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Revision: 01

Title: Capillary Clamp for SAGD Field Installations

Table of Contents

1. Related Documents

R & M Energy Systems, 2011, *Hercules General Products* Catalog, C-3001-0411, http://www.rmenergy.com, (30 July 2012).

2. Report Summary

The purpose of this technical report is to describe the design and construction of a device that can be attached to capillary cable and used hold it in place during SAGD field installations. As observed during testing, this capillary clamp is capable of being applied to the capillary cable and resisting 1500 lbs. of tension loading without deforming the capillary cable.

3. Report Detail

Based on conversations with completions engineering staff, it has come to light that it is necessary to prevent the capillary cable from slipping into the coil tubing. This can occur during pure vertical installations or installations where friction forces aren't large enough to prevent motion of the capillary cable. To address these concerns, a clamping device was designed capable of restraining the capillary cable.

Basic Design Requirements:

- Easy to apply to capillary cable, with attachment points for lifting.
- Must clamp capillary without permanently deforming it, ensuring Swagelok style fittings can be slide over it after it has been clamped.
- Capillary clamp must be able to resist a force greater than the total weight of the capillary cable for a pure vertical installation.

Inconel 825 tubing is commonly used as capillary cable in SAGD installations, 0.25" OD (6.35 mm) with either a 0.035" or 0.049" wall thickness (0.88-1.24 mm). The weight of capillary cables is given in Tables 1 & 2. It should be noted that the expected length for pure vertical wells is approximately 400-500 m.

Table 1. Cable length and weight for Inconel 825 with 0.035" wall thickness.

cable length l (m)	W (lbs)
500	136.8
1000	273.6
2000	547.3

Table 2. Cable length and weight for

Inconel 825 tubing with 0.049" wall thickness.

cable length l (m)	W (lbs)
500	179.1
1000	358.1
2000	716.3

The upper limit on tension that can be applied to the cable is based on the yield limit of Inconel 825. Annealed Inconel tubing generally has a yield strength of between 35-75 ksi (241-517 MPa). Table 3 lists the maximum tensile load that can be applied to the capillary cable for 0.035” and 0.049” wall thickness tubes. Using this information, the minimum axial load the clamp must resist is 547-716 lbs., while the maximum axial force on the clamp should not exceed 1700-2300 lbs.

Table 3. Maximum tensile force given wall thickness and yield strength of capillary cable.

	Yield stress (ksi)	
wall thickness (in)	35	75
0.035"	**827**	**1773**
0.049"	**1082**	**2320**

Similar clamps, commonly called polished rod clamps, are commercially available for larger sized cables. Several manufacturers were contacted to acquire clamps for 0.25” capillary cable, but they do not make clamps for cable smaller than 1.0” OD (25.4 mm). Figure 1 shows the two different clamping methods, indention clamping and friction clamping. Indention clamping is capable of restraining the cable at higher load levels but leaves the clamped cable permanently deformed, which would prevent fittings from sliding over the capillary cable. Friction clamping is the preferred method for clamping the cable without permanently changing its shape.

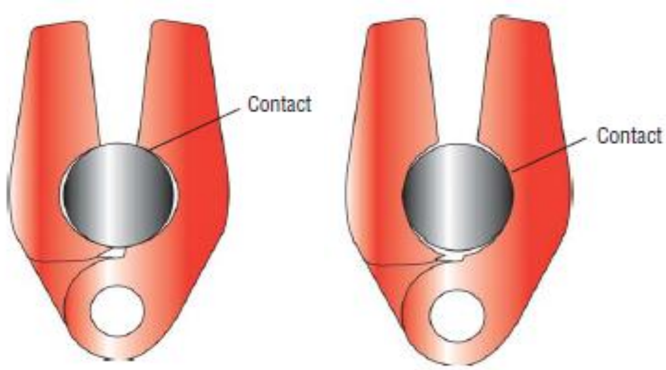

Figure 1. Schematic of indention (left) and friction (right) style polished rod clamps, courtesy of Robbins & Meyers, Inc.

