Capillary Clamp

Design Review

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Design Requirements

Functional Requirements

- Clamp will attach to capillary tube and support weight of cable by friction, allowing cable to be extracted from coiled tube.
- Clamp shall have eyebolts, allowing clamp to be attached to winch and excess capillary to be pulled from coiled tube.
- Clamp will not plastically deform capillary tube, ensuring Swagelok fittings can be slid over clamped regions upon removal of the clamp.
- Clamp will be multi-purpose and easy to apply.

Technical Requirements

- Capillary tube O.D.: 0.250”
- Capillary tube I.D.: 0.180” & 0.152”
- Maximum clamping force on capillary tube: 5000 lbs.

Capillary Cable Restraint

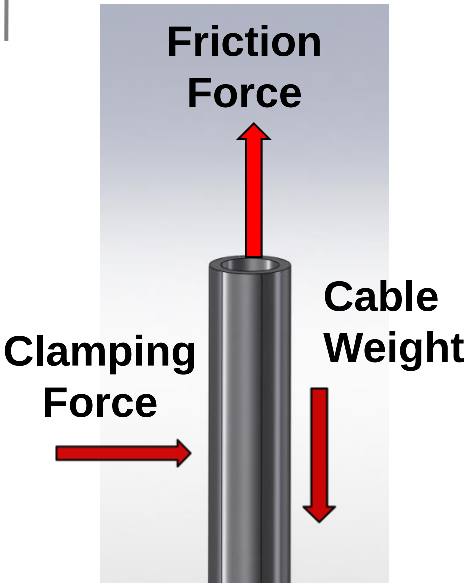

Fig. 1. Diagram of forces acting on capillary tubing.

Capillary cable restraint requirements

- Capillary clamp must attach to capillary, grasping capillary and preventing sliding.
- Two common methods of preventing cable motion; indentation method and friction method.
- Only friction method ensures capillary isn't permanently deformed after clamping.
- Friction force must equal cable weight to prevent motion during hanging. Friction force must be larger than cable weight when being winched to overcome cable weight plus friction inside coiled tubing.
- Table 3 lists the required clamping force for various conditions. Friction coefficient varies from 0.2 for oily tubing to 0.8 for clean & dry tubing.

Table 1. Specifications for 0.035" wall thickness capillary.

cable length l (m)	cable length l (in)	Volume (in3)	W (lbs)
500	19685.0	476.2	140.0
1000	39370.1	952.4	280.0
2000	78740.2	1904.7	560.0

Table 2. Specifications for 0.049" wall thickness capillary.

cable length l (m)	cable length l (in)	Volume (in3)	W (lbs)
500	19685.0	585.2	172.0
1000	39370.1	1170.4	344.1
2000	78740.2	2340.8	688.2

Table 3. Required clamping force given friction force and coefficient of friction.

Friction force (lbs)	Friction coeff.	0.2	0.5	0.8
500	Clamp force (lbs)	2500	1000	625
750	Clamp force (lbs)	3750	1500	937.5
1000	Clamp force (lbs)	5000	2000	1250

