The vibro-acoustic method as fast diagnostic tool on load tap changers through the simultaneous analysis of vibration, dynamic resistance and high speed camera recordings.

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Abstract

Classic testing techniques give very little information on mechanical problems occurring inside an on load tap changer (OLTC) while in service. The vibro-acoustic method is based on the principle that all mechanical operations produce a vibro-acoustic pattern while operating. This pattern is recorded by an accelerometer and converted into a vibro-acoustic signature that is unique for each tap changer, and stable in time in the case of a healthy mechanism.

The functioning of an OLTC is complex since a lot of mechanisms are operating at the same time. To facilitate the comprehension of the vibro-acoustic signature, the following instruments have been used at the same time during the execution of a test:

- A high speed camera (‘’to see’’)
- A vibration transducer (‘’to listen’’)
- A dynamic resistance accessory (to capture the electrical currents)
- A current clamp (to record the motor current, determine the operation synching, and identify the operating range of the taps)

Each of these tests provides a piece of information that, coupled with the other tests, creates a complete picture of the condition of the OLTC. Therefore, the final target of all the tests is to be able to easily detect vibration problems in the future. In fact, the simultaneous correlation of all the signals, images and videos allows a fast understanding of the internal movements of an OLTC. It also improves the knowledge about the vibration for the operator as a reliable interpretation tool to find problems on OLTCs while in service, and before they create an outage.

In the last part of this article, we present examples of interpretation of two vibro-acoustic tests.

Introduction

The on load tap changer (OLTC) is the only mechanical part of a transformer and, as such, its first cause of mechanical failures. The vibro-acoustic method has been proved to be a very effective method for the detection, at the earliest stages, of mechanical and electrical problems in OLTCs. This method is based on the principle that every machine produces a signature, when it operates, that is unique and repeatable in time.

The functioning of an OLTC is complex since a lot of mechanisms are operating at the same time. To facilitate the learning process of the vibro-acoustic signatures, the authors have performed several simultaneous tests on an OLTC ABB UZERN kept open. The standard operating conditions of this OLTC would require the mechanical parts to be completely immersed in oil. However, for the purpose of having a better vision of the internal moving parts, it has been drained. The authors were aware that the acoustic signature would be different. The added mass and the dampening of the oil on the system will have an influence on the frequency content and the signal’s amplitude level. In this article, the focus is put on the timing and the correlation of the major impacts with the images. Furthermore, the signal is primarily composed of the waves propagating in the solid materials like steel and epoxy.

For the execution of the test, the following instruments have been used:

- a FASTEC high speed camera, with recording speed of 500 images per seconds, (‘’to see’’ the switching operation);
- a recording system OTM-X from Zensol connected to :
  - an accelerometer with measurement range 50g (‘’to listen’’ the vibrations);
  - a DC current clamp (for the measurements of electrical currents during OLTC switching). See Fig 1.6 how DC voltage source is connected to the transformer;
  - an AC current clamp, with measurement range 20A, (to record the motor current).

The ability of the vibro-acoustic method to identify problems on online OLTCs, and hence to prevent unplanned outages, has been repeatedly proven by field tests performed in the last few years; Therefore, the objective of this article is to show the ability of the vibro-acoustic method to detect mechanical and electrical problems in a non-invasive way, and to provide more information on the relationship between tap movements and accelerometer signatures, with the scope of facilitating the learning process of the vibro-acoustic curves. In fact, the simultaneous correlation of all the signals, images and videos allows a fast understanding of the internal movements of an OLTC and improves the capability of the operator to determine the condition of any OLTC without downtime.

Test set-up and execution

For the recording of resistance and vibration curves, an acquisition system has been used, the Zensol OTM-X (Fig. 1.1). This instrument is characterized by 6 inputs: 3 analog inputs +/-5V, for vibration transducers, and 3 analog inputs +/-10V, for standard transducers. It has 16bits A/D conversion and configured with a sampling time of 10 microseconds. During the test, one accelerometer has been connected to the +/-5V input, while the current clamp (Fig. 1.2) has been connected to the input +/-10V. The signals transmitted through the accelerometer and the current clamp have been recorded by the OTM-X and processed by a specific software to displays them in graphics.

