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DESIGN AND SIMULATION OF ELECTRIC ARC GENERATOR DEVICE

Bence Eckl[1], Norbert Szabó[2]

[1] BSc electrical engineer, [2] MSc engineer

University of Miskolc

Department of Electrical Engineering & Electronics

1. PROLOGUE

The main topic of our abstract is a device what can produce electric arcs on different energy levels. There are many ways of generating electric arcs, and we wanted to find out, how to reach high voltage levels with simple electric circuits. We designed and built an electric device, what can produces high voltage sparks in every 10 milliseconds. It is an accurate equipment and consumes low power. It is ideal for experimental work, but there are many industrial applications, where it can be used successfully.

2. THE PRINCIPLE OF ELECTRIC ARC GENERATION

Basically, the generation of an electric arc only needs high voltage, but this is not so simple. In our case we used the principle of a car ignition system. It can be seen in the following figure.

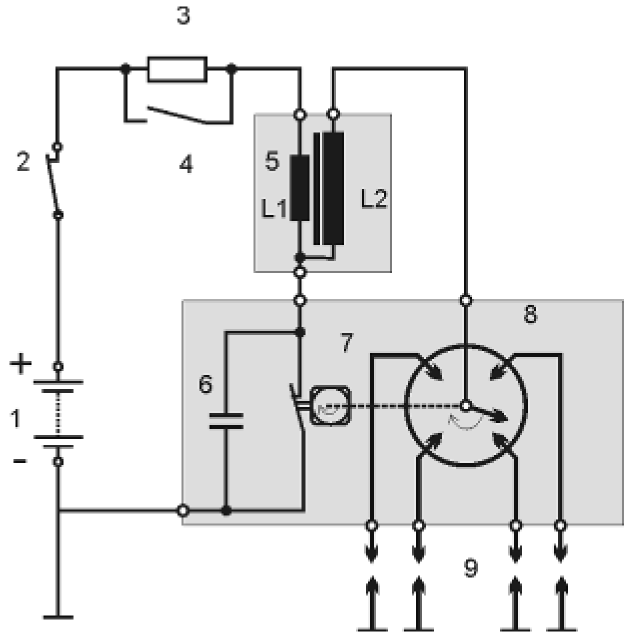

Figure 1
Classical ignition system of an internal combustion engine [1]

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The whole process consists of five steps. First the current in the primary coil of the transformer builds up a magnetic flux. After that, we have to interrupt the circuit and to force the current to decrease so fast, as it is possible, that induces voltage in the primary coil. According to the working principle of the transformer, a high induced voltage will appear in the secondary coil [1]. If the high voltage electrode is close enough to the ground electrode (4-10 mm), then a spark will appear. The only thing that is needed to do is to build a circuit what can do the same process in an accurate and efficient way.

3. THE MAIN BLOCKS OF THE ELECTRICAL ARC GENERATOR

In the following figure it is presented the block diagram of the device.

