THE GAS ATTENUATOR VACUUM SYSTEM OF FERMI@ELETTRA

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Abstract

The FERMI@Elettra Free Electron Laser aims to produce coherent radiation in the EUV-soft X- ray range employing High Gain Harmonic Generation (HGHG) schemes. The ultrafast, high intensity pulses are delivered to the experimental stations by means of a section called PADReS (Photon Analysis Delivery and Reduction System). Since several experiments need to reduce the FEL radiation intensity without changing the machine parameters, PADReS provides an integrated system to measure and reduce it up to 4 orders of magnitude. It is composed by a windowless gas-filled cell, a gas injection system, a differential pumping system, and two intensity monitors. The gas cell can be filled up to 0.15 mbar of nitrogen and the differential pumping system can keep up over 6 orders of magnitude. The pressure is finely regulated in the 10-5 mbar range in the intensity monitor vacuum chamber, almost independently from the gas cell pressure level. The general layout and the performance of the differential pumping system prototype are presented.

INTRODUCTION

The FERMI@Elettra free electron laser (FEL) user facility is in commissioning at Sincrotrone Trieste (Italy). At the end of the linac, the spreader addresses the beam towards two alternative, parallel undulator cascades, FEL 1 and FEL 2. They generate radiation in two different spectral regions: 100 to 20 nm and 20 to 4 nm, respectively [1]. At the end of the undulators and after deviating the electrons from FEL 1 or FEL 2 to a common beam dump, the front end starts. The emitted radiation enters the dedicated diagnostic section called PADReS (Photon Analysis Delivery and Reduction System) before being delivered to the experimental end stations. Photon beam position monitors (Pbpm), intensity monitors (I_0M) and other photon diagnostics are described elsewhere [2]. Another relevant "active" component in PADReS is the vacuum system itself. The gas distribution system and the pumping system are responsible for maintaining the right pressure level in the intensity monitors and in the gas cell where the photon intensity can be reduced up to 4 orders of magnitude.

THE GENERAL LAYOUT

PADReS starts with two identical branches, which are 14.8 m long (fig. 1). They were developed under rigid constraints due to limited spaces in the undulator hall and in the safety hutch, and considering the 3m-thick radioprotection wall. Each one is divided into four different modules. Each module was designed in order to host all the instrumentation and service plants (compressed air, water, electrical junction boxes) necessary to that one, so all the modules were preassembled in laboratory (excluding vacuum pumps and delicate components) and easily connected together after the alignment in the machine tunnel. They are divided into vacuum subsections; vacuum valves separate subsections with different tasks.

I Module

Following the radiation propagation, the first module hosts the photon shutter, the adjustable pinhole and the Pbpm. As it represents the interface to the machine where ultra high vacuum (UHV) condition is maintained, the pressure never exceeds $5 \cdot 10^{-8}$ mbar, so adequate triode ion pumps were chosen.

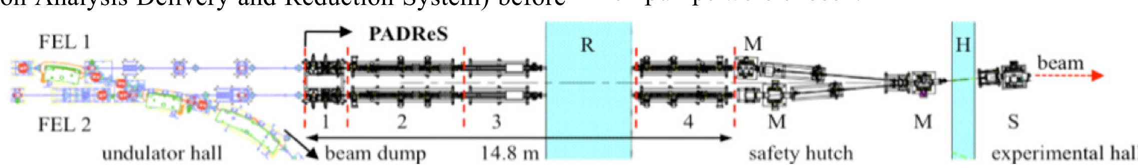

Figure 1: Layout of PADReS: 1, photon shutter and diagnostics; 2 and 4, differential pumping systems; 3, gas cell; M, mirrors vacuum chambers; S, energy spectrometer vac. chamber; R, radioprotection wall; H, safety hutch wall.

II Module

The second module hosts the differential pumping system and the active radioprotection system (fig 2). It preserves the machine vacuum and ensures that high-energy secondary radiation generated by electron beam losses is stopped.

The efficiency of the differential pumping system comes out from a specific combination of turbomolecular pumps and small conductance pipes. For this module, the diameter of the connecting pipes is 18 mm, which represents about 5 times the photon beam diameter. The other relevant dimensions are shown in the figure. The conductance for N_2 of the longest pipe is ≈1.3 l/s, calculated in the intermediate flow regime, at P= 0.15 mbar at the gas inlet [3]. The main task of the first pumping stage is to pump the gas excess coming from the following I_0M vacuum chamber. A gate valve separates the vacuum chamber from the 260 l/s turbomolecular drag pump; it closes when some failure of the pumping station occurs. The second vacuum chamber hosts the I_0M instrumentation. A monostable valve opens allowing nitrogen to be injected at a fixed flow so that the pressure can rise up to 3•10^{-5} mbar. A butterfly valve in front of the 70 l/s turbomolecular pump can be controlled to vary the pressure finely. A feedback system to maintain the equilibrium pressure at a specified level has to be implemented. The pressure is measured by 2 different instruments: an inverted magnetron gauge (IMG) for a general purpose, and a spinning rotor gauge for accurate measurements necessary to the I_0M to determine the incoming photon flux. The third and the fourth pumping stages are responsible for reducing the gas flux to a sufficient low level so that the pressure in the I_0M is only slightly affected. These two vacuum chambers host the movable beamstoppers (BS). Externally, around the connecting pipes, two lead shields complete the radioprotection system. Each chamber is pumped by a 500 l/s turbomolecular drag pump and is protected by a gate valve in front of it. As primary pumps, multi-stage Roots are used behind all the turbopumps.

