INNOVATIVE METHOD OF NON-DESTRUCTIVE TESTING OF WIRE ROPES AND WINDING EQUIPMENT IN MINES VIS-À-VIS CALIBRATION OF DEFECTS

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ABSTRACT

This paper presents the details about Non-destructive testing methods for evaluation of condition of winding equipment used in mining industry. Available statutory provisions related to safety of the winding equipment such as Drum shaft, Brake Tie rods, pins etc., are presented. Non-destructive testing (NDT) on various components of the winding and other mining machinery related to coal and metal mining sectors has been conducted by various organizations. Procedures followed for Ultrasonic and Magnetic Particle testing are also discussed. Case study related to a typical mine winding equipment of underground mine is presented along with the salient findings of the NDT tests. This paper also illustrates the details about calibration of defects; wear and broken wires by electromagnetic method in a wire rope used for hoisting of men and material in mines, aerial rope ways, lifts etc. Electromagnetic method of testing the wire ropes consists of powerful magnets to magnetize the wire rope, and sensors to detect the defects in the wire ropes. A typical instrument used in the investigation consists of the inner coil to detect the local defects like corrosion, pitting, broken wire, wear and nicks. In the present study a method was adopted to simulate the magnitude of the defect signals of wear and broken wear by creating artificially in the laboratory, which can be used for analyzing the actual signals recorded during in-situ testing on wire ropes.

Keywords: Electromagnetic method, wire ropes, winding equipment, defects, calibration

INTRODUCTION

Testing of materials or components without impairing its functional properties is termed as Non Destructive testing. Any manufacturer of components conduct non-destructive tests to check for the quality of the material before dispatching to the customers fro their immediate use. For this purpose, destructive tests cannot be applied due to obvious reasons. Standard tests conducted by manufacturers include; Proof load tests, UFD (Ultrasonic Flaw detection), MPT (Magnetic Particle Tests). However, Proof Load tests cannot be conducted for the mining machinery parts without dismantling the individual parts after its commissioning at the site. Therefore, NDT (Non-Destructive tests such as Ultrasonic and Magnetic particle tests) are required to assess the condition of such mining machinery parts, which is also mandatory as per the DGMS guidelines (DGMS, 2001). At present, manufacturer tests report and customers tests report are only available before commissioning or put to use. Unfortunately, third party testing by any research or academic institutions and associated documentation is not being practiced. This practice would have improved the reliability of evaluation of condition of equipment later while in operation. This unique document would have served the purpose of reference for comparison with the results of subsequent tests for evaluation of condition of respective components. These tests are being widely used for ascertaining and monitoring periodically the health of vital components of winders and suspension gear parts. Safety and efficiency of the winding installations have always been the concern of all the people of the mining community.

It is necessary in this context that all the winding installations and components should be of good quality with high reliability. As most of the winders in our country are old, they need periodic monitoring of the conditions of winding installations. The problem is more critical due to the large number of old engines. In order to ensure the reliability of the winding installations and to prevent failure of the winding equipments and components during service which may result in loss of life and property, it Is all the more important to have a planed periodical testing of the components. The important mining machinery components of winding system are chains, D-shackle, Distribution plate, Chase blocks, Pins, winding engine shafts, brake tie rods etc. In this regard, to ensure the safety of winding operations, statutory provisions are made in Indian mining law (DGMS, 1988).Need for NDT tests were always felt by the owners of the winding equipment to evaluate the condition of the components in the interest of the safety, and productivity. Ultrasonic Flaw Detection Tests and Magnetic Particle Test in various winding installations (NIRM, 2004, 2005a, 2005b) is presented in this paper along with electromagnetic tests conceited on wire ropes using rope-defectograph.

STATUTORY REQUIREMENTS

As per the DGMS technical circular no 10 of 1982, Non-Destructive testing of suspension gear or its components, vital parts of machinery and winding ropes is stipulated. It is recommended that magnetic and ultrasonic test or any other NDT tests, if considered necessary shall be done every 6 months or earlier if required to detect any crack or flaw in the suspension gear or its components which are in regular service. It is also recommended that NDT methods may also be adopted for testing of vital components of machinery, such as drum shafts, brake tie rods, fan blades etc. at suitable intervals.

