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STUDY OF THE INTENSITY RESONANCE FOR A SERIES RLC CIRCUIT IN FORCED SINUSOIDAL MODE

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ABSTRACT

The Resistance-Inductance-Capacity (RLC) circuit is one of the most elementary and important concepts in the electrical field. The objective of this work is to study the intensity resonance for a series RLC circuit in forced sinusoidal mode. The methodological approach consists in carrying out several experimental sessions on three resistors of different resistances, three coils of different inductances and three capacitors of different capacities. Experimental measurements of current intensity as a function of frequency have been used to build intensity-frequency graphs. The results show that the resistance of the resistance, the inductance of the coil and the capacitance of the capacitor all influence the intensity resonance. In addition, the maximum value of the current intensity at resonance depends on the resistance of all resistors in the circuit. However, the resonance frequency does not depend on the resistance of the resistor, but only on the inductance of the coil and the capacitance of the capacitor of the RLC series circuit. Through this research, we confirm that the three parameters resistance of resistance, coil inductance and capacitor capacity influence the intensity resonance and our methodological approach produces a clearly defined experimental optimization protocol that could constitute a new enrichment of the intensity resonance in science at the institute of our training. Physics being a science based on experimental observations, we recommend to complete the lessons by carrying out different types of practical experiments in class or in the laboratory.

Keywords : *series RLC circuit, intensity resonance, forced sinusoidal mode.*

RÉSUMÉ

Étude de la résonance d'intensité pour un circuit RLC série en régime sinusoïdal forcé

Le circuit Résistance-Inductance-Capacité (RLC) est l'un des concepts les plus élémentaires et les plus importants dans le domaine électrique. L'objectif de ce travail est d'étudier la résonance d'intensité pour un circuit RLC série en régime sinusoïdal forcé. L'approche méthodologique consiste à réaliser plusieurs séances expérimentales sur trois conducteurs ohmiques de résistances différentes, trois bobines d'inductances différentes et trois condensateurs de capacités différentes. Des mesures expérimentales de l'intensité du courant en fonction de la fréquence ont été utilisées pour construire des courbes intensité-fréquence. Les résultats montrent que la résistance du conducteur ohmique, l'inductance de la bobine et la capacité du condensateur influencent la résonance d'intensité. En outre, la valeur maximale de l'intensité du courant à la résonance dépend de la résistance de toutes les résistances du circuit. Cependant, la fréquence de résonance ne dépend que de l'inductance de la bobine et de la capacité du condensateur du circuit RLC série. A travers cette recherche, nous confirmons que les trois paramètres résistance du conducteur ohmique, inductance de la bobine et capacité du condensateur influencent la résonance d'intensité et notre approche méthodologique donne un protocole expérimental d'optimisation bien défini qui pourrait constituer un nouvel enrichissement dans l'étude de la résonance d'intensité en science et à l'institut de notre formation. La physique étant une science basée sur des observations expérimentales, nous recommandons de compléter les leçons par différents types d'expériences pratiques en classe ou au laboratoire.

Mots-clés : *circuit RLC série, résonance d'intensité, régime sinusoïdal forcé.*

I - INTRODUCTION

The importance of science and technology in our lives makes it possible to consider scientific education as one of the major challenges of the future in all societies [1 - 3]. One of the scientific fields, which contributes to accelerating the development of new technologies, information technology, medical imaging, etc. in several sectors of activity is Physics [2]. All these scientific revolutions have led to affirm that science is the benefactor of humanity [4 - 7]. Physics, the most fundamental physical science, is concerned with the fundamental principles of the Universe. It is the foundation upon which the other sciences i.e. astronomy, biology, chemistry, and geology are based. It is also the basis of a large number of engineering applications and the beauty of physics lies in the simplicity of its fundamental principles and in the manner in which just a small number of concepts and models can alter and expand our view of the world around us [5 - 7]. Like all other sciences, physics is based on experimental observations and quantitative measurements. It is an experimental science that studies natural phenomena and their evolution and establishes theories that make it possible to model them, to predict [5], etc. The theories established by Physics are applied within well-defined frameworks. There are several branches that make up physics, including electricity. Electricity is the set of phenomena due to electrical charges at rest or in motion [6]. Like any branch of physics or any field of experimental science, its understanding and evolution are closely linked to practical research work. Also, electricity has been known as basic subject in Physics training education, because of its practical applications have a great relevance in our everyday lives, under every aspect of it such as social, cultural, personal, technological, etc.). Parallel RLC circuits with resonance in parallel RLC circuits or series RLC circuits with resonance in series RLC circuits with an emphasis on practical type circuits and their possible applications exist in littérature survey [8 - 12]. In this paper, we report the results on the study of series RLC circuits with resonance in series RLC circuits in forced sinusoidal mode. We measure the resonance frequency and the quality factor of a driven *RLC* circuit by creating a resonance (frequency response) graph.

II - MATERIAL AND METHODS

II-1. Material

The equipment used comes from the laboratory of the Simone Éhivet Gbagbo Municipal High School in Yopougon (Côte d'Ivoire) where our practical internship takes place, and from the training institute, i.e. Ecole Normale Supérieure (ENS) d'Abidjan (Côte d'Ivoire). For our study, we have three resistors ($R_1 = 8\ \Omega$, $R_2 = 100\ \Omega$, $R_3 = 100\ \Omega$), three inductances (($L_1 = 530\ \mu H$, $r_1 = 2{,}2\ \Omega$), ($L_2 = 800\ \mu H$, $r_2 = 3{,}2\ \Omega$), ($L_3 = 2$ mH, $r_3 = 0{,}2\ \Omega$)), three capacitors ($C_1 = 0.47\ \mu F$, $C_2 = 1\ \mu F$, $C_3 = 2.2\ \mu F$), a low frequency generator (GBF), two multimeters with digital display, one in voltmeter mode across the GBF and the other in ampermeter mode, electronic mounting plate and connection wires. ***Figure 1*** presents all the different materials.

