View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Electronic National Technical University "Kharkiv Polytechnic Institute"...

Neuburger M., Lehner W-D.,
Neuburger N.

Germany
Esslingen

Hochschule Esslingen

LIFETIME PREDICTION FOR ELECTRICAL DRIVES – LIMITING FACTOR CAPACITY

Problem Statement. With a rising number of hybrid or electrical vehicles as well as an increased number of distributed power generators, more and more high voltage capacities are applied for energy conversion. These components with a voltage range larger than 200 V are typically taken as dc-link capacitors or as part of reactive power compensation systems. Besides the already pointed out new functional areas it can also occur that new loads are applied to those components within a regular use. Therefore new life time failures can occur which may arise from the capacities' lifetime [1]. The reason for this often originates due to an unknown history of these components. Here a general test procedure needs to be derived to determine the capacities condition ensuring to have a proper working device. This procedure is proposed in this talk.

Function. As a first order approach, the energy storage ability of a capacity can be described with the standard formula for the plate capacity. Typically C named as the capacities' value, ε_0 is the dielectric constant, ε_r the relative dielectric constant of the dielectric material, A the size of the capacities' plates and d the distance between the plates. In order to achieve a maximum capacity, A and / or ε_r need to be maximized whereas d should be as small as possible. Of course all three parameters are optimized in parallel.

In case of the electrolytic capacity, an aluminum plate, carried out as foil 1 in fig. 1, is used as anode.

The anode itself is placed in an electrolyte. A current based anodic oxidation of the anode, also called formation, generates amorphous sapphire (Al_2O_3). This oxide is isolating and forming the dielectric material between the two plates of the capacity. Due to the chemical growth, it can be realized very thin, resulting in a small d. Besides, the plate size A is increased due to a roughness achieved by the oxidation process. The cathode, actually formed by the electrolyte, needs to be electrically contacted, what is realized by a second aluminum plate (foil 2). Finally both plates are electrically connected (contact 1 and 2) and the stack is rolled up to the plate capacity. A housing around the plates keeps the electrolyte inside.

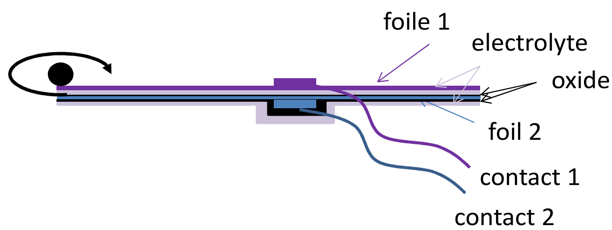

Fig. 1: Sketch of an aluminum based electrolyte ca-

Characterization. In this work a bunch of 20 aluminium based electrolytic capacities is investigated. The capacities are ordered via distributor to have a nominal value of C = 390 µF without of any special request. These components then are numbered as C_1 to C_{20}. From the imprint the age could be identified to be two years old. Now characterization starts to determine the actual condition. This can be done by taking a look at the relevant internal parameters. For this reason a standard equivalent circuit according to fig. 2 is taken.

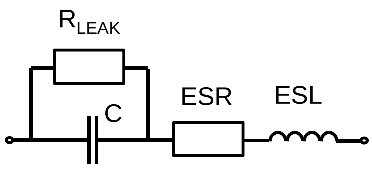

Fig. 2: Equivalent electrical circuit of an aluminum based electrolytic capacity.

The internal circuit consists of an electrical serial resistance (ESR), electrical serial inductivity (ESL), the internal isolation or leakage resistance (R_{LEAK}) as well as the capacitance (C). According to the datasheet, the internal leakage resistance is to be larger than 330 kΩ. The phase shift between voltage and current of tan $\delta < 0.15$ is given furthermore. Finally a continuous load of current ripple ΔI_L = 1.3 A is allowed as maximum.

In a first step, the dc-leakage resistance R_{LEAK} is identified by applying a constant voltage of 350 V. Having a typical decreasing dc-current with the time, resulting in a partial reformation, the remaining current led to leakage resistances within the specification an in the range of mega ohm. However C_2 and C_5 showed a R_{LEAK} = 850 kΩ.

In a second step, small signal measurements are performed. Due to the high R_{LEAK}, the resistance R_{LEAK} can be neglected for this measurement without of any impact on the determination of the rest of the internal components. Taking a look at the electrical equivalent circuit now, a band pass filter with a frequency dependent behavior can be estimated. The performed small signal measurements should validate these principle results however the impedance itself is hard to interpret. Taking into account that the ESL is in the order of Nano henry it becomes relevant with a frequency range larger than several megahertz. The operational point for the electrolytic capacity is in the range of kilo hertz. Hence, a first order model of ESR in series to the capacitance is applied to the small signal measurements. The internal ESR and capacitance is extracted according to fig. 3.

The small signal measurements were performed within a frequency range between 20 Hz and 2 MHz. The applied voltage consists of a constant dc-bias of 40 V with overlying small signal amplitude of 1 V. The results show a decrease of the serial resistance with the frequency. The capacitance itself remains constant until it decreases as well upon a certain frequency. The reason for this behavior can arise from a serial resistance on the plates which prevents charging the full area A for higher frequencies. For low frequencies were the total area is covered with charge, the distance the average charge has to move, increases and with it the series resistance. The other way round, this effect cuts off the outer areas of the capacities plates for higher frequencies resulting in a drop in series resistance and capacity.

