

Implementation of Novel Automated Fire Control System for Multi-cycle Multi-tube Pulse Detonation Test Rig

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ABSTRACT: The Pulse detonation engine (PDE) Fire Control System (FCS) for cyclic firing has been designed and tested successfully by implementing new concepts and sequences. It is a very sophisticated, complex and critical segment of a typical multicycle multi-tube PDE rig, which is in advanced stage of development. The relevant standards, interlocks, safeties and redundancies were built by design. Primary emphasis is placed on the methodical approach required in the design of modern Automated FCS. This approach involves thorough analysis of the particular fire control problem at hand, establishment of the most suitable mathematical model, computerization and realization of the built mathematical models through Labview. The paper deals with modifications processes in ignition, DAQ, instrumentation, sensors, terminations, timing cycles, multicycle/multi-tube fire control and parameters analysis software development challenges and their mitigation techniques. All the problems faced in development are addressed properly by incorporating condenser, hardening mounting brackets and incorporating vibration isolators. Multicycle PDE is being presently, exclusively fired and analysed using the present developed setup.

KEYWORDS: Pulse detonation engine, Automated Fire Control System, Data acquisition, Ignition system, Multi-cycle PDE, Multi-tube PDE

I. INTRODUCTION

PEC is in advanced stage of development of multi-cycle with multi-tube PDE (fig. 1). AFCS is a vital system, which will be detrimental in current system. The AFCS fire control system design architecture provides flexibility for tailoring systems to meet different mission profiles. AFCSs are designed using small proven common modules of single shot PDE also. This partitioning of the different technologies ensures that the whole system runs efficiently in extreme variations of harsh environments.

