Discussion of Comprehensive On-Load Tap Changer Measurements

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Abstract
This article discusses a measurement system that allows for the simultaneous measurement of drive power consumption, diverter switch operating times, selector cage operation, and acoustic measurement.
The measurement is performed using a Zensol measuring device, which utilizes an additional channel to measure the OLTC operating times.
The presentation includes criteria for evaluating the measurement results.

1. Introduction

The VAM vibroacoustic measurement allows for the assessment of the mechanical condition of the tap changer by comparing current measurements with a reference value. During the measurement, signals are received from acceleration sensors and sampled at 250 kHz by the measurement system. The sensors can be mounted on the tank or on the tap changer cover. For measurements on a de-energized transformer, the sensors can be placed on the transformer tank wall or on the OLTC cover, with the latter having been found to provide the best signal-to-noise ratio (SNR). Additionally, it is possible to combine the vibroacoustic measurement with the measurement of the power switch's own times and the measurement of the power consumed by the drive during the switching process.

2. Overview of the measurement system

Vibroacoustic measurements can be performed on an operating or deactivated transformer. Taking measurements with the transformer deactivated allows for mounting sensors in locations with the highest acoustic signal. Taking measurements on an operating transformer limits the sensor's ability to be mounted only on the side wall of the tank. In both cases, it is also possible to record the current or power consumed by the OLTC drive. The measurement system configurations for both cases are shown in Figure 1.

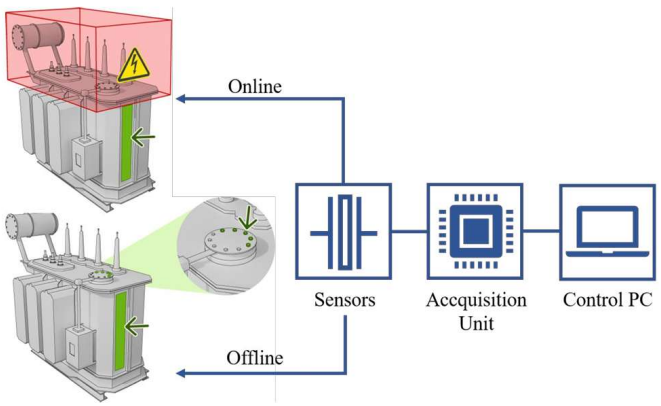


Figure 1. Sensor arrangement during vibroacoustic measurements of the VAM and acquisition unit. [1]

3. Discussion of measurement results

The VAM measurement allows for the analysis of these vibration patterns by comparing the obtained results with reference values. These results form the basis for assessing the mechanical condition of the tap changer. The signals are sampled at a frequency of 250 kHz by a measurement system using integrated piezoelectric electronics (IEPE). Combining the vibroacoustic measurement with the measurement of the diverter switch's internal time allows for obtaining information on contact wear. VAM and internal time measurements are performed over the entire operating range of the OLTC.

Figure 2 shows the acoustic raw signal from the OLTC and the motor current.

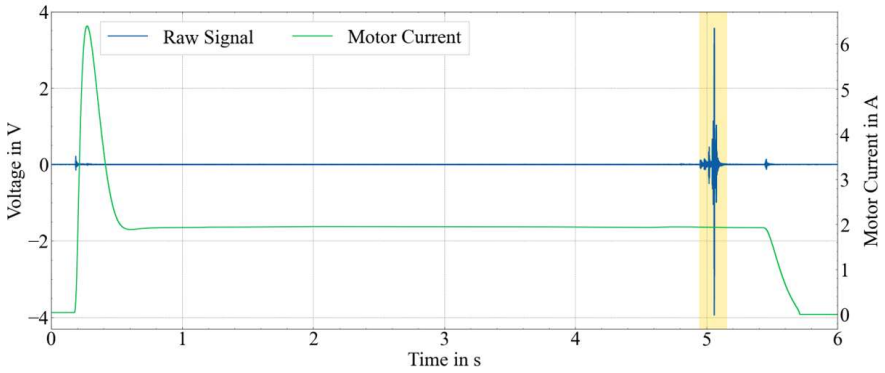


Figure 2: Raw sensor signal (blue) and motor current (green), with the power switch operating after approximately 5 seconds (shaded area). [1]

In this example, the raw signal (blue) shows the motor starting and stopping, as well as the power switch operating (shaded area). The current drawn by the drive is shown in green. To facilitate visual comparison of the results, signal processing was performed. In the first stage of post-processing, a time-frequency analysis is performed by applying a continuous wave transformation to the raw data. The sensor signal is displayed in both the time and frequency domains. This signal is shown in Figure 3.

