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Aluminium Electrolytic Capacitor Research and Development Time Optimization Based on a Measurement Automation System

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Abstract: The aim of this paper is to present partly the Measurement Automation System (MAS) of an Electrolytic Capacitor Development Laboratory at EPCOS Hungary. The main role of the MAS is to facilitate the electrolyte and capacitor research and development, through the automation of the related measurement tasks, and to provide a powerful database system background for data retrieval and research decision support. The paper introduces only a few applications of the entire system. More than 27 different electrolyte and capacitor measurements were automated. All the measurements have been implemented in a similar manner. During the process the user initializes the measurement, sets the measurement environmental parameters, and launches the execution. The program runs on its own, sending automatically the results of the measurement to a database system, from where the data can be retrieved in a predefined or a non-predefined way. For the realization of the above requirements the National Instruments measurement, data acquisition and LabVIEW software development tools were chosen as implementation and development platform. After validation of the system, there are many advantages as making the measurements more precise, more reliable, fault tolerant, parallel running, which all contribute to speed up the research and development of new components and devices.

The developed measurement system controls and harmonizes the different devices and supervises their work. The developers do not have to encroach. The user can simply check the measurement phase by a glance on the screen. The programs estimate and display the running time of the experiments, allowing for the researchers working on the laboratory to manage the instrumental resources in time and to schedule in advance (for hours, weeks and months) the new measurements. Another big advantage is the database system behind, which stores the result of each measurement in an easy searchable way. Different measurement reports and statistical diagrams can be made automatically and the results can be reused in later research. The effectiveness of the system was tested also via the inner gas pressure measurement of electrolytic capacitors to estimate the life-span of the capacitors. According to the experiments the introduction of the MAS system in the Lab the research and development time for new electrolytes and capacitors has been decreased considerably.

Keywords: Measurement automation, test automation, aluminium electrolytic capacitors, data acquisition, data mining.

1. Introduction

Capacitors play a very important role in our world [1], [2]. They can be found in every electronic device around us, they are widespread all over the world used as energy storage elements, filters and decouplers.

The main features of capacitors are: capacity (1pF-1F), operational voltage (from 1,5 V up to some kV), operational temperature (from -55 °C to 125 °C), loss factor, size and shape.

The most frequently used capacitor types in the industry nowadays are: ceramic, foil, aluminium and tantalum capacitors. The four most important application fields for capacitor technologies are radio techniques, electrical power processing, energy storage and power electronics. Except for the first application field electrolyte-capacitors can be used, so this type of capacitor is prevalent.

The main advantage of the electrolytic capacitors is the high capacity and voltage value, which can be attributed to the dielectric layer with very small thickness, but with very large surface. Their disadvantage is the over voltage sensitivity.

The main characteristics of the electrolytic capacitors are determined by the electrolyte, the anode foil and the paper separator.

The electrolyte generally consists of the following components:

- solvent: e.g.: ethylene glycol,
- acids and bases: usually organic,
- different additives.

The electrolytes are characterized by two major features: conductivity and breakdown potential, both of them dependent on the temperature. The change of conductivity as a function of temperature decisively affects the electric parameters of the capacitor. The chemical reactions, which take place inside the electrolyte, are in direct relationship with the conductivity value at different temperatures and the quantification of this relationship is important.

The conductivity and breakdown potential of the electrolyte influences the maximum operating condition of the capacitors. Electrolytes with high conductivity are used in the low voltage capacitors, while the electrolytes with low conductivity are used in the high voltage capacitors.

The paper is organized as follows. The short descriptions of the measurement types, which must be automated, are given in Section 2. The architecture of the proposed measurement system is presented in Section 3. In Section 4 a characteristic measurement "*Conductivity* (*T*)" is presented in detail in order to demonstrate the program structure and some implementation issues. Some characteristic measurement results are given in Section 5, and the conclusions are presented in Section 6.

2. Measurement types

There are two groups of measurements used in electrolyte-capacitor research and development. The first main measurement group is related to electrolytes, while the second main measurement group is related to capacitors. The electrolyte measurement consists of six measurement programs as follows:

- "*Conductivity* (*T*)": measurement on the temperature dependence of conductivity. This is one of the most important measurements, and is presented in details in the next section.
- "*Ph* (*T*)": measurement of the pH value as a function of temperature. The structure of the program is completely similar with the above-mentioned one, with a difference that pH meter is used instead of conductivity meter. The measurement is important because the pH value of the used electrolyte in the electrolytic-capacitor must be in a specified range.
- "*Mixing* (*pH with single temperature*)": measurement of the pH value as a function of the concentration of an electrolyte composition at a specified temperature. As a matter of fact we use this measurement in order to set up the pH value of the electrolyte.
- "*Mixing* (*conductivity with single temperature*)": measurement of the conductivity as a function of the concentration of an electrolyte composition at a specified temperature.
- "*Mixing* (*conductivity with multi temperature*)": measurement of the conductivity as a function of the concentration of an electrolyte composition at several temperatures. This and the former measurement are used to set up the conductivity value of the electrolyte.
- "*Spark detector*": measurement of the breakdown potential of the electrolyte.

