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Correlation between tensile force in conductors and stress loading of tensile towers

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SUMMARY

Determining the sag of the conductor and the tensile forces in the conductors represent an important parameter for ensuring safe clearances as well as the boundary condition for maximum utilization of the high-voltage transmission line respect to thermal loading. Based on continuous measurements of strain in all legs of the transmission line tensile tower and measurements of tensile forces of the conductor with two temperature and angle on-line monitoring devices, a study was performed to determine the correlation between mean tensile forces in all conductors on both sides of the tensile tower. As part of the study, we developed a model for monitoring the tensile forces in the conductor based on measurements of deformations in the supporting profiles of the transmission line tower. Boundary conditions are obtained on the basis of experimental measurements of deformations on the foot profiles L100x100x10 of tower No. 13 as well as measurements of the geometry of the catenary of all three conductors at the span between the towers No. 12 and No. 14 on the Cerkno - Idrija route on the 110 kV transmission line. The theoretical basis of the study is derived from the mathematical equation of the catenary, and then the design of an algorithm to calculate the sag of the conductor.

The results of the study showed that by monitoring the change in strain in the support columns above the foundation, it is possible to detect changes in the forces in the conductor, which may also be due to changes in the sag, either due to mechanical factors per conductor (e.g., extra weight) or temperature changes. The model for the calculation of the change in horizontal force depending on the measured deformations in the towers legs is made a taking into account the strength of the leg profiles. The geometrical characteristics of the L profiles to which the strain gauges were attached were used for the calculation. To calculate the geometry and forces of the catenary, the conductor is divided into left and right sides, from the point of attachment with the insulator to the lowest point corresponding to the maximum point of sag. Measured parameters are used for each side of the conductor and independent equilibrium equations are set for the 2D free-hanging catenary model. The strength calculation of the bending moment and bending elastic deformations in the support profiles of the transmission line tower due to the change of the horizontal force or vertical loads on the conductor. The model was verified through a wider temperature interval of conductor operation. Based on these measurements, the boundary conditions are determined as the first step in the mentioned research for estimating the suspension / temperature / tensile stress in the power line ropes on the basis of diagnostics of the mechanical properties of the relief column. This is an indirect way in which the deformations of the column are actually measured, and the conductor tensile load are determined on the basis of these.

KEYWORDS

Transmission overhead lines monitoring-Strain monitoring-Tensile force-Sag-Weather station

1. INTRODUCTION

The aim of this work is presentation of a system for continuous measurement of the load change in the legs of the towers in correlation with the sag for both side of tower and tensile load of the conductors. Based on the analysis of the project results ELES, Slovenian TSO company, we are establishing system on tower No 13 at OHL 110 kV Cerkno - Idrija at Bevkov vrh for on-line monitoring of conductors and tower's leg. Established system based on the measurements made, will show what kind of loads the tower exposed to over a two-year period.

As well as whether conditions were monitoring, it can be possible to find the influence of temperature and season's changes on the tower and their influence on stress on the tower legs [1]. Temperature of conducter has influence on capacity of overhead transmission line [2-4].

The purpose of these measurements is to evaluate the stress response in the legs of the tower to the mechanical loads of conductors with respect to the temperature condition of the conductors. Since the Bevkov vrh site has been exposed to ice several times in the last two decades and the tower collapse in 2014. Pilot project was started already in year 2013 [5]. It has been proved that a tensile force in conductor has already influence on tower loading [6] and integrity of the towers [7]. The purpose of the project is also to determine the stress state in the tower in the case of icing on the tower and as well as on the power lines.

Within the given project, we developed a system for monitoring deformations in the tower legs and the tower cantilever at the stage where two temperature and angle on-line monitoring devices are also mounted. Synchronization is performed by submitting one-month measurements to the remote server FME (Faculty of Mechanical Engineering) from the temperature and angle on-line monitoring devices, which controls the existing devices and local weather station), and inserts the data from so call the "DynaStat" system into one common excel file for the same month so call Master file.

2. ESTABLISHING THE MEASURING SYSTEM

By measuring the residual stresses in the legs of the tower No 13 at 110 kV of the OHL Cerkno - Idrija, the actual state (direction and height) of the residual stresses at the place of adhesion of the strain gauges to monitor deformations in the legs of the tower is determined. When determining the initial stress state at the point of placement of the dipstick, the actual stress state in the legs of the tower is determined by adding continuously measured deformations, which is a prerequisite for assessing the degree of utilization of the material of the tower and thus its useful life.

Within the scope of the project, the measurement is made in the legs of the tensioning tower No 13, which is made of L profiles 100 x 100 x 10 mm from material S270.

Fig. 1 shows an example of measuring residual stresses at the location of the measuring pad with the PULSTEC μ-360. The legs of the tower are marked around the world, which most closely matches the orientation of the tower legs.

The results of the residual stress measurements are given in Table 1. Based on the residual stress measurements made, it is noticeable that the stresses at the angular tower differ on individual legs as well as on individual parts of the angular profile [8]. Namely, there is a pronounced tensile stress on the 5. and 6. labelled tower, which is relatively high (+190 MPa). Considering the fact that the duration of the x-ray exposure lasts from 2 to 5 minutes, it is considered that the measured average values of the stresses in the legs of the tower.

Strain gauges will measure stresses around these average averages, which are also due to changes in the tensile forces in the conductors.

On the same place where residual stresses have been measured the strain gauges are adhesively bonded and protected as is shown in Fig. 2.