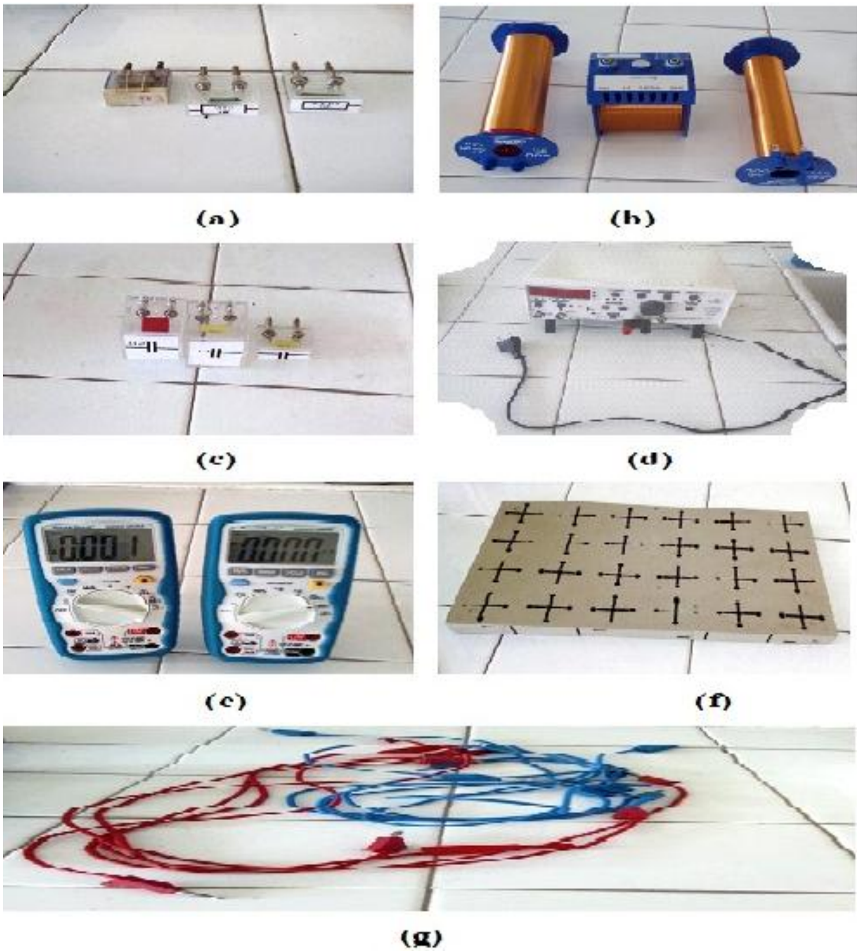

Figure 1 : *Image of the three resistors (a), three* inductors (b), *three capacitors (c), low frequency generator (GBF) (d), two multimeters (e), electronic mounting plate (f) and connection wires (g)*

II-2. Methods

II-2-1. Procedure

- Connect the GBF, resistor, capacitor and coil in series using the connection wires.
- Place a multimeter in voltmeter mode at the GBF terminals to gradually monitor the voltage at the generator terminals.
- Put the second multimeter in ammeter mode and place it in series in the circuit to determine the current intensity as you go along.
- Switch on the GBF from the mains.

Figure 2 shows The series RLC circuit excited by a source and the experimental set-up used to carry out the measurements.

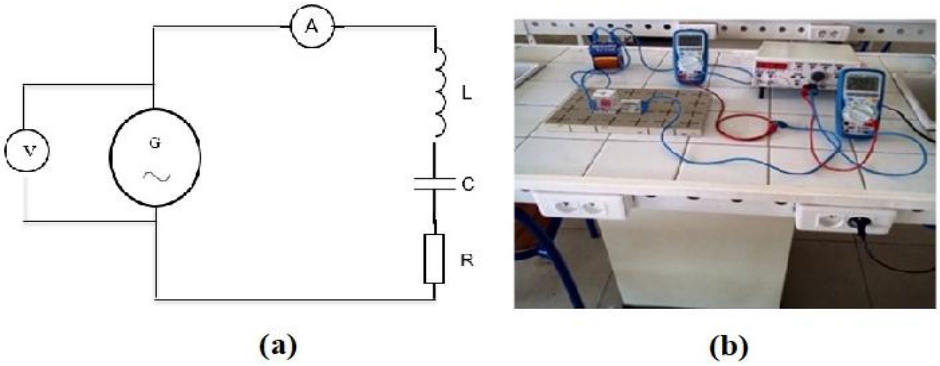

Figure 2 : *Series RLC circuit (a) and setup of the series RLC circuit (b)*

II-2-2. Performing the intensity resonance experiment

- Determine the theoretical value of the resonance frequency ($f_{res} = f_0$) using the formula [13, 14] :

$$N_0 = f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

This makes it possible to know the value around which the intensity resonance will take place.