The main capacitor measurements are as follows:

- "*Spark detector*": this measurement program is similar to the structure of the program used for electrolyte measurement. The only difference is that the object of the measurement is the winding impregnated with the electrolyte. In that case we want to know the breakdown potential of the paper impregnated with different electrolytes.
- "*ESR* (*Equivalent Serial Resistance*)": This measurement is mostly used in order to determine the resistance of the capacitor at different frequencies and temperatures.
- "*Gas pressure*": measurement of the internal gas pressure of the capacitor in various operating conditions.

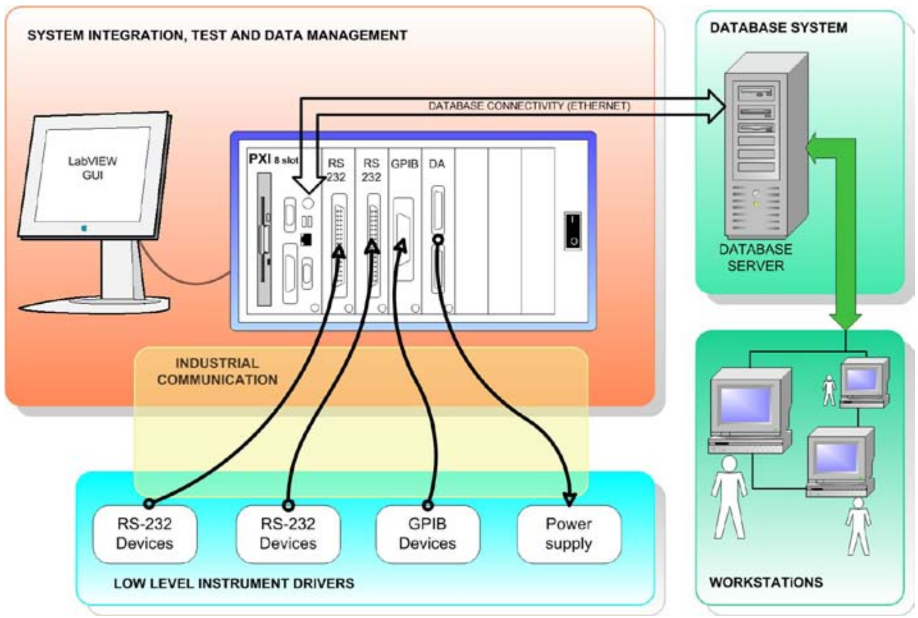

Figure 1: System architecture of the automated measurement system.

3. Architecture of the measurement system

The core of the automated system is the NI PXI-1042 chassis [3], with five modules such as NI PXI-8185 controller [3] (embedded PC), NI PXI-6723 D/A card [3] for controlling the power supplies, NI PXI-8420 and NI PXI-GPIB for communicating with the measurement instruments via RS-232, RS-485 and GPIB [3] (*Fig.1*). This compact form system gives equivalent performance as a PC-based data acquisition and measurement control system but has some added functions, such as trigger buses, increased bus speed, rugged and modular packaging. The different measuring instruments, which can communicate through RS-232, RS-485 and GPIB have been integrated easily in the system, with the help of the above mentioned communication cards (NI PXI-GPIB, NI PXI-8420). In this way also a common development tool, the LabVIEW (for details see [5]), is available to develop the related communication routines (drivers) and the measurement programs too. The measurement results are migrated into a database from where data can be retrieved in non-predicted and predicted way for evaluation and decision support. (For more information about PXI see [4])

There are five electrolytic measurements out of six whose architecture show the same structure (see: *Fig. 2)*. The object of the measurement, the electrolyte, is located inside a double-jacketed vessel. In the external part of the vessel the water is circulated by the thermostat, while the electrolyte is inside the vessel.

