

OPEN ACCESS

SST-1 Gas feed and Gas Exhaust system

To cite this article: Dilip C Raval *et al* 2012 *J. Phys.: Conf. Ser.* **390** 012036

View the [article online](#) for updates and enhancements.

You may also like

- [Baking of SST-1 vacuum vessel modules and sectors](#)
Firozkhan S Pathan, Ziauddin Khan, Paravastu Yuvakiran et al.
- [Upgradation plans of SST-1 Cryogenics system at IPR](#)
V L Tanna, SST-1 Cryo Team and S Pradhan
- [Cryogenic heat loads analysis from SST-1 plasma experiments](#)
N Bairagi, V L Tanna and S Pradhan



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

SST-1 Gas feed and Gas Exhaust system

**Dilip C Raval, Ziauddin Khan, Prashant L Thankey, Kalpesh R Dhanani,
Firozkhan S Pathan, Pratibha Semwal, Siju George, Paravastu Yuvakiran,
Himabindu Manthena and Subrata Pradhan**

Institute for Plasma Research, Near Indira Bridge, Bhat, Gandhinagar – 382428,
Gujarat, India

E-mail: raval@ipr.res.in

Abstract. SST-1 tokamak is a long pulse tokamak designed for the plasma operation up to 1000 sec duration. Gas feed system and gas exhaust management will play a very crucial role during plasma discharge. During the different type of operations of tokamak like wall conditioning, diverter operation and neutral beam injection, a large amount of gas will be fed into the vacuum chamber at different locations. Also during plasma operations, the gas will be fed both in continues and pulse mode. Gas feed will be carried out mainly using piezo-electric valves controlled by PXI based data acquisition and control system. Such operations will lead to a huge amount gas exhaust by the main system which requires good exhaust facility to searches, great care should be taken in constructing both. Also initial pumping of cryostat and vacuum vessel of SST-1 will release a large amount of gas. Exhausted gases from SST –1 will be Hydrogen, Nitrogen, Mixture gases or some toxic gases. Dedicated exhaust system controlling the different gases are installed. Special treatment of hazardous/explosive gases is done before releasing to the atmosphere. This paper describes design and implementations of the complete gas feed and exhaust system of SST-1.

1. Introduction

Vacuum chamber of steady state superconducting (SST-1) tokamak comprises mainly of two vacuum chambers, (1) Vacuum Vessel in which plasma will be produced and confined and (2) Cryostat which will provide working environment for all superconducting magnetic coils [1, 3]. Vacuum vessel and cryostat are designed and fabricated for ultra-high vacuum and high vacuum applications respectively. Ultimate base pressure in vacuum vessel will be $\leq 1.0 \times 10^{-8}$ mbar while that in cryostat will be $\leq 1.0 \times 10^{-5}$ mbar. For tokamak experiments, the gas puffing is carried out to have an initial break down. After break down, the plasma fuelling plays an important role to maintain and control the plasma density. For the tokamak operating in steady state and in divertor mode, the steady state removal of heat and exhaust particles are much required to maintain the plasma density for longer periods. A number of techniques like external gas feed, neutral beam injection and pellet injection etc. are being implemented for fuelling the plasma. Out of these techniques, the gas feed system is the most basic and primary need for tokamak experiment during plasma shot.

Main functions of the gas feed system are (a) the pre-filling of the vessel to a required pressure, (b) feeding of required amount of gas during the plasma current and the density build up phase, (c) feeding of amount of gas to maintain the plasma density at required value, (d) feeding of gases into the vessel during wall conditioning and (e) feeding of required amount of gases in divertor region to

remove the heat and exhaust particles for plasma diagnostic. For all these functions during plasma shot, a very efficient gas feed system is essential.

Further due to very large volumes of the vacuum vessel (16 m^3) and the cryostat (39 m^3), during initial pumping of both of them, a large amount of gases (mainly air) will be extracted and released through the pumps. Also during plasma discharge operation of tokamak, a large amount of hydrogen gas will be released through the pumps as the vacuum vessel's pressure will be maintained $\leq 1 \times 10^{-4}$ mbar during entire plasma discharge of 1000 sec. Special gases like helium, neon and other special gases will also be used for vessel wall conditioning, divertor operations, plasma diagnostics, Neutral Beam Injection etc. So an effective gas exhaust handling system for SST-1 vacuum system as well as other systems is required.