- Vary the frequency N of the voltage given by the GBF and measure the rms current intensity using a multimeter set in ammeter mode.
- After reaching the maximum frequency value of one gauge on the GBF, change the gauge to the next one.
- Gradually read off the frequency values and the corresponding current intensity values.
- Establish the measurement table.
- Draw the curve from the values recorded in the measurement table.

II-2-3. Study of the influence of the resistance of a resistor

To obtain conclusive results, we used three resistors of respective resistances $R_1 = \Omega$; $R_2 = 2\Omega$; $R_3 = 100\ \Omega$. Thus for each resistor inserted in the series RLC circuit, the values of the coil are set to ($L_3 = 2$ mH ; $r_3 = 0.8\ \Omega$) and the capacitor capacity to C_3 = 2.2 µF. The frequency values and the corresponding current intensity values are gradually recorded in the measurement tables, and used to build the different curves.

II-2-4. Study of the influence of the inductance of a coil

As in the case of resistors, we used three respective inductance coils and internal resistances (L_1 = 530 µH ; r_1 = 2,5 Ω) ; (L2 = 800 µH ; r_2 = 3,8 Ω) ; (L_3 = 2mH ; r_3 = 0,5 Ω). Thus for each coil inserted in the series RLC circuit, the values of the resistance of the ohmic conductor are set at R_1 = 2 Ω and the capacitance of the capacitor at C*3* = 2.2 µF. The frequency values and the corresponding current intensity values are gradually recorded in the measurement tables, and used to build the different curves.

II-2-5. Study of the influence of the capacitance of a capacitor

We used three capacitors of respective capacitors C_1 = 0.47 µF ; C_2 = 1 µF ; C_3 = 2.2 µF. Thus for each capacitor inserted in the series RLC circuit, the resistance values of the ohmic conductor are set at R_1 = 2 Ω and the coil at (L_3 = 2 mH ; r_3 = 0.2 Ω). The frequency values and the corresponding current intensity values are gradually recorded in the measurement tables, and used to build the different curves.

II-2-6. Data analysis method

The Q factor (for quality) is a dimensionless quantity which characterizes every RLC circuit, or damped oscillator. It represents the ratio between the energy stored in the circuit and the energy dissipated during the oscillations [15], and measures the narrowness of the bandwidth. A large Q factor denotes a spiky bandwidth. This can also be expressed in power terms [16] :

$$Q = \frac{Lw_0}{\sum R} = \frac{1}{\sum RCw_0} \tag{2}$$

L being the inductance, W_0 ($W_0 = 2\pi N_0$) the clean pulse of series RLC circuit, N_0 the resonance frequency and $\sum R$ the sum of the resistors of the series RLC circuit

III - RESULTS

In this session, we present the results in the form of measurement tables and graphs.

III-1. Influence of the resistance of a resistor on the intensity resonance

III-1-1. Measurement table and graph for $R_1 = 2\ \Omega$

We used of a resistor with resistance equal to $R_1 = 2\ \Omega$ in the series RLC circuit. The experimental values are given in ***Table 1***.

Table 1 : *Measurement table for $R_1 = 2\ \Omega$*

N (Hz)	0	877,95	996,8	1115	1384	1652	1861	1982	**2012**	2162
I (mA)	0	21,85	23,84	25,5	28,11	29,51	30	30 ,11	**30,12**	30,10
N (Hz)	4018	4980	6427	10794	15478	25170	27676	36436	49896	
I (mA)	25,03	21,86	17,80	10,05	6	2,49	2,02	0,99	0,21	

From ***Table 1***, we constructed the current intensity graph as a function of frequency presented in ***Figure 1***.

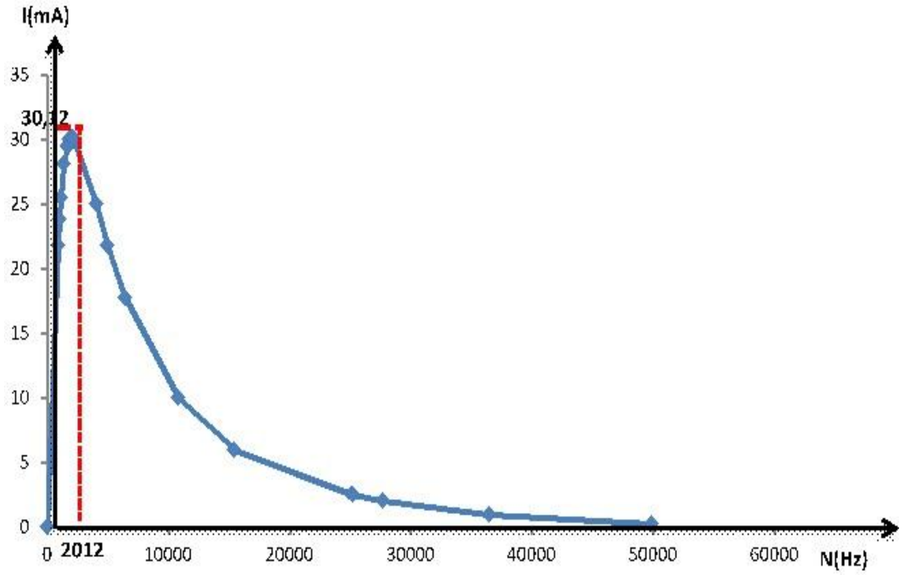

Figure 1 : *Resonance graph $I = f(N)$ for $R_1 = 2\ \Omega$*

With an resistor R_1= 2 Ω, a resonance frequency N_0 = 2012 Hz corresponding to a rms intensity of maximum value at resonance I = 30.12 mA is obtained at the intensity resonance. The quality factor evaluated is Q_1 = 9.03. Q_1 is large, which means the circuit is selective and the resonance is acute.

