GAS FUELLING CONTROL SYSTEM OF ADITYA TOKAMAK

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Abstract

In Tokamak, the “gas fuelling control” plays an important role to produce plasma in different operation phases from plasma current initiation till end. Apart from main gas injection for plasma initiation, several plasma parameters such as density, temperature, and events like recycling, disruption / runaway mitigation etc. are controlled by injecting the fuel gas in different amount and from different locations in the vacuum vessel at different times in the plasma discharge. This requires a programmable, sophisticated and precise gas feed control system for controlling different gas feed valves located on the machine. In Aditya tokamak, a customised gas (feed) fuelling control system has been developed, installed and made operational meeting all the requirements of the plasma operation and control. This control system consists of customised programmable pulse generator, signal condition electronics, power supply, isolation etc. Desirable pulses of designated pulse-widths and amplitudes with designated time delays are generated using LabVIEW [National Instruments] based control panel and fed into the gas-feed valves for gas insertion. This control system is a sub-system of the overall Aditya tokamak central operational system and is properly tagged with central data acquisition. The system has been successfully used for long-pulse high-current discharges of Aditya tokamak in which the density in the current flat-top is efficiently maintained by periodic gas puffs of different magnitudes at varied intervals. Design, development, testing and operation of gas fuelling control system of Aditya tokamak along with the experimental results of the gas fuelling control during plasma operation of Aditya tokamak is presented in this paper.

1. INTRODUCTION

Hydrogen is dominantly utilized as fuelling gas in tokamaks since decades. Fuelling gas is fed to vacuum vessel for generation of plasma. Gas is filled before plasma discharge it call as gas prefill. It is also puffed during the plasma discharge to reduce impurities hard X-ray etc. and to maintain the density. The Aditya gas fuelling control system (AGFCS) consists of piezoelectric gas leak valves and gas reservoir. Gas is puffed during plasma shot using same gas feeding system to reduce hard X-ray and increase plasma density. Additional Gas puffing helps in sustaining the plasma.

![Fig. 1: Aditya U TokamaK vacuum vessel](image-url)
For puffing gas at various instances during plasma discharge, either continuous voltage or voltage pulses of different amplitude and widths are applied to piezoelectric valve (model MV112) to get desired Plasma parameter set by operator. Six piezoelectric gas feed valves are routinely used for feeding the fuel gas in ADITYA Tokamak. The valves are operated linearly with applied voltage. The duration and the amplitude of applied pulse decide the opening of the valve i.e. valve will open more if the amplitude is more and will remain open for longer time for longer pulse width. Opening is varying depending upon voltage and the pulse width of the applied pulse. The valve opened fully in 2 msec.

An in-housed microcontroller based programmable pulse generator (PPG) is used to generate these pulses to control the up to eight valves independence. The output of the programmable pulse generator is amplified with the gain of 20 and applied to the piezoelectric gas leak valve to match the required potential to operate the valve.

Basic idea for the in-housed development is to make the control operation independent of the data acquisition and control system and work as stand-alone user-friendly system. User can set the parameters i.e number of pulses, amplitude, width, delay and channel number etc. using standalone desktop system’s serial port, which interface with LabVIEW control penal.

Fig. 2 shows the block diagram of AGFC is work in two mode manual and pulse. Programmable pulse generator (as shown fig. 3) is getting trigger in two different times one gas pre fill -2.4 sec and two gas puff with loop voltage. Output eight channels are 0 to 10V. Output of PPG is applied to 20 gain HV amplifier with optical isolation. Output of HV amplifier is applied to piezoelectric gas leak valve

**Fig. 2: Functional Block Diagram of Aditya-U Gas fuelling Control System.**

**Fig. 3: PPG Circuit Assembly**

2. EXPERIMENTAL SET-UP

In House developed programmable pulse generator is works in two modes, continues mode and pulse mode. In continues mode DC voltage is set by knob in viewing voltmeter. Valve no. 1 is open as per applied voltage.

As shown fig. 3 Programmable Pulse Generator is designed using AT89S52 microcontroller, AD558 digital to analog converter, EL2003 output driver, IC 6N137 opto-coupler and MAX 232 serial converter.

In pulse mode there is two types pulse generated, prefill and puff. Prefill is triggered optically isolated pulse comes from Aditya Pulse Power System (APPS) -2.4 second of plasma discharge. Delay can set 0 to 2.35 sec. in step of 20 ms and pulse width 1ms to 255ms in step of 1ms. AD558 is 8-bit digital to analog converter, the resolution is 39 mV per bit, so amplitude can set 0 to 10V in step of 39mV and valve no. can selected.

Gas puff generator is triggered by optically isolated signal conditioned loop voltage pulse. It generates pulses of different width (100μs to 25.5 ms in steps of 100 μs), amplitude (0-10 in steps of 39 mV) and delay (between external trigger to first output and between different output from 26 μsec to 255 ms in steps of 1 ms) using Microcontroller and Digital to Analog converter. The pulse then applied to a high voltage amplifier with a gain of 20 to generate required potential to operate the valve. The amplified output is applied to the piezoelectric leak valve, to control the opening of the valve. Minimum delay from the external trigger pulse to the output is 26 μsec.
3. OPERATION OF AGFS

Control panel is design for pulse mode operation as shown in fig. 4. There are four parameter is set in Gas prefill section, Delay time from receiving trigger pulse, pulse width, pulse amplitude, and selection of valve. In Gas Puff section there are five types parameters are set for sixteen pulses, Number of pulse, Delay time, pulse width, pulse amplitude and selection of valve for individual pulse.