As per the DGMS Circular (Tech)/S&T/8 dated 29.6.99, Acceptance criteria for drum shaft is “Isolated flaw indication up to 90% of Full Screen Height (FSH) was allowed”. For other parts of the winder, Cracks are not allowed. In case of inclusions and pores, isolated indication up to 10% of the FSH was allowed.

Code of practice for in situ examination of winding Drum shaft by ultrasonic flaw detection testing technique and recommended frequency of testing was also mentioned in DGMS technical circular no 8 of 1999 as follows:

- Frequency of testing was stipulated for Heavy, medium, and light duty components in the range 1-4 years.
- The duty is based on number of hours the winding engine is working per shift; for Heavy, medium, and light duty the corresponding workings hours are more than 3, between 1 1/2 to 3, and less than 1 1/2 hours.
- The equipment, couplant, reference blocks, surface condition testing method, recording, reporting and acceptance criteria are also stipulated.

Typical experience of observation of fatigue/service cracks/defects only in loaded condition, and absence of such defects, when tested in dismantled condition indicates the need of testing the vital components under loaded condition only. However, the existing statutory provisions does not stipulate the need of testing drum shaft and break tie rods under loaded condition.

NON-DESTRUCTUVE TESTING METHODS

Ultrasonic and Magnetic particle method of non-destructive testing have been widely used. Principle of testing and procedure followed for such tests are illustrated by many investigators (Krautkrammer and Krautkrammer, 1983), and presented in many standards (IS-3703,1998; IS-7743, 1998; IS-4904,1997; IS-9565,1998; IS-8791, 1992). Salient points related to the ultrasonic and magnetic particle tests conducted by NIRM, and results of such tests in typical winder components are presented below:

Ultrasonic Method:

Ultrasonic testing is the most widely practiced non-destructive testing of studying the condition of the mining machinery components to get a comprehensive picture of defects which are both inherent and service defects (Table 1).

In this inspection technique high frequency sound waves are sent into the object under test, the sound waves travel through the material. During their path of travel they suffer loss of energy and are reflected at interfaces. The receiver probe picks up the reflected waves and an analysis of this signal is done to locate flaws in the object under inspection. Sound waves follow the loss of optics in their propagation (Anon, 1997). Further the velocity of propagation of sound in various metals has been very accurately measured. The time taken by the sound pulse to travel through the material is the direct measure of the length of path traveled by it. Ultrasonic inspection both through transmission and pulse echo techniques are used. Pulse echo technique is the most widely used technique in ultrasonic testing (Fig. 1). Ultrasonic can detect cracks, laminations, shrinkage, cavities, flakes, pores and other discontinuities like intrusions etc in plates, pipes, welds, castings, forgings etc. in service defects, such as fatigue cracks, creep cracks, hydrogen embrittlement, stress corrosion etc. as well as thickness determination can e carried out using the ultrasonic pulse echo technique. In the ultrasonic testing conducted by NIRM (NIRM, 2004, 2005a , 2005b, 2005c), ultrasonic equipment of type-MODSONIC GALILEO -100 was deployed. 100% back wall reflection method with manual mode of operation was adopted with a couplant - SAE 20 oil and low melting grease.

IIW block - V1 and Miniature block V2 were used, and 100% FSH echo was observed on the CRT screen of Ultrasonic Detector equipment. Normal beam probe of , 1, 2, 2.4 MHz frequency, 12.5, 19 , and 25 mm dia hard face type was used. Frequency, size and angle of the angle probe that was used for the experiments were 1, 2.2 MHz, 37X17mm, 45, 60, and 70 degrees respectively.

