LOW COST LVDT TRANSDUCER FOR PHYTOMONITORING

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Abstract: This article presents the construction of a low-cost LVDT sensor to be installed in several different parts of a plantation and, with this configuration, allow the agriculturalist and specialist the appropriate moment to invest in culture. The article includes the basic concepts LVDT sensors and phytomonitoring and the importance of water for plant development, together with its correlation with the variation of the stem. The justification here presented for the construction of an LVDT sensor of low cost is the possibility of using several sensors in the plantation and thus be able to seek spatial variation of water. The methodology shows the materials used and also the several stages of the construction (spool, windings, capsuling, nucleus and fixation), as also the trials performed to validate it. In the results, we draw attention to the equation of the constructed sensor, which could be used in a system for data acquisition and analysis (datalogger). As a conclusion, we see that the sensor as proposed in this study showed the construction characteristics of an LVDT with a linearity region and characteristic curve which are analysed according to the Pearson coefficient.

Keywords: phytomonitoring, LVDT sensors, precision agriculture.

1. INTRODUCTION

One of the areas studied by precision agriculture is the area of irrigation automation and control. Precision irrigation monitors the moisture characteristics of a culture and relates it to the soil attribute called drainage, so that the combination between soil and plant has a permeability that can impart maximum productivity to the system.

One of the indicators of the moisture state is the variation in the diameter of the stem, which can be measured through the use of LVDT (Linear Variable Differential Transformer) sensors. LVDT sensors can be characterised by a position transducer.

This work shows the methodology of producing a Dendrometer LVDT sensor of low cost, to monitor the hydraulic stress of the plants.

The results have shown a high degree of reliability, with a Pearson correlation coefficient of 0.9937 for the LVDT characteristic and also a correlation between tension and movement equal to 0.996 for the sensor linearity region, this being a good option for the agriculture market at a low cost.

2. PRECISION AGRICULTURE AND SENSING

Precision agriculture may represent management of the different characteristics of the soil, in order to control such variables to confirm their influence on the production and productivity of the cultivars. Within these attributes, we seek the control of plant growth through techniques of phytomonitoring.

The test that follows addresses the importance of phytomonitoring studies and, among these, the role of the LVDT sensor.

2.1 Importance of water for plants

One of the essential features of the formation, growth and agricultural production is water and the quantity thereof that is available in the soil and on the planet. Water acts as a solvent for the substances, also being a transport agent throughout the body of the plant. This takes place through the polar structure of the water molecule, which can dissolve ions and other small substances [1].

The main functions of water in the plant can be seen in the plant’s structure, growth, transport and metabolism, with the structure making up some 90% of the fresh weight of many part of the plant. The structure allows cohesion, penetrating in most of capillary veins and waterproofing the surface thereof, also controlling internal temperature and supplying the sustenance of the plant itself, giving a high degree of rigidity to the cell structure [2].

In the growth phase, water transports and processes the different substances that are necessary for the plant to grow. It shows itself as a favourable medium for the fertilisation of the movable gametes, also being one of the means of spreading of spores, fruit and seeds.

In plant metabolism, water helps with cytoplasmic movements, transporting oxygen and carbon dioxide that are necessary for respiration and photosynthesis. This is the medium where several biochemical reactions are processed, where the reagents need to be presented in ionic form and where water, apart from making this process easier, adjusts the rate at which these reactions occur.

We also see that a plant that is in a state of water shortage is susceptible to the attack of different pathogens as present in the medium. The production of grains or fruit from the plants is directly dependent on the amount of water available and also the relation between the functions that water carries out on the plant.

2.2 Variation of stem and water situation of plants

One of the parameters used to show the water status of the plant is the radial contraction of the stems and branches of the plants during one day, the amplitude thereof being related to the water condition of the plant [3].

For the authors mentioned, the stem has a reduced size during the day (due to the transpiration of plants) and increased size at night. Another fact confirmed by the authors was that a plant subjected to a state of water stress had a lower daily variation in stem size.

The variation in the diameter of the stem is very small, and the measurement instruments used shall be sensitive to subtle variations of length. One of the sensors that have these characteristics is the LVDT (Linear Variable Differential Transformer) sensor, which works with small variations [4,5].