Capillary Tube FEA

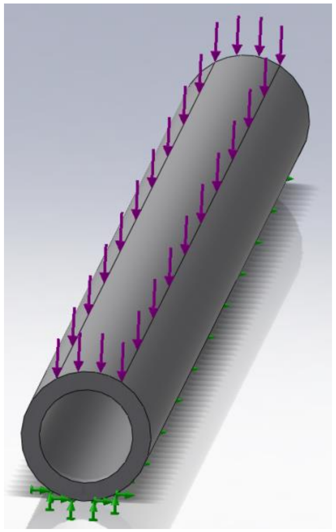

Fig. 2. FEA model of capillary tubing

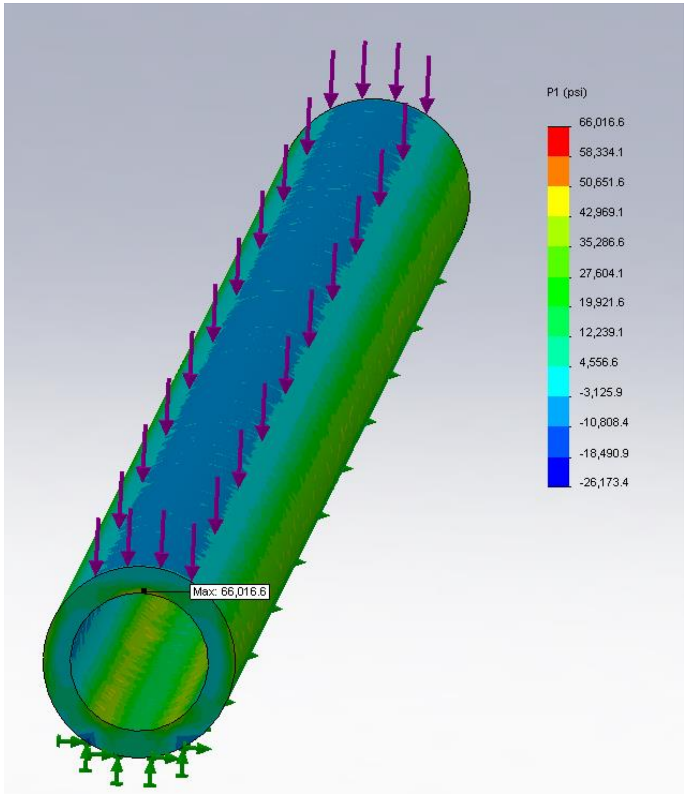

Fig. 3. Stress distribution along capillary tubing with 5000 lb. applied load.

FEA of capillary tube

- Yield stress in Inconel 825 capillary tubing estimated at 89 ksi.
- Maximum stress in tubing from clamp must not exceed 60 ksi, (FOS of 1.5 applied) to avoid plastic deformation in tubing.
- Stress in capillary tubing estimated using FEA, and is approximately 66 ksi with an applied load of 5000 lb.
- Stress in tubing is roughly 13 times the applied force.
- Applied clamping force must not exceed 5000 lbs to prevent yielding.

Table 4. Applied force on vs. maximum stress on capillary tube.

F (lbs)	σ1 (ksi)
1000	13.0
3000	39.0
4000	52.8
5000	66.0

Proposed Capillary Clamp Design

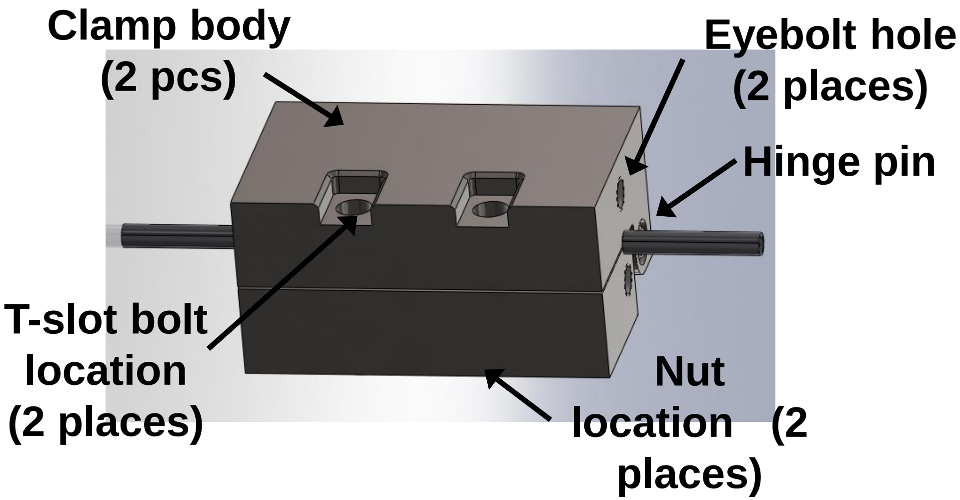

Fig. 4. Isometric view of proposed capillary clamp.

