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PPST Summer Undergraduate Internship

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Working in lab of Professor Szymon Suckewer

On a computer simulation modeling the firing circuit of a plasma spark plug.

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Due to rising gas prices, global warming and a stagnating economy, the demand is greater than ever to find more cost effective solutions in order to resolve or hinder these problems. Combustion engines and similar devices that use spark plug ignition systems are one of the key contributors to the severity of many of the aforementioned problems. The Plasma Spark Plug (PSP) is an invention that improves the efficiency of the fuel burning process, thus using less fuel and providing a more economical engine.

The PSP design and concept was created in part by Professor Szymon Suckewer. The spark plug arrangement consists of three electrodes surrounding a central electrode, all on a ceramic base. The electrodes are composed of a variety of different materials, the most common one being tungsten. The process involves producing short-lived plasma between two electrodes along a ceramic by applying high voltage and high currents. The plasma is then accelerated along the electrodes by Lorentz forces (forces which act along the axis of the electrodes). If certain parameters such as the timing of pulse, peak current and other related properties are correct, the plasma can travel beyond the tip of the electrodes due to the momentum caused by the Lorentz accelerating forces. A large plasma is especially useful in fuel ignition as it provides a great surface area over which fuel can ignite, thus improving the engines efficiency.

The research experience lasted for ten-weeks and was split into three distinct sections. The first and shortest section was a general introduction to the field of Plasma Physics at PPPL; the course gave a broad base of knowledge on the nature of Plasma and its properties. The next four weeks were spent in Professor Suckewers laboratory, directly working with PSP and the firing circuit. With the help of a technician (Nicolas Tkach) experiments and modifications were carried out on the circuit. The nature of these experiments involved testing new configurations of the electrical firing circuit for effectiveness, testing new components (especially toroidal transformers) and carrying out longevity tests for the spark plugs. The third, main part of the research experience was to model the electrical firing circuit as a computer simulation. This involved using a program called Pspice/Cadence to model the primary circuit, other programs were also used in conjunction with Pspice/Cadence to model secondary parts of the circuit e.g. transformers. Overall the program was very user-friendly and responsive to commands.

Working with the circuit on the experimental side and physically testing various parts gave an insight that was very beneficial for the computer simulation. Indeed for the simulation, additional data was required and needed to be collected, the practical skills learnt in the initial four-weeks were very useful for this task. Furthermore, a few of the problems encountered in terms of debugging the computer simulation could be fixed by reevaluating the circuit. The circuit essentially works by producing ~1µs long pulses with a high peak current ~500A and several kV. The short pulses are achieved using fast switches called IGBTs; these are essentially diodes that are very fast at clamping the signal. In addition, the high voltages and currents are partly attributed to the key feature of the circuit, namely the toroidal transformer that steps up the source voltage to a much higher value. The production of all of these is required for the plasma to be created on the electrodes.

As mentioned earlier, the program used to model the firing circuit was Pspice/Cadence. It has a well-known reputation to being very user-friendly and requires little previous programming experience. Due to the nature of the experimental setup, some of the parameters were being tested to their extremes. Therefore, modifications to the pre-programmed attributes of some of the components (the transformer in particular) were required in order to make the program as realistic and reliable as possible.

There were a few obstacles encountered in this project, these can be split into two categories: experimental and bureaucratic. Starting with the former, the main experimental problem encountered was the physics and the dimensional parameters of the transformer. The nature of the circuit and the discharges is that the transformer must reach magnetic saturation in order to achieve a sufficiently high current profile for the spark gap. Magnetic saturation is a phenomenon where the rate of increase of the magnetic field of the transformer decreases significantly after a certain applied field value. Although very uncommon, this process is not unheard of. The computer program being used to model the transformer, had difficulty in accepting the current data for saturation of the core and its parameters which were being used. In order to overcome this program, a contracted Electrical Engineer was contacted for advice, his recommendations were to model the transformer as basic elements and produce a very crude version of the real transformer. This in turn, did not produce a saturated transformer. Unfortunately, this removed some of the reliability of the computer model, as one of the key design parameters of the circuit was saturation. Deciding to run the transformer as close to its saturation in order to try and attain a reasonably realistic answer as possible solved this problem.

In addition, the timer circuit for the larger firing circuit was created specifically for the PSP project, so did not exist in the Pspice database. Therefore, a timer needed to be modeled from basic components, which was very arduous.

The latter also posed a problem in terms of beginning the project. The initial version of Pspice/Cadence being used was the student version; this was sufficient for the basic purposes of tutorial. However, as the student version of the software had fairly limited capabilities, there was the need for the licensed software. An effort was coordinated between several departments including MAE and EE in order to obtain this license. The license was finally obtained with some time lost in pursuing it.

These setbacks, although disadvantageous to the project gave insight into the research process. They show that at times research can be slow with causes that may not be related to anything scientific. In addition, the pursuit of realistic answers is very usually limited by the nature and functions of the equipment, in this case the Pspice/Cadence program. Due to these unforeseen setbacks, the research task is still being completed and it is hoped that the computer simulation will be operational within two months.