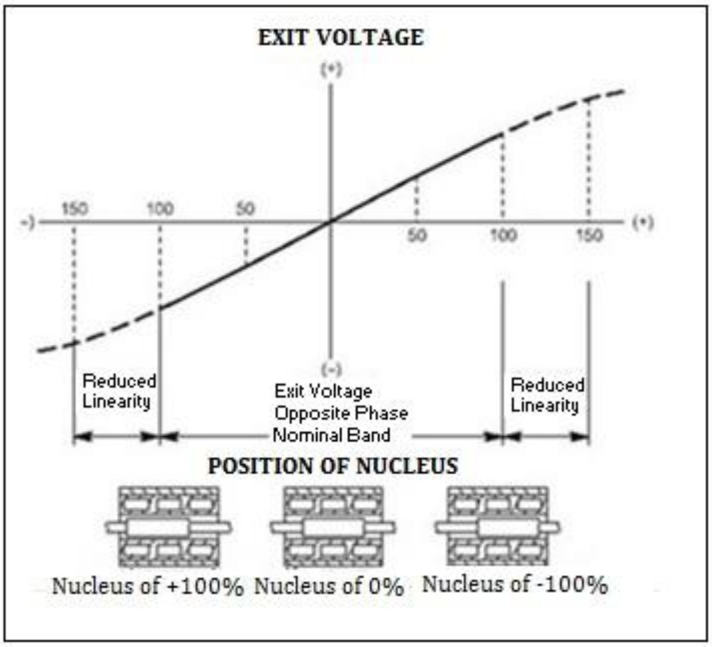
2.3 Operation of the LVDT Sensor

The LVDT sensor is an electromechanical sensor which produces an electrical signal of tension at exit, in proportion to the movement observed in its movable part (magnetic nucleus). Regarding the physical constitution thereof, the LVDT has three concentric and coaxial coils, wrapped by a capsule system, and the central spool is known as the magnetic emitting circuit, which is supplied by a high-frequency alternating current. Around the emptying spool, the secondary enwrapments are allocated [6].

The movable part of the sensor makes up the nucleus, which is made of a material of high magnetic permeability (which could be steel with nickel or chrome). When the nucleus moves from the central position, where it gives an exit voltage of zero, the intensity of voltage in the secondary positions in a certain direction of the movement of the nucleus increases, while the movement in the opposite direction makes this voltage decline. Graph 1 as shown is an example of the characteristics of the work of the transducer according to the position of the Nucleus [7].

As we can see in Graph 1, the sensor has a so-called reliable linear Nominal Band ranging from -100% to 100% of the position of the nucleus, which refers to the harnessing area of greater linearity for the exit signal for electric voltage (V) [7].

This means that the sensor, when used, shall contain a measurement which is a bit bigger than that requested, as one intrinsic characteristic of this sensor is a loss of linearity at the ends of the sensor.



Graph 1. A characteristic model of a response to an LVTD sensor [7]

With this variation of voltage according to the position of the nucleus, one can detect the variation of the diameter on making a non-intrusive coupling of the nucleus of the sensor on the surface of the stem.

3. MATERIALS AND METHODS

The development of the sensor took place on the Medianeira Campus of the Federal Technological University of Paraná (UTFPR), in the laboratories attached to the course of Electromechanical Technology.

The project was started by drawing the shapes of the sensor, so that this could bear the interferences of the elements and be attached to the plant without causing any kind of damage to the plant or to the acquisition of the data concerned.

Based on this fact, there was the development of the design of the "dendrometer" sensor with the use of an LVDT sensor that can be adapted to several different plants.

3.1. Material Used

The material chosen for the sensor structure was Nylon Technyl, which is a light material, highly resistant to several climate and weather conditions such as moisture, ultraviolet radiation and corrosion, among others, therefore being an excellent solution to implement the measures, as these shall not affect the measurement made, resulting in satisfactory and reliable readings. To give shape to the support for the coils and other components, used was made of an engineering tool called a transversal lathe. AWG32 wire with 600 coils in each partition of the general spool was used to construct the magnetic circuit of the sensor.

The nucleus of the sensor was constructed using a part of Nickel Steel Alloy and also a contact stem connected to a light-force spring.