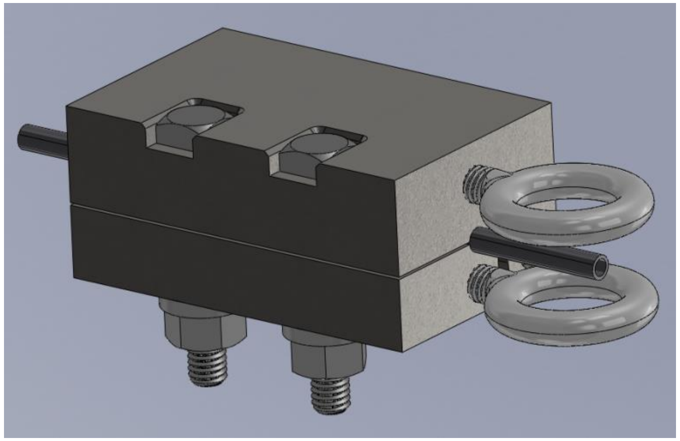

Fig. 5. Isometric view of proposed capillary clamp with eyebolts.

<u>Clamp design details</u>

- Two part clamp with hinge, allows clamp to be easily applied to capillary tube.
- Bolts (2) apply compressive force to lock capillary in place.
- T-slot bolt head is recessed on left side, nut on right side is tightened to prescribed torque value to apply force.
- 3/8” eyebolts can be used to attached capillary clamp to hoist cable and pull capillary tubing.
- Eyebolts rated for 1480 lb. load (each), capable of 2960 lb. total load.

Capillary Clamp Analysis

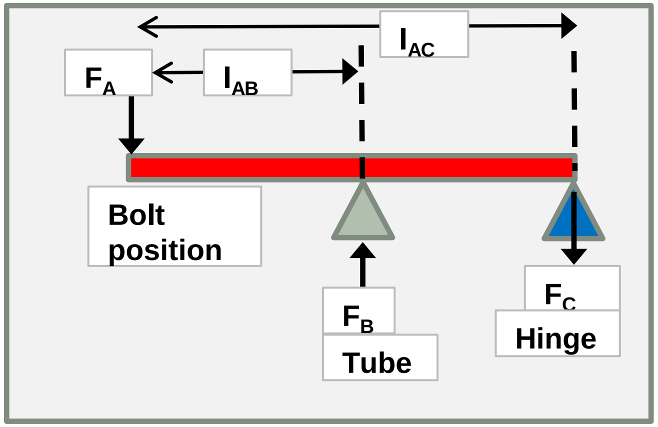

Fig. 6. Free body diagram of one side of capillary clamp.

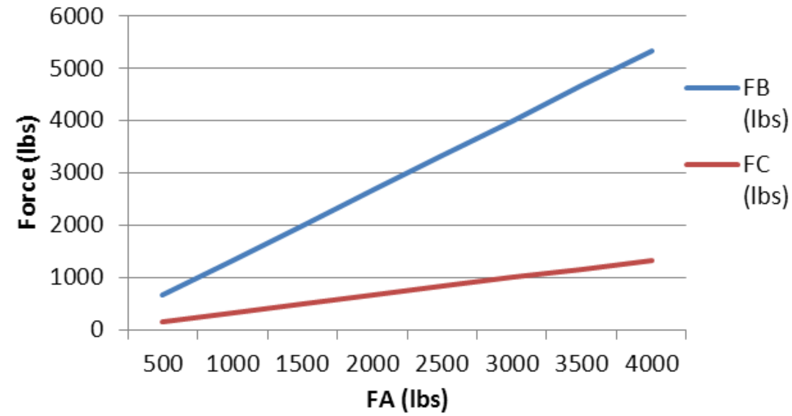

Fig. 8. Force at F_B & F_C vs applied force at F_A for $l_{AB}=0.75*l_{AC}$.

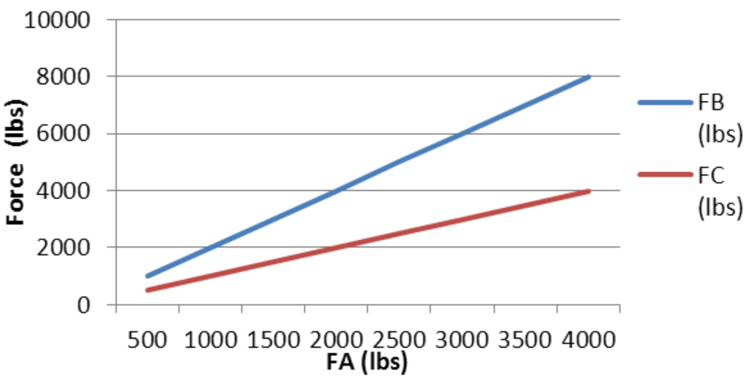

Fig. 7. Force at F_B & F_C vs applied force at F_A for $l_{AB}=l_{AC}/2$.