The most important parameters are provided by the pH meter and the conductivity meter. Each instrument has got an electrode that can be used to measure the temperature too. Only one of them is used during an experiment. The experimental setup requires the simultaneous operation of four individual instruments such as Thermostat [6], pH meter [7], [8], Conductivity meter [7], [9], Burette. Controlling and following up the temperature precisely is essential during the measurements so the Thermostat device is connected to the system every time. The Burette is only used when the variation of the pH or conductivity value as a function of a composition must be known. The mixing type measurements give the relation of the conductivity or pH to the concentration of the examined component.

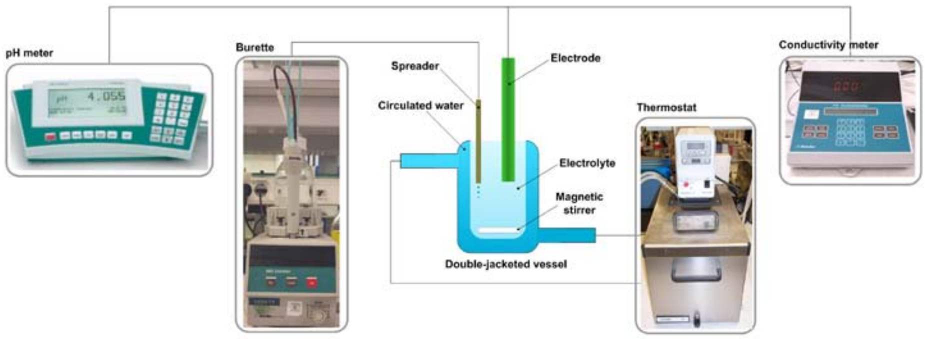

Figure 2: Diagram of the electrolytic measurements.

4. "Conductivity(T)" measurement

The base of the whole software system is a framework which was originally designed to provide a common user interface for the different measurement programs. In spite of the fact that all the measurements have an individual character, they were integrated into the above mentioned framework, in order to manage the communication ports and instruments, and to provide the parallel run of the programs.

The measurement system includes at least 27 different measurements, whose presentation can not be done here. All the measurements have been implemented in a similar manner. Firstly the user initializes the measurement, sets the measurement parameters, launches the execution and leaves the program to run on its own, sending the results of the measurement to a database system. This process is presented afterwards through the "*Conductivity* (*T*)" measurement.

Two instruments are involved in this measurement: the thermostat and the conductivity meter.

Before launching the program the user initializes the measurement. During the measurement the user can choose between two main tab controls ① in *Fig.3*. The "*Set parameters*" tab contains the parameters set of the measurement, while the "*Measurement*" tab shows the state flow of the measurement, graphs and displays. The program executes the same steps cyclically. The state diagram ③ shows the current state of the measurement and the remaining time before the next phase. Firstly the program sets up the temperature. On the temperature graphs ② the temperature of the measuring probe and of the thermostat can be followed up. During the *stabilization time* the temperature of the electrolyte becomes the same as the thermostat's. Through *measuring & saving* phase the important conductivity values ⑤ are measured and stored locally. *The remaining time before the next measurement* is indicated with a progress bar ④. After the *measuring & saving* phase the program calculates the mean value from the stored conductivity data and only the result is migrated into the database. On the ⑦ and ⑧ graphs the conductivity and the temperature as a function of the number of measurements can be seen. These are the most important graphs, because the electrolyte forming can be directly correlated with the temperature. The measurement is ended after the conductivity is measured at all of the settled temperatures. The remaining time before the end of the experiment is shown during the measurements ⑥. The program can be stopped with the *STOP* button ⑨.

