Automatic detection of defects in pre-stressed multi strand wires using hall effect sensor

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Abstract: Pre-stressed wire ropes are the steel-reinforced cables used in bridges to carry loads and to prevent the bridges from displacements. Steel strands are of different orientations and with arbitrary number of wires within it. This strands twisted one over the other to form the steel ropes, which plays a major role for supportive purpose and any defects in the strand wires leads to failure of the rope and the structures which it supports. So it became essential to inspect periodically, to ensure the safety operation. But, the challenges are that the ropes are at the non-accessible and non-demandable locations, thereby the common inspection methods are limited. So in this research, inspection of wire ropes had done by using a robot with Hall Effect sensor. This developed robot has to be allowed to pass over the cable and the detector detects the defects, if any based on the flux variations at the broken steel strands. The experimentation results proved that the developed robot is at par in detection and it can be used to detect the defects for various applications.

Keywords: Robots; Non-destructive testing; Hall effect sensor; Detection; Ardino.

1. Introduction

Pre-Stressed Cables (PSC) are mainly composed of bunch of steel strands twisted over one another at different orientations. Set of high strength steel wires are twisted to form strands and the group of strands are twisted to form the ropes. The twisting action creates stress on the cable and the alternate twisting creates permanent pre stress on the cables or wires, there by the rope will not deformed due to major loads and these type of pre stressed cables can be used in the bridges, which will not accept any more
stress and thereby it became rigid. The number of wires and the strands are based on the strength required
to support the loads acting on it. So each and every steel wires/strands in pre-stressed cables have a very
strong impact on the safety. Even though the cables are designed with high factor of safety, during the
long-term outer door service, the wires in the strands may get damaged by shock load, fatigue, lightning
strike, over loading, corrosion of chemical contaminants, surface rusting, pitting, wind vibration,
galloping, external disturbances, etc. [1]. The cable design is such a way that the entire loads have to be
distributed to the each and every wire and on the other hand, any defects in a single wire of any strand
will lead to drastic failures in course of time. This failure and the propagation of the failure may leads
to some fatal accidents. So it became essential to recognize and restore the faults well in advance. This
can be done by periodic inspection of the cables to ensure the safe operation. The common means to be
used for latent faults inspection is by manual examination with hand-held tools. These methods are
having constraints like less precision, dangerous to inspectors, more safety devises required for the
inspection persons, more time consuming, more fatigue to labors, high cost involving, difficult in
accessing, destructive inspection not possible, etc. Due to these constraints the gap of periodic inspection
prolonged [2]. The only solution to satisfy all the above constraints is the usage of the robots, because
the robots will operate in the areas where the humans having a unsafe environment and inaccessible
locations. Recently, with the revolution in the digital technologies and low weight actuators, robots are
commonly used in many applications where the humans faced difficulty. So in this research, robots have
been used to inspect the cables using hall effect sensor. Hall effect sensor is a kind of sensor which
has advantages in identifying the defects such as high precision, low power consumption, etc [3]. So hall effect sensor is becoming a valuable tool for the inspection in this research.

2. Literature Survey

This research is mainly concentrated on identifying the defects in the steel cables. There are many
techniques available in detecting the internal and external defects in the cables and few major techniques
have been discussed in this section. Ultrasonic testing uses the sound reflection technique to detect the
faults and is one of the widely used techniques for inspecting the internal defects [1]. However,
ultrasonic suffers in detecting the defects in the multi layered structures. Other non destructive testing
techniques also been used by the researchers for inspecting the defects are X-ray [3], acoustic emission
[4], eddy current thermography [5] and microwave [6]. Even though there are many more methods are
available for inspection, majorities of the inspection methods are having the limitations with regard to
costs, complexity in measurement, requires closed environment, etc. which are infeasible in the open
application inspections, like bridge wire defect inspection. Consequently, eddy current defect testing is
proposed by many inspection researchers as a powerful inspection technique. So in this research, eddy
current technique sensors have been used to detect the defects in the steel cables.

One of the major significant tasks for the researchers is the development and utilization of the micro-
electro-mechanical systems for the wide range needy applications. Recent years, magnetic sensors are
playing a prominent role in the fied of automatic inspections, as the magnetic sensors are utilizing the
principle of Hall effect [7]. Even though the principle of hall effect are having wide scope, the calibration
will be challenging task. The calibration of Hall sensors requires the determination of the offset voltage
Voff and the formula is given in the Equation 1.

\[ V_{off} = VH(0) = \frac{R_h}{t} GL_p B_t \]  

Whereas, Rh, t, and G are the standard values represents Hall coefficient, thickness and the
geometrical correction factor respectively. The value of Voff can be directly measured in the absence of
magnetic field. Moreover, this technique of calibration is to cancel the undesired offset effects by
appropriate circuitry [8]. But the difficulties exist in the identification of the hall effect sensitivity factors
SV and SI, as it requires complex measurement systems with skilled operators. This paper discusses the
feasibility of non-destructive testing for pre stressed steel cables by using eddy current sensor [9].
3. Cable Inspection Robot

