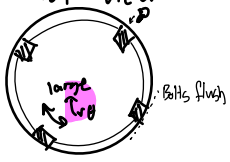
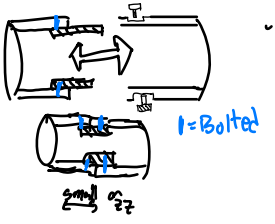
(1) Recessed bolts w/ connecting beams

Axial view



Radial View

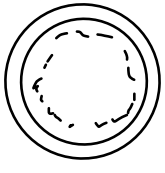


Drawbacks to each design in purple

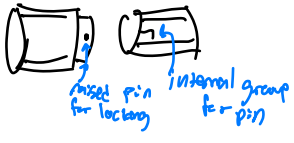
(2) Concentric internal flange, rotating pin-lock mechanism

Could only safely operate in one direction $\hat{\theta}$

Axial:



Radial:

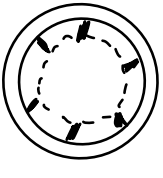


2D projection of locking mech

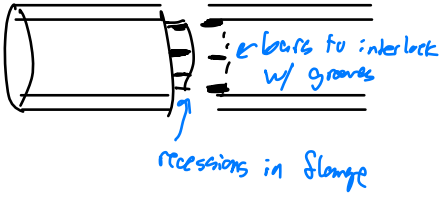
pin slides in, rotates

(3) Axial grooves on internal flange; simple but relies on compression, can separate

Axial:



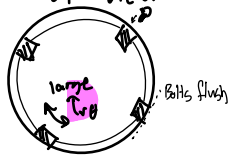
Radial:



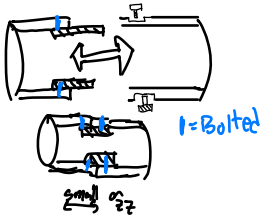
Flange not absolutely necessary, can have grooves on internal surface + bars

(1) Recessed bolts w/ connecting beams

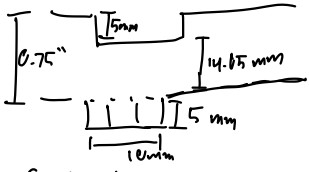
Axial view



Radial View



Selected



Functional requirements:
- Connect TBM segments: immobilize in $\hat{z}$ and $\hat{\theta}$
- Minimal (near-zero!) bending under load
- Distribute forces around TBM shell (reduce stress concentration)
- Easily reversible → bolts removable from outside
- -2.478 kN·m torque from motor for cutterhead, or max rated to 4.78 kN·m (2)

Constraints:
- Limited radial space (2.361" minimum between shield & motor
0.75" TBM shell thickness, 6.441" total space
OD = 550 mm → radius ≈ 10.826" = 27.5 cm ... concave parts
Radius @ ID: 27.5 - 0.75" · 25.4 mm/in = 25.55 cm (4)

Stress calculations:

Assume bolts experience shear stress $\tau_{r\theta}$ only, no tension on TBM pipe segments bear compressive load
shear force (from cutterhead) distributed uniformly across bolts on a single half (i.e., if 6 supports, 12 bolts, there are 2 sets of 6 bolts bearing full load)
100% rotational force transferred from motor segment (2/2) to main segment (1/2)

$$M_{resisting} = n \cdot F_{bolt} \cdot r \rightarrow F_{bolt} = \frac{M}{n \cdot r}, \quad \tau = \left\{\frac{F}{A}\right\}_{bolt} = \frac{M}{n \cdot r} \cdot \frac{4}{\pi d^2} \rightarrow d^2 = \frac{4M}{n \pi \tau}$$

$d(n=6) = 1.819$
$d(n=4) = 2.228$

$M = 2.476 \times 10^3$ N·m (1), n: 6, initial guess, $r = (0.25595\ m)$ (2), $\tau = 15 \times 10^3 psi \cdot 0.6 = 90 \times 10^3 psi = 620.5\ MPa = 620.5 \times 10^6 \frac{N}{m^2}$

↑ McMaster ↑ conservative tensile → shear estimate

M6 bolt has minor diameter = 4.917 mm, 2.21 FOS for n=4

Bolt length: $L_{engagement} = 1.5\,d = 1.5(6\,mm) = 9\,mm$ minimum

0.75" TBM thickness = 19.05 mm... 19.05 mm - (4 mm head height + 1 mm clearance) = 14.05 mm

See Fig (A) above

14.05 mm TBM + 5.2 mm nut + 3 mm protrusion = 22 mm
↑ safety, ~1.5× nut

Selections

M6×1mm nut: 10mm wide, 5.2mm high

M6×1mm bolt: 4mm head, 10mm wide, 22mm len