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DETERMINATION OF CRACKS IN WIND TURBINE BLADES BY SIMULATING SENSORS THROUGH FINITE ELEMENT STUDIES

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Abstract: The importance of wind energy is increasing due to its relative share in the global market. Especially in Argentina, projections are important, which not only concerns operation, but also maintenance tasks. These tasks can have a great impact on productivity if stop times are significantly prolonged. Based on several investigations carried out during two years, we continued with the study of a three-dimensional model of a wind turbine blade, using the finite element analysis technique, to determine the presence of cracks in the part by means of the analysis of deformations due to the wind forces to which it is subjected. The detections of the changes in the mechanical behavior of the blades will allow us to consider that they can be monitored in real time and determine if they present anomalies due to failures in their structure. In addition, it is intended as one of the purposes to determine the characteristics such as the shape of the crack which according to this can help the optimization and implementation of a maintenance plan.
Keywords: blades, structure, wind turbines, finite elements. structural health monitoring

INTRODUCTION

Currently, wind energy production has grown significantly worldwide. With the objective of reducing fossil fuels as a primary source of energy generation, the world is in the process of transitioning the energy matrix towards more environmentally friendly options. Specifically, wind energy production continues to grow and surpass historical production records as shown in Figure 1 [1].

In the Argentine Patagonia, there is a great opportunity to grow this matrix due to the presence of average high wind speeds [2]. However, the natural conditions of the area present challenges to improve the maintenance of the blades, which can degrade for various reasons, forcing the wind turbine to stop operating for unscheduled periods with the consequence of economic losses due to the inoperability of these systems. An important aspect when considering a project of this magnitude is the management of maintenance tasks. Large resources are deployed for this purpose in order to maximize the useful life and performance of the wind turbines. Wind turbine failures can occur for various reasons, one of them being blade breakage. The blades of a wind turbine can fail structurally due to different causes, which can be: high intensity external forces, fatigue, natural degradation of materials, erosion by soil or rain, bird or lightning strikes, and combinations of all these possibilities. Considering that maintenance costs represent approximately 25% of the cost of energy in the case of an offshore wind turbine [3], it can be concluded that the optimization of these tasks would imply an increase in economic gains and savings in production downtime.

In reference to maintenance techniques, there are two approaches: corrective and preventive. The latter is based on the ability to perform scheduled evaluations in order to verify the state of the system and determine the necessary actions to prevent degradation that compromises the operation of the wind turbine [4]. Also within this approach are real-time assessment techniques such as Structural Health Monitoring (SHM), which is a process that involves the observation of a system using periodic sampling of a sensor array. The subsequent statistical analysis of such information will serve to determine the state of the system [5]. Several studies were conducted on wind turbines and their components with SHM, providing valuable results [6]. However, few studies exist in reference to the detection of cracks through the simulation of extensometer sensors in blades, which represent more than 60% of the occurrences of failures [7].