The tower is equipped with acidometers for vibrations measurement. The two accelerometers are attached to the frame of tower.

Fig. 3 shows a tower No 13 with a system for stress and vibration measurements so called "DynaStat". Stress was measured by pair of strain gauges, one in longitudinal and second in transversal direction. As shown in Fig. 3, several independent measuring systems are installed on the No 13, which measure different parameters on the tower and on conductors by temperature and angle on-line monitoring system as well as the weather conditions in the tower neighbourhood. The variety of parameters in the same weather conditions and at the same time allows the establishment of a system for evaluating the interaction of measured quantities with each other. Accordingly, it is advisable to establish a database of measured data.

Fig. 1. Measurement of residual stresses on the SW leg at the 6th measuring point

Fig. 2. Adhesive strain gauges at the location of the measured residual stresses on the L profile

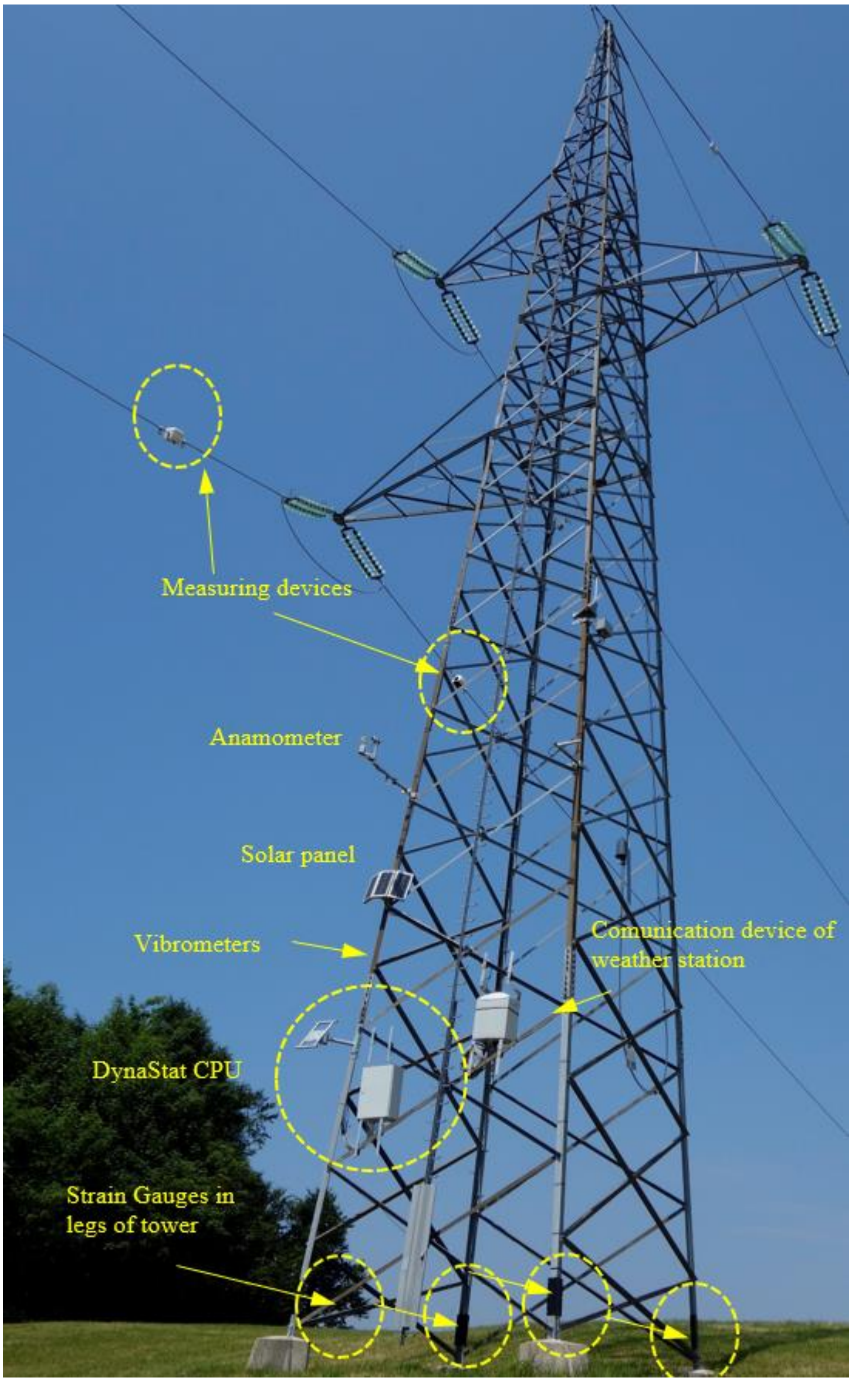

Fig. 3. Installation of a measuring system with a unit for capturing and processing signals and sending data with its own power supply and solar panel

Table 1: Measured average values of residual stresses at individual measuring points

	Legs of tower No 13							
Mesuring place	1.	2.	3.	4.	5.	6.	7.	8.
Measured stress, MPa	+22	-217	+41	+98	**+190**	+29	-150	-381

Above plot shows vibration change, middle plot shows temperature chance in legs of conductor and below plots shows stress change during September 2019.
It is possible to see some periodical repeating of plot. It is possible to export file and save as excel database.