Table 1: Ultrasonic testing details

1.	Type of equipment used	MODSONIC GALILEO-100
2.	Method of testing	'A' Scan, 100% back wall reflection method
3.	Mode of operation	Manual
4.	Couplant used	SAE 20 oil and low melting grease
5.	Calibration block	IIW block – V_1 & Miniature block – V_2
6.	Probe details	(i) Normal beam probe Frequency : 1, 2, and 2.4 MHz Size : 12.5, 19 and 25mm dia Type : Hard face (ii) Angle beam probe Frequency : 1 and 2.2 MHz **Size : 37 x 17 mm** Angle : 45^o, 60^o, and 70^o

Magnetic Particle method:

Electromagnetic crack detector of Yoke Model was used with longitudinal method of magnetism. Method of inspection was fluorescent technique examined under ultraviolet black lamp. Magnetic particle testing is a sensitive method of locating surface and subsurface defects in ferromagnetic components. When these components are magnetized, magnetic discontinuities that lie in a direction approximately perpendicular to the field direction result in the formation of a strong leakage field (Anon, 1994). In the present testing, Yoke was used to magnetize the testing specimen (Fig 2 and 3).

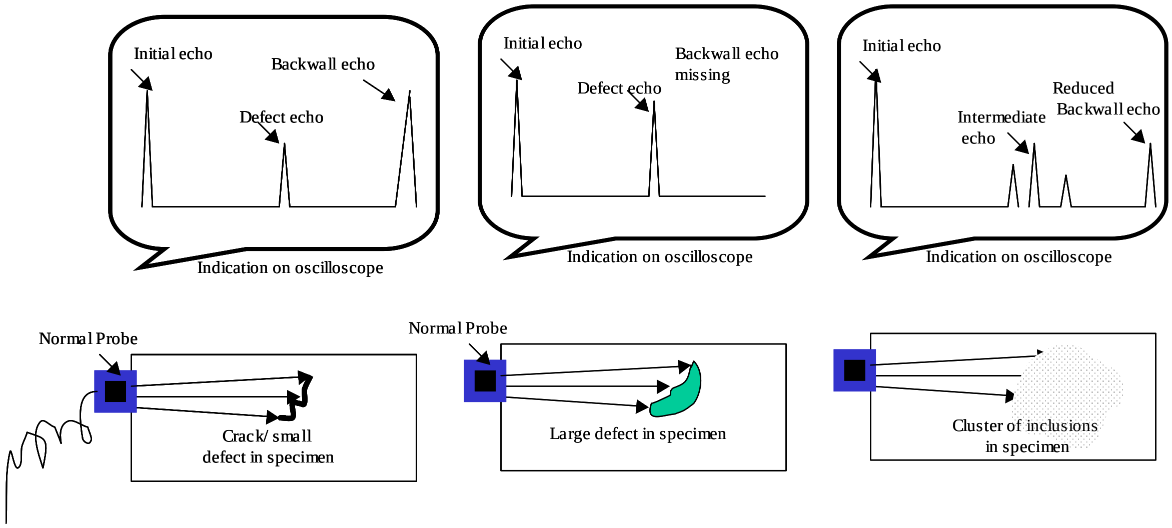

Fig 1 : Principle of ultrasonic testing-Pulse echo method

This leakage field is present at and above the surface of the magnetized components and its presence can be visibly detected by the utilization of finely divided magnetic particle. Application of dry particles or wet particles in a liquid carrier, over the surface of the components, result in a collection of magnetic particles at a discontinuity. The magnetic-bridge so formed indicates the location, size and shape of the discontinuity. Magnetization may be induced in a component by using permanent magnets, electromagnets or by passing high currents through or around the component (Table 2).

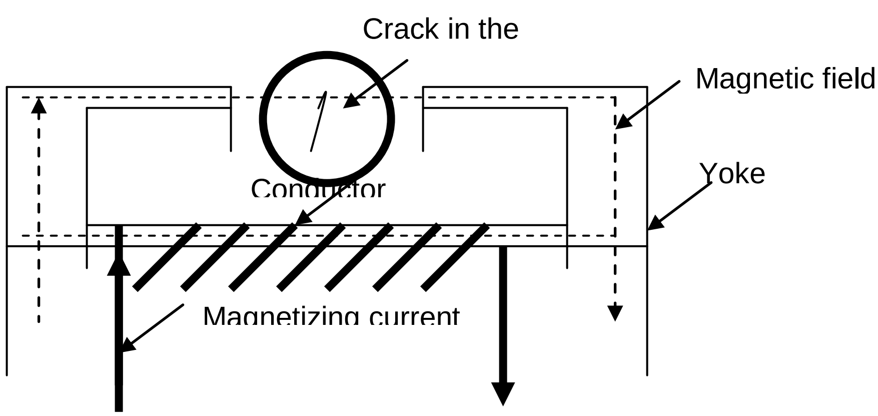

Fig 2: Longitudinal Magnetization with yoke for magnetic particle testing

The direction of a magnetic field in an electromagnetic circuit is controlled by the direction of current flow and the magnetic lines of force are always at right angle to the direction of the current flow in a conductor.

