Design and Development of Three Arms Transmission Line Inspection Robot

Muhammad Fairuz bin Abdul Jalal*, Khairul Salleh Mohamed Sahari, Ho Ming Fei, Justin Chan Tuck Leong
Department of Mechanical Engineering, College of Engineering, Universiti Tenaga Nasionaly, Jalan IKRAM-UNITEN, Kajang, Selangor 43000, Malaysia

E-mail: mfairuz@uniten.edu.my, khairuls@uniten.edu.my
www.uniten.edu.my

Abstract

The high-voltage transmission line had been used primarily for power distribution from power plant or power station to the end users. However, the transmission line is highly prone to damage due to exposure to various thermal - mechanical loadings and material degradation. Therefore, periodical inspection on transmission line after prolonged service is needed to prevent any failure before it happens. In this paper, we present a new design of three arms inspection robot for transmission lines. The robot is able to transverse along the line and bypass the in-line obstacles namely the anti-vibration hammers, spacer, strain clamps and others. The design of the inspection robot in term of the robot design and configuration with slotted cam at each arm is presented. The detailed analysis via simulation with respect to the robot stability; kinematic and movement analysis; and power consumption during operation is executed to make sure the proposed design able to do the inspection without any unexpected difficulties. Later, the lab testing on the developed prototype is done for feasibility study and validation.

Keywords: inspection robot, transmission line, power line, obstacle avoidance, robot design, mobile robot

Introduction

High-voltage transmission lines is one of the main elements in power distribution from the power plant or power station to the customer. However, the transmissions is exposed the harsh environment conditions that leads to damages by various circumstances namely effect of mechanical tension, material degradation and flashover. The transmissions lines undergoing such circumstances eventually lead to many problems such electrical breakdown or even major accident if transmissions lines were not being inspect, fixed and replaced in appropriate time[1].

The process of inspections of transmission line involved activities such as changing the ceramic insulators and switching on or off the circuit in between poles[2]. However, the manual inspection process of transmission line exposed the workers to various unfavorable circumstance of dangerous working environment that is taxing with long duration[3]. Therefore, it is crucial demand to develop a mobile inspection robot to replace manual transmission line inspection job. The development of the mobile inspection robot will not only create a safer work environment in the transmission line inspection job, but also improve the efficiency of the inspection process[3]. A two arms transmission line robot is developed by Wang et al.[4] utilize a line walking mechanism that based on biped structure either having both feet placed on the line or each feet is placed alternatively on and off the line. Another dual arm robot self-balancing was developed by Songyi et al. The two arm of the robot hold onto the transmission line and move with the wheel installed on the arm. The robot is integrated with counter weight to improve the robot stability while travelling on the transmission line[5].

Xu et al.[6] developed a 3-arms transmission line robot that features 2 supporting arms and 1 assistant arm placed in between both supporting arms. This robot was designed to overcome obstacles by evading them with the lifting mechanism on each arm. Rui et al.[7] developed 3-arm transmission line inspection robot. The robot arms consist of rubber wheel and the both outer arm installed with gripper to hold unto the line. The rubber wheel enables the robot to pass over minor obstacles like the splicer and damper without avoiding them.

Our research group already took initiatives to propose various conceptual design and selection based on requirement set by Tenaga Nasional Berhad (TNB), the main utility supplier to peninsular Malaysia[8].

Transmission Line inspection Robot Design

General Design Requirement

There are many components, which are installed on the transmission line for various purposes namely tension insulator chain, suspension clamp, damper, tension clamp, jumper, splicing sleeve and others depending on type of transmission line as shown in Fig. 1. It is deemed necessary for robot to bypass these in-line components so that the inspection process can be executed effectively[9].

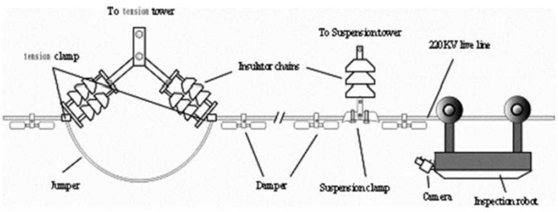

Fig. 1. Transmission line environment[9].

Transmission Line Inspection Robot

The robot travel on the transmission line with the help of rollers that installed in each arm and cross obstacles by moving its arm up by rotating the power screw installed in each arm. The robot is installed with six motors; three motors run the roller at each arm for traversing on the transmission line and the others three motors attached to the power screw for obstacles crossing process. The conceptual design and the prototype are shown in Fig. 2.

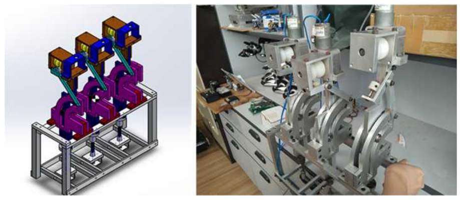

Fig. 2. The conceptual design (left) and prototype of the three arms transmission line inspection robot (right).

