MULTI-SYSTEM OVERHEAD LINES INSPECTIONS – THE EXPERIENCE OF LABELEC WITH EDP DISTRIBUTION LINES

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ABSTRACT
The long experience of LABELEC in airborne infrared (IR) and visual inspections of EDP Distribution overhead electric lines (OHL) is now enriched with the possibility of measuring and localising abnormal clearances between cables and trees or other obstacles. This was achieved using a Laser-Global Positioning System (GPS) solution that started being developed in LABELEC and later on was set ready for operation by Albatroz Engineering. Previously, some experimental track clearances measurements were carried out in distribution OHL, using high-quality but high-cost airborne-topography equipments. Now, the IR detected hotspots and visible anomalies information can be complemented with sufficiently accurate track clearances and its GPS information, using Albatroz system, with only a small increase in operational costs. The three types of inspection can be performed with a single flight over the transmission or distribution lines, using a medium operational cost helicopter like the Eurocopter Colibri EC 120 B.

The near future may bring the integration of corona effect detection and visualisation into LABELEC multi-system OHL inspections, further contributing to a higher level of efficiency in lines maintenance activities.

INTRODUCTION
After LABELEC started airborne inspections of overhead electric transmission and distribution lines in 1995, the benefits for proper OHL maintenance were quickly recognized, as it became possible to detect hotspots and visible faults in one day, with a single team (one pilot, one thermographic inspector and one visual inspector in a helicopter), in a length of lines that was 20 times greater than in ground inspections. The helicopter costs were compensated by the reduction of the inspection time, by the higher sophistication and resolution of the IR airborne camera and by a different and closer field of view during the inspections.

Every year hundreds of hot spots and thousands of visual anomalies are detected during OHL inspections, providing information that can be used by the maintenance personnel in scheduling inspection and repair works on the lines, budgeting and planning of repair operations and evaluating the performance of line components, leading to a maintenance strategy that may avoid many catastrophic failures. The need to measure power lines clearances arose from the importance of avoiding line outings due to excessive growth of trees in the power lines tracks, which can also be a cause for forest fires and other accidents. The information available from previous inspections was not accurate, as it was based on a visual evaluation of the airborne inspectors. Track clearance measurement had already been tried using high accuracy airborne Laser Imaging Detection and Ranging (LIDAR) systems that were not possible to integrate with LABELEC infrared and visual airborne inspections, unlike the present solution.

The new solution provides an output of abnormal laser measured distances, classified into 3 different categories of severity, with GPS localization. This list of abnormal distances is complemented with images of the laser echoes and a laser associated visual image.

Information from the multi-system inspections, including hotspots, visible faults and abnormal distances, can be associated with Geographic Information Systems (GIS), providing a new tool for maintenance planning. The new system digital recordings of geo-referenced data and moving images make it easier to check the inspection results.

INFRARED INSPECTION
IR Inspection Equipment
The infrared airborne inspection system consists of a remotely controlled FLIR Thermovision 1000 infrared camera installed in a gyro-stabilized ball, outside the helicopter. The gimbal also includes a visual (TV) camera that helps the operator identifying the images seen with the IR camera whenever it is necessary and that may record zoomed in images of details of visible faults detected.

The IR camera has a Multi element MCT SPRITE, working in the 8-12µm waveband, with an integral Stirling cooler; it includes two lenses, one with an instantaneous field of view of 0.6 x 0.6mRad and field of view of 20° x 13° (wide lens) and the other with an instantaneous field of view of 0.15 x
0.15mRad and field of view of 5° x 3.3° (narrow lens), with a switching time between them of less than 1 sec; the minimum resolvable temperature is < 0.1°C; these IR camera characteristics are an evidence of the IR image quality, with high field resolution and a short switching time between wide and telephoto type images, which are fundamental aspects for airborne IR inspections.

**IR Inspection Procedures**

The IR inspector sits on the helicopter backseat, controls the gimbal, IR camera and TV camera, switches on or off most of the electronic inspection and recording equipment and supervises the laser scanning field in a computer monitor. Typical inspection distances range from 15 to 30m. The inspector observes the power line from an oblique angle, using the wide lens and switches to the narrow lens when it is necessary to watch in more detail or when a possible hotspot is detected. All discontinuities in the power cables are observed in detail. Every hotspot image is carefully framed in the monitor and stored in the computer of the IR inspection system, together with all the object parameters, for further analysis in the office.

For safety reasons, Medium Voltage (MV) lines, closer to ground and with more superior crossings from High Voltage (HV) lines and transmission lines, are some times inspected only after a previous reconnaissance flight, at a higher speed and altitude. The load of the line is taken in consideration before the inspection is initiated, with inferior limits agreed with the client. Also the wind speed is taken in consideration, due to its cooling effect; wind speeds on the ground of 5m/sec are usually considered the limit.