![Control Panel (LabVIEW)](image1.png)

**Fig. 4: Control Panel (LabVIEW)**

When press ‘PLOT button, one plot is generate in as per selection of timing and amplitude data in new window shown in figure 5. After selections all parameter press ‘SEND’ button all parameter value is load in memory of hardware through selected serial port and Green LED is blink on control panel and current time & date is display in Time dialogs box. When press ‘SAVE’ button all loaded parameter is save as text file with date and time stamping in given path and file number.

![Preview Plot](image2.png)

**Fig. 5: Preview Plot**

As shown in the figure 6, the front panel has ‘Ready” LED for indication of readiness of the system for data transmission or waiting for external trigger and a push button for Manual trigger. It has one SPST key for switching On/Off power supply. Programmable Pulse Generator output and optically isolated external trigger input are available on BNC connector while manual trigger is given by push button switch. It has in-built regulated D C power supply which can be controlled by power ON switch on front panel. The parameter data is loaded to the controller memory through 9 pin D type serial connector LabVIEW control panel.
Switch on AGFCS, Select mode by two toggle switches. When continues mode selected the front panel only blue LED is glow and volt meter of continues mode is on. Now turn the knob clockwise voltage is increase, output on Ch-1 only, other channel are disable. Value and index meter display according to vacuum of vessels. When select pulse mode red and green LED will glow. Red LED indicate pulse mode selected. While transferring the parameter via serial port the front panel green LED will be ‘Off’, indicating the transfer is going on. After transmission over, the green LED will be ‘On’ again, indicating the system readiness for trigger. System works in two different trigger modes prefill and puff, Manual trigger or External Trigger mode. The trigger input (TTL) is isolated from the enclosure and is applied using BNC connectors. The manual trigger is using Push button switches.

3.1 Receiving the external trigger for prefill

After receiving trigger (Ext. / Man.) a pulse is generating according to prefill data on control panel. Selected valve is operated with delay time, on time, amplitude.

3.2 Receiving the external trigger for puff

After receiving trigger (Ext. / Man.) pulses are generates according to puff data on control panel. Selected valves are operated with delay time, on time, amplitude in different pulses.

To generate delay or low time, “TL loop” will be executed, while to generate width or high time “TH loop” will be executed. On receiving trigger either manually or from external trigger, TL 1 loop will be executed. Then V1 data will be loaded to DAC and TH1 loop will start executing. After TH 1 loop will be over, DAC will be reset. So output will be low. Output will remain low till TL 2 loop will finish execution. Again V2 data will be loaded to DAC and TH 2 loop will start execution and so on until all pulses will be generated according to loaded “pulse number”.

4. TEST RESULTS

In figure 7, ch1 is an input trigger TTL pulse of gas puff system, pulse width is 5µs. Ch-2 to ch-9 is output channel, Output pulse is 0.1ms of PPG. In figure 8 output ch1 of PPG is describe 48 pulses of different delay time, on time and amplitude.
5. EXPERIMENTAL RESULTS

![Diagram](image_url)

**Fig: 9** Effect in plasma current related to pre fill pressure variation by three various Gas pre-fill Pulses as (i) Shot No. 32074; Pre-fill pulse: 7 V, 8.5 ms (ii) Shot No. 32045; Pre-fill pulse: 7 V, 7.7 ms (iii) Shot No. 32039; Pre-fill pulse: 7 V, 8.8 ms

As mentioned in fig.9, three various hydrogen fill pressure is set and precisely controlled by pre-fill pulses generated by gas fuelling control system. The precise changes in Hydrogen fill pressure from $3 \times 10^{-5}$ to $4 \times 10^{-5}$ Torr affects the plasma current in the three different shots.

![Diagram](image_url)

**Fig: 10** Effect in plasma density rise ($n_e$) and temperature rise (SXR signal) due to applied multiple small gas puffs (more than 10 nos., 4V, 0.5 to 1 ms ranges)

As plasma operation requirement to maintain fill pressure for long time, the gas fuelling control system generates the series of small gas puffs for precision gas fuelling. The system provides highly controlled pulsed in the time volts control as 0.1 milli seconds/ 0.1Volts. In fig.10, the multiple gas puffs effect is observed in the plasma density rise ($n_e$) and temperature rise (SXR signal). The single big puff of 20 ms size effect is also observed in plasma density rise ($n_e$) and temperature rise (SXR signal) in Fig.11.
Fig: 11 Effect in plasma density rise ($n_e$) and temperature rise (SX signal) due to applied big gas puff (20 ms)

Fig: 12 Effect in plasma temperature rise (SX signal) due to neon gas puff (5 ms, 6V) from valve-2 and the effect in H-$\alpha$ emission line due to Hydrogen multiple gas puff from valve-1

In gas fuelling control system, total eight valves can be operated simultaneously as per requirement of plasma operation. As mentioned in Fig.12, the two gas valves were operated for different gases neon and hydrogen in plasma operation to increase density rise by neon puffing.

6. CONCLUSION

In house developed microcontroller based Programmable Pulse Generator is tested for its rugged performance and then it was utilized for controlling of gas fuelling in Aditya and Aditya-U tokamak. The old CAMAC based controller system is now replaced by this new developed stand-alone hardware and software based control system. Software tool provides better option to operator during pulsed plasma experiments, however it has option to switch operation mode form pulsed to continuous/DC mode if there is any such need. Gas fuelling in
in pulsed mode widely utilizes to avoid wall loading on first wall, plasma facing components. This system has played a key role during repeatable long high current plasma discharge.

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