Finite Element Analysis of a Wheel Assembly for a Pipeline Corrosion Inspection Robot

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Abstract: A pipeline network is critical in allowing for transportation of matter for various applications. One of the major issues of concern for this area is with respect to corrosion and/erosion of the pipelines. A pipeline corrosion inspection robot is commonly used for reconnaissance purposes. The aim of this study was to determine the stress distribution and the safety factor at the back wheel assembly of the pipeline corrosion inspection robot during operation. The assessment was made with respect to operation within the pipeline and under the pressure of flowing fluid. The back wheel assembly was designed via Computer-Aided Design (CAD) and the Finite Element Analysis (FEA) was conducted via ANSYS Software. The result showed that recorded equivalent stress, total deformation and safety factor of the back wheel assembly are 192.35Ma, 0.06534mm, and 1.43 respectively. Thus, this result clearly indicated that the back wheel assembly is indeed capable in performing operations within the pipeline without experiencing unwanted damage. In short, the design of the back wheel assembly of the pipeline corrosion inspection robot is optimized. For future studies, assessments on the back wheel assembly under various loading conditions could be performed.

Keywords: Corrosion, inspection robot, Pugh method, engineering design

Introduction

A pipeline network is critical in allowing for transportation of matter for various applications (Chala et al., 2018). One of the major issues of concern for this area is with respect to corrosion and/erosion of the pipelines. A pipeline corrosion inspection robot is commonly used for reconnaissance purposes (Choo et al., 2020). An enormous level of importance is accorded to the investigation of corrosion which is surely an undeniable incident in tubing so as proper maintenance planning can be done. Corrosion is a complicated reaction that decrease the structural stability which may induce several kinds of failures. Furthermore, the circumstances in which these pipes operate often support the expansion of corrosion. A typical failure mode for intact and corroded pipelines is failure because of internal pressure, which can be regarded as the leading failure in high strength pipes. As aforementioned, the content of the pipeline may be harmful to

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the environment and workers so appropriate inspection must be carried out (Bhardwaj, 2019). Thus, continuous research and advancement in technology are indeed warranted.

According to Mai (2016) and Iszmir (2012) in utilizing traditional inspection devices, for instance the intelligent pig; can be unusually challenging with an enormous economic cost. One of all the choices being explored is the application of robots to analyse the underground pipeline or constricted areas to boost investigation and maintenance quality (e.g. sewers). The foremost possible solutions seem to be the implementation of robot as it is devised to minimize the use of human labour and having the capacity to operate either autonomously or remotely controlled in unattainable areas (Kurata, 2010). In addition, lengthened exposure to the unhealthy environment such as biological contagions, toxic or dangerous gases would be a great risk to the well-being of human labour. Moreover, automation is the way of the future and promises a higher level of accuracy and labour force savings (Seet, 2018). Nowadays, several piping inspection robots exist that are used in their respective industry. Most of them make use of mechanical locomotion system which utilize wheels, pulleys, telescopic, impact or natural peristalsis while bio-inspired robot applies locomotion principles that are mimicked from animals such as: worms, snakes, lizards or octopus (Ankit Nayak, 2014). Nonetheless, there are four (4) main drawbacks with a pipeline inspection robot namely: (i) movement of the device due to the tube diameter changes, bends, elbows and tubing position, (ii) the precise location of the device inside the pipe, (iii) the efficient transmission of data between the on-board sensors and the monitoring device, and (iv) resisting vibration forces produced by mounted equipments carrying out mechanical tasks. Therefore, a vast opportunity is indeed present for these areas of research.

A research carried by Bhadoriya et al., 2018 investigated an IPIR robot using convectional actuators (DC motor). The research was carried in two phases with the first stage focusing on the robot's theoretical modelling and the second phase deals with the creation of the robot prototype. In the theoretical phase, Solidworks was used to modelled the IPIR with convectional actuator. The device includes of a "driving wheel and two backup wheels" to establish the necessary reaction force against the surface of the tube. The driving wheel's primary function is to supply the robot with the sufficient power to drive it inside the tube while the backup wheels are employed "in the opposite direction of the driving wheel" to supply the device with the appropriate support against the tube wall. A BO motor drives the driving wheel and a DC motor drives the backup wheels. Using a link, the backup wheels are driven by spur gears. The linkage is positioned on the gear and the other side is aligned with the backup wheel core. Since two backup wheels are being used the same amounts of links and gears are mounted with the gears being mesh with each other and one of them is positioned on the shaft of DC motor. "The driving wheel is connected to the shaft of the BO motor" Bhadoriya et al., (2018). The robotic arms in this design which connected to the wheel will retract the wheel to allow the circumference of the robot to decrease the size in diameter, which allow to travel into smaller pipeline.

