# Direct current measurements of the SPIDER beam: a comparison to existing beam diagnostics


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## Abstract

For negative ion beam sources there are several methods of measuring the accelerated beam current, namely electrical measurements at the power supply and calorimetric measurements. On SPIDER, the ITER Heating Neutral Beam full-scale beam source, electrical measurements at the acceleration grid power supply (AGPS) are complemented by polarizing the diagnostic calorimeter STRIKE to provide an additional electrical measurement of the accelerated current. This is in addition to the calorimetric measurements provided by STRIKE. These diagnostics give differing measurements of the beam current. Exploiting the reduced number of open apertures on SPIDER a new beam diagnostic has been installed to measure the individual beamlet currents directly. The so called Beamlet Current Monitor (BCM) has been used to measure the current of five beamlets during the most recent SPIDER campaign.

This work compares the BCM current to the electrical measurements at the Acceleration Grid Power Supply (AGPS) and STRIKE calorimeter. The average BCM current agrees well with the STRIKE measurements, indicating that the AGPS overestimates the beam current. The individual beamlets are compared to the STRIKE calorimetric measurements, showing similar current trends with the source parameters.


## SPIDER beam measurements

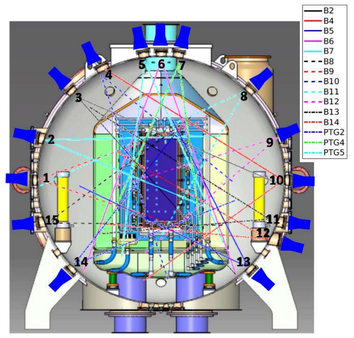
**Several SPIDER diagnostics measure the beam current (with PG mask 28 apertures).**

Power supply drain currents (**total beam**) → **ISEG**, **AGPS**

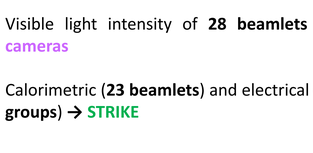
Magnetic measurement of **5 beamlets** → **BCM**

Visible light intensity of **28 beamlets** → **Visible cameras**

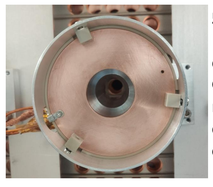
Calorimetric (**23 beamlets**) and electrical (**8 beamlet groups**) → **STRIKE**




**Visible camera LOS.** Beamlet intensity determined through tomographic reconstruction. [1]




**16 STRIKE tiles.** Positively **b**iased to collect negative charges. IR calorimetry performed from the back of the tiles. [3]

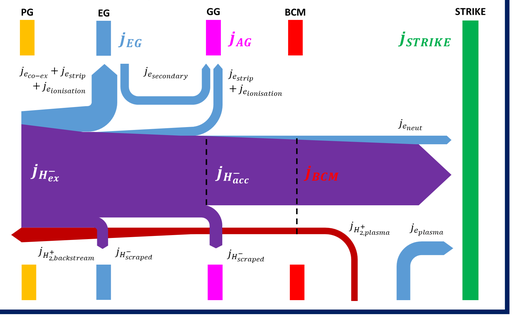


**5 BCM sensors.** Mounted downstream of GG, measure magnetic flux due to beamlet current. [2]

Electrical measurements of beam current complicated by:

- **co-extracted electrons**,
- volume contributions → **stripping** + **ionisation**
- surface contributions → **beam scraping** + **secondary electrons**,
- Vessel contributions → **beam generated plasma**.

**How to define beam current with available diagnostics?**

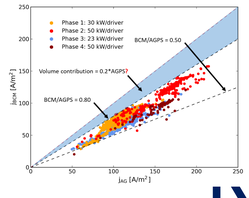


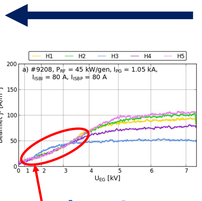

## Current comparison

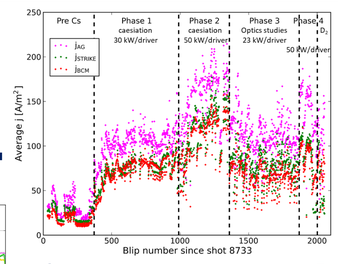
**BCM/STRIKE vs AGPS**

$$j_{AG} = j_{H^-_{acc}} + j_{e_{secondary}} + j_{e_{strip,GG}} + j_{e_{ionisation}} + j_{H^+_{2,backstream}}$$

$$j_{BCM} = j_{H^-_{acc}} - \gamma j_{e_{strip,vessel}} + j_{H^+_{2,plasma}}$$



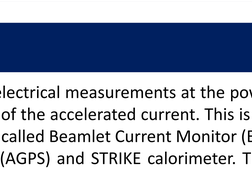




↑ perv ↓ e/H⁻ ↑ BCM/AGPS

During initial ceasiation (phase 1)


BCM/AGPS and STRIKE/AGPS improve with optics

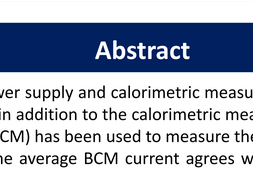



↓ $U_{EG}$ ↓ BCM/AGPS

Interception on EG


BCM/AGPS and STRIKE/AGPS worse over perveance

↑ over perv or $U_{EG}$ ↑ $I_{EG}$




**AGPS**

Measures accelerated current plus + charges born in accelerator:

- Assume 20% volume losses,
  - → stripping + ionisation,
  - → Stripping 6-7% with PG mask (E. Sartori SOFT2022),
- No clear trend with $P_{source}$ or $P_{vessel}$.


