Parameters study of the electric power cables

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Abstract. – *This paper constructs a brief presentation of the electric cables, industrial connectors and cable carriers used to power electric devices. The measuring of the electric cables' parameters has been performed with the LCR Meter Instek 6100. The obtained results verify and validate the mathematical relationships which resulted by modelling the electric cables' parameters. The ÖLFLEX Classic, Servo and Heat electric cables are manufactured by the Lapp Group Company. They have first been tested in accordance to the factory parameters and then were subjected to drag chain and heating tests. These tests and results are presented and discussed in this paper.*

Cuvinte cheie: electric cable, DC and AC measurement, electrical parameters.

1. Introduction

An electric cable represents the assembly of insulated conductors, mechanically grouped and electrically separated. Most of the electric cables have metallic shielding and heavy duty plastic cover. This plastic cover serves as protection against chemical and mechanical actions while the shielding protects the cable against interference from exterior electric and magnetic fields.

With respect to their intended use, the electric cables can be divided into the following categories:

- energy or power cables used for the transportation and distribution of AC and DC currents;
- command and signaling cables used in systems of control, measuring, signaling, protection and automation;
- communication cables used in installations of telecommunication, telephony, telex, remote sensing, fire alarm systems, etc.;
- data cables used to send information to computing systems.

The electric cables must have optimal electrical characteristics in order to provide power to the connected receivers. This implies low electrical parameters (resistance, capacitance and impedance) and high mechanical characteristics (flexibility, tensile strength, heat resistance).

The safety of the electric installation is an important and timely topic. A low maintenance – high durability electric installation requires the following conditions:

- the components have to be properly chosen (cables, connectors, cable glands, protection and switching equipment);
- the shielding has to be checked in advance;
- the fault tolerance must be ensured in case of electric failure.

The industrial applications involving mobile and flexible elements imply the use of electric conductors in cable carriers. In automation, the electric cables, the connectors and cable carriers have to ensure good transportation conditions. Also, the cable carriers and the electric cables are expected to adhere to the electric domain directives and industry standards (RoHS 2011/65/CE, DEEE 2012/19/CE) [1].

The transmission quality accomplished by the cable carriers depends on the electrical and mechanical properties of the electric cables and connectors. The electric cables and connectors used in these applications provide better transmission properties, high contact force and excellent conductivity.

2. Mathematical modeling of the electric cables' parameters

An electric cable is characterized by impedance (Z) that consists of resistance (R) and reactance (X); the reactance can be inductive (L) or capacitive (C). The impedance is the inverse of admittance (Y).

The cable's resistance is positive and the reactance can be positive (mostly inductive) or negative (mostly capacitive). Resistance varies in relation to the power source's frequency, while the reactance always increases with the voltage's frequency.

The physical modeling behavior that approximates the fluctuation of the electric parameters versus the power source's frequency [2, 3, 4], it is based on the below equivalent series or parallel schemes.

The quality factor for a predominantly inductive load is:

$$Q = \frac{\omega L_s}{R_s} = \frac{R_p}{\omega L_p} \quad (1)$$

where: Ls, Lp are the series and parallel inductances of a cable and, Rs, Rp are the series and parallel resistances of the electric cable.

In case of predominantly capacitive load, the quality factor is:

$$Q = \frac{1}{\omega R_s C_s} = \omega R_p C_p \quad (2)$$

where: Cs, Cp are the series and parallel capacitances of the electric cable.

The mathematical modeling equivalence formulas are:

$$R_p = R_s \cdot \left(1 + Q^2\right), \;\; C_s = C_p \cdot \frac{Q^2}{1+Q^2}, \;\; L_p = L_s \cdot \frac{1+Q^2}{Q^2} \quad (3)$$

In case of cables with low quality factor (less than 0.1), the mathematical relationships between series and parallel schemes are:

$$R_p = R_s, \;\; C_s = C_p \cdot Q^2, \;\; L_p = L_s \cdot \frac{1}{Q^2} \quad (4)$$

In case of cables with high quality factor (over 10), the relations between the series and parallel schemes become:

$$R_p = Q^2 \cdot R_s, \;\; C_s = C_p, \;\; L_p = L_s \quad (5)$$

3. Measuring of the electric cables' parameters

3.1. The measuring of the electric cables resistance in continuous current circuit

For measuring the resistance of an electric cable in continuous current circuit, a multimeter or LCR meter can be used. In this case, the LCR/6100 Meter produced by the Instek Company was used.

