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Analysis of the influence of strong magnetic field on unmanned aircrafts, using Helmholtz coil.

***Abstract**. The aim of experimental research was to measure disturbances in the unmanned aircraft circuits subjected to pulsed, strong magnetic field. It's equal to the disturbances during lightning strike. The Marx generator and the Helmloltz coil were used for the tests. The tested object was placed in the center of Helmholtz coil.*

Streszczenie.** Celem badań eksperymentalnych był pomiar zakłóceń w obwodach bezzałogowych statków powietrznych poddanych działaniu impulsowego, silnego pola magnetycznego. Odzwierciedlało to zakłócenia powstające podczas wyładowania atmosferycznego. Do badań wykorzystano generator Marksa oraz cewkę Helmloltza. Badany obiekt umieszczono wewnątrz cewki Helmholtza. **Analiza wpływu silnego pola magnetycznego na samoloty bezzałogowe z wykorzystaniem cewki Helmholtza.

Keywords: lightning, aircraft, Helmloltz coil, Marx generator
Słowa kluczowe: wyładowania, statki powietrzne, cewka Helmholtza, generator Marksa

Introduction

Unmanned aircrafts (drones) find a wide applications in industry and are just no more for entertainment but those machines are working in good and bad weather [1]. Sometimes, they are used for geodetic measurements, air quality tests and the collection of other data for scientific and commercial purposes. It is necessary to work in various atmospheric conditions, including the nearby of the storm front. Thus, the question arises about the resistance of those machines to lightning strike and related electromagnetic interference. For this purpose, the tested object was placed inside the Helmholtz coil. This made it possible to simulate a strong, homogeneous, pulsed magnetic field, with drone located in the center. The coil supplying pulse was generated in the Marx generator. The shape of the pulse was a very important because it was necessary to get closest to the standard signals. The characteristic of signal was: *1.5/5 μs* (Fig.4.). There is no doubt that a direct discharge into the machine case causes its destruction. The weight as small as possible makes it impossible to use an aluminium casing or other protective screens. Drones are unmanned aircraft, so it is possible to apply standards for aviation and measurements as for aircraft avionics. There is no standard for unmanned aircraft. The research results shows what kind of disturbances in various parts of the drone circuits, during the magnetic impulsewere induced. On this basis, conclusions can be drawn regarding the damages. Helmholtz's coil was used in the tests to irradiate the machine, avoiding direct injection of the impulse into it [2].

Magnetic field generating system

A. Helmholtz coil as the source of the uniform magnetic field

The Helmholtz coil witch was used during tests, to generate uniform magnetic field, consist of two single turn coils. The radius of the coils was 1 meter and was equal to the distance between them. Both windings were connected in series, so the current flowing through the coils was the same and has the same direction.

Thanks to that, between the coils an almost homogeneous magnetic field was obtained. The Helmholtz coil and it's magnetic field is shown in figure 1.

The equation describing the intensity of the magnetic field inside the coil, at any point on the X axis, taking the form [5]:

$$H_X = \frac{NI}{2r}\left\{\left[1+\left(\frac{1}{2}-\frac{x}{r}\right)^2\right]^{-\frac{3}{2}}+\left[1+\left(\frac{1}{2}+\frac{x}{r}\right)^2\right]^{-\frac{3}{2}}\right\} \quad (1)$$

where: N – the number of turns of each coil, r – coils radius [m], I – current [A], x - the distance of point on X axis from point $s(0,0)$ [m].

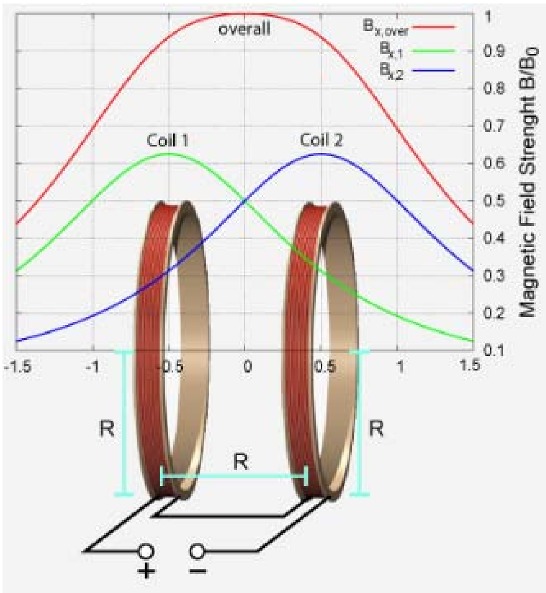

Fig.1. Helmholtz coil and its magnetic field [3,4]