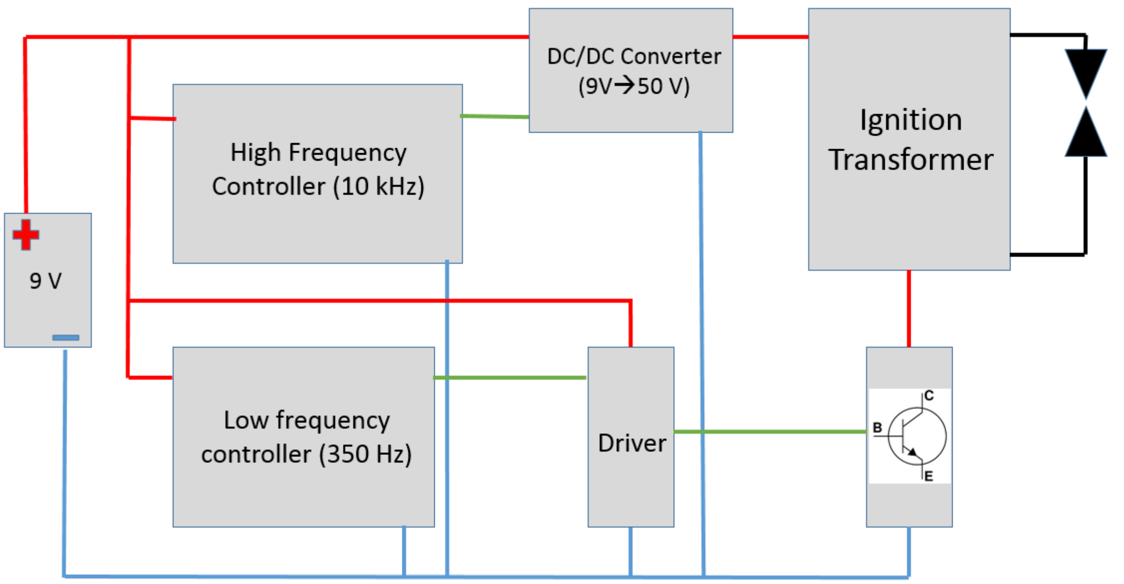

Figure 2
The block diagram of the arc generator device

The power supply of this device is a simple 9 V battery (Li-ion). It can produce high current for a short time (1-2 seconds). There are two controllers. They generate the basic signals for operation. The first one is a higher frequency oscillator implemented with an NE555 integrated circuit, and a second one is also an oscillator with the same IC, but it works with lower frequency. The first one drives a transistor of a boost-converter, and the second one drives a power transistor, what can switch on and off the current of the primary coil. The main element of the circuit is an ignition transformer. It has 1:100 voltage ratio, so if there is 200 V induced voltage at the primary coil, there will be 20 kV at the secondary coil. According to this block diagram, we designed a circuit for these purposes. It can be seen in the next figure.

