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# Hybrid Data Acquisition and Analysis System for Flowing Medium Lasers

Rajeev K. Dohare[#,*], Mainuddin[@], and Gaurav Singhal[#]

[#]*DRDO-Laser Science & Technology Centre, Delhi - 110 054, India*
[@]*Department of Electronics & Communication Engineering, Jamia Millia Islamia, New Delhi - 110 025, India*
[*]*E-mail: rajeevkumardohre@lastec.drdo.in*

**ABSTRACT**

The medium gas lasers involves in-situ generation of the lasing medium, hence are associated with several complex processes including mixing of pumping and lasing species, energy exchange between the species, heat generation during reaction and its influence on the flow domain to list a few. Thus, the characterisation of lasing medium, condition of operation of individual critical subsystems and corresponding phenomenon thereof is essential in real time. It is here that a customised data acquisition and analysis system (DAAS) plays a key role. The paper dwells on the realisation of a customised hybrid DAAS with a master-slave architecture, which is portable and provides remote system operation. The noteworthy aspects of the developed DAAS include capability to handle close to 150 channels [64 analog input, 64 digital output, 5 analog output and 17 digital input] simultaneously with varied sampling rates requirement ranging from 100 samples/s to 200 k samples/s, modularity in design enabling scalability. Further, the efficacy of the developed DAAS has been tested by conducting several real time experiments with an existing chemical oxygen iodine laser source with a mass flow rate of 2.3 moles.$s^{-1}$ both from close ranges and at line of sight remote distances of up to 80 m and nearly 35 m with obstacles.

**Keywords**: Data acquisition; Gas lasers; Flow rate; Safety interlocking scheme; Power measurement

## 1. INTRODUCTION

The development of flowing medium lasers[1-3] require precise operation, accurate flow control, real time monitoring and analysis of run parameters. This is essential for characterisation of several complex, obscure phenomenons occurring in the laser flow channel and to form requisite understanding for the same.

Typically, most reported high power flowing medium laser systems have utilised wired networking technologies for data acquisition and analysis system (DAAS) since it is a proven technology[4-5] for such high end, complex applications. However, wired networks are associated with certain measurable shortcomings, e.g. accessibility, mobility, and cost associated with cabling along with trouble shooting.

A plausible alternative is presented by wireless based technologies for development of DAAS. Wireless measurement, monitoring and control (data transmission) systems provide an opportunity to reduce installation and system costs, reduction in size, increase flexibility, simplify system deployments. Different wireless technologies are available with their pros and cons such as RFID, IEEE 802.15.1 Bluetooth, IEEE 802.11 (b/a/g/n/ac) Wi-Fi and IEEE 802.15.4 ZigBee[6]. Typically, Wi-Fi also provides better resistance to interference, reliable secure and better encryption with high performance and acceptable bit error rate of ~ $10^{-9}$, high throughput (more bandwidth than ZigBee or Bluetooth), low power consumption, large range, high data rate and sampling rate over others. It uses IEEE 802.11i security standard with 128 bit AES encryption. It also implements IEEE 802.1X, which is used for network authentication[7].

Thus, with a set of advantages of wireless technologies, it is prudent to examine the possibility of utilising it for complex applications such as flowing medium lasers simultaneously finding ways to address the points of concern. In this context, hybrid data acquisition techniques utilise benefits of both wired and wireless technologies and have been implemented in various practical scenarios like smart grid applications[8], power grid[9], greenhouse management[10], monitoring of cultural heritage physical parameters[11], turbine power generation system[12], automobile[13], offshore[14].

Hence, a hybrid DAAS appears to be an appropriate solution for use in a complex scenario such as flowing medium gas lasers and mitigating the shortfalls of a purely wired systems. Prime emphasis of the present work is to implement the hybrid DAAS for flowing medium gas laser and assessing its efficacy. Developed hybrid DAAS system has significant advantages over wired DAAS such as reduction in installation cost, weight and size and allows field deployability however, wireless system has limitations in terms of RF background noise, attenuation and limited line of sight distance.

## 2. HYBRID DAAS - STRUCTURE AND IMPLEMENTATION

A flowing medium infrared laser systems such as chemical oxygen iodine laser (COIL), $CO_2$ gas dynamic laser (GDL),

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hydrogen fluoride/deuterium fluoride (HF/DF) laser have the requirements of real time operation, pre-decided sequence controller, on line monitoring and display of analog & digital information, implementation of diagnostic schemes, storage of parameters for post run performance analysis and safety interlock implementation. To fulfill these requirements, a real time, portable, remote multichannel, hybrid (combination of wired and wireless) DAAS based on Wi-Fi architecture and master-slave topology has been developed for the operation and optimisation of flowing medium laser system. To the best of our knowledge, we have not come across any such hybrid DAAS been reported in open literature for use in flowing medium gas lasers.