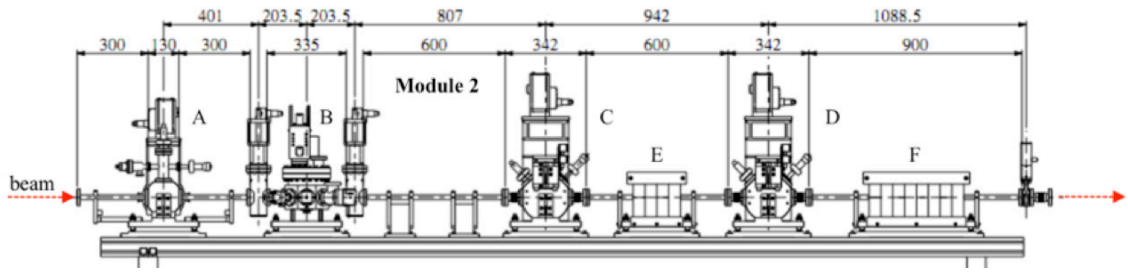

Figure 2: The 2nd module: A, interface to the ultra high vacuum chamber in module 1; B, intensity monitor; C, 1st beam stopper; D, 2nd BS; E and F, lead blocks around the connecting pipes.

III Module

The third module represents the gas cell itself. It consists of a 6 m pipe (63 mm–internal diameter); a part of it is inserted into the safety wall. Approximately in the middle of the gas cell, up to 4 different gases can be injected into the gas cell, namely N_2, Ar, Xe, Kr. A stable flux in a wide range of pressures, 1•10^{-5} to 1•10^{-1} mbar, will be obtained after implementing a feedback system acting on the gas dosing valves. Capacitive sensors and a general purpose IMG are installed in order to measure the pressure in the middle and at both sides of the long pipe. The first data indicate that, using N_2, the maximum pressure drop is less than 20% at the lowest pressures and less than 10% in the highest range of pressures, when the gas cell is pumped only through the section valves. Close to the gas injection system, a dry pumping station is connected to the gas cell by a gate valve. The valve is opened only when it is necessary to quickly evacuate this sector.

IV Module

The fourth module is built specular to the second module (in fig. 2, the beam direction is opposite) and is placed after the radioprotection wall, in the safety hutch. There are only three differences. The first one is the diameter of the connecting pipes, increased to 22 mm, which takes into account the natural divergence of the radiation beam. The calculated conductance in the intermediate flow regime is ≈2.9 l/s for the longest pipe. The second one is that the 900 mm pipe is almost completely inserted into the larger pipe of the previous module, because of missing space in the safety hutch, reducing the length of the absorbing region to about 5.3 m. The third difference is that there are not in-vacuum beamstoppers and external lead blocks: all spurious dangerous radiation generated out of the electron beam trajectory is stopped in the machine tunnel, as remarked before.

Other Vacuum Chambers

All the following vacuum chambers in the safety hutch host mirrors, Pbpm's and other diagnostics. The pressure never exceeds 5•10^{-8} mbar and often is better than 5•10^{-9} mbar, using adequate triode ion pumps.

All the vacuum sections host at least one vacuum gauge. Their controllers and the vacuum pump controllers provide analog and digital signals that are collected by a PLC (Programmable Logic Controller) that is in charge for the vacuum interlock system.

FIRST RESULTS

The differential pumping system was tested in laboratory using the fourth module because of the higher conductance of the connecting pipes. A leak valve and a full range vacuum gauge (5•10^{-9}~1000 mbar) were installed at the end of the 900 mm pipe, on a crosspiece, in order to control the pressure at the gas inlet. Full range vacuum gauges were also used in the other vacuum chambers. A further leak valve was installed in the intensity monitor. Only N_2 was used in the system. In order to check the performances under different fluxes, three tests were planned.

The first idea was to verify how much the variable valve affects the vacuum in the intensity monitor chamber when it is moved from the close to the open position, injecting a fixed gas flux by means of a leak valve mounted directly on the I_0M. The figure 3 indicates that one order of magnitude in pressure can be finely regulated by the butterfly valve. Since the target pressure in this subsection is about 1•10^{-5} mbar, we kept the valve angle at 40°, using the "flux 2" condition (fig. 3), in order to stay in the middle of the working pressure range during the further two tests.

