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Identification of Electromagnetic Waves Produced by a Magnetic Pulse Generator

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The study of the electromagnetic waves generated by an electromagnetic pulse generator is compelling either for the safety of instrumental equipment but more important for human being health. This is a major step to do in order to examine and explore the impact of the intense electromagnetic pulse machine before integrating it into an industrial environment. The electromagnetic pulse generator is used in many industrial applications such as forming, crimping, and welding of dissimilar materials. It is based on an RLC circuit connected to a one-turn massive coil, where the current pulse discharged in the coil is experimentally measured using a Rogowski coil. In this paper, we discuss the electromagnetic field generated around this generator since it is a mandatory step in the process of the deformation of metal parts. To measure the electromagnetic waves generated by the massive coil, we used a dipole antenna located in different positions around the coil. Results given by this experimental setup gives new insights about the electromagnetic field and specify its intensity and frequency.

Index Terms—Dipole antenna, magnetic pulse generator, magnetic pulse joining, magnetic field, electromagnetic waves propagation.

I. INTRODUCTION

The present research work is about discussing an experimental setup to measure the electromagnetic field generated by the electromagnetic pulse. The generator is used in the deformation and assembling of metal pieces of dissimilar materials. For joining process, a massive one turn coil is used in this process. According to previous studied (Choi et al.) (Mansouri et al., 2016) (Psyk et al., 2011), a one turn coil is more adapted and very robust than a multi turn one. Many researchers used a field shaper with the massive coil, which is more adapted and economical to use instead of specific coils for each geometry of the workpiece (Yu et al., 2005) (Zhang, 2004). A previous study shows how the field shaper contributes to the increase and uniform distribution of magnetic pressure (Akram et al., 2014). The main components of this generator are the bank of capacitors, the coil and metal workpieces as well as high current switches named Spark-Gaps. The magnetic field generates eddy current in the mobile tube which is the outer workpiece and generates radially a high Lorentz force density. This force produces either welding or crimping of the outer tube with the inner tube depending on their thickness and the energy provided by an AC power supply. The level of the current can reach several tens or even hundreds of kA and produces around and in the coil a magnetic field magnitude of micro teslas to some teslas in the center of the coil (Sofi et al., 2018). Previous experimental investigations of the thermal behavior in the generator show that the temperature in the coil is generally around 34C at a peak current of 150 kA (Sofi et al., 2017). The magnetic pressure created by the Lorentz force on the workpiece can be determined using an analytical method for multi-tun coil (Kinsey and Nassiri, 2017) and it decreases at the center of the workpiece (Zhong et al., 2015). In order to investigate the

lorentz force, recents studies are concentrated on numerical simulation of the workpiece deformation using finite element method and boundary element method Haiping and Chunfeng (2009) (Choi et al.) (Yu et al., 2005). The purpose of this paper is to discuss the electromagnetic waves produced by a magnetic pulse generator using a massive one turn coil. This investigation provides new insight to the propagation of EM waves around the generator and will furthermore contribute in defining the impact of these waves on the humans health and the deformation process. A full discussion of the direction of the EM waves lies beyond the scope of this study. The remaining parts of the paper proceeds as follows: in the first section, we attempt to show the importance of using a dipole antenna to measure EM waves produced by the massive coil, then we describe the design of the experimental measurement setup using a dipole antenna and electromagnetic pulse generator, the antenna is located in different direction and variable distance from the generator. In this part, we characterize the antenna using its geometry in order to define its main parameters. The second section reports the main results concluded from the experimental measurements while the last section discusses and examines the magnitude and frequency of the signals measured by the antenna using an oscilloscope. The experimental work presented here provides on of the first investigation into how to examine the electromagnetic waves when using high and intense current pulses.

II. METHOD

Different methods have been proposed to classify the magnetic field generated by the EM pulse generator using a one turn massive coil (Sofi et al., 2018). However we adopt one more method to describe the propagation of these electromagnetic waves generated by the same coil as the one

used in (Sofi et al., 2018). This method ensures to measure precisely the EM waves around the massive coil. Magnetic and Electrical vibration are both measured by the antenna. During the experimental setup, the antenna was able to capture waves whether it was placed horizontally or vertically to the axis of the coil. Figure 1 represents the general electrical scheme of the generator connected to the coil as well as the measurement setup presented by a dipole antenna connected to an oscilloscope of band width of 1 GHz.