3.2 Methodology for sensor construction

3.2.1. Reel

The drawing and the size of the structure supporting the spools is shown to follow, in Figure 1. After passing through the milling process, the next step was a continuation of the wrapping of the spools, with each one having 600 coils, allowing a high sensitivity to variations to the position of the nucleus.

Sensitivity is assessed by the accuracy of the measurement system, where measurement errors should be considered, and where the presence of the linearity characteristic of LVDT sensors is also considered, as also the effects of hysteresis.

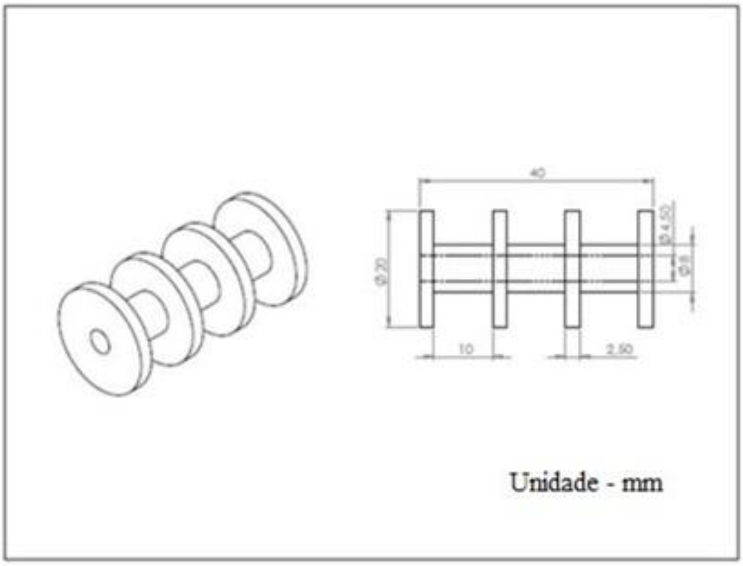


Figure 1: Illustration of the Spool Element

Figure 1 shows the spool divided into three sections, around which the solenoid coils are wrapped.

3.2.2. Capsuling

The capsuling of the sensor, as according to CRESCINI (1995) consists of the protection of the magnetic circuit against mechanical shocks or against the elements. Figure 2 shows the capsuling system used in this study.

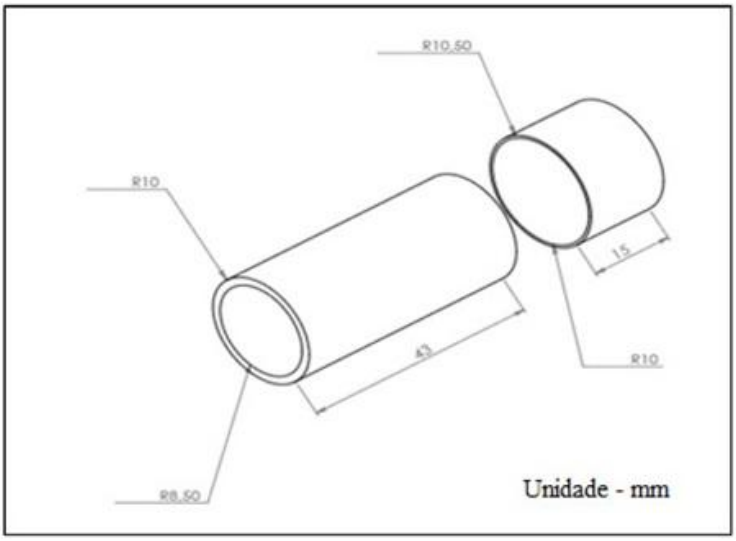


Figure 2. Capsuling and resin insertion element for the protection of connections.

With the intention of making the device lighter and more resistant, the capsuling was developed using Technuyl nylon material which provides relevant physical characteristics, as the polymer used is of low density and highly resistant to the elements. These requirements are essential when choosing the material due to the application of the sensor, that requires a system with the least possible interference in cultural development.

In Figure 2, we also highlight the format and the measurements of the capsule developed for this application, in the laboratory.