III-1-2. Measurement table and graph for R_2 = 46 Ω

*The use of an ohmic conductor with resistance R_2 = 46 Ω in the series RLC circuit gives **Table 2**.*

Table 2 : *Measurement table for R_2 = 46 Ω*

N (Hz)	0	787,4	936	966	1025	1114	1558	1678	**2012**	2500
I (mA)	0	16,84	18,08	18,27	18,61	19,03	20	20,07	**20,08**	20,07
N (Hz)	2989	3676	4006	4576	4937	6000	9800	15500	27676	
I (mA)	20	18,5	17,47	14,56	15,99	11	6	3,2	1,02	

From ***Table 2***, we have constructed the current intensity curve as a function of frequency presented in ***Figure 2***. ***Figure 2*** presents the resonance graph I = f (N) with a resistance R_2 = 46 Ω.

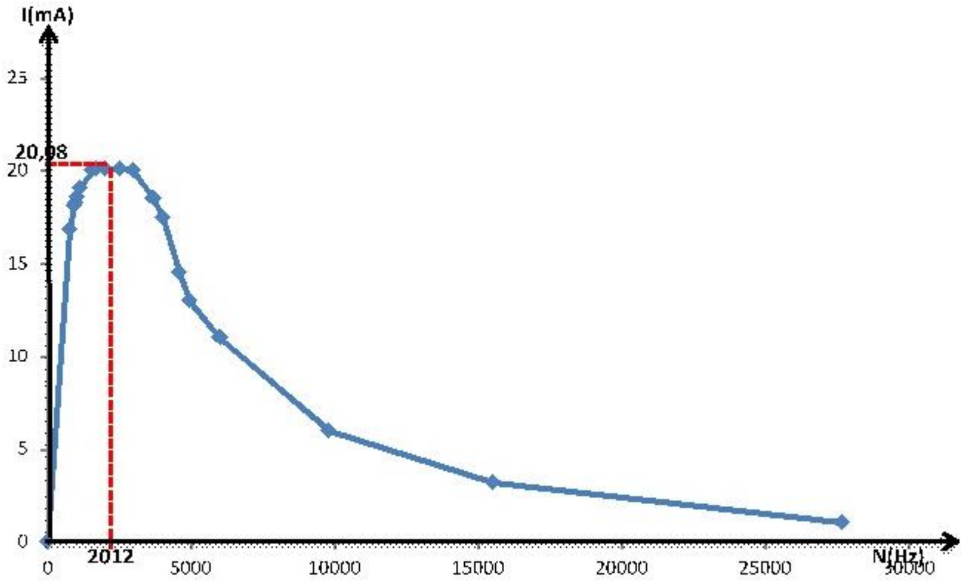

Figure 2 : *Resonance graph I = f (N) with a resistance R_2 = 46 Ω*

With an ohmic resistance conductor R_2 = 46 Ω, the same resonance frequency No = 2012 Hz is obtained at the intensity resonance, but with an rms intensity whose maximum resonance value is I = 20.08 mA. The quality factor Q_2 = 0.54. Q_2 < 1, the resonance is fuzzy.

III-1-3. Measurement table and graph for R_3 = 100 Ω

The use of an ohmic resistance conductor R_3 = 100 Ω in the series RLC circuit gives ***Table 3***.

Table 3 : *Measurement table for R_3 = 100 Ω*

N(Hz)	0	784,6	814,7	962,3	1081	1262	1440	1900
I(mA)	0	13,23	13,4	13,8	14,02	14,2	14,25	14,26
N(Hz)	**2012**	2100	2190	3000	6000	20500	30500	46440
I(mA)	**14,27**	14,26	14,24	14	12,52	6	3	0,3

From this table, we have constructed the current intensity curve as a function of frequency as follows.

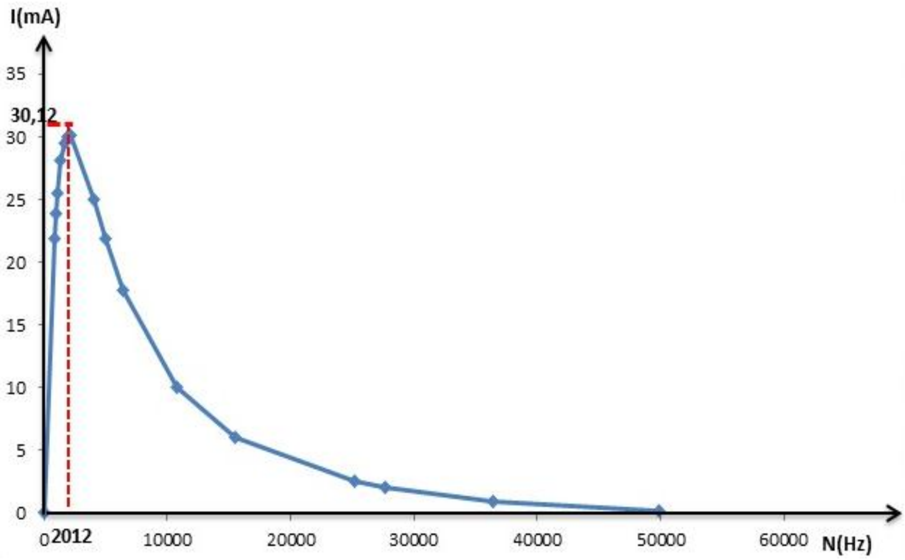

Figure 3 : *Resonance graph with a resistor R3 = 100 Ω*

The insertion of the resistance ohmic conductor R3 = 100Ω gives the intensity resonance the same resonance frequency N_0 = 2012 Hz but with an rms