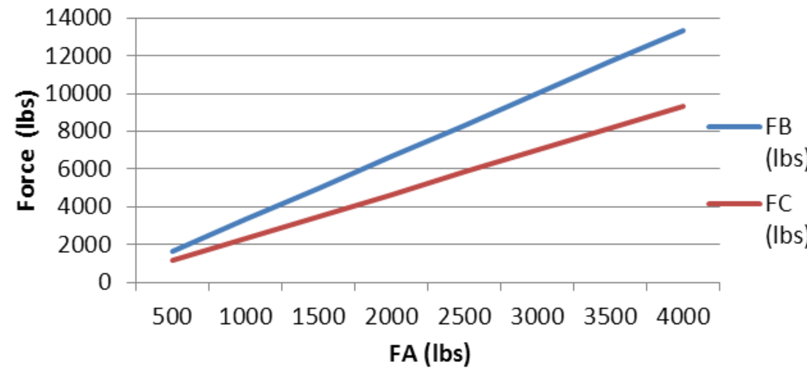

Fig. 9. Force at F_B & F_C vs applied force at F_A for $l_{AB}=0.3*l_{AC}$.

- Figures 7-9 show capillary clamp provides mechanical advantage to tube compression.
- For $l_{AB}=l_{AC}/2$, capillary clamp provides twice the input force to the capillary tube, reducing the input force required by the operator.

Capillary Clamp Analysis Cont'd

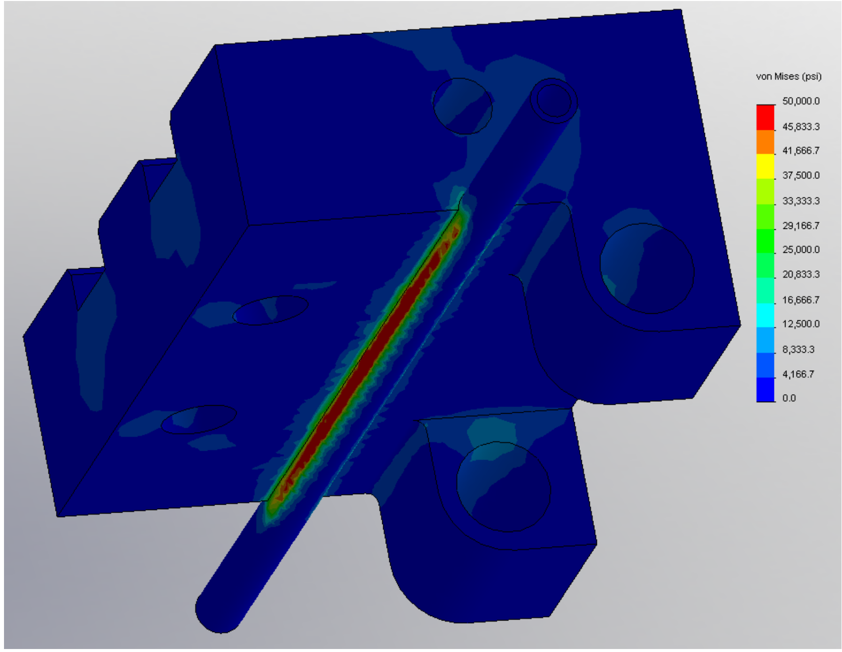

Fig. 10. Stress distribution in capillary clamp with 5000 lb. applied load (2500 lbs per bolt.)