3.2.3. Assembly of the Spools

An LVDT sensor with high capacity and precision shall have at least 1,000 coils per spool, thus producing larger sensors. However, the device that has been developed in this project has sought small size, light weight and low cost; for this purpose, the size of the reel has been reduced and the material has been chosen because of its lightness, and then, atop them, the spools of the primary and secondary locations have been wound. For this purpose, AWG32 wire was used with 600 coils in each of the reel's partitions. Figure 3 shows the reel with its magnetic circuits [8].

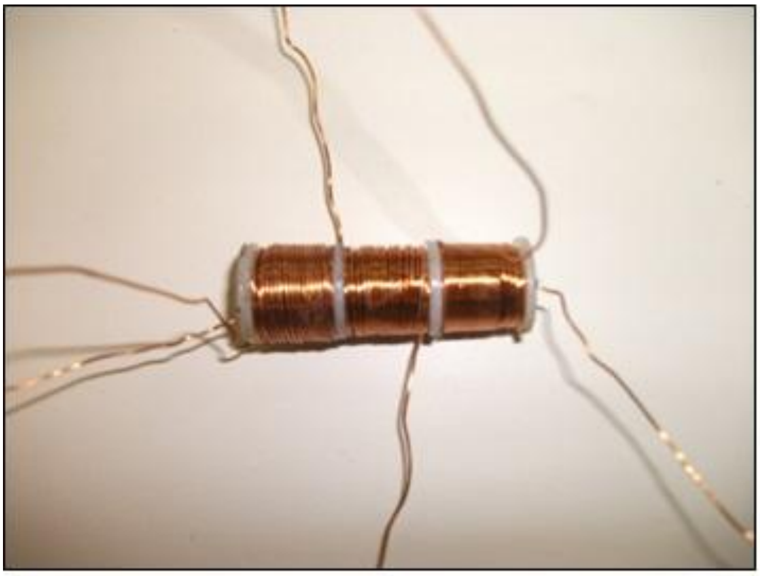


Figure 3. An LVDT reel after winding the magnetic circuits.

3.2.4. The Nucleus of the Sensor

This element is responsible for the variation of the exit signal, as it causes a dislocation of the concentration of magnetic flow according to movement, which either intensifies or reduces the signal according to its position. Its composition for this work was a Nickel Steel Alloy with Chromium, and attached to this element a contact rod was inserted, attached in turn to a light-force spring. In this way, one end of the spring is attached to the reel (and its structure) while the other end of the spring is tied up to the tip of the rod.

In this way, the rod is pressed by the spring, against the stem of the plant. As the spring has a low force. this pressure shall not damage the stem and shall also ensure the necessary contact for the sensor to operate correctly.

3.2.5. Method of Attachment of the Sensor

The LVDT sensor constructed for phytomonitoring and its fixation system have been developed to serve the coupling of the sensor to plants. Thus, we have seen the development of the fixation according to Figure 4, which consists of two parts: one upper flat board and a lower angular board. These boards are used to attach the LVDT and also to couple the complex to the plant [9].