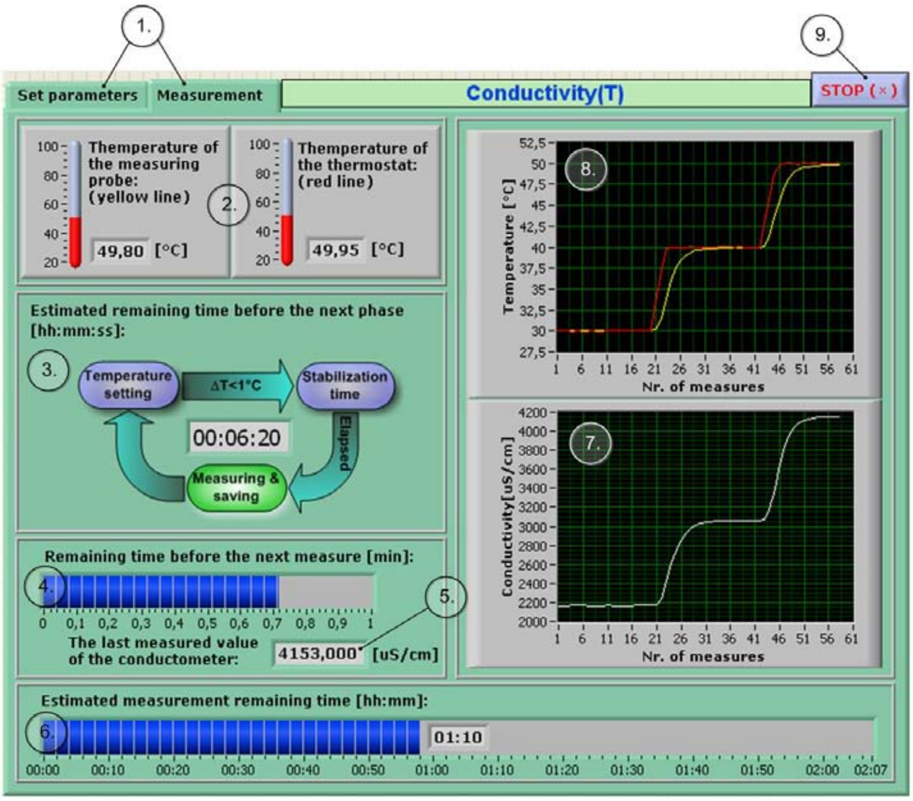

Figure 3: Graphic User Interface (GUI) of the "Conductivity(T)" measurement program.

5. Results

In *Fig. 4* it is demonstrated how decisions are supported by the automated measurement system. Each dot represents a separate "*Conductivity* (*T*)" and "*Sparkling voltage*" measurement at 85 degree Celsius- result obtained by the automated system. By graphical evaluation electrolytes with specific conductivity or sparkling voltage can be selected for further research.

With the help of the currently automated system the forming of an electrolyte as a function of the temperature can be followed up. In *Fig. 5* measurement results of Electrolyte 1 and Electrolyte 2, which has been obtained using the "*Conductivity* (*T*)" measurement program are demonstrated. The conductivity of the electrolyte is measured more than once (usually 10 times) at the specified temperatures. A mathematical mean is calculated from the measurement values at one temperature, which is indicated by dots in *Fig. 5*. As mentioned, the conductivity of the electrolyte significantly influences the electric parameters of the capacitor. Conductivity between 900 and 3000 μS/cm at 30 degree Celsius is considered low, and conductivity values exceeding 10000μS/cm in similar thermal conditions is considered high. As shown in *Fig. 5*, the conductivity of Electrolyte 1 measured at 30 degree Celsius is 1500 μS/cm and the Electrolyte 2 has 2300 μs/cm at the same temperature which indicates low conductivity in both cases, resulting in high breakdown potential. From this reason both electrolytes can be used in high voltage capacitors.

In *Fig. 6* the results of a capacitor type measurement – named ”*ESR*”, mentioned shortly in the second chapter can be seen. The resistance values of a capacitor as a function of frequency at different temperatures are given.

During capacitor development we aspire to obtain as low serial resistance as possible. To achieve this goal a series of experiments have to be done using different types of electrolyte and paper constructions.

As can be seen in the *Fig. 6* the capacitor resistance below zero degrees Celsius is linearly dependent on frequencies up to 1 KHz. For positive temperatures it can be observed that the resistance values have linear variation on frequencies above 1 KHz.

The application areas of the capacitors are based on the frequency dependence of the resistance value in different temperature ranges.

The “*Mixing* (*conductivity with multi temperature*)” measurement is an extended version of the “*Conductivity* (*T*)” measurement, which is completed with one measurement device: a burette. With the “*Mixing*” measurement the conductivity value as a function of a key component concentration of the used electrolyte can be observed on *Fig. 7*. First of all the conductivity of the electrolyte is measured at 25 C°, 40 C°, 60 C° and 85 C° many times (usually 10), without dosing the conductive salt solution. Each dot on *Fig. 7* represents a mathematical mean which is calculated from the measurement values at each temperature. After that a predefined dosage from the conductive salt solution is added to the electrolyte and the measurements of the conductivity at different temperatures are repeated. The measurements are repeated 16 times adding each time a new predefined conductive salt solution dosage to the electrolyte. Finally the “*Mixing*” measurement results in 17 dots at each temperature.

According to the readings the increase of the conductivity of the electrolyte is in direct relationship to the quantity of the conductive salt solution.

The results can be applied in order to set up the conductivity value of an electrolyte.