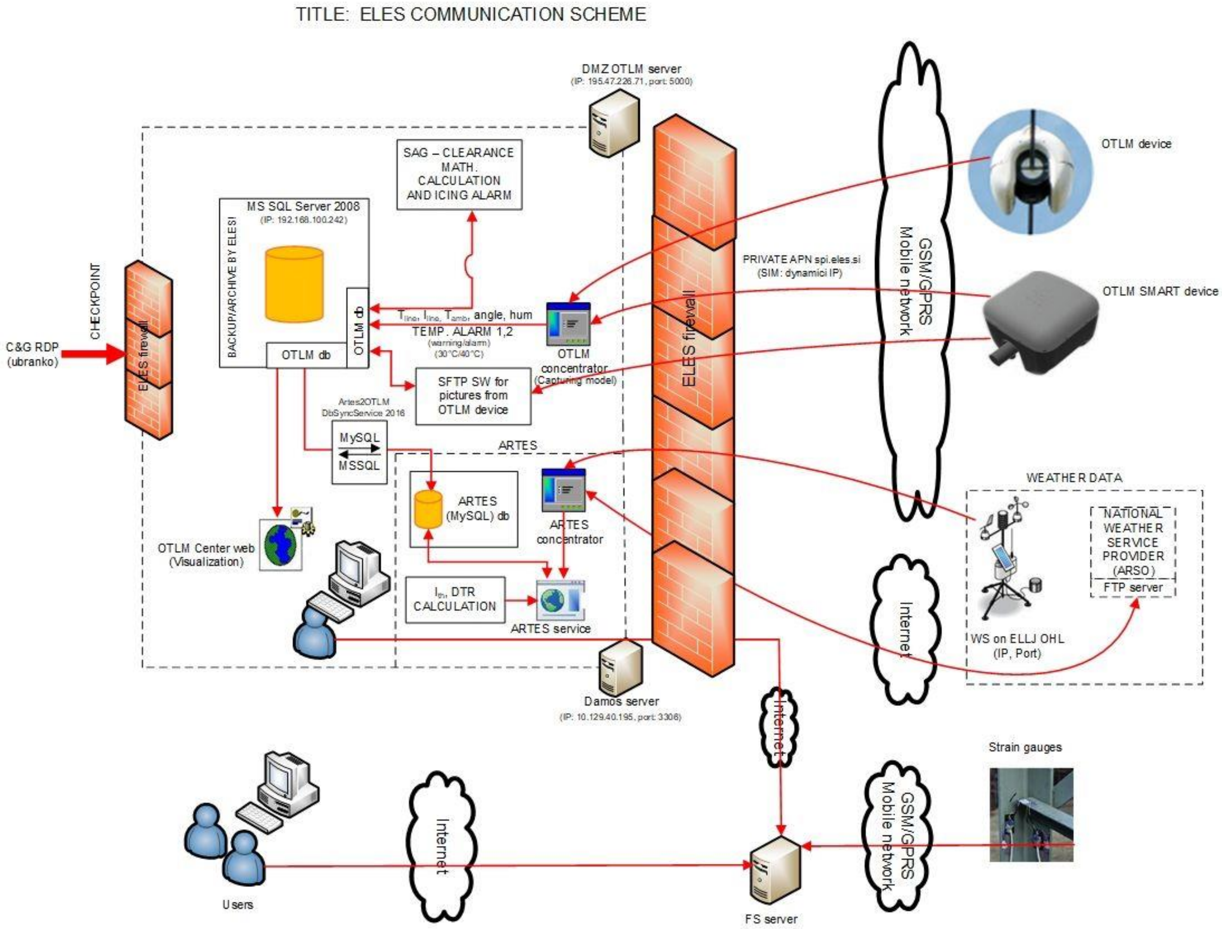

Fig. 4. Communication scheme of the entire measurement system on the No 13 tower (in coordination with the temperature and angle on-line monitoring Center)

3. CATENARY MEASUREMENT

The purpose of measurements of catenaries between towers No 14-13-12 of OHL110 kV Idrija - Cerkno is to determine the actual condition of conductor lengths and height of tension forces in conductors between towers No 14-13-12 [9]. Based on measured temperatures, sag of conductor calibrated with temperature measurements and the angle with the temperature and angle on-line monitoring smart system provides the necessary safety heights and monitoring the behaviour of the conductors at different temperatures and weather conditions. The conductors are ACSR 240/40 with a complete conductor diameter of 21.9 mm. Appendix 1 shows photographs of chain measurements. A graphical representation of the conductor chain at the 1st measurement on both sides of the span is shown in Fig. 5 for both the No 12-13 span and the No 13-14 span.

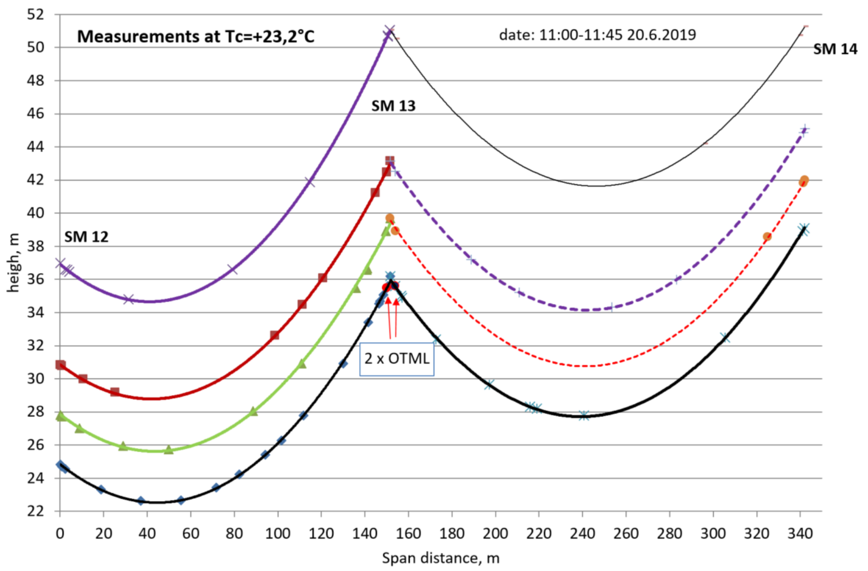

Fig. 5. Results of catenary measurements of all conductors including for both side of tower No 13

