DIELECTRIC RELAXATION SPECTROSCOPY WITH KEITHLEY 617 IN WIDER FREQUENCY RANGE

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ABSTRACT

The article describes Keithley 617 electrometer in discharge characteristics measurement for dielectric relaxation spectroscopy object. The first chapter deals with the basic electrical parameters of dielectric and insulation materials. The next chapter describes dielectric relaxation spectroscopy theory and a possible implementation of measuring equipment used in time domain. Features of available electrometer are discussed in the third chapter. The fourth chapter contains the results of experimental test of electrometer preamplifier and scanned discharge characteristics. Main features of existing experimental measurement are summed up in the final chapter.

1. INTRODUCTION

We know from the theory that an ideal dielectric or an insulator is made of substance, which contains charges bound only by electrostatic forces [1]. Real dielectric materials contain not just bounded charges, but even some free charges, which causes its adverse electrical conductivity. The physics of dielectrics consider processes, which take place in materials due to the presence of electrical field, and then mentioned motions of electrical charges. In dielectrics designed for capacitors, the basic physics process is dielectric polarization, which is the effect combined with motion of the bound charges. In real dielectrics we should actually consider electrical conductivity and combined effects of free charge motion. The electrical properties depend on the chemical structure, the state and the stage of the dielectric material. The basic electrical values describing properties of dielectrics in electrical field over specific temperature, humidity and frequency are: relative permittivity ε' (-), internal resistivity ρ_V (Ωm), surface resistivity ρ_P (Ω), loss factor $tg\delta$ (-), breakdown strength E_P (Vm^{-1}).

Dielectric polarization is the effect, where electrical bound charges move by activity of outside or inside field from its balanced positions to new positions for low finite distances. If material contains polar molecules, they orient in the direction of electric field. The polarization scale of material is polarization vector and relative permittivity. A few polarization mechanisms usually exist in dielectric materials. The weaker of them can be overlay by more powerful mechanisms. We make out two types of polarization from polarization time: flexible and relaxation polarization. The flexible polarizations can quickly pass without power losses. These polarizations are frequency independent in the radio frequency range. The relaxation polarization consists in the following effect. The polarization increases slowly after electric field application and has similar effect after electric field is removed. The time which is necessary to stabilize these effects is relatively long. The time dependence of relaxation polarization after removing electrical field is characterized by response function. Study and analysis of this function is the basic subject of dielectric relaxation spectroscopy. The response function is in first simplify exponential function with time constant called relaxation time. The slow polarizations are temperature dependent and attended by dielectric power dissipation.

2. DIELECTRIC RELAXATION SPECTROSCOPY

Many methods exist for dielectric and insulation materials diagnostic. Dielectric relaxation spectroscopy (DRS) is nondestructive method [1]. From global look DRS is broadband measuring method with frequency range starting from about a few Hz and finishing at frequencies of optical radiation. The focus of DRS is to get complex permittivity ($\hat{\varepsilon} = \varepsilon' - \mathrm{j}\varepsilon''$) relation on frequency and eventually other parameters. The most important parameter, which makes fundamental interest in dielectric parameters, is work temperature, eventually possibility to submit the tested sample by temperature deterioration process. Two DRS methods are used in radio frequency range: in the time domain or the frequency domain. Frequency domain DRS is based on alternate measurements. A dielectric sample is exposed into harmonic voltage activity with required frequency range and we can find the response, which is amplitude and phase of harmonic current. Time domain DRS is used for frequency range from very low frequencies about a few μHz. The dielectric sample is exposed to step change voltage and measured response is time dependence of dielectric current.

Time domain DRS is the subject of this paper. This measurement set records time response (current) by step changing voltage [2]. It’s necessary to transfer the recorded data into frequency domain by suitable way [3], only this transformation allows us to fully use time domain data. We know from the theory, that complex permittivity and measured discharge characteristic are reciprocally transferable by of Fourier transformation:

$$\hat{\varepsilon} = \varepsilon_\infty + (\varepsilon_S - \varepsilon_\infty)\int_0^\infty \varphi(x)\mathrm{e}^{(-j\omega x)}dx, \tag{1}$$

where ε_∞ is optical permittivity, ε_S static permittivity, $\varphi(x)$ decay function, expressed the time development of discharging current. One of the simple methods for approximately quick calculating loss number from measured discharge characteristic in time domain, is use of Hamon’s approximation:

$$\varepsilon''(f) = \frac{i(t)}{2\pi f C_0 U_C}, \tag{2}$$

where $i(t)$ is measured discharge current in time, $f = \frac{0,1}{t}$ frequency, C_0 geometric capacity of the sample, U_C is the value of charging voltage. Like every metering technique, time domain DRS has also specific troubles dedicated by measuring circuit parameters. The measured time dependence is monotonously increasing or decreasing function and measured values are very small, the range is usually about 1.10^{-14} A, so not noise resistant. Corresponding measured maximum time is very long, for example up to a few days. The long measurement times require the stability of measured internal area as temperature or humidity. By explicit facts, time domain DRS demands full computer controlled workplace, for data record and processing. In fig.1 taken from [4] is displayed possible solution of time domain measuring circuit. Personal computer of this system reserves at least measuring control and data record.