The operation of flowing gas lasers requires analog as well as digital inputs and outputs to perform analog and digital acquisition and on-off sequential control. As far as the analog acquisition is concerned, laser operation requires monitoring of primary parameters such as temperature, pressure, flow, level, photo diode signal, diagnostics, continuously without human intervention. The digital parameters involve monitoring of on-off status and readiness of subsystems for laser operation. Analog control is required for on line variation of flow rates of gases involved in operation whereas digital control is required for on-off control of actuators/ valves/ pressure reducers in a predefined sequence with proper safety interlocks. To implement the above requirements, the hybrid DAAS is divided into Power module, Sensor module, Signal acquisition and control module (control panel), control (slave) and communication module, master controller (display and control device with application software).

Figure 1 shows the block diagram of developed DAAS. This system comprises of 150 channels and it is configured using Advantech data acquisition cards. Power module fulfils all the power requirements of DAAS. It provides 24 V dc supply for data acquisition cards in control panel, pressure sensors and actuation of valves and operation of pressure reducer. The conversion of 24 V to ± 12 V is made to meet the voltage requirement of ARK 1122C (Intel Atom N2600 fan less Embedded box PC) and photo detectors being used for optical diagnostics.

Sensors and Diagnostics module comprises primarily the temperature, pressure, and level sensors. K-type thermocouple [RS Components and Controls (I) Ltd., Stock No 6212170, response time- 20 ms and accuracy: ±0.5% (of FSR)] and connectors: Make: Omega, USA) has been used for measurement ranges of -20 °C to 50 °C and 20 °C to 150 °C with requirement of compatibility with corrosive chemicals and gases. Hence, sensors were fitted with SS-316 sheath to work in Basic Hydrogen Peroxide (BHP) or in Chlorine/iodine environment. Pressure sensors [accuracy: ±0.1% (of FSR), response time- 1ms] fitted with stainless steel diaphragm with viton seal from M/s Metran, Russia and M/s Xi'an Yunyi Instrument Co. Ltd., China have been used for ranges of 0-100 Torr, 0-10 bar and 1- 200 bar. To measure the level of liquid reagent i.e. BHP inside the tank, level sensors (Metran, Model no. 3536) has been utilised which is compatible with corrosive BHP liquid. These pressure and level sensors provide 4-20 mA current signal and operate with the excitation voltage of 24V dc. The output 4-20 mA is useful as it is less susceptible to noise as compared to voltage output.

Silicon and Germanium (Ge) photo-diodes (Centronic, RS Components, Stock no:303674 and Judson technologies, Model no: J16D-M204-R05M-60 respectively) along with an amplifier and signal conditioning module (ADAM 3014) are used for measurement of iodine and laser power backscattered signal at 490 nm and 1315 nm, respectively. The amplifier output is fed to the control and communication