The relevant span length is the length between the two grips of the insulator and the conductor, which results in smaller span distances being measure than indicated in the mounting tables, where the distance between the two column centres is measured. Two measurements of catenaries are performed first at - 2.3°C (Nov. 18th 2018) and second at + 26.2°C (June 20th 2019). Results of measurements are listing at both temperature in the Table 2 and Table 3 for span distance No 12-13 and No 13-14, respectively.

Table 2: Results of both measurements and calculation of span distance No.12-13 for device

SM 12-13		measured					Calculated by model			
					angle					
	T_c, °C	f_{max}, m	span, m	x_{device} m	Leica, °	device °	model, °	f_{max}, m	H_1, kN	H_2, kN
1	-2,4	6,364	152,32	2,51	13,48	12,7	13,48	6,32	4,48	5,13
2	23,6	6,719	151,85	1,88	14,06	10,82	13,98	6,71	4,2	4,56
	26°	0,355	-0,47	-0,63	0,58	-1,88	0,5	0,39	-0,28	-0,57

Table 3: Results of both measurements and calculation of span distance No. 13-14 for temperature and angle on-line monitoring device

SM 13-14		measured					Calculated by model			
					angle					
	T_c, °C	f_{max}, m	span, m	x_{device} m	Leica, °	device °	model, °	f_{max}, m	H_1, kN	H_2, kN
1	-2,3	9,461	190,07	1,94	10,21	13,12	10,21	9,46	4,73	4,68
2	26,2	9,749	190,04	1,92	10,56	13,47	10,56	9,75	4,54	4,51
	28,5	0,288	-0,03	-0,02	0,35	0,35	0,35	0,29	-0,19	- 0,17

Fig. 6 shows a panel with results of measurements with DynaStat system. Above plot shows vibration change, middle plot shows temperature chance in legs of conductor and below plots show stress change during September 2019. It is possible to see some periodical repeating of plot. Results of measurement were exported in ASCII file and save as excel database.

4. ANALYSIS OF RESULTS

At the CIGRE Symposium in Ljubljana 2021, the authors presented the results of measuring deformations in the tower legs and the change in vibrations depending on the temperature of the tower and the conductor. In this paper, we present the correlation of tensile forces in the conductor and deformations in the legs of the tower, which represents a direct cause-and-effect relationship between the mechanical load of the tower and the conductor [10].

The measured data is stored in a buffer of the DynaStat measuring system on the No 13 tower. From the temporary memory of the system, they are transmitted via the communication platform to the FME server in the form of an excel file (* .csv) and then to a personal computer for further analysis.

The record from both temperature and angle on-line monitoring devices also in the form of excel (* .csv or * .xlsx) file is transferred to a personal computer, where it is synchronized with the file from the DynaStat system in a sequential order and thus is formed in a line.

The DynaStat measuring system was established to measure the input parameters for mechanical analysis (stresses, temperatures and vibrations) of the tension tower (No 13). We measured the information in time with the temperature and angle on-line monitoring measuring system on the conductor on both sides of the tower.

The established measuring system and computer programs for data capture and processing and programs on the communication platform enable quality analysis and recording of the measuring quantities used to build the database.

Depending on the expert analysis of the collected "master files", the dependencies between individual measured parameters of the hybrid measurement system (temperature and angle on-line monitoring + DynaStat), as well as the dependence and change of the measured parameters on the time and weather conditions at the Bevkov vrh.