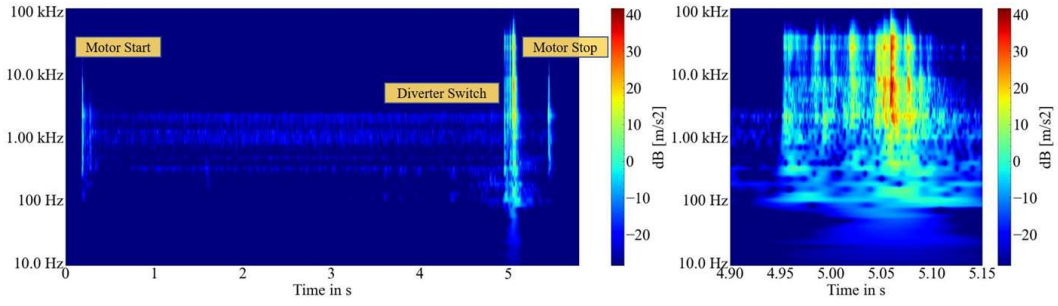


Figure 3. Frequency-time graph on the left and a selected area of the power switch operation graph on the right. [1]

The x-axis shows the time axis, and the y-axis shows the frequency in the range from 10 Hz to 100 kHz. Color coding represents the signal level in decibels relative to m/s^2 (individual frequency components). EMC interference can be easily identified, but it can

complicate the evaluation of the results. In addition to the frequency-time graph, integration of the typical frequency and subsequent Gaussian filtering produces an envelope curve in the range from 10 kHz to 100 kHz. The resulting curve reflects the energy of the raw signal in the defined frequency range and can be used for comparison with reference data such as factory fingerprints or data from sister units. Figure 4 shows the corresponding signal curves in dB versus time.

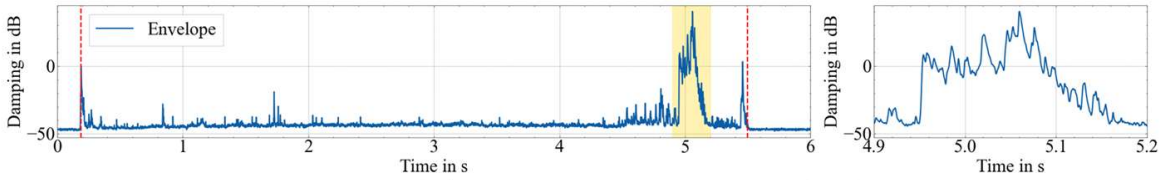


Figure 4: Envelope graph in dB versus time (left) and selected operating area of the power switch (right) [1]

The VAM graph highlights the area where the power switch is tripped.
Measurement of VAM and DRM self-times enables a combined assessment.
Figure 5 shows the VAM envelope curve, which can be assigned to individual stages of the power switch switching cycle. The DRM measurement represents mechanical and electrical time sequences, enabling a combined assessment that generates complementary data. This allows the envelope curve to be assigned to individual movements, such as opening or closing contacts. Using vibroacoustic measurement, all OLTC components generating sufficient vibration can be included in the overall assessment. However, some operations do not produce any recordings. Only operations that cause a change in the measurement current affect the resistance measurement. A graph showing the switch operating envelope curve and the DRM current measurement during the switching cycle is shown in Figure 5.