2. SST-1 gas feed system

For proper fulfilment of SST-1 tokamak requirements, the gas feed system is divided into two sub-systems. First sub-system will be used for plasma fuelling in which wall conditioning, pre-filling and the density control will be carried out. Second sub-system will be used for divertor fuelling. Total twenty-two numbers (22) of piezoelectric gas feed valves will be used in SST-1. Piezoelectric gas feed valve works on 100 VDC and starts functioning above 30 VDC. By varying applied voltage, the required gas throughput from this valve can be varied. Gas feed pulse shape can also be adjusted as per requirement using PXI based control system.

2.1. Plasma fuelling

Eight (08) numbers of piezoelectric valves will be mounted diagonally opposite to each other at four radial ports to maintain the overall balance of gas distribution inside the vessel over a given period of time. These valves will be used for wall conditioning, boronization, pre-filling and density control. During all above phases, hydrogen gas of very high purity of $\sim 99.9999\%$ will be injected into the vessel through these valves. The hydrogen gas of such purity will be obtained by feeding the supplied gas of 99.95% purity through a hydrogen purifier of the same order. This ultra-high pure gas cannot be fed into the vessel on line due to variation of gas requirements in different phases. Also the function of hydrogen purifier, incorporated with a palladium cell consisting of palladium alloy tubing which acts as the diffusion element, depends on the inlet and outlet pressures.

SST-1 tokamak is a long pulse tokamak with maximum plasma duration of 1000 seconds and the amount of high purity hydrogen gas required during single plasma shot will be approximately 80,000 torr litre. To fulfil these requirements, one buffer chamber is used for storage of ultra-high pure hydrogen gas. As the outlet pressure of the hydrogen purifier is 5 bar, the buffer chamber will be maintained at the same pressure. At room temperature and 5 bar, a buffer chamber of 30 litre will be sufficient for storage of gases required for at least 2 cycles. During different phases, the amount of gas feed into the vessel should be known so that the behaviour of the graphite surface absorption can be determined for next plasma discharge. For this purpose, a mass flow meter for hydrogen gas is being used for measuring the amount of gas puffed during operation. Since these values are operated using DC voltage, they should be isolated from both the high-pressure side and the low-pressure side of the vacuum vessel by using vacuum isolators to avoid the grounding, which may lead to change in the amplitude of the applied signal. Before the piezoelectric valve, a known conductance and a pressure gauge will be mounted to measure the quantity of gas being puffed to the vessel by each piezoelectric valve.

During wall conditioning, the mixture of hydrogen and helium gas will be puffed to the vessel. The mixture of required percentage of hydrogen and helium gases will be carried in the 10 litre chamber by puffing these gases into this chamber through mass flow meters for each of them. The entire installation of the gas feed line will be carried out by the polished SS 316 tubes and swagelock type quick connectors. Since the entire line will be bifurcated towards the different radial ports as per requirement, the ON/OFF valves will be provided at each line for functioning of the respective line whenever required. Before operation, the entire gas feed line will be pumped to a pressure below 10^{-3}

mbar using the dry rotary pumps, followed by the baking of line at 150° C for few hours. The schematic of plasma fuelling is shown in the figure 1.

