Praise Worthy Prize

Mechanical Structure Optimization of Sewerage Inspection Robot

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Abstract –*The sewerage inspection robot is a distance controllable robot by a human operator during the sewerage pipe inspection operation. It travel on wheels and is composed of mechanism like a mobile robot. The concept of this inspection robot is used to inspect the sewerage pipe that is not accessible and hazardous for human. The sewerage inspection robot will detect and inform the defect location for any maintenance and repair works. The common problems in the sewerage pipe are breakage, crack and obstacles between the connections. The developed sewerage inspection robot needs to be designed to withstand the collapse of the sewerage pipe so that the robot is fit to be used for next jobs. The project presents the mechanical structure optimization of sewerage inspection robot. The robot is solid rectangular shape and a designed for sewerage pipe. The paper also focused on the structural analysis of the developed robot.* **Copyright © 2009 Praise Worthy Prize S.r.l. - All rights reserved.**

Keywords: Sewerage System, Inspection Robot, Mechanical Structure

I.   Introduction

For a city and town in Malaysia, the largest infrastructure investment is the sewerage system. Due to the high investment cost, the sewerage system needs to be maintaining well by inspection, maintenance as well as repair. The public sewerage system in Malaysia is more than 50,000 km long and it is a big challenge to maintain it. The most common sewerage pipe that used in Malaysia is about 200-900 mm inner diameter which is the focus for our research. Obviously, most of the systems are not accessible and hazardous to human. The current method to maintain such sewerage system is to use the telescopic camera to check the sewerage system. The telescopic camera is consists of a cable with energy supply, data transmission (distance and video) and as a lifeline. However, the current platform is restricted of its mobility due to radius constraint and complexity of design of the sewerage pipe line. The constraint is causing high inspection cost due to the frequent haul in and move to its next entry point. Moreover, the inspection area needs to be clear and shut down so that the inspection can be executed. Human were used to check the sewerage systems but only limited to the man-sized passable sewerage pipe. The usage of human inspection is dangerous, time consuming and expensive. Robot is an integration of mechanical, electrical and computer science that can use to perform the task in hazardous environment [6-9]. The inspection robot is used to gather additional information about the condition in the sewerage system access points. The inspection robot is low cost to manufacture, easy to maintain, customizable, operate continuously, record the condition of inspection area and waterproof. The sewerage inspection robot is beneficial to Malaysia building services, sanitary and HVAC industry. Mechanical structure analysis of the sewerage inspection robot is described in this paper.

II.   Sewerage System in Malaysia

Sewerage system is a place where the domestic waste and waste water from house and business premises to be collected and dispose off. In Malaysia, sewerage systems range from toilet, private treatment plants and public sewerage plants that manage and maintain by Indah Water Konsortium (IWK) [3]. In order to make sure all the underground pipe system works without a problem, these underground pipes had been designed into two section, a) Public pipe (under IWK) and b) Private pipe (individual responsibility). The IWK underground pipe is made on Vertical clay pipe (VCP) so it will more expose to the breakage [3].

III.   Sewerage Inspection Robot

Several researchers and companies were developed sewerage inspection robot to diagnose the sewerage system. Rome et al. [4] developed an autonomous service robot for performing inspection tasks in sewerage systems that are inaccessible for humans. The robot is embedded with the artificial intelligence technology for self operating. The developed sewer robot is equipped with worm-like wheels to improve its mobility inside the sewerage system. The robot is able to map the sewerage system and analyze the sewerage condition. Cordes et al. [1] developed an autonomous multi-articulated robot that can operate wirelessly in the sewerage system. Meanwhile, Siegel et al. [5] designed a robot to inspect the outer body of aircraft for cracks and delimitation defect of skin joint. Fukuda et al. [2] used a robot to detect the defect of pipelines by scanning mechanism. The robot equipped with sensors to sense the sewerage system.

IV. Development of Sewerage Inspection Robot

The sewerage inspection robot is designed to inspect and diagnose the sewerage system in Malaysia. Different technology such as mechanical, electrical, and electronic were integrated into the sewerage inspection robot.