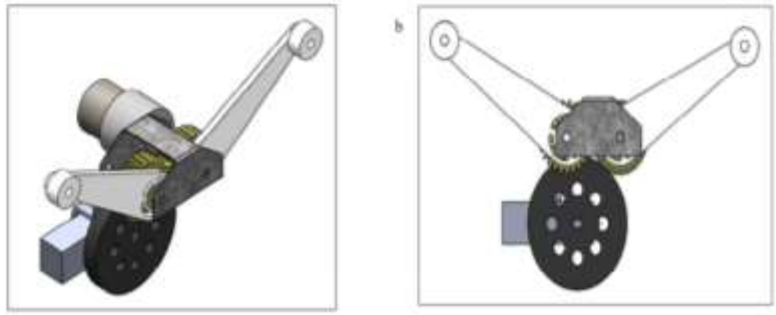

Figure 1. Benchmark design for the wheel assembly (Apoorv, 2018)

The aim of this study was to determine the stress distribution and the safety factor at the back wheel assembly of the pipeline corrosion inspection robot during operation. It is to ensure that the wheel will not fail during the inspection operation and stuck inside the pipeline. The available of computer simulation such as Finite Element Analysis (FEA) will give an advantage to this research regarding the material that use for the robot wheel is suitable or not suitable without performing real-world simulation which will increase the cost of research, and this will help the researcher to determine a material that will give the low running cost as maintenance will be minimize with a material that will sustain the stress and not fail easily, which will give a dangerous risk for human labour to go near the piping area which contain hazard to human health.

Methodology

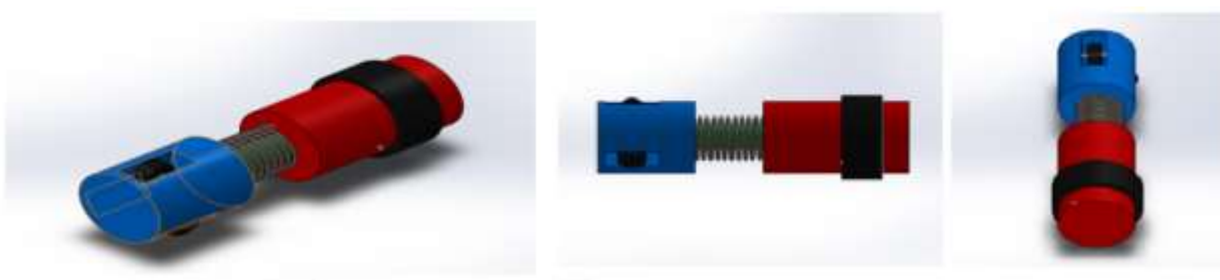

Figure 2. Design of the mechanism and robotic shape.

The assessment was made with respect to operation within the pipeline and under the pressure of flowing fluid. The back wheel assembly was designed via Computer-Aided Design (CAD) and the Finite Element Analysis (FEA) was conducted via ANSYS Software.

Table 1: Data from Ansys Database Source: Ansys Database

Property	Value
Tensile ultimate strength	460 MPa
Tensile yield strength	250 MPa
Young’s modulus	2×10^{11} Pa
Poisson’s ratio	0.3
Bulk modulus	1.6667×10^{11} Pa
Shear modulus	7.6923×10^{10} Pa

Material selected was Structural steel as it is a strong material with density of 7850 kg.m^3, young modulus of 2E+11Pa, Poisson's ratio of 0.3 and tensile yield strength of 275 MPa. The force applied to the sample was 0.3094N based on the formulas and values. The values taken into consideration while calculating the force are from standards of oil transportation industry and the dimensions of the device. The initial force obtained was 1.857N, however, this force is divided among the six wheels therefore reducing the force to one wheel to be 0.3094N.

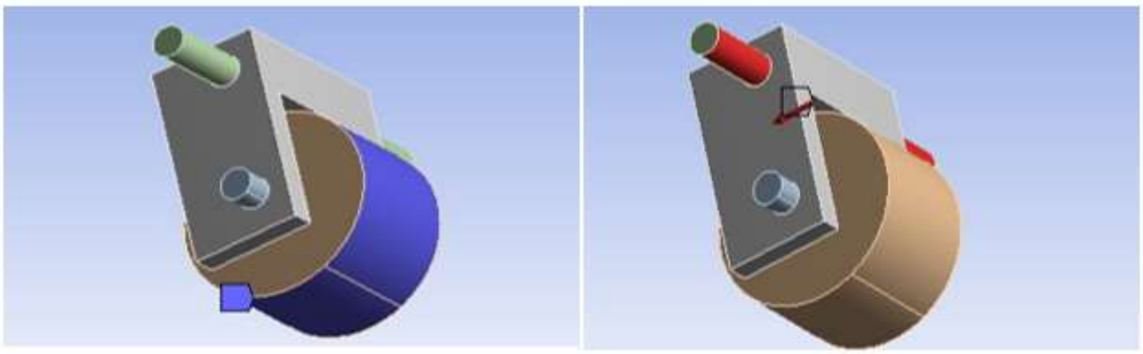

Figure 3. Force act on the fixed support sample.