intensity that passes through a smaller maximum value, i. e. I = 14.27 mA. The quality factor is the lowest Q_3 = 0.25. Q is close to zero. The resonance is fuzzy. By comparing the data in Figures 23, 24 and 25, it appears that the lower the damping of the oscillator, the greater the quality factor Q, i.e. the lower the resistance R of the circuit. $R_1 < R_2 < R_3$ therefore $Q_1 > Q_2 > Q_3$.
Thus the resistance of the ohmic conductor has a significant influence on the acuity of the intensity resonance. On the other hand, the change of the different ohmic conductors in the series RLC circuit does not affect the resonance frequency, which remains equal to 2012 Hz.

III-2. Influence of the inductance of a coil on the intensity resonance

III-2-1. Measurement table and graph for L_1= 530 µH

The use of the characteristic coil (L_1 = 530 µH ; r_1 = 2,8 Ω) in the serial RLC circuit gives ***Table 4***.

Table 4 : *Measurement table for L_1 = 530 µH*

N(Hz)	0	810,9	1017	2025	2509	2540	2570	2600	**2692**
I(mA)	0	19,98	23,13	29,21	29,72	29,73	29,74	29,75	**29,77**
N(Hz)	2784	3951	4972	5160	7971	10462	21382	33244	49846
I(mA)	29,75	28,99	27,76	27,52	23,55	20,16	10,01	5,01	2,02

From this table, we have constructed the current intensity curve as a function of frequency as follows.

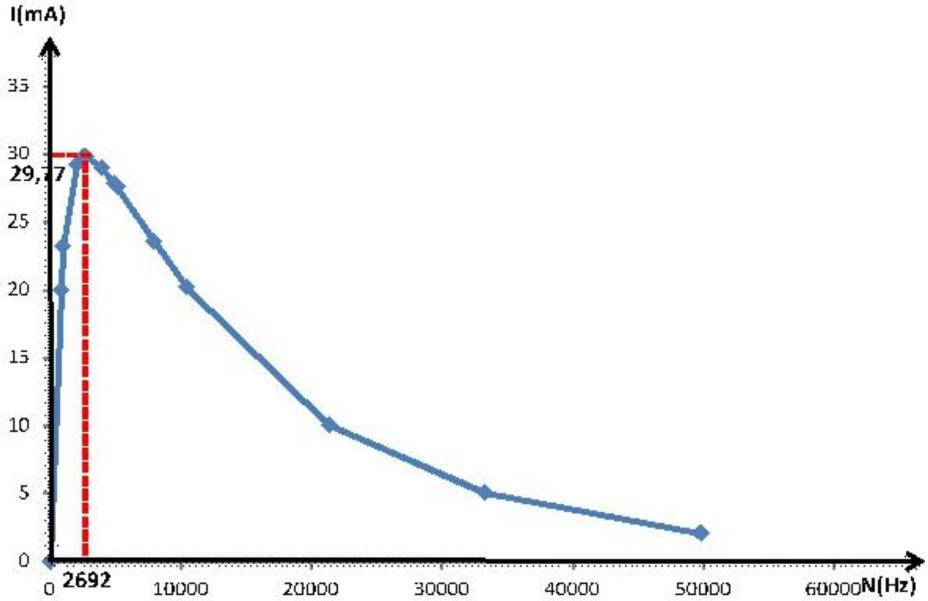

Figure 4 : *Resonance graph I=f(N) with an inductance L1 = 530 µH*

With an inductance coil L^1 = 530 µH, at the intensity resonance, a resonance frequency N_0= 2692 Hz corresponding to a maximum rms intensity of value at resonance I = 29.77 mA is obtained. The quality factor Q_1 = 1.87.

III-2-2. Measurement table and graph for L_2 = 800 µH

The use of the characteristic coil (L_2 = 800µH ; r_2= 3,5Ω) in the serial RLC circuit gives the following ***Table 5***.

Table 5 : *Measurement table for L_2 = 800 µH*

N (Hz)	0	841	989	1315	2026	2328	2480	**2540**	2721
I (mA)	0	20,55	22,80	26,20	29,17	29,50	29,55	**29,56**	29,54
N (Hz)	3558	4518	8961	12076	18320	28000	4239 0	4708 8	
I(mA)	28,91	27,64	20,44	16,05	9,91	5,03	2,02	1,50	

From this table, we have constructed the current intensity curve as a function of the following frequency.