**IR Inspection Results**

The hundreds of hotspots detected are registered on data bases after the inspection flight. The IR images scales are adjusted, object parameters are corrected if necessary, analysis tools are used, and descriptions of the faults and their localizations are made. The hotspots are highlighted and their temperature differences to reference objects that are not overheated are given. Each overheating is classified into 1 of 4 categories of severity, allowing the maintenance people to act according to the severity of the detected faults.

**VISUAL INSPECTION**

**Visual Inspection Equipment**

The most important “equipments” for airborne OHL visual inspections are the human eyes, with a help from the stabilized binoculars and the video camera zoom. The video camera is installed in the gyro-stabilized ball under the IR camera and has a powerful optical zoom that allows detailed observation of insulators, poles and pylons, cables and cable fittings and other accessories.

**Visual Inspection Procedures**

The Visual inspector sits on the front helicopter seat and takes notes of every visual fault detected on the line. When necessary he uses the stabilized binoculars to see details of the anomaly. The zoom of the video camera, operated by the IR inspector, can also help on this task, and its digitally recorded images can be used later to support inspection results information. The visual inspector also cooperates with the pilot, watching out for possible obstacles (mainly other power lines) crossing the helicopter path.

**Visual Inspection Results**

Thousands of visible faults can be detected in a year of distribution lines inspections. Most of these faults are damaged insulators. Many faults are also found in the power line pylons (mostly corrosion).

In 2008 nearly 58 visible faults per 100km were detected in inspected distribution lines. All faults are given a code and registered in a data base together with a description of their localization.

In 2008 in a total of 8163km distribution power lines inspected, there were more than 2 hotspots detected per 100km. They occurred in compression dead end clamps, cable connectors, aerial disconnectors, mid span conductor joints…

**Figure 3 – Hotspots in HV and MV lines**

In 2008 nearly 58 visible faults per 100km were detected in inspected distribution lines. All faults are given a code and registered in a data base together with a description of their localization.

**Figure 4 - Broken insulator; broken ground wire**

**Figure 5 – Replacement of broken insulators detected during an airborne inspection in a 130 kV distribution line**
DIGITAL RECORDINGS AND INTERFACE

The Albatroz and LABELEC developed Digital Recording and Interface system and Laser Track Clearances Inspection system give a new dimension to the airborne OHL inspections of LABELEC. The Digital Recording and Interface system provides on-line access to all data being recorded and synchronises all data through a common clock. The operators can record information on observed faults on-line, using a touch-screen computer (PC) that is also used to see the images of the IR and visible cameras, moving graphics of the laser inspection, corona inspection images (to be used in the future) and distances to the ground, to the line and the helicopter speed.

All operator input information, images, laser data, GPS data and voice comments made during the aerial inspection are recorded on the hard disk drive (HDD) of the on-board server and later transferred to data bases in LABELEC, where they will be used to generate the customer reports.

![On-board server and touch-screen tablet PC](image)

Figure 6 – On-board server and touch-screen tablet PC

![One of several possible image views on the Tablet PC, with on-line laser data and associated image](image)

Figure 7 - One of several possible image views on the Tablet PC, with on-line laser data and associated image

TRACK CLEARANCES INSPECTIONS

Abnormal clearances had always been registered in LABELEC airborne OHL inspections, but relying only on the visual observation of power line inspectors. Measuring them and geo-referencing them using a reliable system during routine IR and visual airborne inspections is now a normal procedure in EDP Distribution lines and also in transmission lines. Thousands of anomalous situations have been detected during the 2008 inspections and their classification into three severity classes can help maintenance personnel paying special attention to the most critical situations and planning a more efficient intervention in power line track vegetation management, by integrating that data with geographical information systems.

![Laser footprints; higher sweep frequency (above); lower frequency sweep (below)](image)

Figure 8 – Laser footprints; higher sweep frequency (above); lower frequency sweep (below)

Track Clearance Inspection Equipment

The system fundamental parts are the laser and the software developed by Albatroz that identifies cables, pylons, vegetation and ground. Previous experiences with high-end systems provided very accurate data but were incompatible with routine inspections. So LABELEC set the specifications for maintenance and commissioned a system above these thresholds: there is no need for 1cm measurement errors, as the wind and tree growth would change the results, 20 cm are acceptable; there is no need for localisation errors below 1m when an error limited to 5m, supported by graphs identifies the hazard unambiguously. Nevertheless, windows were left open for improvement, such as the use of an Inertial Navigation System in case more accuracy or three dimension modelling are required.

The laser scanner range error is < 0.2m and its effective range is < 40m for wires, < 60m for trees and ground. The GPS has a position error of < 15m.

A compromise had to be found when the sweep frequency was chosen: lower frequency would result in a higher density of the 10kHz laser footprints (higher transversal resolution) but also in a higher spacing between scans as the helicopter moves forward (lower longitudinal resolution).