Fig. 1.1 Zensol OTM-X - Instrument for the acquisition of vibration, current and voltage signals.

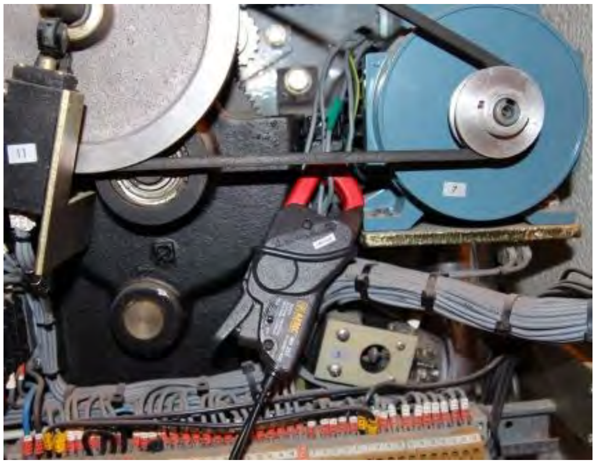


Fig. 1.2 Current clamp connected to the OLTC motor.

In order to catch the highest amplitude of noise, the accelerometer has been located as close as possible to the moving taps. At the same time, a high speed camera has been placed in front of the mechanism to record the OLTC in operation (Fig. 1.3).

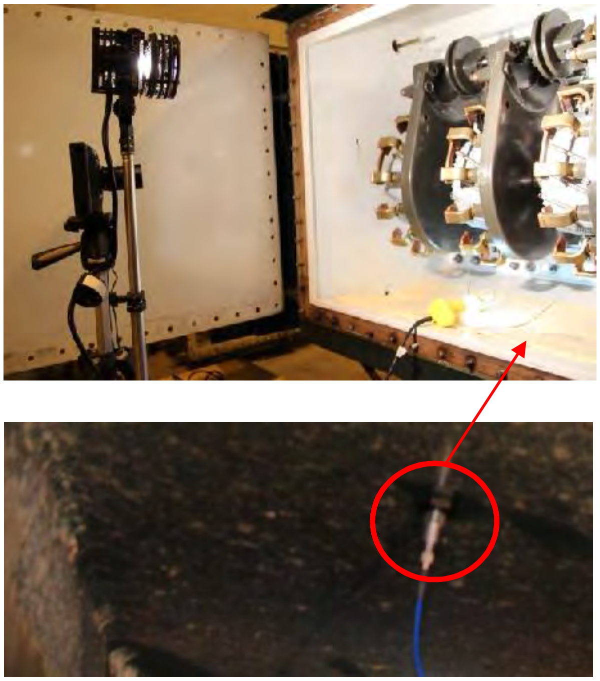


Fig. 1.3 High speed camera and position of accelerometer under OLTC.

To complete the set-up, a DC voltage source and a DC current clamp have been connected on the transformer, as shown in Fig. 1.4, Fig. 1.5 and Fig. 1.6.

Fig. 1.4 DC voltage source and current clamp

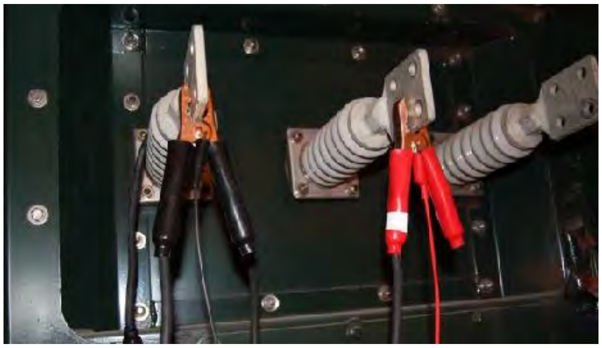


Fig. 1.5 Connection of contact clamps on the transformer

The OLTC under study is an ABB UZERN 250/300 with 17 taps. It was installed on a FERRANTI PACKARD transformer with 1 MVA power, 7,2kV / 347Y600 voltage, and characterized by Dyn1 coupling.