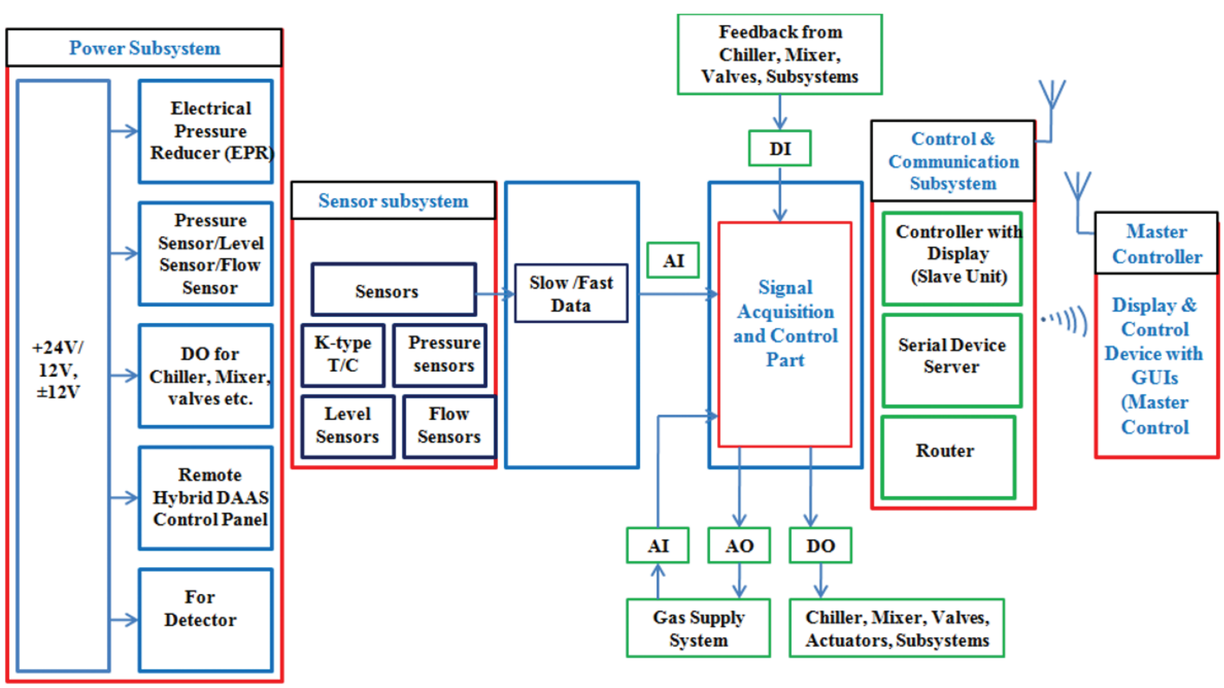


**Figure 1. Block diagram for overall hybrid DAAS.**

system through an analog input of the hybrid DAAS (USB 4716) for the post run analysis.

The multichannel analog signals are sampled at 100 sample/s (temperature) and 200 k sample/s (pressure signals and diagnostics such as gain) by cards which utilise a wireless serial server card EKI-1361, ARK-1122C and Router wireless AC750 dual band router.

Signal acquisition and control module comprise viz., signal conditioner; gas feed control system, digital status or control system. Signal conditioner utilises filter, amplifier circuit to make the signal acceptable to DAAS cards like Model No. 4117, 4118, and 4015 for slow sampling and USB 4716 for fast sampling of data with 16 bit resolution. Gas feed control system[15] controls the flow of the gaseous constituents (mainly nitrogen) using DAAS cards like 4024 and USB 4716. Digital status system records the status of the subsystems of the laser system using ADAM 4051 and digital control is utilised for the actuation of the different valves such as solenoid valves, electro-pneumatic valves using ADAM 4069 (power relay module) with Modbus protocol. The sequential operation of the flowing medium lasers is possible only due to the actuation of these valves in a predefined, predictable and timely manner.

The control (Slave) and communication module consists of a transceiver EKI-1361, processor ARK controller ARK-1122C (slave unit), and router D-Link wireless AC750. EKI-1361 is a wireless serial device server card which brings RS-232/422/485 to Wi-Fi. It allows nearly any device with serial ports to connect and communicate through Wi-Fi (802.11.b/g/n) to the display and control device with application software. The overall operation of the flowing medium lasers i.e. sequential control, monitoring and acquisition of various laser parameters and implementation of safety interlocks is performed by the master unit. Slave unit performs any action only when it receives the signal (permission) from master-controller, which is at the remote location, keeping in mind all the safety aspects related to the COIL like flowing laser system. Hence it is best suited to use the master/slave architecture in hybrid DAAS, which is the need for safe operation of laser system.

The application software program performs a number of applications like monitoring of different parameters at various locations, switching of valves, checking the status of subsystems, flow control of gases and contains a number of algorithms programmed in a specific manner for various sequence of operations. The software was developed using NI LabVIEW suite.

Figure 2 shows the control panel which is an integral part in the development of any DAAS. It acts as a bridge between physical subsystems and display and control device (master control). It consists of Power module, all DAAS cards, Solid state relays (SSRs), control and communication module viz., ARK controller (slave unit), EKI-1361 (transceiver), and router AC750. Figure 3 shows the developed photograph of control panel of hybrid DAAS.


