Non-destructive evaluation of haulage ropes in mono-cable aerial ropeways: a comparative case study

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Non-destructive evaluation of rope improves the reliability of the initial identification of the location of significant degradation along a rope. Magnetic flaw detectors, which measure loss of metallic area (LMA) and detect local faults (LF) such as broken wires and other faults in the ropes, are used to determine rope wearing. In the present paper, non-destructive evaluation has been carried out for comparison of the condition of different haulage ropes in seven mono-cable aerial ropeway installations through a case study over a period of 1½ years.

Keywords: Non-destructive evaluation, aerial ropes, magnetisation.

Introduction

Steel winding ropes used in aerial ropeway installations deteriorate with use. Ropes used in aerial ropeway passenger cable car installations cannot be assessed by destructive investigation due to non-availability of rope length for destructive analysis. Under these situations, non-destructive investigation is the only means for its evaluation to study the behaviour and condition in ropeway installations.

Non-destructive evaluation and objectives of aerial rope study

The most conventional inspection method for aerial wire ropes – track or haulage or both – is visual inspection, which for obvious reasons cannot evaluate the inner damage such as that caused by corrosion. Moreover, it is hard and nearly impossible to review thoroughly a rope covered by lubricant and grime when a rope length is up to a hundred metres. Additionally, only surface faults of the rope can be detected and this is insufficient to define its condition correctly.

Visual inspection alone cannot provide a real definition of the rope degradation level. Using the magnetic method, the rope condition can be evaluated conveniently and convincingly.

The principle of operation for electromagnetic non-destructive evaluation of wire rope systems employ:

- ❑ measurements of fringe fields near the surface of the rope to detect local defects such as broken wires, corrosion pitting, local wear;
- ❑ measurements of changes in magnetic flux passing through a short length of rope to quantify changes in metallic cross-section.

Magnetic non-destructive evaluation of wire ropes has been in regular use in a number of countries for more than fifty years. Presently used equipment/method is based on magnetisation of the rope with permanent magnets and detection of the changes of magnetic field around the rope and total magnetic flux.

The rope rejection criteria can be divided into qualitative and quantitative ones. The qualitative criteria are: (1) various types of deformation, (2) damage as a result of high temperature or of a flash influence, (3) strand or metallic core break. The quantitative criteria are: (1) diameter change, (2) surface or inner abrasive wear and (or) (3) corrosion of wires which lead to loss of metallic cross-sectional area (LMA), (4) quantity of breaks of outer and inner wires over specified lengths (usually per 6d, 30d or 40d, where d is the rope diameter in mm). The last criterion belongs to the family of faults known as rope local faults (LF), whereas the LMA one belongs to a family known as dispersed faults. Evidently, the visual method of rope inspection is subjective and it allows one to define the rope condition relative to the qualitative criteria only.

The main objectives for non-destructive evaluation of steel wire ropes used in aerial ropeways are listed below:

- ❑ study the condition of ropes over a period of time at regular intervals of three months/six months/one year, depending on age, condition of ropes etc. in the installation
- ❑ assess the suitability of ropes by non-destructive evaluation
- ❑ achieve the optimum safety, economy and reliability during operation of the ropes in current installation

Case study

The seven different mono-cable aerial ropeway installations where non-destructive evaluation methods have been applied for study of different haulage ropes are mentioned in Table 1. The haulage ropes in seven different mono-cable ropeway installations are designated as HR-1, HR-2, HR-3, … HR-7 respectively.

Critical non-destructive evaluation

The haulage ropes have been subjected to non-destructive investigation *in situ* for monitoring their present condition and suitability in the respective installation using an MD 120B Wirerope Defectograph of Polish origin. The wire rope defectograph has been calibrated each time by 80 sq mm and 20 sq mm rods (Figures 1(a), 2(a), 3(a), 4(a), 5(a), 6 and 7). For calculation of relative loss in cross-sectional area, it has been taken into account that steel cross-sectional area for stranded rope is about 55% of the full cross-sectional area. The findings for the seven haulage ropes are detailed below:

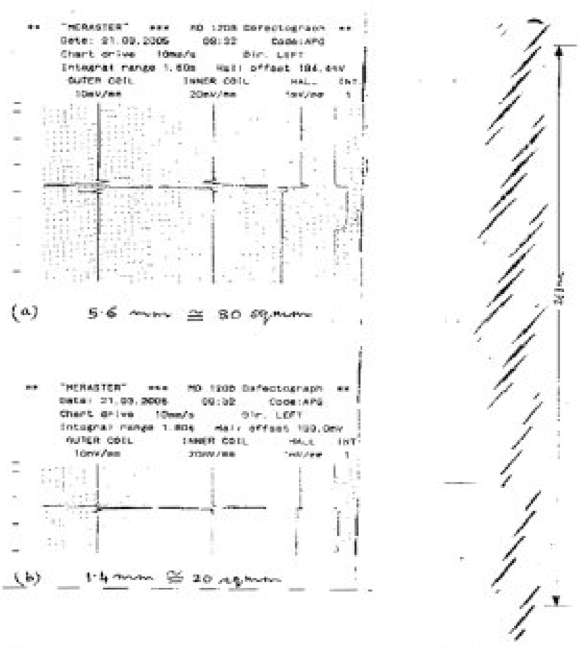
HR-1

The investigation had been carried out on the rope for the first time after five months in the installation. The minimum and maximum

Table 1. Ropeway installations under study

Identification of haulage rope	Nominal diameter (in mm)	Observed diameters (in mm)	Construction	Spliced length (in metres)	Type of core/lay	Lay-length (in mm)	Investigation conducted at a period after installation (in months)	No of flaws/ broken points	Relative loss in metallic cross-sectional area	Approx. total length (in metres)
HR-1	40	39.9, 39.2, 39.7, 39.5	6X19S (9/9/1) Preformed, ungalvanised	48.5	FMC (Sisal) Lay-LHL	268	5	nil	negligible	620
HR-2	38	37.4, 37.1, 37.6, 36.9	6X17S	41, 42, 50, 40, 41 (5 splices)	FMC (Sisal)	–	82	52		4500
HR-3	40	39.9, 39.8, 39.7	6X19S (9/9/1) galvanised	43	Hemp core Lay-LHL	271	8	8	1.6% (max)	835
HR-4	36	36.1, 35.2, 35.0, 35.8	6X19 (9/9/1) Preformed, ungalvanised	42	FMC (Sisal) Lay-RHL	250	9	1	0.87% (max)	1040
HR-5	40	38.2, 39.0, 39.1, 38.7	6X36 WS [6{1+7+(7+7)+14}] ungalvanised	53, 53 (2 splices)	FMC Lay-RHL	291	72	56 (33+23)	4.07% (max)	2150
HR-6	33	32, 32.1, 31.9, 31.7	6X17S ungalvanised	41	FMC Lay-RHL	–	24	7	5.4% (max)	1150
HR-7	36	35, 35.1, 35.7, 35.7	6X19S ungalvanised	41	FMC Lay-RHL	–	24	8	3.5% (max)	1565

diameters observed during study are 39.2 mm and 39.9 mm respectively against nominal diameter of 40 mm. The lay-length (Figure 1(b)) is 268 mm (6.7d, where d is the diameter in mm) and spliced length is 48.5 m (1212.5d). The total length of the rope was 620 m. The rope speed during investigation was approximately 1.0 m/s. No flaw was observed and the percentage loss in relative cross-sectional area was negligible.

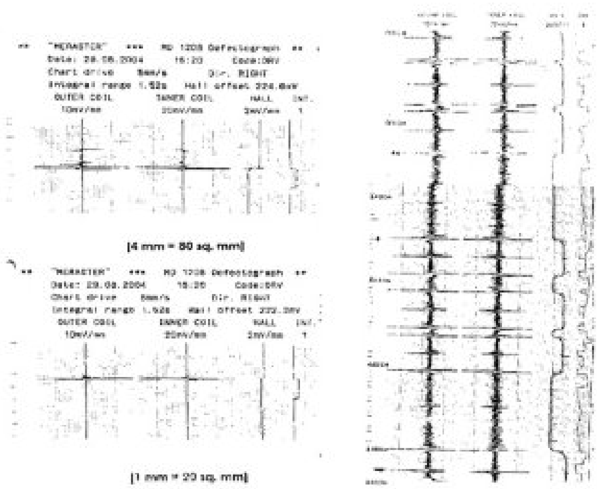


(a) (b)