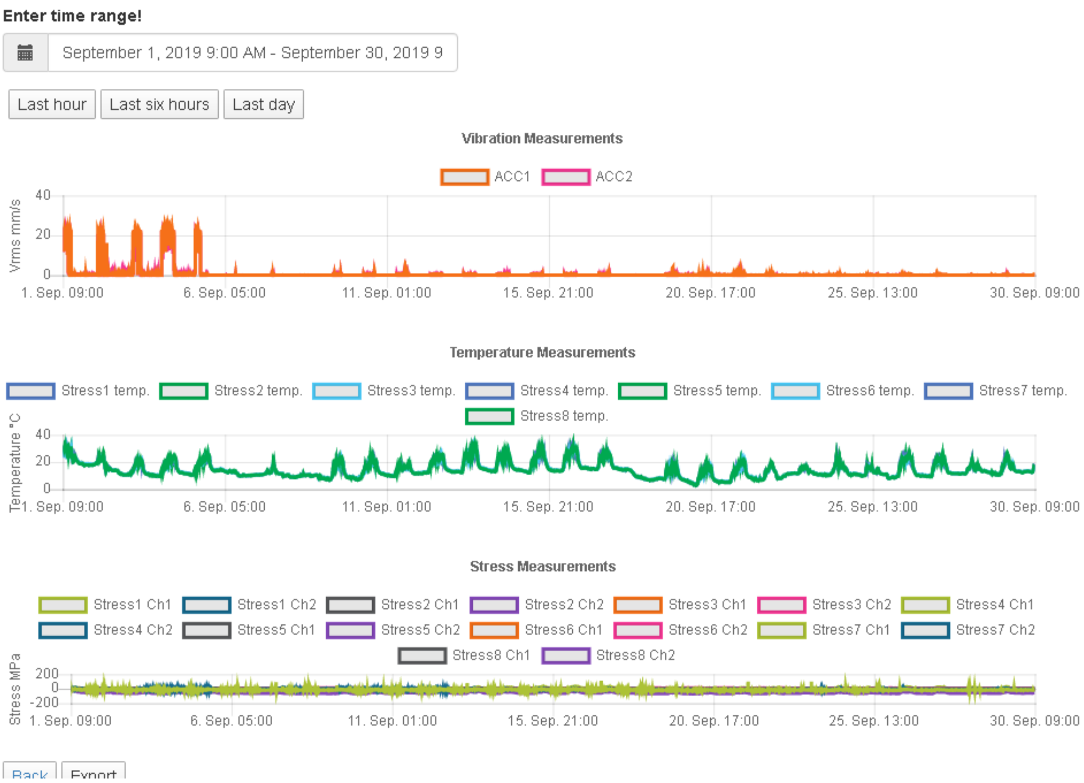

Fig. 6. Panel with results of measurements by DynaStat systems

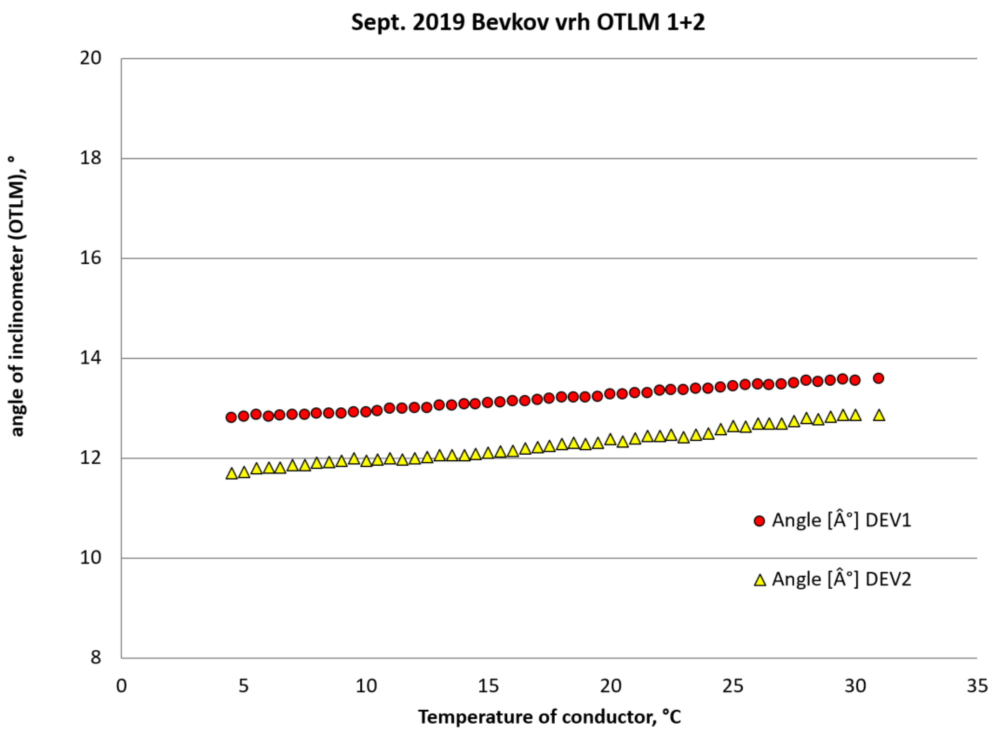

Fig. 7. Temperature of conductor 1 vs. angle of both inclinometers

Fig. 7 shows Temperature of conductor (span No 12-13) vs. temperature of conductor (span No 13-14) and measured angle of inclinometers in temperature and angle on-line monitoring 1 and 2 devices.

Fig. 8 shows results of catenaries measurements shows also almost linear increasing of sag vs. temperature of conductor.

