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DIELECTRIC CHARACTERIZATION OF UNSATURATED POLYESTERIMIDE RESINS FOR TRACTION MOTORS IMPREGNATION

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SUBJECTS

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1. PRESENTATION OF THE HOST INSTITUTION

1.1. UNIVERSITY OF SALERNO

The University of Salerno (Università degli Studi di Salerno) has very ancient origins as it is one of the oldest universities in Europe together with Paris and Bologna.

The Salerno School of Medicine was founded in the 8th century reaching its utmost splendor during the Middle Ages. The university remained active until 1811, when it was closed by royal decree under the Napoleonic government of Joachim Murat. In 1944 the university was re-opened by King Vittorio Emanuele II, and the Istituto Universitario di Magistero "Giovanni Cuomo" was founded, which became state-controlled in 1968 as the Facoltà di Magistero of the University of Salerno.

Within a few years other faculties were founded and they formed the basis of an important university. In 1988, the University, which now has over 43,000 students, moved to the village of Fisciano in the Irno valley, a few kilometers from Salerno. Its structure is that of a university campus and its modern buildings offer many efficient services for teaching, research and student life in general.

The University of Salerno, one of the largest in southern Italy, is still growing. The presence of multimedia facilities, halls of residence, a modern library, as well as places to meet and eat, and green spaces make it an excellent university college and a pleasant place to study. [1]

1.2. LCEM

This study was carried out in the Laboratory of Electromagnetic Characterization of Materials (LCEM), whose research consists of methods and techniques for the characterization and modelling of materials, those based on innovative polymers and composites, the design and optimization of electrical and electronic components and systems. In particular, the skills of the LCEM team concern the following topics:

- Characterization and electromagnetic treatment of innovative materials and components;
- Development of innovative diagnostics for the evaluation of the properties of materials;
- Innovative methods for robust design.

The lab activity is based on accurate comparisons of theoretical models of physical mechanisms and data from experimental tests. The achieved skills make it possible to design and carry out tests on materials and components both in accordance with international standards and on specific requirements. [2]

2. INTRODUCTION

2.1. BRIEF HISTORICAL OVERVIEW OF RAILWAY ELECTRIC TRACTION

Electric motor is the machine intended to convert electrical energy into mechanical energy (rotation). Its basic purpose is to drive all types of mechanical systems and, since the end of the 19th century, it has been widely applied in the rail transport segment.

After the Great War, the price of coal undergoes a significant increase, and an important amount of electricity is produced from water resources. The performance of electric locomotives is greatly improved, so much so that it outperforms the steam ones by withstanding almost double the mass with almost double the speed. Moreover, there is no smoke emission, so considering tunnel sections, it is no longer necessary to wait for the dispersion of the smoke before retracing the same section, providing an advantageous increase in railway traffic. [3]

For these reasonable advantages, electric traction was quickly applied around the world, particularly for routes with dense traffic, like urban and suburban railways, or long-distance, high-speed lines which needed electric traction to obtain the speeds required for inter-city travel. [4]

2.2. PROPOSED RESEARCH

In the manufacture of electric motors, the different materials applied are constantly being developed and characterized. Among such materials, the presented object of study: impregnation resins employed to insulate asynchronous motors for railways traction.

The increased performance of these motors has led to an increase in operating temperatures, which requires the use of resins that are more chemically stable and resistant to heat. Resins based on imide functions have been shown to be adequate in these aspects. Therefore, this work will approach the dielectric characterization of unsaturated polyesterimide resins for the mentioned application, to particularly perform comparative analysis of electrical impedance values in correlation with different polymerization conditions.

3. STATE OF THE ART

3.1. BASIC STRUCTURE OF TRACTION MOTORS

Traction motors, like any electric motor, have two fundamental parts: stator (stationary component) and rotor (moving component). The first is attached to the motor frame and its function is to amplify the magnetic flux generated by the electric current applied. It is basically constituted by stacked circular steel sheets with characteristic grooves, where coils are placed. The rotor has a similar construction to the stator, it is attached to the shaft and both will rotate with the applied magnetic field. **Figure 1** shows a schematic of an AC motor, the type used for most equipment manufactured nowadays.

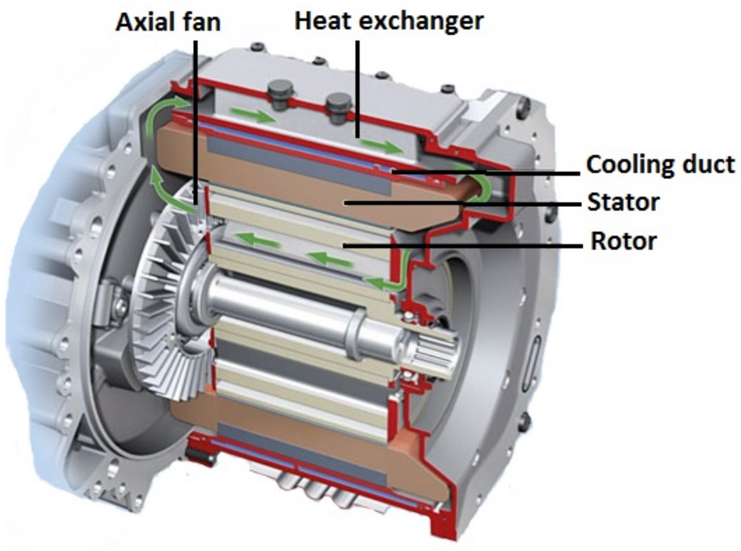

Figure 1 *– Schematic of an AC traction motor. Source: https://www.newkidscar.com/electric-car/electric-traction-motor-construction/*

3.1.1.RESIN IMPREGNATED COILS

The impregnation process aims to fill the empty spaces between wires of wound stators or rotors, providing the following characteristics:

- Higher dielectric strength;
- Increased mechanical strength;
- Greater thermal conductivity;
- Superior protection against the ingress of water, chemical and containments.

For this purpose, impregnating materials based on polyester, epoxy or silicone are applied in the liquid state to facilitate penetration (**Figure 2**).

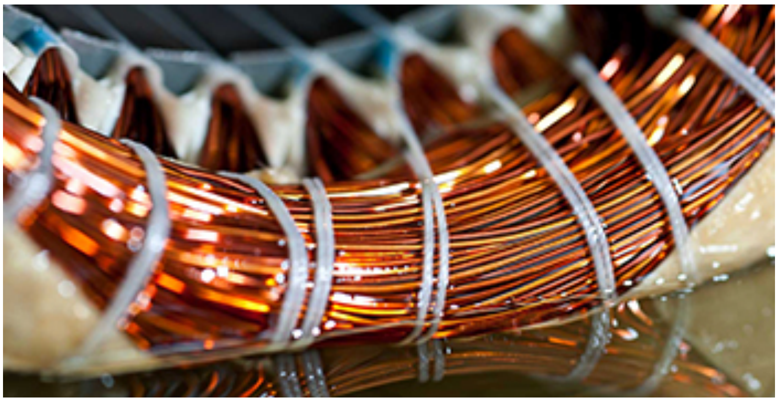

Figure 2 - Dip-roll impregnation process. Source: Elantas Europe S.r.l.