Figure 1. (a) Calibration charts, (b) Lay length chart of HR-1 rope

HR-2

The investigation was carried out on the rope after 82 months in the installation. The minimum and maximum diameters observed during study were 36.9 mm and 37.6 mm respectively against nominal diameter of 38 mm. There were five splices in the length of 4500 m. The spliced lengths (Figures 2(b), 2(c), 2(d) and 2(e)) were 41 m, 42 m, 50 m (approx.), 40 m and 41 m [1053d to 1316d]. Resplicing in the third spliced region (from the reference point) was recommended since its condition had been very poor. The number of flaws was found as 52. The average rope speed during investigation had been approximately 0.6 m/s.



(a) (b)

Figure 2. (a) Calibration charts, (b) First (reference) splicing of HR-2 rope

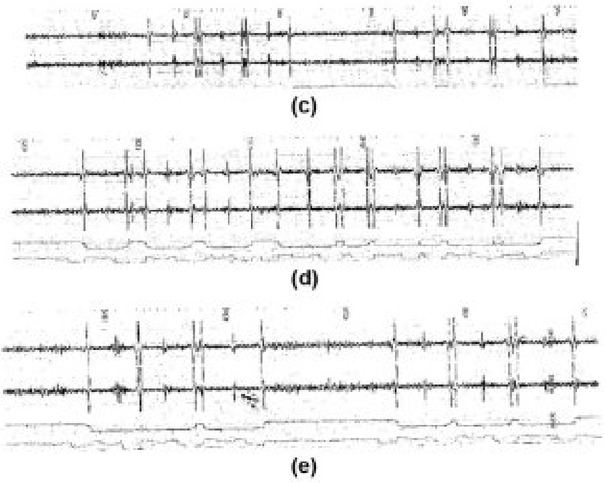
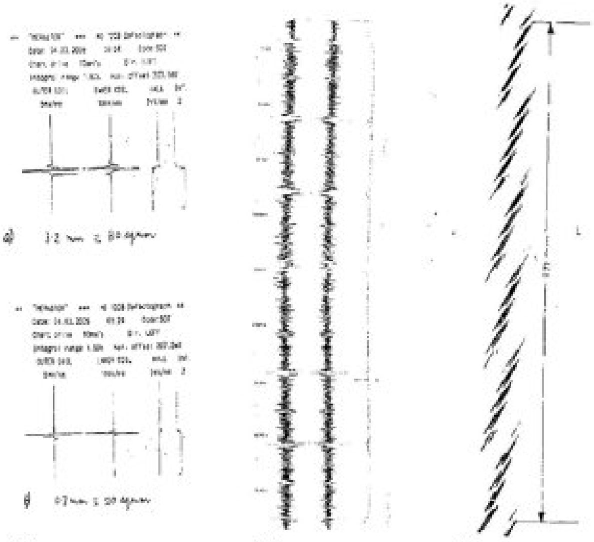


Figure 2. (c) Second splicing, (d) Fourth splicing, (e) Fifth splicing of HR-2 rope

HR-3

The investigation had been carried out on the rope for the first time after eight months in the installation. The minimum and maximum diameters observed during study were 39.7 mm and 39.9 mm respectively against nominal diameter of 40 mm. The lay-length (Figure 3(c)) was 271 mm (6.8d, where d is the diameter in mm) and spliced length (Figure 3(b)) was 43 m (1075d). The total length of the rope was 835 m. The rope speed during investigation was approximately 1.0 m/s. Eight flaws had been observed and the percentage loss in relative cross-sectional area had been found as 1.6%. The rope was found to be corroded.



