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New Electrical Design Challenges for Pulse Detonation Test Rig

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Abstract: The design of a cyclic Pulse Tube for detonation of gaseous fuel using C_2H_2 & O_2 was derived from single shot PDE system. During the trials of this PDE, the detonation parameters are being critically analysed. The data generated will help in designing of future pulse detonation propulsion system for variety of applications. The aim of the paper is bring out new electrical integration problems faced by the team and its solution designs to improve the positive detonation initiations each time. The modifications covered in the current paper, are in the areas of termination sockets, ignition coil, igniter and condenser etc. These improvements will increase the efficiency of the system resulting in repeatable better thrust with low electric energy inputs. The analysis of the data gathered by firing of PDE system after incorporating the above changes also endorsed the claims of the designers in terms of repetitive high energy detonations with significant increase in thrust/impulse. Earlier, during conversion of Single shot rig to cyclic PDE system, various challenges were faced by the team. Due to these challenges, the performance of the system was significantly degraded and remedies became absolutely necessary. Paper also deals at length to deal the challenges faced including remedial actions in subsequent paras. Subsequently, the system results brought out are highly encouraging.

Keywords: Cyclic Pulse detonation engine, ignition system, Igniter, grounding and earthing, Data acquisition, Instrumentation

1. INTRODUCTION

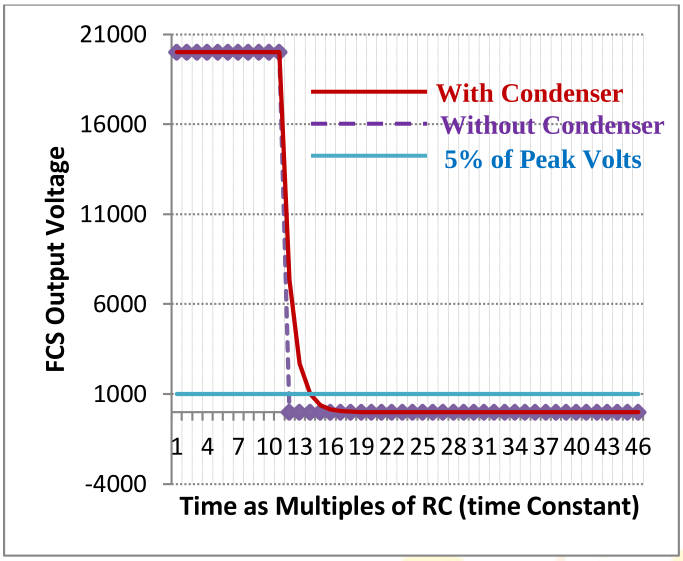
A Pulse Detonation Engine (PDE) is a type of aerospace propulsive system that uses detonation energy achieved from combustion of fuel / oxidizer mixture [1]. The PDE is pulsed, because the mixture must be refilled in the detonation chamber between each cycle. Theoretically, a PDE can operate from subsonic up to a hypersonic flight speed of roughly Mach 5 [2]. An ideal PDE design can have a thermodynamic efficiency higher than other designs like turbojets and turbofans because a detonation wave rapidly compresses the mixture and adds heat at constant volume. Consequently, moving parts like compressor spools are not necessarily required in the engine, which could significantly reduce overall weight and cost. PDEs have been considered for propulsion for over 70 years. Key issues for further development include fast and efficient mixing of the fuel and oxidizer, the prevention of auto-ignition, and integration with an inlet and nozzle [3]. After successful single shot pulse detonation rig at PEC [4], to improve reliability of PDE, electrical design was revamped and new modifications are dealt in coming paras.

A key area explored during this conversion is electrical connectivity and interfacing[5]. This aspect is covered in current paper. The performance, safety and life of the system have also got quantum jump, which is covered in subsequent paras in the current paper.

2. INCORPORATION OF CONDENSER

Since in single shot application, the igniter need to fired once only. so the ignition current required is sufficiently produced required for detonation. However, when multi-cycle operations are planned, need of longer ignition spark consistently with less decay is becoming challenge [6]. Design of appropriate condenser is carried out and incorporated in ignition system (fig. 1). This has resulted in more spark energy with steady decay enhancing detonation durations (fig. 2) [11].

Fig. 1 Condenser mounting in ignition circuit



. 2 Decay Plot of Voltage with and Without Condenser

Mathematically, this is derived from first principles. The charge decay equation is as shown in equation I.

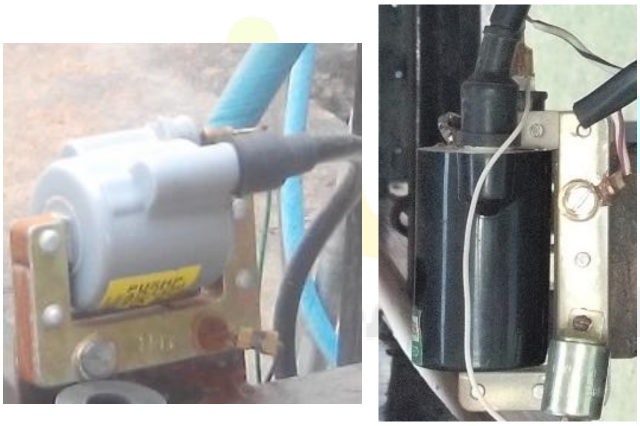
$$Q = Q_{Max}\left[1 - e^{-\frac{t}{RC}}\right] \qquad \text{........I}$$

So, it is clear that charge of the ignition system will decay slowly due condenser.
When converting this into Voltage outputs, it is:

$$V = V_0 \times e^{\frac{-t}{RC}} \qquad \text{.......II}$$

3. INDUCTION COIL

As it is the case of condenser, similarly, induction coil change (fig. 3 (a)) was identified to get better detonation persistently with efficient current utilization. New induction coil with better winding with higher no. of output turns, large soft iron core including better connectivity was selected (fig. 3 (b)).