The electric cables used for testing belong to the Lapp Group Company, each of them having a length of one meter and the conductor sections of 0,75 mm^2, 1 mm^2, 1,5mm^2, 2,5 mm^2 and 4 mm^2. Using the DCR function of the LCR meter, the following results have been obtained (shown in table I).

Table 1. The electric cables' resistance

s[mm^2]	0.75	1	1.5	2.5	4
DCR measured ÖLFLEX Classic	0.02601	0.01438	0.00916	0.00715	0.00452
DCR measured ÖLFLEX Servo	0.02593	0.0176	0.01017	0.00727	0.0046
DCR measured ÖLFLEX Heat	0.02569	0.0194	0.01414	0.00789	0.0051
DCR in factory	0.0267	0.0182	0.0122	0.00756	0.0047

The electric cable's resistance, specified by the manufacturer, complies with IEC 60228/DIN EN60228 (VDE0295) standards for copper core cables. The obtained measurements are concurrent with the manufacturer's specifications.

3.2. The measuring of the impedance and reactance of the electric cables' in alternative current schemes

For the measuring of the electric resistance, inductance, capacity, impedance modulus, dissipation factor and the phase shift, the LCR/6100 Meter was used. This LCR meter can accurately measure impedance at a specific frequency as simply L, C and R in serial or parallel circuits [5]. The LCR meter was programmed via the serial interface to communicate with the computer at the baud rate of 115200byte/second.

The parameters of the electric cables have been determined according to the following frequencies: 10Hz, 50Hz, 60Hz, 100Hz, 120Hz, 1kHz, 2kHz, 10kHz, 20kHz, 40kHz, 50kHz, 100kHz.

The first measurements were performed on ÖLFLEX CLASSIC 100 cables.

To achieve the automatic measurements, the LCR Meter was programmed based on the graphic user interface presented in Fig. 1.

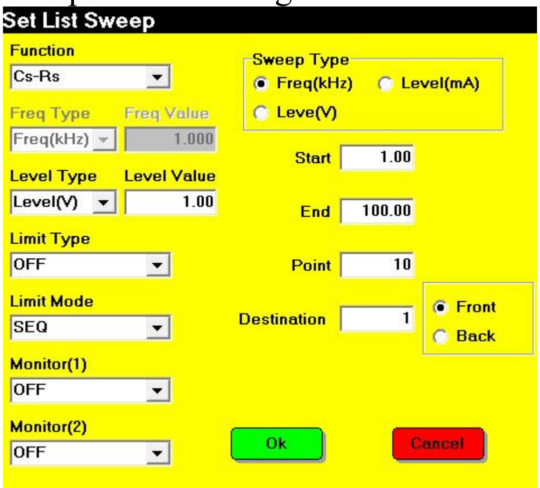
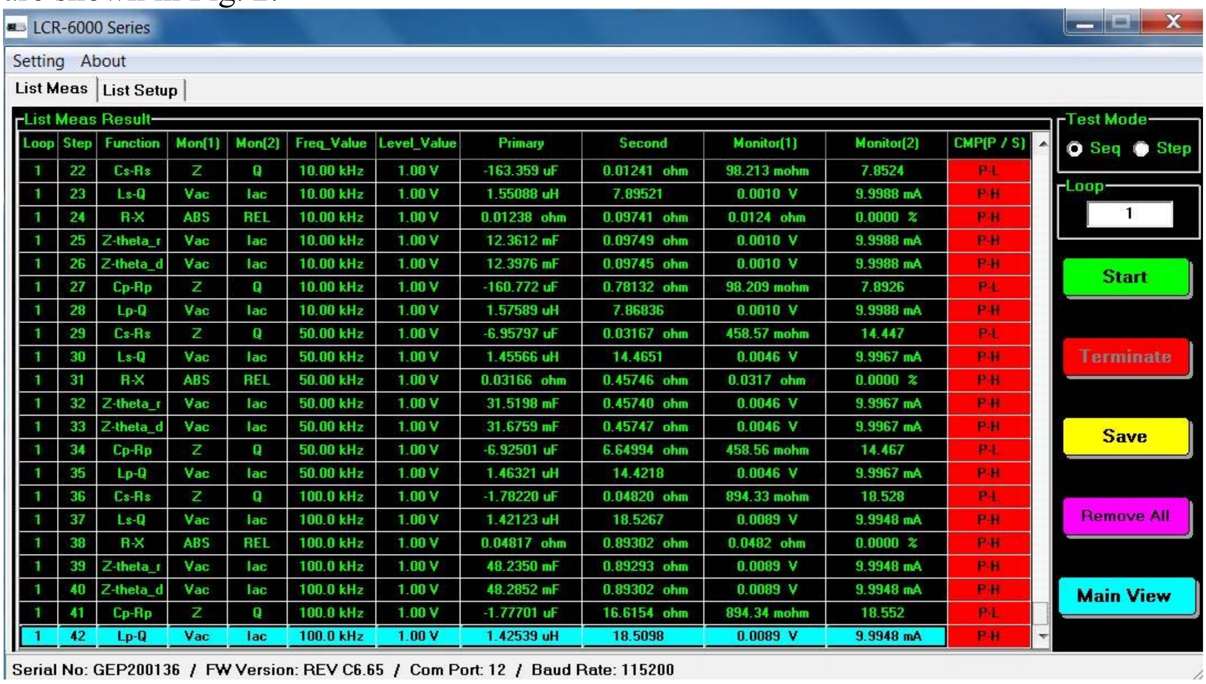


