DESIGN AND PERFORMANCE OF SHATTERED PELLET INJECTION SYSTEMS FOR JET AND KSTAR DISRUPTION MITIGATION RESEARCH IN SUPPORT OF ITER

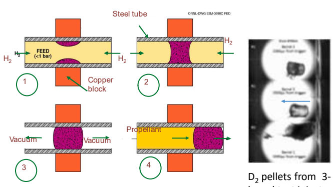
ID 854

L.R. Baylor[1], S.J. Meitner[1], T.E. Gebhart[1], J.B.O. Caughman[1], D. Shiraki[1], J.R. Wilson[2], D. Craven[2], M. Fortune[2], S. Silburn[2], A. Muir[5], A. T. Peacock[3], S.H. Park[4], K.P. Kim[4], J. H. Kim[4], K.S. Lee[4], G. Ellwood[5], S. Jachmich[5], U. Kruezi[5], M. Lehnen[5], and JET Contributors*

[1]Oak Ridge National Laboratory, Oak Ridge, TN, USA, [2]Culham Centre for Fusion Energy, Abingdon, UK , [3]JET Exploitation Unit, Culham Science Centre, Abingdon, UK
[4]National Fusion Research Institute, Daejeon 34133, Republic of Korea, [5]ITER Organization, route de Vinon sur Verdon, 13067 St Paul Lez Durance, France

Shattered Pellet Injection

Shattered pellet injectors have been fabricated and installed on JET and KSTAR to gain more physics understanding of the SPI in shutting down tokamak plasmas in support of ITER DMS design. These injectors use the pipegun formation method [1] below to make pellets that are broken free and accelerated by high pressure gas. Mechanical punches have also been utilized on JET.



D_2 pellets from 3-barrel test injector [2]

Pellet Sizes for JET and KSTAR

Table 1. Sizes of the pellets in the three barrels and number of atoms and bar-L gas equivalent of D_2 or Ne contained in a full pellet.

Device	Diameter (mm)	Len/Diam	Natoms (bar-L) D_2	Natoms (bar-L) Ne
JET	4.5	1.4	6.3E+21 (0.10)	4.5E+21 (0.14)
	8.1	1.6	4E+22 (0.71)	2.9E+22 (1.01)
	12.5	1.5	1.4E+23 (2.15)	1E+23 (3.78)
KSTAR	4.5	1.5	6.5E+21 (0.11)	4.6E+21 (0.16)
	7	1.5	2.4E+22 (0.44)	1.7E+22 (0.63)
	8.5	1.5	4.4E+22 (0.81)	3.1E+22 (1.15)

*KSTAR 8.5 mm changed to 7 mm in 2020.

ITER SPI pellet sizes are currently anticipated to be 28 mm with L/D of 2 providing 2×10^{24} atoms (43 bar-L) of D_2.

SPI Design Features

These SPIs all utilize a 3-barrel design to provide different pellet sizes for flexibility. The barrels combine with a collector funnel into a common injection line. The funnel was designed to allow 2-degree impacts with less than 20 m/s normal impact velocity [2].

Temperature is controlled with heaters that are feedback controlled by a PID loop in the PLC.

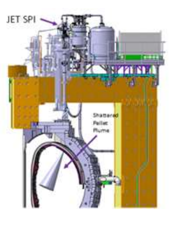
JET SPI showing the three barrels connected to the cold helium gas cooled copper coldhead. Bellows are used for all metal seal on barrels exit from guard vacuum. Automation implemented to form pellets reliably.

KSTAR SPI internals showing the three barrels connected to the cryocooler cooled copper coldhead. Temperature oscillates +/- 0.5 K from cryocooler.

Microwave cavity design used in both SPI systems. Perforated plates allow for good flow and vacuum pumping of the gas trapped in the cavity gap.

JET SPI Installation and Operation

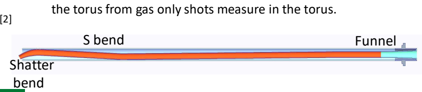
JET SPI is mounted vertically from the top of Octant 1 [3.4].



(Left) CAD model of SPI installation showing injection cone into the vessel.

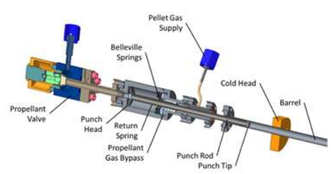
(Top) Picture of SPI installation on top of JET.

CCFE designed and installed the cryogenic and vacuum systems [3.4]. The injection line has 3 gaps of 5 cm (1st) and 10 cm and a large 1000 L ballast tank connected to the first two gaps. Less that 0.4% of D_2 propellant gas fired reaches the torus from gas only shots measure in the torus.



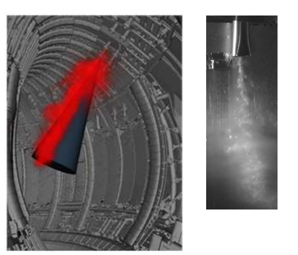
The shatter tube had to fit in a vertical port with a 40 mm diameter opening and 1 m length. In order to fit a 20° final bend an S bend was implemented after testing. Results from testing show 1.6 ms duration anticipated for 700 m/s pellets.[5]

The end of the shatter tube is ~40 cm from the top of the plasma where the fragments enter.