In the manufacture of medium and high voltage motors, the process usually applied is vacuum pressure impregnation (VPI), by which a fully wound electric apparatus stator or rotor is completely submerged in resin. Through a combination of dry and wet vacuum and pressure cycles, the resin is assimilated throughout the insulation system. Once thermally processed, the impregnated windings become a monolithic and homogenous structure (**Figure 3**). [5]

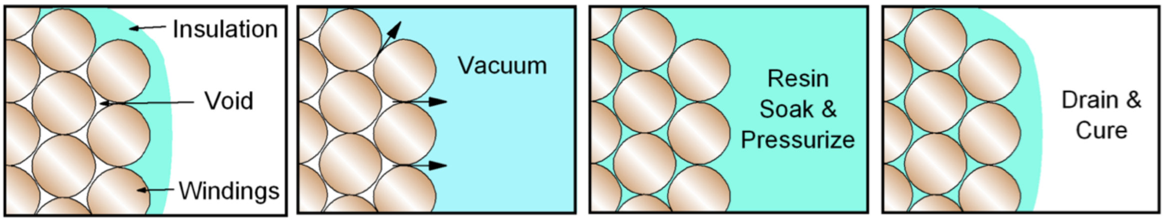

Figure 3 - Vacuum pressure impregnation process. Source: Teledyne Hasting Instruments

3.2. UNSATURATED POLYESTERIMIDE RESINS

Among the methods used to provide more resistance to unsaturated polyester resins is the addition of imide functions, either at the end of the molecules or in the backbone. In the first case, unsaturated polyesterimide oligomer disfunctionalized imide is diluted in styrene, resulting in unsaturated polyester resins with terminal functions of imide. Therefore, the unsaturated polyester structures are partially modified to improve their properties. The unsaturations located on the end chains do not participate in the copolymerization reaction with the reactive diluent. Consequently, these end chain unsaturations do not take part in building the 3D network, providing few improvements to the resin properties. [6]

The other method is the modification of unsaturated polyester chains by incorporating imide structures in the backbone, thus using directly unsaturated polyesterimide prepolymers. This method provides many more improvements in thermal and mechanical properties, but then an issue of imide homopolarization occurs. The formation of polyesterimide blocks with high molar masses tends to increase the viscosity of the resin that constitutes a problematic implementation. [6]

The syntheses of polyesterimide resins are generally performed in three steps [7,8]. The first step consists of the synthesis of the unsaturated polyesterimide prepolymer, which involves a polycondensation reaction between hydroxylamine and a heated anhydride. This is followed by a radical copolymerization reaction between the unsaturations of the prepolymer and those of the reactive diluent, which is generally styrene or vinyltoluene [9]. This copolymerization step is needed to form the 3D cross-linked network (**Figure 4**), which consists of transition of the polymer from a liquid state to a viscoelastic one.

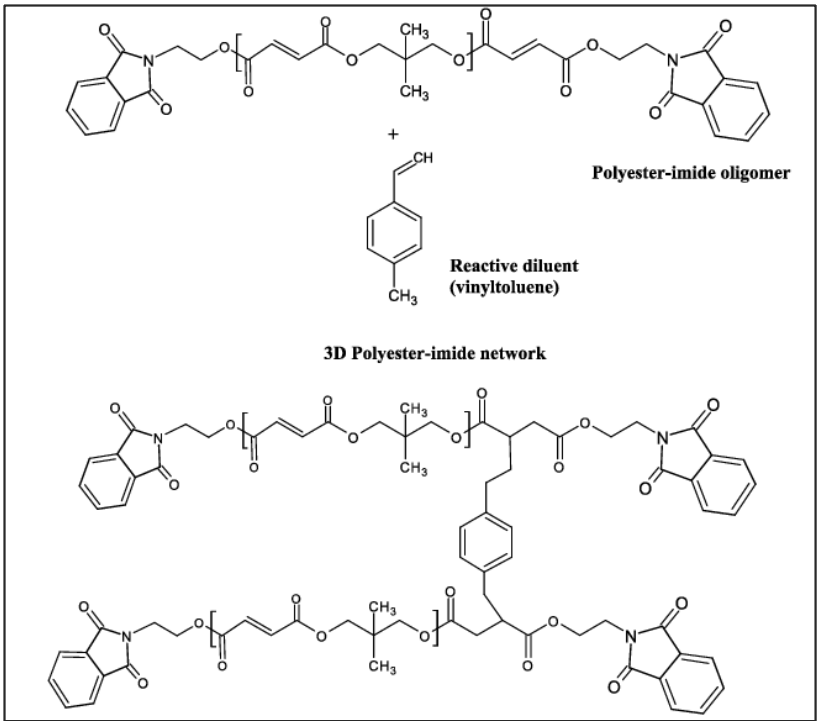

Figure 4 *- An example of the cross-linking process diagram using a polyester oligomer with end chain imide functions and a reactive diluent such as vinyltoluene*

3.3. DIELECTRIC CHARATERIZATON

Considering the intended application of the material, dielectric properties are the main interest of this study, in particular the impedance. Electrical Impedance is the total opposition that a circuit presents to alternating current. It changes according to the components in the circuit and the frequency of the applied AC. [11]

In a circuit supplied by DC, resistance is the ratio of applied voltage (V) to resulting current (I). This is Ohm's Law:

$$R = \frac{V}{I}$$

An alternating current regularly reverses its polarity. When an AC circuit contains only resistance, the circuit resistance is determined by Ohm's Law, too. However, when capacitance and/or inductance are present in an AC circuit, they cause the voltage and current to be out of phase. Therefore, Ohm's law must be modified by substituting resistance (*R*) for impedance (*Z*), which presents magnitude (|*Z*|) and phase (θ). Ohm's Law becomes:

$$Z = \frac{V}{I} = R + jX$$

Where *Z* is a complex number, it has a real component (*R*) and an imaginary component (*jX*), called reactance. When signal frequency increases, the capacitive reactance (X_C) decreases, while the inductive reactance (X_L) increases. This leads to changes in the total impedance as a function of frequency. From there, it is possible to determine:

$$|Z| = \sqrt{(Z_{real})^2 + (Z_{imag})^2} = \sqrt{R^2 + (X_L - X_C)^2}$$

Where $\quad Z_{real} = |Z|\cos(\theta)$ and $Z_{imag} = |Z|\sin(\theta)$

Therefore, $\quad \theta = tan^{-1}\left(\frac{Z_{imag}}{Z_{real}}\right)$

Instruments commonly used to measure this physical property are LCR meters (**Figure 5**), in which the sample is positioned between cylindrical electrodes, as shown in **Figure 6**.