This force acts as the boundary condition of the experiment and is applied throughout the sample as can be seen from Figure 3 while the fixed support is placed at tire as it will be the one in constant contact to inner walls of pipe as can be seen in Figure 3. Utilizing the mesh generated from the software, the solutions for Equivalent Stress and Total Deformation were solved. The result of the simulations was tabulated in Table 2. The Stress and Deformation listed in the table is the maximum values obtained.

1. Results and Discussion

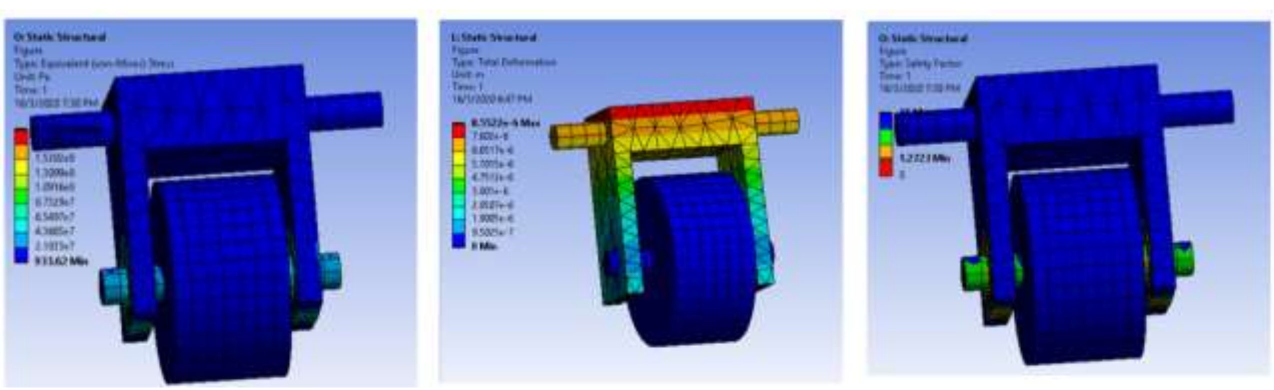

Figure 4. Equivalent (Von-Mises) Stress (MPa), Total Deformation (mm) and Safety Factor

Table 2: Finite Element Analysis Result

Sample	Equivalent (Von-Mises) Stress (MPa)	Total Deformation (mm)	Safety Factor
1	192.35	0.065346	1.43

The FEA simulations were carried out in ANSYS to determine the stress and total deformation due to the effect of the pressure of the flowing fluid on the back wheel assembly of the robot based on the calculations and initial conditions mentioned. The safety factor is then calculated. The result of the ANSYS simulation for “sample 1” is shown. The Stress deformation and factor of safety obtained from the result is shown in Table 2.

The result showed that recorded equivalent stress, total deformation, strength and safety factor of the back wheel assembly are 192.35Ma, 0.065346mm, 275 MPa and 1.43 respectively. Thus, this result clearly indicated that the back wheel assembly is indeed capable in performing operations within the pipeline without experiencing unwanted damage. Structural steel is able to withstand the equivalent Von Mises stress of 192.35MPa which are obtained from the finite elements analysis simulation. In referring to Table 1, the tensile yield strength and the ultimate strength of this material is higher than the equivalent (Von-Mises) stress from the “sample 1” result that is obtain from the FEA. Hence, the deformation that will occur in the wheel will be minimize as the total deformation from the result sample is 0.0625346mm. From the Finite Element Analysis, it is shown that the safety factor is around 1.43, which is consider safe and suitable to be use for this mechanism, and fracture will less likely to occur because the structural steel has a tensile ultimate strength of 460MPa.

Conclusion

In short, the design of the back wheel assembly of the pipeline corrosion inspection robot is optimized. The result clearly indicated that the back wheel assembly is indeed capable in performing operations within the pipeline without experiencing unwanted damage. The safety factor could still be considered marginally over-designed. For the purpose of continuous improvement and sustainability, other aspects of the designs could be examined further. For instances the size of the wheel, the wheel’s design, the fastening methods of the designs etc. In addition, assessments on the back wheel assembly under various loading conditions could also be performed.

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