Table 2: Magnetic Particle Testing Details

1.	Type of equipment used	Electromagnetic crack detector Yoke model
2.	Method of magnetism	Longitudinal
3.	Current used	HWDC
4.	Method of inspection	Fluorescent technique, examined under Ultraviolet black lamp

TESTING OF WINDER VITAL COMPONENTS

Prior to the testing, the suspension gear parts were cleaned with solvent (Diesel) and then dried with compressed air. Indian Standards were followed while conducting the non-destructive tests (IS-3703,1998; IS-7743, 1998; IS-4904,1997; IS-9565,1998; IS-8791, 1992). These components were physically examined whether they are free from pitting, corrosion, wear and deformation in the body. All the components were tested under loaded condition.

- All the components were scanned along the longitudinal and transverse direction using normal beam probes.
- Angle beam probe (45^o) was also used for scanning along the transverse direction.

A) **Suspension Gear Parts:** All components were magnetized by Yoke type Electromagnetic crack detector and viewed with Ultraviolet lamp. All the suspension gear parts such as rope cappel with pin, Egg-link, D-Shackle with pin, Safety Hook, Top D-Shackle, Distribution Plate, Bottom D-Shackle, Bridle Chains & Cage D-Shackle with pins are all free from surface and sub-surface defects. All the load carrying pins were tested with normal beam probe longitudinally does not reveal any internal flaws.

B) **Drum shaft:** The shaft was divided into number of zones. Testing was carried out with both normal and angle beam probes in loaded condition (Fig 4).

Fig 3: Magnetic particle testing of components of suspension gear parts

The shaft was rotated 180^o to test all the points the drum shaft was scanned with normal probe radially and axially. The entire length of the shaft was also scanned longitudinally from one end. Then the shaft was scanned with 45^o angle beam probe. The drum shaft does not reveal any internal flaws.

C) Sheave Wheel Shafts: The end covers and top bearing covers were removed and the accessible portions were tested with normal and angle beam probes. The shafts were also scanned longitudinally with normal beam probes. Careful scanning in the accessible portions of the shafts did not reveal any internal flaws.

D) Load Carrying Pins (East & West): All the Load carrying pins were scanned from both the ends longitudinally with normal beam probe. The pins did not reveal any internal flaws.

Fig 4: Ultrasonic testing of typical drum shaft with normal probe

E) **Vertical Brake Tie Rod:**The entire tie rods were scanned with both normal and angle beam probes. Tie rods do not reveal any internal flaws (Fig 5).

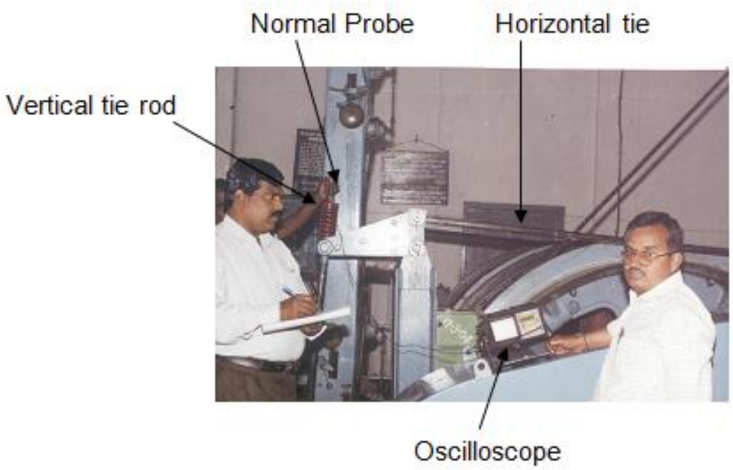

Fig 5: Ultrasonic testing of typical vertical brake tie rod

F) Horizontal Brake Tie Rod: The entire Brake Tie Rods were scanned with normal and angle beam probes. The threaded portions of the tie rods were also tested longitudinally from one end with normal beam probe. The tie rods are free from internal flaws.