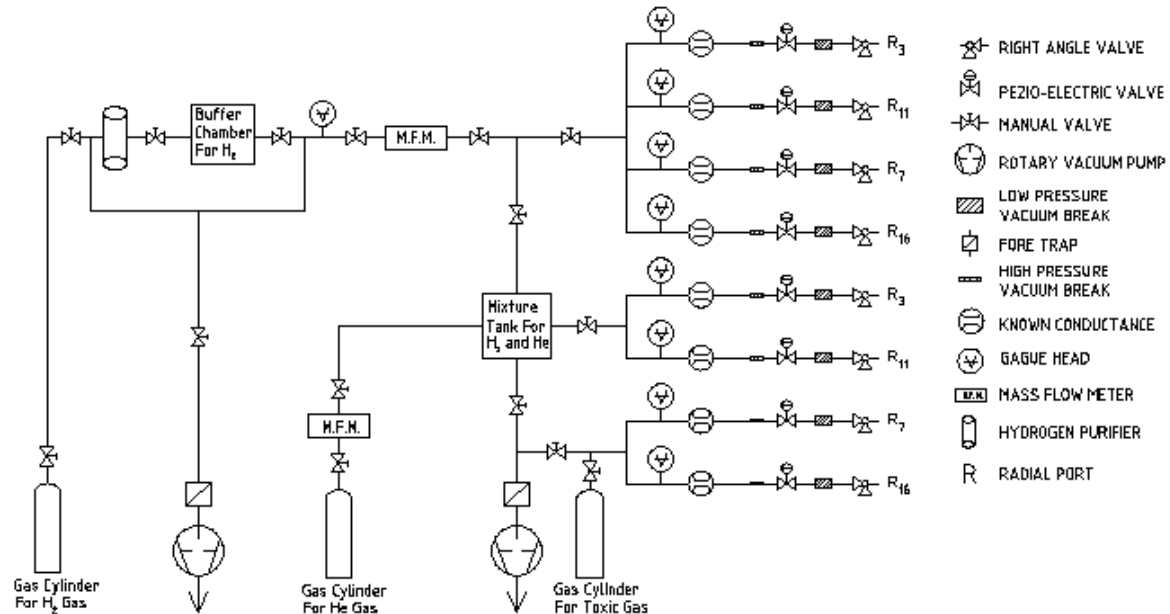


Figure 1. Schematic for SST-1 Gas-feed System

2.2 Divertor fuelling

Divertor fuelling schematic of SST-1 is shown in the figure 2. The integration of this supply line will be carried out in the same manner that to previous one. Here each of eight piezoelectric valves will be connected to the top and bottom vertical ports respectively. In both top and bottom regions, the feeding will be performed through eight outer ports and four inner ports. The amount of gas required will be supplied from another 10 litre chamber. If mixture of gases is desired for puffing in divertor region, then mixing of gases can be done in the same chamber using mass flow meter.

3. SST-1 Gas Exhaust System

Apart from SST-1 main vacuum system, a large number of other subsystems will also be connected to SST-1 vacuum vessel for plasma heating, plasma current drive, plasma diagnostics etc. Many of these subsystems will be using their own dedicated vacuum systems. So, an effective gas exhaust handling system for SST-1 vacuum system as well as other subsystems is required.

3.1 Design Calculation

One roots rotary pumping station of 1800 m³/hr will be used for initial roughing of the vacuum vessel from atmosphere to 1.0×10^{-3} mbar. Two numbers of turbo-molecular pumps, each having 5000 l/s (N₂) pumping speed and two numbers of closed cycle cryo-pumps (each of 10,000 l/s pumping speed for water vapor) will be used to pump down vessel from 1.0×10^{-3} mbar to $\leq 1.0 \times 10^{-8}$ mbar. Sixteen (16) numbers of similar turbo-molecular pumps will be used to pump the divertor region during steady state (1000 sec) plasma discharge. Vacuum vessel pumping system will have to remove about 60 mbar l/s hydrogen gas during this phase of operation.

Two numbers of roots rotary pumping stations, each of 1800 m³/hr will be used for initial rough pumping of cryostat from atmosphere to 1.0×10^{-3} mbar. Three numbers of turbo-molecular pumps each having 5000 l/s pumping speed will be used to pump the cryostat from 1.0×10^{-3} mbar to $< 1.0 \times 10^{-5}$ mbar. During normal operation of cryostat at pressure $< 1.0 \times 10^{-5}$ mbar, liquid nitrogen (LN₂)

panels will be cooled down to 80 °K and super-conducting coils will be cooled down to 4.5 K. These cold surfaces will provide large pumping speed for all gases except hydrogen and helium. So, the gas load will be very small during normal operation of cryostat. However, during rough pumping as well as thermal run away (cold surfaces getting warmed up accidentally), very large amount of gases will be exhausted from cryostat. Total gas load from all other systems connected with SST–1 (e.g. plasma diagnostic etc.) is assumed to be much less than the gas loads from vacuum vessel and cryostat.