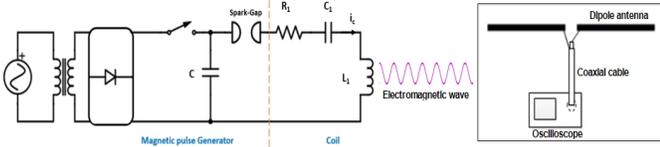


Figure 1: Electromagnetic wave measurements using an antenna

A. Characterization of the antenna

Since we used a dipole antenna to measure electromagnetic waves generated by the massive coil, we need to characterize this antenna in order to define its main parameters, which are, the frequency, the direction of the wave, the wave length and the impedance. The main scheme of the dipole antenna is illustrated in figure 2.

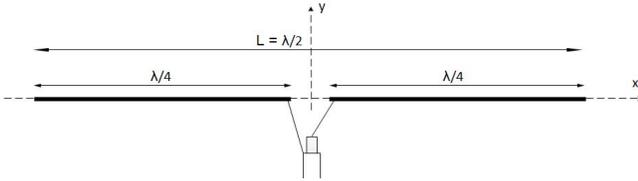


Figure 2: Characterization of the dipole antenna

The antenna is characterized by the following parameters: $\lambda = \frac{c}{f} = \frac{c}{T}$ presents the wave length. c is the speed of light, f is the frequency and T is the period. The length of the antenna is given as half wave length, which is $L = \frac{\lambda}{2}$.

B. Experimental setup

In this section we performed 3 experimental setups depending on the position of the antenna and the coil in order to define the direction of the EM waves. The experimental setup is based on figure 1.

At the beginning, the antenna is located horizontally to the coil as illustrated in 3-1, the second setup is when the antenna is located vertically to the coil as shown in figure 3-2 and the last one, the antenna is located horizontally to the axis z of the coil as observed in figure 3-3. In the 3 setups, the antenna is placed a distance of $1m$ from the coil.

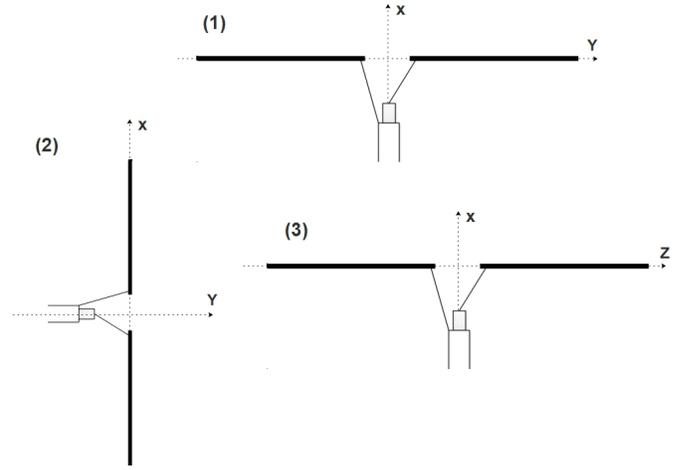


Figure 3: Configurations of the dipole antenna

III. RESULTS AND DISCUSSION

Once we charge capacitors of the generator, we discharge them instantly in the coil with high speed. The current pulse in the massive coil is then measured by a Rogowski coil located at the input and output bars of the current. Figure 4 shows how the current pulse variation through time at different voltages $2.5kV$, $5.5kV$ and $8.5kV$. As we can observe in this figure, the current pulse increases when the voltage increase and the pulse duration is about $250 \mu s$. The magnitude of the current pulse is very high and the variation goes from $180kA$ at $2.5kV$ to $500kA$ at $8.5kV$. we can observe how the 3 curves have almost the same frequency, which is about $18kHz$.

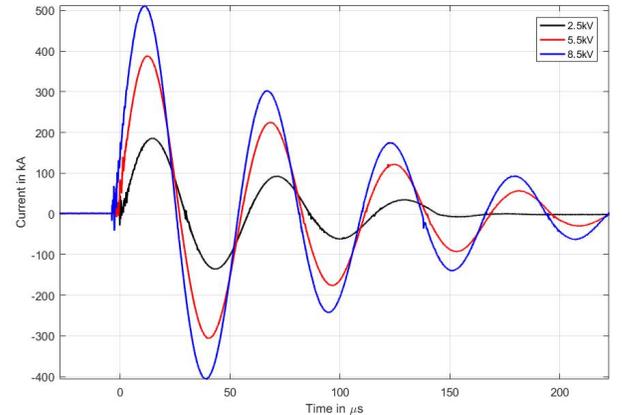


Figure 4: Current pulse variation in the coil

According to the direction and position of the antenna and the coil, we get different results about the magnitude of the electromagnetic field and its frequency. Since we performed 3 configurations of the experimental measurement setup, we have 3 sets of results.

