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An integral approach to ensuring the integrity of the tower and conductors

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SUMMARY

Ensuring the transmission of electricity by transmission overhead lines on safe way depends on ensuring the structural integrity of the towers and conductors. The towers of the an older power lines are manufactured at different time periods and are exposed to different mechanical stresses on the same overhead transmission line, due to different degradation of the materials and thus a different lifetime of the towers. However, the towers and transmission line are exposed hush climate and weather conditions which can lead to incidents or collapse of towers or conductor damages. The tower can be exposed to ice and wind loads, corrosion in legs. Today, many institutes and commercial companies are dealing with monitoring of transmission line conductors and towers. Recently, especial effort was made to development of anti-icing coatings of conductor and measurement of ice on conductors. The purpose of the paper is to present a novel method for monitoring of condition assessment and analysis of the results of continuous measurements of deformations in the legs of the towers and the temperature of the conductor with an expert system, which makes it possible to determine the different degree of the tower degradation. Not only tower degradation, but also in some cases the towers can be tilted or even pull out of base fundaments. Within the framework of the project task, a test system is installed on the 110 kV OHL Idrija – Cerkno, ELES, in Slovenia at the critical point of mountain peak The results of continuous monitoring are pre-processed on the autonomous system, which is on the tower itself and sent via the GSM network to the control centre. The results of the measurements are saved in the database for further expertise which quantifies the conditions on the transmission line under different weather conditions as well as the power transmission regime. Measured results are statistically analysed during last 30 seconds of measurements and presented in graphical and numerical form for expert system analysis. On the basis of such an integral approach and analysis of the results of continuous measurements it is possible to determine the influence of individual parameters (influence of climatic conditions and current loads) on the behaviour of the conductor (bends, tensile forces) as well as the tower (change of own frequencies, state of profiles, ...) with the aim of interpolating these impacts over a long period of time to the estimation the actual lifetime of the tower construction and to ensure safety of operation regarding to the external clearances of the overhead line.

KEYWORDS

Transmission overhead lines monitoring, sag monitoring, strain monitoring, weather station

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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 static and dynamic loads of the conductors. Based on the analysis of the project results ELES, Slovenian TSO company, will also receive an answer on the appropriateness of dimensioning of the tower No 13 at OHL 110 kV Cerkno-Idrija at Bevkov vrh. Established system is based on the measurements made, will show what kind of loads the tower is exposed to over a two-year period. As well as whether conditions are 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.
The strain measurements and the temperature in the legs of the tower and vibration measurements are performed to determine oscillation frequencies. 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 decade and the tower collapse in 2014. 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 OTLM (Overhead Transmission 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 OTLM Center, which controls the existing OTLM system (OTLM + local weather station), and inserts the data from 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. Namely, there is a pronounced tensile stress on the 5. and 6. labelled tower, which is relatively high (+190 MPa), which leads to the fatigue of the 5. and 6. leg of the tower sooner, compared to the 1. and 2., which exhibits extremely compressive residual stresses. It should be emphasized that the measured residual stresses are not only the stresses of technological processing of the profile, but in addition to the processing state, they are also composed of stresses due to the distributed self-weight of the tower, the tensile forces in the conductor at the time of measurements, as well as the loaded equipment on the tower. 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.

Fig. 1. Measurement of residual stresses on the NE leg at the 1st measuring point

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

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

	Leg of tower No 13							
Mesuring place	1.	2.	3.	4.	5.	6.	7.	8.
Measured values	+22	-217	+41	+98	+190	+29	-150	-381

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. The transverse strain gauge compensates for the influence of temperature on each measuring point. The strain gauges are protected against mechanical damage by covers enclosing the L corner and connected to the signal capture system by cables. The attached sensor equipment for diagnostics of the deformation state has its own independent power supply with a battery which is charged with a solar panel allowing 2 years of continuous power supply, as is shown in Fig. 3. Software has been developed for the processing of measured signals, analysis and communication with the server and external users. 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 OTLM 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. 4 shows the communication scheme of the whole system, covering the above mentioned system 2x OTLM device, weather station and DynaStat system. The communication platform for the DynaStat measuring system is designed for a server (FME server) that displays the results of current measurements as well as the results of measurements up to 24 hours back if measurements are taken every 5 minutes. The operator at FME, as a partner in the project, is given access to the data a month ago. Communication with the measuring system is carried out by means of a server (FME Server), which in turn communicates with the GSM network via DynaStat. For qualitative analysis of measured quantities, in addition to the capture programs, programs for processing and analysing these quantities and displaying the processed values in graphical form and storing them in a file with numerical values are made, which is the starting point for establishing a database for storing the measurement results. Based on the performed programming of the measurement capture and the processing and analysis of the measured quantities, the basis for the integral database was stored to data base of the measurement results in such a way that the measurement results of the OTLM devices and DynaStat systems are synchronized.