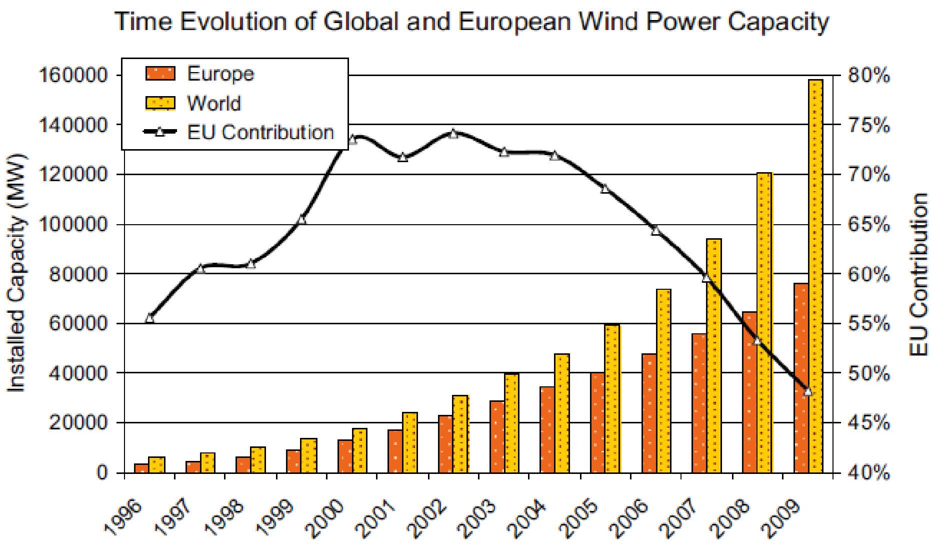

Figure 1: Historical evolution of wind power production in the world [1]

The objective of this work is to use a simplified blade model and sensors in order to detect anomalies such as cracks. In this way, it is expected that the effect of the presence of these defects, site and shape of the same, can be determined to then schedule a preventive maintenance and thus extend the life of wind turbines and continue with the operation of the same

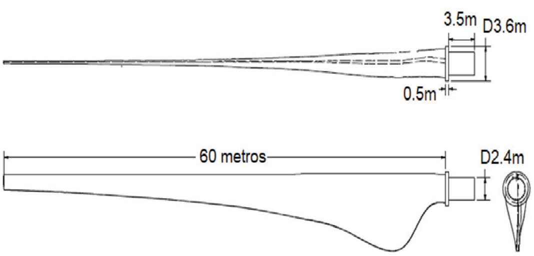

Figure 2: Overall external dimensions of the vane, units in m

MATERIALS AND METHODS

BLADE DESIGN

The blade used in this work is based on a model used in previous works [8]. It is considered in this first approach that the blade is made of a single material whose properties are presented in Table 1. General dimensions are presented in Figure 2.

Mechanical Property	Value	Unit
Young's modulus	133	*GPa*
Poisson coefficient	0,39	(dimensionless)
Shear modulus	53000	*MPa*
Density	1,430	g/cm^3
Elastic Limit	300	*MPa*
Tensile Strength	577	*MPa*

Table 1: Mechanical properties of simulated material

As studied in the previously mentioned work, it was possible to identify the regions of greatest blade deformation, except for the internal structure, whose function is to absorb the main wind loads. Only XX strain were considered to simplify this first failure analysis. These deformations are mainly located at the leading edge of the blade (Figure 3).

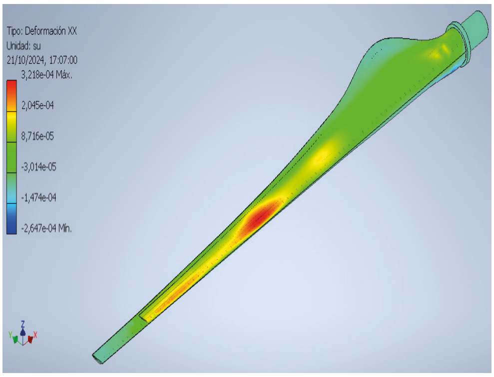

Figure 3: XX strain on the blade surface

CRACK DESIGN

A crack (Figure 4) with a random shape and size was generated on the blade, representing a discontinuity. This discontinuity was placed in the areas of greatest deformations of the blade so the greatest stresses can be concentrated there. The crack is approximately 50 mm at its widest part and 250 mm at its longest part, its maximum depth is approximately 25 mm

