EUROfusion

Status of the PLS and the "Design 100" proposal

P. T. Lang for the PLS Team

IPP

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PLS Team

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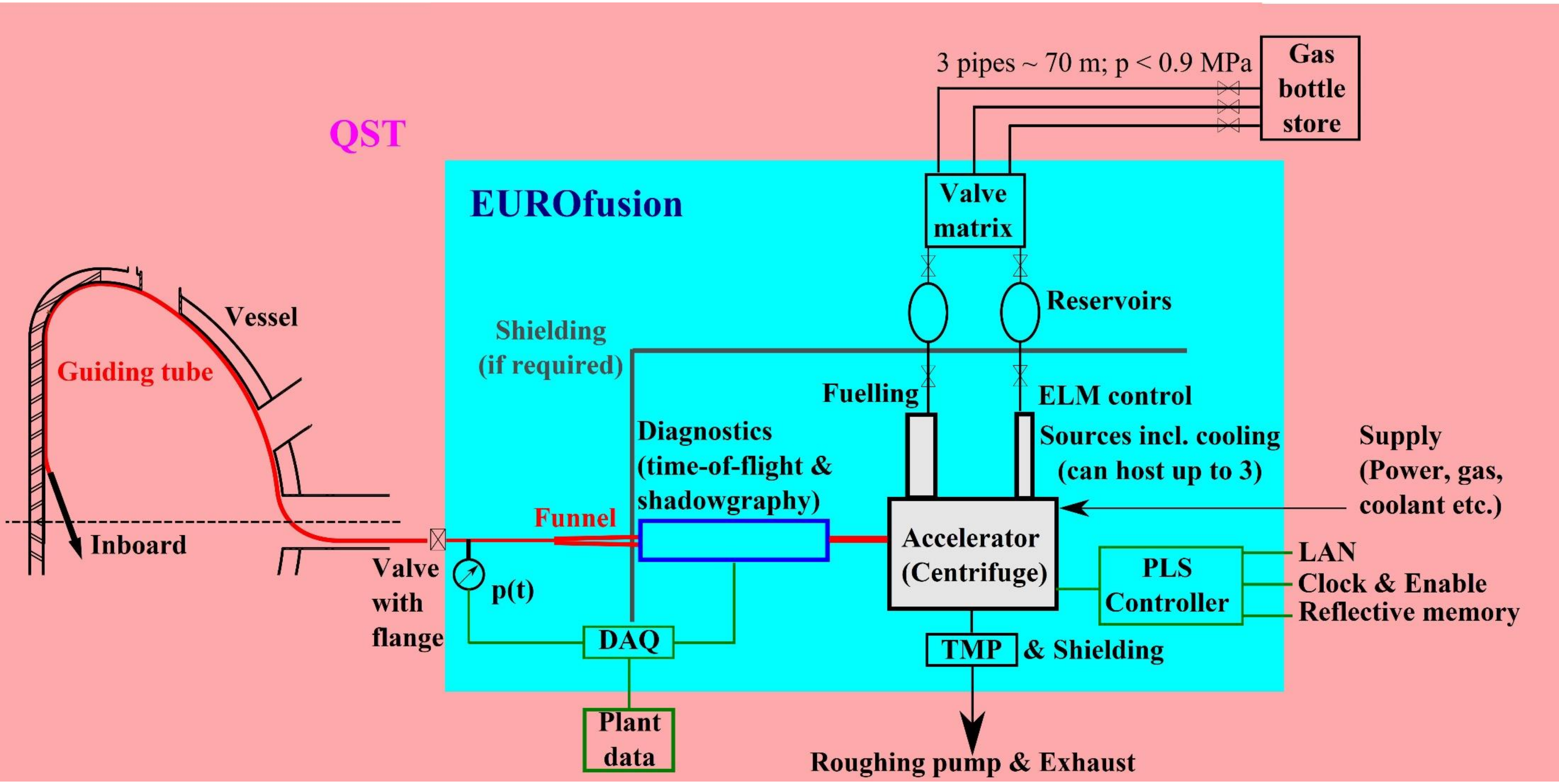
FUSION FOR ENERGY

Sam Davis

Manfred Wanner

PELLET LAUNCHING SYSTEM LAYOUT

PLS scheme with projected responsibility as shared between QST and EUROfusion



Status since first working meeting in Naka (February 2019)

Update

Achievements since 6th WPSA PPM Sevilla

● **Enhancement Project ongoing**

Contracts for both extruders negotiated

Call for tender “Centrifuge” in preparation

Preparation for diagnostics ongoing

● **Team modifications and enhancements**

Cooperation with 3rd QST pellet team established

(Satoshi Yamamoto, Shigetoshi Nakamura)