Fig. 1. Set list sweep

The selected functions were: Cs-Rs, Cs-D, Cp-Rp, Cp-D, Lp-Rp, Lp-Q, Ls-Rs, Ls-Q, Rs-Q, Rp-Q, R-X, Z-theta_r, Z-theta_d, Z-D, Z-Q, monitor(1) respective monitor(2): Z, D, Q, Vac, Iac, ABS, REL.

The results obtained from the measurements (after the running of the program) are shown in Fig. 2.



Loop	Step	Function	Mon(1)	Mon(2)	Freq_Value	Level_Value	Primary	Second	Monitor(1)	Monitor(2)	CMP(P / S)
1	22	Cs-Rs	Z	Q	10.00 kHz	1.00 V	-163.359 uF	0.01241 ohm	98.213 mohm	7.8524	P-L
1	23	Ls-Q	Vac	Iac	10.00 kHz	1.00 V	1.55088 uH	7.89521	0.0010 V	9.9988 mA	P-H
1	24	R-X	ABS	REL	10.00 kHz	1.00 V	0.01238 ohm	0.09741 ohm	0.0124 ohm	0.0000 %	P-H
1	25	Z-theta_r	Vac	Iac	10.00 kHz	1.00 V	12.3612 mF	0.09749 ohm	0.0010 V	9.9988 mA	P-H
1	26	Z-theta_d	Vac	Iac	10.00 kHz	1.00 V	12.3976 mF	0.09745 ohm	0.0010 V	9.9988 mA	P-H
1	27	Cp-Rp	Z	Q	10.00 kHz	1.00 V	-160.772 uF	0.78132 ohm	98.209 mohm	7.8926	P-L
1	28	Lp-Q	Vac	Iac	10.00 kHz	1.00 V	1.57589 uH	7.86836	0.0010 V	9.9988 mA	P-H
1	29	Cs-Rs	Z	Q	50.00 kHz	1.00 V	-6.95797 uF	0.03167 ohm	458.57 mohm	14.447	P-L
1	30	Ls-Q	Vac	Iac	50.00 kHz	1.00 V	1.45566 uH	14.4651	0.0046 V	9.9967 mA	P-H
1	31	R-X	ABS	REL	50.00 kHz	1.00 V	0.03166 ohm	0.45746 ohm	0.0317 ohm	0.0000 %	P-H
1	32	Z-theta_r	Vac	Iac	50.00 kHz	1.00 V	31.5198 mF	0.45740 ohm	0.0046 V	9.9967 mA	P-H
1	33	Z-theta_d	Vac	Iac	50.00 kHz	1.00 V	31.6759 mF	0.45747 ohm	0.0046 V	9.9967 mA	P-H
1	34	Cp-Rp	Z	Q	50.00 kHz	1.00 V	-6.92501 uF	6.64994 ohm	458.56 mohm	14.467	P-L
1	35	Lp-Q	Vac	Iac	50.00 kHz	1.00 V	1.46321 uH	14.4218	0.0046 V	9.9967 mA	P-H
1	36	Cs-Rs	Z	Q	100.0 kHz	1.00 V	-1.78220 uF	0.04820 ohm	894.33 mohm	18.528	P-L
1	37	Ls-Q	Vac	Iac	100.0 kHz	1.00 V	1.42123 uH	18.5267	0.0089 V	9.9948 mA	P-H
1	38	R-X	ABS	REL	100.0 kHz	1.00 V	0.04817 ohm	0.89302 ohm	0.0482 ohm	0.0000 %	P-H
1	39	Z-theta_r	Vac	Iac	100.0 kHz	1.00 V	48.2350 mF	0.89293 ohm	0.0089 V	9.9948 mA	P-H
1	40	Z-theta_d	Vac	Iac	100.0 kHz	1.00 V	48.2852 mF	0.89302 ohm	0.0089 V	9.9948 mA	P-H
1	41	Cp-Rp	Z	Q	100.0 kHz	1.00 V	-1.77701 uF	16.6154 ohm	894.34 mohm	18.552	P-L
1	42	Lp-Q	Vac	Iac	100.0 kHz	1.00 V	1.42539 uH	18.5098	0.0089 V	9.9948 mA	P-H

Fig. 2. List measurement

By processing the data concerning the ÖLFLEX CLASSIC 100 4G0.75, 4G1, 4G1.5 cables at different frequencies, the following charts resulted: resistance, capacitance and inductance series (Fig.3).