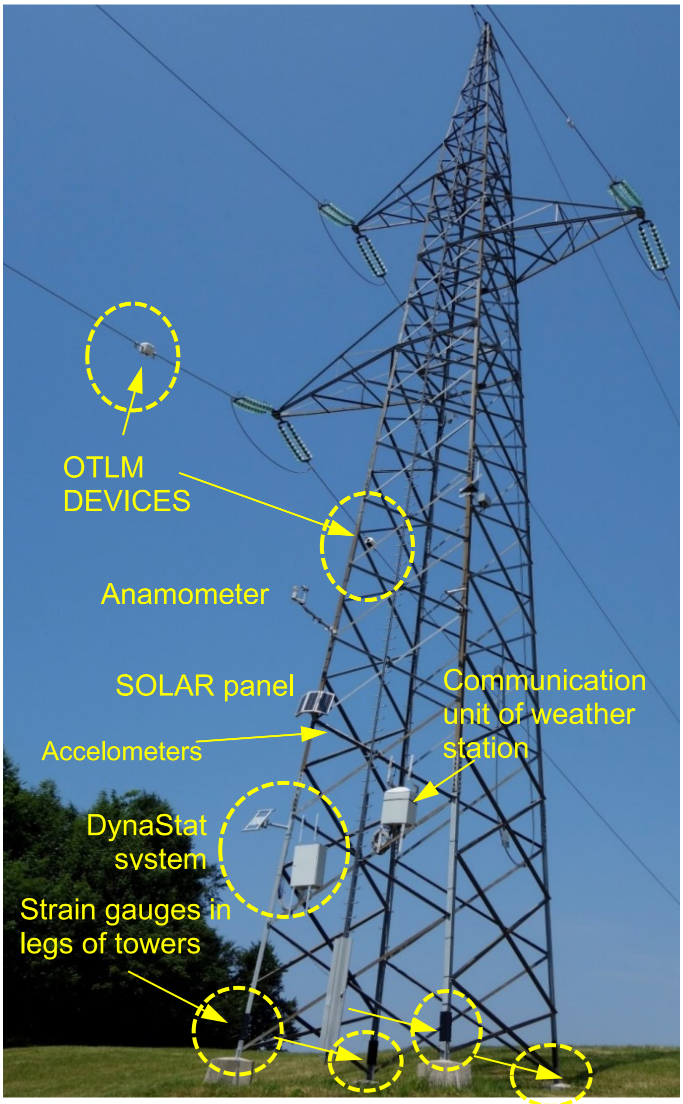

Fig. 3. Installation of a measuring system with a unit for capturing and processing signals and sending data with its own power supply and solar panel