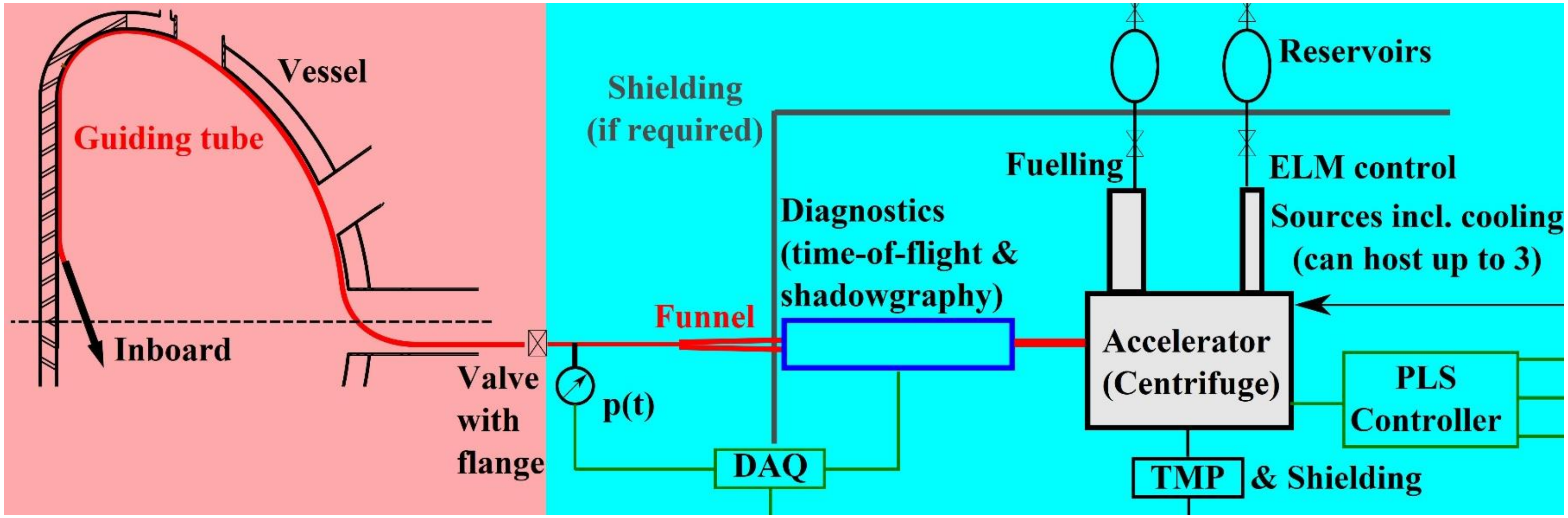
-> In-vessel guiding tube, QST –EUROfusion Interfaces

IPP pellet team reinforced by Carla Piccinni (EE Grant)

- Contribution to EPS submitted (after triple clearance)

Overview

- Guiding tube
- Extruders
- Interface Extruders-Centrifuge
- Centrifuge design
- Diagnosing during R&D phase
- The “Design 100” proposal



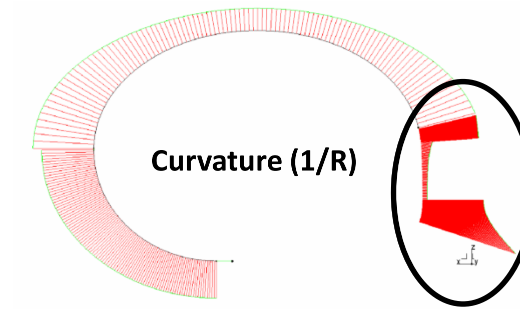
GUIDING TUBE DESIGN

AUG had to replace in-vessel guiding tube due to corrosion after steam leak damage

Old track:

Steps in curvature

Lowest R in final part



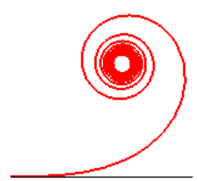
New track:

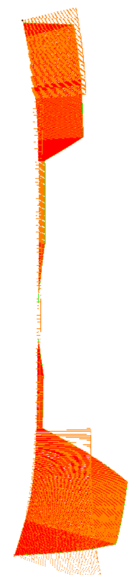
Avoid steps in curvature

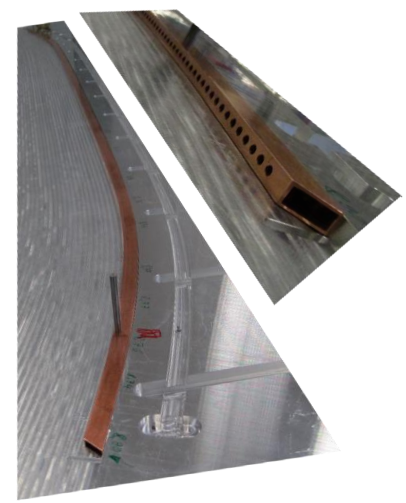
Applying clothoid shape

(Cornu spiral: L ~ 1/R)

Improved maintainability







Revised system commissioned and showed sound behaviour

GUIDING TUBE DESIGN

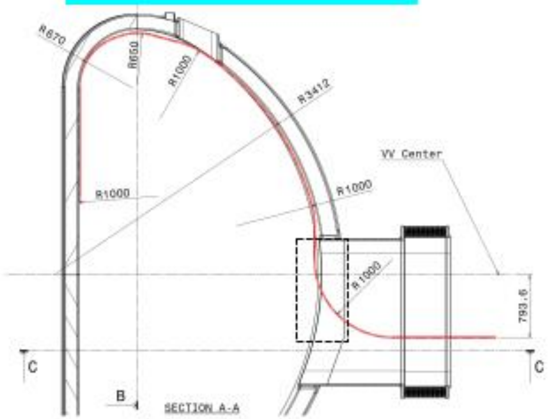
Replacement of in-vessel guiding tube on AUG