IV.1. System Description

The sewerage inspection robot is a mobile robot that designed to inspect the sewerage system. The inspection operation is to gather additional information about what is taking place between sewer pipe access points. Human are used to check sewerage systems but only limited to the man-sized passable sewerage pipes. The usage of human inspection is hazardous, time consuming and expensive. The sewerage inspection robot is equipped with CCTV camera to view and recording the sewer systems. The robot can be controlled to move forward and backward as well as pan and tilt function to get better view of the inspected area. Fig. 1 shows the Sewer Pipe Inspection System.
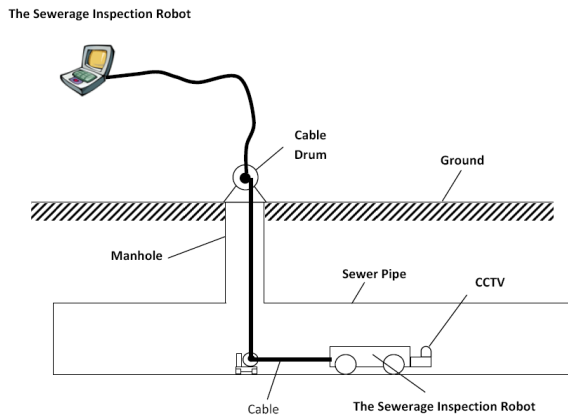

Fig. 1. The sewerage pipe inspection system

IV.2. Hardware Architecture

Mechanical Design

Fig. 2 shows the model of the sewerage inspection robot. The unit is propelled by a gear type servo motor and it is a four wheel drive robot. The body is made from high quality stainless steel. The robot is sealed hermetically, both air tight and waterproof. The robot head is equipped by camera to record the HVAC conditions. A sensor unit is also attached with the robot to record the humidity level, temperature, air flow and indoor air quality.

Signal Processing

Components used within the signal processing group are programmable logic controller (PLC) and motor encoder. The PLC equipped with high speed counter where single phase: 4ch, total 10KHz. The counter range from -8,388,608 to +8,288,607. The PLC also equipped with

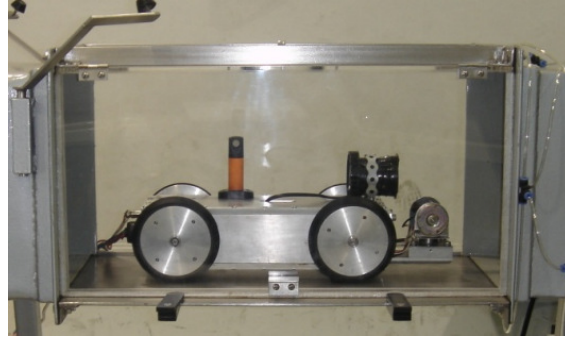PID algorithm, I-PD algorithm, 10ms cycle to 10s cycle and have 16 loops.

Fig. 2. The sewerage inspection robot

Robot Console Unit

Fig. 3 shows the main robot console unit comprises of a touch screen control panel with necessary control button and switch. This console unit is to control the forward, reverse of the robot and the movement of the CCTV. In addition, the touch screens also displays the travel distance, humidity level, temperature, air flow and air quality from sensor unit.

Fig. 3. The main console unit

Sensor System

The sensors consist of temperature, humidity, air quality and air flow sensor. The sensor nodes consist of sensors board and a Windows[TM] based computer (PC) installed anywhere around the world. The sensors board was built by a microcontroller and several sensors such as temperature sensor, pressure sensor, humidity sensor, and air quality sensor. This sensor board will do all the weather sensing, and return the data to PC via RS-232 link when requested by preset command. A Visual Basic program was developed for data transferring task between weather sensors board and PC and from PC to main weather server via TCP/IP connection.

Camera Unit

The camera is the pan and tilt type, i.e. the camera lens rotate 360˚ around its axis and able to pan minimum 140˚ each side in order to inspect any damage at any location in an angle of minimum 90˚ ± 50˚. The speed of the camera in the robot is limited to 0.1 m/s for the duct diameter less than 200mm, 0.15m/s for diameter exceeding 200mm but not exceeding 310mm and 0.20m/s for diameters exceeding 310mm. Figure 6 shows the schematic of the camera unit.

Display Unit

The unit using the state-of-the-art wireless technology to transmit the visual data from the sewerage inspection robot to the console unit or else.

The system equipped with a wireless receiver, a digital video recorder (DVR) and 8" TFT monitor. The wireless receiver will receive the visual signal from main console unit. The visual signal will be recorded into the digital video recorder or view by using the TFT monitor. The DVR and the monitor can be remotely controlled. The aluminium case is used to protect the system. Figure 7 shows the portable suitcase for visual display and recording purpose.

V.   Mechanical Structure Analysis

The purpose of structural analysis is to find the critical part of the mobile robot structure when the load is applied. The CATIA analysis software is used to analyse the robot structure. The software is used to check the deflection and the stress (Von misses and maximum shear) when 5 kg to 15 kg of load being applied. The analysis software also has the ability simulate the deflections of the structure.