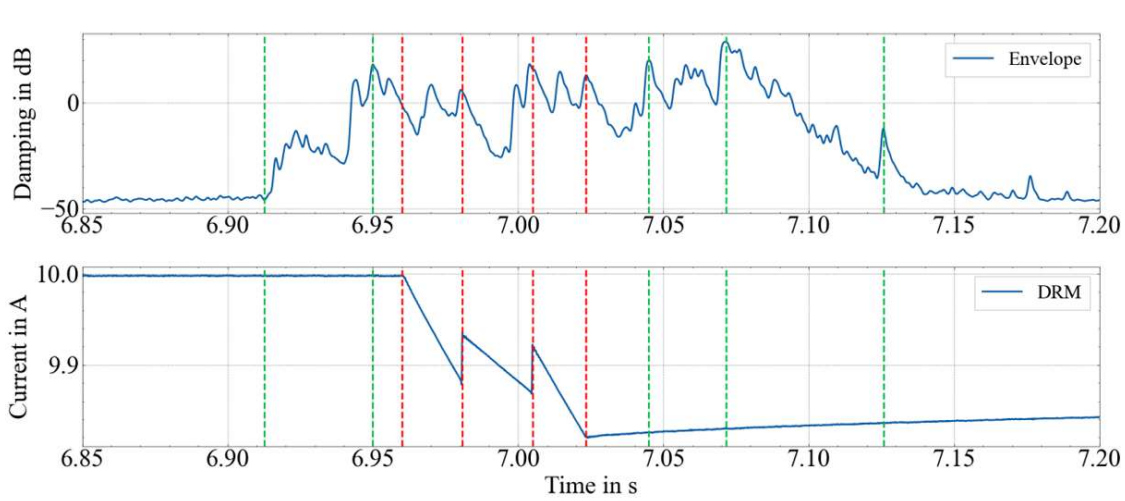


Figure 4: VAM diagram describing the operation of the power switch (top graph) and the intrinsic time graph of the DRM power switch [1]

The dashed lines indicate all events detected by the VAM or DRM. Red lines indicate events based on the DRM curve, such as opening and closing of the contact on the power switch. However, the envelope curve clearly shows that there are numerous mechanical events received during switch operation that are not represented in the DRM. Comparing these events, it is noticeable that the last three DRM events coincide with the peaks of the envelope curve; however, the first event of the DRM curve is not visible in the envelope curve. The first event that causes a change in resistance and thus affects the DRM curve is the opening of the main contact. While opening the contact can cause less vibration than closing, this case is likely only represented in the DRM curve. Additionally, the comparison shows that the actual start of the diverter switch operation is captured only by the envelope curve (at approximately 6.90 s). This comparison demonstrates that combining both types of measurements allows for a detailed assessment of the OLTC's mechanical integrity. Furthermore, combining DRM and VAM data allows for the identification of individual peak values and monitoring any changes between maintenance intervals. The location of the sensor for signal acquisition has a significant impact on the signal amplitude.

Figure 7 shows the signals collected from the tank and cover of the diverter switch.

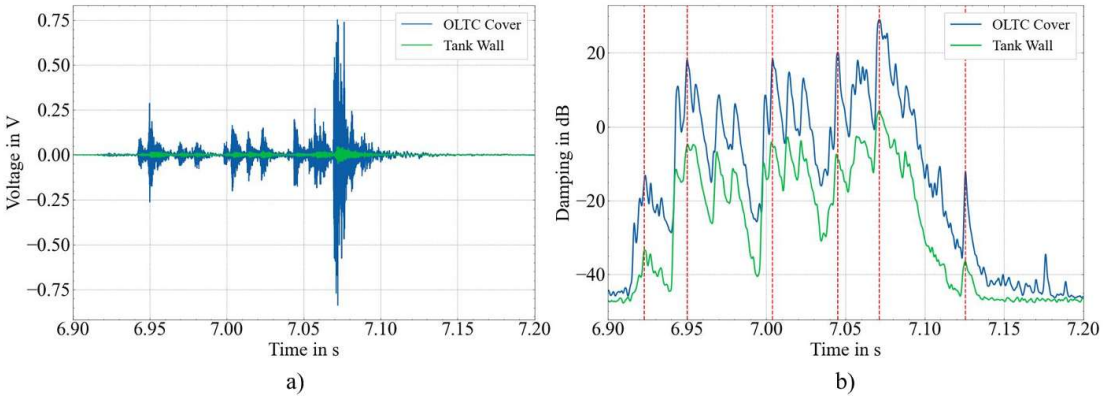


Figure 7 a) Sensor signals with high (blue) and low (green) signal strength. b) Envelope curves of weak and strong signals [1]