QST team visited and watched…

… and decided to follow the AUG approach

GUIDING TUBE DESIGN (Yamamoto, TCM34)

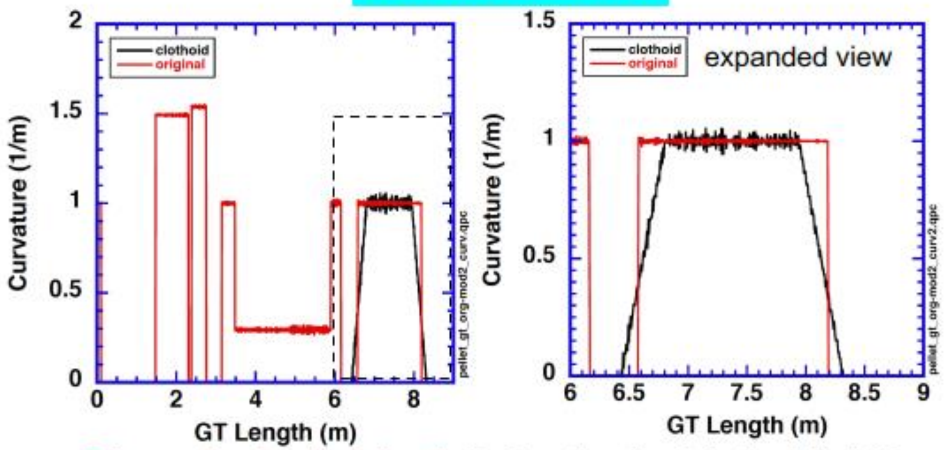
Current routing



- ✓ Optimization of guiding tube (GT) is ongoing.
  - ➢ Find better routing of GT
  - ➢ Apply clothoid curve to have gentle change of curvature
  - ➢ Pellet speed depends upon effective radius R_{eff}
    - ➡ R_{eff} ~ 343 (m) [current route]
    - ➡ critical trans. v_c ~ 435 (m/s)

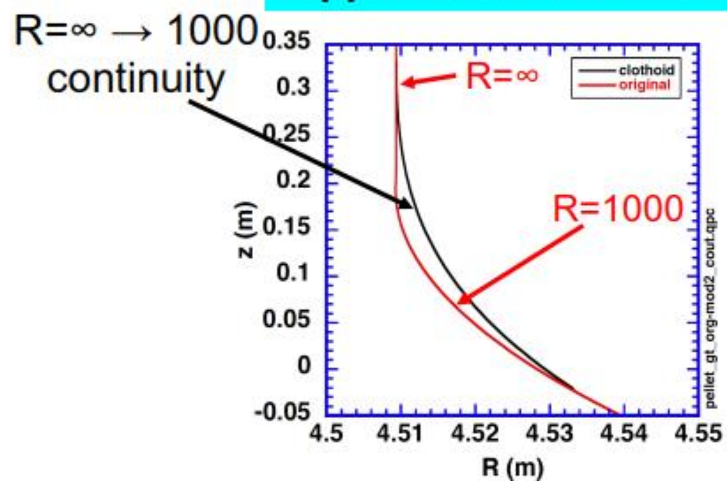
Interchange

Curvature 1/R



Discontinuity (original) & Continuity (clothoid) 1/R

Application of clothoid



Optimisation still under way – Tests envisaged to determine v_c

EXTRUSION SYSTEMS (FUELLING & PACING)

Procurement contracts in preparation

Fuelling extruder:

D = L = 2.4 mm (10.8 x 10^{20} e) at 20 Hz ➔ 2.2 x 10^{22} /s flux

Throughput 350 mm^3/s but priority sound pellets at 20 Hz

Operation with D, H, HD mixture, doping (e.g. N, Ne) up to 2%

Pacing extruder:

D = L = 1.2 mm at 50 Hz

Throughput 100 mm^3/s but priority sound pellets at 50 Hz

Operation with D, H, HD mixture

Size flexibility (D/L optional 1.2, 1.5, 2.4 mm)

➔ 9 possible pellet sizes possible (only 5 useful)

INTERFACE EXTRUDERS-CENTRIFUGE

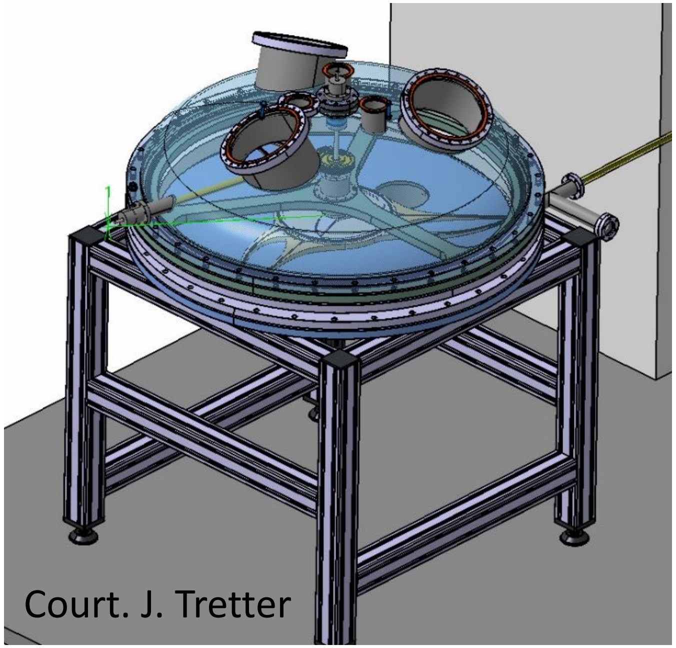
The feed-in from the extruders to the stop cylinder is considered as the technical key issue of the PLS