V.1.   Von Misses Stress

The determination of distortion energy in a material of the energy associated with changes in shape in the material (the energy changes in volume in the same material). Fig. 4 show Von Misses in the structure. The Von Misses stress difference between both materials is high. Fig. 5 shows the minimum difference of Von Misses stress and Fig. 6 show the difference for maximum Von Misses stress.
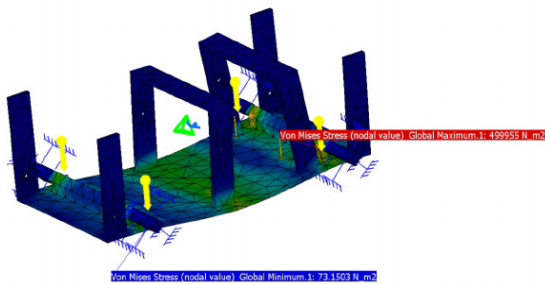

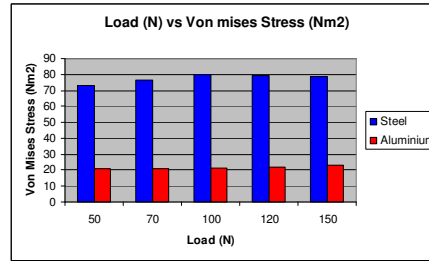Fig. 4. Von Misses stress for 50N
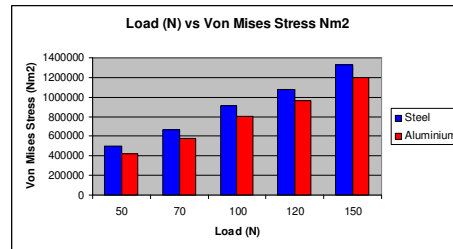

Fig. 5. Load (N) vs. Von Misses stress for minimum value

Fig. 6. Load (N) vs. Von Misses stress for maximum value

V.2.   Principal Stress

The brittle material can be easily fail due to the tension. The fact $\sigma_m > \sigma_{all}$ indicated that | M | $_{max}$ is too large for cross section selected, but does not provide any information on the actual mechanism of failure. Similarly the fact $\tau_m > \tau_{all}$ simply indicated that |V|$_{max}$ is too large for the cross section. While the danger for a ductile material is actually to fail in shear, the danger for brittle material is actually to fail in tension under the principle stresses (Fig. 7). The differential of principle stress between two materials is small. Fig. 8 shows the minimum differential for principle stress. At load 150N there is a high difference between these two materials for maximum principle stress (Fig. 9).
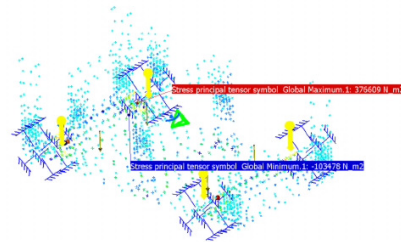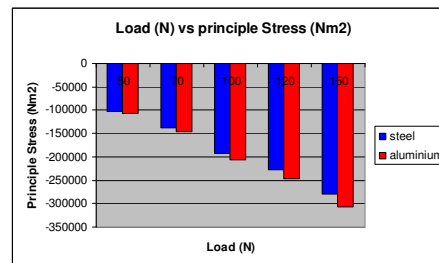

Fig. 7. Principle Stress (Nm^2) for 50

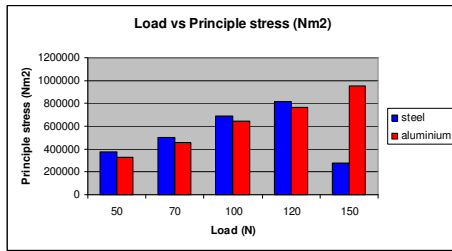Fig. 8. Load (N) Vs Principle Stress (Nm^2) for minimum value

Fig. 9. Load (N) Vs Principle Stress (Nm^2) for maximum value

V.3. Estimated Local Error

Local error (refer Fig. 10) is the section in the structure that most critical to fail when load was applied. This section need to improve depend how critical it is. The estimated local errors are different between these two materials. For minimum estimated local error there are a big different for both material. Fig. 11 shows the graph of differential for minimum. Fig. 12 shows estimated local error for maximum.
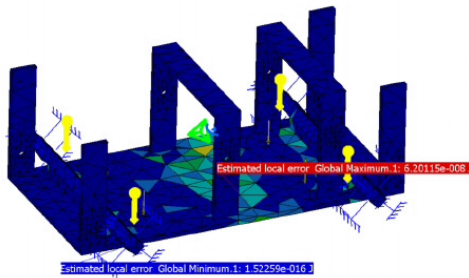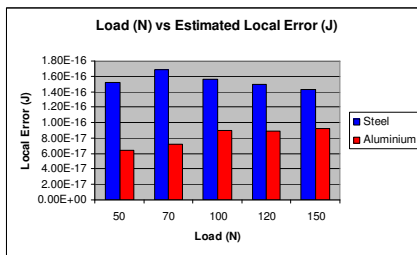