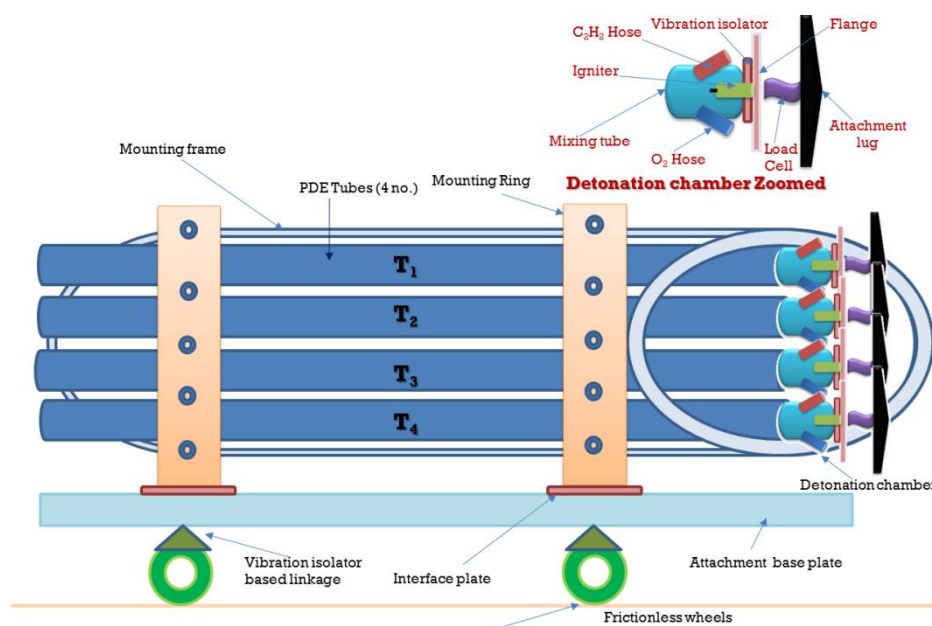


Fig. 1: Multi-tube Multi-cycle PDE rig

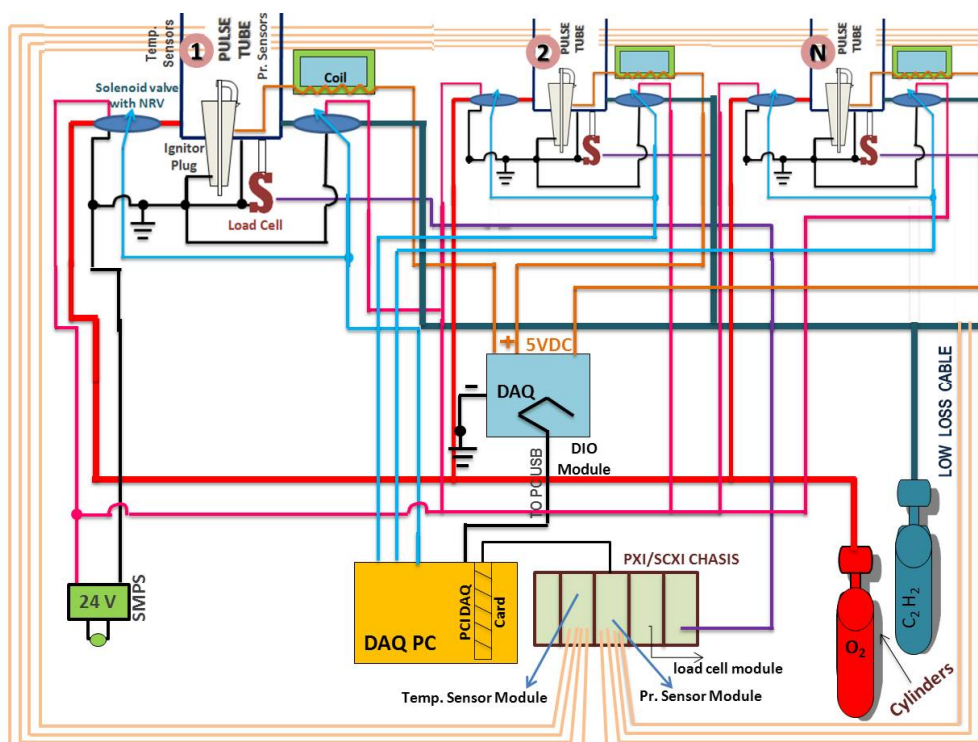


Fig.2: Multi-tube Multi-cycle PDE AFCS– Electrical connectivity line diagram

AFCS needs to be built with stand-off safeties, reliability and mission criticalities etc. The technology survey was carried out to create the specifications, which need to address. The key options for choices of implementation technologies was carried out and hence achieved to fabricate the hardware and software. The software based designed allowed a vast configurability coupled with safeties at various folds. LABVIEW based structured design of FCS is carried out. Fig. 2 shows the schematics of PEC AFCS [8] showing all its major constituents and their interconnectivity.

II. CYCLIC IGNITION SYSTEM

The AFCS is coupled with cyclic ignition system, which consists of a 24 V DC Condenser (fig. 3) and multiple no. of Igniter plug (fig. 4) arrangement. The control for the igniter plug ignition is with the control circuit only, which is executed by AFCS. The Labview VI based controller gives an option to fire the igniter plug after the gas has been released into the system for the required specified amount of time. The O_2 inlet and the C_2H_2 inlet are near the Igniterto start the combustion, by imparting a high voltage spark to the gases.