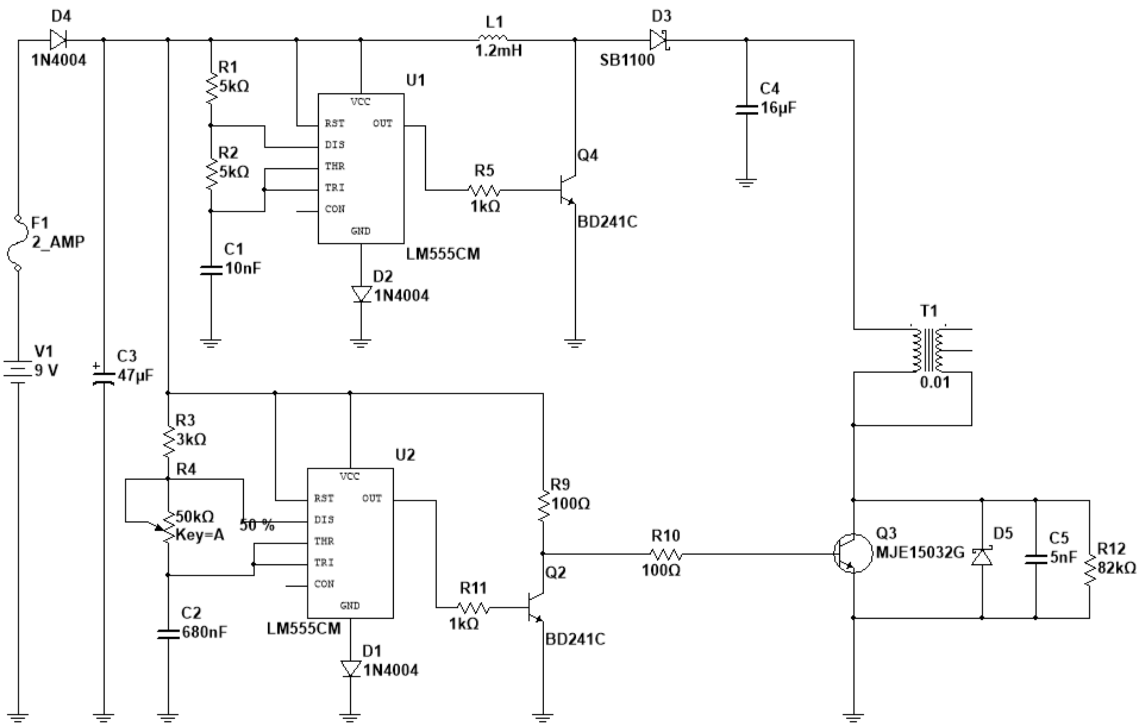

Figure 3
The electric circuit of the arc generator

Now we examine the figure step by step. At the output of the 9 V battery you can see a 2 A fuse, and a simple diode. These parts protect the device from damage. After that, there are two signal generators. The first one produces a square wave signal with 10 kHz frequency, and the output load can be 15 mA. The second one provides a square wave with 350 Hz, and it has also 15 mA output. The boost-converter consists of four elements, an inductor (L1), a transistor (Q4), a Schottky-diode (D3), and a capacitor (C4). The ignition transformer connects to the output of the boost-converter, than a power transistor (Q3) cuts off the current of the primary coil in every period. These main elements of the circuit are the most important parts of the device. Before we built it together, we have done some simulation on each blocks of the device. Firstly the signals of the control block were examined.

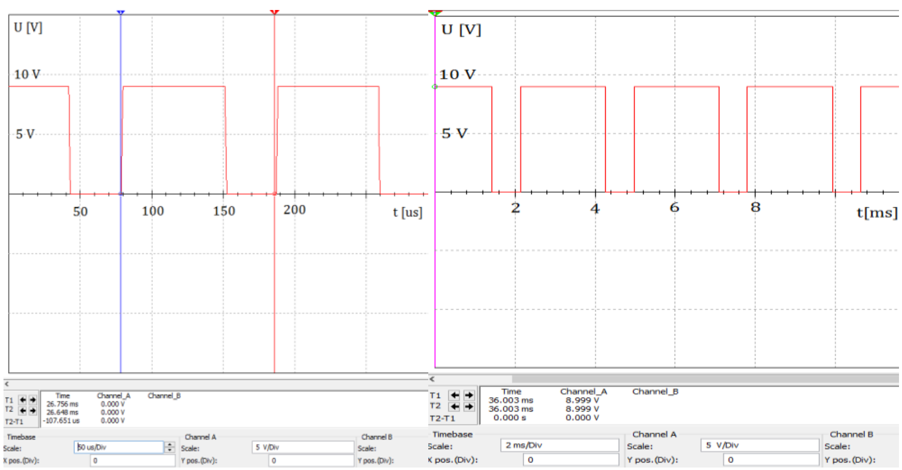

Figure 4
Simulation results at higher (left) and lower (right) frequency control circuit output

It can be seen that the control circuits work well with the calculated parameters. Both duties are 80 %. It is a random data, and it can be changed on the real circuit using a potentiometer. The simulation results of the output section of the boost converter is presented in the figure below.