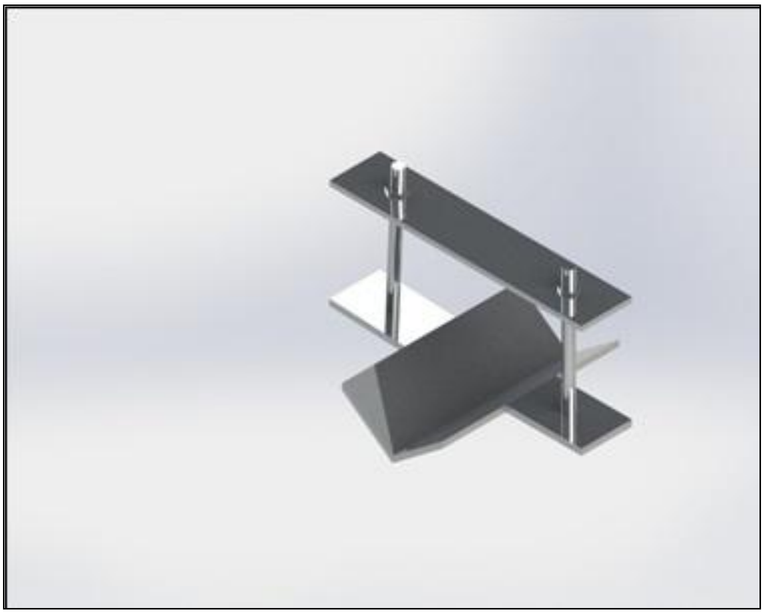


Figure 4. Fixation model used

It can be seen in Figure 4 that the angular board of the LVDT was developed so it could be coupled to the species (plant) with good fixation, as the element developed presents itself as a triangle. The installation of the sensor has a greater area of contact compared with the fixation with two flat boards.

Figure 5, presented below, shows the fixation situations mentioned here. There are other advantages, mentioned by the author, in the contact between the sensor as formed, at right angles to the stem, which avoids strangulation and also increases stability.

The device for fixation with an angular base comes up as the best solution for this application, as it allows the existence of a greater area of contact between the metallic structure and the stem of the plant, ensuring stability of the initial position, and also the lack of strong pressure on the plant, thus causing no damage, apart from ensuring that the contact stem is always at right angles to the stem, eliminating mistakes and increasing the reliability of readings.

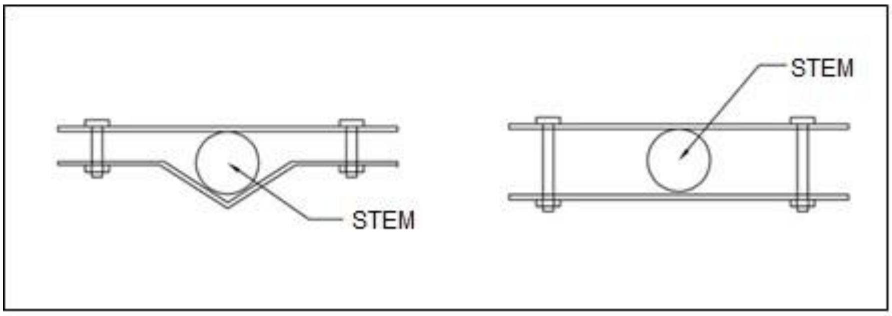


Figure 5. Comparison between fixation systems

3.2.6. Calibration trials and checking the linearity of the sensor

Once the sensor was constructed, trials were then performed to check the linearity and also calibration. To calibrate the sensor, there was the use of a circuit for feeding, adjustment and acquisition of voltage data, developed for this specific sensor. The scheme for checking is shown in Figure 6.

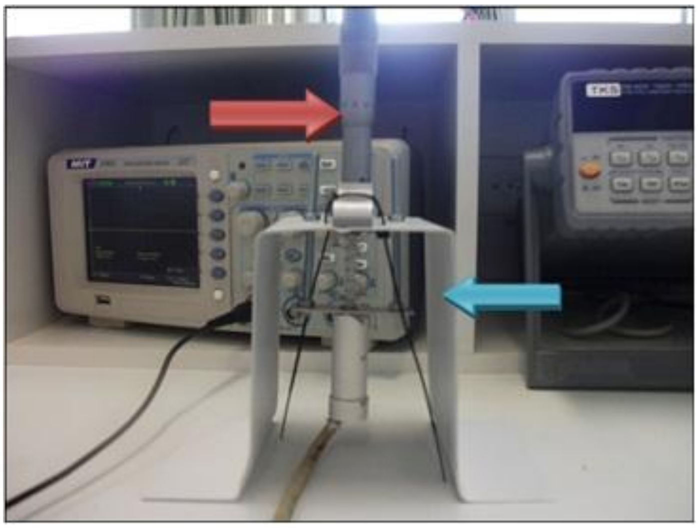


Figure 6. Structure prepared for checking the sensor

The structure for calibration is a metallic static structure used to attach the sensor shown by the blue arrow, where the movement of its nucleus is made with the high-precision instrument to measure dislocation; in the case at hand, a depth micrometer was used, here shown by the red arrow.

A total of 4 repetitions was performed (these being known as 1, 2, 3 and 4) with variation of the movement of the sensor and analysis of electrical voltage. With this data, there was the construction of a graph of variables, showing electrical voltage against movement.