The measurement results are typical for the capacities except C_{17}. This behavior is unusual because here the value even increases with the frequency. It is important to note that it is the first time C_{17} shows unexpected behavior.

Next, large signal measurements are performed. Here, the capacities are operated with an adjustable ripple current still in specification. The components are charged and fully discharged. The maximum voltage as well as the period time mainly depend on the charging and discharging current as well as the correlated charging / discharging time. The capacity's average of the current is zero and the maximum voltage is limited from external.

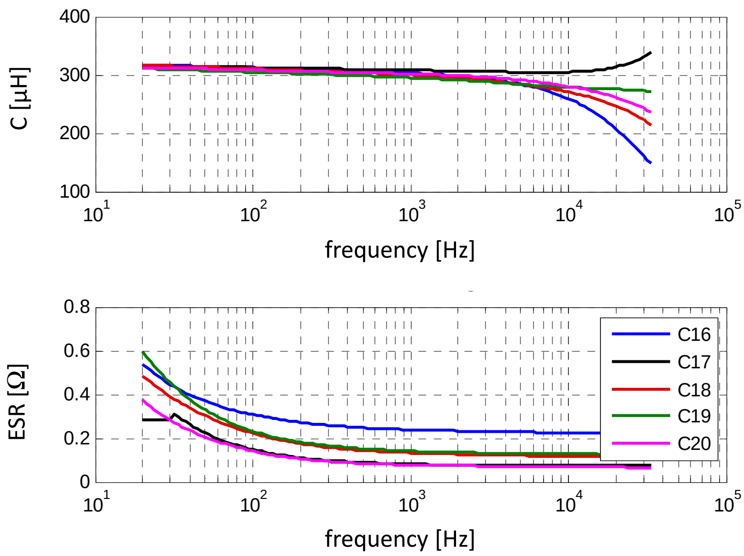

Fig. 3. Small signal measurement of some of the aluminum based electrolytic capacities.

One principle measurement example is shown in fig. 4 for a ripple current of 800 mA and a maximum charging voltage of 220 V, were five capacities were driven in parallel. During the entire setup, the cable lengths on the anode as well as on the cathode have been identical to prevent unwanted parasitic effects.

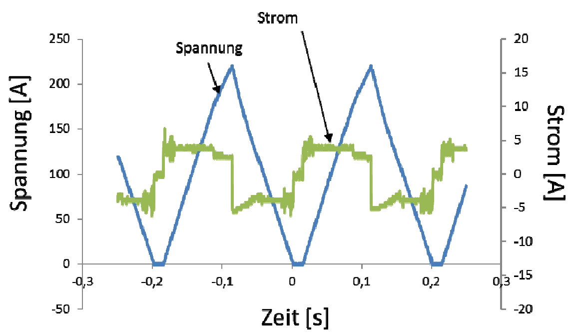

Fig. 4. One principle current and voltage profile for an applied large signal measurement.

The measurement started with a ripple current of zero. Next the load and correlated with it the ripple current is increased in steps up to 1.2 A per capacity. During the ongoing measurement the surface temperature of all capacities is measured. Each operational point is hold until a thermal equilibrium is achieved. Depending on the working point it can take more than 30 minutes each. The temperature itself is measured by an infrared camera and is plotted versus ripple current, shown in fig. 5.

For all devices under test an increase in surface temperature is determined with increasing ripple current. In fig. 5, it can be seen that all capacities are heating up similarly except C_{20} which heats up stronger. The uneven temperature curve for this capacity arises from variances in the measured surface point.

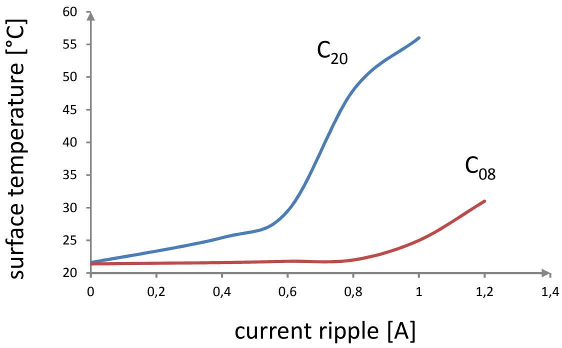

Fig. 5. Surface temperature versus ripple current of some capacities.

Results / Discussion. As can be seen from the measurements, the capacity C_{20} seems to behave like a classical capacity according to the standard characterization procedure however performing large signal measurements it turns out that this device generates a thermal runaway. The reason for this behavior is not fully understood. It could arise from defects in the oxide, which are activated under large signal load conditions. These results strongly indicate that aluminum based electrolytic capacities with unknown history should be characterized in small as well as large signal conditions to ensure proper working. Otherwise this capacity will age much faster compared to its counter parts and finally will limit the control unit's lifetime.

References:

1. Lewis, E.E., Evanston, Hsin-Chieh Chen, „Load-capacity interference and the bathtub curve", Reliability, IEEE Transactions on, Vol.:43 , Issue: 3, 1994.