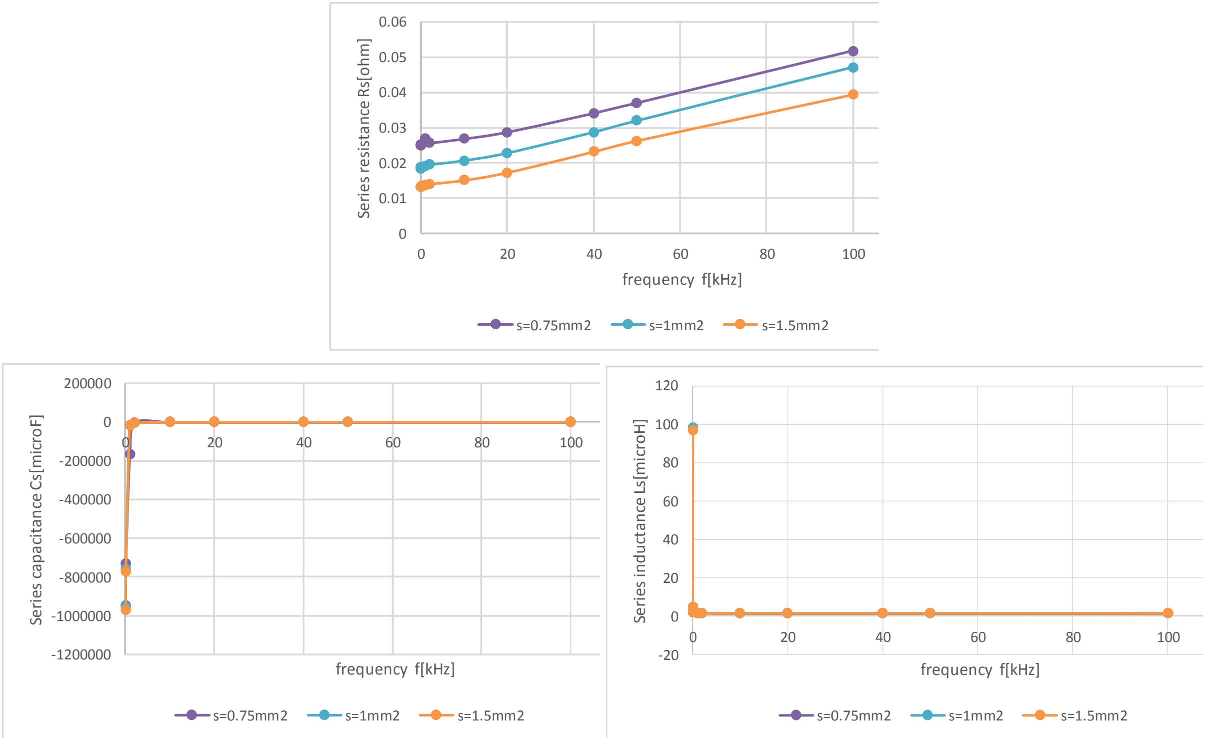


Fig. 3. Series resistance, capacitance and inductance function of frequency

The frequency's dependences function of the parallel resistance, capacitance and inductance (Fig.4) were obtained using the same parameters as for the test above.