Feed-in from up to three sources

Steady state extrusion requires “high” ice temperature

➔ High repulsion force from ablating gas

IPP- engineer dedicated to this task



DESIGN CENTRIFUGE

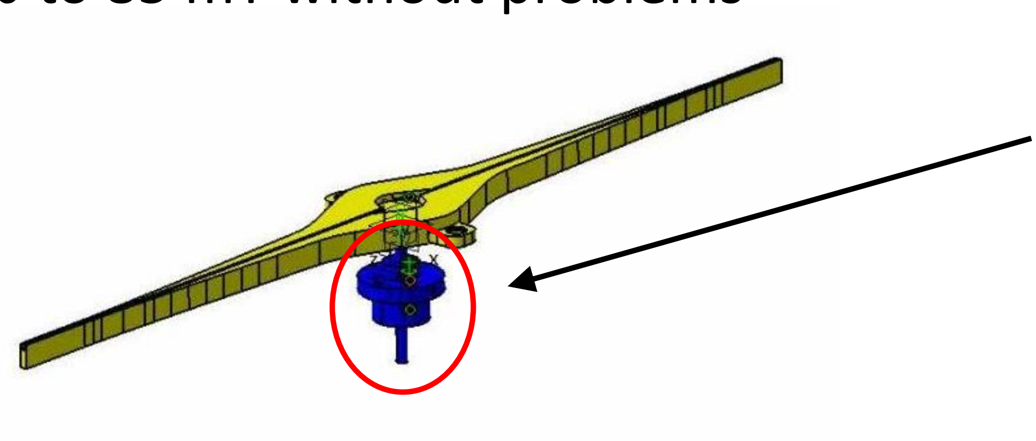
Call for tender in preparation

Centrifuge design, in particular stop cylinder design, must be compatible with extruder design

Layout, in particular launch speed, must be compatible with guiding tube design (v_C)

Modernized approach with magnetic fluid sealed rotary feedthrough:

Tests up to 85 mT without problems



DIAGNOSING DURING R&D PHASE

Several tasks assigned to diagnostics & ….:
- Monitoring ice extrusion/pellet production
- Monitoring pellet behavior in stop cylinder
- Measure pellet speed and mass/size at PLS exit (later @ torus valve)

For first extruder tests:
Analysis of ice quality and extrusion speed

Suggestion: take solution chosen for IPP-ORNL project
Project aim: investigate > 10 s extrusion for
H, D, D with up to 2% Ne ice, D = 1.9 or 2.4 mm
Straight or 90^o bend extrusion geometry
Double extrusion die
Video observation, analysis by "Optical flow" tool

DIAGNOSTICS

Video:

- Original overview
- Zimmermann part full speed
- Zimmermann part 5x slowmo

“DESIGN 100” Proposal

In a centrifuge accelerator, there is a correlation between
Revolution frequency - Pellet speed – Pellet rate – Pellet flux
Set by the design parameters:
Driving potential (-> minimum and maximum revolution frequency)
Number of acceleration arms
Stop cylinder diameter
Outer acceleration arm diameter

There are many combinations possible
Initial design had potential to achieve pellet rate up to 600 Hz
Advantage: high temporal resolution for pellet investigations (1.7 ms)
Disadvantage: high technical effort for centrifuge and local controller
With designed extruders (20 Hz fuelling and 50 Hz pacing):
Max pellet rate of 70 Hz

“DESIGN 100” Proposal

During PLS working meeting 2/2019 it became clear:

The SCSDAS density and heating controller has a response time of 10ms
Regarded sufficient for proper parameter adjustment

Energy and particle confinement times are significantly longer

➔ Same response time regarded sufficient for the PLS control system

Assume PLS controller has dt = 10 ms:

Can select any available pellet per SCSDAS cycle

➔ Simple and straightforward control approach

In order to get PLS controller capable for $f_P > 100$ Hz:

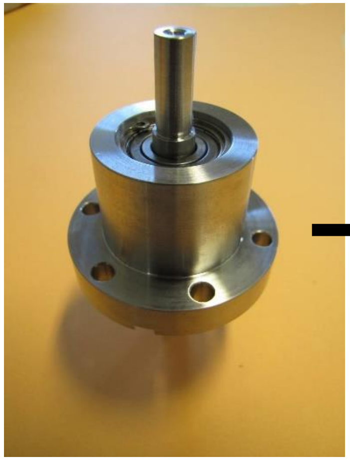
Needs to launch “pellet bursts” within one SCSDAS cycle

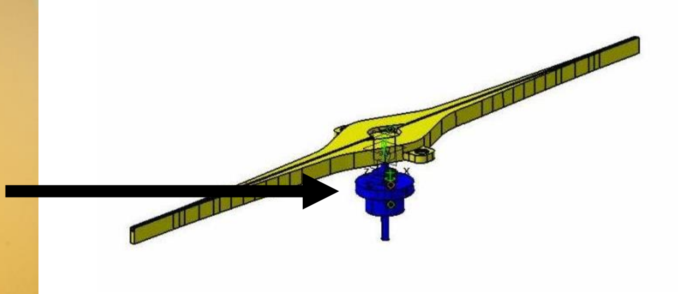
➔ Needs internal sequence handling – Complicated! ➔ Disregarded