As can be seen, the main features of both curves are similar in terms of the number of events and time. Comparison of the graphs in Figure 7b shows that there is a high repeatability of the envelope curves, even in the case shown in Figure 7a for the strongly attenuated signal (blue). Furthermore, the curves are consistent, as illustrated by the peak patterns shown in Figure 7b. Therefore, comparing online and offline results is also possible, although the sensors may not be mounted in the same location due to lack of access.

4. Using VAM measurements to assess the correct operation of a power switch

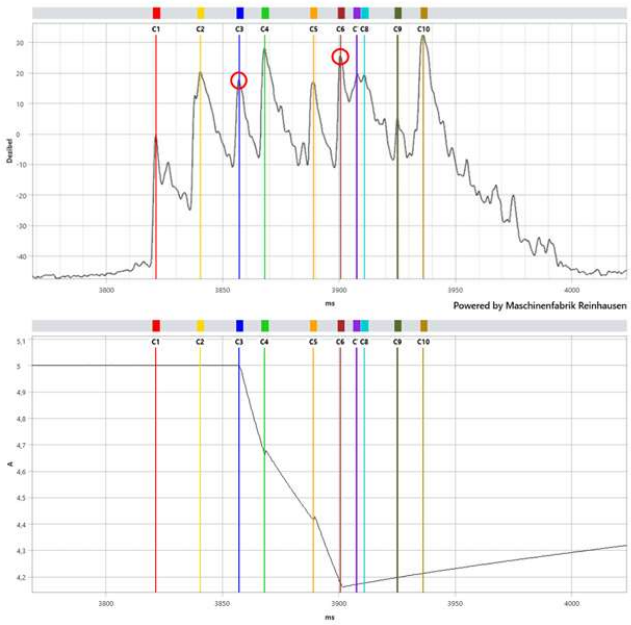


Figure 7 Drawing of the VAM envelope and the current waveform during the switching cycle of the power switch [3]

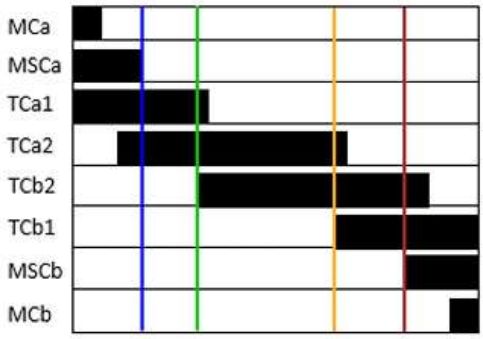


Figure 8: Sequence of operation of the power switch contacts [3]

Figure 8 shows the switching stages of the power switch contacts, as shown in Figure 7, which shows the VAM graph and the current waveform during the switch switching cycle. Individual stages are marked with vertical lines and symbols C1–C10.
Current changes during switching are described by symbols C3–C6, where:
C3: Opening of the main switching contact MSCa, the load is transferred to the stepped resistor contacts TCa1 and TCa2
C4: Switching to the stepped resistor contact TCb2 with a short overlap of TCa1 and TCb2
C5: Switching to the stepped resistor contact TCb1 with a short overlap of TCa2 and TCb1
C6: Closing of the main switching contact MSCb. The switching time of the diverter switch is the time between events C3 and C6. It is determined during internal time measurements.
During VAM measurements, amplitude changes occur that are not determined during internal time measurements but provide valuable diagnostic information.