**Figure 3. Developed DAAS control panel.**

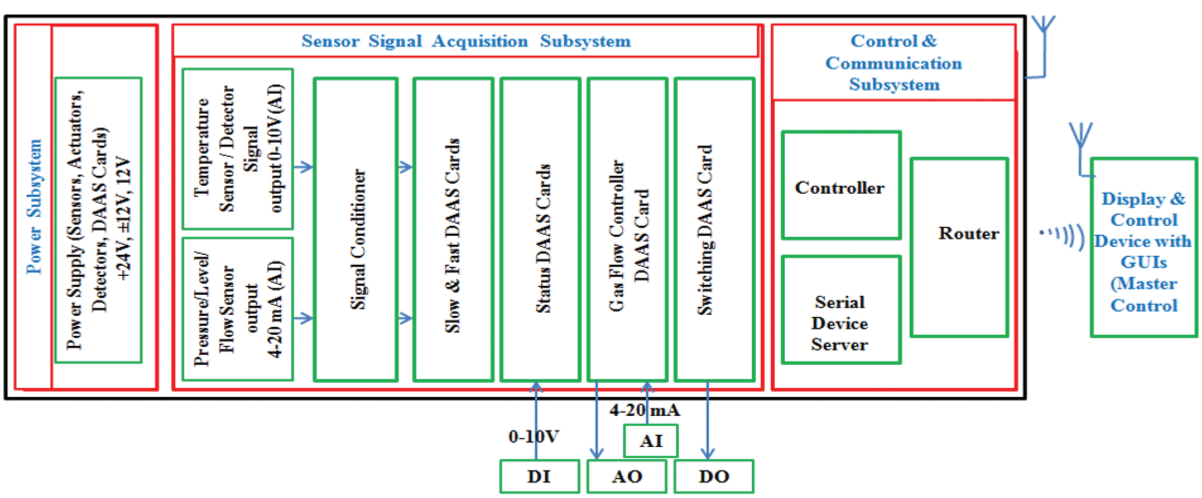


**Figure 2. Block diagram for the control panel.**

### 2.1 Graphical User Interface Windows

An application software with customised graphical user interfaces (GUI) developed in LabVIEW-2014 to control the functioning of the actuators and to monitor the system conditions from the data retrieved by the sensors. The operation has been divided in to eight GUIs namely: Main, SOG, Iodine evaporator, BHP, Reducer, Cyclogram, Calibration, and Graphs.

Figure 4 shows a typical GUI window, i.e. the *Main* GUI, which depicts real time sensor data, current status of actuators and other subsystems. The operation of the laser system is also initiated by this Main GUI window by pressing START switch. Necessary feedbacks and interlocks are provided for the operator to ensure that the system is in appropriate condition to initiate operation. For example, in case of COIL operation, it is mandatory that slit valve (connecting SOG to plenum) is closed at the start of the operation. In case the valve is open and an attempt is made to start the laser, the sequence of operation is not executed and warning indication is flashed. The sequence is executed only when the interlock condition is resolved i.e. when the slit valve is closed before experiment. It also contains all the emergency situations (safety interlocks).

## 3. VALIDATION AND TESTING

The developed 150 channels Hybrid DAAS has been validated by employing it to operate one of the most challenging flowing gas laser source COIL. A number of experiments (more than 100) have been carried out for optimisation of this laser system.

The 56 digital output (DO) channels are used to operate solenoid/electro-pneumatic valves/SSRs wirelessly according to the sequence /timings fed into the master controller (display and control device). Although, developed system has been tested for COIL operation but it may be used for any flowing medium laser source such as Diode Pumped Alkali Laser (DPAL), Liquid laser, $CO_2$ Gas Dynamic Laser, Hydrogen/ Deuterium Fluoride (HF/DF) etc.

Figure 5 shows the pressure variation acquired and displayed in one of the GUI "Graph" in the laser source flow tunnel.

A single pressure plot is usually employed showing temporal variations at several critical locations, which is usually termed as complex plot in flowing gas laser parlance. The complex pressure plot represents the effectiveness of the DAAS and records temporal pressure variations at various