Mechanical Design of Capillary Clamp:

The free body diagram (FBD) for the capillary cable is given in Fig. 2. To prevent motion by the capillary cable the friction force, $F_{friction}$, must equal the cable weight, F_{weight}, on the cable. Additionally, the friction force must be greater than the cable weight alone to ensure the cable can be pulled from the coiled tube. The friction force is proportional to the clamping force, and is given as Eq. (1), where μ is the coefficient of static friction.

$$F_{friction} = \mu F_{clamp} \tag{1}$$

The coefficient of static friction for steel on steel varies from 0.2 (oily surfaces) to 0.8 (clean, dry surfaces). Table 4 listed the clamping force for a given cable weight and friction condition.

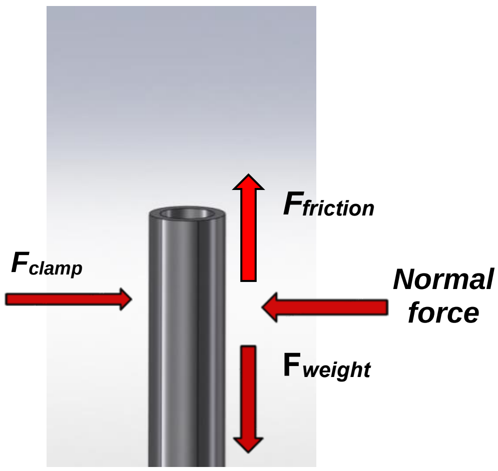

Fig. 2. FBD of capillary cable under static loading.

Table 4. Required clamping force, in lbs., given the pulling force and friction coefficient.

	Coeff. of static friction, μ		
Pulling force (lbs)	0.2	0.5	0.8
500	**2500**	**1000**	**625**
750	**3750**	**1500**	**937.5**
1000	**5000**	**2000**	**1250**

Based on the weight of the cable alone, this suggests the minimum clamping force must be at least 2500 lbs. to account for conditions where the capillary cable is oily and cannot easily be cleaned. To resist the maximum expected force of 2320 lbs., clamping forces of 2875 to 11,500 lbs., for μ=0.8 and μ=0.2 respectively, would need to be applied.

Clamping forces applied to the capillary cable must restrain the cable without deforming it. To determine the maximum force that could be applied to the capillary tube with deforming it, a finite element analysis (FEA) was performed. The maximum stress on the tube under clamping load was determined for tube with a yield stress of 75 ksi. Figure 3 shows the result of this effort for a 5000 lb. load.

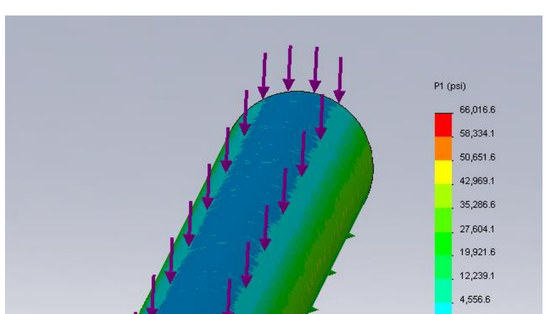

Table 5. Maximum principal stress in the capillary tube for an applied clamping force.

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

Using the data from the FEA, listed in Table 5, this suggests a maximum clamping force of 5600 lbs. can be applied to the capillary tube before it is plastically deformed.

A simple two part clamp was designed using these estimates for sizes and required clamping forces, as seen in Fig. 4. This design used two 3/8”-16 bolts to apply the clamping force to the tube and ensure it does not slide in the clamp. Two eyebolts are used to give an attachment point on the clamp for lifting purposes. Figure 5 shows the machined capillary clamp open with the capillary tube in the clamp. A coiled spring pin is used to join the two halves of the clamp; an interference fit on one half of the clamp ensures the pin doesn’t fall out of the clamp, while a running fit on the other half allows the clamp to open freely. The capillary path was positioned to maximize the mechanical advantage of the capillary clamp, providing high clamping force for minimal input bolt load, as well as minimizing the load on the hinge pin. Figure 6 shows the result of this effort; locating the tube half way between the hinge and the bolt point doubles the force on the tube and sets the force acting on the hinge pin equal to the bolt force.