On the whole, the above tests of suspension gear parts and winder components by ultrasonic and magnetic particle tests indicated no defects. In rare circumstances, when defects such as inclusions, cracks were noticed, it was immediately replaced by defect free components.

G) Winding ropes: Electromagnetic method of testing the wire rope is the most widely practiced non-destructive method of studying the condition of wire rope under in-situ conditions. In this method, wire rope is magnetized using powerful magnets [1,2]. The magnetic lines of forces travel along the axis of wire rope. If there is a discontinuity, the magnetic lines of forces deviate from their path and there will be a leakage field to the air. Using suitable sensors, leakage fields are detected, recorded and analyzed to identify the type of discontinuity. Fig. 1 shows the schematic layout of the equipment used in electromagnetic testing. faults, which includes broken wire, wear,corrosion, pitting, and inter strand nicking. Inductive coils are used to detect these defects. This is detected by the inner coil of the equipment.

• LMA Sensors: LMA means loss of metallic area. Hall sensors are used to measure this parameter. This is detected by the outer coil (Hall sensor) of the equipment.

Defects in Wire Ropes

In order to analyze the defects in a wire rope by the electro-magnetic method, there should be a prior knowledge of the possible defects. The defects (Fig 6) usually present in a rope which was put into many years of service are Wear ,Nicks ,Corrosion ,Pitting ,Broken wire.All these defects appear as local faults (LF). The loss of cross sectional area due to these defects appears as LMA. Inner coil detects the LF defects and Hall sensor detects LMA.

The signals detected by the inner and outer coils are in the range of milli-volts. LMA signals are easy to analyse, as the shift in voltage from the base line is easily correlated with the loss in area calibrated using calibration rod before recording the test data. The difficulty arises in analyzing the inner coil signals, which detects the signals from wear, corrosion, pitting, nicks and broken wire. It is very difficult to distinguish the LF signals if they are of the same magnitude. A prior knowledge of the type of defects present in the rope helps in characterization of the various defects.Apart from the defect signals, inner coil also records signals due to the construction of rope, called as lay noise. These signals are usually measured from the non-defective portions of the rope, which may be about 75- 100 mV depending on the construction of the wire rope and its usage.

Defect Patterns

Inner coil voltage variation is an indication of the presence of defects. Few of the typical defect patterns recorded are illustrated here. If the wire rope is free from defects, the variation of inner coil voltage is small, and is uniform throughout the length of the wire rope. This pattern arises due to the construction of wire rope, termed as lay noise. A typical pattern of a lay noise is shown in the Fig. 7. The Y-axis represents the magnitude of the inner coil voltage and X-axis, the linear dimension of the rope.Fig. 8 & 9 shows a gradual increase in inner coil voltage, which arises due to the presence of defects possibly due to wear, nick and few broken wires. Defects due to broken wires are shown in Fig. 10. In general, it Is not possible to distinguish the signals due to nick and broken wires.

Calibration

In atypical defect pattern shown in Fig. 6, possible defects were only wear and the broken wires. Form these patterns; it is not possible to distinguish the wear and broken wires and also the number of broken wires. In order to estimate the signal level due to wear and broken wires, calibration tests were carried out in the laboratory by creating artificial defects.

Calibration for wear

Wires with different percentage of wear were artificially prepared by grinding the wire surface. The equipment consisting of magnetic head and the sensors was kept in the vertical position and the wires were allowed to fall freely in between the powerful magnet, and the inner coil voltage was recorded.

Calibration of broken wire

To estimate the signal due to broken wire, cross sectional area of the individual wires was considered. Wire rope with various numbers of broken wires was artificially created and was allowed to fall freely in between the powerful magnet, and the inner coil voltage was recorded. These calibration results as cross sectional area vs. the inner coil voltage are presented in Fig 5.