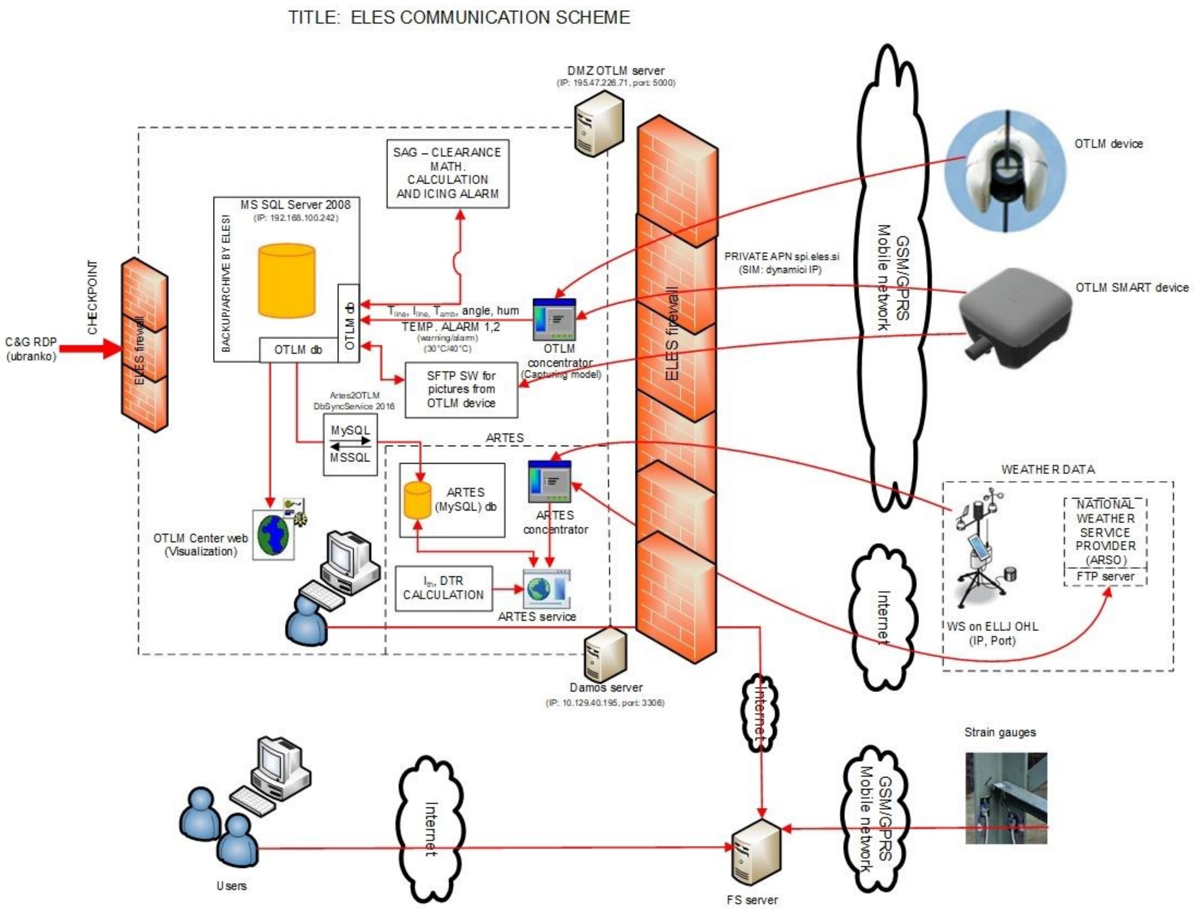

Fig. 4. Communication scheme of the entire measurement system on the No 13 tower (in coordination with the OTLM Center)

At a time when the DynaStat system also measures OTLM devices at the same time measurements and intervals send data to the OTLM center, as shown in the communication scheme in Fig. 4. Fig. 5 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 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 data base.

Fig. 6 shows an excel spreadsheet giving data for both OTLM devices and OTLM-1 sits in the No 13-14 range and OTLM-2 in the range No 12-13. All values are measured at 10-minute intervals. It is possible to export file with measured values of angle, conductor temperature and ambient temperature, current in guide, atmospheric humidity and inclinometer angle as detail on file for September 2019.

Fig. 7 shows results of measurement by DynaStat system. DynaStat controller software performs, analyses and stores data with measurement vibrations, temperature voltage on No 13 tower. Fig. 7 shows a file of measured values in the calculated measurement values with DynaStat post measuring application.

An operator combines both files from the OTLM center (Fig. 6) and the file from the DynaStat system (Fig. 7) by entering all measurement data in one row for the same measurement time interval. The values are written to a single "Master file" as shown in Fig. 7. This file contained a synchronized measured parameter from all three systems, which consists of conductor data (from OTLM devices), weather and voltage states and vibrations on the tower, as well as voltage states on the tower console No 13 with the phase on which both are mounted OTLM.