The three arms robot is hanged to the transmission line by means of roller and lower jaw as a griping element. The movement is propelled by the roller at each arm. Each roller is powered by a motor as shown in Fig. 3.

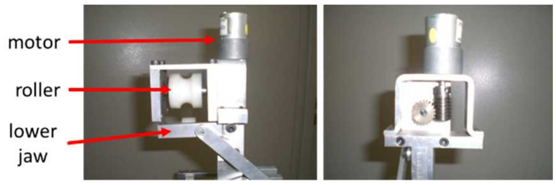

Fig. 3. The front view (left) and side view (right) of the gripper.

The mechanism to bypass obstacle is illustrated in Fig. 4.

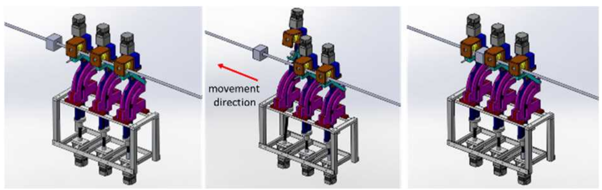

Fig. 4. Mechanism to bypass inline obstacles.

The gripping position and bypassing obstacle movement are realized by the rotational direction of the motor linked to power screw. To bypass the in-line obstacle, the motor is then actuated. The power screw pushes the arm upwards. As the arm moves up, it follows the curve of the slotted profile. The bottom of the arm will have a pin joint with a support to enable it to rotate as the arm follows the curve of the slot. The arm will move back to its original position by reversing the motor direction and the wheel on arm attached back to the line. The same step applied to the following next two arm. The mechanism to bypass the obstacles is shown in Fig. 5.

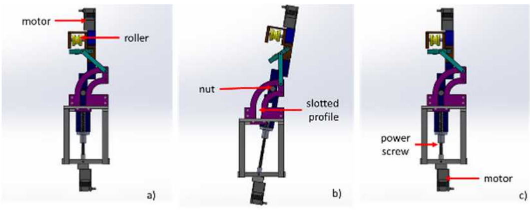

Fig. 5. The arm movement to bypass obstacles.

The stability of the transmission line inspection robot is an important aspect to be considered as it influences the overall quality of the image taken during the inspection process.

Result and Discussion

Capability to bypass obstacles

The robot must be able to avoid obstacles along the transmission line or else the design will be deemed as a failure. Fig. 6 shows that the roller and lower jaw do not interfere with the line as the arm gripper loosening and tightening its grip.

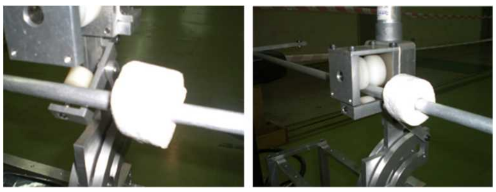

Fig. 6. The arm gripper during loosening (left) and tightening (right) its grip to the line.

The clearance between the arm and the obstacles is ranged from 90mm to 130mm with the maximum angle of arm rotation 21.6° as shown in Fig. 7.

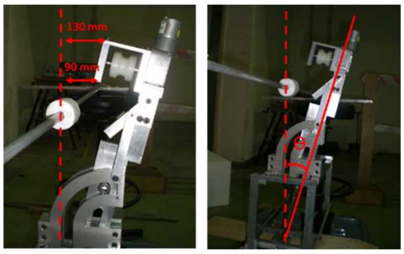

Fig. 7. The arm gripper during loosening (left) and tightening (right) its grip to the line.

Stability analysis

The significant changes of robot center of mass during the process to bypass the obstacle provide instability and tendency for the robot to swing. The analysis of the design center of gravity is done by means of center of mass analysis of the following arm configurations:

Configuration 1: original configuration; all the arms rest on the transmission line

Configuration 2: the first arm move up to avoid obstacles while the other two arm rest on the line

Configuration 3: the second arm move up to avoid obstacles while the other two arm rest on the line

Configuration 4: the third arm move up to avoid obstacles while the other two arm rest on the line

The robot xyz axis and value of center of mass for each configuration is extracted from the CAD software as is shown in Fig. 8. The coordinate center of mass of the different arm configuration is tabulated in the Table 1.

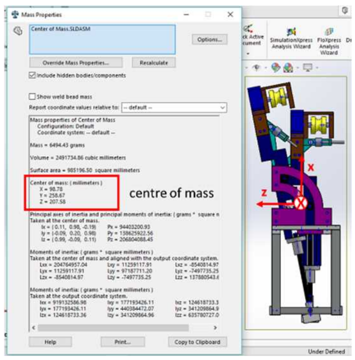

Fig. 8. The arm gripper during loosening (left) and tightening (right) its grip to the line.

Table 1. The coordinate of the center of mass by various arm configuration.