To better understand the disposition of the instruments, a symbolic scheme has been drawn and reported in Fig.1.6. The left part represents the set-up built by the authors - which includes the DC voltage source and current clamp - while the right part represents the transformer with its OLTC.

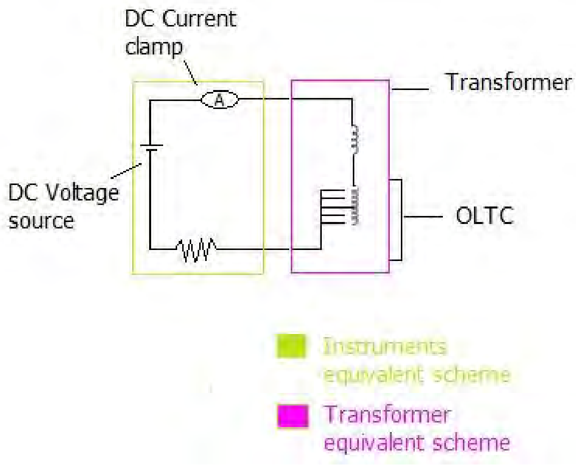


Fig. 1.6 Equivalent scheme of transformer and instruments

Interpretation of results

During the test, several tap operations have been performed.

Fig. 1.7 shows the test results of the operation of the OLTC moving from tap 8 to tap 9. Starting from the top, this graphic shows: the dynamic current curve, the accelerometer signature and the motor current profile.

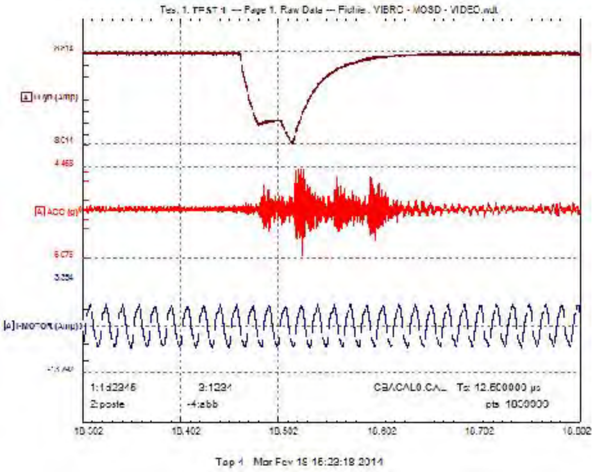


Fig. 1.7 Expanded test results for test 8 --> 9

As it can be observed, the accelerometer signature is characterized by 4 main peaks, the two first corresponding to a specific value of current. With the support of the video, these first two peaks have been identified as follows:

- 1st impact: noise of the first auxiliary contact entering the new tap position (Fig. 1.8)
- 2nd impact: noise of the main contact entering the new tap position (Fig 1.9)

