HIGH PRESSURE RINSING SYSTEM STUDIES*

D. Sertore, M. Fusetti, P. Michelato, C. Pagani, INFN Milano-LASA, I-20090 Segrate (MI), Italy
T. Higo, J. Hong, K. Saito, KEK, Tsukuba, Japan,
G. Ciovati, T. Rothgeb, JLAB, Newport News, VA 23606, USA
A. Matheisen, N. Krupka, DESY, Hamburg, Germany.

Abstract

High pressure rinsing (HPR) is a key process for the surface preparation of high field superconducting cavities. HPR water jets used in different laboratories have been characterized measuring the transferred momentum between the water jet and a target connected to a load cell. The information taken during these measurements, combined with HPR process parameters, allow calculating new significant measurable variables such as the jet power, the deposited energy on the cavity surfaces and the pressure.

INTRODUCTION

The achievement of high accelerating fields in superconducting RF cavities is the combination of different processes for the cavity preparation. Among these, HPR is used to remove chemical residuals and particles from the resonator walls [1, 2]. This process is widely used during different steps of the cavity preparation and its understanding has many practical outcomes. For a massive cavity production of future SCRF projects like the European XFEL and the proposed International Linear Collider (ILC) an optimization of the HPR parameters is enviable in view of a reduction of costs and decrease of the cavity performance spread. Each of these outcomes strongly depends on the characterization and understanding of the present high pressure rinsing cleaning systems.

In this paper we present the experimental set-up we have developed and used in the three different labs (DESY, JLAB, KEK) in operative condition of the HPR systems. The data acquired with the present system allows extrapolating some interesting parameters related to the HPR water jet. The results of the characterization of the HPR systems are summarized for each of the labs. Although a validated model for the HPR cleaning mechanism is still missing, we compare the system based on quantities that are extrapolated from the data available after each system characterization.

EXPERIMENTAL SETUP

Each HPR system is characterized by measuring the properties of the water jet at different distances and angles, in order to reproduce the effect of the jet itself on a 1.3 GHz cavity wall. The distances resemble the iris, middle wall and equator measures of the SCRF cavity. We measure the force exerted by the water jet on a load cell, properly modified to withstand the wet environment of the HPR system [3]. The load cell is a TEDEA HUNTLEIGH mod. 505H-2M-2 and has 2 kg dynamic range and 1 g resolution. On top of the load cell, targets with different shapes are mounted to simulate the effect of the water jet on the angled wall typical of SCRF resonators.

The measuring device is portable and it is easily installable in an HPR system. It has its own acquisition system based on a LabVIEW program. These units can be used to characterize HPR systems but also to routinely check the status of the nozzles and of the overall HPR performances within a Quality Control loop.

Figure 1 shows a typical installation of the load cell system at DESY during summer 2007. Since the nozzles are installed on the head at 60° inclined with respect to the axis, the load cell with the target are also mounted at the same angle to have the jet incident normal to the target itself for simplifying the data analysis.

Figure 1. DESY setup for HPR water jet characterization with load-cell. The nozzle is 60° inclined with respect to the axis. For these measurements, the load cell (blue box on the left corner) has been installed parallel to the nozzle exit.

The device has been used to characterize the following HPR systems:

- DESY: system for the treatment of cavities used in TTF and now in FLASH;
- JLAB Production: system for the treatment of cavities for JLAB and SNS;
- JLAB R&D: R&D laboratory for SCRF cavities characterization;
- KEK Tsukuba: R&D laboratory for SCRF cavities characterization;
- KEK Nomura Plating: system for treatment of cavity used at KEK.

#daniele.sertore@mi.infn.it

Table 1 summarizes the HPR system parameters during the tests presented in this paper.

Table 1: HPR parameters of the different systems characterized in this study. Sapphire and Stainless Steel (SS) nozzles produce round jet. Fan jet are produced using specific Spraying System Co. Stainless Steel FAN (SSC-FAN) nozzles.

Lab.	**# nozzles**	**Tested nozzles**	**Flow [l/min]** (1 nozzle)	**Pump Press [bar]**
JLAB Prod	2	SSC-FAN: 1502 4002 40015	5@85 bar	85
JLAB R&D	2 9	SSC-FAN 1502 Φ=0.4 mm Sapphire	5@85 bar ---	85
KEK Tsukuba	8	Φ=0.6 mm SS	1.5@70 bar	70-50
KEK Nomura	8	Φ=0.6 mm SS Φ=0.6 mm SS	1.1@50 bar 0.9@40 bar	50-40
DESY	8	Φ=0.6 mm Sapphire	1.6@100 bar	90-110

JET PARAMETERS

Force

The force exerted on a target mounted on the load cell and perpendicular to the jet is the first check of the consistency of the parameters presented in Table 1 with the water jet produced.