As can be seen from Figure 8, the switching cycle includes a stage in which the main contact MCa is disconnected, and conduction is transferred to the auxiliary contact MCSa.
Similarly, there is no time associated with the transfer of conduction from the auxiliary contact MSCb to the main contact MCb.
The operation of the main switching spring, which is responsible for arming the switching mechanism and ensuring the diverter switches to the second position, requires a separate discussion.
The zones covering the area to the left of line C3 and to the right of line C6 require a separate discussion. Figure 8 shows a graph of the vibration amplitude of the SRKO switch. and included in [2]. The measurements were performed on a tap changer disassembled from the transformer, which allowed the top cover of the diverter switch to be lifted and the contact movement to be recorded using a high-speed camera. Simultaneous recording of the current flowing through the windings (oscillography measurement of the natural time) and measurement of the amplitude of vibrations induced by the switch current allowed for the determination of characteristic zones in the recorded signals. However, it should be noted that not every phenomenon occurring in the diverter switch is reflected in all the characteristics. Figure 9 presents a comparison of the vibroacoustic characteristics with the characteristic of the measurement of the natural time of the diverter switch recorded during the switching between taps 5 and 6.

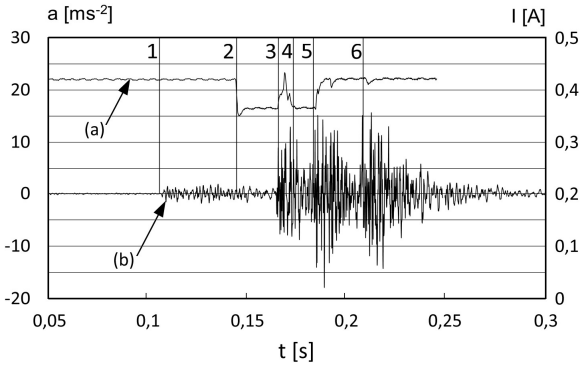
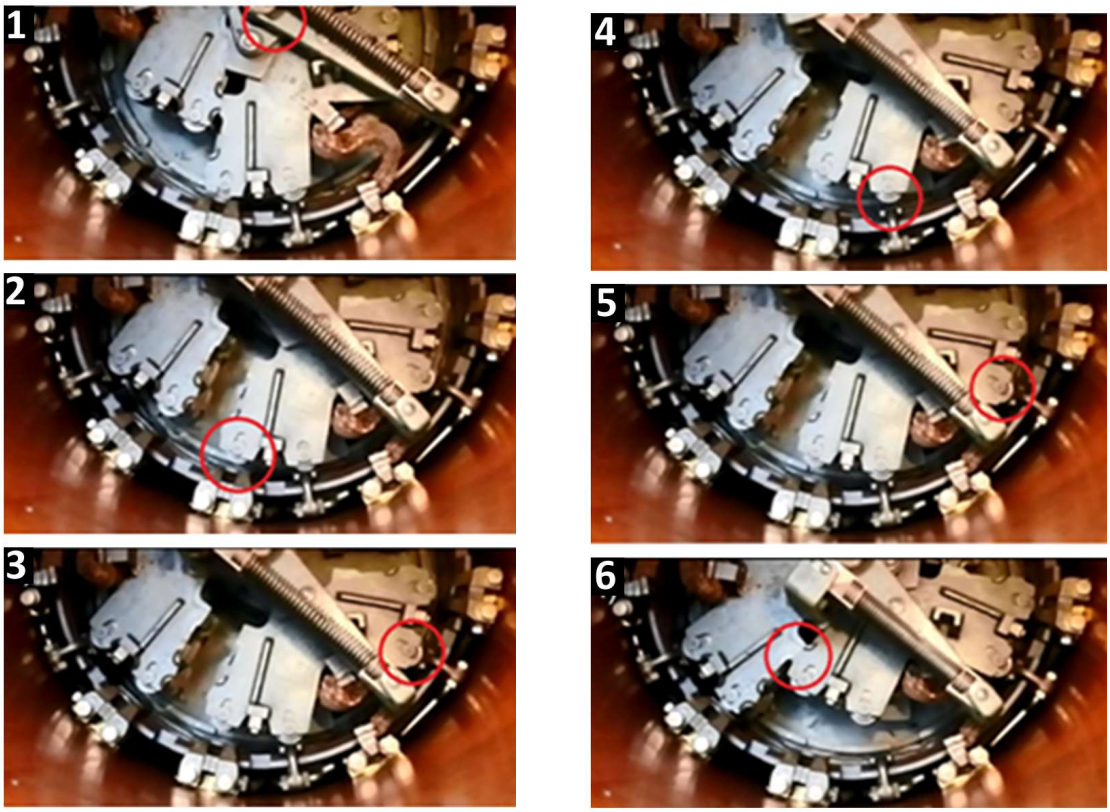