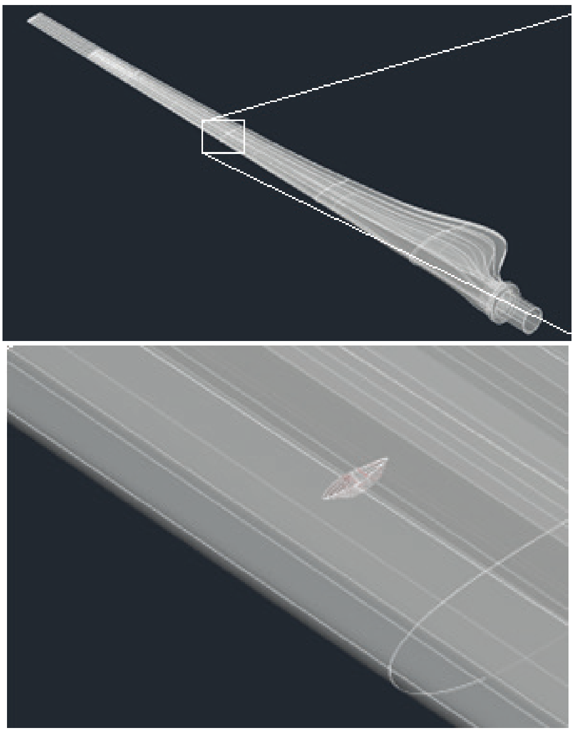

Figure 4: Crack positioning

SENSORS

The types of sensors selected are strain gauges (Figure 5). These sensors emit signals from their deformation, providing data on the tensions or compressions of the element under study. A feature to detail about the gauges is that data obtained from them were from the geometric center of the gauges.

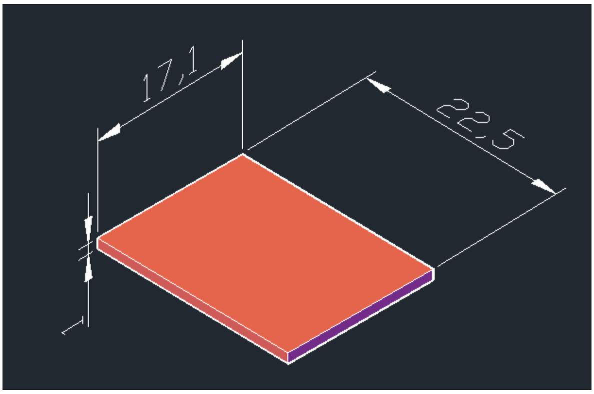

Figure 5: Representation of strain gage, units in mm

Regarding how the sensors were positioned, the length of the crack has been considered as a reference value. Then, sensors were installed in proportional distances to a fraction of that length. As can be seen in Figure 6, the first sensor was at a distance equals to 25% of the crack length, the second at 50% and so on. Furthermore, different set of sensors were considered around the crack depending on the distance, each set is represented by a different color. Furthermore, regarding the position four families (upper left and right, bottom left and right) were designated as can be seen in Figure 6 too.

After setting the location of the sensors, simulation was performed calculating the load on the blades, which, according to an estimate of the average wind in the Patagonian region, is determined to be 6.12 m/s.

As a result of this first simulation, one of the sensors set were selected, in this case the sixth position (means a distance of 150%), to position the gauges following this pattern along the entire length of the blade.

RESULTS AND ANALYSIS

EQUIVALENT STRAIN

Sensor families were studied measuring equivalent strain under average wind, and their behavior was as shown in Figure 7.