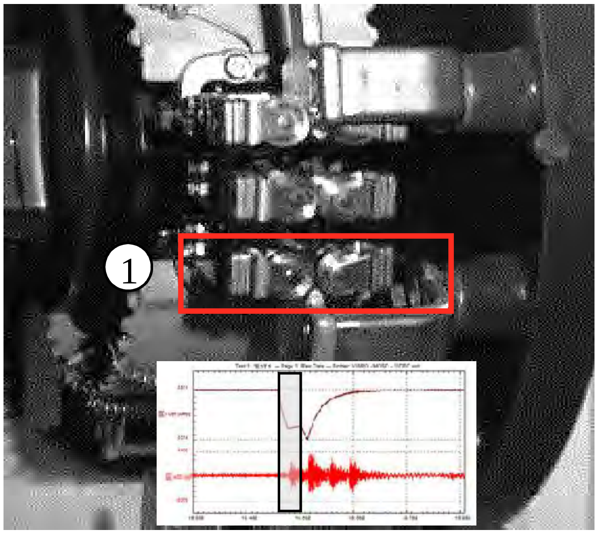


Fig. 1.8 First impact of the moving contacts

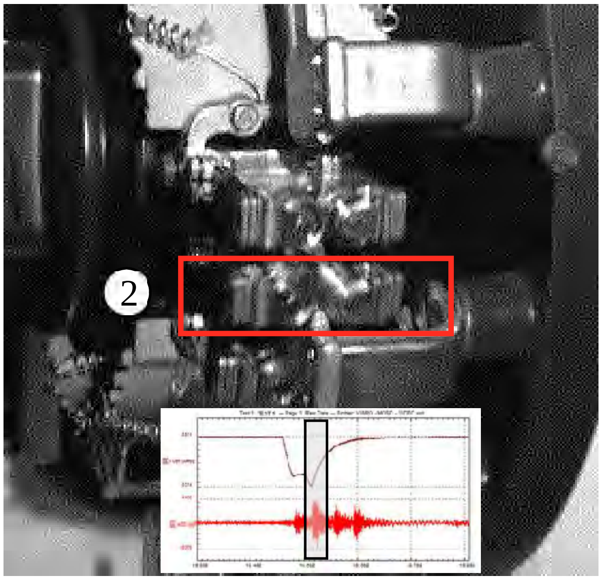


Fig.1.9 Second impact of the moving contacts

For each of these operations a change in the current curve has been recorded. For example, in correspondence of the first vibration impact, (Fig.1.8), the current diminishes reaching a first cusp. When the second impact occurs, (Fig.1.9), the current diminished even further reaching a second cusp, which is followed by a gradual restoration of the current profile to its original state. Unlike what one might think, the two final impacts are not related to the main contacts of the switching taps.

The truthfulness of this conclusion has been proved by the signatures recorded by a second accelerometer, installed directly on the mounting base of the fixed contacts (Fig.1.10). Fig. 1.11 shows a comparison of the two accelerometers signatures with respect to the dynamic current curve. As it can be observed, the relation between the current and the movements of the operating contacts is confirmed in both the accelerometer signatures. The additional two impacts of the external accelerometer (in red) can be probably related to ancillary mechanisms operating around the OLTC (such as brakes or springs).

The good synchronization of the curves represents a crucial criterion for a correct analysis of the results. However, reaching the required level of synchronization has not been a straightforward operation: It has required several manipulations (including the adaptation of the sampling speed between the video and the sound) before reaching the desired levels.

Fig. 1.10 Posi of the secon celerometer (Blue)

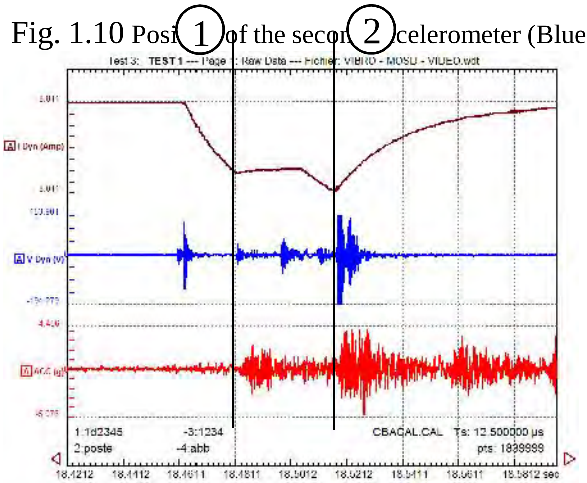


Fig. 1.11 Comparison of the two accelerometers signatures

Conclusion

In this paper, the existence of a tight correlation between the dynamic resistance curve and the vibration signatures of the tap operations has been proven by recording the movements with a high speed camera. As a consequence, the ability of the operator to determine with certainty the condition of the contacts of this model of OLTC, without need of visual verifications or invasive inspections, has been further improved.

The authors believe that further studies on different brands and models could be conducted with the same method to provide additional knowledge to tap changer maintenance experts.

Examples of interpretation of vibro-acoustic tests

This brief section will show how a good use of the vibro-acoustic method can lead to successful interventions and reduced maintenance.