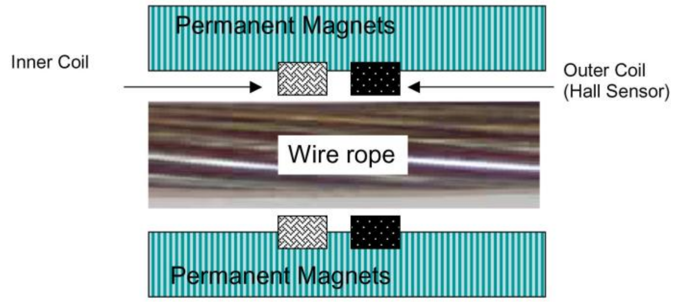

Fig. 6: Schematic layout of equipment used in electromagnetic testing

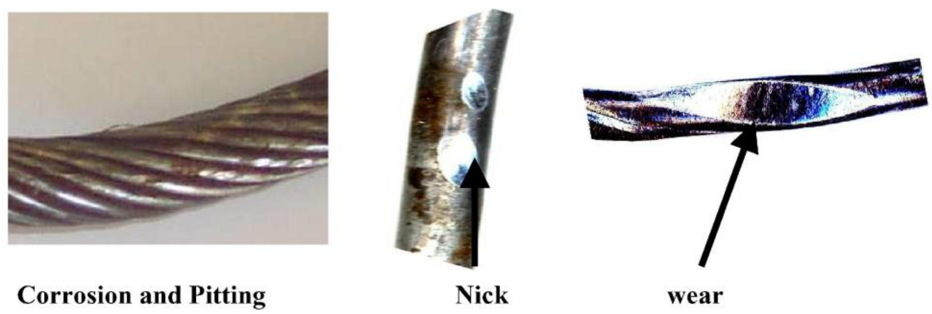

Fig. 7: A typical rope sample with defects

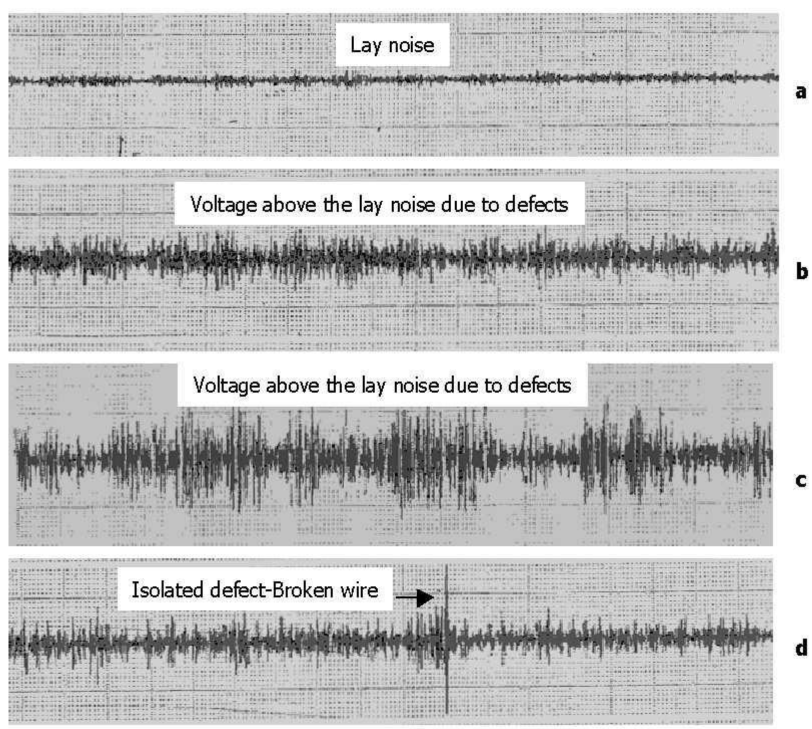

Fig. 8: Defect pattern in a typical wire rope

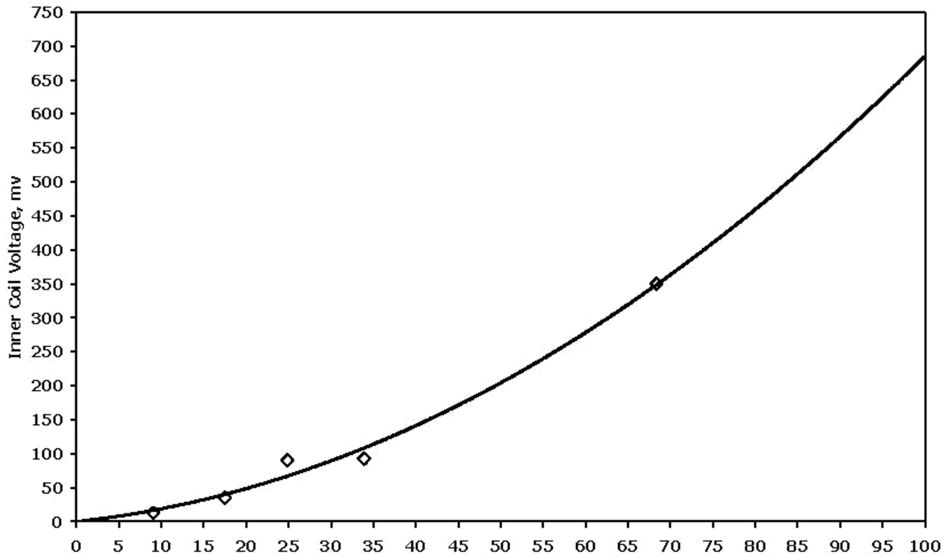

Fig. 9: Calibration curve of wear Vs inner coil voltage

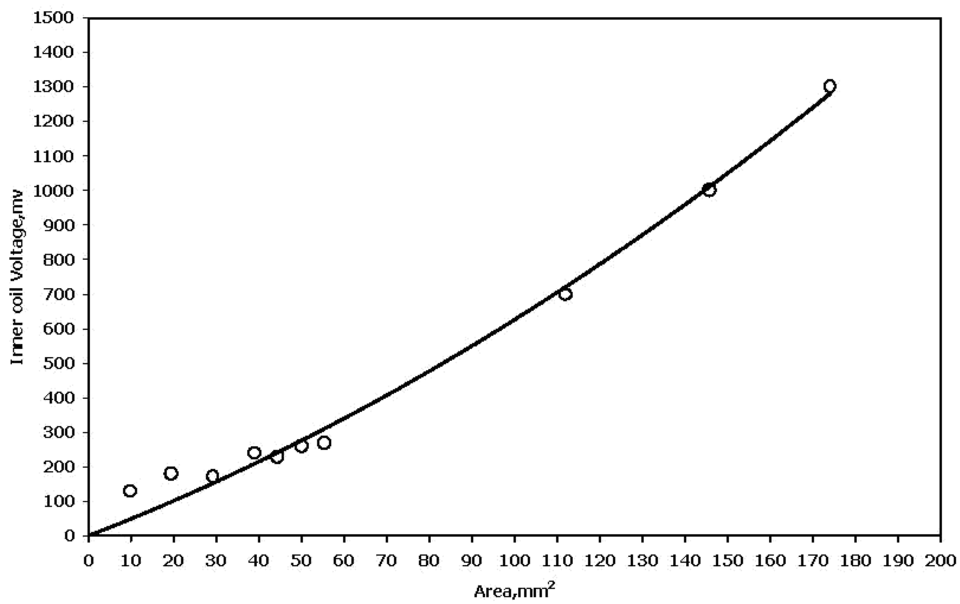

Fig. 10: Calibration curve of area of broken wires Vs inner coil voltage

Based on the recorded inner coil voltage, the percentage wears and the area of the broken wires is estimated from these calibration curves. From the area, the number of broken wires was estimated based on the construction of the rope. It is assumed that when the wear of wire reaches 50% of its original diameter, the wire breaks. From this graph it is inferred, that any inner coil voltage less than 200 mV is treated as wear. It should be noted, that the inner coil signal up to 30% of wear could not be distinguished as it merges with the lay noise. Fig. 10 shows the calibration curve of inner coil voltage due to broken wires vs area of the wires. It is inferred that approximately one broken wire of diameter 3.26mm (for a typical construction of a wire rope) produces a signal of 40.88 mV, which is merged with the lay noise. Approximate voltage output from different number of wires is presented in Table 3 for a typical rope. Fig. 11 demonstrates a Rope defectograph commissioned in a typical underground mine for NDT test on winding rope.