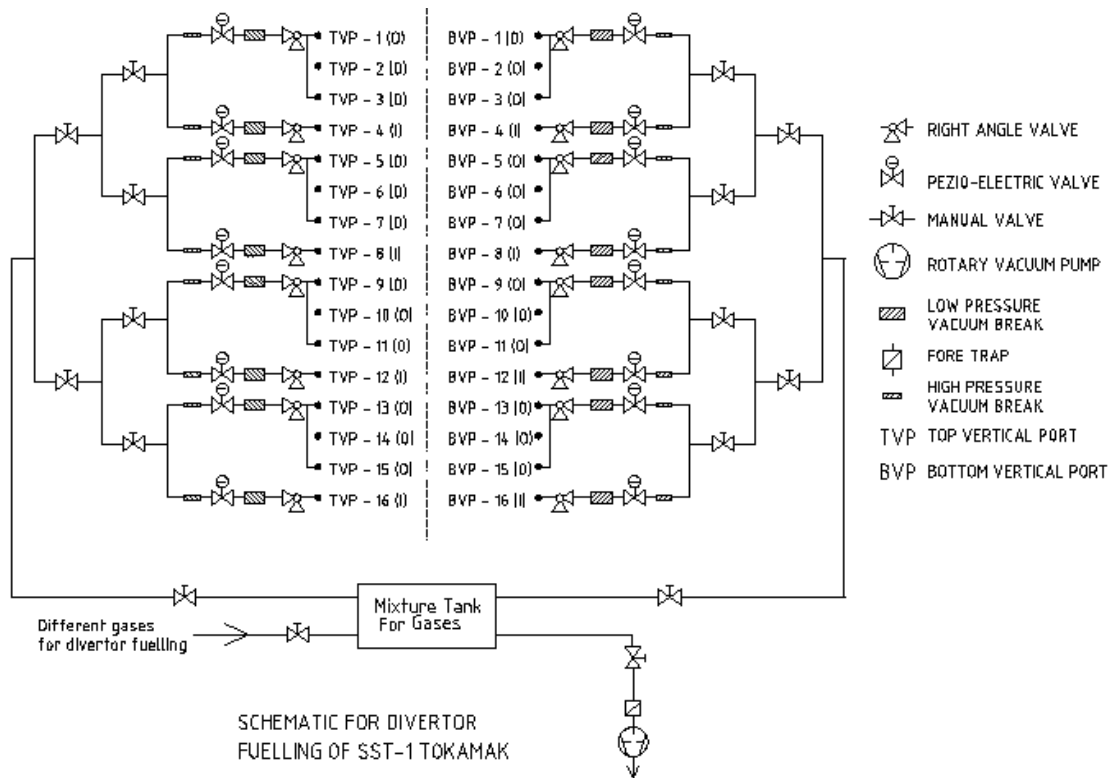


Figure 2. Schematic for SST-1 Divertor Fueling System

As a design criterion, it is important to ensure that gas exhaust system removes the gas from the exhaust port of the rotary pump with a speed such that pressure more than 1.2 bar (a) is not built up at the exhaust port of the pump. This is because feather valve of the rotary pump exhaust port is designed to operate efficiently at this pressure on its exhaust side. The volumetric flow rate (speed) for different inlet pressure is given in the table 1 for these root pumps.

Table 1. Volumetric flow rate of root pumps at different pressures

Pressure (mbar)	Volumetric flow rate (m ³ /hr)	Total throughput Q (mbar l/s)
1.0×10^3	250	69.42×10^3
1.0×10^2	320	8.88×10^3
10	1.0×10^3	2.77×10^3
1	1.7×10^3	4.72×10^2
1.0×10^{-1}	1.8×10^3	50.00
1.0×10^{-2}	1.6×10^3	4.47
1.0×10^{-3}	1.1×10^3	0.305

The maximum throughput that will be exhausted by a single pump in SST–1 vacuum system is $Q = 69.42 \times 10^3$ mbar l/s. Thus the net gas throughput that will be exhausted to the exhaust line by all three pumps is $Q = 2.08 \times 10^5$ mbar l/s. For proper functioning of rotary pump, the pressure at its exhaust should not exceed 1.2 bar (a). This is possible by the use of pipeline of suitable conductance. The conductance needed to maintain the pressure difference of $\Delta p = 0.2$ bar for above throughput is $C = Q / \Delta p = 1.041 \times 10^3$ l/s. This is the minimum required conductance that the line should have to maintain 0.2 bar pressure difference between inlet point of gas exhaust line (i.e. outlet of rotary pump) and outlet of gas exhaust line (i.e. 1 bar (a)).

