Problem No.15 – Transmission of Energy

Introduction

We have to transfer as large a part of a capacitor s energy as possible to some distance and measure the transmitted energy, i.e. to find out our method's efficiency. We've explained the limitation "wireless" in such a way that the direct connection between the capacitor and a device for measuring energy (such as voltmeter) is inadmissible. Different explanation of the limitation is misleading, because we couldn't obtain any energy out of the capacitor without wires.

Solution

The task could be solved in many ways. The different manners of solving it could be divided into three branches according to the energy to which the capacitors energy is transferred.

1. electrical

2. mechanical

3. via rays (elmag. wawes)

Now we'll describe these methods:

1. This method is based on recharging some other capacitor using the charged capacitor and measuring its energy. It could be done by several manners:

a) We connect our capacitors paralelly. If we connect these capacitors together, 50 % of the initial energy will disappear not depending on R.

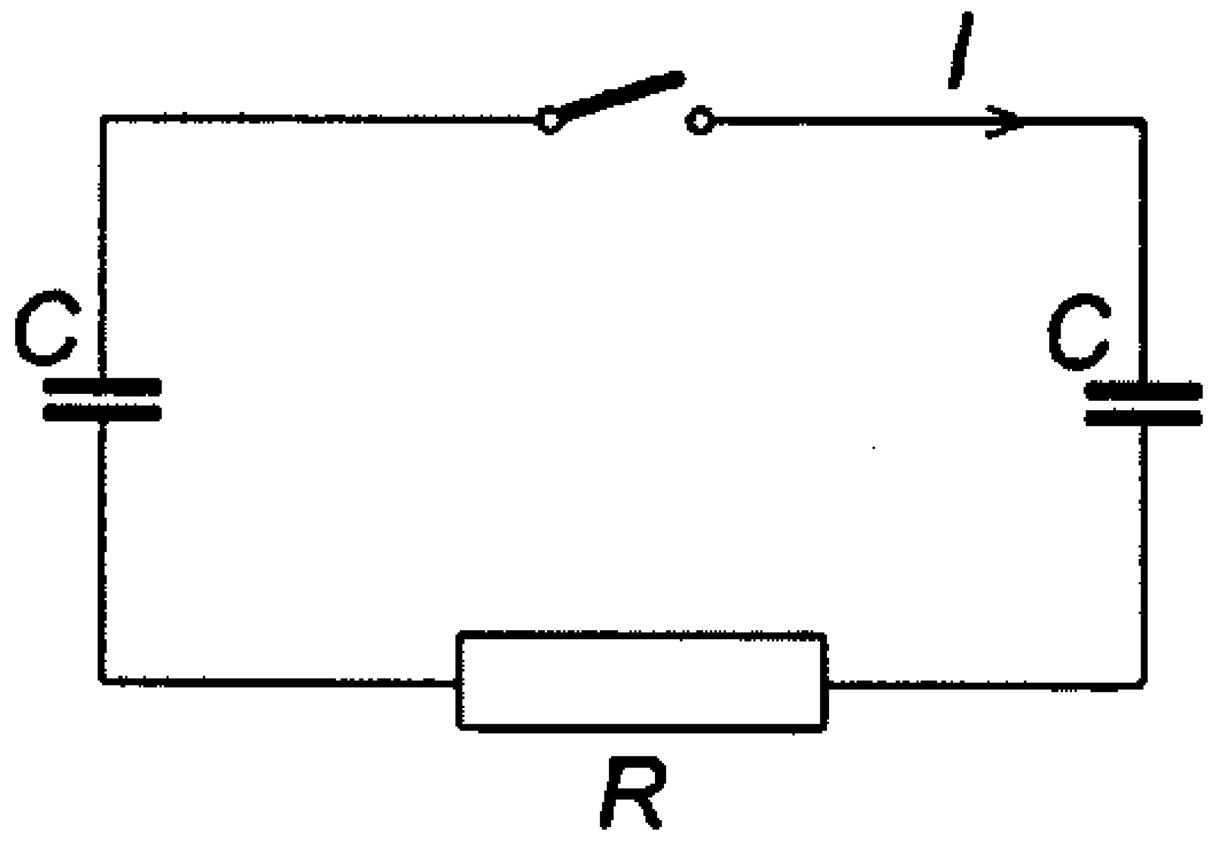

Fig.28

$$U_1 - U_2 = RI, \quad \frac{Q_1 - Q_2}{C} = RI \quad \Rightarrow \quad (-I)/C - I/C = R\,\mathrm{d}I/\mathrm{d}t$$

$$I = \mathrm{d}Q_2/\mathrm{d}t - \mathrm{d}Q_1/\mathrm{d}t \qquad R\,\mathrm{d}I/\mathrm{d}t = -2I/C$$

$$\mathrm{d}I/\mathrm{d}t + 2I/(RC) = 0$$

This equation could be solved by the method of the variable separation.