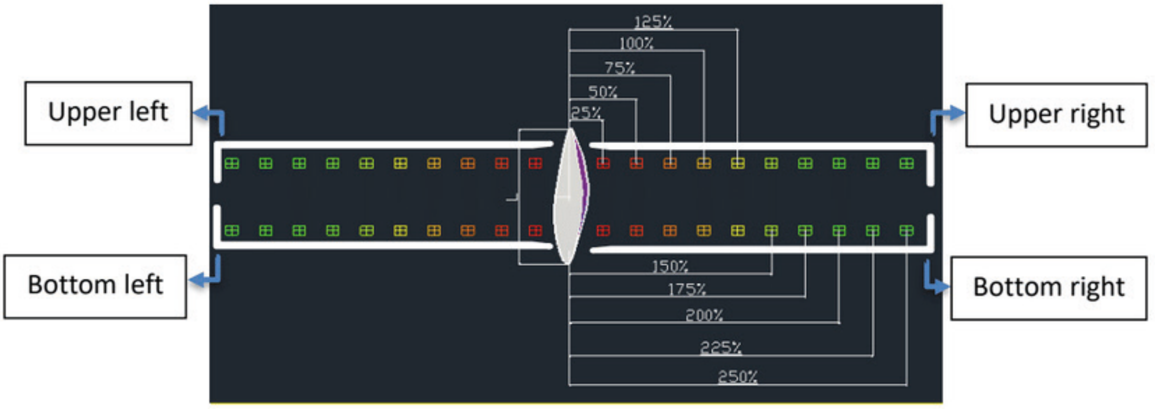

Figure 6: Schematic representation of strain gauges

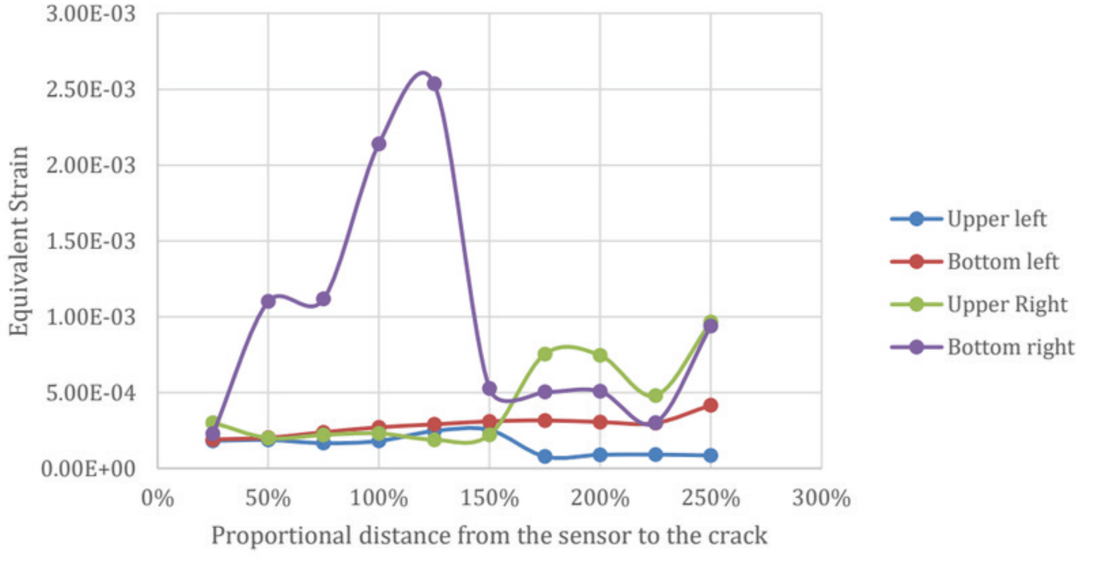

Figure 7: Equivalent deflection at average wind load

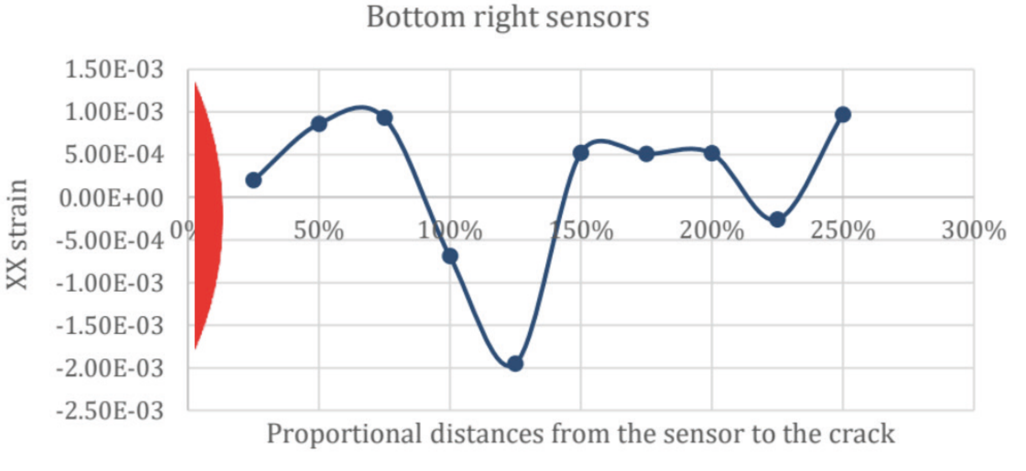

Figure 8: XX strainat average wind loading

It can be seen that the deformation behavior varies among the different families of sensors under the same wind condition, specially those from the bottom right family.

XX STRAIN

To simplify the analysis of the results, the bottom right family was selected, because it seems to be more sensitive, from the four families of sensors to see how behaves under XX strain measurement as it is shown in Figure 8

ALONG THE BLADE

As it was mentioned in 2.3, sensors positioned at a distance equivalent to 150% of the crack length were selected and used to mark two rows along the blade, taking as zero point the base of the blade. Between these two rows, their behavior pattern is compared within a blade, under average wind load, uncracked (Figure 9) and the same with cracking (Figure 10). For the following graphs, ten sensors were taken close to the crack zone, five on each side.

In this case it can be seen how strain behavior changes between the two simulations. The results of the two rows are then placed along the entire length of the blade to get a complete view of all the sensors (Figure 11). Each row has seventy-seven sensors, giving a total of one hundred and fifty-four sensors between the two rows.