(a) (b)
Fig. 3 Induction coil Installation

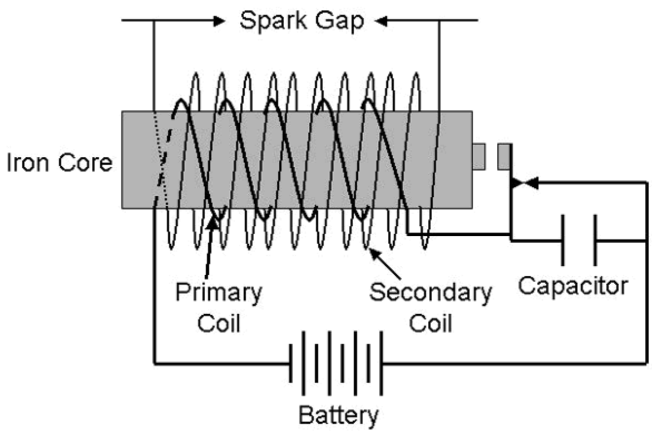


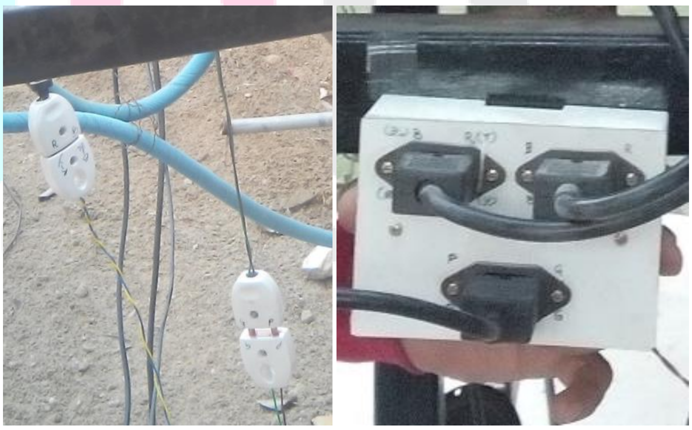
Fig. 4 Induction coil Installation in ignition system

$$V_S = \frac{N_S}{N_P} V_P \qquad \text{......III}$$

For induction coil (fig. 4), keeping all the input parameters same and doubling no. of turns to secondary coil will result in double output voltage [12], which in turn will result in better detonation.

4. ELECTRICAL CONNECTIVITY

The existing PDE firing commands are connected using commercial available mail female type sockets (fig. 5 a) [7]. It is having frequent problems of connection failure due high vibrations and shock in hanging mode. Euro type connectors were implemented on custom build mica sheet boards (fig. 5 b). Connections became firm concealed (hermetically resistant) and less prone to vibrations due better box mounting too. It also resulted in better cable routing due structured cabling. Ground was also built on box to give better signal stability. This has reduced chattering of terminals. Design has eliminated the possibility of polarity reversion chances too. In future, researchers can follow colour coding of power lines to give further better traceability. General reliability of system has improved many folds including better labelling resulting in distinct identification and traceability.



(a) (b)
Fig. 5 Interfacing Flow and Firing Command Connectivity

5. CABLE CHAMBER

During the past firings of PDE, it is observed that cable looms are required due frequent shifting of rig due various reasons and getting some cushion for defect investigation / repair (fig. 6 a). These issues are handled by making a covered cable chamber in the new hard stand (fig. 6 b). PVC pipes were laid before hard stand casting. Proper design of entry, exit and bends was carried out to ease the laying of data and power cables from PDE rig to control room and back. Colour coding and tagging has been also implemented in cabling. So, the system maintainability and defect identification cum removal has become handy and easy. It has provided flexibility of inter-changeability of instruments' and sensors too. It has proved to be advantageous against rodent attacks and weather exposures too.

(a)

(b)

Fig. 6 Cable routing on PDE rig

6. REMOTE FIRE CONTROL ROOM

Remote fire control room was desired to give the researchers better safety, while operating cyclic PDE. This was achieved by adding a buffer wall between PDE facility and Fire control through remote with built new safety features including better emergency stop alongwith fuel shut off valves.

7. TERMINATION, EARTHING AND COMMON GROUNDING

In the past, we have seen that Intermittent/loose connections are giving under higher vibration cycle during detonation cycles. Same was restrained by incorporating new National Instruments SCB-68 [10] termination box to ensure firm connections against shock and vibration for sensor outputs/inputs for firm joints [9]. It resulted in improved reliability of data even in critical trials too.

Earthing of the complete electrical hardware are connected through Copper earth with chemical treatment for better effectively. This also provides protection to the hardware. Sensitive electronic hardware is provided with electrical connectivity through surge and spike protection.

All electronic hardware is grounded at a common location to avoid potential difference between various grounds of different hardware and proving better sensors accuracy.

8. ACHIEVEMENTS FROM THE PROJECT

After modifying PDE electrical hardware as above, significant reliability improvement along with efficiency gain has been observed [8]. 40+ firings have been carried out successfully and experimental data is obtained by researchers for further work. This will further analysed for carrying out research. The process of experimental analysis is perfectly established. All the operational range of sensors is also established. The specifications of DAQ and response times for sensors are now changed. Technology of design of test rig, pulse tube, helical, cabling, igniters, cylinders, piping, and wiring are established to very high level of confidence. So the project has achieved all its objectives and created an infrastructure for future research work too.

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BIOGRAPHIES

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