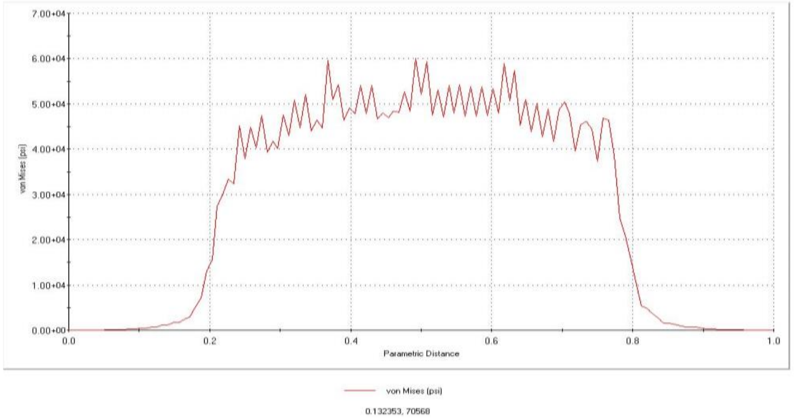

Fig. 11. Maximum stress along capillary tubing during clamping.

<u>Capillary Clamp FEA</u>

- **Capillary clamp analysis is supported by FEA results.**
- **5000 lbs. applied load to clamp yields a maximum stress of approx. 60 ksi, and a resultant force of 10,000 lbs. on the capillary tubing.**
- **Figure 11. shows the maximum stress (Von Mises) along the capillary tubing, with the tube section outside the clamp exhibiting near zero stresses.**

Capillary Clamp Assembly

Assembly details

- Applied LN (interference fit) to clamp's left half, shown in red in Fig. 11.
- Applied LC fit (clearance fit) to clamp's right half.
- Coiled spring pin, 0.3125" nominal, 8700 lbs. breaking strength, used as hinge pin.
- Coiled spring pin will be captured by left half interference fit and allowed to rotate freely about right half. Eliminates need for bolt/nut to hold pin in place, allows clamp to swivel while retaining pin in place.

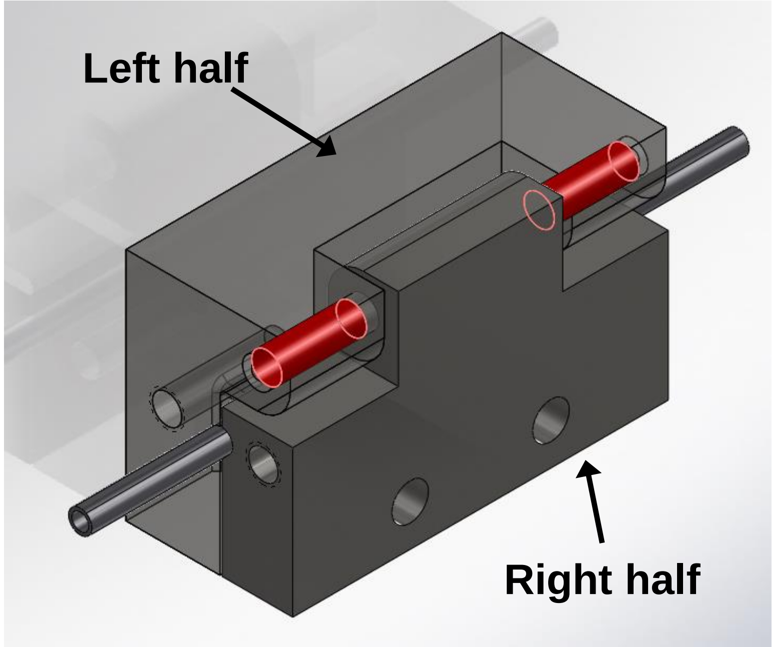

Fig. 12. Isometric view of assembled capillary clamp, with interference areas highlighted.

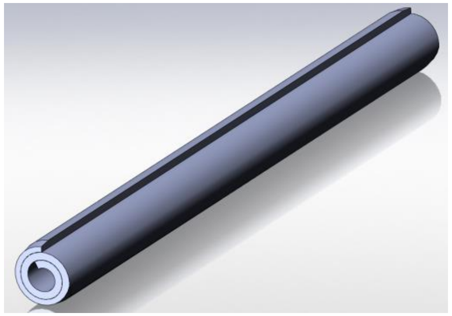

Fig. 13. Coiled spring pin, McMaster #91598A544