The relation between the throughput (mbar l/s) and the diameter (cm) of the pipe for turbulent flow ($Q > 196$ d) [4] shows that for the tube up to 806 cm diameter, we will get turbulent flow. Again the conductance of a circular tube of diameter (d) cm and length (l) cm in viscous flow is given by

$$c = 182 \left(\frac{d^4}{l} \right) \left(\frac{p_1 + p_2}{2} \right) \quad \text{l/s} \quad (1)$$

where $p_1 = 1.2$ bar is the pressure at entrance of the pipe,
 $p_2 = 1.0$ bar is the pressure at exit of the pipe.

The velocity of exhaust gas for a given diameter d (m) is given by

$$v = \frac{4 v'}{\pi d^2} \quad \text{m/hr} \quad (2)$$

where v' is the volumetric flow rate in m^3/hr .

According to the possible lay out of the gas exhaust line in SST–1 hall, the effective length of the exhaust line (including bends etc) in the design is 80 meter. Thus for this length and different diameter of the pipe, the conductance of the pipe is as follows

- | | | |
|---------|----------------|-----------------------------|
| (1) For | $d = 6.5$ cm, | $C = 0.340 \times 10^5$ l/s |
| (2) For | $d = 10$ cm, | $C = 0.830 \times 10^5$ l/s |
| (3) For | $d = 10$ cm, | $C = 2.026 \times 10^5$ l/s |
| (4) For | $d = 12.5$ cm, | $C = 4.947 \times 10^5$ l/s |
| (5) For | $d = 15.0$ cm, | $C = 1.025 \times 10^6$ l/s |

The above calculations and comparison between two conductance show that the pipe of 10.0 cm diameter is suitable for exhaust line.

3.2. Gas Exhaust Line Layout

SST–1 gas exhaust system is designed to remove (a) air during normal pumping of vacuum vessel and cryostat, (b) hydrogen during plasma operation, (c) some special gases for plasma diagnostics and wall conditioning. Considering this, three exhaust lines are designed for SST–1 tokamak. First line will be used only for main vessel and cryostat pumping system of SST–1 tokamak. Second one will be used by all other sub-systems connected to vacuum vessel. Third exhaust line will be used for special gases. These three lines are labeled as (1) VACUUM SYSTEM EXHAUST, (2) DIAGNOSTIC SYSTEMS EXHAUST and (3) SPECIAL GASES EXHAUST respectively. A standard rigid PVC pipes are selected for different exhaust lines. Vacuum System exhaust line has 104 mm internal diameter for vessel and cryostat pumping system due to very high gas loads. Exhaust line for diagnostics and other subsystems attached to SST–1 vacuum vessel has 84 mm internal diameter because it has relatively

low gas load as compare to main pumping system. Special gases exhaust line has 57 mm internal diameter. Each line will have a number of ports to connect the exhaust line to the exhaust port of rotary pump. Each port will have cap to close the port when it is not being used to stop gas from re-entering in SST-1 hall. All three lines will be taken into exhaust gas treatment room and connected to the centrifugal blowers. Special gases exhaust line can be converted into toxic gas exhaust line, if required, by connecting toxic gas treatment chamber in its series. After commissioning, all three gas exhaust lines will be helium leak tested for leak rate $\leq 1.0 \times 10^{-5}$ mbar liter/sec at 1.2 bar (a) internal pressure with sniffer probe.

A number of sensors for hydrogen, helium and toxic gas (if required) will be deployed in SST-1 hall as well as exhaust gas treatment room to detect the leakage of these gases either from supply lines or from exhaust lines. Oxygen level sensors will also be deployed in SST-1 hall and exhaust gas treatment room to monitor safe working level of oxygen concentration.

4. Conclusion

Gas feed system for SST-1 is commissioned and tested for its functionality for 1st first plasma operation i.e. for circular plasma operation. This gas feed system will be extended further for divertor fuelling in future. Also exhaust system commission is over. The probability of back trust of exhaust gases from pumps is eliminated by use of higher capacity bowers operation.

References

- [1] Bhise M K et al 1996 *Fusion Technology* vol 1 p 805
- [2] Ranga Nath T et al 1997 *17th SOFE* vol 1
- [3] Pradhan S & SST-1 Mission Team 2010 *J. Plasma Fusion Res. SERIES* vol 9 p 650
- [4] Armand Berman 1992 *Vacuum Engineering calculations, Formulas, and Solved Exercises* (Academic Press Inc, New York) p 81