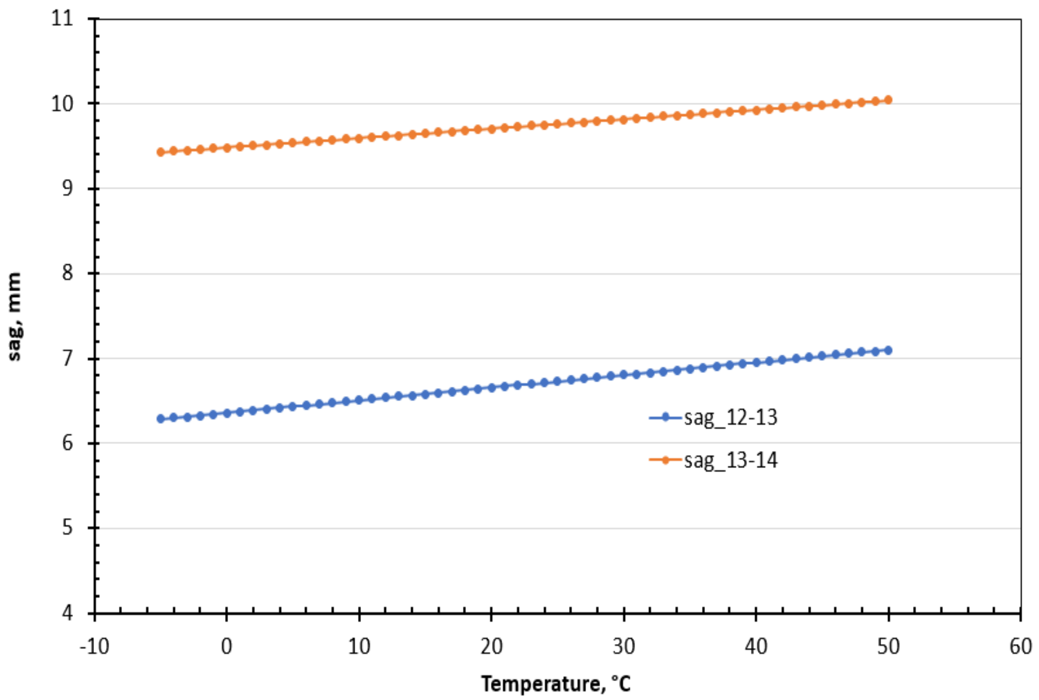

Fig. 8. Linear increasing of sag vs. temperature of conductor

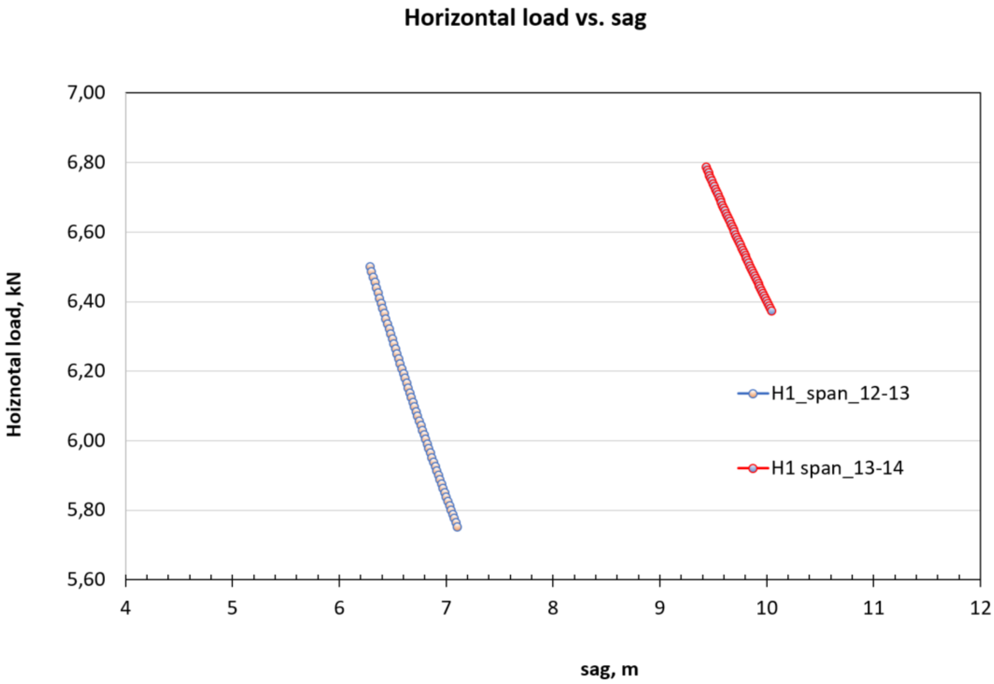

Fig. 9. Horizontal load in both conductor from both side of tower No 13

Results of tensile load measurements vs. sag shows decreasing of tensile load with increasing of sag, as is shown in Fig. 9. It is also obvious that span No. 12-13 has lower tensile load than span between towers No. 13-14.

Fig. 10 shows results of as-measured stress measurements in leg S-W leg (No. 3-1) vs. horizontal tensile load of both span distances. One can recognized that scatter of results are significant, but also correlation is obvious and stresses in the legs are decreasing with increasing of both tensile horizontal load.

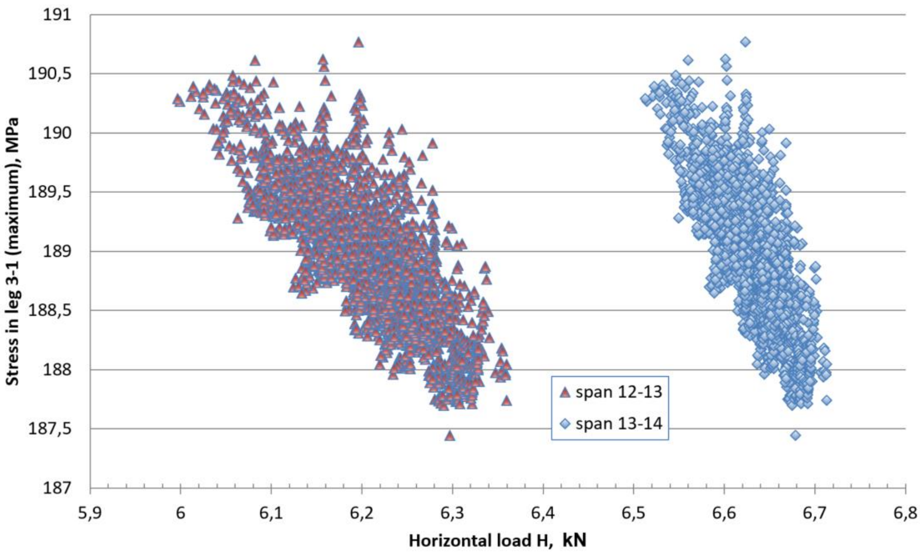

Fig. 10. Measurements of stress in leg S-W leg (No. 3-1) vs. horizontal tensile load

Therefore, we can apply statistical treatment of results and try to find correlation between temperatures of ambient and stresses in the legs, as is shown in Fig. 11. Respect to measuring of residual stresses we can see that each strain gauge has own middle values where stress oscillate. More or less, the correlation between stresses and temperature is linear.