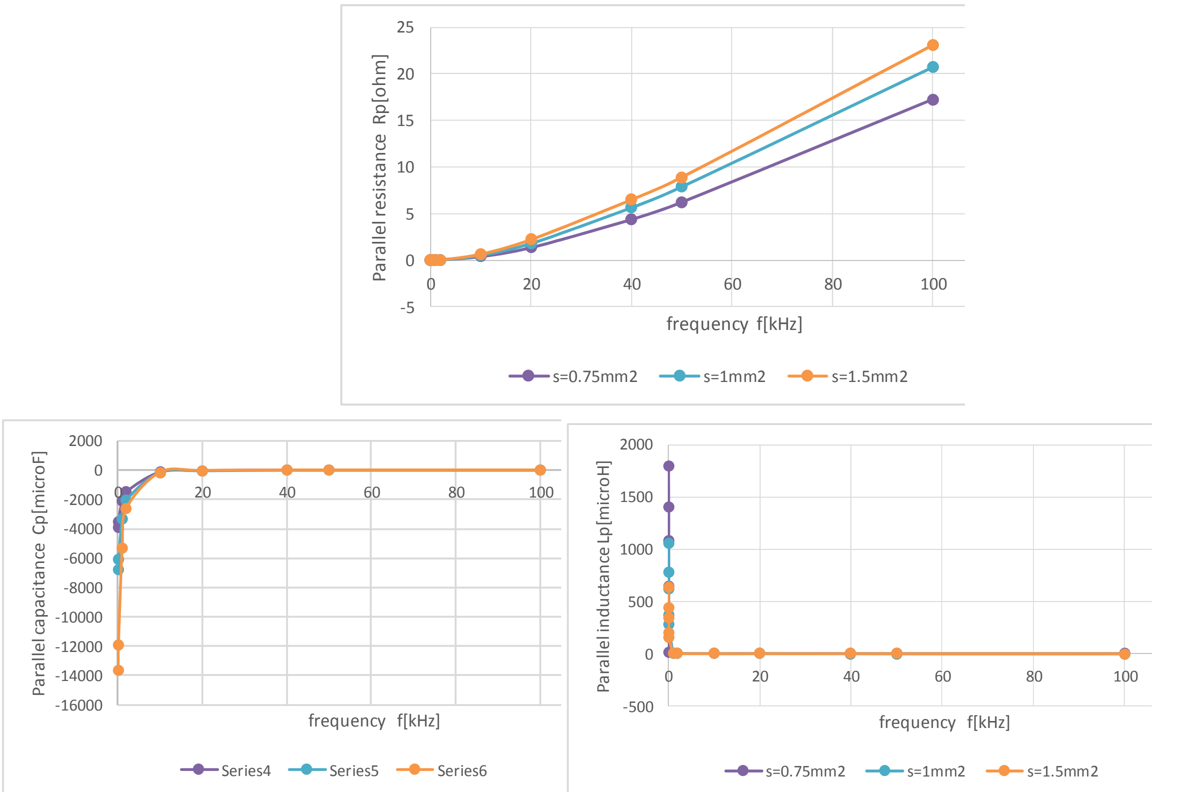


Fig. 4. Parallel capacitance and parallel inductance versus frequency

Two other important electric cables' parameters consist of impedance and quality factor whose dependency is presented in the charts from Fig. 5.

