh method

The Pugh method was used as a selection process to list down and allocates points to all the designs based on several crucial criteria. From the Pugh analysis it can be found that based on 6 criteria (stability, mobility, adaptability, flexibility, strength, hydrodynamic). In the case where the substitute design is superior to the reference model for each feature, it scores a "+" and if the opposite happens it earns a "-". It scores a "S" if no difference is detected from the reference. At the end of this step the total score of each alternative is calculated based on the number of "+", "-" and "S" it got with a "+" is 1 point, "-" is -1 and "S"is 0. The design with the highest number of points is considered as the optimum.

Results

(a) Design 1

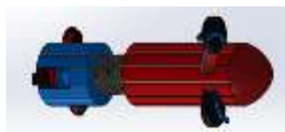
(b) Design 2

(c) Design 3

(d) Design 4

(e) Design 5

(f) Design 6



(g) Design 7

Figure 1 Designs considered in this study

Results and Discussion

Table 1: Pugh Matrix result

	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7
Stability	+	+ +	+ + +	+ + +	+ + +	+ + +	+ + +
Mobility	+ +	+ +	+	+	+ +	+ +	+ +
Adaptability	+ +	+ +	-	-	+ +	+ +	+ +
Flexibility	-	+	- -	- -	+	+	+
Strength	- -	-	+ +	+ +	+ +	+ +	+ +
Hydrodynamic	- - -	- - -	-	+	-	+	+ +

The designs for the Pipeline Investigation Robot is as shown in Figure 1 and the result for the Pugh matrix is as illustrated in Table 1. Design 1 has been design while keeping simplicity as the main focal point. Consisting of two extendable or retractable arms this device can fairly adapt to change in pipe diameter. The wheels' assembly is made to be able to rotate to act as a steering mechanism and the main body is used as a storage for the electrical components and sensor. However, in terms of strength and flexibility it might fall on the poor category due to the fact that the two arms might come into contact with some internal piping debris which could result in fracture or tumble the device. In the case where the wheels are not in contact with the walls of the pipe it would be difficult for the device to navigate in tight spaces.

Design 2 made in an attempt to overcome the shortcoming of Design 1 by consisting of a total of 3 pairs of sliding arms. While the sliding factor offers adaptability, the additional arm offers stability and strength. By use of pressure sensors, the exact force to be exerted by the arms and wheels to the walls can be known so as to allow smooth motion. The arms are connected in the midpoint and use a scissor effect to while sliding in a straight path. However, when the arms are fully extended they are still vulnerable to debris. Besides, the shape is not ideal in regards to hydrodynamics therefore, will require more power to overcome the resistive forces.

Design 3 involves two main part connected together by means of a flexible rod surrounded by a spring. The front part consists of a single huge wheel while the back has three wheels placed at 120o apart. Even though being extremely stable this device lack enormously in the adaptability sector. Such device will be suitable to travel in a single diameter pipe but not in pipeline networks consisting of several diameters and pipe connection. The reason a flexible middle part is used is allow the device to follow angle changes pipes. Design 4 is an attempt to increase the hydrodynamic factor of Design 3 by attaching a conical head to the front part of the device to give it a bullet shape which is known specially for the mentioned property.

Designs 5, 6 and 7 are attempts to increase the adaptability and hydrodynamics of Design 3 and 4 by utilizing a retracting wheel system. This design was inspired by compliance mechanism. As it can be seen the wheel assemblies can be fully retracted inside the body, thus, leaving only the tires exposed or they can be fully extended proving the maximum diameter that this device can achieve. Furthermore, this model was designed to create a hybrid between wall pressed robot and screw type robots. The front wheels are placed at an angle of 80 degrees which allows the robot to travel in a helical motion which facilitates vertical motion. While Design 7 has groove like structures on its surface to increase hydrodynamic properties.

The Pugh method was used as a selection process to list down and allocates points to all the designs based on several crucial criteria. From the Pugh analysis it can be found that based on 6 criteria (stability, mobility, adaptability, flexibility, strength, hydrodynamic). The assessment showed in Table 4 critically highlighted that the design element presented by Design 7 has high stability rating, though, at par with Design 3, 4, 5 and 6 respectively at 3 points. From the mobility point of view, at the rating of 2 points, this design is as good as Design 1, 2, 5 and 6. This is further apparent for the category of Adaptability, Flexibility and Strength where Design 5, 6 and 7 shared similar ratings. Even so, the tide breaker between Design 5, 6 and 7 is that Design 7 illustrated greater hydrodynamic characteristic with respect to its design. The shuttle characteristics of Design 7 allows for the robot to pierce through fluid (in this case – water or other liquid) at greater level of prowess. In the end, the overall rating of Design 1, Design 2, Design 3, Design 4, Design 5, Design 6, and Design 7 are -1, +3, +2, +4, +9, +11, and +12 points respectively out of a total of +18 points. It can be seen that the best model is Design 7 and the lowest is Design 1 having a difference of 13 points between them.

Conclusion

This paper presents the selection of pipeline investigation robot via Pugh method. The resulting outputs were seven (7) potential designs for the corrosion investigation robot. The ratings for the Design 1, Design 2, Design 3, Design 4, Design 5, Design 6, and Design 7 are -1, +3, +2, +4, +9, +11, and +12 points respectively out of a total of +18 points. Conclusively, Design 7 was selected based on the Pugh method. This study further cemented the benefit in the use of Pugh matrix in engineering design selections. For future studies, it is recommended that further analysis such as finite element analysis (FEA) is conducted on Design 7.

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