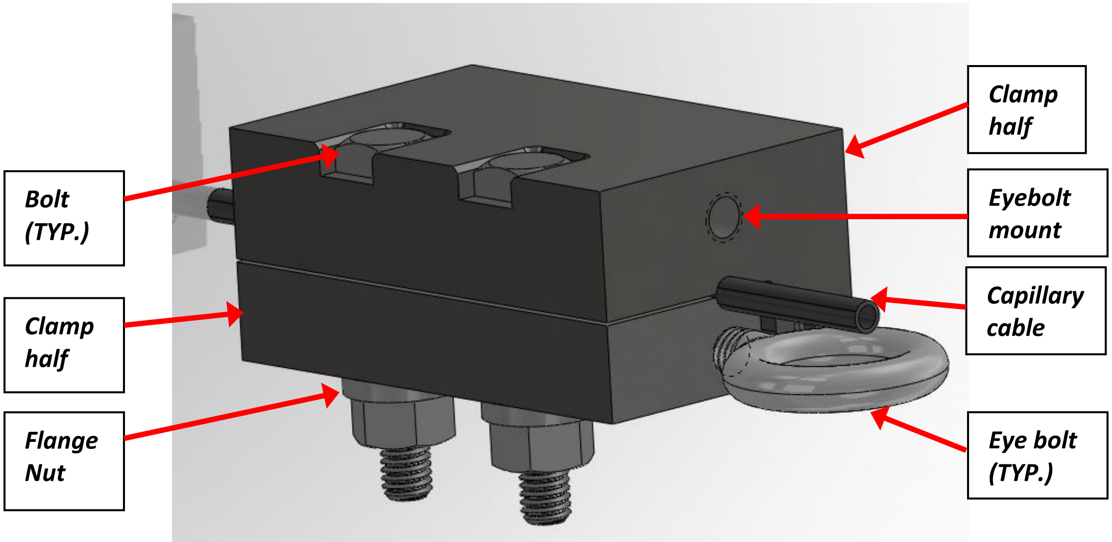

Figure 4. CAD assembly of capillary clamp.

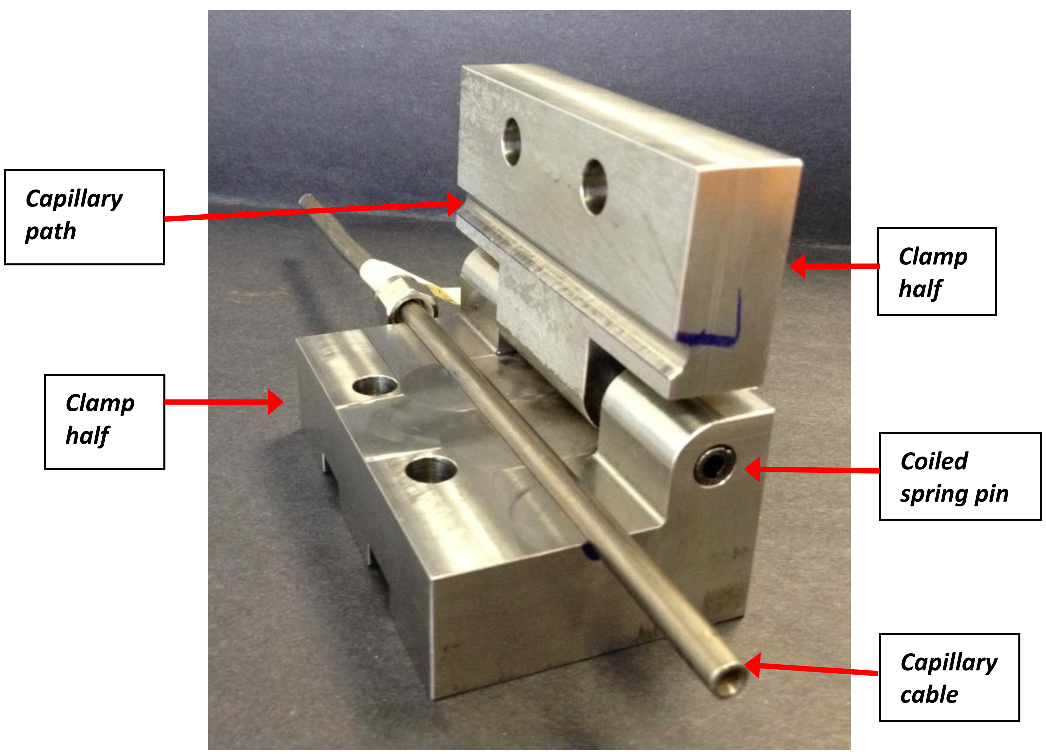

Fig. 5. Capillary clamp and Inconel tube section.