“DESIGN 100” Proposal

New approach for centrifuge drive:
Use of a magnetic fluid sealed rotary feedthrough
➔ Installation of the motor on atmosphere

Expected possible up to
166 Hz revolution rate
Expected simple up to
100 Hz revolution rate





Initial design proposed multi arm acceleration scheme
Possible, but requires high temporal and spatial accuracy
Single inner arm scheme relaxes these requirements

“DESIGN 100” Proposal

Adjust PLS layout to SCSDAS density controller response time of 10 ms:

PLS “Design 100”

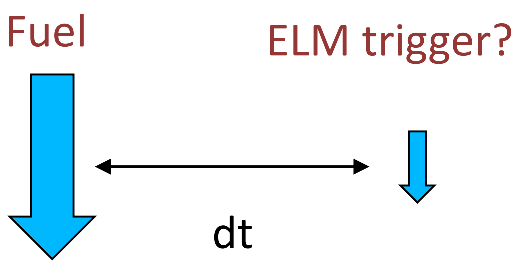
► Centrifuge revolution frequency 100 Hz

► Single inner arm scheme (keep at least double outer arm)

➔ dt = 10 ms (upgrade to 5 ms if required adding second inner arm)

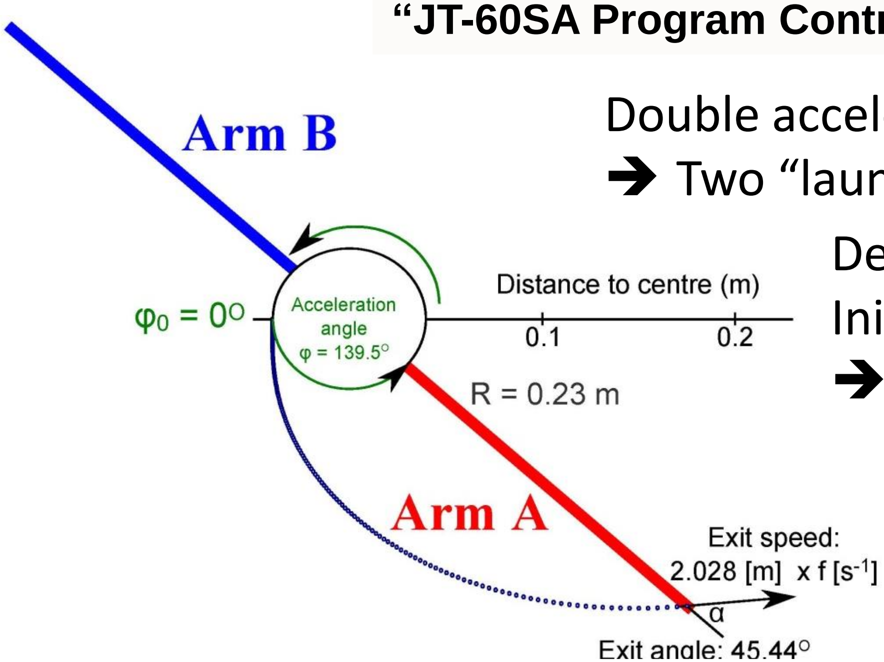
Maximum averaged pellet rate of 70 Hz not limited