Assuming, that the tested subject is exactly in $s(0,0)$ point, the equation witch can be used to calculate intensity of the magnetic field can be written as [5]:

$$H_X = \frac{NI}{r(1.25)^{\frac{3}{2}}} \approx \frac{0.7155NI}{r} \quad (2)$$

B. Marx generator as the source of impulse

Marx generator was used as a source of the impulses. The parameters of the entire system were chosen so that the current pulse shape, similar to the normalized lightning current pulse could be obtained. The Marx generator consist of five sections of high voltage capacitors, *4 μF* capacity each. The maximum voltage on the output of generator equals to *300 kV*. The capacitors can store *10 kJ* of energy witch is definitely enough for those tests. The diagram of the generator is shown in figure 2

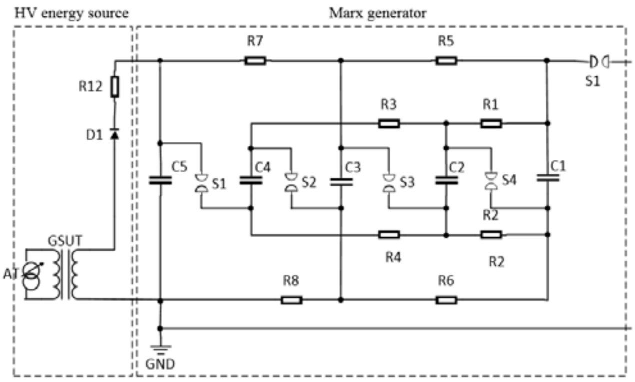

Fig.2. The Marx generator diagram.

On the diagram above, HV energy source consist of autotransformer on the low side of the voltage (AT), step-up transformer (GSUIT), rectifier diode (D1), and resistor R12 limiting capacitors charging current. S1 is the spark gap, witch electrodes are moved away by a distance of one centimeter. It is simple, but very important part of the system. The simplifying diagram of complete system is shown in figure 3 and can be successfully used in simulations.

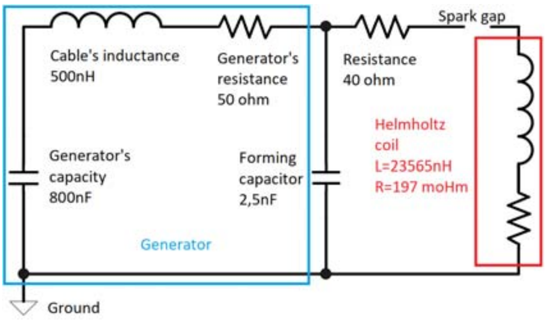

Fig.3. Simplified system for uniform magnetic field of lightning-like electromagnetic pulse.

Research and measurements - tests

During the measurements, many of instruments were used. For measuring the Marx generator output voltage, the Rigol RP1018H high voltage probe was used.

The results were observed at the Rigol DS1052E digital oscilloscope and saved on the pendrive as *.csv files to further analysis. The shape and parameters of measured voltage in three ranges are shown figure 4.