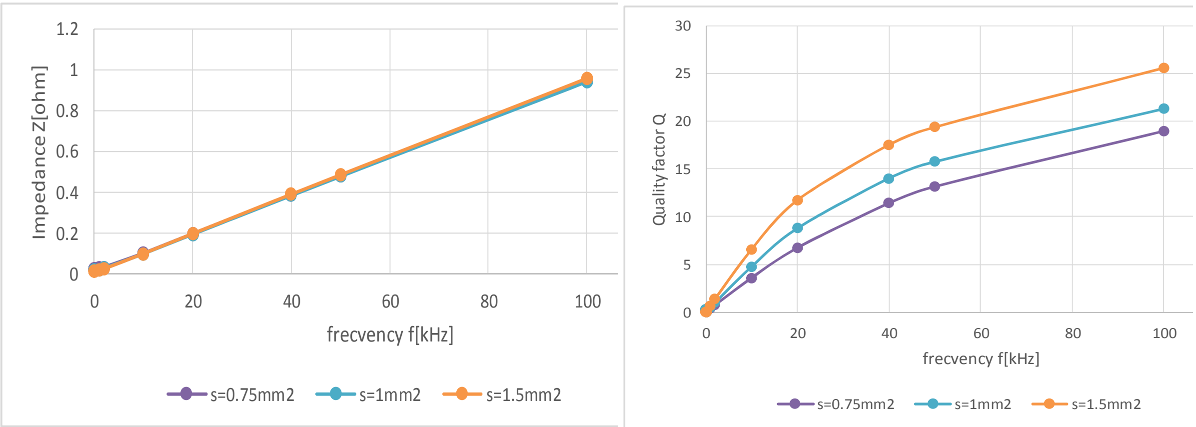


Fig. 5. Impedance and quality factor versus frequency

Similar results were obtained for the following electric cables:
ÖLFLEX CLASSIC 110 CY, ÖLFLEX SERVO FD 796CP and ÖLFLEX HEAT 180.

4. The stresses of the electric cables

4.1. The electric cables' reaction to overheating

The study of the electric cables' reaction to overheating was conducted for the ÖLFLEX CLASSIC 110 CY 4G1.5 and ÖLFLEX CLASSIC 110 CY 4G2.5 electric cables. Both were kept one hour in the oven. The first electric cable was heated to a temperature of 80 degrees Celsius while the second one was heated to 120 degrees Celsius.

Fig. 6 presents the electric oven used to heat up the electric cables and the placement of the cable inside the oven.

Fig. 6. Electric oven

Fig.7 show the frequency dependence of the quality factor. This factor is represented with orange for an unheated electric cable and with blue if the electric cable was heated.