Figure 9: Comparison of the vibroacoustic characteristics with the characteristic of the switch's natural times [2]

The time instants (1 to 6) that correspond to the successive phases of the power switch's operation are also marked:
A photograph of each stage of the switching cycle is shown in Figure 10.



Description of the switching cycle stages

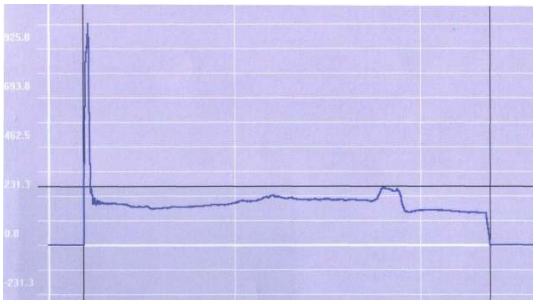
1. Release of the mechanism and release of the energy stored in the tensioner spring. The time course of the vibration acceleration is characteristic of a vibrating spring.
2. Disconnection of the first main contact – this event causes a decrease in the current value, but it is not reflected in the vibroacoustic characteristic.
3. Engagement of the second resistance contact – this event causes an increase in the current and a distinct change in the vibroacoustic characteristic in the form of a damped pulse.
4. Disconnection of the first resistance contact – this event is characterized by a decrease in the current, but disconnection of the contact does not cause a distinct change in the vibroacoustic characteristic.
5. Engagement of the second main contact – a distinct vibroacoustic pulse and an increase in current.
6. Collision of the segments on which the moving contacts are mounted – a distinct vibroacoustic pulse, no change in the current value (the tap switching process has already been completed at point 5). The collision of segments means that the switch is set in the starting position for the next switching operation.

Figure 10 Photographic documentation of the switching cycle stages [2]

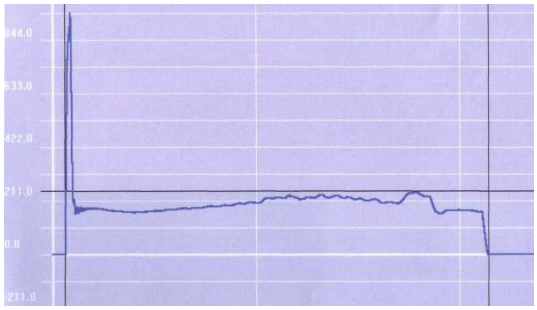
The research conducted allowed us to clarify the missing stages that are not recorded during the time-of-flight measurements. The vibrations occurring in stages 1-2 were related to the release of the spring mechanism and the release of the energy stored in the spring. However, the vibrations after the complete switching cycle from positions 5-6 were related to the collision of the segments on which the moving contacts are mounted. The information obtained from the switch measurements can be used to explain vibroacoustic measurements on other types of switches.

5. Discussion of the method for measuring the power absorbed by the OLTC drive

This is a diagnostic measurement of the on-load tap changer. It involves sampling the active power drawn by the OLTC drive motor throughout the entire switching cycle. The measurement is highly sensitive and allows for the detection of not only serious damage, but also, for example, the lubrication status of mechanical parts or changes indicating slow degradation of the switch. The basis for assessing the mechanical condition of the OLTC drive system is the analysis of the recorded active power consumption by the drive motor during individual phases of the switching cycle. In the event of a defect, this analysis also allows for the location of its occurrence with a high degree of probability. Proper interpretation of measurement results requires detailed knowledge of the design and operation of the given switch. Figure 11 presents the results of measurements of the power drawn by the OLTC drive, while Figure 12 provides a detailed description. Analysis of the power measurement results is performed by comparing the obtained results with the factory measurements. The absence of significant differences does not require a deeper analysis. Such analysis is necessary if differences from the reference graphs are observed. In such a case, it is very helpful to have a description of the switch's switching cycle with the angular or time values of the individual phases of the switch's movement marked.