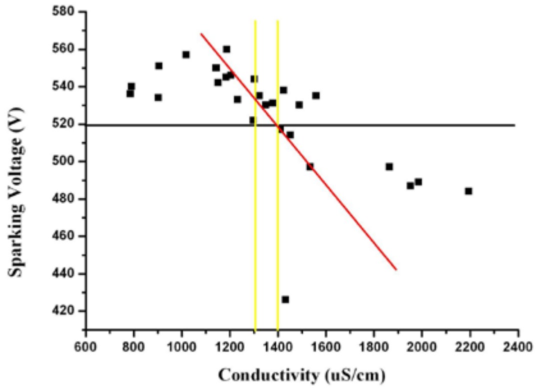

Figure 4: Conductivity vs. Sparkling Voltage of various electrolyte at 85 degrees Celsius.

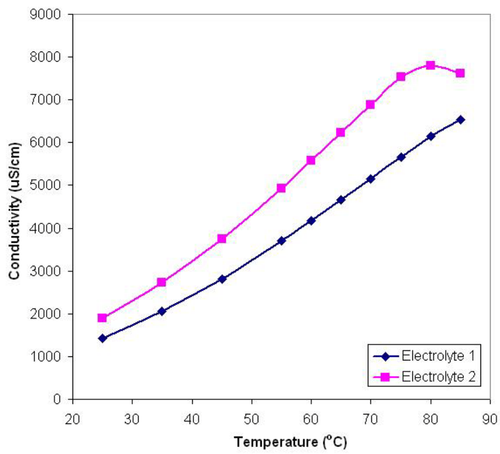

Figure 5: Result of the measurement of conductivity as a function of temperature of Electrolyte 1 and Electrolyte 2.

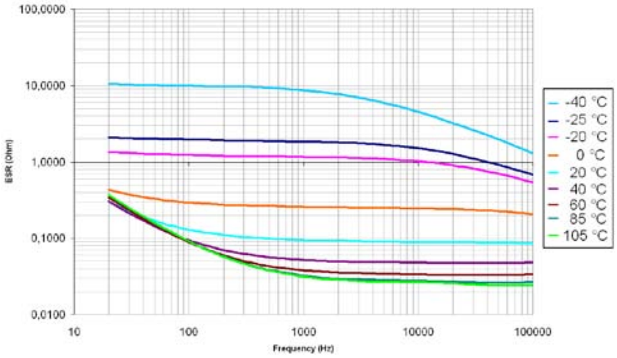

Figure 6: Result of the capacitor resistance (ESR) as a function of frequency at different temperatures.

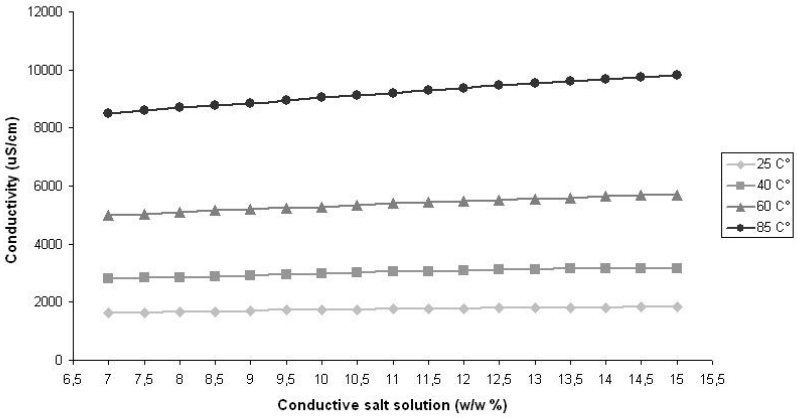

Figure 7: Variation of conductivity of Electrolyte 1 as a function of the conductive salt solution concentration.

6. Conclusions

More than 27 different electrolyte and capacitor measurements, have been automated. All the measurements have been implemented in a similar manner. Firstly the user initializes the measurement, sets the measurement parameters, launches the execution and leaves the program to run on its own, sending the results of the measurement to a database system, from where the data can be retrieved in a predefined or a non-predefined way. After validation of the MAS, there are many advantages as making the measurements more precise and more reliable, fault tolerant (i.e.: monitoring functions are implemented like detection of missing of line voltage, open gate etc.), running multiple measurements in parallel, which all contribute to speed up the research and development of new components and devices.

The developers do not have to encroach. The developed measurement system controls and harmonizes the different devices and supervises their work. The user can simply check the measurement phase by a glance at the screen. The program estimates and displays the running time of the experiment, allowing for the researchers working on the Lab to manage the instrumental resources in time and to schedule in advance (for hours, weeks and months) the new measurements. Another big advantage is the database system, which stores the result of each measurement in an easy searchable way. Measurement reports and diagrams can be made automatically and the results can be reused in later research.

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