Fig. 10 . Estimated local error for 50

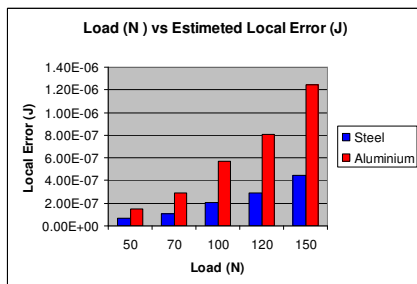Fig. 11. Load (N) Estimated local error (J) for minimum

Fig. 12. Load (N) Estimated local error (J) for maximum

V.4. Translational Displacement

Displacement (refer Fig. 13) is a bending that occurs when the load was applied. Displacement is depending to the moment at each end. If the moment can against the load, the displacement is not occurring.
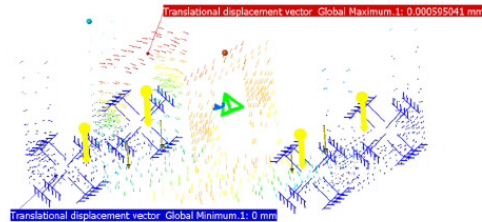

Fig. 13. Translation displacement for 50 (N)

As refer to Fig. 14, the displacement value between aluminium and steel. The steel value demonstrates the lower value than aluminum. Percentages of range between these two materials are 62% when 100 N was applied. Aluminum got the high value because the characteristic of yield strength is 55 MPa and value of yield strength for steel is about 145 MPa. But this result is still too small for displacement. Both materials (steel and aluminium) are good in displacement perspective from this analysis.
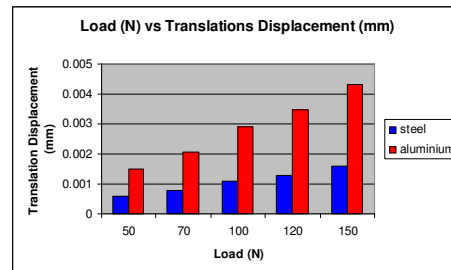

Fig. 14. Load (N) Translation Displacement (mm) for maximum

V.5. Material

From the analysis by Catia Analysis software, the most suitable material for the inner structure is Alloy 1100-H14 (99%Al) as show in Table 1. From the deformation that occur while load is applied to the critical part on the structural, the most lower reading of deformation state by steel structural (ASTM-A36). The Alloy 1100-H14 (99%Al) show the suitable reading compare with the other material.

Table 1. The properties of aluminum

Material	Density (kg/m^3)	Tension (MPa)	Shear (MPa)	Tension (MPa)	Shear (MPa)	Modulus of Elasticity (GPa)	Modulus of Rigidity (GPa)	Coefficient of Thermal Expansion (10e6/°C)
Alloy 1100-H14 (99%Al)	2710	110	70	95	55	70	26	23.6
Alloy 2014-T6	2800	455	275	400		75	27	23
Alloy 2014-T4	2800	470	280	325		73		23.2
Alloy 5456-H116	2360	315	185	230	130	72		23.9
Alloy 6061-T6	2710	260	165	240	140	70	26	23.6
Alloy 7075-T6	2800	570	330	500		72	28	23.6

For example of the 100 kg applied load to the critical part (local error), the reading for Alloy 1100-H14 (99%Al) equal to 9.01144e-17 J for steel structural (ASTM-A36) is equal to 1.56104e-16 J and for steel structural (ASTM-A36) the displacement is about 0.00108999 mm and for Alloy 1100-H14 (99%Al) 0.00289913 mm.

In this case the displacements reading for each material show a really small deflection occur and it can be conclude that all the material is suitable for this design. So another criterion to define the most suitable material is by knowing the advantages of the material.

VI. Conclusion

The paper presents the structural analysis for the sewerage inspection robot. The robot meets all requirements regarding sensors, modularity and adaptation. The mechanical design of robot also meets the strength requirement by analyzed using the CATIA analysis software. From the experimental results, it is showed that Alloy 1100-H14 (99%Al) is the best material to use as the robot structure as compare to other materials. The sewerage inspection robot needs to design to resist the water and collapse of the sewerage system. The sewerage inspection robot can be used to replace the human for sewer system inspection and maintenance. The robot also equipped with various sensors system to check the sewerage conditions. Currently, the developed sewerage inspection robot is still under upgrading to enhance the capabilities and durability of the system.

Acknowledgements

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