The curves arising from the 4 tests mentioned above were then superimposed to assess the behaviour of hysteresis.

The trial was made with known variations of 0.5 mm, collecting the voltage data at the exit, using the acquisition system.

4. RESULTS AND DISCUSSIONS

The sensor constructed was installed on a test bench, and is shown in Figure 7 which follows.

Figure 7: LVDT Sensor constructed in the laboratory

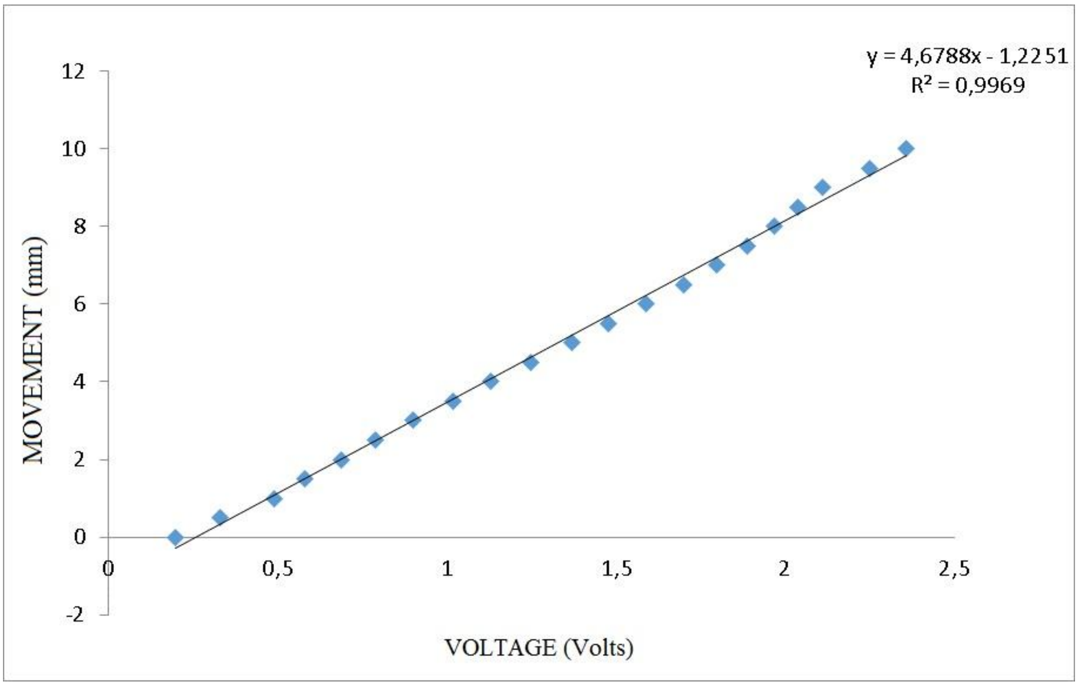
Through the applied methodology, the tests were carried out on the sensor for obtaining the calibration curve.

The structure conceived by the researchers for laboratory trials is shown in Figure 8, which follows:

Figure 8. Trial structure as conceived for the calibration process.

The structure is simple and functional, consisting of a digital oscilloscope, a dendometer and a multitest measuring equipment selected to carry out the electrical voltage function.

Graph 2 shows one of the trials to measure the variation of the electrical voltage related to the movement of the sensor. In the graph, we see a correlation factor of 0.9937 for the given equation of linear regression.