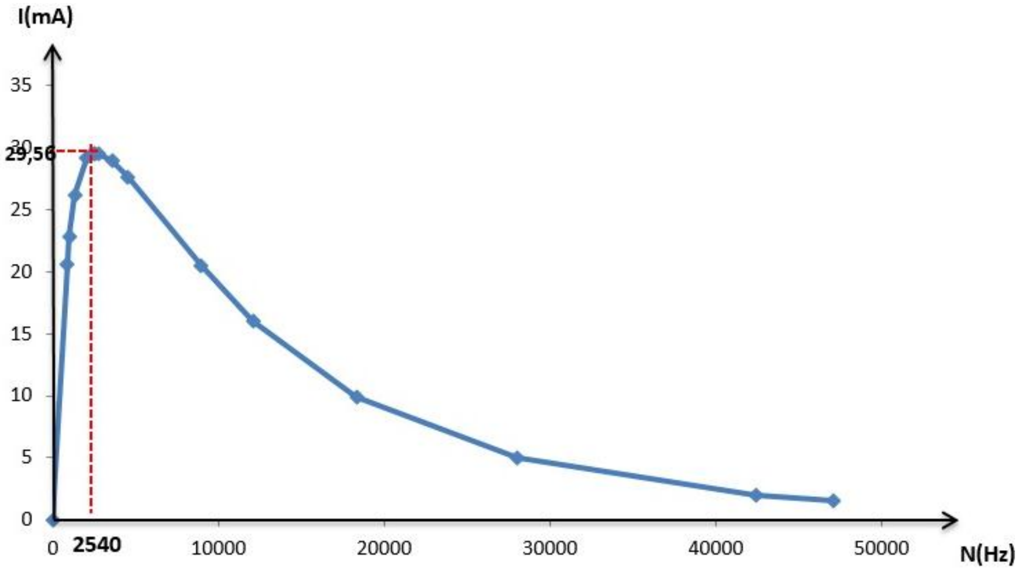

Figure 5 : *Resonance graph with an inductance L_2 = 800 µH*

With an inductance coil L_2 = 800 µH, a resonance frequency N_0 = 2540 Hz is obtained at the intensity resonance. The maximum rms intensity of value at resonance is I = 29.56 mA. The quality factor has the value Q_2 = 2.32.

III-2-3. Measurement table and graph for L_3 = 2 mH

The use of the characteristic coil (L_3 = 2mH ; r_3 = 0.8 Ω) in the serial RLC circuit gives ***Table 6***.

Table 6 : *Measurement table for L_3 = 2 mH*

N(Hz)	0	877,95	996,8	1115	1384	1652	1861	1982	**2012**	2162
I(mA)	0	21,85	23,84	25,5	28,11	29,51	30	30 ,11	**30,12**	30,10
N(Hz)	4018	4980	6427	10794	15478	25170	27676	36436	49896	
I(mA)	25,03	21,86	17,80	10,05	6	2,49	2,02	0,99	0,21	

From this table, we have constructed the current intensity curve as a function of the following frequency.

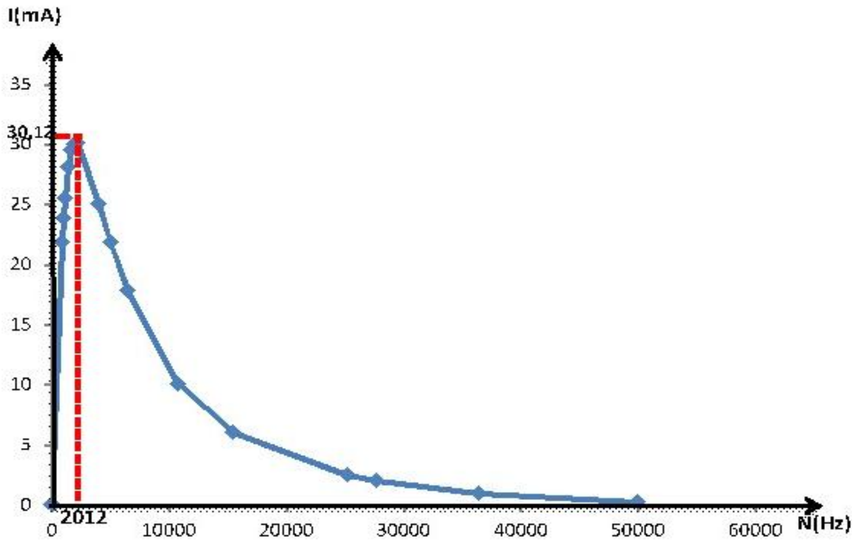

Figure 6 : *Resonance graph with an inductance L_3 = 2 mH.*

The insertion of an inductance coil L_3 = 2 mH gives the intensity resonance a resonance frequency N_0 = 2012 Hz but with a maximum rms intensity of I = 30.12 mA. The quality factor is the highest Q_3 = 9.03. The resonance is high. The data in Figures 26, 27 and 28 show that the quality factor Q is proportional to the inductance of the coil. The higher the inductance of the coil, the higher the quality factor. L1 < L_2 < L_3 therefore $Q_1 < Q_2 < Q_3$. In addition, we observe that the current intensity on the three figures is close to 30 mA. Thus the inductance of the coil influences the acuity of the intensity resonance.

III-3. Influence of capacitance on intensity resonance

III-3-1. Measurement table and graph for C_1 = 0.47 µF

The use of a capacitor with capacitance C_1 = 0.47µF in the serial RLC circuit gives ***Table 7***.

Table 7 : *Resonance graph for C_1 = 0.47 µF*

N(Hz)	0	896	1013	2514	3492	4004	4222	4254	4557	
I(mA)	0	5,77	6,52	15,99	22,43	25,23	25,97	26,05	26,57	
N(Hz)	4653	**4719**	4800	4996	7655	10760	15430	17932	23240	28234
I(mA)	26,63	**26,64**	26,63	26,49	18,62	11,57	6,48	4,99	3,05	2,00

From this table, we have constructed the current intensity curve as a function of the following frequency.