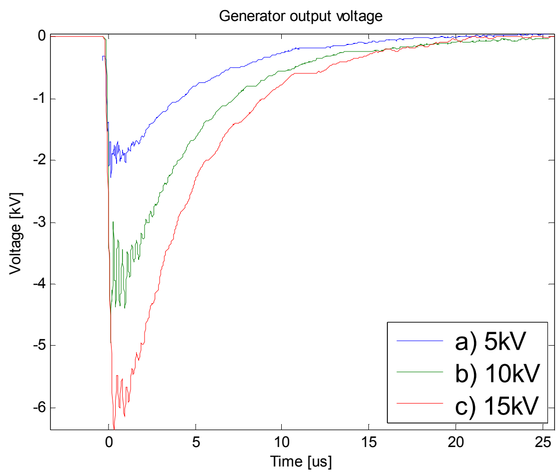

Fig.4. The Voltage produced by Marx generator in three ranges: *5 kV*, *10 kV* and *15 kV*.

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The current flowing through the Helmholtz coil (Fig.5.) was measured by Rogowski coil with Rogowski current waveform transducer type CWT 60B.

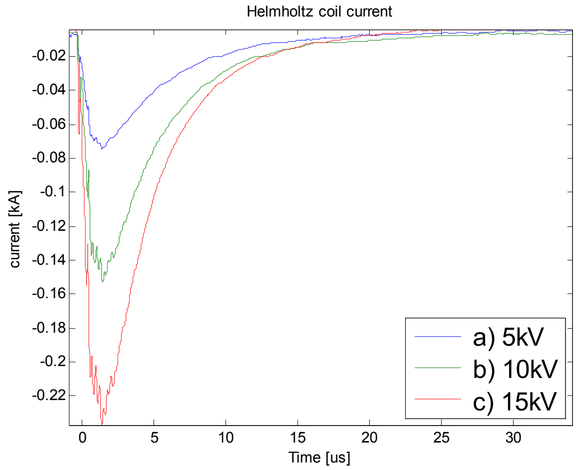

Fig.5. Current flowing through the Helmholtz coil, measured at *5 kV*, *10 kV* and *15 kV*, using Rogowski coil with Rogowski current waveform transducer CWT 60B.

To obtain magnetic field intensity in the centre of the Helmholtz coil, equation (2) can be used. The results are shown in Fig.6.

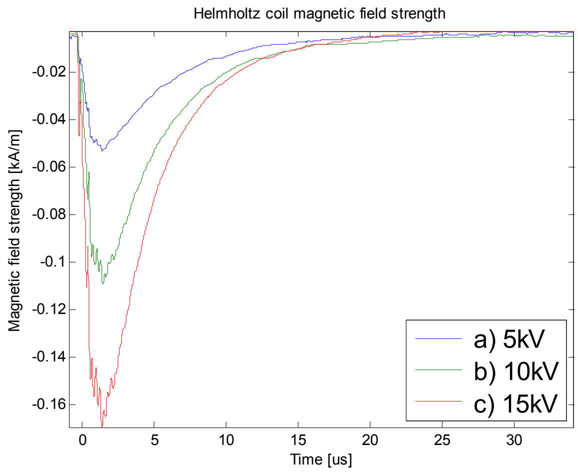

Fig.6. Intensity of the magnetic field in the centre of the Helmholtz coil at *5 kV*, *10 kV* and *15 kV*.

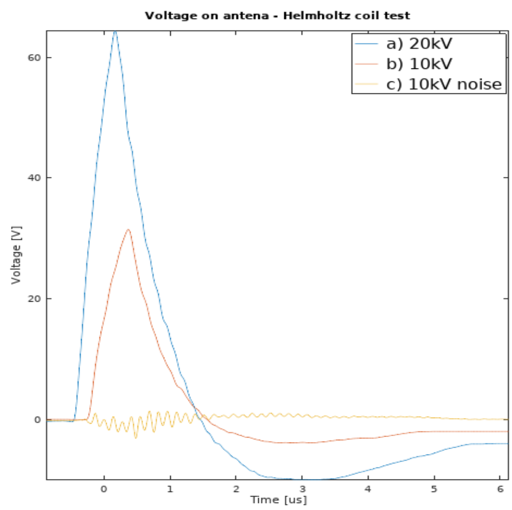

Fig.7. The disturbances induced in measuring lines at 10 *kV (20 kV for comparison)*.

The simulated cutoff frequency value of the circuit is *1 MHz*. So, it is possible to carry out measurements for pulses lasting longer than *1 μs*. In our research, we used *1.5/5 μs* pulses.