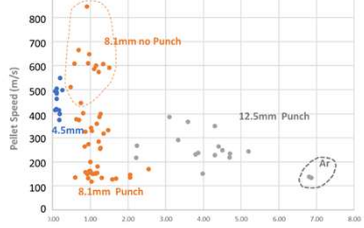


JET SPI uses a gas operated mechanical punch [1] to release solid argon pellets. It was used to produce slower D_2-Ne mixture pellets but leads to some breakage.

Pellet Shattering and Dispersion



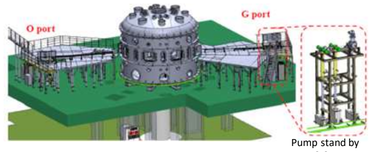
Fragment plume is slightly inside of expected 15° cone from lab testing. Duration of plume in some cases longer than the 1.6ms expected, possible breakage in S bend of shatter tube.



JET SPI pellet speeds as a function of the microwave cavity mass signal for the different size pellets. Pellets contain various amounts of neon leading to scatter in the mass.

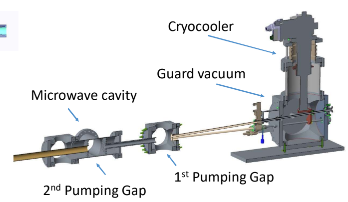
KSTAR SPI Installation and Operation

Two identical SPIs are installed on KSTAR 180 degrees apart as described by S.H. Park [6]. Vacuum system provided by NFRI with 28L of ballast volumes connected to two gaps of 10 cm are under the SPI and injection line platform. Less than 0.5% of propellant gas measured to enter the torus without a pellet.



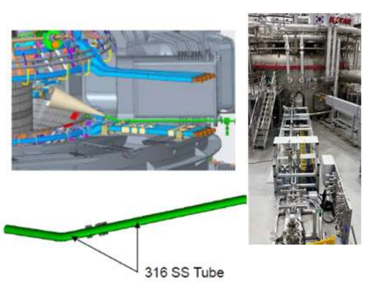
Pump stand by NFRI [3]

The KSTAR SPI is cooled with a cryocooler that reaches ~8 K temperature on the coldhead. Cooldown takes ~1.5 hours. Pellets are fired at 11 K using heaters on the coldhead to control the temperature.



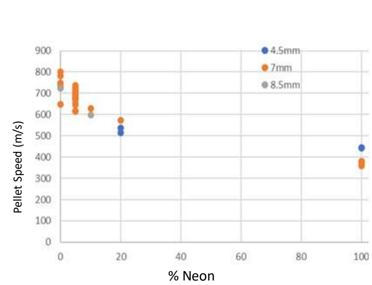
Pellet Shattering and Dispersion

The shatter tubes enter under diagnostics/heating systems in midplane ports and aim to the plasma center. A 20-degree bent tube of 32mm ID is used to shatter pellets, identical what is used on DIII-D. [2]. Pellets jump across a gate valve at the entrance to the shatter tube that has no pumping.



20° shatter tube 32mm diameter

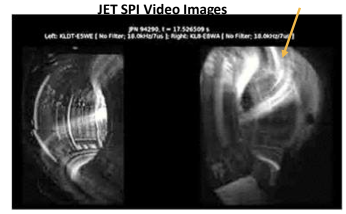
Plasma is ~50cm from end of shatter tube, extends plume duration from 0.4 to under 1ms. Fast video images show less than 1ms plume duration in the plasma for 700 m/s 5% neon pellets.



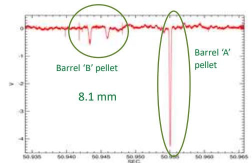
KSTAR SPI pellet speeds as a function of the percent of neon in the pellet. Heavier neon pellet are slower as expected. Statistics of 7 mm pellets in 2020 campaign show 93% successful good pellet in 120 attempts.

SPI Research Results

JET SPI Video Images

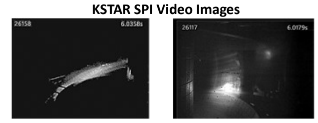


JET Video system shows significant helical structure in the radiation when the SPI fragments are assimilated into the plasma. These unique images are crucial in understanding the assimilation and radiation asymmetry [7]

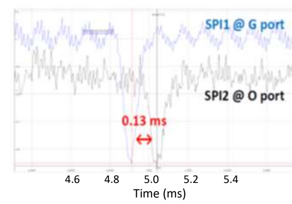


JET two SPI pulse with 15ms delay showing microwave cavity signals. Broken 2nd pellet is easily detectable.

KSTAR SPI Video Images



Examples of Gport and Oport fast camera views of the SPI fragment interaction with the plasma. Duration of plume fragments < 1 ms, consistent with lab fragment analysis. [5]



The unique KSTAR dual SPI configuration has been used to study synchronization effects on the assimilation and radiation. Synchronization from the two SPIs as close as 0.13 ms at the microwave cavity has been achieved. [6,8]

References

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Acknowledgments

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*See the author list of 'Overview of JET results for optimising ITER operation' by J. Mailloux et al to be published in Nuclear Fusion Special issue: Overview and Summary Papers from the 28th Fusion Energy Conference (Nice, France, 10-15 May 2021)