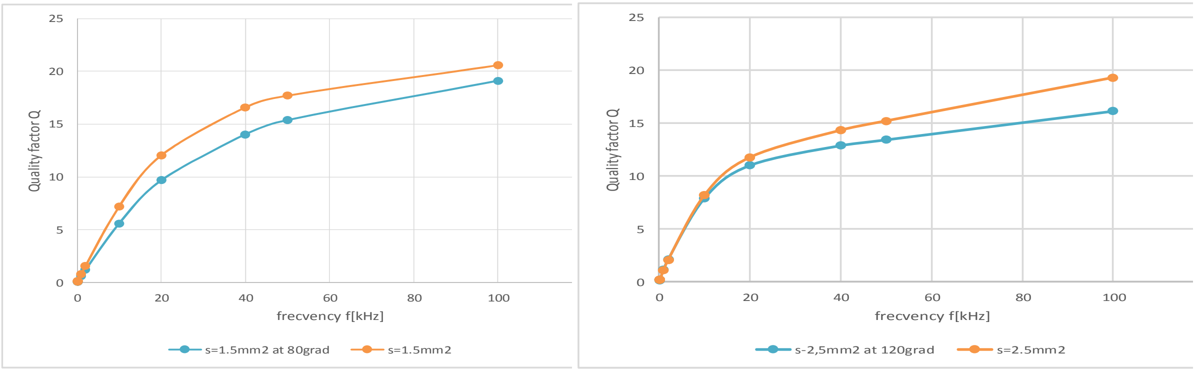


Fig. 7. Quality factor versus frequency for ÖLFLEX CLASSIC 110 CY 4G1,5 and 4G2.5 electric cable

The results of the measurements made on overburdened heating cables led to the following conclusions:

- series resistance was increased;
- series capacity and inductance were decreased;
- parallel resistance was reduced;
- parallel capacity and inductance widened;
- quality factor respectively impedance decreased.

4.1. Drag chain system

The study of the electric cables' behaviour at the stretching test was conducted for the ÖLFLEX SERVO FD 796CP 4G1,5 and ÖLFLEX SERVO FD 796CP 4G2,5 electric cables. The electric cable under test was installed into a power chain and "suffered" a number of 1000 cycles stretching. The system used to perform this stretching is present in Fig. 8.

Fig.8. Drag chain system

At the end of the stretching tests on the ÖLFLEX SERVO FD 796CP electric cables, the measurements confirmed the insignificant changes of the electric parameters.

Fig.9 shows the quality factor's dependence on the stretching maneuvers; the red curve shows the quality factor before stretching and the green curve shows the quality factor's graphic after the electric cable performed 1,000 stretching cycles.

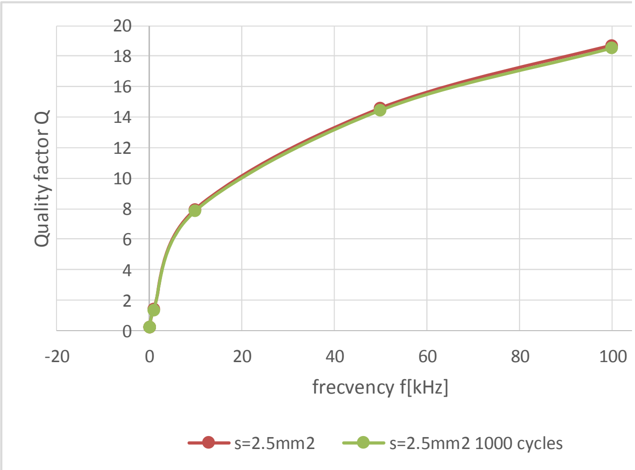


Fig. 9. Quality factor versus frequency for SERVO FD 796CP 4G2,5 electric cable

5. Conclusions

The electric measurements and tests performed on the electric cables send to the following conclusions:

- the DC resistance of all three types of electric cables ÖLFLEX Classic, Servo și Heat meet the Lapp specified corporate data and specifications;
- the measured electric parameters, using series and parallel schemes, totally check and comply with the math models and relations 4 and 5;
- the resistance and the reactance per the length unit are compatible with the results presented in journal specialized articles [11, 12, 13].

The selection of the electric cables, able to power diverse devices, has to be done in accordance to the following regulations: application range, product features, norm references and technical data specified by the manufacturer. The technical data of the electric cables consist in the core identification code, conductor stranding, torsion movement, minimum bending radius, nominal voltage, test voltage and the temperature range.

The electric cables and connectors dedicated to various types of applications must ensure good transmission properties, high contact force and excellent conductivity. Transmission of information depends on the electrical and mechanical properties of the cables and the placement of the electric cables into the cable channel.

The current and future automation technology solutions include complete cabling and connection systems for integrated networking at the sensor/actuator and control levels, right through to inventory management systems. One part of this is automation engineering, which continues to play a key role within the industry and which continues to pose a challenge through its continual demand for innovation. Highly specialized requirements for cables and accessories also characterize the food processing industry.

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