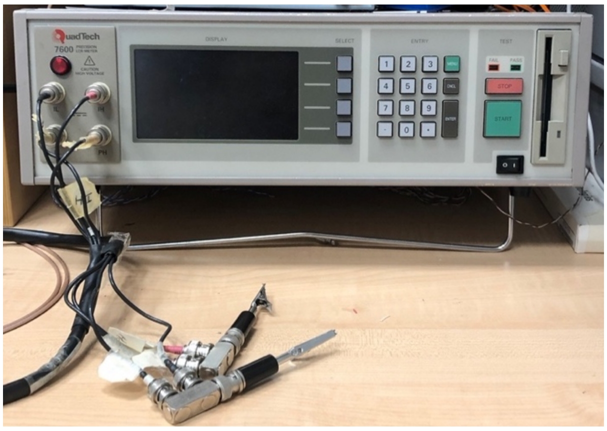

Figure 5 *- Quadtech 7600 LCR meter*

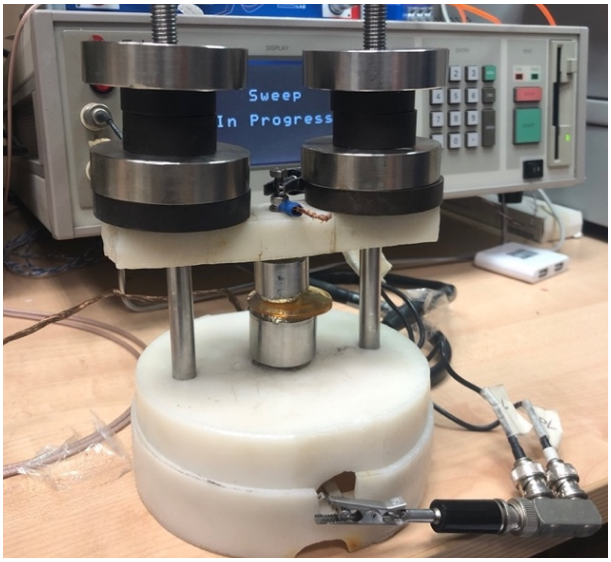

Figure 6 *– Experimental setup of the LCR meter*

Since impedance is expressed as a number on a complex plane, LCR meters measure its magnitude and the phase difference between current and voltage waveforms (**Figure 7**). For a perfect resistor, the voltage drop and current are always in phase with each other, and so the impedance angle of a resistor is said to be 0°. For a perfect inductor, voltage drop always leads current by 90°, and so an inductor's impedance phase angle is said to be +90°. For a perfect capacitor, voltage drop always lags current by 90°, and so a capacitor's impedance phase angle is said to be -90°. [12]

$$\dot{Z} = \frac{\dot{V}}{\dot{I}} = \frac{|V|\angle\theta_V}{|I|\angle\theta_I} = \frac{|V|}{|I|}\angle(\theta_V - \theta_I) = |Z|\angle\theta$$

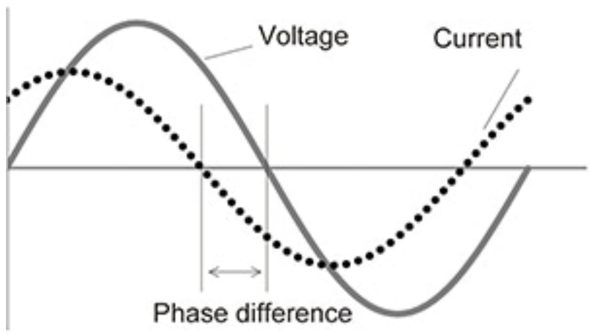

Figure 7 *– Phase difference (θ) between voltage (V) and current (I). Source:* [*https://www.hioki.com/global/learning/usage/lcr-meters_1.html*](https://www.hioki.com/global/learning/usage/lcr-meters_1.html)

Nevertheless, the measurement frequency of LCR cannot be displayed graphically and works only for lower frequency ranges (~ 10Hz to 20MHz). For higher frequency ranges (~ 1MHz to 3GHz), more advanced equipments known as impedance analyzers are employed (**Figure 8**). The accuracy of both equipment is similar, ranging from 0,01% to 1%.

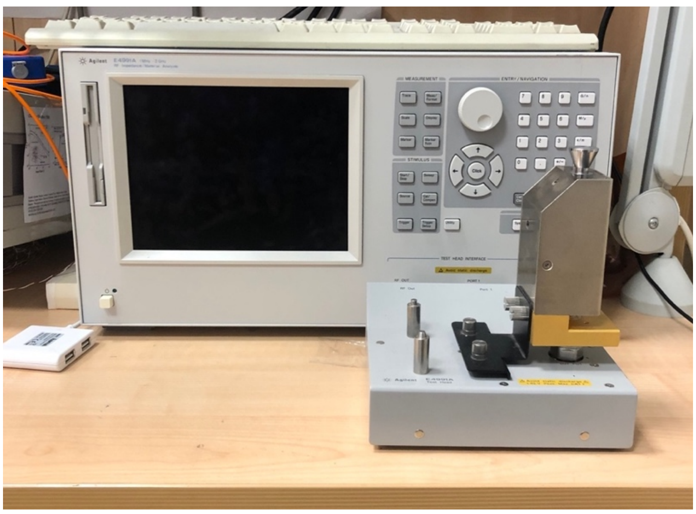

Figure 8 *- Agilent E4991A RF Impedance/Material Analyzer*

4. EXPERIMENTS

The three analyzed samples are commercial unsaturated polyesterimide resins (**Figure 9**). These resins are one-component (no additive or hardener added), characterized by low viscosity, thermal class higher than 180°C and Volatile Organic Compounds (VOC) free. The adopted acronyms are: VOLTATEX, VOTASTAT and DAMISOL. Following a standard procedure, the samples are registered in the laboratory's database, with the proper identification names, dates and descriptions (**Appendix 1**).

Figure 9 *- Analyzed samples*

In this case, different polymerization conditions are presented, which are:

- VOLTATEX: 2 hours at 130°C + 1 hour at 150°C
- VOTASTAT: 16 hours at 140°C
- DAMISOL: 2 hours at 150°C

The following topics contain the impedance curves obtained for each sample in both equipment (**Figure 10** to **Figure 15**), as well as the parameters set in each of them. In the case of the LCR meter, a MATLAB script (**Appendix 2**) was applied to plot the curves, since the text files exported from the equipment presented unit variations and other issues.