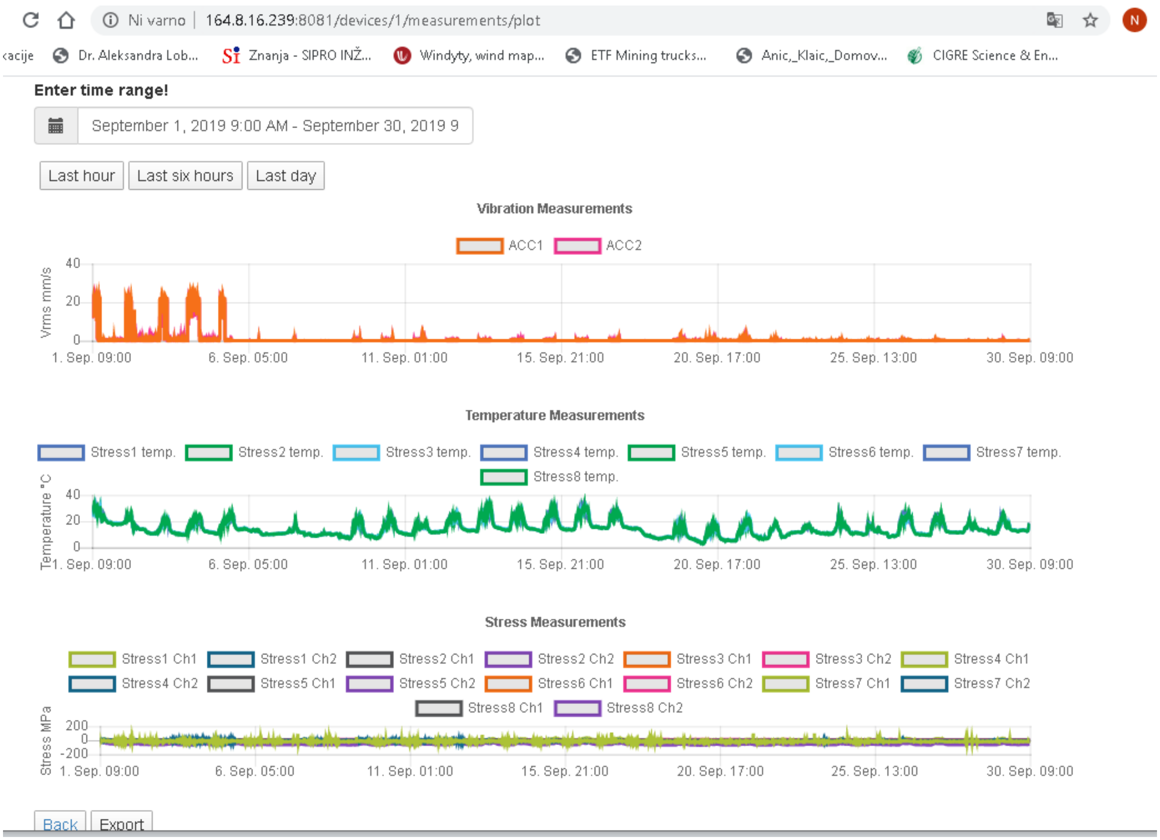

Fig. 5. Panel with results of measurements by DynaStat systems

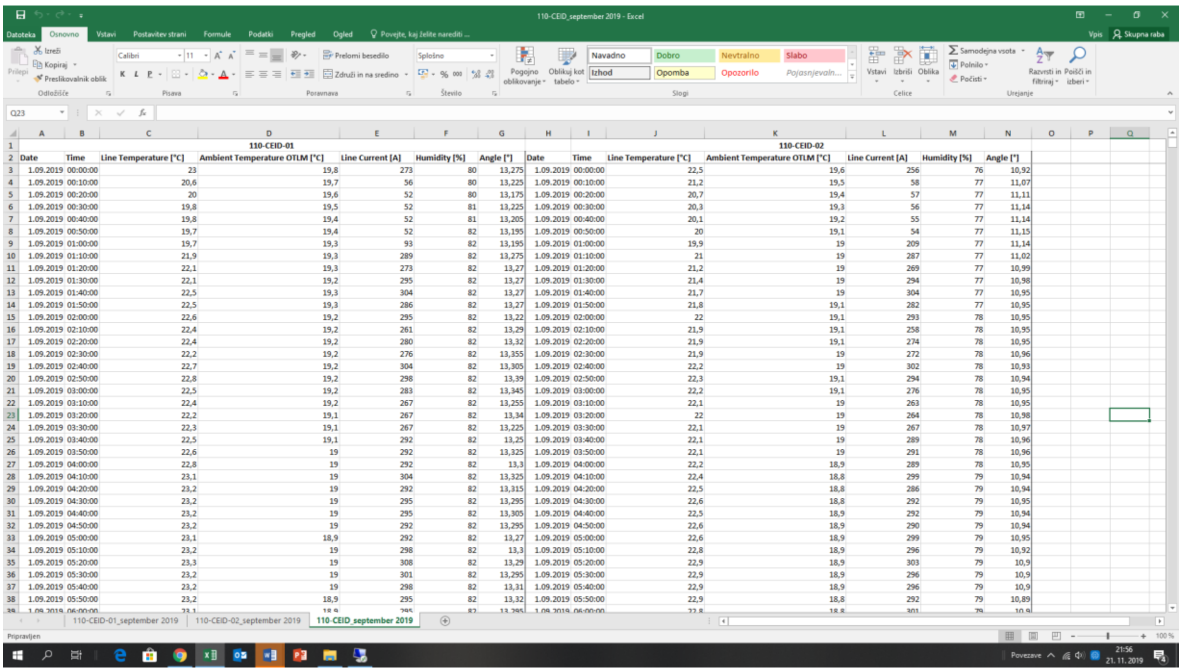

Fig. 6. Results of measurement by OTLM system for both OTLM devices

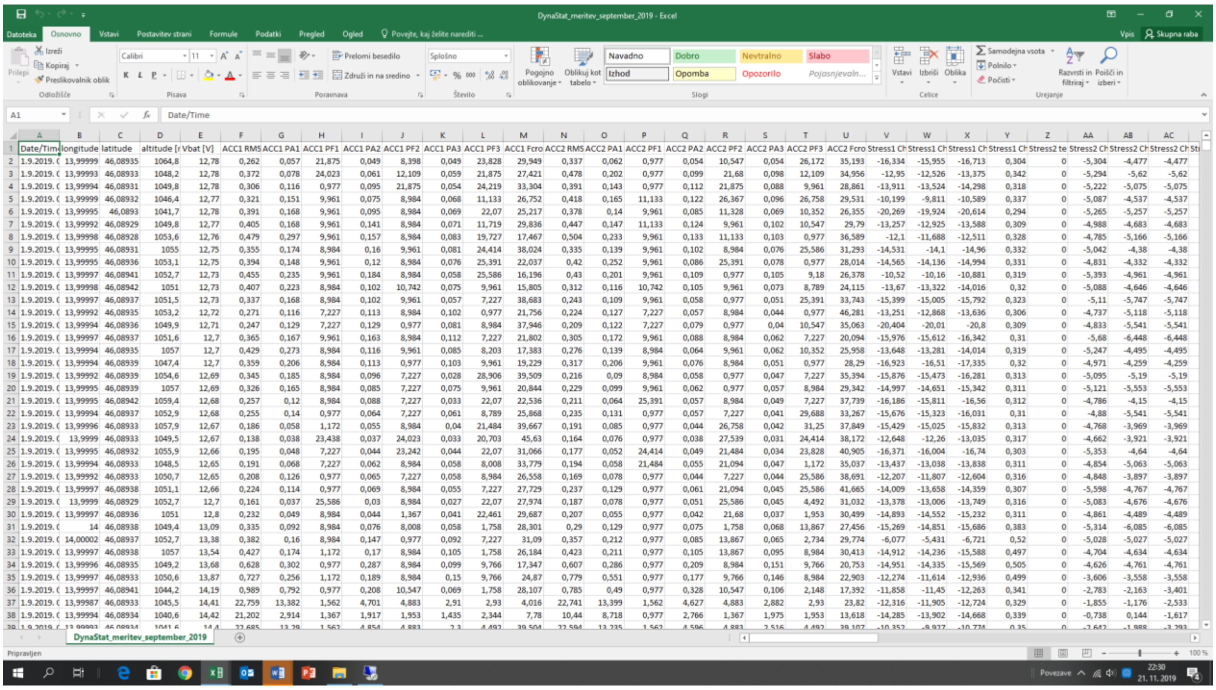

Fig. 7. Results of measurement with DynaStat system

3. ANALYSIS OF RESULTS

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 OTLM 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 M13). We measured the measured information in time with the OTLM 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 (OTLM + DynaStat), as well as the dependence and change of the measured parameters on the time and weather conditions at the Bevkov vrh.

Fig. 8 shows Temperature of conductor (span No 12-13) vs. temperature of conductor (span No 13-14) and measured angle of inclinometers in OTLM 1 and OTLM-2 device.

Results shows that with increasing of temperature of conductor an angle in inclinometer increasing, too.