The theoretical force that a water jet exerts on a perpendicular surface might be calculated referring to Bernoulli law and momentum conservation [4]. For a water jet exiting a nozzle at pressure p, Bernoulli states that the velocity u is

$$u = \sqrt{\frac{2 \cdot p}{\rho}}$$

where ρ is the water density. If we now take into account the momentum conservation, the force on the target normal to the jet is

$$F = \rho \cdot Q \cdot u$$

where Q is the water flow from the nozzle. This theoretical value has to be corrected for the losses in the nozzle and the measured force is usually 10-20 % lower than expected. Table 2 reports the expected and measured forces for water jets. The good agreement between the theoretical and experimental values is observed both for round and fan jets.

For the SSC-FAN nozzles the jet is a fan type and the exit is nearly elliptical but this simple analysis allows to have a good estimation of the expected force.

Table 2. Theoretical and measured water jet forces exerted on normal targets.

System	Theor. Force [N]	Meas. Force [N]
DESY	3.6	3.2
JLAB Prod SSC-FAN 1502	10.8	9.5
KEK Tsukuba	2.9	2.5
KEK Nomura	1.8 (@ 50 bar)	1.6
	1.3 (@ 40 bar)	1.2

Profile

Another easy measure of the water jet is the force distribution in the jet. This measurement is done moving the water jet on the target and measuring the corresponding force exerted on the load cell. The result is the integral of the force along the direction of motion.

A typical example of a measurement of this kind done at DESY is reported in Figure 2. Due to the inclined target, the distance between target and nozzle changes while the jet is moving. The jet is narrower on one edge then on the other and this effect is visible in the asymmetry of the acquired profile.

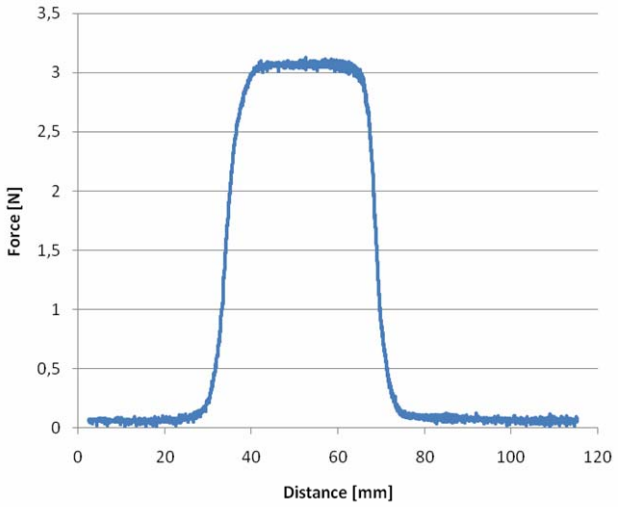

Figure 2. Typical water jet profile measured at DESY at mean distance of 54 mm between nozzle and target. At the leading edge the distance is 63 mm and at the falling edge is 45 mm.

Water jet force sigma

From the profile measurements, with simple assumptions on its shape, it is possible to calculate the sigma of the force distribution.

The main assumption is that the jet is fully integrated in one direction and the target edge is indeed integrating only the orthogonal direction.

In the case of round jet, the simplest assumption is that the profile has a Gaussian dependence. In this case the integrated profile follows

$$F(z) = \frac{F_0}{2}\left[1 + Erf\left(\frac{z - z_0}{\sqrt{2}\sigma}\right)\right]$$

where F_0 is the total force exerted by the jet and σ is its sigma. Figure 3 shows a typical example of fitting the profile to the experimental data in the case of a Gaussian profile.