In order to verify the disturbances induced in the measuring lines, the experiment by arranging an identical measuring cable next to the working one was carried out. Then the measurements were made by analyzing how large disturbances induce in the measuring path itself. Three variants were considered: an open line, a compact line and a line terminated with a load that simulates the tested object. It turned out that the level of interference induced in the measurement line was negligible compared to the value of the measured signal in the drone circuits. The results are presented in Figure 7. This analysis allowed determined the differential levelling of the measurement path distortions by an additional signal from a line arranged in parallel along the entire length.

Drone measurements

Inserting the drone inside Helmholtz coil enabled analysis of the effect of a homogeneous magnetic field on its work. Such devices do not have any shield that would protect them from both: the magnetic field and the electromagnetic wave [6]. Of course, this is due to minimizing the weight of the aircraft. The location of the machine in a homogeneous field allowed to determine the level of disturbances observed at various measuring points from the magnitude of magnetic field. The presented configuration was designed to simulate a close lightning discharge (not directly on the machine, but very close). We know that a direct impact causes total destruction [7]. The other aspect are computer simulations [8], however there is no substitute for measurements of the real model. The tested device was placed centrally inside the described Helmholtz coil, in the flight position. During the research, the drone was powered from its own battery and its electronics were turned on. Figure 8 presents the block diagram of the drone, with its most important elements.

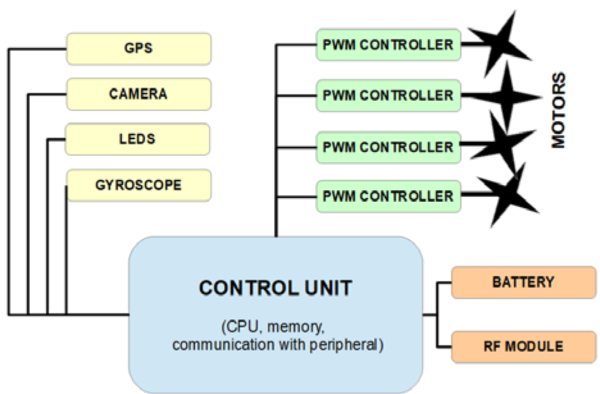

Fig. 8. Block diagram showing the most important elements of the drone.

The observation of the interfering voltage was carried out by an oscilloscope. That allowed for accurate time analysis of interfering signals. A shielded cable was used to minimize the amount of interference induced in the measuring path. To determine the magnitude of these disturbances, a second identical measuring line ended with a *50 Ohm* non-inductance resistor was placed next to the first. This made it possible to determine what disturbances were observed in the drone electronics and which in the measurement cables. Difference these results from each other and filtering the signals allowed to obtain satisfactory result signals. In order to reduce interference (switching noise, reflection, etc.), it was decided to use a median filter. All of the following results were subjected to such treatment in order to extract the right signal from the noise.

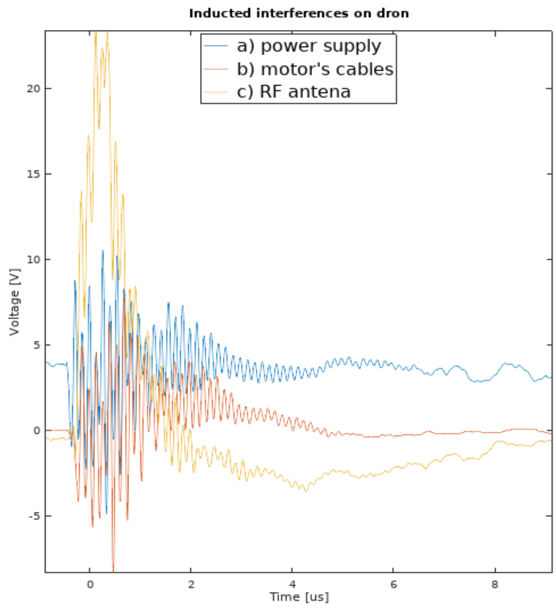

Fig. 9. Induced interference in selected, critical elements of the drone.