4.1. LCR METER RESULTS

Model: Quadtech 7600
Frequency range: 10Hz - 1MHz
Number of points: 50
Average: 5
Parameter 1: |z|
Parameter 2: θ
Temperature: 25°C

VOLTATEX:

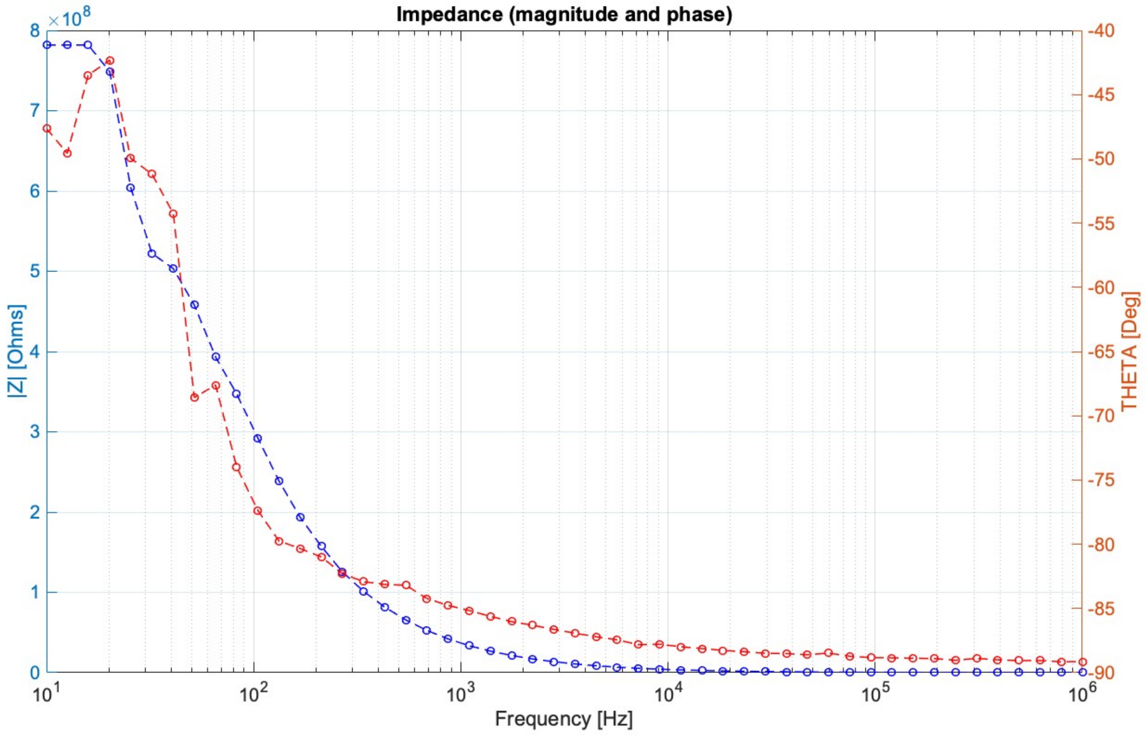

Figure 10 *- Impedance magnitude and phase as a function of the frequency for VOLTATEX*

VOTASTAT:

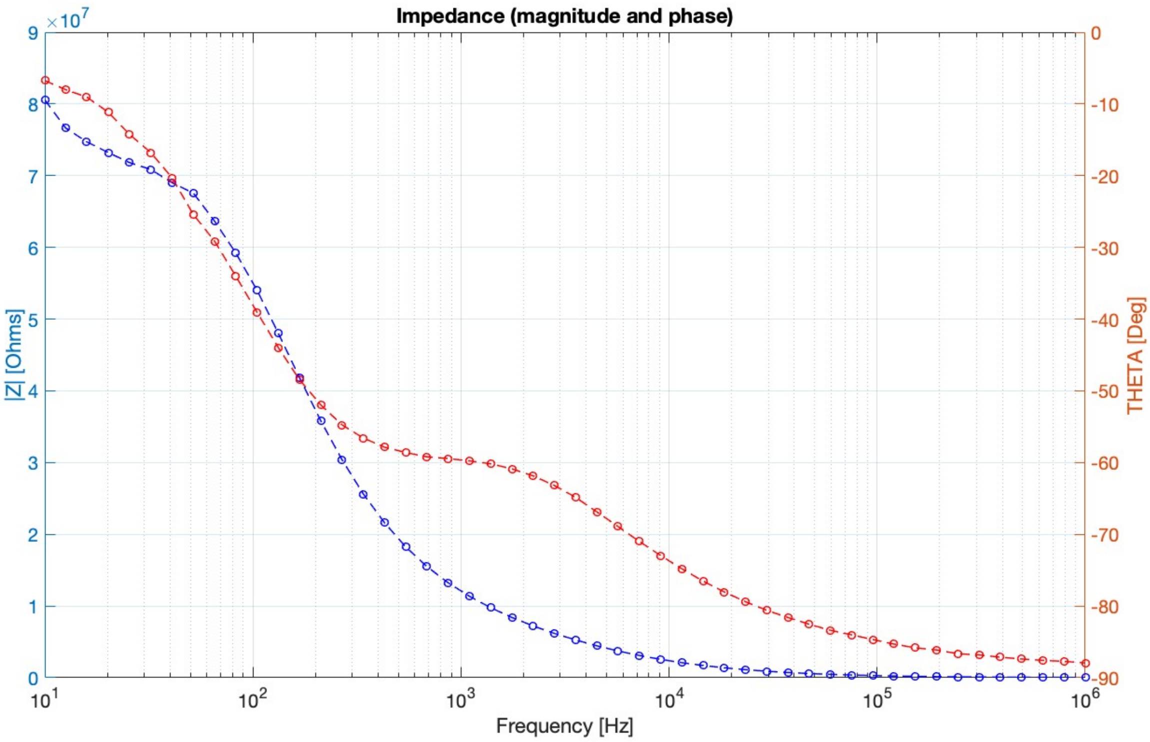

Figure 11 *- Impedance magnitude and phase as a function of the frequency for VOTASTAT*

DAMISOL:

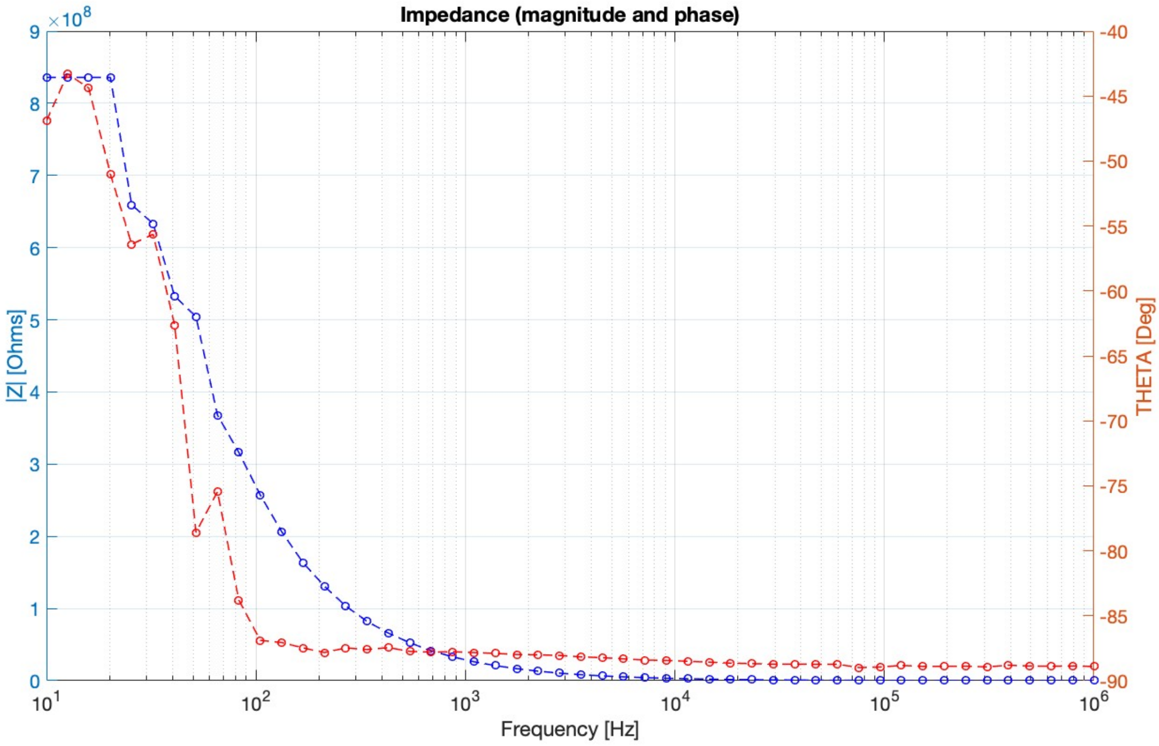

Figure 12 *- Impedance magnitude and phase as a function of the frequency for DAMISOL*

For the frequency range considered, a similar behavior is observed between the curves of VOLTATEX and DAMISOL (**Figure 10** and **Figure 12**): maximum impedance values around $8\times10^{8}\Omega$ at the lowest frequency and minimum values around $4\times10^{4}\Omega$ at the highest frequency. There is also a similarity in the phase curves, that range from approximately -47° to -90°, not showing a pure dielectric character of both samples, but a combination of resistive and capacitive character over most of the frequency range. Given the polymerization conditions of these two resins (relatively close curing times), the similar behavior was expected.

Regarding VOTASTAT (**Figure 11**), the phase curve puts in view a sharp transition between the resistive (≈ 0°) and capacitive (≈ -90°) character of the material. The sample presented significantly lower values of impedance at low frequencies when compared to the other two, with a maximum magnitude value of $8\times10^{7}\Omega$.

4.2. IMPEDANCE ANALYZER RESULTS

Model: Agilent E4991A RF
Frequency range: 1MHz – 3GHz
Number of points: 201
Average: 5
Parameter 1: |z| real part
Parameter 2: |z| imaginary part
Temperature: 25°C

VOLTATEX:

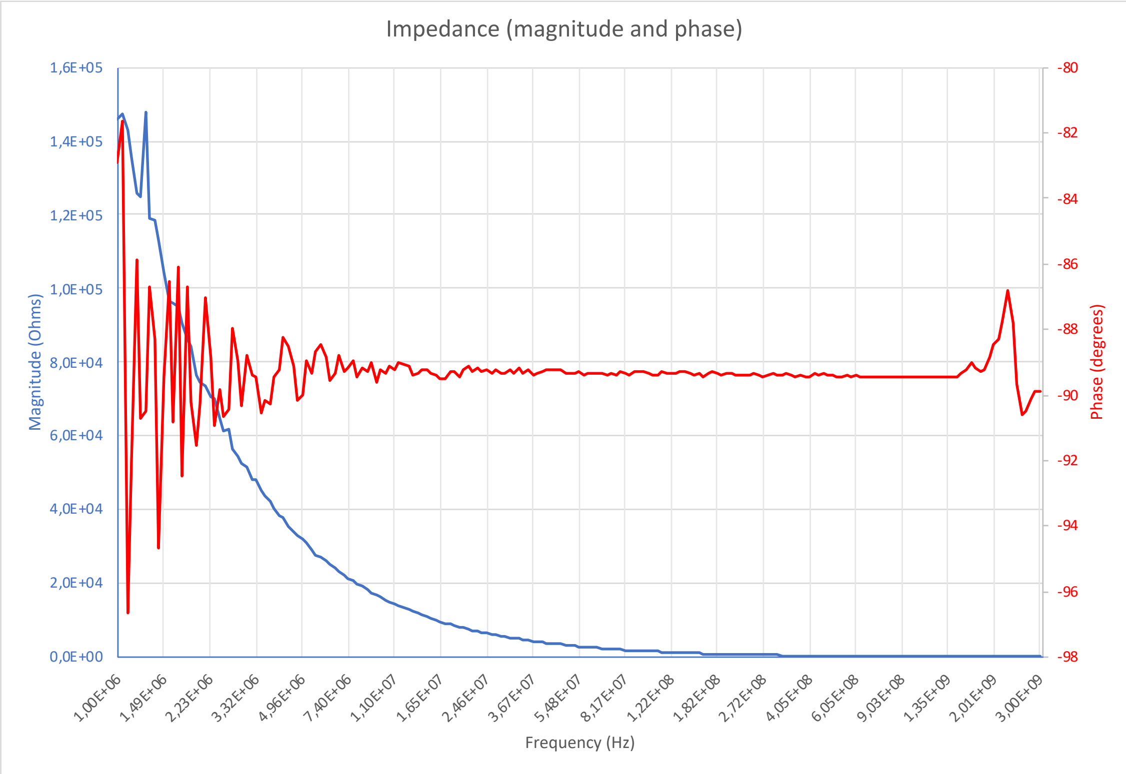

Figure 13 *- Impedance (real and imaginary part) as a function of frequency for VOLTATEX*

VOTASTAT:

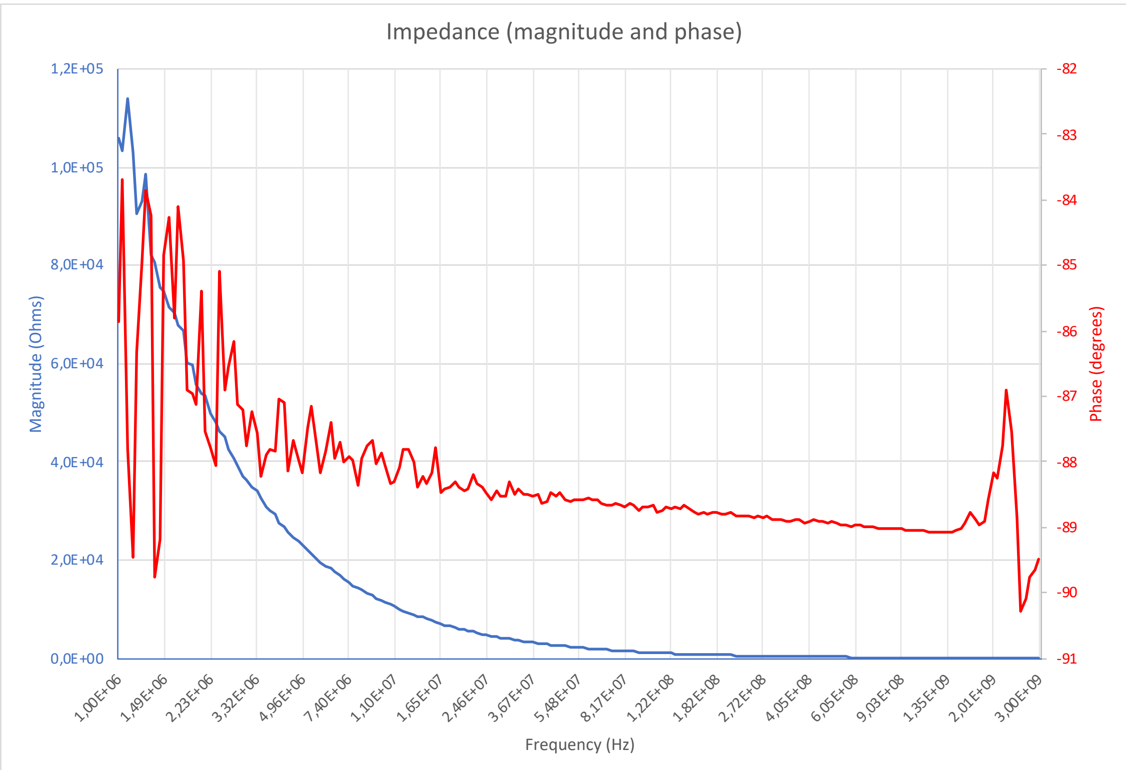

Figure 14 *-Impedance (real and imaginary part) as a function of frequency for VOTASTAT*

DAMISOL:

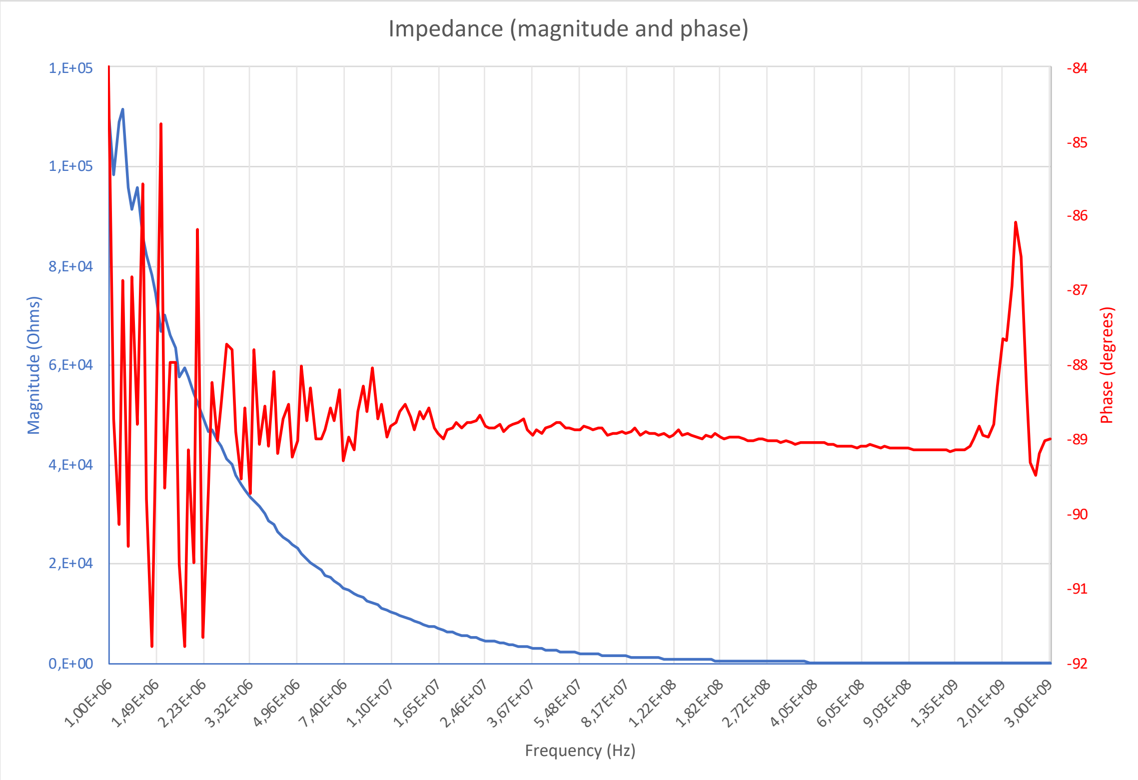

***Figure 15** - Impedance (real and imaginary part) as a function of frequency for DAMISOL*

The impedance analyzer plots values of the real and imaginary part of impedance, which put into the equations mentioned in topic 3.3 will give impedance magnitude and phase, analogue to the LCR meter.

For the higher frequency range (1MHz – 3GHz), obtained with the impedance analyzer, the capacitive character is present for all samples, with values tending to -90 degrees.

Coherently, impedance magnitude values decreased with the continuous increase in frequency. VOLTATEX (**Figure 13**) showed a slightly better performance when compared to the other samples (**Figure 14** and **Figure 15**), with a maximum magnitude value of $1{,}46 \times 10^5 \Omega$ and minimum of $5{,}85\Omega$. In the comparative analysis, no disparity was observed as for the values obtained with the LCR meter.

5. CONCLUSIONS AND PERSPECTIVES

This work focused on the dielectric behavior of three unsaturated polyesterimide resins, representing suitable candidates as impregnating materials for traction motors.

Regarding the tests carried out with the LCR meter, the sample VOTASTAT presented the lowest performance in terms of impedance magnitude. The most likely hypothesis is that the low values are related to the polymerization conditions. The sample was submitted to a longer curing process (16h at 140°C), which favored, through factors such as the slight increase in the rate of crystallinity, the constitution of a less prominent dielectric character of the molecule. VOLTATEX and DAMISOL showed similar behavior for magnitude and phase curves, which is consistent considering the similar polymerization conditions.

At the higher frequency range, obtained using the impedance analyzer, VOLTATEX presented slightly higher performance in terms of impedance magnitude. However, under these conditions, there were no significant variations in the comparative analysis. Similar magnitude curves were observed, along with phase approaching -90°, highlighting the capacitive character of the material.

Tests with DC current on a picoammeter were attempted, but the results were not considered as the displayed resistance values were not stable and therefore unreliable.