At the beginning it can be seen that both rows have the same behavioral tendencies, with slight variations in their deformations. As one moves towards the zone of greater blade deformation, one can see how the sensors also show higher values, even though they maintain a certain pattern of equality. Towards the end of the part, a greater difference between the readings of the two rows is shown. At present we do not have certain explanations for these behaviors. We assume that it is due to the transition from the hollow part of the blade to an entirely solid zone.

With the crack presence, the analysis is started in the same way as with the previous graph. Initially, the behavior pattern has the same trend between the two rows. Before reaching the crack zone, erratic behavior can be seen between the two rows (Figure 12). Such irregularities can be seen on both sides of the crack, giving indications that structural anomalies may be detected by sensors. It ends up returning to a more even behavior towards the end.

THE SENSOR

Earlier we mentioned the deformation value obtained in the sensors. Our reasons for this are due to the fact that the represented sensor did not deform uniformly (Figure 13). This non-uniformity makes it difficult to get an accurate reading, so we chose to take the strain from the center of the sensor. The representation of the strain gauge showed that for this first approach to the study, the results obtained are appreciable.

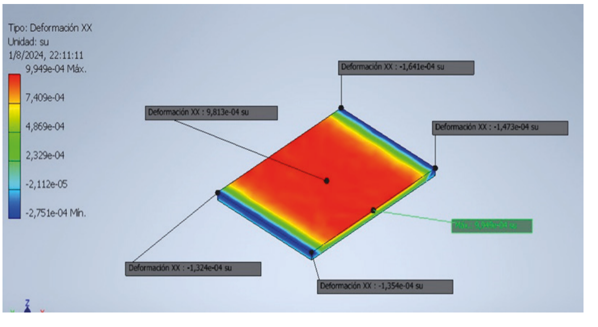

Figure 13: Strain XX of a strain gage

CONCLUSIONS

After the completion of the analysis of the data we obtained and during the process of conducting the tests, we have seen that they can be improved since we have not taken into account greater possibilities of factors such as the location of the sensors, their orientation, and deformations that can occur in it.