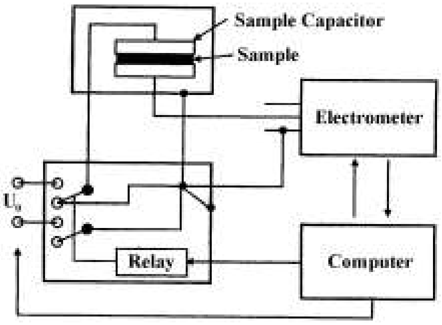
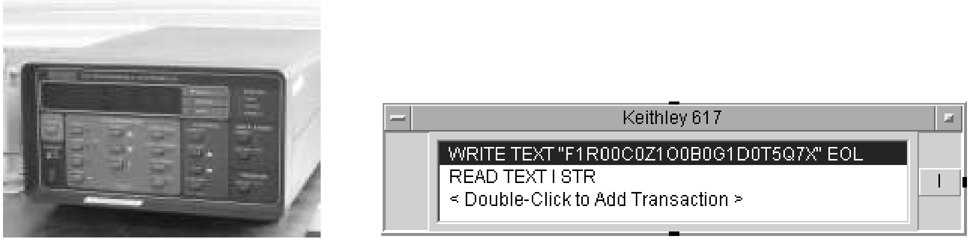


Fig. 1: Basic circuit for time domain measurements

3. DIELECTRIC RELAXATION SPECTROSCOPY WORKPLACE

As it was said in previous chapter, we need digital controlled electrometer for time domain DRS measuring. There is available programmable electrometer Keithley 617 on our workplace, which has required hardware equipment and software. It's high sensitive device, which also contains auxiliary voltage source [5]. The electrometer will work at very small currents measuring mode for our needs. Certain disadvantage of this instrument for eventually precise DRS measuring consists in insufficient quick sampling of input signal and in impossibility to the sample input signal with accurate time independent on the personal computer. Used measuring workplace is in principle realized from fig.1.



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WRITE TEXT "F1R00C0Z1O0B0G1D0T5Q7X" EOL
READ TEXT I STR
< Double-Click to Add Transaction >
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Fig. 2: Keithley 617 and VEE Pro software

This experiment used set consisted of shield metal box, the tested dielectric sample with electrodes and four correed relays, which switch the circuit to charging dielectric or its discharge over current reading electrometer. As control software there was used graphical programming language Agilent Vee Pro [6]. The discharge current measuring ran with variable time sampling by reason of data reduction. Variable time sampling is realized by step change of constant time interval after selected time intervals.

4. TESTING

As it was mentioned above, we should extend frequency range of the existing workplace. Measuring to higher frequencies so shorter sampling intervals can be realized by taking of electrometer analog output, but only on condition that electrometer input amplifier has enough bandwidth. Following this require of frequency characteristic it was necessary to verify, whether instrument amplifier is right for our interest. The metering passed using Agilent 32220A generator and Agilent 54621A oscilloscope. Electrometer input amplifier was measured in current mode on 200 µA range. The harmonic signal from generator was brought through serial resistor to electrometer input. It provided safe excitation of electrometer input by generated current. Because of spurious signals on workplace the metering wasn't running on the most sensitive electrometer range. The generator output was used to suppress ground loop effect, because this output is isolated from device chassis connected with equipment grounding conductor. Found frequency characteristic is displayed in fig. 3, however the results showed very low cut off frequency of instrument amplifier for our object, which value is about 20 Hz. Due to this fact, there's no point in increasing sampling rate with external analog to digital converter upon standard sampling rate of instrument built-in converter. Internal converter offers sample time 330 ms in free running mode.

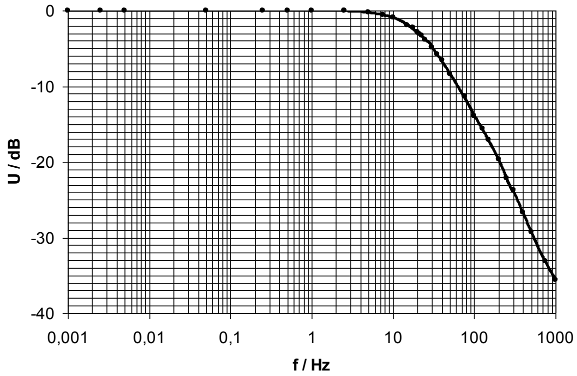

Fig. 3: Frequency characteristics of Keithley 617 amplifier

The next picture presents found resorption characteristic of the dielectric sample and frequency dependence of its loss number, which was calculated by means of Hamon's approximation. The tested plastic film sample with electrodes of 15 µm thickness and 19 mm diameter was measured with realized workplace. In measured frequency function wasn't located any detectable relaxation maximum.

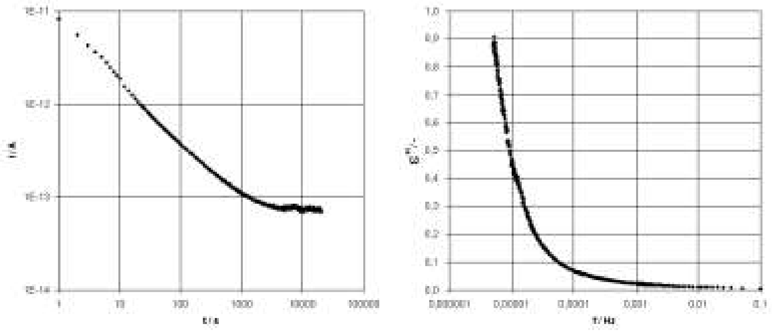

Fig. 4: Measured discharge characteristic and loss number dependent

5. CONCLUSION

From executed experimental metering follows, that existing workplace with available electrometer isn't possible to extend for measuring at shorter time intervals, because instrument amplifier hasn't enough bandwidth. The auxiliary output cannot be used to sample more quickly than the internal analog to digital converter; in this case the measuring accuracy would be unsuitable at shorter time intervals by decreasing amplification of electrometer amplifier. The only way, how to increase the use value of the instrument, consists in improving the shielding, which provides to us make the best of electrometer on its most sensitive range. For the biggest possible metering extension to lowest frequencies, it will be necessary to implement digital filtration of measured signals according to ambient noise.

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