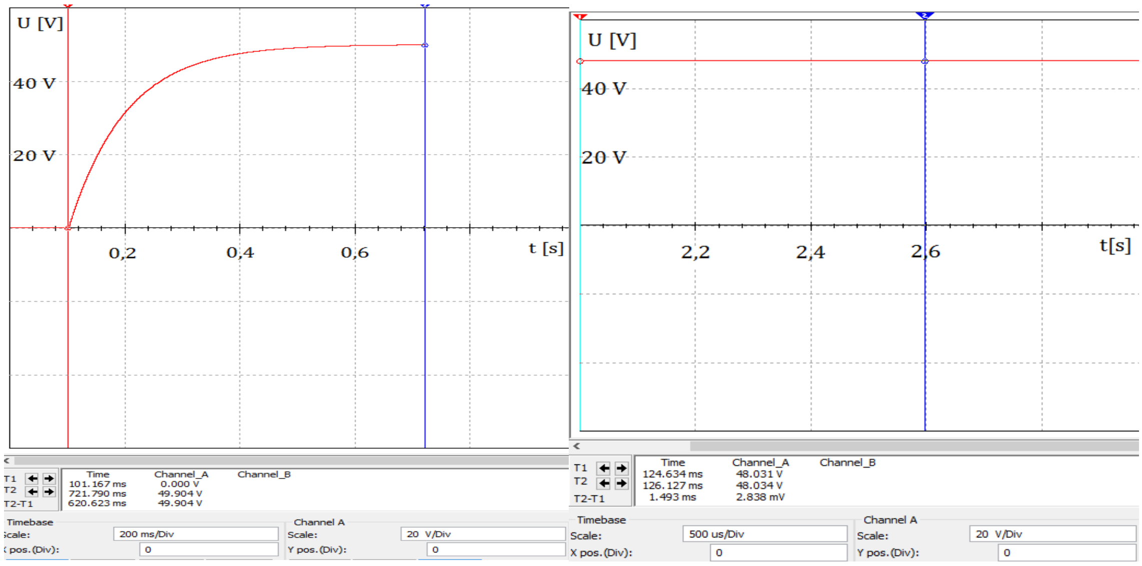

Figure 4

The simulation results at the output of Boost-converter

As it is shown the transient voltage has a quite long time constant, but after the transient process the output voltage is correctly 48 V. This is the highest voltage level we could reach with this simple converter, and it is enough for the correct operation. Thereafter it was examined the voltage between the collector and emitter of the power transistor.

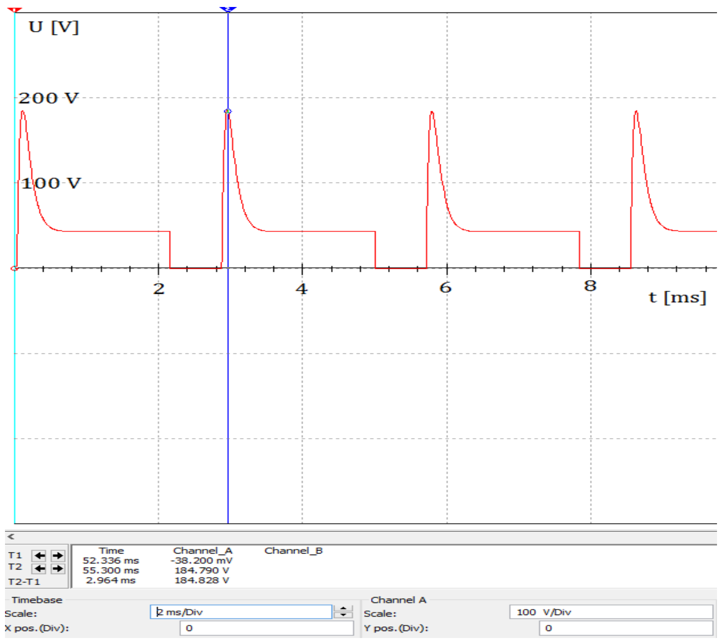

Figure 5

The collector-emitter voltage of the power transistor

The maximum level of this voltage was set up by the parallel R_{12} and C_5 devices. Over 250 V the power transistor can be damaged. After the simulation, the only thing that we had to do, was to build the circuit according to the design and the simulation.

4. IMPLEMENTATION AND TESTS

Firstly, the electric circuit was assembled according to the design, then we placed in a plastic chassis. After these steps, the device was finished. It can be seen it in the following figure.