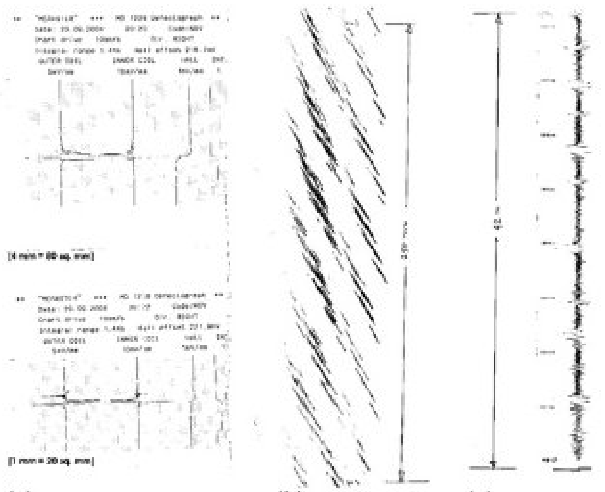
(a) (b) (c)

Figure 3. (a) Calibration charts, (b) Spliced length, (c) Lay-length of HR-3 rope

The earlier rope was installed for a period of 65 months. The last investigation on earlier rope showed the number of flaws as 12 after 57 months (7 found after 45 months in installation) and maximum relative loss in metallic cross-sectional area was 4.2%.

HR-4

The investigation had been carried out on the rope for the first time after nine months in the installation. The minimum and maximum diameters observed during study were 35.0 mm and 36.1 mm respectively against nominal diameter of 36 mm. The lay-length (Figure 4(b)) was 250 mm (6.9d, where d is the diameter in mm) and spliced length (Figure 4(c)) is 42 m (1167d). The total length of the rope was 1040 m. The rope speed during investigation was approximately 1.0 m/s. One flaw had been observed and the maximum percentage loss in relative cross-sectional area had been found as 0.87%.

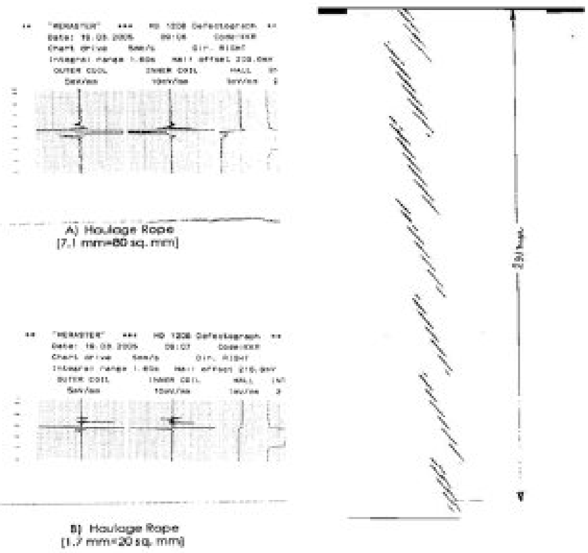


(a) (b) (c)

Figure 4. (a) Calibration charts, (b) Lay-length, (c) Spliced length of HR-4 rope

HR-5

The investigation had been carried out on the rope for the second time after 72 months in the installation. The minimum and maximum diameters observed during study were 38.2 mm and 39.1 mm respectively against nominal diameter of 40 mm. There were two splicing zones in the total length of 2150 m. The number of flaws observed had been 56 (33+23)[48 found after 51 months] and the maximum percentage loss in relative cross-sectional area was found as 4.07%. The lay-length (Figure 5(b)) and spliced lengths were 291 mm (7.3d, where d is the diameter in mm) and 53 m (1325d) respectively. The rope speed during investigation was approximately 1.0 m/s.



(a) (b)

Figure 5. (a) Calibration charts, (b) Lay-length of HR-5 rope

HR-6

The investigation had been carried out on the rope after 24 months in the installation. The minimum and maximum diameters observed during study were 31.7 mm and 32.1 mm respectively against nominal diameter of 33 mm. The splicing portion was not good enough. The number of flaws observed was seven and the maximum percentage loss in relative cross-sectional area had been found as 5.4% compared to a healthy portion of rope. The spliced length was 41 m (1242d). The total length of the rope was 1150 m. The rope speed during investigation was approximately 1.0 m/s.