$\mathrm{d}I/I = -2/(RC)\,\mathrm{d}t$, integrate:

$\ln(I) = -2t/(RC) + \ln(K)$, where $\ln(K)$ is integration constant

$\ln(I/K) = -2t/(RC)$

$I = K\exp(-2t/(RC))$

Now we have to determine the $\underline{K}$. It could be easily done if $t = 0$, because $I = I_m$ and $\exp(...) = 1$ in this case. Consequently:

$$K = I_m = U_0/R, \text{ by substitution:}$$

$$I = U_0/R \exp(-2t/(RC))$$

The energy of capacitor C_2 is:

$$E_2 = R\, I^2 dt = R \quad U_0^2/R^2 \exp(-2t/(RC)) = U_0^2/R^2 \exp(-2t/(RC))$$

Let us write: $z = -4t/(RC)$, i.m. : $dz = -4t/(RC)\, dt$

$$E_2 = -U_0^2/R^2 \quad e^z RC/(-4dz) = -U_0^2/R^2$$

$$e^z dz = -U_0^2/R^2 e^z = -U_0^2 C/4[\exp(-4t/(RC))]$$

The upper boundary is $t = \infty$ and the lower one $t = 0$.

$$E_2 = 0 - (-U_0^2 C/4)$$

The efficiency of this method could be obtained by comparing the initial energy E_0 and the get energy E_2.

$$E_0 = \tfrac{1}{2} C_1 U_0^2$$

$$U_1 = U_2 = U, \qquad Q = CU$$

$$Q_1 + Q_2 = Q_0, \qquad Q_0 = \frac{C_1}{C_2} Q_2$$

$$Q_2 = Q_1 - \frac{C_1}{C_2} Q_2$$

$$E_2 = \tfrac{1}{2} C_2 U_2^2 = \tfrac{1}{2} C_2 Q_2^2/C_2^2 =$$

$$\tfrac{1}{2} C_2 Q_0^2 C_2/(C + C_2)^2 =$$

$$\tfrac{1}{2} C_2/(C + C_2)^2 C_1^2 U_0^2 =$$

$$\tfrac{1}{2} C_1 U_0^2 C_1 C_2/(C + C_2)^2 = E_0 C_1 C_2/(C + C_2)^2$$

$$E_2 = E_0 C_1 C_2/(C + C_2)^2$$

Let us differenciate this equation:

$$dE_2/C_2 = -E_0 C_1 (C_2 - C_1)/(C_2 + C_1)^3 = 0 \Leftrightarrow C_2 = C_1 \Rightarrow E_1 = E_2 = \tfrac{1}{4} E_0$$

$$d^2E_2/C_2^2 = 2E_0 C_1 (C_2 - 2C_1)/(C_2 + C_1)^4; \; C_2 = C_1 \Rightarrow d^2E_2/C_2^2 < 0$$

As we see, we can not reach more then 25% of the initial energy. This is not a sufficient amount, consequently we have to think about something else.

b) Our method is described on the scheme below:

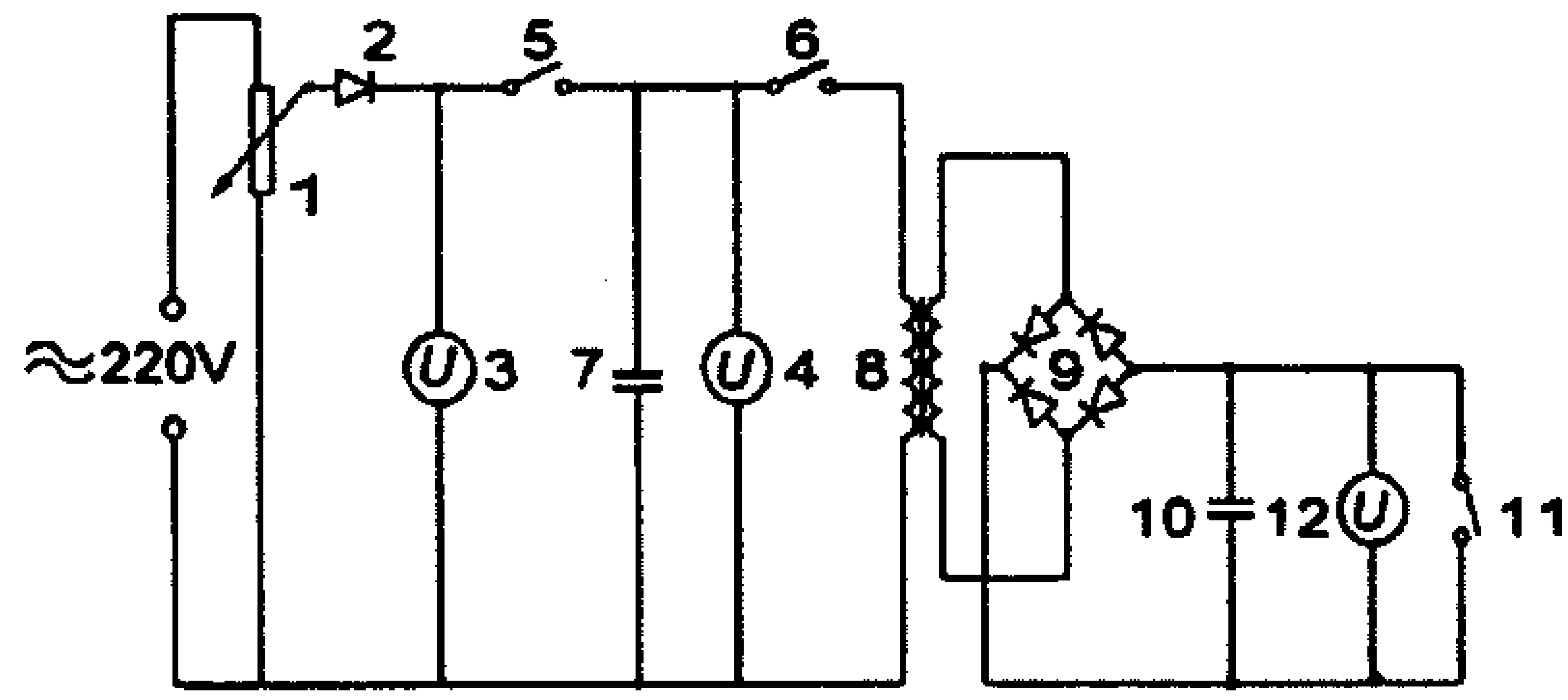

Fig.29

The description of design:

1 ... rheostat 2500 Ω
2 ... diode KY 725
3 ... voltameter for measuring voltage on rheostat
4 ... voltameter for measuring voltage on capacitor C_1
5 ... switch charging C_1
6 ... switch charging C_2
7 ... capacitor C_1
8 ... transformer with the ratio 5, 10, 20 up (the first spool has 60 coils, the second 300, 600, 1200)
9 ... Graetz's a.c. bridge
10 ... capacitor C_2
11 ... button for discharging C_2

The description of the function:

First of all, we charge C_1 to 100 V. We set up the charging voltage exactly at 100 V by means of the rheostat 2. Then we discharge the capacitor C_1 into the first coil of the transformer. The circuit of the first transformer coil starts to oscillate for this reason. There is an inducted voltage higher than in the first coil in the second coil.

The capacitor is charged only in the time of the first quarter of wave, because in the time $T/4$ the capacitor is charged to the highest possible voltage and any lower voltage cannot influence its voltage. The diode cuts off the negative half of the wawe to stop the oscillations in its part of the device. The polarity of the diode matters, because the oscillation is subdued. The first half the wawe is higher than the first one for this reason - experiments say that 2.4 times. It's necessary to use a diode with the lowest possible reverse current otherwise the capacitoris going to discharge through it. A suitable diode to use is for example KY 725.

It's also possible to use a Graetz's a.c. bridge instead of the diod. We found out that it's better to use this bridge than only one diod (see tab).

Having performed the experiment, we found out that the voltage on C_2 abruptly ros to some value and then it slowly went down to zero. We can easily find out that this is caused by attached voltmeter and correct it by using a digital voltameter which has lesser internal resistance than an analog one.

We ought to use the capacitors different from electrolytical ones.

We have done several experiments with different values of the capacity C_2 and transformer ratios as well. We have found that the best ratio is 1 : 5 but we think the best ratio should be about 2 : 5, but we didn't have suitable coils (we have used standard school system).

It's possible to see in the graph, our efficiency was higher than 50 % in some cases, and so this method is much better than the 1.a).

2. The next possible way of transport is based on changing the capacitor's energy to the mechanical one.

a) We could use so called electromagnetical gun and shot a ring vertically up. This problem was described in the previous YPT. The efficiency of this method was estimated to 2 %, what's really not too much.

b) We could convert the capacitor s energy into an internal energy of some medium and measure its increment.

A similar experiment was performed previous year. The main difference is in the capacitors energy, it was 45 J, this year we have the disposal of enerrgy only 0.05. Even in the first case we were very close to the boundary of the distinguishability. Obviously, this is not a good way.

3. Next possible method of solving this problem is to radiate capacitor energy to the surrounding environment as a electromagnetical wawes. These methods have one great advantage: we are able to transfer the energy at large distances.

a) We form an oscillating LC circle and we try to intercept the energy by means of receiver.

The disadvantage of this method is large dispersion of the transmitted energy – we can receive just a little bit of it. To remove the shortcoming of this method we have to emit on cm or shorter wawelenths. This wawes should be routed so as we could get large part of transmittes energy.

According to formula $\Omega = 1/\sqrt{LC}$ we would have to use a coil with inductance about 10^{-16} H. Even a piece of wire has a higher one.

b) We could emit the energy by means of a bulb and measure amount of the transferred energy by a electric cell.

The problem is that the voltage on capacitor will rapidly exponencially-like decrease. This causes that the bulb will radiate just very little light, most energy will be wasted while warming up the fibre – it will dispers as a warmth. We should also notice that the efficiency of heated bulb is about 5 %. We will hardly warm up the fibre by 0.05 J.

A bulb designed to lower voltage will be blown in the first part of radiating. Similar problem goes with semiconductive lasers. There is another problem – lasers need 200ns pulses.

The summary

We found out that the most effective method of the ones we were contemplating is to charge the capacitor via the transformer. We can achieve more than 50 % of original energy this way.