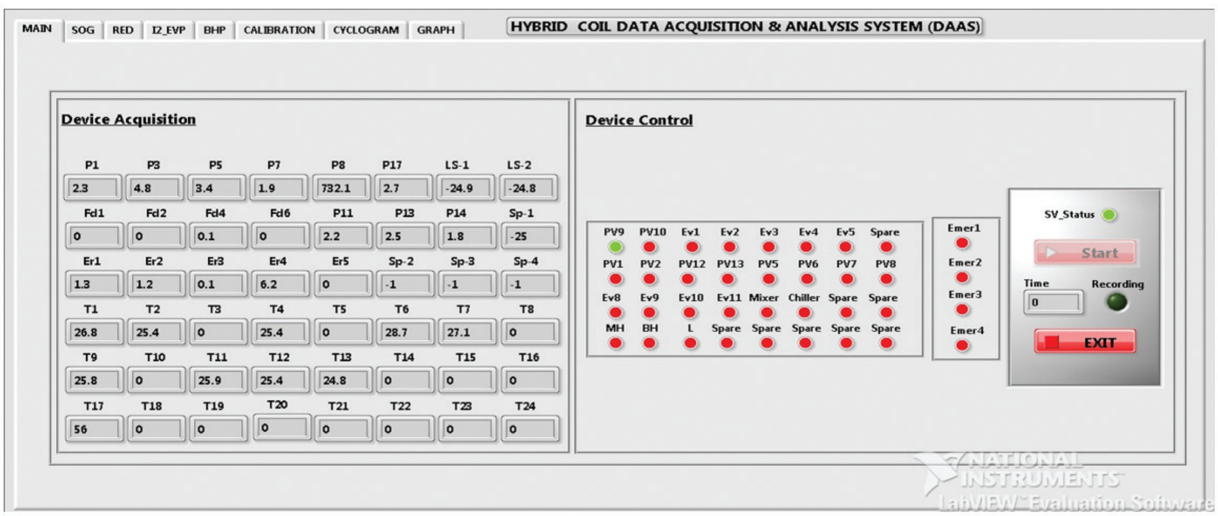


**Figure 4. Main GUI.**

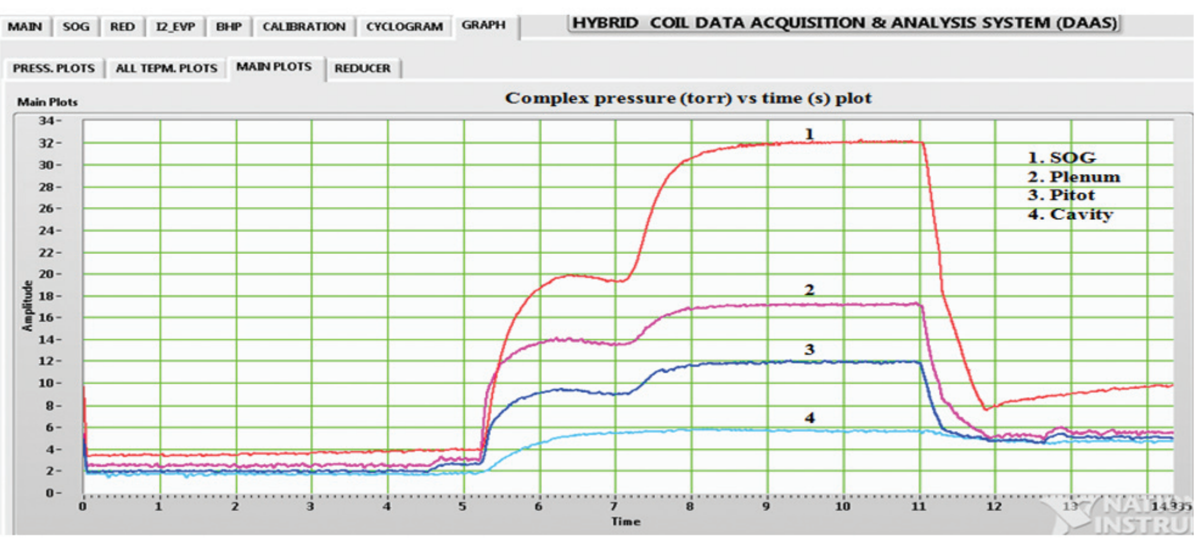


**Figure 5. Temporal pressure variation, Pressure (torr) vs. Time (s).**

critical locations in a COIL source, viz. SOG, Plenum, Pitot and Cavity. The primary aim is to maintain the cavity pressure as constant during the run at around 3-6 Torr. Hence, initially the primary buffer (at 5.3 s) ($I^{st}$ hump) for diluting singlet oxygen is started effectively compensating the chlorine flow (0.45 moles.$s^{-1}$), which is started at 7.4 s, and the primary flow rates are then restored to their typical flow of 1.0 moles.$s^{-1}$. This is followed by initiation of secondary nitrogen flow (0.5 moles.$s^{-1}$) along with iodine (at 7.2s) ($II^{nd}$ hump). Thus, the typical stable pressures for SOG, Plenum, Pitot and Cavity are 32 torr, 17 torr, 12 torr, and 5.5 torr, respectively during the period of 7.5 s to 11.5 s. It is also corroborated by the flow plots of primary nitrogen and chlorine during the time period of 7.5s to 11.5 s. The flow rates also have been obtained directly in *flow plots* (under Graph GUI), refer Fig. 6.