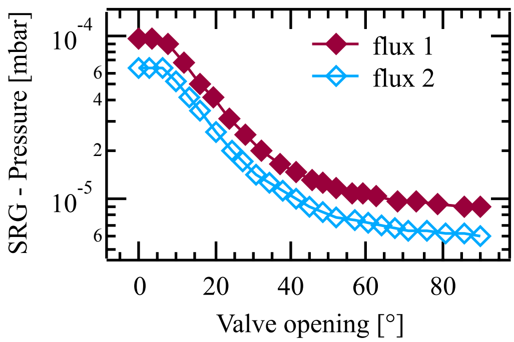

Figure 3: Pressure variation in the I_0M when a gas flux is injected and the butterfly valve angle is changed.

The second idea was to check the maximum efficiency of the pumping system, without any gas flux injected directly in the I_0M. The maximum working pressure foreseen in the gas cell is 0.15 mbar. At this level, the pressure in the 4th pumping stage is ~$1{\bullet}10^{-8}$ mbar. In this case, the pressure ratio between the gas inlet and the 4th pumping stage is better than 10^7 (fig. 4). During the test a maximum pressure of 0.25 mbar was reached at the gas inlet and kept up for 24h. The first pumping stage reached $2.7{\bullet}10^{-3}$ mbar without any problem of overheating or breaking. At low pressures, the measurements in the 2nd and 4th pumping stage were limited by the pressure gauge.

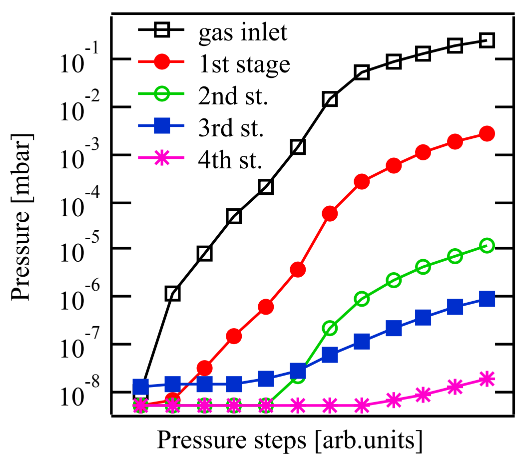

Figure 4. Effect of a pressure variation at the gas inlet on the differential pumping system.

In the last test, the pressure in the I_0M was fixed at $1{\bullet}10^{-5}$ mbar (measured by the SRG) and the pressure at the gas inlet was changed over the region of interest (fig. 5). The readings from the spinning rotor gauge and the full range pressure gauge differ by about 20%, probably due to a calibration error of the last one but within the error bar (± 30%). The pressure ratio between the gas inlet and the 4th pumping stage is better than 10^6 at the maximum working pressure. In this case the I_0M pressure rises less than 8%. In the 4th pumping stage, the pressure increases up to ~$1{\bullet}10^{-7}$ mbar due to the flux coming from the I_0M and less than 8% due to the flux at the gas coming from the gas inlet. Since the last 300 mm long pipe connecting the UHV side has a conductance of ~4 l/s in the molecular regime, it is possible to obtain easily a pressure less than $1{\bullet}10^{-8}$ mbar in the following vacuum chamber equipped with an adequate sputter ion pump.

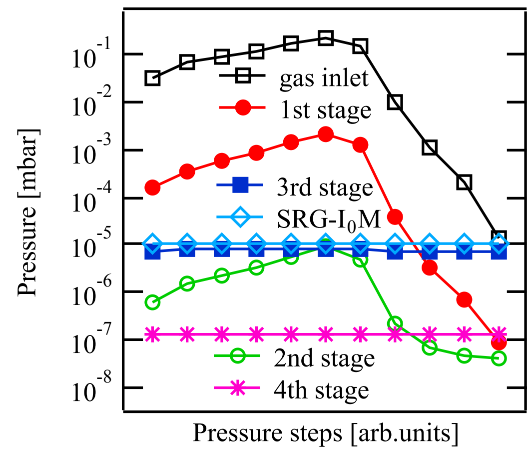

Figure 5: Effect of a pressure variation at the gas inlet on the differential pumping system when the I_0M is kept up to the nominal pressure.

CONCLUSIONS

FEL 1 and its respective front end were completed in 2010; FEL 2 and the gas distribution system are under construction. The final prototype of the differential pumping system has been tested. The first results fulfill the requirements and no effects of the high pressure gas cell is expected to both UHV sides. New measurements of the gas attenuator performances are foreseen in real conditions in order to obtain a better evaluation of the radiation attenuation capabilities when the machine will operate at its maximum power.

ACKNOWLEDGEMENTS

The PADReS team wants to thank K. Casarin for the useful information and support about the radioprotection issues and the Vacuum Laboratory for hosting the differential pumping prototype during these first tests.

This work was supported in part by the Italian Ministry of University and Research under grants FIRB-RBAP045JF2 and FIRB-RBAP06AWK3.

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