Initially, the 3D simulation models have been developed and simulated as the steel cables are used in the bridges and are in the inaccessible locations, trial experimentations might not be possible [10]. This simulation had been carried out in the electromagnetic simulation module of Comsol software. From the simulation model results, it has been concluded to have the two eddy current modes (transverse and longitudinal) to determine the defects. In this research simulation, three-dimensional eddy current testing rectangular probe model had been simulated with the Comsol Multiphysics 4.4, as the results of this software are in the satisfactory level. The simulation model parameter size was set to 100 x 50 x 8 mm with the longitudinal, transverse and cross conductivity of 100 S/m, 95 S/m, and 98 S/m respectively [11]. The square wave frequency is set to 100 Hz. As the simulation results produces better quality of waves which can be best suited for the cable inspection, the same setting have been used in the real time inspection. Also the same software has been used to simulate the robot movements. Based on the mechanical architecture, the inspection robot can be wheeled type, caterpillar type, snake type, walking type, etc. In this research, wheel type robot has been used, as the robot have to climb over the steel rope and requires more grip to climb, which might be more difficult with the other types of robots. Recent researchers are developing the wheeled type of robots to clean the cables and to move inside the cylindrical objects or on the horizontal sections, so the wheels are having the sufficient grip for the movement and the stability also in the satisfactory level. But in this research, the major challenge with this type of wheeled robots is that they can’t have enough support for its movements over the cables, especially in the vertical cables. Also the surfaces of the cables are having many ups and downs in irregular fashion. Surface roughness, orientation and position of the cables are also in the arbitrary and unpredictable in nature. So the body of the robot was divided into four major modules for better performance [12].

The first module is carriage, which carry hall effect sensor for doing inspection tasks. The second module is the locomotive module, which have actuators for the movement over the cables autonomously and can able take small radius turns. The third module is the control architecture which can perform several tasks intelligently. The fourth module is the clamping module, which is actuated manually to hold and un hold the cable at the desired locations [13]. The developed robotic system aimed to collect the inspection data from the cables. As the developed robot inspection is based on the principle of magnetic flux, it can work in the environments of dark, toxic, vibrating, oscillating and very dangerous for the human beings to inspect and collect the data. The speed and motion of the robot can be pre-set and also can be controlled by using the joystick. The user is able to monitor the sensor output continuously and any variation in the EMF will be indicated in the monitor and interpretation, suitable action can be taken. The developed robot used PIC16F series controller and visual basic 6.0 for front end interfacing with the computer. Servo motors are used for the forward and backward motion of the robot over the cable and the motors are controlled by the relays and the driver circuits. The Chassis is having the carriage, front and rear wheel arrangements [14].

The robotic system developed in this research is able to move over the cables with the help of contracting spring wheels. The ply provided in the wheels is to support the flexibility when the robot meets a knot or irregularities while travelling over the cables. The positioning base is the fixed base in the robot frame, which is used for pointing the hall effect sensor to the desired point over the cable, such that the entire cable has to be covered for inspection. The voltage supplied to the hall effect sensor is converted in to the flex, when it pass over the conducting pre stressed steel cables, and the generated flex had amplified to the desired level voltage and send to the controller [15]. In order to get the information regarding the breakage of wire, the variation in the flex generated will support to interpret the same. The wireless transmission technology is for the distance between 3 m to 5 m, beyond which the battery required is of high energy and proportionally larger the size and weight, so wired transmission had been used in this research. The hall effect technology is designed to detect the defect for the distances upto maximum of 25 cms.
The sensor system of the developed robot consists of various types of sensors like ultrasonic scanners, hall effect unit to determine the cracks, gyro meter for orientation measurement, and IR sensor for detecting the blocks and knots. These sensors are attached over the frame at different locations and the frame was placed on the wheels with two segments, so that the robot can be adjustable while passing over the knots and joints. The four toothed rubber spike wheels are driven by independent motors i.e. four-wheel drive and will give support to the robot body. The rubber toothed wheels will not cause any damage or impressions over the cable and will follow the same path while withdrawing the device from the cable after inspection. In case of the jamming, high voltage will be supplied to the wheel motors and thereby the motors propel the wheels in moving up from the location. The inclined metal plate in the front of the robot is used to press the projected debris in to the cables along the direction of motion, because this debris should not affect the hall effect sensor, as the sensor is having very less clearance gap. There are different types of debris removal mechanisms like flap, bristle, plough, twister, V presser, etc are available and can be used based on the applications. In this research, pressurizes have not been used as the debris are off not having much influencing over the performance of the robot[16]. There are two portions of the body which are used to bend the robot while crossing the knots and joints in the cables. The hall effect sensor is for inspecting the interior of the cables and when there any changes in the voltage values, then it denotes the presence of flaws in the cable. The hall effect sensor in this system is having some ply for smaller angle rotation to clearly identify and interpret the defects. The communications between the robot and the system is by means of serial communication cables. Marking the defect location by painting have not been performed as it requires high voltage and proper grounding have to be done, which will complicate the system and it has left for the future scope of this research.