Small caveat: Fast “probing” experiments restricted to dt = 10 ms as well



“DESIGN 100” Proposal

Y. Kamada, Invited talk, SOFT 2018
“JT-60SA Program Contribution to Fusion Energy”

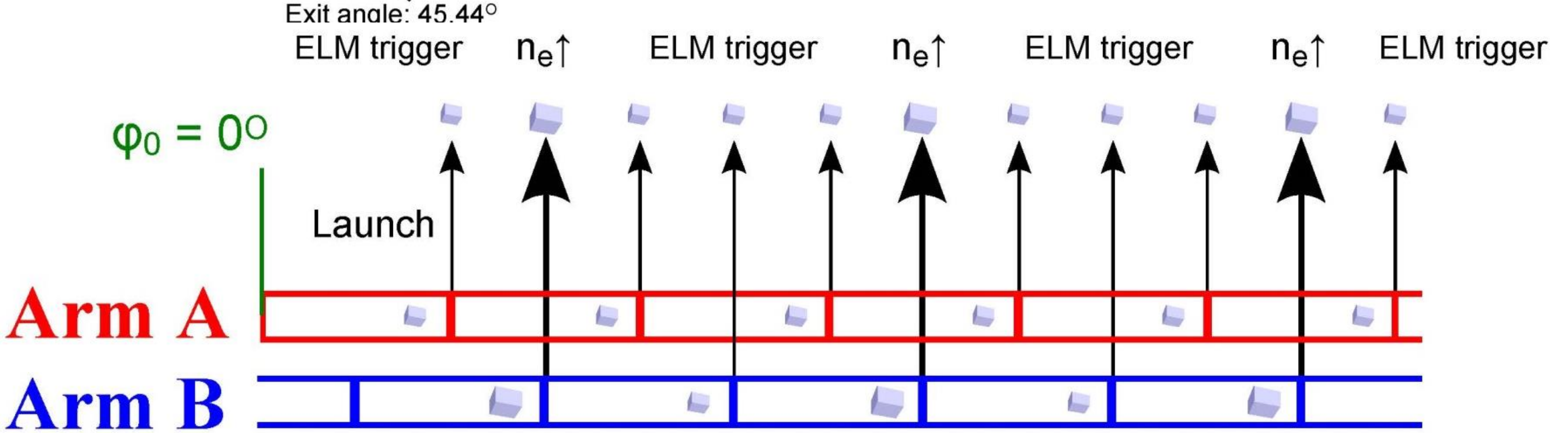


Double accelerator arm approach:
➔ Two “launching slots” per revolution

Design can host up to 3 different extruders
Initial configuration employing 2 extruders
➔ Variability during experiment, e.g.

Combined fuelling & pacing

…↑↑↑↑↑↑↑↑↑↑↑ …



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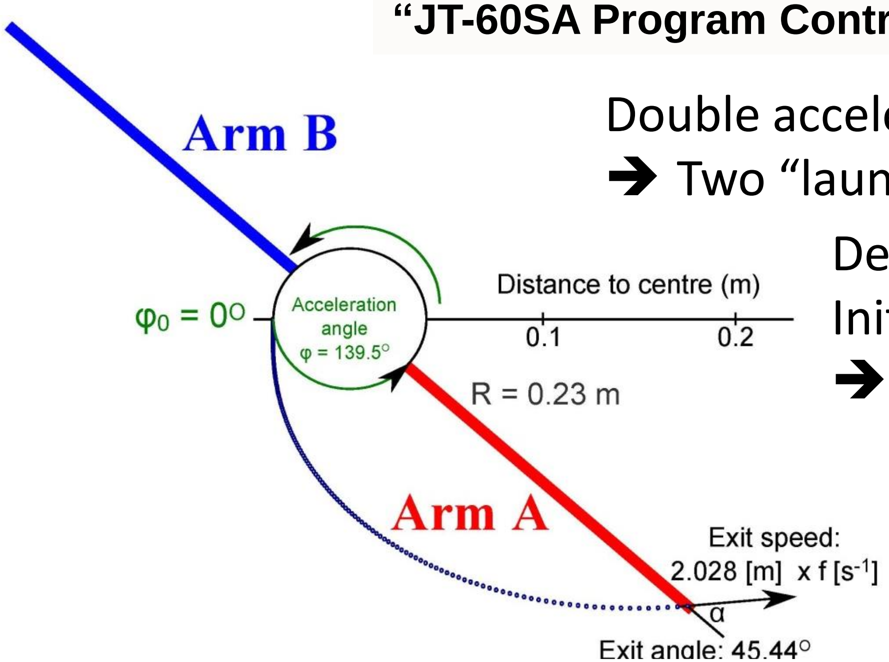