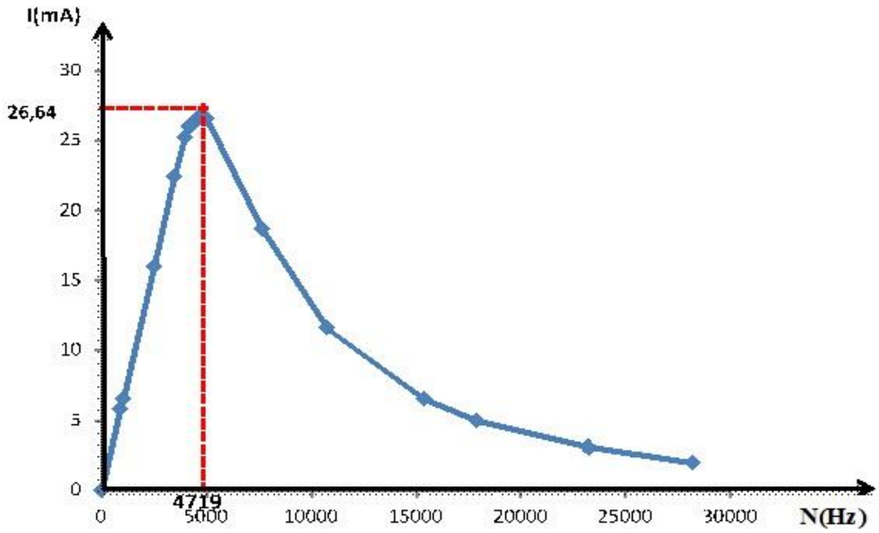

Figure 7 : *Resonance graph with a capacitance C_1 = 0.47 µF*

With a capacitance capacitor C_1 = 0.47 µF, at the intensity resonance, a resonance frequency N_0 = 4719 Hz corresponding to a maximum rms intensity value at resonance I = 26.64 mA is obtained. The quality factor Q = 25.63. Q is large, the circuit is selective and the resonance is acute.

III-3-2. Measurement table and graph for C_2 = 1 µF

The use of a capacitor with capacitance C_2 = 1µF in the serial RLC circuit gives ***Table 8***.

Table 8 : *Measurement table for C_2 = 1 µF*

N(Hz)	0	911,5	1033	1417	1804	2161	2281	2401	2551	
I(mA)	0	10,68	12,09	16,53	**20,81**	24,25	25,19	26,00	26,85	
N(Hz)	2701	3031	3123	3193	**3253**	3283	5593	11206	16198	25260
I(mA)	27,50	28,30	28,37	28,38	28,39	28,38	22,05	9,97	5,70	2,5

From this table, we have constructed the current intensity curve as a function of the following frequency.

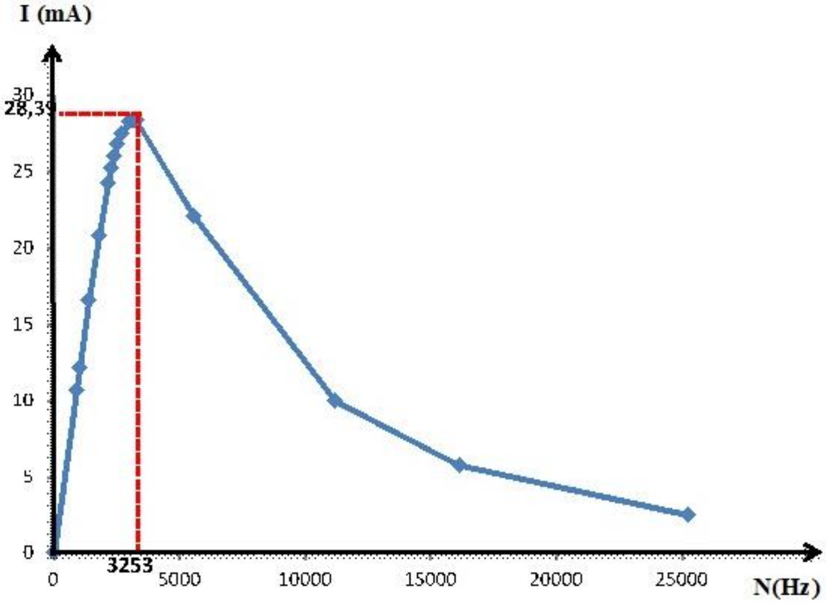

Figure 8 : *Resonance graph with a capacitance C_2 = 1µF*

By taking a capacitor with a larger capacitance C_2 = 1 µF, we obtain at the intensity resonance, a resonance frequency N_0 = 3253 Hz corresponding to a maximum rms intensity value at the resonance I = 28.39 mA. The quality factor is lower at Q = 17.47.

III-3-3. Measurement table and graph for C_3 = 2.2 µF

The use of a capacitor with capacitance C_3 = 2.2µF in the serial RLC circuit gives ***Table 9***.

Table 9 : *Measurement table for C_3 = 2.2µF*

N(Hz)	0	877,95	996,8	1115	1384	1652	1861	1982	**2012**	2162
I(mA)	0	21,85	23,84	25,5	28,11	29,51	30	30 ,11	**30,12**	30,10
N(Hz)	4018	4980	6427	10794	15478	25170	27676	36436	49896	
I(mA)	25,03	21,86	17,80	10,05	6	2,49	2,02	0,99	0,21	

From this table, we have constructed the current intensity curve as a function of the following frequency.