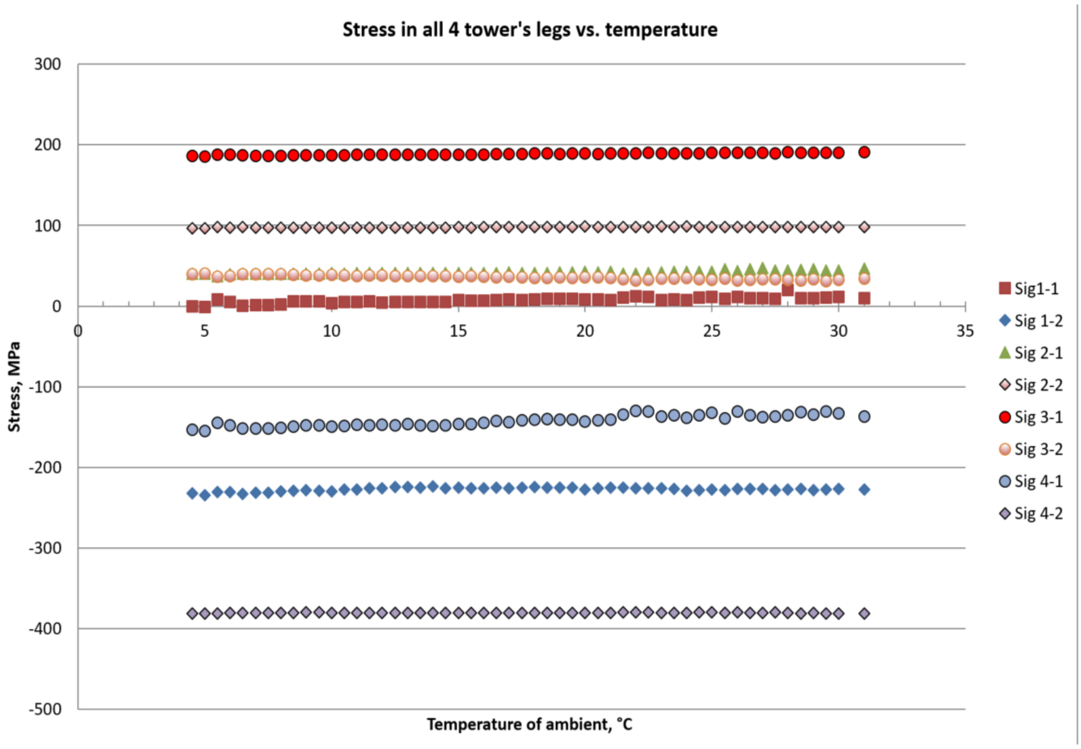

Fig. 11. Results of average measured stress vs. temperature at all 8 measured points

Fig. 12 shows also almost linear correlation between horizontal load and measured stresses in all 8 positions. It is obvious that the horizontal loads shifted for each span distance, also.

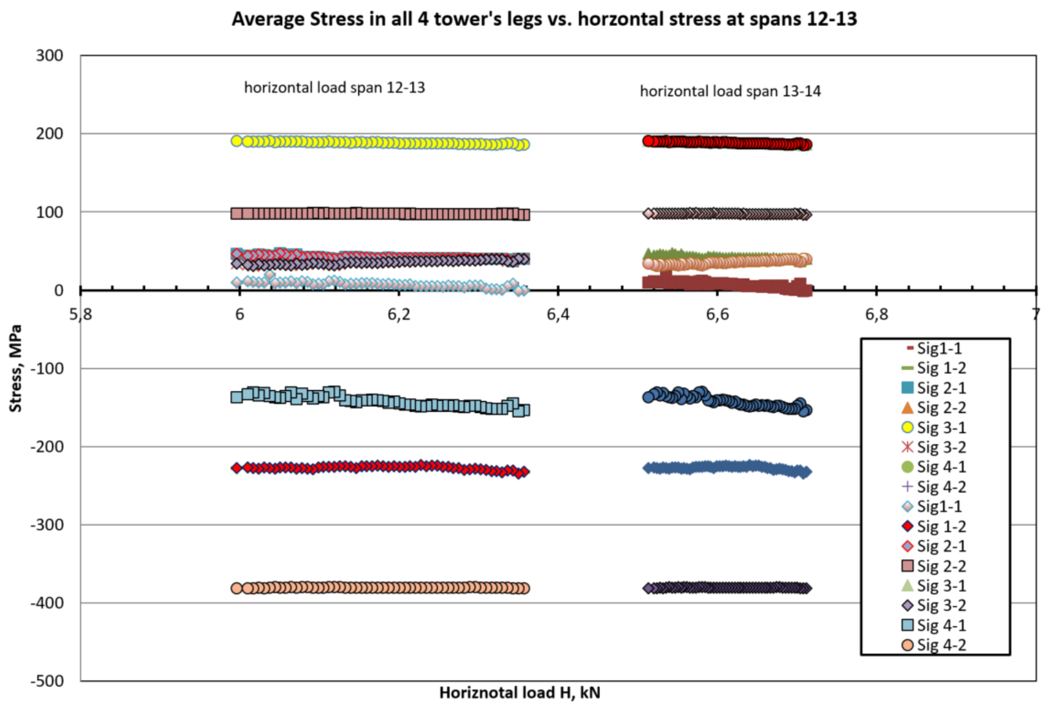

Fig. 12. Correlation between horizontal load and measured stresses in all 8 positions