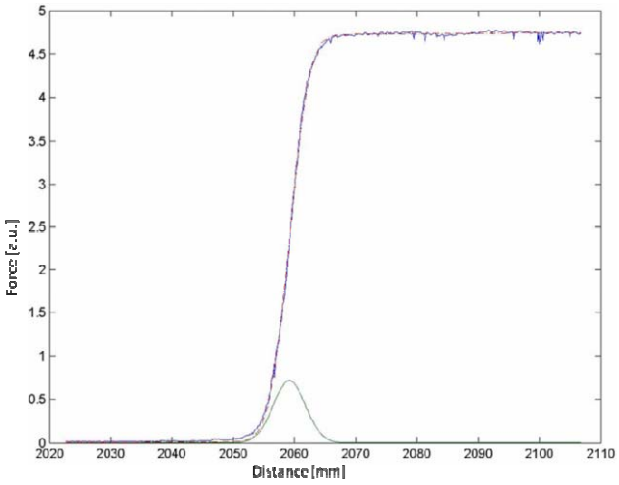

Figure 3. Typical interpolation for evaluating the sigma of the round jet incidents on the target. We have assumed a Gaussian function for the profile (green line)

For the SSC-FAN jets, we approximate the profile with a Gaussian function in one direction and a constant function with Gaussian tails in the other direction. The integrate profile has not a simple analytical expression and has been fitted on the experimental data minimizing the Chi Square. The result of such a fitting procedure is shown in Figure 4.

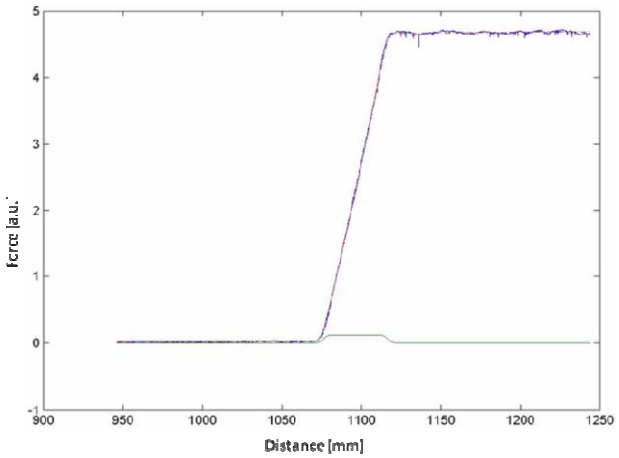

Figure 4. Typical interpolation for evaluating the sigma of the fan jet incidents on the target. A Gaussian and a flat top (plateau) with Gaussian tails are used for the interpolation (green line).

Sigma at different distances

The possibility of measuring profiles at different distances from the nozzle allows us to quantify the evolution of the jet while moving toward the cavity wall.

This measurement is important for assessing the water jet parameters on the different point of impact on the cavity wall. This measure allows detecting nozzle deterioration during operation as we have done at KEK and it is reported in the section below dedicated to the measurements done in the different labs.

HPR WATER SYSTEMS

DESY

The DESY HPR system is routinely used for processing the SCRF cavities operating at TTF (Tesla Test Facility), now FLASH. The system consists of 90-110 bar pump, a cleaning head with jet at +/- 60 ° with respect to the SCRF cavity axis. For the installed 8 nozzles, the flow rate is about 12.4 $l \cdot min^{-1}$. The HPR cabinet is accessible from a 100 and 10000 clean room.

We had performed profiles and sigma measurements at different distances between nozzle and target during a measurement campaign in August 2007. The data presented here is the result of a preliminary analysis still ongoing.

The target is normal to the jet and both are angled 60° with respect to the axis of the system. With this configuration, the distance of the nozzle on the upper and lower edge of the target is different (see Figure 1). Figure 5 reports the sigma enlargement with distance from the nozzle. The two series of data correspond to the jet moving up or down. The data scattering is due to changes in the water pressure during the measurement ranging from 91 bar to 108 bar.

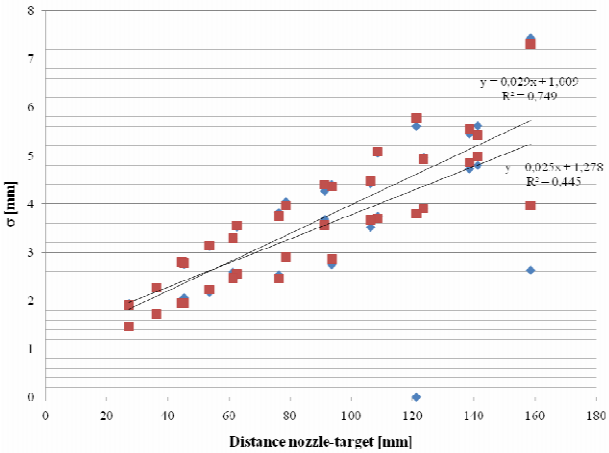

Figure 5. Evolution of the jet sigma versus distance nozzle-target. The intercept of the linear fit shows an unexpected large sigma values at zero distance.