Figure 6
The finished arc generator device

There is a potentiometer on the left side of the device. The duty of the square wave signal at the power transistor can be set by that to change the level of the induced voltage. There is also an activator switch and a stand-by LED on the top of the device. When the activator switch is in ON state, high voltage arcs will be generated. After assembling, we have done some tests to confirm the simulation results.

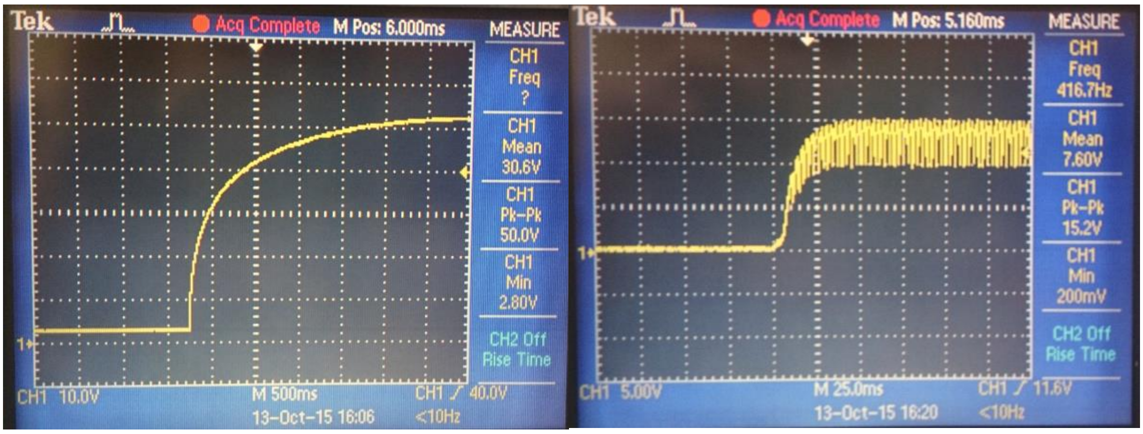

Figure 7
The voltage transient at the output of boost-converter without load (left) and with nominal load (right)

In the left figure it can be observed the voltage has reached the expected value (around 50 V), and in the right, the DC value of voltage is around 12 V. The control signals were the followings:

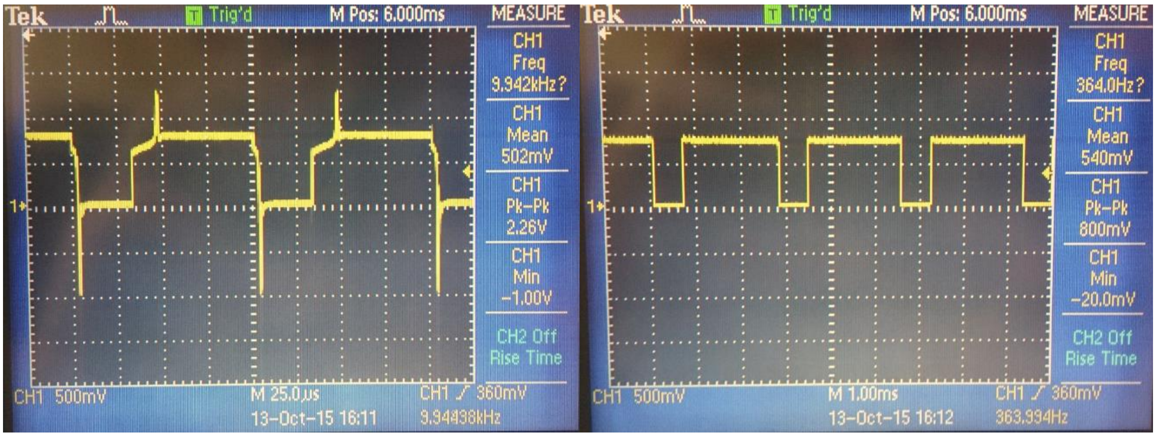

Figure 8
Control signals of the higher frequency output (left),
and lower frequency output (right)

The higher frequency output is a quite noisy because of the inductance at the input of boost-converter, but the frequency is right, almost 10 kHz. At the lower frequency output, the voltage and the frequency is appropriate, 800 mV, and 364 Hz. In this case the duty was set to 80 %. After the control signal tests, we must test the weak points in the circuit, the collector-emitter of the power transistor, and the secondary coil of the transformer.