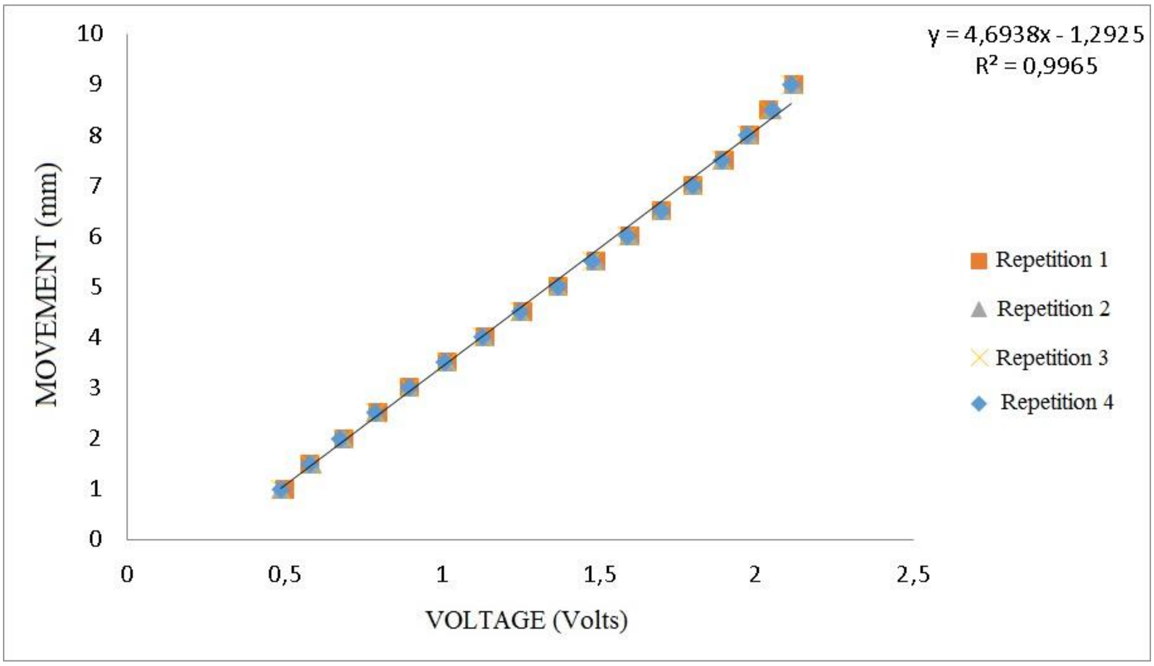


Graph 2. Checking the linearity of the LVDT sensor developed in the laboratory

Graph 2 shows a linear region between 1 mm and 9 mm, also showing a camber at the edges. This loss of linearity of exit voltage at the edges shows that the sensor has shown the characteristics of a LVDT.

Once related to a distance between 1 mm and 9 mm (linear) in four different analyses conducted on the sensor, as according to the methodology, there was the construction of Graph 3 which shows the four tests superimposed. One of the aims of this trial is to assess the presence of a behaviour pattern amounting to hysteresis, which could lead to serious errors in measurement.

Graph 3 has shown little or no presence of hysteresis in the sensor through residual magnetic charge in the nucleus.



Graph 3. Checking for Hysteresis in the LVDT sensor developed in the laboratory

After the four repetitions, we obtained the equation of the sensor's line of best fit, which produces the total movement which occurred as from the variation of voltage. Equation 1 produced a Pearson correlation coefficient of 0.966 which shows a highly reliable correlation between voltage and movement. Equation 1 has been proved as follows:

$$Y(mm) = 4.6938 * U - 1.2925 \qquad [1]$$

where Y represents the movement of the sensor (in millimetres, mm) and U is the electrical voltage in microvolts (μV).

5. CONCLUSIONS AND RECOMMENDATIONS

The LVDT sensor, as shown in this study, showed a high degree of reliability with a Pearson correlation coefficient of 0.9937 for LVDT characteristics.

The LVDT sensor as here presented here also shows a high degree of reliability with a correlation between voltage and movement equal to 0.996 for a linearity region of the sensor.

The linearity region has been proven as being that for movement between 1 mm and 9 mm. The curves show camber at the ends, as according to the building characteristics of an LVDT sensor.

This sensor appears as a good option for the agricultural market for measuring plants whose stems show a variation in diameter between 0.5 mm and 4.5 mm, without adjustments, due to the construction characteristics of measurement of expansion (positive movement) or contraction (negative movement). If the plant exceeds the starting parameterisation of the sensor, showing growth of more than 4.5 mm, then it is possible to reposition the sensor and prepare it for new measurements, based on the data obtained the last time the plant stem was measured.

This sensor has low construction cost, and this makes it feasible to use several sensors at the same time within the same plantation, helping the agricultural worker (or specialist) in making decisions based on a higher number of information, when the spatial distribution of the feature studied interferes with the decision to be taken.

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