Fig 3: Ignition Systems –Condenser mounting



Fig. 4: Igniter plug mounting on flange

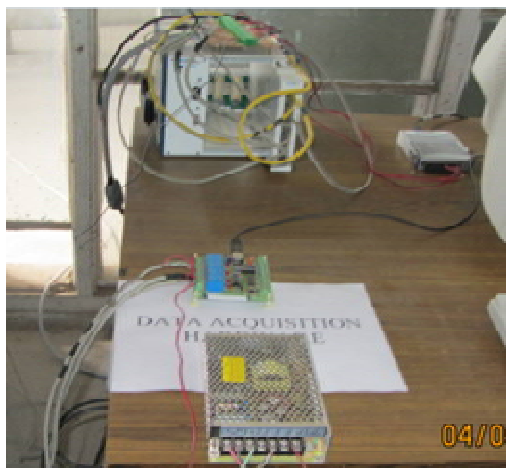


Fig.5: DAQ &a portion of FCS setup

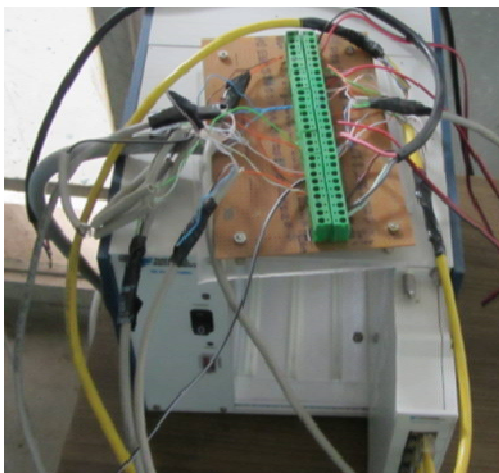


Fig.6: Terminator box, SCXI chassis & Thermocouple module

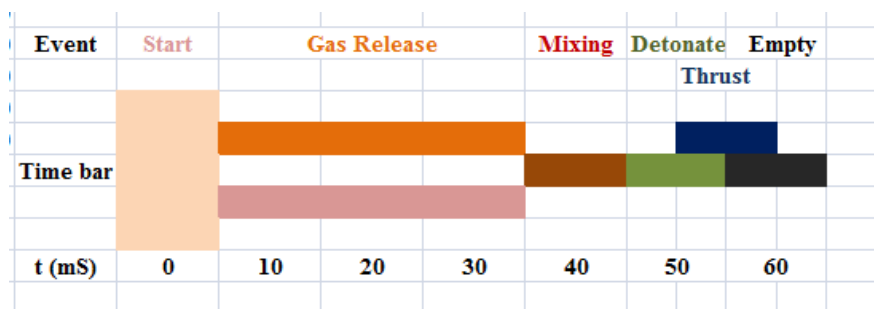
III. MULTICYCLE PDE CONTROL

The cyclic PDE engine system is centrally controlled by a National Instruments (NI) Labview based new VI software program developed and installed on a DAQ computer [3] in the control room (fig. 5) with terminations (fig. 6). The DAQ computer is linked to a NI PXI-1000B controller in the rig through a network connection to the PXI IP address. The program controlled engine operation by managing engine supply gas operation via solenoid valves using opening time programmed located in the rig. A D-sub μ -connector based pulse generator also located in the control room controlled timing of trigger signals sent to both the fuel igniters via electrical relays of the system. 24 VDC and 220 VAC master power switches are also installed in control room, and an emergency shutoff button coupled with on rig emergency stop button too. The electrical switches controlled power within the rig for engine control and instrumentation, i.e. temperature and pressure transducers connected through termination boxes (fig. 6). The flow of gases inside pulse tube is controlled by solenoid based flow control valves with Non-return valve for safety purposes. Additionally, the emergency shutoff button was provided as a safety feature and would disable rig by closing all supply gas ball valves, it will also interrupt fuel injection coupled with stoppage of ignition trigger signals.

IV. MULTICYCLE DATA ACQUISITION

Data acquisition was controlled via the PC in the control room. The PC was linked to the SCXI-1000B controller mounted on the wall in the test cell, which in turn was linked to three NI data acquisition devices (DAQ) located on the engine stand. The PXI-6031E is 8channels, 16 bit card which collected operational parameters such as various engine temperatures and pressures, supply gas pressures and thrust at a rate of 10 kHz using Labview programs. A data file path designated on the control program directed data in the form of an excel spreadsheet to a selected location. These data streams were used to calibrate the stand prior to the commencement of testing, and record thrust data during engine operation. A second file path designated on the control panel directed thrust, pr. & tempt data in the form of an excel spreadsheet to a selected location. Additionally, this data was streamed to the control program GUI for real-time monitoring.