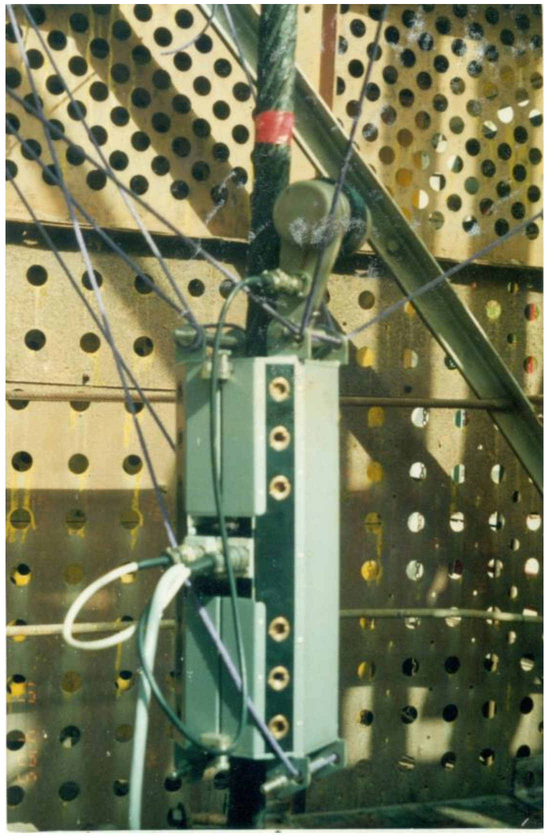

Fig. 11: Rope defectograph commissioned in a typical underground mine for NDT test on winding rope

Table 3: Approximate Voltage Output from Different Number of Wires

Inner coil voltage (mV)	No. of Broken wires
40.88 1	1
122.64 3	3
204.4	5
327.04	8
367.92 9	9

From the Table.3, it is clear that if 3 wires are broken, the signal voltage merges with the lay noise (about 100 mV), and signal voltage due to wear (Fig 4). Therefore, it is not possible to distinguish lay noise, wear and broken wire in case of signal levels of about 120 mV. To consider a signal due to broken wire, the voltage should exceed 200 mV. It may be noted that the voltage exceeding 200 mV corresponds to a breakage of 5 wires. This calibration curve helps in calculating the number of wires, considering the construction of the wire rope.

CONCLUSIONS

In case of any new equipment, non-destructive testing of its components is required before they are put to use. For this purpose, Ultrasonic and Magnetic particle tests are most widely used, in addition to proof load tests by manufacturers and customers. Based on non-destructive evaluation of various mining machinery components, it is recommended that a document of such tests by other than the manufacturer/mining industry (i.e by any research/academic organisation recognized by DGMS) would be useful for better evaluation of condition of the equipment later in working condition. Major/vital components such as drum shaft and brake tie rods need to be tested in loaded condition for better evaluation of safety of the equipment. In view of absence of such clause in the existing mining law, it is also suggested to modify the testing procedures, accordingly. Magnitude of the defect signals were simulated with rope-defectograph by creating artificial defects in the laboratory, which can be used for analyzing the actual signals recorded during in-situ testing on wire ropes. Calibration methodology was based on fundamental principles, keeping the objective of quantifying the LF results, which helps to study the condition of the wire rope. The calibration curves and typical signal patterns of lay noise, various defects in a wire rope are illustrated. The major problem in analyzing the defects is owing to the presence of the noise caused by the construction of the wire rope, which interferes with the signals due to the defects. The difficulty arises in distinguishing the inner coil signals from wear and broken wire. Additional studies are required for standardizing the method of calibration for wide application to various industrial purposes.

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