Fig. 9 shows results from integrated master file as effect of ambient temperature on stress in one leg and temperature of conductor. Significant scatter for measurement of stress in the leg over temperature range occur in September 2019. Therefore, it is necessary to apply statistical tool to analysis results of stress in the legs.

Fig. 10 shows average stress in each of tower's leg, where stress is measured at each leg in two position with taking in account measured residual stresses. Presented values are mean values after statistical analysis. It is possible to recognize that mean stress values in some leg are slightly increasing or decreasing with temperature.

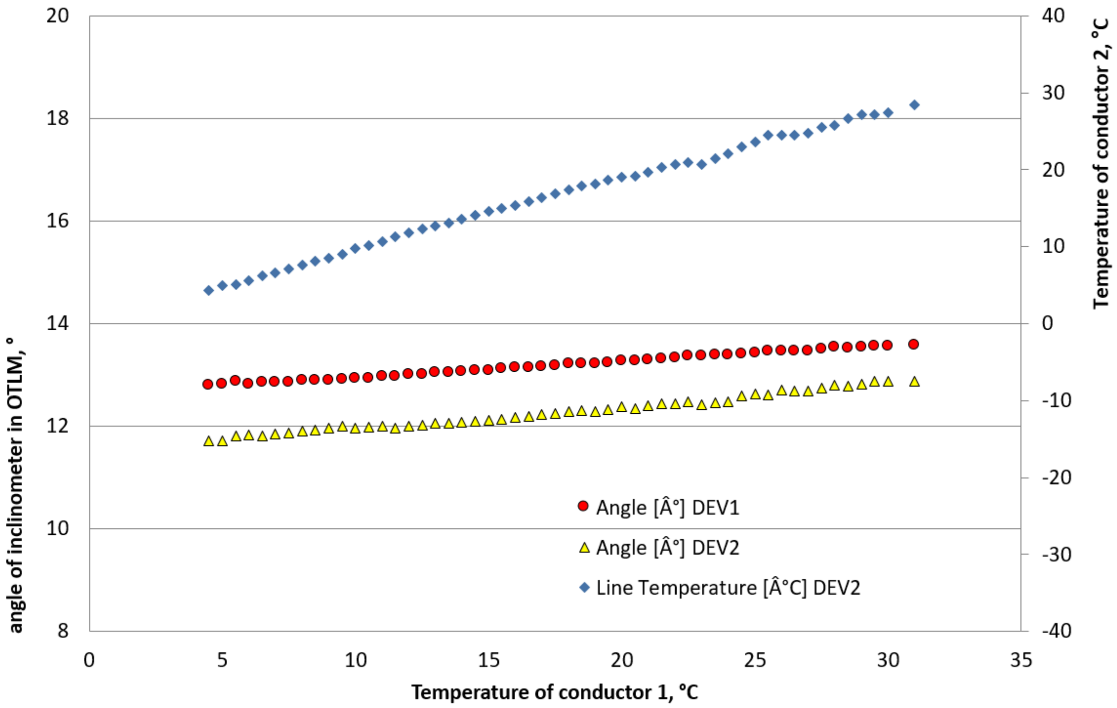

Fig. 8. Temperature of conductor 1 vs. angle of both inclinometers

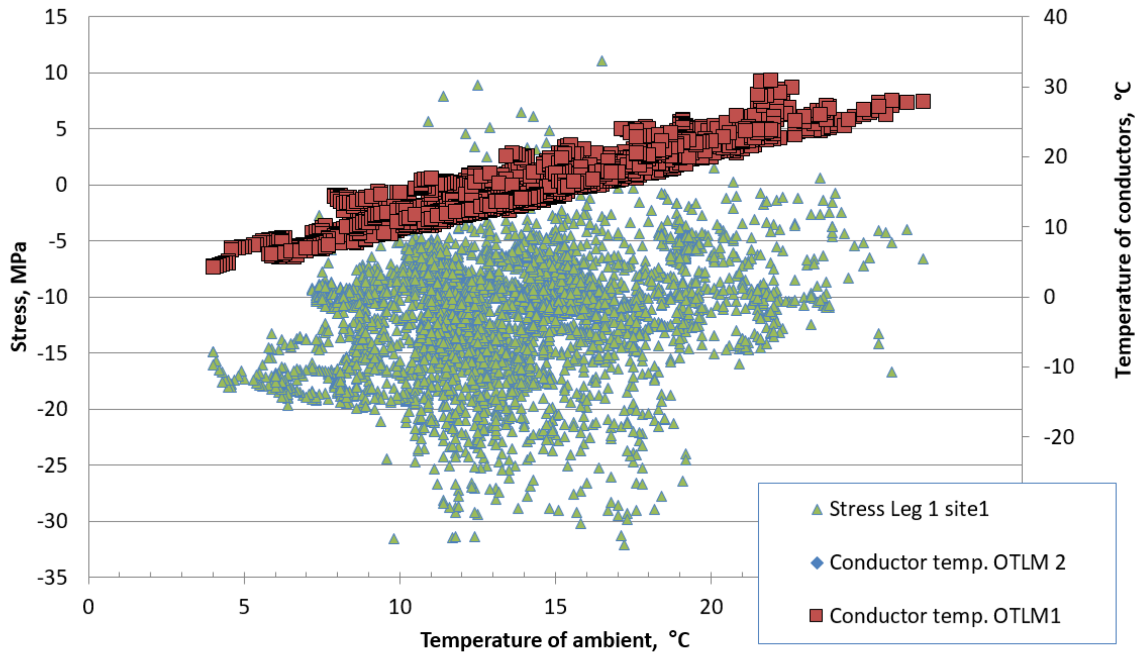

Fig. 9. Temperature of environment vs. temperature of conductor (span No 13-14) and stress measurement in leg of tower.

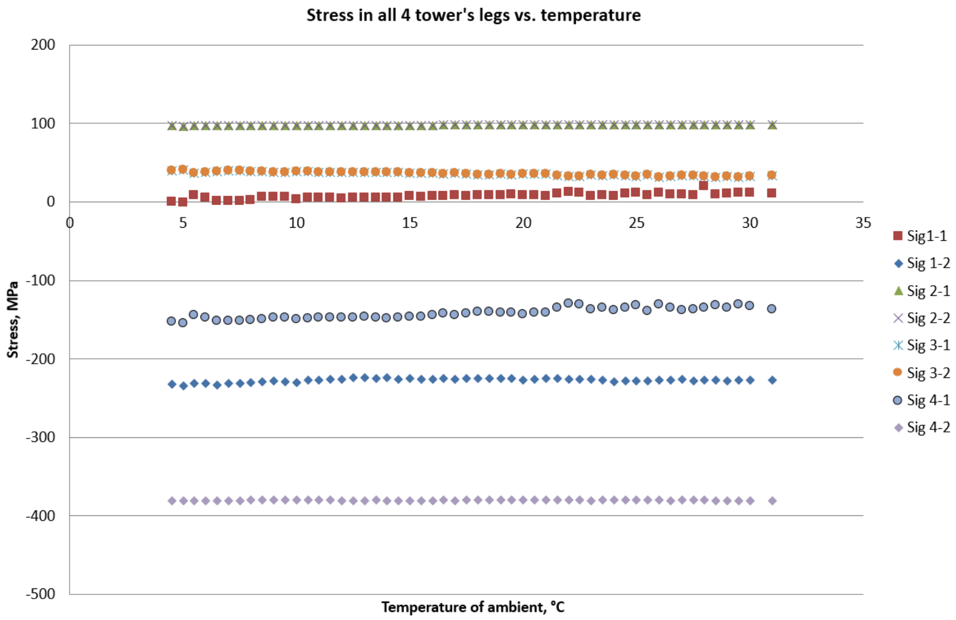

Fig. 10. Temperature of conductor vs. mean measured stresses in the legs of tower