Typical multi-cycle multi-tube firing cycle in PDE is under achievement is as per fig. 7:



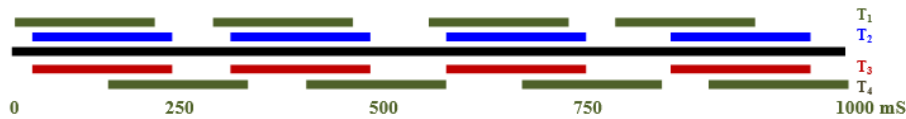


Fig. 7: Fire timing diagram with 4 tube 4 Hz cycle

V. MULTITUBE MULTICYCLE CASE APPLICATION

Time Taken for one cycle = 65 mS
 Max achievable frequency in single tube = $1000/65$
 = 15.4 Hz \approx 15 Hz

Assume 4 tubes fired at time spaced gaps,
 Gross Achievable frequency = $15 \times 4 = 60$ Hz
 In missile configuration with PDE engine, boost phase can be requiring higher thrust and coasting phase may require less thrust, so proposed configuration can be:

Boost phase frequency = 15 Hz
 No. of tubes = 4
 Average thrust / per cycle = 250 N
 Gross thrust developed = $15 \times 4 \times 250$
 = 15 kN

Sustainer phase frequency = 5 Hz
 No. of tubes = 2
 Average thrust / per cycle = 250 N
 Gross thrust developed = $5 \times 2 \times 250$
 = 2.5 kN

The above cited example is a relevant application of multi-cycle and multi-tube operations.

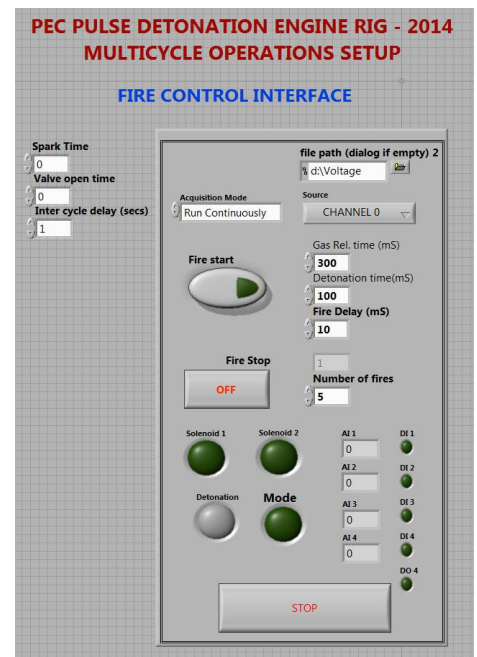


Fig.8: Firing software GUI

VI. INSTRUMENTED DATA ACCURACY

Data accuracy for the TMS/low pass filter system described above was computed using the root mean square function. The two major sources of error were introduced by the data acquisition [2] hardware (NI DAQ) and calibration/strain gauge fidelity of the TMS. National Instruments lists on their website detailed accuracy analysis of all supported DAQ equipment [1]. For the hardware installed on this rig, the company cites offset, system noise and temperature drift as the predominant error sources, and reports a system absolute accuracy of $\pm 0.377\%$.

VII. AUTOMATED MULTICYCLE FCS SOFTWARE DEVELOPMENT FOR PDE

Software is especially designed to give the commands for firing of PDE and record the outputs in correct sequences and timings.

The software is written in NILabview working in robust test environment with NiDAQ and DOP libraries. The detailed analysis and plotting is carried out in Matlab [8].

The software is divided into three parts as below:

- Firing control software
- DAQ Analog input/output software module
- Matlab based analysis utility

These are explained as below:

1.1 Firing Control Software

The software screen of National Instruments Labview [2] Firing Control Software (fig. 8) is as under:

The software allow user to select the gas release time in GUI Environment. Then Gas release button knob is pressed. The gas release is indicated by green lights through solenoid valves release feedback. After countdown, when 'Detonation' button is pressed, firing command is issued to igniter to detonate the accumulated gases using the program scheme, which is explained thru flow chart in fig. 9.