Power consumption diagram of the PO 400/110 switch drive, switching from tap 3-2 Tx = 5196 ms Pmax = 269.1 W



Power consumption diagram of the PO 400/110 switch drive, switching from tap 2-1 Tx= 4944ms Pmax = 243.6 W

Figure 11. Power consumption diagram for the drive of a PO-type [7] on-load tap changer.

Figure 12 shows the switching cycle of an ELTA PO1 - 400 tap changer and the power consumption curve of the drive motor, recorded on a 25 MVA transformer. The time axis in the figure is scaled in terms of the main drive shaft rotation angle and in seconds. In this case, six characteristic phases in the switching cycle are also distinguished. Based on previous experience, the evaluation criteria (values compared to the reference waveform) are as follows:

• Normal condition - power in individual movement phases does not differ by more than 30%,

• Warning condition - power increase within the range of 30-60% throughout the entire switching cycle,

• Alarm condition - power increase within the range of 60-100% throughout the entire switching cycle, with a 50% increase in power now of contact bridge engagement,
• Emergency condition - power consumption increase of 100% or more in any movement phase.

If a warning occurs, maintenance of the drive and gear or an inspection of the switch should be planned soon. In the event of an alarm condition, the drive should be disabled, and the cause of the malfunction should be clarified. Emergency conditions prevent any switch operation. An increase in power consumption by the drive now of contact bridge engagement may indicate a shift in the moving contact relative to the fixed contact or increased resistance caused by burnt contact surfaces. In several cases, comparing the recorded power graphs with the switching waveform of the selector or changer cage allows for a more precise determination of the causes of the malfunction.

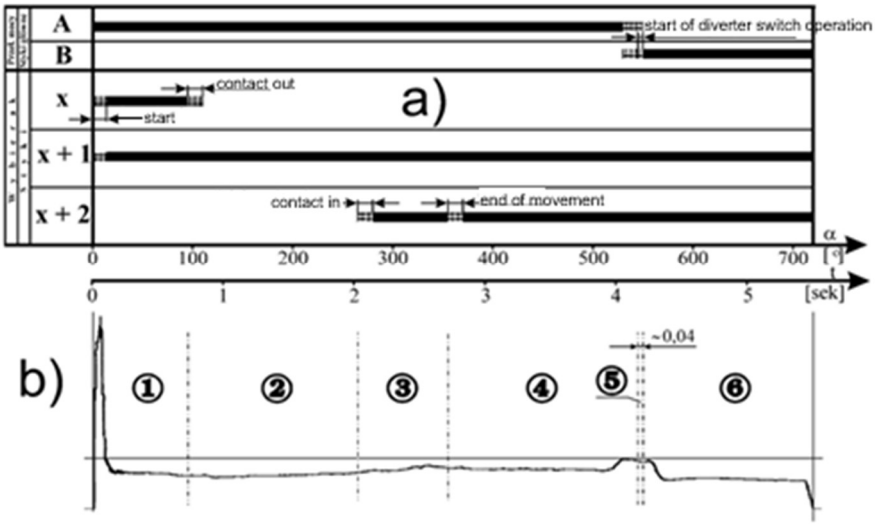


Figure 12. a) Switching cycle from tap "x+1" to "x+2" (without the changer) in an on-load tap changer type PO1 – 400 (drawing according to [8]); b) Power consumption waveform of the drive motor, recorded on a 25 MVA transformer when switching from position 2 to 3. [7]

5. Final Conclusions

• The VAM vibroacoustic measurement method can be used to measure and assess the technical condition of the diverter switch.

• VAM vibroacoustic measurements do not require disconnecting and disconnecting the transformer for testing.

References

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