In Figure 5 an unexpected large sigma at zero distance from the nozzle results and this effect is under investigation.

JLAB

Two different HPR systems have been investigated at JLAB, the production system and the R&D system. Both of them use a water pressure of 85 bar with a flow rate of 5 l·min^{-1}. They differ in the type of nozzles used for cavity processing. During our measurement campaign, we have tested 3 different nozzles on the HPR dedicated to cavity production, namely: SSC 1502, 4002 and 40015. The 1502 has a fan angle of 15°, while nozzles of the series 4 have 40° fan angle but diverse throughput. The 4002 nozzle has the same throughput of the 1502. In the R&D system, we have tested the SSC 1502 and also Sapphire nozzle with 0.4 mm diameter. From a comparison of the two nozzles, we have estimated that the fan jets have a flow rate about five time larger than the round jets.

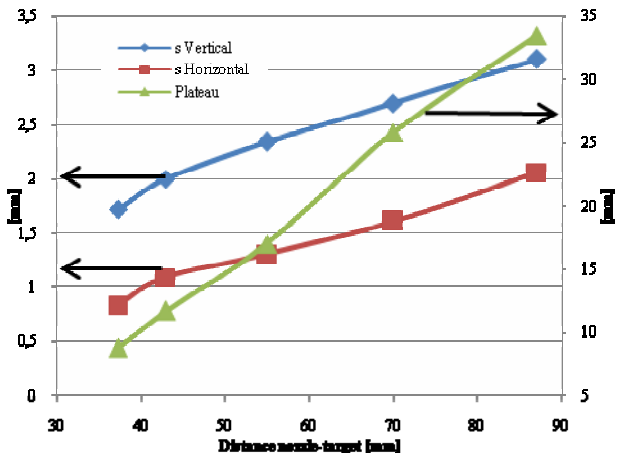

Figure 6. Evolution of horizontal and vertical sigma and vertical plateau length for a fan jet type of series 40015. The sigma are reported on the vertical left axis while the plateau is reported on the right axis.

Since JLAB is, at this time, the only laboratory using fan jets, we have reported in Figure 6 the evolution of the sigma of the jet in the two orthogonal directions, for the SSC-FAN 40015 jet.

The horizontal part has been interpolated with a Gaussian function characterized by σ Horizontal whose evolution is near to be linear. The vertical component is instead characterized by a plateau and a sigma (σ Vertical) that determines the edges. The plateau increases linearly with distance as well as the corresponding sigma.

KEK

The cavity processing at KEK is performed both at Nomura Plating and at KEK, Tsukuba. The peculiarity of the KEK systems is the use of SS nozzles, with drilled holes. These nozzles suffer from wear due to their use. We observed their deterioration as enlargement of the jet (larger sigma) [5]. The nozzles deterioration has been confirmed also by SEM (Secondary Electron Microscope) images where damages of the round hole have been clearly observed [6, 7].

JET PERFORMANCES

The main purpose of the HPR treatment on the SCRF cavities is the removal of chemical residuals from previous preparation and of dust particles on the wall surfaces to reduce field emission. While the effect on chemical residuals is mainly a dilution of the compounds and their removal, the effect on dust particles is still not fully understood.

A model was presented in the '60s [2] and was based on the effect of the water shear stress on particles adhered on the cavity walls. Based on this model, the particles, bounded on the wall surface by chemical and physical forces (e. g. Van der Walls forces), are dislodged either by sliding, rolling effects or a combination of both. The rolling mechanism is the more favorable in detaching the particles from the surfaces through the shear flow while sliding mainly moves the particle around on the wall surface. Considering the rolling mechanism as responsible for the particle detachment, a critical shear stress is introduced for taking into account surface roughness and adhesion force.

The outcome of this model is that the key parameters for particle removal are the flow rate, the pressure and the dimension of the nozzle. The flow rate influence the shear stress and hence the size of the particle to be removed

Table 3. Basic water jet parameters comparison.