Arm Configuration

Coordinate	1	2	3	4
x	88.45	98.78	98.80	98.80
y	250.65	258.67	258.83	258.83
z	207.58	207.58	207.58	207.58

There is a small change of the coordinate of the center of mass in the x-axis and y-axis as the robot change it configurations from the original configuration while the z-axis remained constant throughout the operation. The average change of x-axis is 10.33 mm and y-axis is 8.07 mm. The average distance between center of mass in various arm configuration is 13.1 mm. The results are plotted in in x-y plane as shown in Fig. 9.

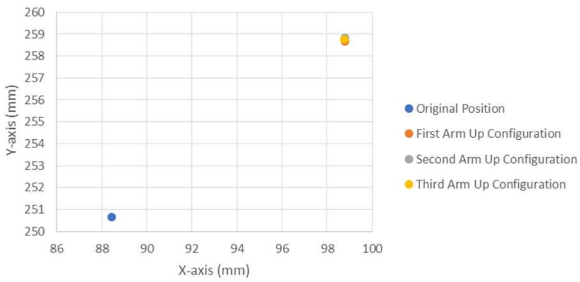

Fig. 9. The coordinate of robot center of mass in x-y plane for different arm configuration

Motor Torque and Power Consumption

The value of the motor torque required to rotate the power screw to move the arm up for bypassing the obstacle is analyzed in Solidworks Motion. The motor speed is set to reach 225 RPM based on the motor specification. The time needed for the arm to move up to bypass the obstacle is 20 seconds. The average motor torque and power consumption are 13Nmm and 0.254W. The graph of the motor torque and power consumption against time is shown in Fig 10.

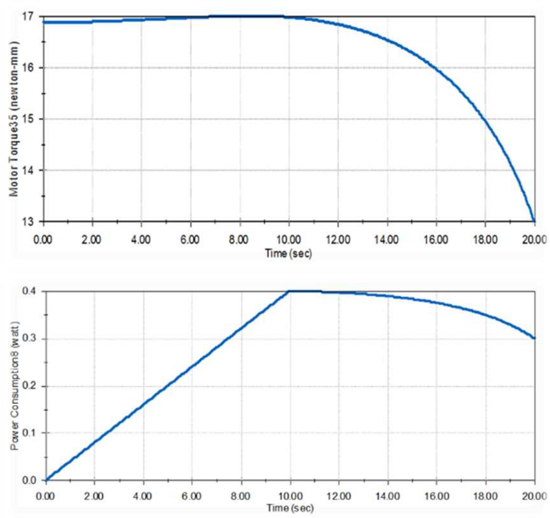

Fig. 10. Graph of motor torque (top) and power consumption (bottom) against time.

Conclusion

In this paper, the three arms transmission line inspection robot is presented. The mechanism to bypass the obstacles is achieved by using power screw and slotted profile. The robot is considered stabile during operation due to minimal changes of its centre of mass. The testing and analysis in term of robot capability to bypass the obstacles as well as analysis of motor torque and power consumption.

Acknowledgements

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References

Y.C. Zhang, Z.Z. Liang and M. Tan, Mobile Robot for Overhead Powerline Inspection-a Review, in *Robot* 9(5) (2009), pp. 467-473.

L.E. Parker and J.V. Draper (1998). *Robotics applications in maintenance and repair*, in Handbook of Industrial Robotics (1998) pp. 1023-1036.

F.Y. Zhou, J.D. Wang, Y.B. Li, and H.R. Xiao, Control of an inspection robot for 110KV power transmission lines based on expert system design methods, in *Proc. 2005 IEEE Conf. on Control Applications* (2005), pp. 1563-1568.

L. Wang, F. Liu, Z. Wang, S. Xu, S. Cheng and J. Zhang, Development of a practical power transmission line inspection robot based on a novel line walking mechanism, in *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems* (2010), pp. 222-227.

D. Songyi, W. Xuefeng, D. Hang, and W. Tao, Development of a self-balance dual-arm robot for inspection of high-voltage power transmission lines, in *IEEE Int. Conf. on Mechatronics and Automation* (2012), pp. 2482-2487.

B. Xu, X. Wang, Y. Zhu and H. Chen, Design of obstacle crossing mechanism of high-voltage transmission line inspection robot, in *IEEE Int. Conf. on Robotics and Biomimetics* (2015), pp. 2539-2544.

G. Rui, Z. Feng, C. Lei and Y. Jun, A mobile robot for inspection of overhead transmission lines, in *Proc. of the 3rd Int. Conf. on Applied Robotics for the Power Industry* (2014), pp. 1-3.

M.F. Abdul Jalal, K.S. Mohamed Sahari, A. Anuar, A.D. Mohd Arshad, M.S. Idris, Conceptual design for transmission line inspection robot, in *IOP Conf. Ser.: Earth and Environmental Science*, (2013).

G. Wu, T. Zheng, H. Xiao and C. Li, Navigation, location and non-collision obstacles overcoming for high-voltage power transmission-line inspection robot, in *Int. Conf. on Mechatronics and Automation* (2009), pp. 2014-2020.