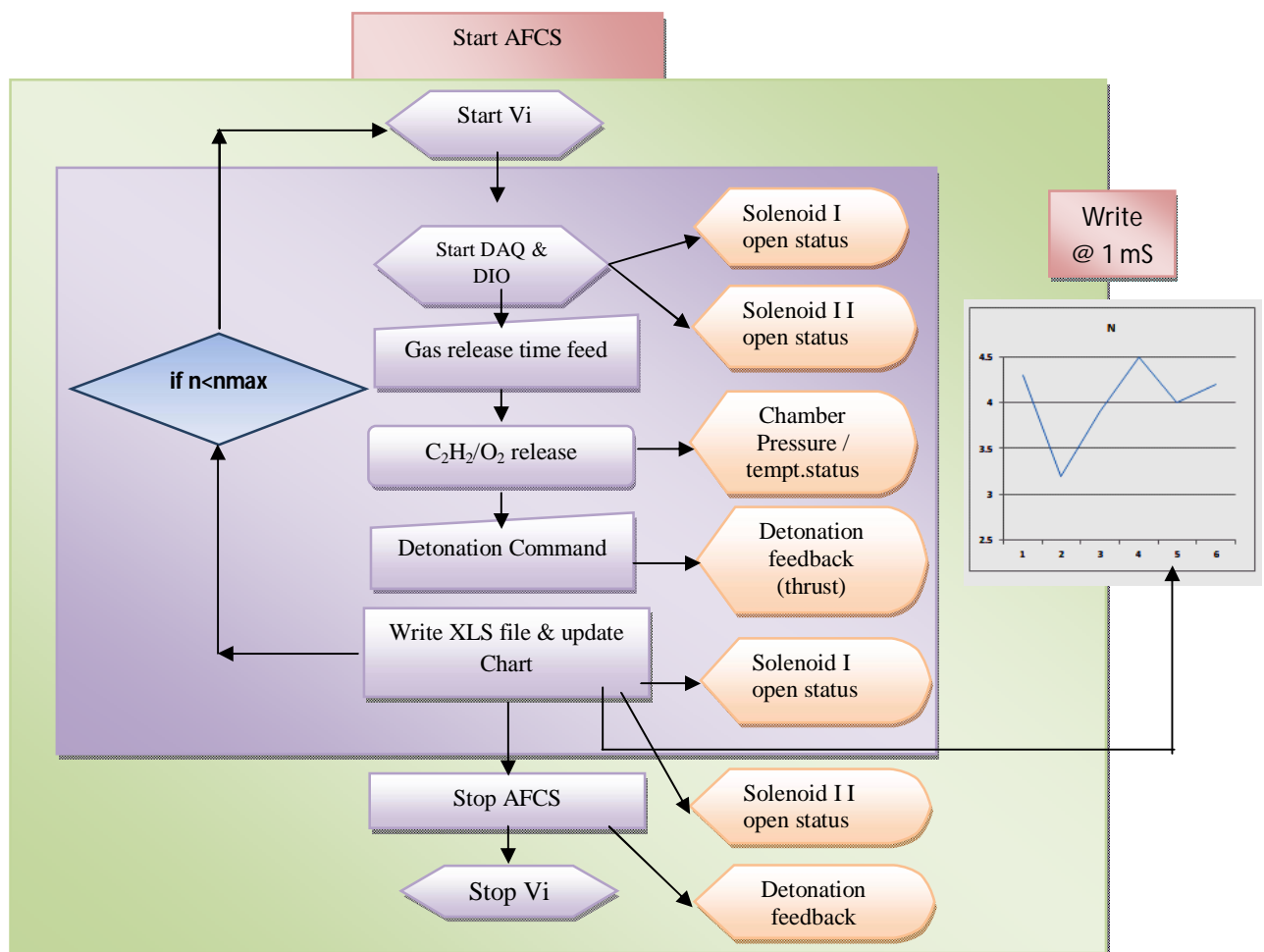


Fig. 9: Flow Chart of FCS

1.2 DAQ Analog input/output software module

NI DAQ [4] cards will generate Analog input commands in form of voltages, which will generate commands to open solenoid valves, firing spark initiations through command signals. NI DAQ cards will also monitor pressures thru pressure sensors converted voltages, Thrust through load cells converted voltages, temperatures thru thermocouple converted voltages sensed by DAQ [6] and fed back to VI for display & storage to .xls file as shown in fig 10. It is visually explained through flowchart in fig 11.