Example 1:

Tests done on a single phase transformer with two internal MR TI2000 tap changers showed major timing differences. In this real case, a potentially critical failure was avoided because an intervention was made before too much damage was done. Fig. 1.12 shows the result of both tap changers on the same time scale. The red line represents the expected signature and the blue line represents the problematic one. The switching time of the TI2000 should be around 150ms, where the blue curve takes almost double that amount. The big gap was attributed to a problem with the coupling of the drive shaft on one of the two tap changers. This timing difference could have created circulating currents in between the tap changers. Fig 1.13 shows that after maintenance, this 200ms delay was corrected.

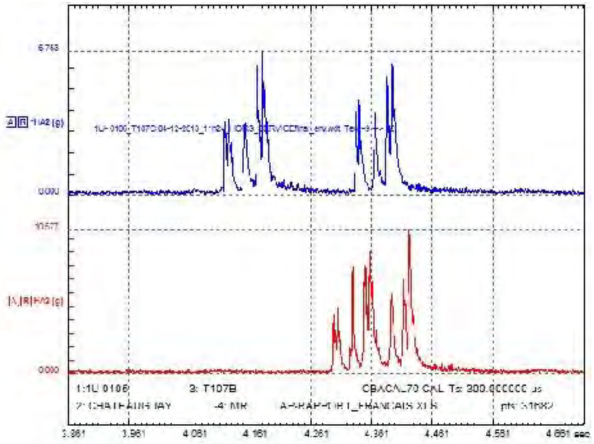


Fig. 1.12 Before maintenance 200ms gap

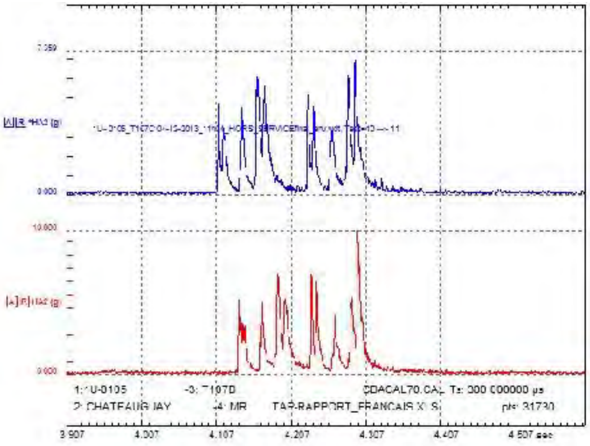


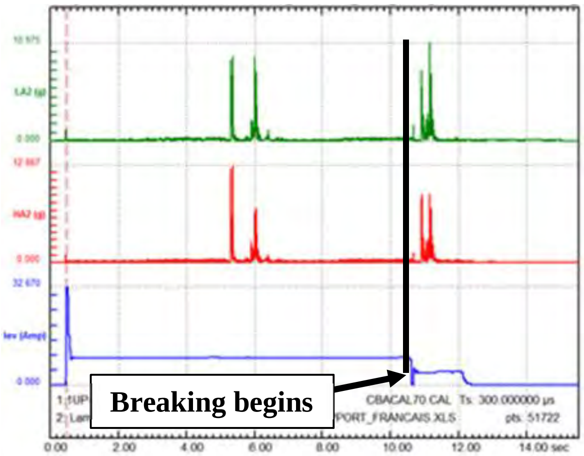
Fig. 1.13 After maintenance, no more gap

Example 2:

As a second example, here are tests done on a Federal Pioneer TC546. Over a three year period multiple interventions were done where the vibro-acoustic measurements were recorded, but not analyzed. In 2013, high values in dissolved gas analysis were picked up. The vibro-acoustic measurement were done before and after the maintenance as their norm specify. When they opened the tap changer, they discovered a lot of coking and burnt contacts. (Fig 1.14)

Fig. 1.14 Coking and burnt contacts of a TC-546

The sequence of movements in the tap changer must follow a predetermined order. In 2013, the breaks were applied too early and the final movements of the tap changer end after the expected time (Fig. 1.15). Still in 2013, after maintenance, they didn't realize that the timing was still off and it even got worse.



