LASER BASED SCANNING SYSTEM FOR HIGH VOLTAGE POWER LINES CONDUCTORS MONITORING

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ABSTRACT
We have developed a laser based scanning system capable of monitoring both the ice accretion rate on conductors and the conductors sag in overhead lines. The paper will report the description of the system as well as preliminary results relevant to laboratory tests performed under controlled condition.

INTRODUCTION
As it is known, ice accretion phenomena on overhead conductors do represent a severe problem for power transmission lines located in regions where freezing temperatures occur frequently [1,2]. In fact, when a substantial amount of ice is deposited on the conductors, dangerous effects like broken conductors and toppled towers, can be observed. Since damage to structures by ice loads causes huge economic losses and operational difficulties in power industry, we have developed an optical system for monitoring critical situations, which can also be used to get quantitative data for implementing safety aspects in new power lines design. The measuring apparatus is a laser based scanning system capable of monitoring both the ice accretion rate and the conductors sag (or the clearance to ground).

As far as the conductor sag detection is concerned, it should be noted that the measurement of the conductor height above the ground makes it also possible to trace the variation in conductor temperature through its variation in sag. The installation of the developed device in critical spans (with reference to clearance to ground and conductor temperature) would thus allow a real time monitoring of maximum transmission capacity of the overhead line.

PRINCIPLE OF OPERATION
The principle of operation of the laser based scanning system is schematically shown in Fig. 1. It relies on the detection of the intensity backscattered by the conductor under inspection once it is intercepted by a properly driven scanning beam. The time duration of the backscattered signal is in fact proportional to the wire diameter while its relative temporal position with respect to the scanner driving signal provides the information relevant to the sag. Measurements are performed by positioning the measuring unit (where the laser source, the detector and the scanning system are located) on ground at a distance of approximately 20 meters from the electric line.

DESCRIPTION OF THE SYSTEM
A schematic description of the measuring system is provided in Fig. 2. As shown in the figure, the collimated beam generated by a 30 mW diode laser ($\lambda = 635$ nm) impinges onto a tilting mirror driven by means of a galvanometric scanner, the driving signal being a 1 Hz triangular wave. The beam reflected by the tilting mirror, which oscillates in the vertical plane, leaves the measuring head exploring an angular region of $\pm 15^\circ$ (with respect to the line of sight). Once the conductor under inspection is intercepted by the beam, it generates a backscattered signal.
A fraction of the backscattered light is gathered by the collecting optics (a 0.4 f-number Fresnel lens) that forms an image of the wire onto a circular photodetector (75 mm² active area).

It should be pointed out that the use of a very low f-number collecting lens is a consequence of a double requirement, i.e. the need of maximising the gathered signal (which is proportional to the lens collecting surface) and at the same time the requirement of minimizing the image magnification so to allow the whole explored area (eight meters in the vertical direction) to fall within the detector active area.

To improve the signal to noise ratio, an interference filter centred at the laser line (80 nm bandwidth) is positioned between the collecting lens and the photodetector so to prevent undesired light contributions (in particular during daytime) to fall onto the detector.

A picture of the developed system is shown in Fig. 3.

EXPERIMENTAL RESULTS

Experimental activity has been carried out aimed at testing the instrument capability to monitor both the ice accretion phenomenon and the conductors sag.

Ice accretion monitoring

The ice accretion phenomenon has been simulated in our laboratory by means of a properly prepared mock up. The mock up has been obtained by filling a metallic pipe (30 mm outer diameter) with dry ice (sublimation temperature -78.5 °C) and by spraying pulverized water on its surface. To get a radially symmetric ice distribution, the pipe was rotated around its longitudinal axis at a constant speed during the whole ice accretion procedure.

The mock up is shown in Fig. 4 (the central portion of the accreted ice has been removed after measurements to show the thickness of the ice layer).

A number of tests has been carried out by positioning the instrument at a distance of about 20 meters from the mock up. An example of these measurements is presented in Fig. 5. The two plots show the signals (amplitude vs. recording time) detected both in the absence (Fig. 5a) and in the presence (Fig. 5b) of the ice layer on the conductor (which means 30 mm and ~ 60 mm outer diameter respectively). The highest peaks represent the contribution of the light backscattered by the conductor, while secondary peaks are due to reflections from the background.

As it can be noticed, the width of the highest peaks in the two plots is proportional to the conductor diameter (with and without ice, respectively). In particular, by taking into account that the width of the peak relevant to the iced conductor (Fig. 5b) is 0.05 seconds, which corresponds to 2000 samples of the recorded signal, it comes out that by assuming a detection accuracy of about ± 20 samples, the ice accretion rate can be estimated with an accuracy of about 0.5 mm.
Conductor sag monitoring

An example of the preliminary measurements carried out in the laboratory under controlled conditions is reported in Fig. 6. It shows the result of a test carried out utilizing two vertically displaced parallel conductors (31.5 mm in diameter) positioned 1.2 meters apart in a plane perpendicular to the scanning plane. The measuring head was positioned at a distance of 15 meters from the wires. The lower wire (reference wire) was kept in a fixed position while the upper one (test wire) was displaced by known quantities in the vertical plane. The two plots in Fig. 6 show the signals (amplitude vs. sample number) detected respectively before (Fig. 6a) and after (Fig.6b) the test wire had been displaced from its original position by 50 mm. The two peaks in each plot correspond to the backscattered signals relevant to the reference wire (the peak on the right) and to the test wire (the peak on the left) respectively.

As it can be noticed the 50 mm displacement causes the peak relevant to the test wire to temporally shift by a well resolved quantity (Δt in the figure). Since the measured Δt corresponds to about 270 samples, the estimated resolution in this case is 0.18 mm/sample. By assuming a detection accuracy of ± 20 samples, we get a measurement accuracy of ± 3.6 mm. Since the scanned distance is greater than 1200 mm (i.e. the distance between the two wires), it comes out that we can estimate sag variations as small as 0.6% of the explored angular region.

The measuring system has also been tested under simulated bad weather conditions (i.e. in the presence of heavy rain). As shown in Fig. 7, measurements have been carried out on a conductor sprayed by a number of water jets. Also in this case measurement results have been quite satisfactory.

Fig. 6 - Experimental results relevant to a test carried out utilizing two vertically displaced parallel wires

![Fig. 6 - Experimental results relevant to a test carried out utilizing two vertically displaced parallel wires](image)

Fig. 7 – Experimental apparatus utilized to simulate rainy conditions

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We have described an innovative laser based scanning system properly conceived for monitoring both the ice accretion rate and the conductors sag in high voltage aerial electric lines. Preliminary results relevant to laboratory tests have been presented. Future activity will mainly be devoted to characterize the instrument behavior in real situations like e.g. monitoring aerial electric lines in different ambient/weather conditions.

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REFERENCES

[1] CIGRE – Working Group B2.06 – February 2001- “Guidelines for field measurement of ice loadings on overhead power line conductors” Brochure n. 244.