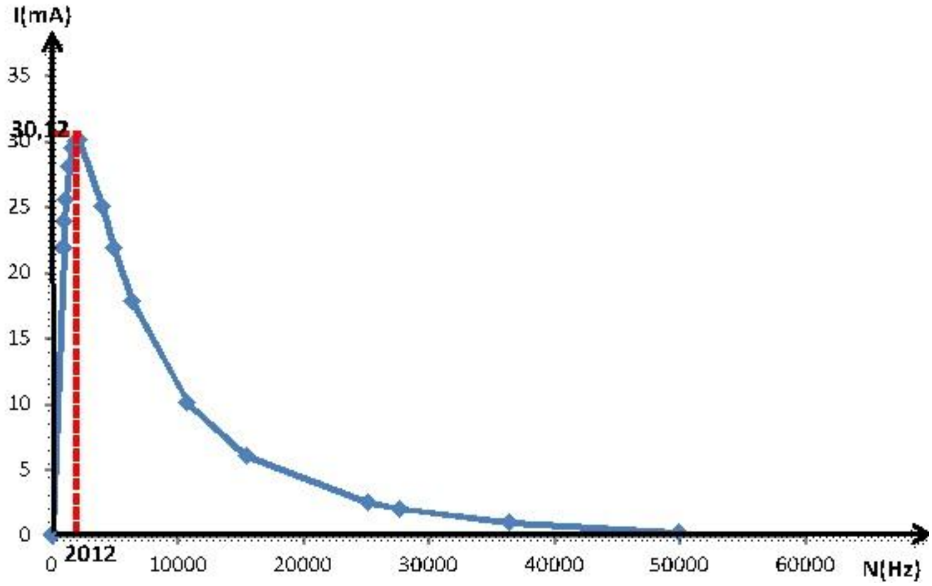

Figure 9 : *Resonance graph with a capacitance C_3 = 2.2 µF*

By inserting an even larger capacitance capacitor C3 = 2.2 µF, a lower resonance frequency N_0 = 2012 Hz is obtained at the intensity resonance with a rms intensity of maximum value I = 30.12 mA. The quality factor is the lowest Q = 9.03. Data in ***Figures 7***, ***8*** and ***9*** show that the quality factor Q is proportional to the capacitance of the capacitor. The higher the capacitance of the capacitor, the lower the quality factor. $C_1 < C_2 < C_3$ therefore $Q_1 > Q_2 > Q_3$. Thus the capacitance of the capacitor has an influence on the acuity of the intensity resonance.

IV - DISCUSSION

By observing ***Figures 1***, ***2*** and ***3*** and comparing the different values of the quality factor, it is clear that the higher the oscillator is weakly damped, the greater the quality factor Q is, i.e. the lower the resistance R of the circuit. $R_1 < R_2 < R_3$ leads to $Q_1 > Q_2 > Q_3$. In addition, at the intensity resonance, the high resistance ohmic conductor is much more resistant to current flow than a low resistance ohmic conductor [6 - 8]. This confirms the main characteristic of an ohmic conductor, which is to have a greater or lesser resistance to the flow of electrical current. Thus the resistance of the ohmic conductor has a significant influence on the acuity of the intensity resonance. On the other hand, changing the different ohmic conductors in the series RLC circuit does not affect the resonance frequency [4]. This hypothesis is supported by the different values of the quality factor and ***Figures 4***, ***5*** and ***6*** which show that the quality factor Q is proportional to the inductance of the coil. The higher the inductance of the coil, the higher the quality factor. $L_1 < L_2 < L_3$ leads to $Q_1 < Q_2 < Q_3$. The quality factor then increases with the inductance of the coil. This confirms the expression used in equation 2. Therefore the inductance of the coil influences the acuity of the intensity resonance [9]. To test the hypothesis that the capacitance of a capacitor has an influence on the intensity resonance, we used the different values of the quality factor. The quality factor Q is proportional to the capacitance of the capacitor ***(Figures 7**, **8** and **9)***. The higher the capacitance of the capacitor, the lower the quality factor. $C_1 < C_2 < C_3$ lies to $Q_1 > Q_2 > Q_3$. The quality factor then decreases as the capacitance of the capacitor increases. This allows the expression in equation 2. So the capacitance of the capacitor has an influence on the acuity of the intensity resonance. In short, it should be noted that the resonance frequency does not depend on the resistance of the ohmic conductor. It depends only on the inductance of the coil and the capacitance of the capacitor of the series RLC circuit [5]. This is confirmed by the expression of the resonance frequency jn equation 1. In addition, at current resonance, the maximum value of current intensity does not depend on the inductance of the coil or the capacitance of the capacitor. It only depends on the sum of the resistors in the series RLC circuit. To increase the quality factor at current resonance, it is necessary to increase the inductance of the coil, decrease the capacitance of the capacitor or decrease the resistance of the ohmic conductor. This is in accordance with the expressions of the quality factor [8].

V - CONCLUSION

We have successfully studied the intensity resonance for a series RLC circuit in forced sinusoidal mode. The results obtained confirm that the resistance of the resistor, the inductance of the coil and the capacitance of the capacitor influence the intensity resonance. The resonance frequency does not depend on the resistance of the resistor. It is only depends on the inductance of the coil and the capacitance of the capacitor of the series RLC circuit. In addition, at current resonance, the maximum value of current intensity is independent of the coil inductance and capacitor capacity, but it is a function of the sum of the circuit resistances. To increase the quality factor at the intensity resonance, it is necessary to increase the inductance of the coil and decrease the capacitance of the capacitor or the resistance of the ohmic conductor. Our setup produces a clearly defined experimental optimization protocol that could constitute a new enrichment of the intensity resonance in science, and at the institute of our training.

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