The Fig. 1.15 **2013** Before maintenance, timing problem

The last impact is seen on the next test, since the tap changer didn’t stop at the right place. (Fig 1.16)

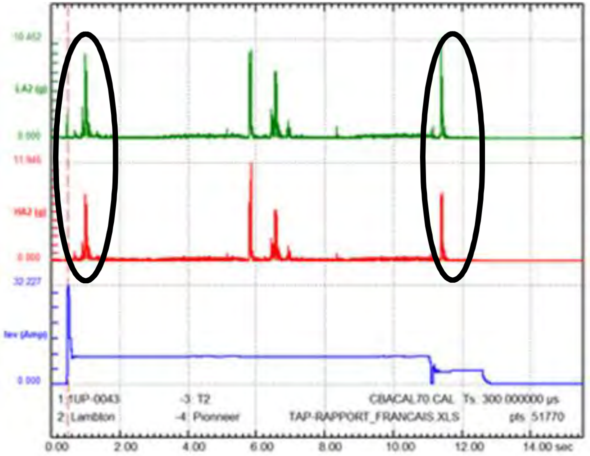


Fig. 1.16 **2013** After maintenance, worse timing problems.

It doesn’t end there, following another dissolved gas analysis, they went back to open the tap changer to find it in an even worse condition. They cleaned everything and replaced the burnt parts again. They corrected part of the timing issue but a new problem appears, the drive chain has been tightened too much and we can see it as spikes on the motor current. (Fig 1.17)

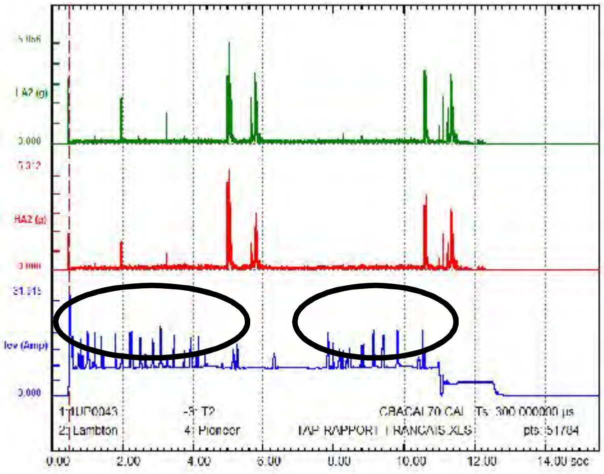


Fig. 1.17 **2014** After maintenance, current spikes.

If they would have analyzed the results before, they would have prevented another unplanned maintenance.

Biographies

Dr. Fouad Brikci is the president of Zensol Automation Inc. He was the first to introduce the concept of truly-computerized test equipment in the field of circuit breaker analyzers. As a former university teacher in Ecole Polytechnique - Algiers and CNRS LAAS researcher in France, Dr. Brikci has developed experience in the fields of electronics, automation, and computer science. Most activities were focused on the industrial application of computers. Among his achievements are the development of fully computerized measuring systems for quality control in circuit breaker manufacturing, laboratories, and maintenance services of electric utilities. Dr. Brikci holds a PhD in Electronics and a Master in Sciences in EEA (electronics, electrotechnics, and automation) from the University of Bordeaux, France.

Mathieu Soares graduated from Cégep André-Laurendeau in physical technologies in 2001. He gets his first job as a technician in instruments and control at the IREQ research institute of Hydro-Québec. In 2009 he received the title of expert technician in mechanics after 8 years of specialization on vibrations and acoustics. He participated in the development of diagnosis tools used by Hydro-Québec like a partial discharge localization system and a system for the tap changers and circuit breakers diagnosis using the vibro-acoustic method. He presently works on different R&D projects where the application of different non-destructive methods are required.

Pier-Antoine Giguère graduated from Cégep Lionel-Groulx in computer programming in 2006. After a three months internship at Zensol, he took the role of technical support and programmer for the user softwares. He participated in the R&D of the TAP-4 project at Zensol, developing the high speed USB communication link required for the application. He also helped develop the analysis reports, services and training courses for the vibro-acoustic tests done on tap changers and circuit breakers.

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