Laboratory	Distance from axis [mm]	Force [N]	Velocity at nozzle exit [m·s^{-1}]	Power [W]	σ [mm]	Peak Pressure [N·mm^{-2}]
DESY	35	3.2	120	186	1.73	0.169
	103.3				3.71	0.037
JLAB Production SSC-FAN 1502	35	9.4	112.8	530	1.734 (σ_x) 0.826(σ_y)/7.515 (plateau)	0.226
	103.3				3.578 (σ_x) 2.937 (σ_y)/41.87 (plateau)	0.021
JLAB R&D	35	1.3	-	-	1.75	0.068
	103.3				4.42	0.011
KEK Tsukuba	35	2.5	100.0	125	0.49	1.657
	103.3				0.899	0.492
KEK Nomura (50 bar-used)	35	1.6	87.3	70	1.32	0.146
	103.3				3.50	0.021

Pressure and nozzle dimension instead mainly influence the region of effective cleaning.

To our knowledge there are no experimental data that might confirm the validity of such a model on the cleaning efficiency of HPR for SCRF cavity treatment as well as other model that can be applied to select proper parameters for qualify the water jet used in the HPR process.

For these reasons, we present some basic parameters of the water jet that can be calculated from the measurements done in the different labs and that can be used to compare the different systems. The parameters easily available are jet force, velocity, power, sigma and peak pressure. These parameters are evaluated at iris (35 mm) and equator (103.3 mm) distances of a 1.3 GHz cavity and reported in Table 3

While the round jets have forces around few Newton, the fan jet have force value larger by at least a factor 3. The velocities at the nozzle exit, based on the measured forces and flow rate from specifications, are all in the 100 $m \cdot s^{-1}$ region. Since the flow rate of the fan jet is larger than for the round jets and the velocity are nearly the same, the power in the fan jet is exceeding by a factor of three the power of round jets. Of course in the interaction with the cavity wall, the area covered by the jet is of primary importance. The area is evaluated by considering one sigma distance. The sigma reported in Table 3 for round jets show large variation. The smaller water jet are produced at KEK while JLAB and DESY have larger but comparable values. It is worthwhile to remember that the nozzle diameter at JLAB is 0.4 mm while at KEK and at DESY is as large as 0.6 mm meaning a much less divergent jet in the KEK case. However, the Stainless Steel nozzles of KEK deteriorates during operation and the value measured at KEK Nomura, corresponding to used nozzles, are similar to JLAB and DESY measurements.

If we now consider the force of the jet and the corresponding area at the distance of the wall we calculate the peak pressure. At the iris distance, the highest pressure is produced at KEK while the lowest is measured in the R&D system at JLAB with round jets. The KEK jet has also the highest pressure at the equator distance. Again JLAB R&D with round jet has the lowest peak pressure value at equator. If we now consider the used nozzle of KEK as reference instead of the new one, we see that the fan jet have the highest value at the iris while the DESY round jet have the largest peak pressure at the equator.

If we now consider the properties of the HPR systems analyzed up to now, we would like to have a system able to clean a large area with high efficiency. If we identify in the flow rate (as suggested in the model presented before) or the peak pressure as efficiency indicator, the measurements suggest that, apart KEK new nozzle, the JLAB fan jets are the most efficient in the iris region having large interested area and large peak pressure. At the equator, the JLAB fan jet have still the largest cover area but the peak pressure is not the highest, being represented by the round jet at DESY.

CONCLUSIONS

The need to identify the main parameters that characterize the high pressure rinsing process is pushing the study and the understanding of the cleaning process.

We have started to study the performances of the different system where the HPR is routinely used. Our main interest has been in qualifying the water jets measuring their main properties. We have involved three international laboratories, namely DESY, JLAB and KEK. In these laboratories we have studied different jets operated in diverse configurations. The outcome of these measurements is summarized in this paper and particularly in Table 3.

The lack of a clear understanding of the HPR process limits, at present, a more detailed comparison of the systems and of their cleaning efficiencies. It is then warmly welcome any advance in the understanding of this process, not only for identifying the significant parameters but also for allowing an optimization that nowadays is still not possible. In particular, this optimization will be a key point for cost saving and improving of cavity performances for the next large SC projects the European XFEL and the proposed International Linear Collider.

REFERENCES

[1] P. Kneisel and B. Lewis, Part. Accel. **53** (1996), 97.
[2] R. Gim at al., 4th Symposium on Particle on Surface, p. 379.
[3] E. Cavaliere et al., Physica C, **441** (2006), 254.
[4] R. Reitz, “Fluid Mechanics”, CRC Press LLC, 1999.
[5] D. Sertore et al., Proceedings PAC07, Albuquerque, NM, USA.
[6] T. Higo, ILC Asia 2007-01.
[7] D. Wright, J. Wolgamott, G. Zink, WJTA Conf., 2003.