### 3.1 Power Measurement

One of the essential diagnostics[16] for characterising the laser source is the measurement of output power. Power measurement of high power lasers for more than tens of kilowatt level is carried out using indirect laser beam absorption method. This technique is based upon calorimetric principle $(Q \propto\sim m*s*\Delta T)$. Where, *m* is mass flow-rate (kg/s) of water, s is specific heat of water (4179 J/kg°C) and ΔT is the change in temperature.

The laser beam is focused on to a cone calorimeter with its periphery lined with copper tubing. It is a hollow cone of high thermal conductivity material such as copper or aluminum. To maximise laser energy absorption the internal surface of the cone is blackened by electroplating a thin layer of platinum or nickel. Cone shaped geometry is ideal to ensure multiple reflections of the beam and it's near complete absorption. Thus for half apex angle less than $18^{o}$ not only near complete absorption is feasible but also the energy density is also within required limits to avoid any deleterious effects on the calorimeter material. The scheme is shown in Fig. 7.

The absorbed laser beam results in rise in temperature of flowing water which is directly proportional to the power of the incident laser beam. Also, the water which flows continuously inside the calorimeter has to be monitored critically in terms of its inlet temperature, outlet temperature, mass flow rates to accurately determine the laser power. Further, necessary pressurising provisions are incorporated not only to maintain a constant flow rate but also to vary the water mass flow rates precisely.

The temperature at the inlet and outlet are measured with the help of customised fast response, grounded K- type thermocouples and monitored with the help of Advantech 4118 (slow sampling) on the Master controller unit of hybrid DAAS and power is computed and recorded/ displayed on to hybrid DAAS. Flow meter provides 4-20 mA output and corresponding flow rate is monitored on the Hybrid DAAS with the use of Advantech USB 4716 (fast sampling). A backscattered signal is obtained at the back mirror (Reflectivity, R=99.99 %) end to ascertain the duration over which the power pulse is obtained. Figure 8 shows temporal variation of obtained power pulse (1315 nm) employing a suitable Infrared (IR) - detector (Germanium Ge photo-diode, Make: Judson technologies, Model no: J16D-M204-R05M-60). This is essential for accurately estimating the power output of the laser source. The designed power