HR-7

The investigation had been carried out on the rope after 24 months in the installation. The minimum and maximum diameters observed during study were 35.0 mm and 35.7 mm respectively against nominal diameter of 36 mm. The number of flaws observed was eight and the maximum percentage loss in relative cross-sectional area was found to be 3.5% compared to a healthy portion of rope. The spliced length was 41 m (1138d). The total length of the rope was 1565 m. The rope speed during investigation was approximately 1.0 m/s.

Results and discussion

For calculation of maximum loss in relative cross-sectional area of rope, 55% of full cross-sectional area had been assumed as reference and comparison. The particular rope had been calibrated first with the metallic rod of known cross-sectional area of 80 sq mm and 20 sq mm in each case before the actual scanning of rope. The condition of haulage ropes has been compared in the following three sections:

(A) When the haulage ropes of same diameters are compared, the observations are as follows:

Rope name	Nominal diameter (in mm)	Period when studied	Relative maximum loss in cross-sectional area	No of flaws	Spliced length (metres)	Lay-length (in mm)
HR-1	40 mm	After 5 months	Negligible	Nil	1212.5d	6.7d
HR-3	40 mm	After 8 months	1.6%	8	1075d	6.8d
HR-5	40 mm	After 72 months	4.07%	56	1325d	7.3d

Rope name	Nominal diameter (in mm)	Period when studied	Relative maximum loss in cross-sectional area	No of flaws	Spliced length (metres)	Lay-length (in mm)
HR-4	36 mm	After 9 months	0.87%	1	1167d	6.9d
HR-7	36 mm	After 24 months	3.5%	8	1139d	–

Rope name	Nominal diameter (in mm)	Period when studied	Relative maximum loss in cross-sectional area	No of flaws	Spliced length (meters)	Lay-length (in mm)
HR-2	38 mm	After 82 months	–	52	1053d to 1316d	–
HR-6	33 mm	After 24 months	5.4%	7	1242d	–

The lay-lengths observed were within the range of 6d to 8d. The spliced lengths were from 1000d to 1300d except in HR-5 and in one splicing point of HR-2.

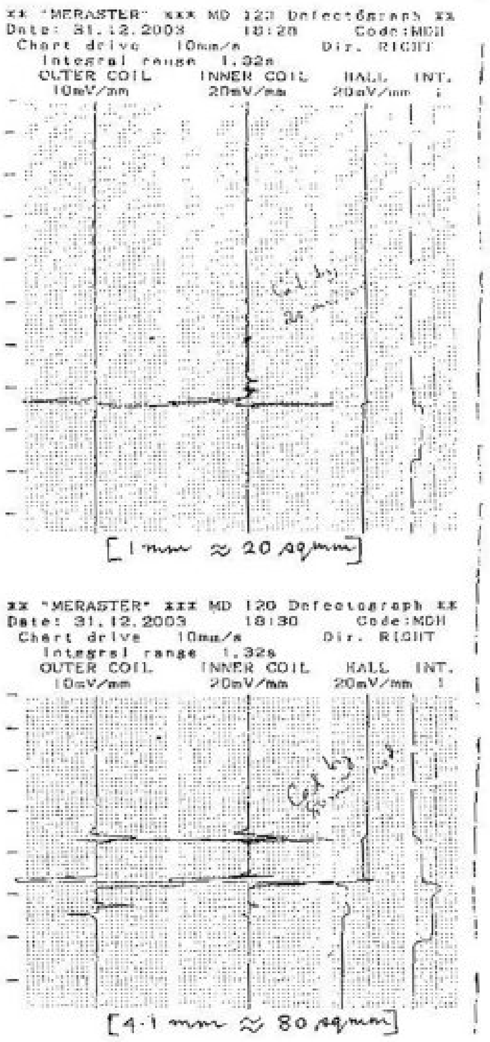


Figure 6. Calibration charts of HR-6 rope

(B) Most of the ropes were having the construction (Figure 8) of 6X19 Seale: HR-1, HR-3, HR-7. The other constructions are 6X17 Seale (HR-2 and HR-6), 6X19 (HR-4) and 6X36 Warrington-Seale (HR-5).