Errors and variations inherent to the methods and/or procedures applied must not be discarded, such as improper positioning of the samples and, especially in the case of the impedance analyzer, variations in the measurement of the thickness of the samples.

All tests were performed at room temperature. However, the Class H resins investigated have high chemical stability and are recommended to suit high service temperatures (≈180°C). That being the case, further tests could be carried out to validate the dielectric behavior at such temperatures.

6. REFERENCES

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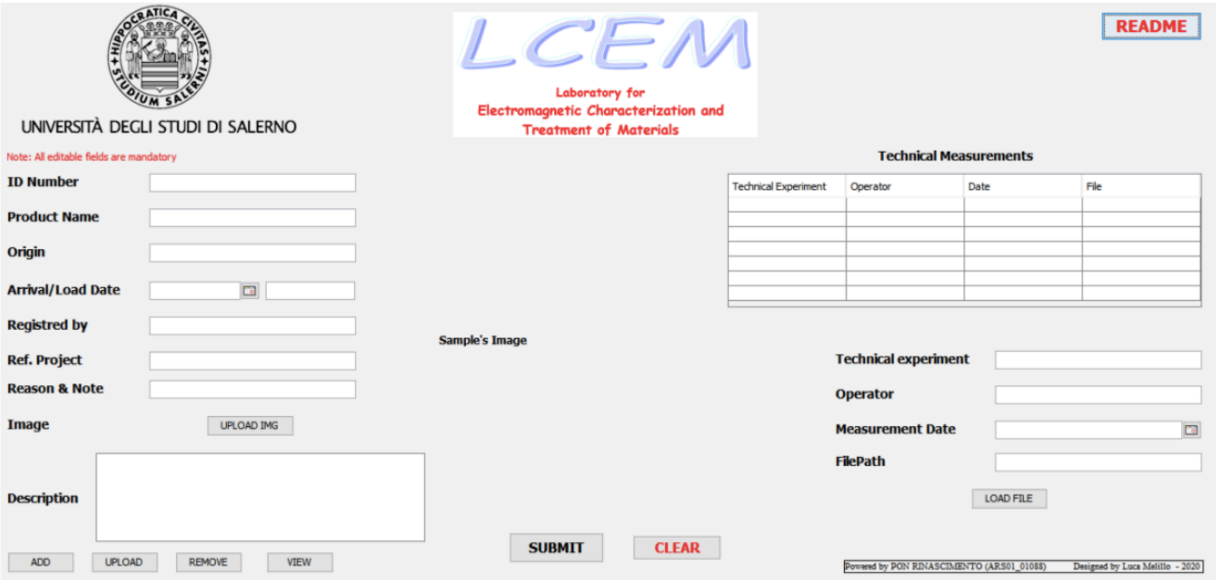
APPENDIX