Figures 5, 6 and 7 are illustrating respectively the differential potential measured by the antenna for configuration 1, 2 and 3.

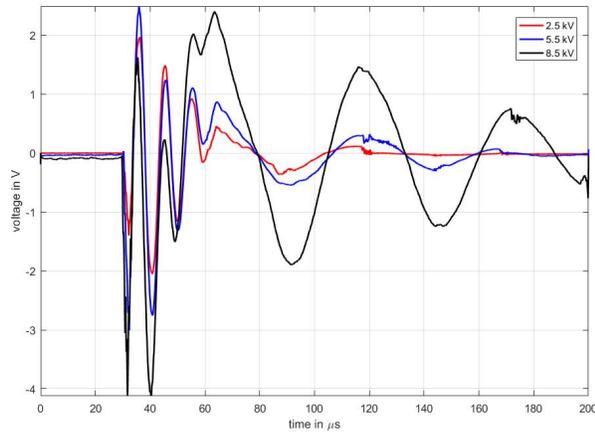


Figure 5: Voltage variation during the current pulse for configuration 1

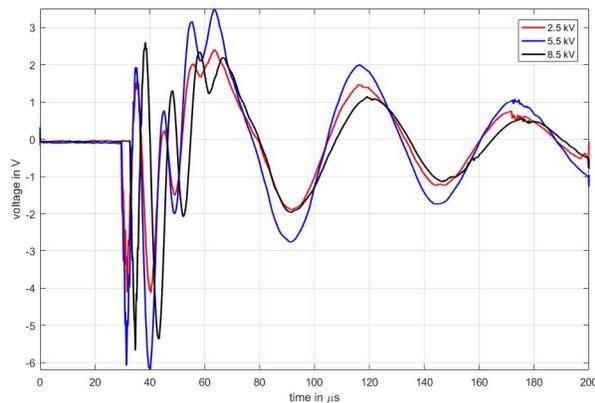


Figure 6: Voltage variation during the current pulse for configuration 2

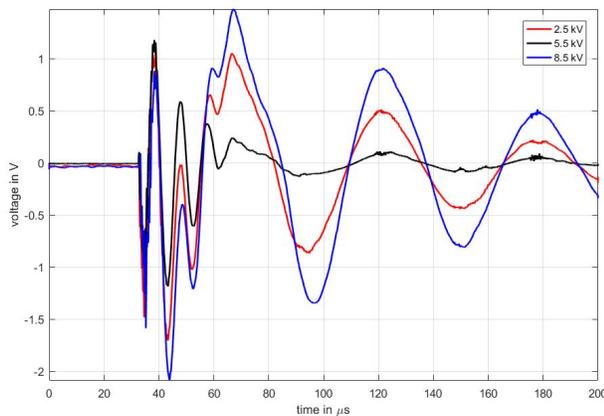


Figure 7: Voltage variation during the current pulse for configuration 3

Closer inspection of these figures shows how the frequency of the voltage in the antenna changes during the current pulse. It is important to report that the frequency in the 3 figures is about 111kHz that corresponds to the first peak of the current pulse. However after $50\mu\text{s}$, the frequency is close to the one of the current pulse which is 18kHz . Another result to report is when the current pulse increases, the maximum magnitude is also increasing in a range from 1V to 3V . This results shows that the electromagnetic waves produced by the generator are not intense, however more research work needs to be done about the impact of these waves on human health.

IV. CONCLUSION

This study set out a new experimental setup method to measure the electromagnetic wave produced by a one turn massive coil used in electromagnetic pulse generator. This research work has shown that a dipole antenna can be used to determine the electromagnetic wave propagation during the deformation process. The most obvious finding to emerge from this work is that the frequency of the electromagnetic wave is about 10 times more than the current pulse discharged in the massive coil. These findings also suggest to study the influence of the waves magnitude and frequency on human health and instrumental equipment used in the automation of the process. As perspectives of this work, one of the most mandatory study that need to be done is the optimization of the generator by optimizing Spark-Gaps and transmission cables. Another major research work is about discussing the impact of intense magnetic field on measuring instruments. Characterization of the magnetic pulse welding generator by a transfer function that links the current pulse in the coil and the magnetic force (mechanical force) applied on the tubes.

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