The next table gives an idea of the distance between two consecutive sweeps, in meters, as a function of the helicopter speed. A 20Hz sweep frequency at helicopter speeds of 30 to 35knots will provide an adequate number of laser spots per sweep (allied with line cables interpolation) and an adequate distance between sweeps, as LABELEC experience on several thousands of km of distribution lines track clearances inspections has proved.

<table>
<thead>
<tr>
<th>Sweep frequency [Hz]</th>
<th>8.33</th>
<th>10</th>
<th>12.5</th>
<th>16</th>
<th>18</th>
<th>20</th>
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<tr>
<td>spots/sweep</td>
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<td>1000</td>
<td>800</td>
<td>625</td>
<td>556</td>
<td>500</td>
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<tr>
<td></td>
<td>19.40</td>
<td>1.20</td>
<td>1.00</td>
<td>0.80</td>
<td>0.63</td>
<td>0.56</td>
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<td></td>
<td>27.16</td>
<td>1.68</td>
<td>1.40</td>
<td>1.12</td>
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<td>0.78</td>
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<td></td>
<td>34.92</td>
<td>2.16</td>
<td>1.80</td>
<td>1.44</td>
<td>1.13</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>38.8</td>
<td>2.40</td>
<td>2.00</td>
<td>1.60</td>
<td>1.25</td>
<td>1.11</td>
</tr>
<tr>
<td>[m/s] Helicopter speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.20</td>
<td>1.00</td>
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<td>1.60</td>
<td>1.25</td>
<td>1.11</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 1 – Distances between consecutive laser sweeps for different sweep frequencies and different helicopter speeds
Track Clearance Inspection Procedures

When the operator gets the system ready for the Track Clearance Inspection he inputs information on the line voltage and geometry using the tablet PC. During the flight the operator should regularly check that the laser beam is reaching all expected points on the track, by looking at the image on the tablet PC. If necessary, he will ask the pilot to change the helicopter position or speed. Safety constraints and good observation angles determine that the helicopter must not fly over the OHL, but at its side and a little above it at a distance from the power cables between 15 and 50m.

When the on-line inspection is over, the operator brings data and images home and runs the off-line inspection software that acts on the data and image files installed in a dedicated server. A list of anomalous track clearances is generated, with each item on that list related with a graphic image of the laser sweep and the associated video image. All sweeps with anomalies are classified using a voltage dependent three level code for clearances thresholds around each conductor: A) critical anomaly – infringes regulations; B) severe anomaly – might infringe regulation, depending on obstacle type or is likely to infringe regulation before next inspection; C) moderate anomaly – could get to level B) before next inspection. For instance, in 60kV lines the thresholds are: A), 4m; B), 6m C), 9m. The sweeps that have anomalies are represented with the laser echoes colour coded: red for the cables, green for vegetation and other obstacles, black for the pylon, brown for the ground and gray for optical cables; the shortest distance between cable and obstacle is identified and its value can be read.

After the first report is generated, the operator checks for system errors in laser echoes classification and in detected abnormal distances, and corrects them. (The system may have wrongly identified a neighbour line as the line to be inspected, or part of a pylon may sometimes have been identified as an obstacle too close to the cables, or other errors may occur that must be detected and corrected by human intervention). The final report is usually ready within a week from the operator return to base.

Track Clearance Inspection Results

The results during the 2008 campaign showed that almost every line inspected has track clearances problems that may be classified into one of the three levels of thresholds. The maintenance services received lists of thousands of infringements that may be input into Geographic Information Systems of the company or even into Google Earth, for intervention planning, or may be input into portable GPS equipments for field work.

![Figure 9 – Recommended helicopter position and laser beam for inspections on 60kV lines with the clearance track width](image)

![Figure 10 – Part of a list of anomalous track clearances (red - critical; orange - severe; yellow – mild)](image)

CONCLUSIONS, DEVELOPMENTS

The first year of LABELEC multi-system OHL airborne inspections, integrating IR, Visual and LIDAR inspections had a wide acceptance in maintenance departments. The moderate increase of inspection prices (around 6%), due to the integration of the LIDAR system, compared to the previous airborne inspection prices, already a very much used tool in preventive maintenance, together with the huge number of anomalous track clearances detected, contributed to this acceptance. As a benefit for distribution lines maintenance, ground inspections heavy costs are being reduced as most of these inspections tend to be abandoned, and money previously spent on them will be used in track vegetation maintenance, technical inspections and network rehabilitation.

Improvements are expected, to increase the accuracy of the LIDAR results, to develop digital inputs of visible faults and to develop better interfaces with GIS of the maintenance departments. Inclusion in the airborne inspection system of Corona Visualizing inspections is also being considered.

REFERENCES

LABELEC inspections data bases and images; Albatroz images and technical data; CIGRE 2006 B2/D2-107 paper; EDP Distribuição maintenance data.