(C) According to lay direction and type of core of rope, the following comparisons could be obtained:
   (i) LHL (Left hand Lang's lay) – HR-1, HR-3.
   (ii) RHL (Right hand Lang's lay) – HR-4, HR-5, HR-6, HR-7.

Lay of HR-2 has not been noted.

All the cores of ropes were FMC (Sisal) [Fibre Main Core] except HR-3 (which was with hemp core).

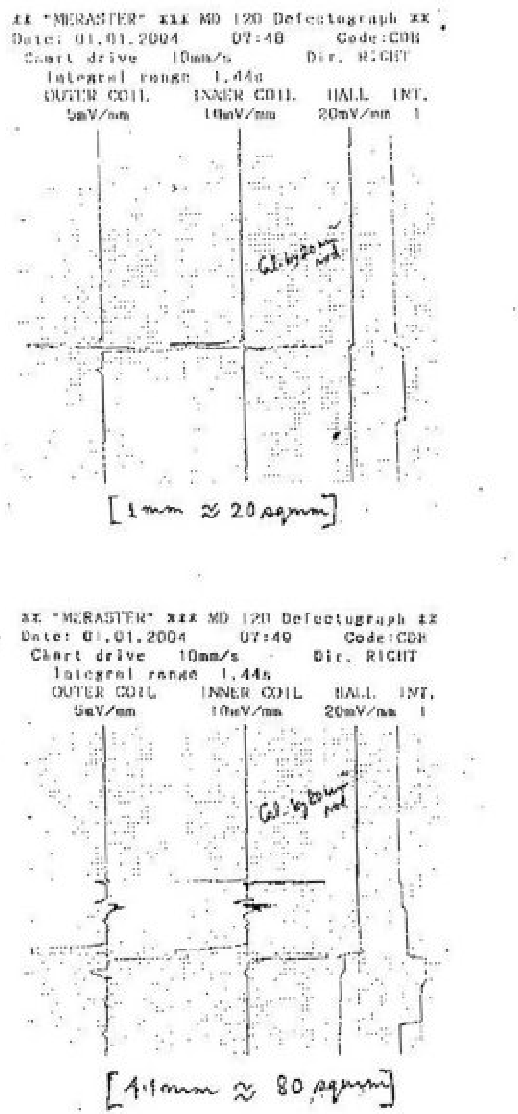


Figure 7. Calibration charts of HR-7 rope

Conclusion

The output of the study will be useful for continuous monitoring of rope condition of aerial ropes in ropeway installations. Periodic *in situ* measurement of faults in ropes would help to establish the effects of various parameters on rope life. It also emphasises the priorities of wire break discard criteria supported theoretically and experimentally. The present non-destructive study on haulage ropes does not include the aspect of fatigue which may develop in ropes in course of time. With the results and recommendations of the study, it will be possible for management to make a decision either to remove the ropes in use from the installation or to extend the life of existing ropes.

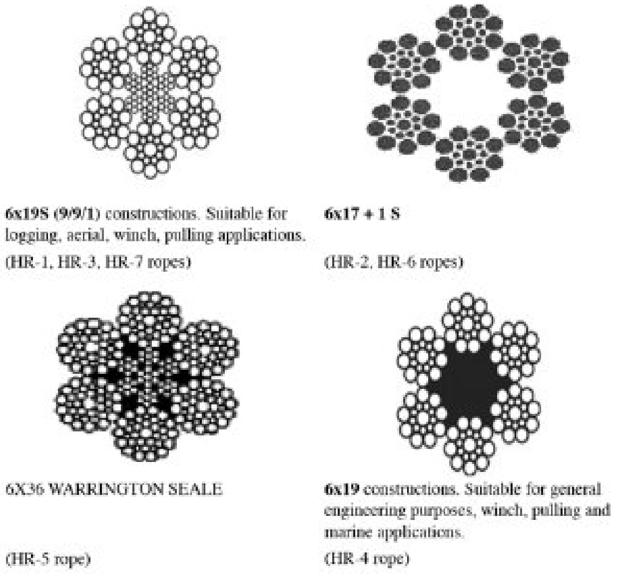


Figure 8. Construction of haulage ropes

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