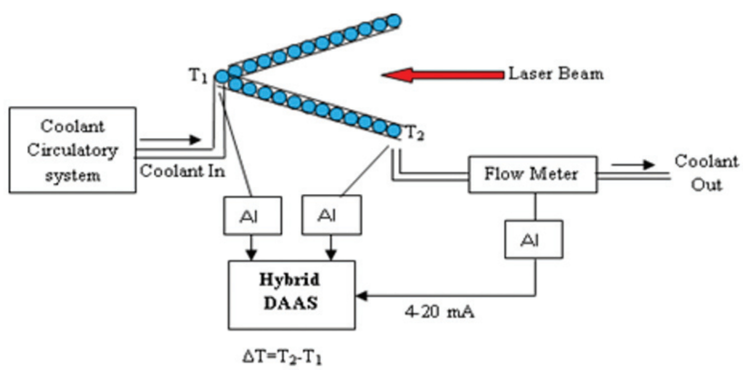


**Figure 7. Implemented power measurement scheme.**

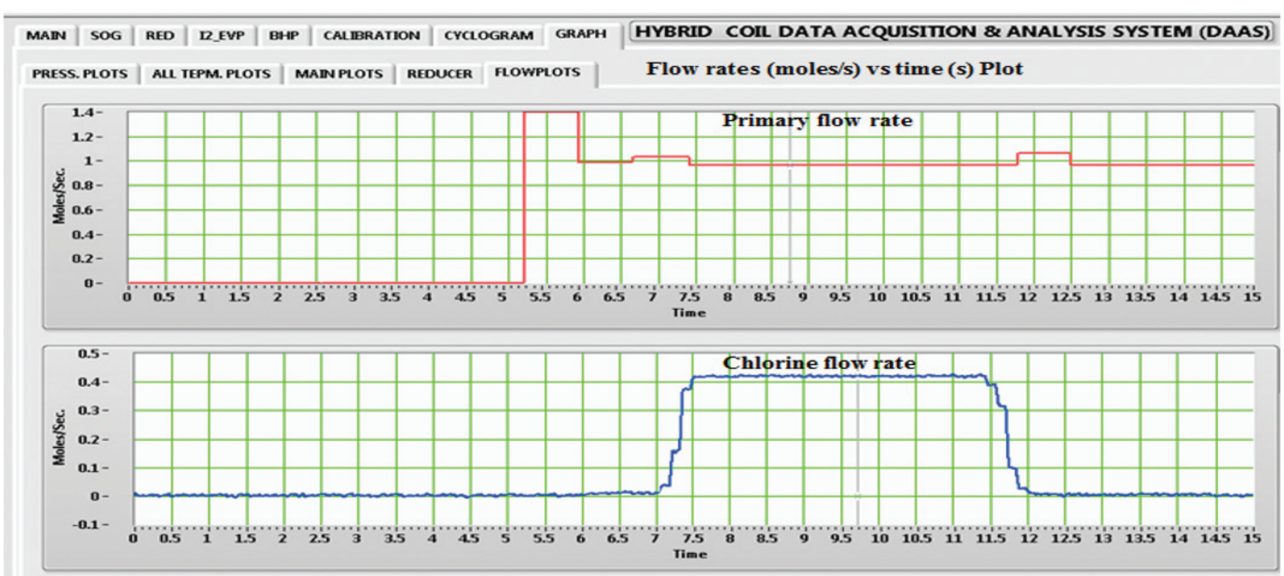


**Figure 6. Temporal flow rate variation, flow rate (moles.$s^{-1}$) *vs* Time (s).**

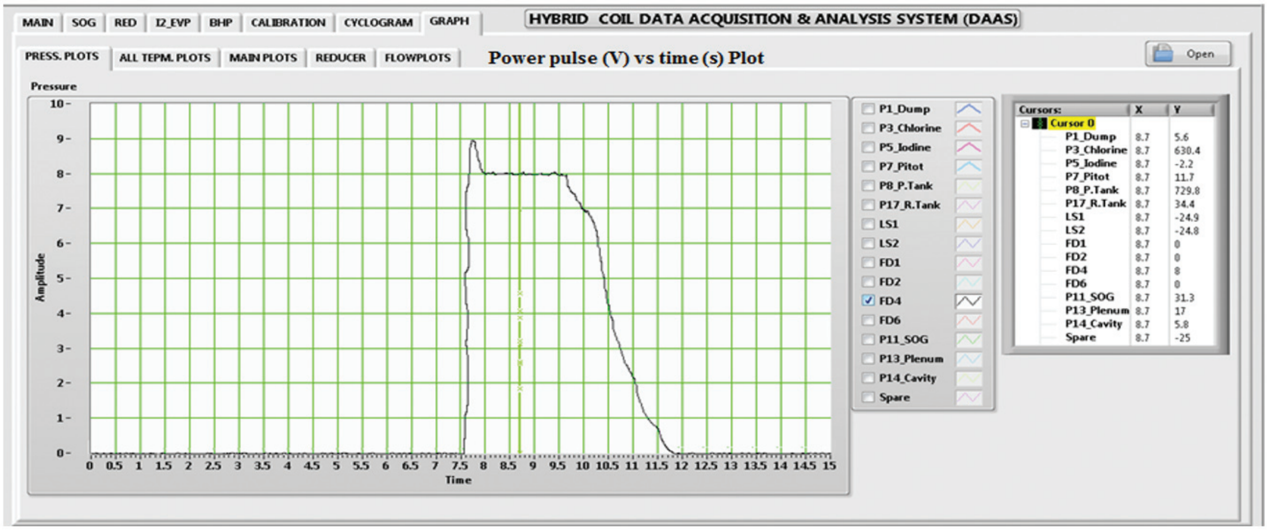


**Figure 8. Temporal variation of obtained power pulse, Amplitude (V) vs. Time (s).**

measurement system is capable to measure output power of high power COIL up to 30 kW with measurement accuracy of ± 5 % and response time of 0.2 s.

### 3.2 Safety Interlocking Scheme

Operation of the COIL laser system involves hazardous chemicals such as chlorine gas, iodine vapor and liquid reagent namely basic hydrogen peroxide (BHP) solution. Therefore, for the safe operation of COIL it is very important to incorporate the safety equipment and interlocks for shutting down the system. BHP is hazardous due to its exothermic nature. Hence, from the point of view of safety it is desirable to monitor (using Advantech 4118 and USB 4716) and maintain BHP tank temperature < -10 °C and tank pressure < 1.5 bar. In case any of these parameters reach beyond the set limits as shown in Fig. 9, DAAS system automatically takes action through implemented software interlocks and operates the BHP drain valve to drain the BHP or in the latter case switching on the air inlet valve simultaneously preventing BHP transfer during run.