On the other hand, we obtained as a result that the cracks could be detected by a sensor; it was demonstrated that anomalies in the bla-

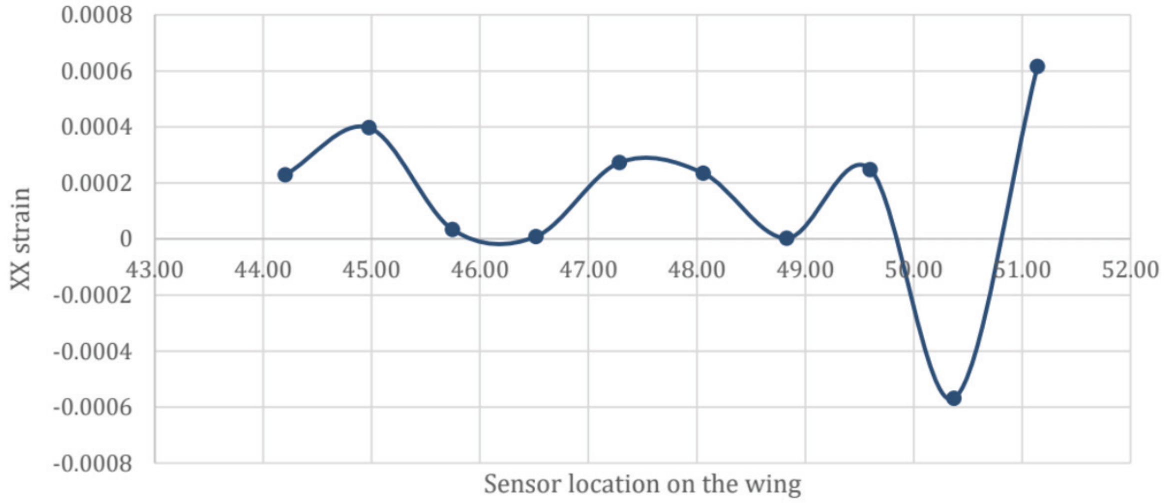

Figure 9: XX strain with uncracked blade.

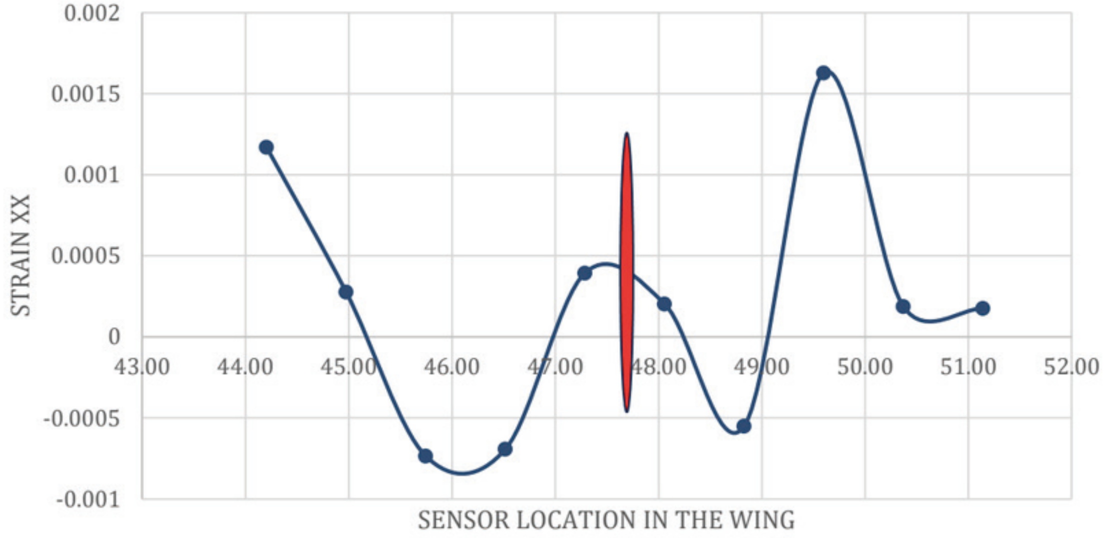

Figure 10: XX strain with cracked blade.