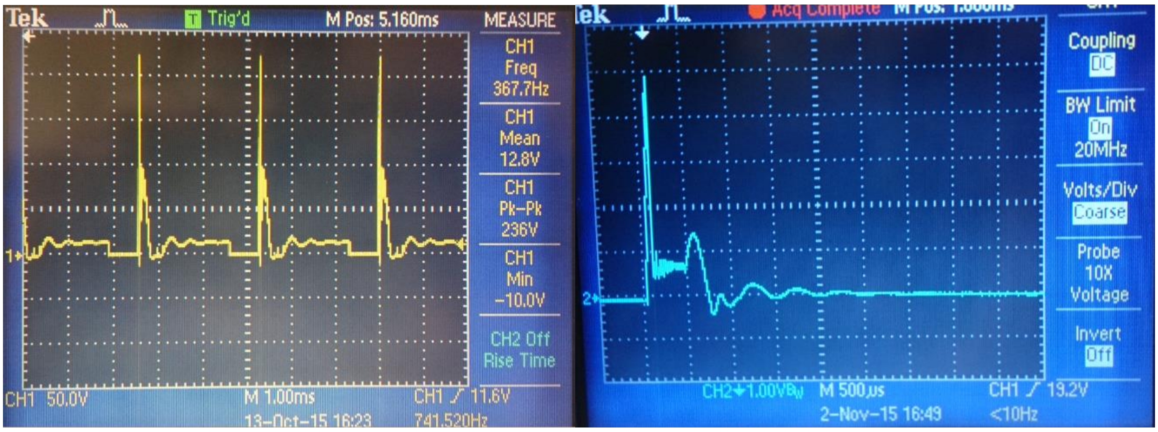

Figure 9
The collector-emitter voltage at the power transistor (left) and the voltage at the high voltage output (right)

The voltage peak is 236 V at the power transistor. It is high, but it does not damage the transistor. At the output of the secondary coil, the voltage is incredibly high. According to the transformers voltage ratio, it is around 23 kV. It is far enough to ionize the air and a spark is created. The measurement of these signals were done at the following parameters: power supply is 9 V, the duty of the low frequency control signal is 80 % and the voltage ratio of the ignition transformer is 1:100. After all we examined the power consumption of the device at different voltage levels.

Table 1
Power consumption measurement on different power supply levels

Power consumption measurement								
Voltage [V]	5	6	7	8	9	10	11	12
Current [mA]	160	220	300	360	410	500	590	660
Power [W]	0.8	1.32	2.1	2.88	3.69	5	6.49	7.92

At 9 V, the device consumes 3.7 W. It is able to work on 12 V, but over that level the correct behaviour is not guaranteed.

5. CONCLUSION

During this project we recognized many effects caused by high voltage arcs, and we have got lot of experience about the behaviour of a generator circuit. Certainly there are several development challenges in this device, but the created generator is a quite significant result. Anyone can examine the high voltage arcs using this item. It can also be applied in the education at the university, especially in the field of electrical engineering and electronics. Finally, it can be the basic unit of many high voltage devices, for example insulation examiner, cosmetic applications, and plasma speaker system. All in all, we produced a useful, versatile product and learnt a lot about high voltage electronic equipment.

6. REFERENCES

[1] Cs. BLÁGA: **Gépjárművek Otto-motorjai gyújtóberendezéseinek vizsgálata áramkör-szimulációs programcsomag segítségével** – Elektrotechnika magazine 7/88, July 1995, pp. 343-345.