4. Pre stressed Cable Inspection

The pre stressed cable inspection robot is having major four modules, namely, carriage module, locomotive module, control module and clamping module. The first module is carriage module, which carry hall effect sensor for doing inspection tasks. The hall effect sensor is having 10 degree swing-type ply mechanism, this rotation mechanism is for tilting the hall effect sensor when the robot encounter a knot or a joint. So that the entire cable can be inspected, in general these types of robots didn’t not inspect the knots and the joints. This rotation mechanism rotates the hall effect sensor module in both the directions with respect the longitudinal axis of the robot at the very low speed. In the normal conditions, the rotation or the swing has been arrested and thereby the cable defects are identified. The ply-type cable inspection robot has the advantages of being rapid in inspection operation, convenient to use with ease, high in inspection efficiency, inspect the entire cable i.e. both the normal cable and the joints. This carriage is attached with the frame. The frame is having the wheels for movements. The developed carriage is given in the Figure 1.

Figure 1. Developed Robot and Carriage
The second module is the locomotive module, which have actuators for the movement over the cables autonomously and can able take small radius turns. Cable inspection robot that uses a V grooved wheels for moving all over the cable. The angle of the groove is set to orthogonal in this developed robot for better gripping. The width of the wheel groove should be little larger or equal to the diameter of the cable to be inspected. Thereby the entire cable is covered by the wheel and due to it, more the surface of contact and thereby increasing the friction. Once the friction is higher, gripping is also high. Thus the robot can roll over the cable without much slippage. There are four driving wheels for the travel and all the wheels are independent and self-driven by means of individual motors. This independent locomotive mechanism is mainly focused on how to move over the knots and joints in a narrow cable and to drive the mobile cable inspection robot over the cable. The independent driven grooved wheels provide more gripping abilities than a standard wheel type. The wheels groove size changed according to the cable diameter for better for fast inspection and for superior performance in all types of complex networks of cables.

The third module is the control architecture which can perform several tasks intelligently. It is developed using Ardino controller, which will work in two modes, intelligent mode and the manual control mode. The intelligent mode uses the data from the sensors and acts accordingly. This control system only triggers the hall effect sensor and actuates the wheel motors. The architecture of the developed robot is shown in the Figure 3. Based on the obtained results, the speed of the robot can be refined to detect the structure defects exactly and thereby error can be avoided. The inspected results will be send to the cloud using the Node MCU board and the data are interpreted by the inspection experts at any place, but the challenge is that providing wifi around the inspection area. In this research, Matlab cloud space have used for the experimentation. So as the alternative, cables are provided for data transmission. Also the cables are used to supply the power to the robot, as the batteries are adding weight to the robots. The battery used in the robot is used as the secondary power source. The fourth module is the clamping module, which is actuated manually to hold and un-hold the cable at the desired locations. The robot was able to move in the cable with diameter 30 cm to 400 cm. For the smaller diameter cables, toothed wheels need to be mounted and for the larger diameters, grooved wheels need to be mounted for gripping. The front and back portion of the robot frame contains cutting plate that is used for removing waste accumulated in the cable and support in gripping, when robot isis in rest i.e. the plate fitted between the valleys of the cables and in between the strands. In the invented mechanism, the wheels are held at 20 degree angles to improve the gripping force, i.e the load of the robot acts as the gripping force enhancer and the spike rubber gripper wheels are used for the smaller diameter cables, which holds the cable very efficiently.

5. Results and Discussion

The developed robot has been inspecting the steel cables using hall effect sensor in an efficient way. The developed robot had been tested with the arbitrary diameter cables of round shapes and the performance are at par with the commercial robots. The power consumption of the developed are also analyzed, more power is consuming while inspecting and climbing over the cable, on the other hand comparatively less power have been consumed while the inspection is carried out at the downward motion. So the climbing up is considered as the pre run and the downward is considered for the inspection of the cables. Also the developed robot is experimented for various conditions, cable angles, etc. As the result of experimentation, it has been found that the that the developed robot was inefficient in inspection the elbows, corners and joints, because the hall effect sensor will perform good for the constant diameter cables, so whenever there is change in the diameter of the cable, the output of the hall effect sensor varies. Moreover, the robots failed in inspect the bolts and the nuts near the joints. Finally, the inspection robot works well with the cable diameter between the 60cm to 300 cm and the orientation of 0 degree to 45 degrees. The flexible two segmented body mechanism prevents the body to roll outside the cable at the joints and the turns. All the conditions of robot stability, movement and the inspection were analyzed and experimented with various conditions and there by a successful robot had been developed for inspection using non-destructive sensors.
6. Conclusion

The developed cable inspection robot with hall effect sensor can be applied to inspect the defects in the steel cables and the performance had been found satisfactory. The NDT based hall effect sensor model uses magnetic flux for detecting broken steel strands in pre-stressed cables without damaging the cable. The exterior disturbance has no impact on the performance of the robot, as the robot uses the cloud for store the inspection results and the gripping wheels used for movements over the cables and the designed locomotive mechanisms are to guide the robot over the cables, joints, smaller knots, turns, etc.

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