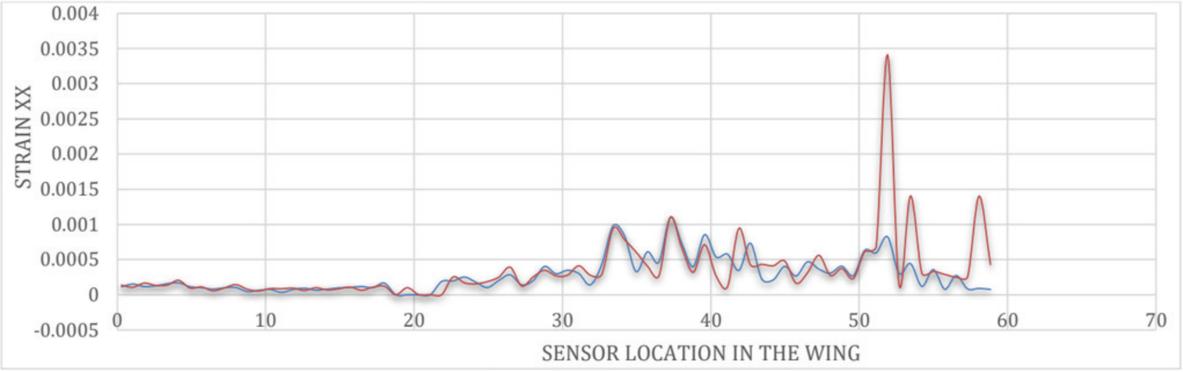

Figure 11: XX strain with uncracked blade

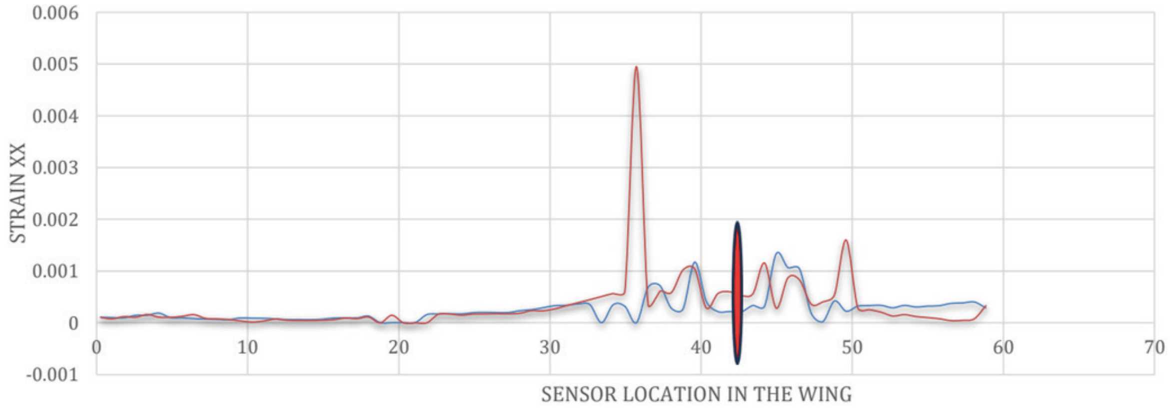

Figure 12: XX strain with cracked blade

de can be detected, even when the behavior pattern is not understood.

If we look at the graphs, we can see that the deformation variations can be recorded from a distance of 7 meters.

It is crucial to take into account certain improvements for enhance the study and simulation of the phenomena to be considered. It is necessary to be closer to the real model of a blade, as well as its materials. Simulate situations increasingly closer to reality in order to know the dynamic stresses to which the blade will be subjected. This leads to an improvement in the optimization of technological resources in order to obtain more and more accurate data.

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