The research was performed by measuring the voltage level in several selected machine construction points. These elements are important points where the interference is most likely to be induced. It was:

a) power connectors of a drone from a li-pol battery
b) antenna connector from the radio module
c) power cables for motors

The results are shown in Figure 9.

The tests above were carried out for the Helmholtz coil supply voltage of *10 kV*. In order to determine the dependence of the voltage of the interfering pulse and the induced voltages observed with the measuring probe, measurements were made for other supply voltages.

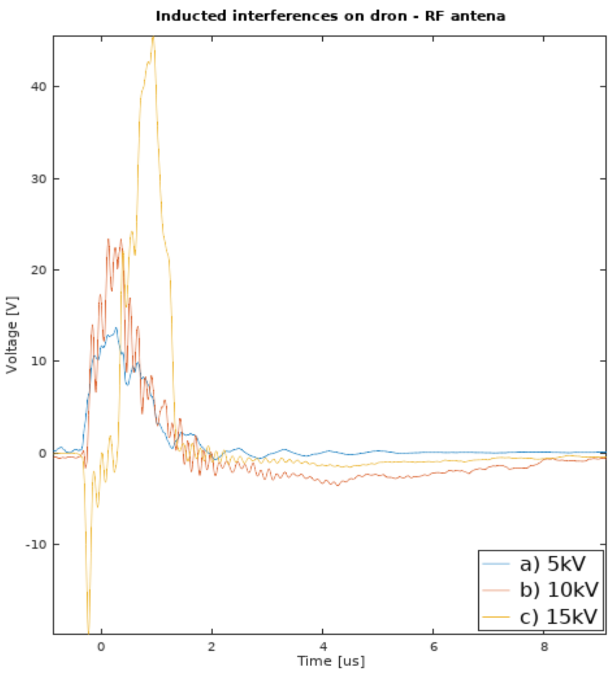

Fig. 10. Disturbance Induced in RF antenna at excitation voltage: *5 kV*, *10 kV* and *15 kV*.

Figure 10 shows the results for *5 kV*, *10 kV* and *15 kV* impulses. Moreover, the regression curve developed on this basis is also marked.

For the *5 kV, 10 kV* and *15 kV* measurements, you can observe a linear increase in induction voltages in the machine's circuits. This increase is proportional to the increasing voltage supplying the Helmholtz coil. It shows how strong disturbances can be induced form a lightning discharge, characterized by a greater charge. Of course, remember about the distance of the drone from the discharge, because the electromagnetic wave decreases with the square of the distance.

It can be seen that disturbed signals of considerable size appear in the machine's circuits by the induction of a magnetic field. The level of voltage is important compared to the voltage supplying the electronics and maximum levels of overvoltages. The *40 Vpp* pulses are capable of burning electronic components, in particular integrated circuits [9].

The drone during the tests was destroyed. Contact with it was lost during antenna interference detection. At the end of the tests, the machine did not responded to the pilot's commands and one of the engines was blocked in the working position. The electronics were damaged, however, the motors and battery proved to be resistant to the tests. The resistance of the battery stems from its metal housing, which is the shield for the electromagnetic wave. The motors are more resistant to temporary voltage spikes exceeding their nominal operating range.

The magnetic field at a 15 *kV* impact equal around $4{\bullet}10^{-4}$ *T* ($4{\bullet}10^{-4}$ Wb/m^2). This level of intensity corresponds to a lightning strike several to tens meters from the drone [10, 11].

Conclusion

The test results show how large disturbances induce in the drone circuits during atmospheric discharges. Experiments carried out only up to *15 kV* showed that the voltage induced in its circuits can reach a value of over *40 V*. Such large impulses are capable of damaging the control unit. The motors and the battery are resistant. The greatest distortions are induced at the antenna's terminals. A part of the observed disturbances of the measured results come from reflections of the magnetic impulse form the Helmholtz coil from the walls. Signals with a lower value of external interference can only be measured in an anechoic chamber. It is also possible to use the differential method, subtracting the noise from the signal by measuring two paths at the same time.

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