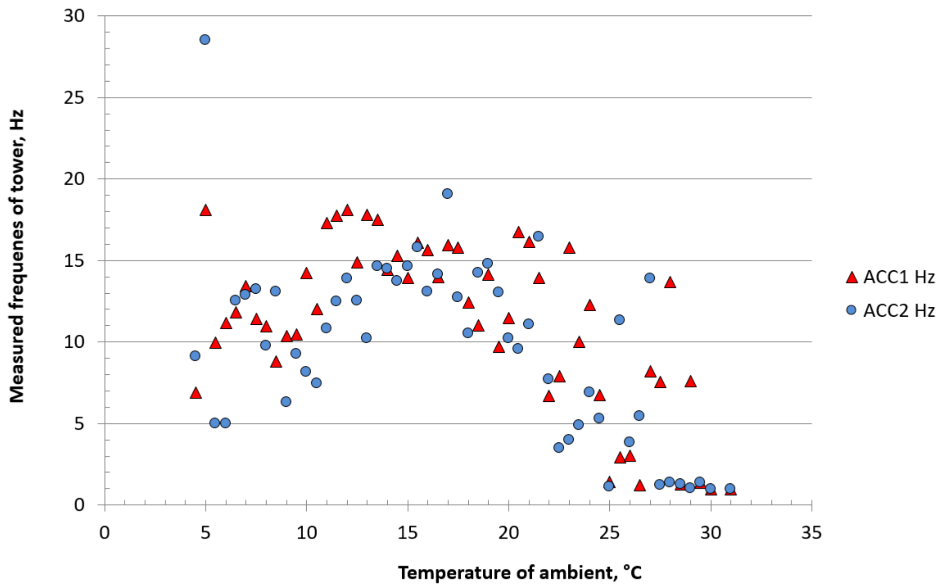

Fig. 11. Temperature of ambient vs. measured frequencies of tower

Fig. 11 shows vary of vibration with temperature of ambient. It is possible to see that the frequencies in both directions has stochastic features, and frequencies of tower in both direction are different for all temperature range. Such scatter of vibration can be effected by wind and other weather conditions e.g. rain. Change of environment temperature, can have also effect on length of tower and consequently on frequencies of tower as structural system.

4. CONCLUSIONS

Based on the measured stress in the tower's legs of the transmission line, it will be possible to estimate the utilization rate of the tower under regular operating conditions. Measured stresses in each of tower leg vary with temperature and with wind influence as well as the mechanical

behaviour of the tower. 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. Results of measurement in period of one month show that from static loading point of view the tower is well dimensioned. For asset management it is necessary to observe loading during longer period actually whole year and taking account number of loading cycles during this period. We are assuming that based on the actual tower loads over a 2-year period, the tower loads over the next several decades will be estimated, and thus the life of the tower. Due to the monitoring of vibrations and deformations, it will be possible to detect also changes in the behaviour of the tower through different temperature conditions, as well as in case of more pronounced deviations, the possible loosening-loosening of the screw connections of profiles without physical inspection of the No 13 tower.
The findings and changes in the status of the tower through different temperature conditions in different weather situations and different operating conditions of the conductors will be reported in the final report after 2 years of the project (September 2021), when a database will be built and a detailed analysis of all measured quantities will be carried out and determined.

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BIBLIOGRAPHY

[1] *Meritev zaostalih napetosti na nogah stebra SM13 za matematično modeliranje DLR na DV Bevkov vrh (Cerkno-Idrija) : poročilo*. Maribor: Fakulteta za strojništvo, 2018.

[2] *Meritev verižnic za določitev funkcijske odvisnosti za matematično modeliranje in spremljanje deformacij v nogah stebrov na DV Idrija Cerkno na lokaciji Bevkov vrh med stebri SM 14-13-12 poročilo*. Maribor: Fakulteta za strojništvo, 2019.

[3] CIGRE Brochure no. 498 "Guide for Application of Direct Real-Time Monitoring Systems, Paris, 2012.

[4] CIGRE Brochure no. 425 "Increasing Capacity of Overhead Transmission Lines: Needs and solutions, Paris, 2010.

[5] McGuinness Sean, Doyle Ray: *Rating System Implementation & Analysis*, DLR Condition Monitoring, Sept. 2011.

[6] Real time Ampacity Monitoring with Ampacimon™, Version 0.1, University of Liege, Department of Electricity, Electronics and Computer Sciences, Belgium, Dec. 2008.

[7] N. Gubeljak, K. Bakic, F. Jakl, A. Veg, J. Predan: "*An Attempt to OHL Conductor Dynamic Line Rating by Strain-Vibration Detection of Tower*", International Symposium CIGRE Best Practice in Transmission and Distribution in a Changing Environment, Auckland, New Zealand, September 16.-17., 2013.

[8] K. Bakić, N. Gubeljak, J. Predan, F. Jakl, R. Maruša, E. Veg, V. Lovrenčić: "*Estimation of Tensile Force in Conductor by Vibration and Strain Measurment in Pillar's Legs of Transmission Line*", CIGRE, 2018 Paris Session, August 26.-31., 2018.