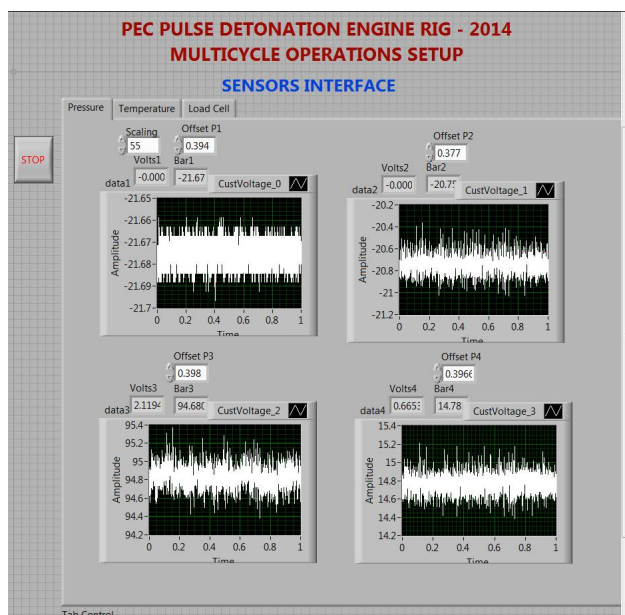


Fig.10: Online plot of Pressure DAQ GUI

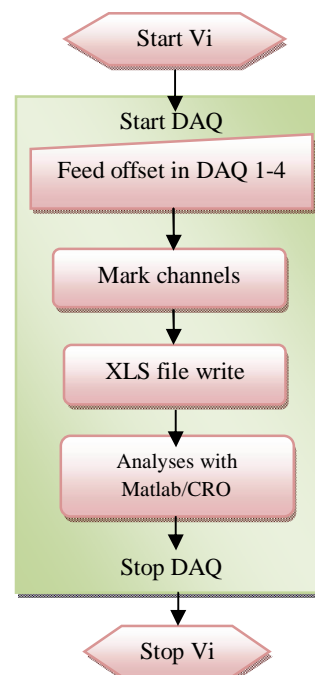


Fig. 11: Flow Chart of DAQ Records

7.3 Matlab based analysis Utility

This explains the development of Matlabbased software AFCS for PDE analysing detonation [10], signal conditioning, display & .XLS file save for further analysis [9].

Matlab [6] program was written to analyse, filter, plot, compare and conclude the test achievements for further collaborations [3]. Since it is involving highly flammable fuels at closed vicinity of PDE system so appropriate check lists were developed for further enhancing g safeties.

VIII. CONVERSION OF SINGLE SHOT FCS TO MULTI-TUBE &MULTICYCLE FCS

AFCS for multi-cycle multi-tube operations is a mission critical hardware [7]. The derived scheme for multi-tube multicycle operations is shown in fig. 2 [4].

The design is similar to single shot, but large no. of components makes it impossible to ensure high reliability and safety. The system is under testing and further modifications are expected in future also.

IX. CONCLUSIONS

The designed system was analysed rigorously validated against specifications. It was also tested in live firing after going through various qualifications/ verifications during various stages of development. The unit is operating reasonably satisfactory and will be utilized for future firings with further enhanced capabilities. The AFCS is a high end hardware/software component for PDE firing & analysing. It has been thoroughly examined through software development life cycle in an interactive manner. It has been re-validated a lot in live observation of flight trials & further enhancement. It is being analysed to modify it for multi cycle operations & better filters in near future.

ACKNOWLEDGEMENTS

Authors are thankful to Head of Aerospace Engg. Dept. along with Director, PEC University of Technology, Chandigarh, India. Authors are also thankful to Director, TBRL for his support in PDE research.

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BIOGRAPHY



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