The other safety interlocks pertain to the permissible pressure ranges for SOG, iodine and chlorine systems. The maximum permissible limits for SOG pressure, iodine pressure and chlorine pressure are 60 torr, 400 torr, and 1.2 bar respectively. If they reach beyond the prescribed limit, developed DAAS system automatically initiates action to undertake safety interlocking measures. Developed hybrid DAAS system continuously monitors sensors output and if a sensor fails during operation, provision has been made to cater the emergency situation. In this case, DAAS system indicates sensor's failure and gives alarm signal to initiate the manual safety command. An emergency switch is also employed to switch off all the actuator's/valve's power in case of emergency during laser operation.

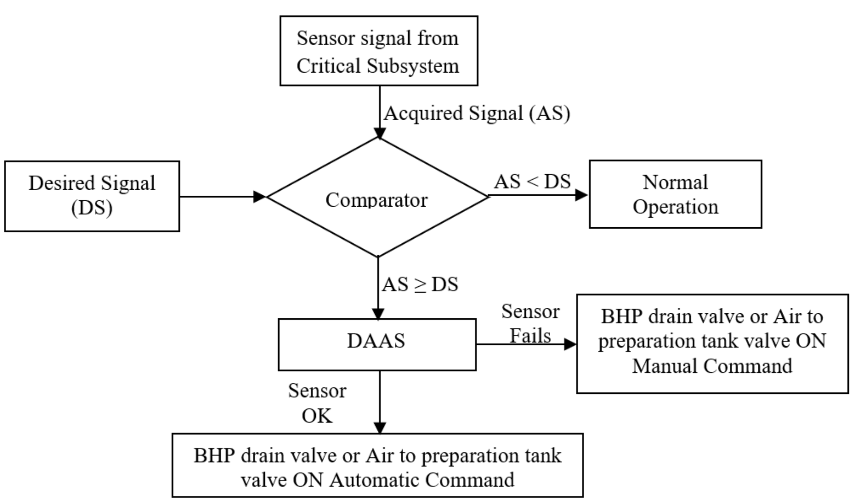


**Figure 9. Safety interlocking scheme.**

## 4. CONCLUSIONS

A remote portable hybrid DAAS based on wireless interface with 150 channels has been developed and successfully tested for operation and investigations of complex processes in flowing medium lasers. The developed 150 channel hybrid DAAS is capable of being utilised for optimum functioning of flowing gas laser systems at par with any wired DAAS. The efficacy of the developed system has been tested in sequence running of different solenoid/electro-pneumatic valves and monitoring and acquisition of various parameters by operating master controller both from close and remote ranges (with and without obstacles) during COIL laser operations. Hybrid DAAS based on Wi-Fi interface has several advantages in terms of getting rid of cluster of wires along with providing necessary mobility. Also, DAAS system supports different essential custom diagnostics required for better comprehension of behaviour of lasing medium under various operation scenarios. The implementation of one such diagnostics i.e. calorimetric power measurement of laser source has been discussed in detail. Although the developed system has been operated in conjunction with a COIL source but its modularity and configuration design entails the capability of being used in any flowing medium laser viz., DPAL, Liquid laser, $CO_2$ Gas Dynamic Laser. It may also be used in lasers other than flowing lasers after the required modifications as per requirements of the laser system.

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## CONTRIBUTORS

**Mr Rajeev Kumar Dohare** obtained his MTech (Electronics & Communication Engineering) from Amity University, Noidain 2013. Presently, he is working as a Scientist in DRDO-Laser Science and Technology Centre, Delhi, India. His field of interest includes: data acquisition and control/ electronics/ high power lasers/ optical diagnostics.
In the current study, he has carried out for complete design and development scheme and written/prepared the manuscript.

**Dr Mainuddin** received his ME from Delhi College of Engineering, Delhi in 2003 and PhD in 2008 from JMI, New Delhi. He is presently working as a Professor in Department of Electronics & Communication Engineering, JMI, New Delhi. His research interests include: Optical diagnostics, High power lasers, data communication, optical communication and computer networks.
In the current study, he has carried out LabVIEW based software and Graphical User Interface windows (GUI) development suitable for laser experiments.

**Dr Gaurav Singhal** received BE (Mechanical Engineering) from JMI, New Delhi, in 1998and PhD from IIT, Delhi, in 2008. Presently, he is working as a Scientist in DRDO-Laser Science and Technology Centre, Delhi, India. His research interests include: High power lasers, high speed unsteady flows, turbulent mixing, laser diagnostics, CFD techniques etc.
In the current study, he has carried out the entire sensor selection for acquisition of laser parameters during laser operation and optimisation through various experiments.