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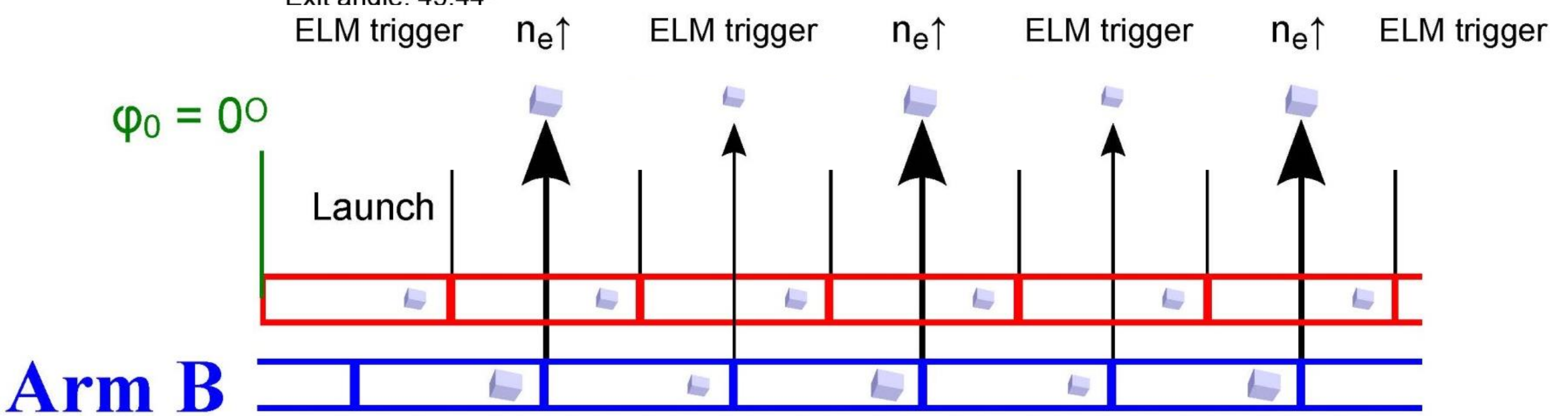
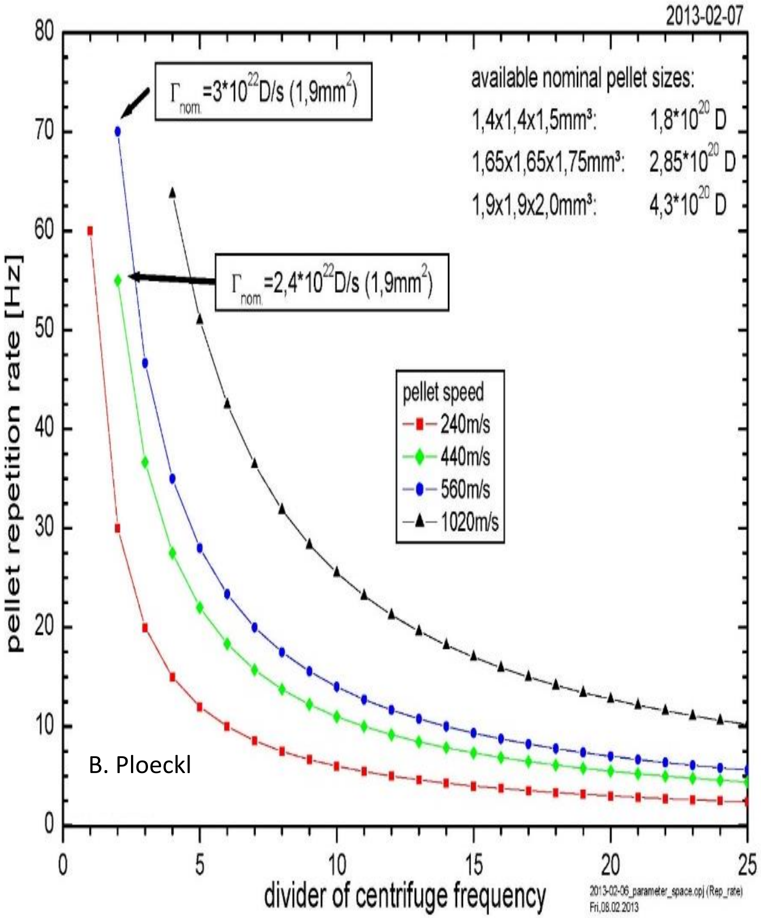
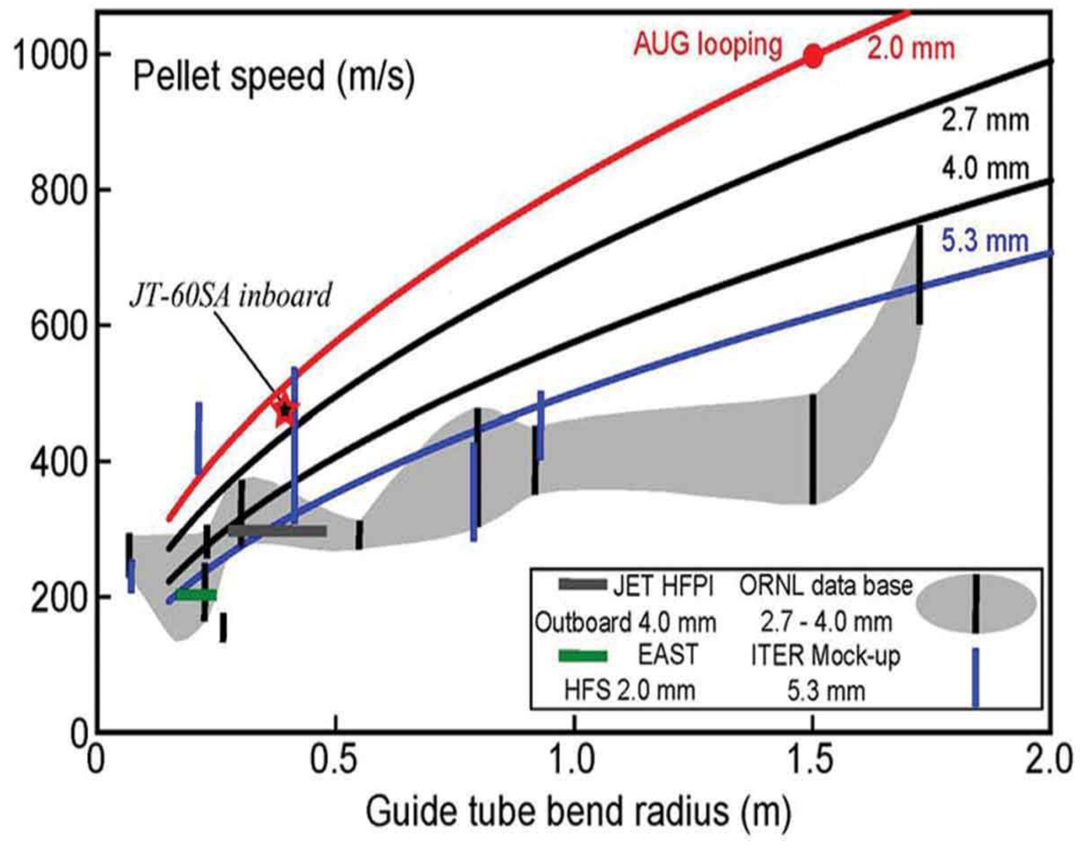


“DESIGN 100” Proposal

Operational points are correlated to pellet speed (AUG example)



Applicable pellet speed is correlated with guiding tube geometry



“DESIGN 100” Proposal

Adjust PLS layout to SCSDAS density controller response time of 10 ms:

Assume maximum pellet transfer speed is 500 m/s

Layout of stop cylinder diameter and outer arm length to fulfil

v_P [m/s] = 5 x f_C [Hz]

➔ Maximum f_P (70 Hz) can be provided until v_P = 350 m/s

➔ Still f_P = 50 Hz until v_P = 250 m/s

“Granularity” of possible “short term” repetition rates f_C/n with n integer

e.g. 100 Hz – 50 Hz – 33.3 Hz – 25 Hz – 20 Hz - 16.6 Hz - 14.3 Hz…

Can be refined for averaged flux with new suggested AUG control approach

50 Hz: ▲x▲x▲x▲ 75 Hz: ▲x▲ ▲x▲ 100 Hz: ▲ ▲ ▲ ▲

"DESIGN 100" Proposal

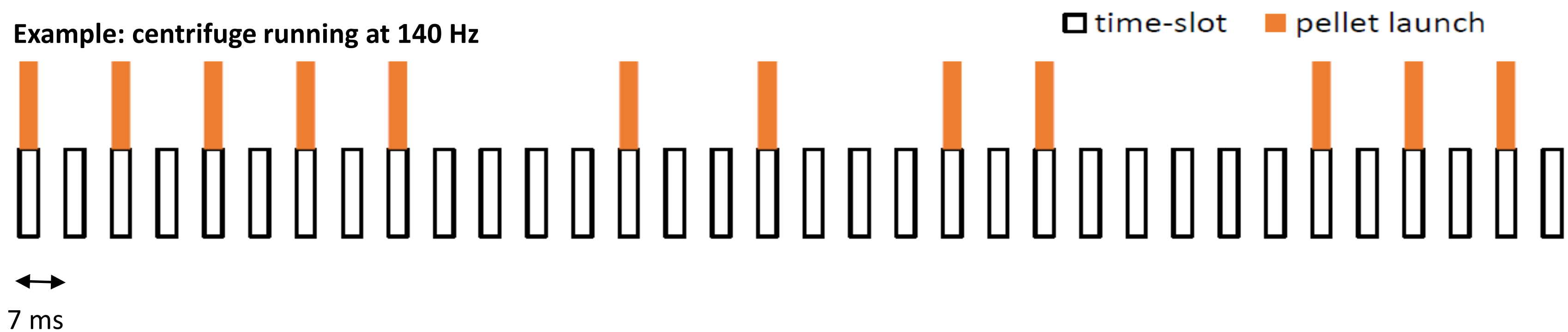
"Launch slot selection"

Abandon concept of predefined repetition rates

Controller selects next available launching slot

Fastest response, more flexibility

Work is in progress



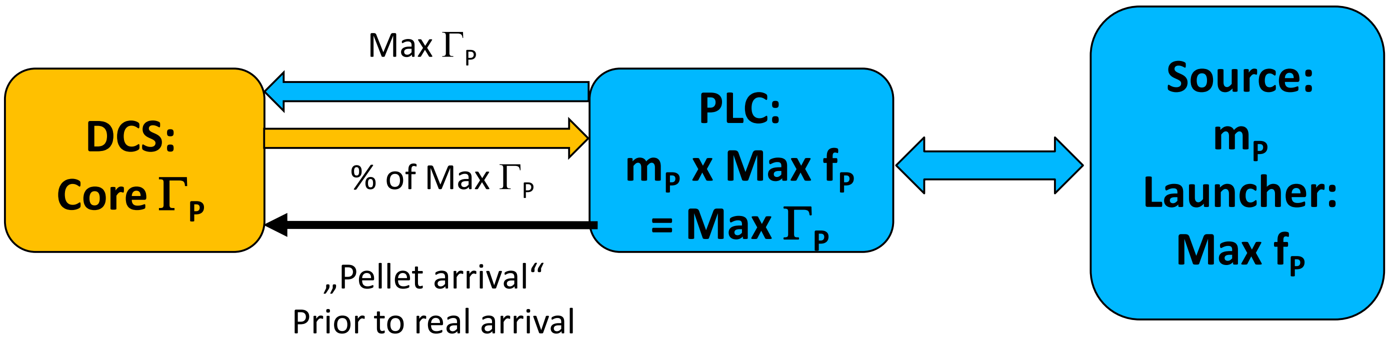
Concept from IPP suitable for single pellet source only

For JT-60SA, upgraded version needed to enable selection from different pellet sources as well

We are going step-by-step!

“DESIGN 100” Proposal

Revised IPP Discharge Control System (DCS) approach for single pellet source:



Suggested approach for fuelling & pacing sources:
SCSDAS requests independent fuelling flux and pacing rate
PLC controller takes care for pacing flux balancing
SCSDAS cares for handling of cases which would require
Pacing flux > Fuelling flux (PLC could provide “alarm signal”)

"DESIGN 100" Proposal

How to go on:?

- Discussion at PPM Budapest
- Agree on with QST
- Agree on max pellet speed (and impact on v_P and f_P range)
- Fix stop cylinder diameter r_0
- Fix outer acceleration arm length R
- Fix design of centrifuge

$$R = \frac{1}{\sqrt{2}} \sqrt{\left(\frac{v_P}{2\pi f_C}\right)^2 + r_0{}^2}$$

THANK YOU FOR YOUR ATTENTION

Pellets on the move

“CENTRIFUGE CLOCK”