**BCM**

Measures accelerated current:

- Assume stripping losses low and backstreaming ion current lower than electron current collected by STRIKE.

**STRIKE**

Measures accelerated current plus beam driven plasma:

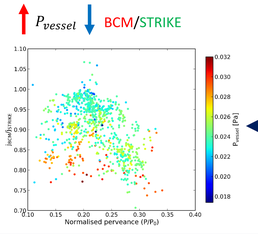
- Assume electrons from neutralisation in vessel collected.

**BCM** and **STRIKE** both measure $j_{H^-_{acc}}$ with main difference being the beam plasma.

$$j_{STRIKE} = j_{BCM} + j_{plasma}$$

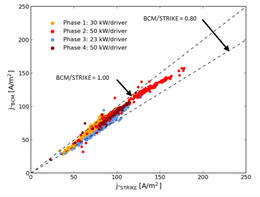
Reducing additional electrons in accelerator moves $j_{AG}$ towards $j_{BCM}$ and $j_{STRIKE}$.

↑ $P_{vessel}$ ↓ BCM/STRIKE

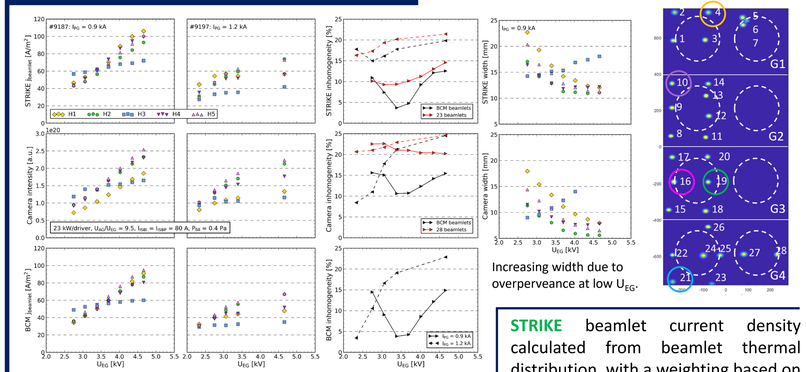



**BCM vs STRIKE**

$$j_{STRIKE} = j_{H^-_{acc}} + j_{plasma}$$




## Individual beamlets




Increasing width due to overperveance at low $U_{EG}$.

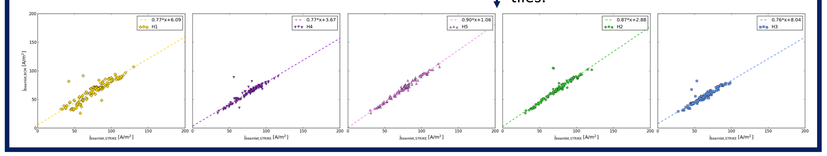
**STRIKE** beamlet current density calculated from beamlet thermal distribution, with a weighting based on the electrical measurement.

**BCM** beamlets follow the same trends with $U_{ex}$, bias (not shown – ***see contribution by M. Agostini***) and filter field for **all diagnostics**.

**BCM** and **STRIKE** beamlet currents show similar inhomogeneity. **Visible cameras** less variation due to lower top beamlet current. Inhomogeneity for all beamlets higher.

BCM/STRIKE for individual beamlets falls between 75-90%. Core beamlets (**H5** and **H2**) have higher ratio.

Emissivity varies between and within tiles.




## Summary and next steps

**BCM** and **STRIKE** measure accelerated beam current:
→ Beam generated plasma → $P_{vessel}$

$$j_{H^-_{acc}} = 0.9 * j_{STRIKE} \pm 10\%$$
near perveance match ($0.22P_0$)

**AGPS** current overestimates accelerated current:
→ over perveance (low $U_{EG}$) → scraping → secondary electrons (up to 13% $j_{AG}$**?**)
→ stripping + ionisation (20% $j_{AG}$**?**)
Quantifying losses (add additions) in accelerator and vessel requires modelling.
**Beamlet Group Current Monitors** in conceptual design phase for full aperture operation.

**BCM**, **STRIKE** and **visible cameras** show similar behaviour for individual beamlets:
→ **Increasing** the number of **BCM** sensors for next campaign would improve comparison.


[1] M. Ugoletti *et al.*, Fusion Eng. Des. **169**, 112667 (2021); https://doi.org/10.1016/j.fusengdes.2021.112667.
[2] A. Shepherd *et al.*, IEEE Trans. Plasma Sci.; https://doi.org/10.1109/TPS.2022.3176757.
[3] A. Pimazzoni *et al.*, Rev. Sci. Instrum. **91**, 033301 (2020); https://doi.org/10.1063/1.5128562.
[4] P. Agostinetti *et al.*, Nucl. Fusion **52** 063004 (2011); https://doi.org/10.1088/0029-5515/51/6/063004.



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