Since, we have linear correlation between sag and horizontal load for each span distance and also linear correlation between horizontal load and measured stresses, we can establish also linear correlation between measured stresses in legs of tower and sag, too, as is shown in Fig. 13.

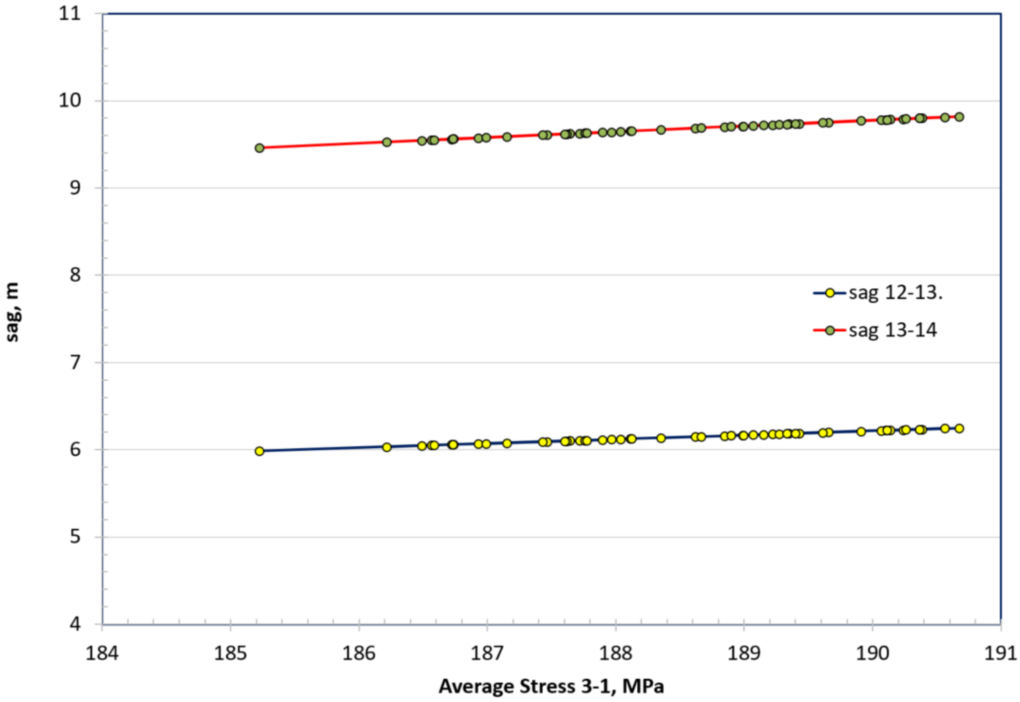

Fig. 13. Linear correlation between measured stresses in leg (position 3-1) and sag of both span distances

5. CONCLUSIONS

Based on the measured stress in the tower's legs of the transmission line, it will be possible to estimate horizontal tensile load of conductor. Measured stresses in each of tower leg vary with temperature and with wind influence as well as the mechanical behaviour of the tower. Results of measurement in period of one month show that results of stresses can be used for span distances for both sides of tower. Each span distance had different tensile load.

Since in observed temperature interval we obtained linear correlation between sag vs. horizontal load and horizontal load vs. stresses in the legs we can also find correlation between stresses in the legs and sag for both span distances.

However, this approach can be extended to observing stress behaviour during icing, since the stress conditions is going to be changed by icing of conductors and/or towers substructure. One can expected that, in the case of ice accumulation, under extraordinary but realistic loading conditions, the stress values will strongly be deviated from ordinary operating conditions, what can be sign that mechanical loading increasing as consequence of snow or ice loading.

After reviewing the vibrations of a particular tower on which vibration measurements are made, it is possible to conclude only comparatively about the state of the tower by comparing the results of vibrations at the same temperature and presumably under the same weather conditions.

Namely, if there is a significant difference in natural frequencies at the same temperature over a long period of time (e.g., one year), we can conclude that there has been a change in the stiffness of the tower. The reasons for this can be various, from loosening of screw joints to

removal of diagonals. In any case, the causes must be determined by a direct inspection of the tower.
The study shows essentially an alternative measurement of the sag and tensile forces in the conductor in an indirect way. The presented method, in addition to the mentioned correlations, also gives data on the condition of the conductor and on the condition of the steel part of the tower.
Of course, only the method is presented here, but the final assessment of the state of the tower and conductor will be possible by developing an algorithm that will perform comparative statistical analyzes with data captured throughout the continuous measurement period. The artificial intelligence system itself gave an assessment of whether the condition of the stem has changed throughout the period and what this change means.
It is understandable that the cause-and-effect relationship between the tower and the conductor could also be due to other factors such as rain or wind speed and direction, but their share needs to be directly defined in more detail.

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