***Appendix 1**: Graphical user interface of LCEM samples database*



***Appendix 2**: MATLAB script to rectify Quadtech 7600 data*

```
%% Files selection and import the data
txt_msg=sprintf("Select a txt file with QuadTech Measurements.\nB6R files
cannot be used; convert them to a txt file before using this program.");
uiwait(msgbox(txt_msg, "Help Message", "help"))
[fname, path, txt]=uigetfile('*.txt'); % 'MultiSelect','on');
% Check sulla corretta selezione dei files e verifica del numero di files
if txt == 1
    if iscell(fname)
        n_files=length(fname);
    else
        n_files=1;
        fname={fname};
    end

    % Importazione dei dati
    n_total_acquisition=0;
    QuadTechData=struct(); % Inizializzazione della struttura in cui
saranno salvati i dati
    for jj=1:n_files
        % Estrapolazione dati dal file jj-esimo
        data = readtable(fullfile(path, fname{jj}));
        [len, ~]=size(data);
        idx_start=0; % indice per indicare la riga di partenza deii dati
        flag_start=0; % flag quando si individua la riga di partenza
        n_file_acquisition=0;
        % Definizione inizio dati di interesse
        while idx_start<len && flag_start == 0
            idx_start=idx_start+1;
```

```
            if ~isnan(data{idx_start, 2})
                flag_start=1;
            end
        end
        idx_table=idx_start;
        % Definizione vettore Frequenza
        freq_string=["Hz", "kHz", "MHz"];
        while idx_table<=len % while per scorrere tutte le righe del file
            % (potrebbero esserci più acquisizioni nel file)
            flag_stop=0; % flag per stoppare quando termina la singola
acquisizione
            prev_freq=0;
            idx=0;
            freq=zeros(1,100);
            while idx_table<=len && flag_stop == 0 % while per individuare
la singola acquisizione
                idx=idx+1;
                % switch per separare le varie stringhe dei multipli della
frequenza
                switch string(data{idx_table, 3})
                    case freq_string(1)
                        freq(idx)=data{idx_table, 2};
                    case freq_string(2)
                        freq(idx)=data{idx_table, 2}*1e3;
                    case freq_string(3)
                        freq(idx)=data{idx_table, 2}*1e6;
                    otherwise
                        disp('Error');
                end
                % Check se il vettore frequenza ha andamento crescente
                if freq(idx)>prev_freq
                    prev_freq=freq(idx);
                else % se la frequenza letta è minore di quella precedente
                    flag_stop=1;
                    idx_table=idx_table-1;
                end
                idx_table=idx_table+1;
            end

            % Definizione corretta lunghezza del vettore frequenza
            if idx_table<=len
                freq=freq(1:idx-1);
            else
                freq=freq(1:idx);
            end

            n_file_acquisition=n_file_acquisition+1;
            n_total_acquisition=n_total_acquisition+1;
            % Definizione ALTRI PARAMETRI
            res_string=["OHMS", "kOHMS", "MOHMS"];
            res_mul=[1, 1e3, 1e6];
            cap_string=["pF", "nF", "uF"];
            cap_mul=[1e-12, 1e-9, 1e-6];
            zabs_string=["OHMS", "kOHMS", "MOHMS"];
            zabs_mul=[1, 1e3, 1e6];
            % Aggiungere altri paramtri
            parameters=["Rp", "Rs", "Cp", "Cs", "|Z|", "THETA"];

            % Si individuano i parametri presenti
            % Primo parametro
            switch string(data{idx_start, 4})
```

```
    case parameters(1) %Rp
        par1=strcat(parameters(1), " [Ohms]");
        par1_string=res_string;
        par1_mul=res_mul;
    case parameters(2) %Rs
        par1=strcat(parameters(2), " [Ohms]");
        par1_string=res_string;
        par1_mul=res_mul;
    case parameters(3) %Cp
        par1=strcat(parameters(3), " [F]");
        par1_string=cap_string;
        par1_mul=cap_mul;
    case parameters(4) %Cs
        par1=strcat(parameters(4), " [F]");
        par1_string=cap_string;
        par1_mul=cap_mul;
    case parameters(5) %|Z|
        par1=strcat(parameters(5), " [Ohms]");
        par1_string=zabs_string;
        par1_mul=zabs_mul;
    case parameters(6) % THETA
        par1=strcat(parameters(6), " [Deg]");
        par1_string="DEGREES";
        par1_mul=1;
    otherwise
        disp('Parameter not available');
end
% Secondo parametro
switch string(data{idx_start, 7})
    case parameters(1) %Rp
        par2=strcat(parameters(1), " [Ohms]");
        par2_string=res_string;
        par2_mul=res_mul;
    case parameters(2) %Rs
        par2=strcat(parameters(2), " [Ohms]");
        par2_string=res_string;
        par2_mul=res_mul;
    case parameters(3) %Cp
        par2=strcat(parameters(3), " [F]");
        par2_string=cap_string;
        par2_mul=cap_mul;
    case parameters(4) %Cs
        par2=strcat(parameters(4), " [F]");
        par2_string=cap_string;
        par2_mul=cap_mul;
    case parameters(5) %|Z|
        par2=strcat(parameters(5), " [Ohms]");
        par2_string=zabs_string;
        par2_mul=zabs_mul;
    case parameters(6) %THETA
        par2=strcat(parameters(6), " [Deg]");
        par2_string="DEGREES";
        par2_mul=1;
    otherwise
        disp('Parameter not available');
end

% Sono estrapolate dal file le informazioni dei 2 parametri
val_par1=zeros(size(freq));
val_par2=zeros(size(freq));
for j=idx_start:idx_table-1
```

```
            % Primo parametro
            switch string(data{j, 6})
                case par1_string(1)
                    val_par1(j-idx_start+1)=data{j, 5}*par1_mul(1);
                case par1_string(2)
                    val_par1(j-idx_start+1)=data{j, 5}*par1_mul(2);
                case par1_string(3)
                    val_par1(j-idx_start+1)=data{j, 5}*par1_mul(3);
                otherwise
                    val_par1(j-idx_start+1)=NaN;
                    disp('Error param1');
            end
            % Secondo parametro
            switch string(data{j, 9})
                case par2_string(1)
                    val_par2(j-idx_start+1)=data{j, 8}*par2_mul(1);
                case par2_string(2)
                    val_par2(j-idx_start+1)=data{j, 8}*par2_mul(2);
                case par2_string(3)
                    val_par2(j-idx_start+1)=data{j, 8}*par2_mul(3);
                otherwise
                    val_par2(j-idx_start+1)=NaN;
                    disp('Error param2');
            end
        end
        idx_start=idx_table;

        % Salvataggio dei dati nell struttura
        QuadTechData(n_total_acquisition,1).Filename=fname{jj};

QuadTechData(n_total_acquisition,1).N_FileAcquisition=n_file_acquisition;
        QuadTechData(n_total_acquisition,1).Frequency=freq';
        QuadTechData(n_total_acquisition,1).Var1Name=par1;
        QuadTechData(n_total_acquisition,1).Var1Values=val_par1';
        QuadTechData(n_total_acquisition,1).Var2Name=par2;
        QuadTechData(n_total_acquisition,1).Var2Values=val_par2';

QuadTechData(n_total_acquisition,1).ValuesTable=table(freq',val_par1',val_p
ar2',...
            'VariableNames',{'Frequency',char(par1), char(par2)});
        % Creazione tabella generale con tutte le misure
        p1=sprintf("Meas. %d: %s", n_total_acquisition, par1);
        p2=sprintf("Meas. %d: %s", n_total_acquisition, par2);
        if n_total_acquisition == 1

GeneralTab=table(freq',val_par1',val_par2','VariableNames',{'Frequency',cha
r(p1), char(p2)});
        else
            GeneralTab.(p1)=val_par1';
            GeneralTab.(p2)=val_par2';
        end

        % Grafici momentanei delle variabili
        figure(n_total_acquisition)
        yyaxis left
        semilogx(freq, val_par1, 'b--o', 'Linewidth', 1.5,
'MarkerSize', 8); grid on;
        xlabel('Frequency [Hz]'); ylabel(par1);
        yyaxis right
        semilogx(freq, val_par2,'r--o', 'Linewidth', 1.5, 'MarkerSize',
8); grid on;
```

```
            xlabel('Frequency [Hz]'); ylabel(par2);
            tit=sprintf('file %s - acquisition %d', fname{jj},
n_file_acquisition);
            title(tit);

        end % Fine letterura jj-esimo file
    end

    % Si apre la finestra di dialogo per il salvataggio del file
    [filepath,name,~] = fileparts(fullfile(path, fname{1}));
    xlsm_name=strcat(name, ".xlsm");
    mat_name=strcat(name, ".mat");
    writetable(GeneralTab, xlsm_name, 'WriteVariableNames',true);
    save(mat_name, 'QuadTechData');
%     else % se si chiude la finestra non viene salvato nessun dato
%         uiwait(errordlg('Data not saved.','Attention'));
%     end
    clearvars -except QuadTechData

else
    uiwait(errordlg('Wrong or unselected files.','File Error'));
end
```

Résumé

Le présent travail a été réalisé lors du stage de 2éme année, au Laboratoire de Caractérisation Électromagnétique des Matériaux (LCEM) de l'Université de Salerne. Il aborde la caractérisation diélectrique des résines polyesterimides insaturées, utilisées comme matériaux d'imprégnation des moteurs de traction ferroviaire. L'augmentation des performances des moteurs de traction a conduit à une augmentation des températures de fonctionnement, ce qui nécessite l'utilisation de telles résines à haute stabilité thermique pour isoler les bobinages des moteurs. Une analyse comparative d'impédance électrique a été réalisée, en corrélation avec différentes conditions de polymérisation de 3 résines commerciales. Un compteur LCR et un analyseur d'impédance étaient les équipements de mesure utilisés pour obtenir des courbes d'amplitude et de phase dans différentes plages de fréquences, permettant une analyse qualitative et quantitative du caractère diélectrique des échantillons.

Mots Clés : caractérisation diélectrique, polyesterimide, imprégnation

Summary

The present work was performed during an internship in the Laboratory of Electromagnetic Characterization of Materials (LCEM), at the University of Salerno. It approaches the dielectric characterization of unsaturated polyesterimide resins, employed as impregnating materials for railway traction motors. The increasing performance of traction motors has led to an increase in operating temperatures, which requires the use of such resins with high thermal stability to insulate motor windings. A comparative analysis of electrical impedance was carried out, in correlation with different polymerization conditions of 3 commercial resins. An LCR meter and an impedance analyzer were the measuring equipment used to obtain magnitude and phase curves in different frequency ranges, enabling a qualitative and quantitative analysis of the dielectric character of the samples.

Keywords: dielectric characterization, polyesterimide, impregnation

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