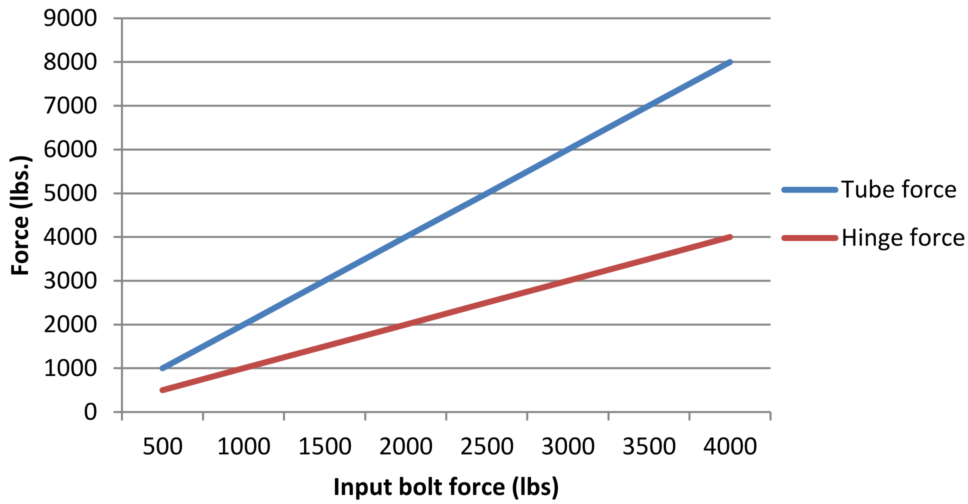

Fig. 6. Force on tube and hinge vs. input bolt force.

Based on Fig. 6 and a maximum applied force to the capillary tube of 5600 lbs., this suggests a maximum load on the bolts and the hinge pin of 2800 lbs. each. The coiled spring pin used to join the clamp halves is 5/16" OD x 4" long and has a breaking strength of 8700 lbs.

Figure 7 shows the results of the FEA on the capillary clamp design, and Fig. 8 shows a plot of maximum stress along the capillary tubing. As seen in Fig. 8, the maximum stress in the capillary tube is slightly lower than the general FEA result shown in Fig. 3, but within the expected range. The combined effect of the clamping load and an applied load on the capillary is shown in Fig. 9.

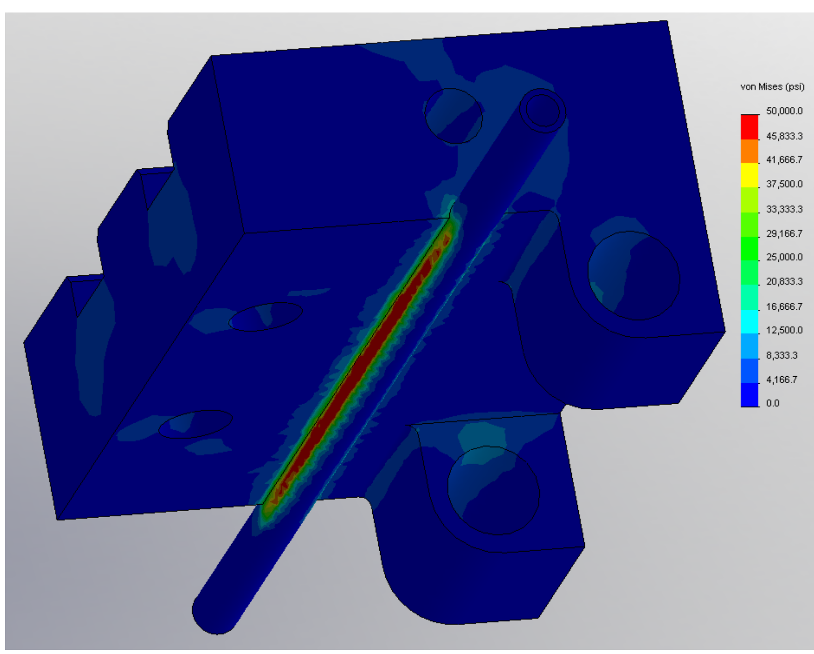

Fig. 7. Stress distribution in capillary clamp with 5000 lb. applied load (2500 lbs. per bolt).

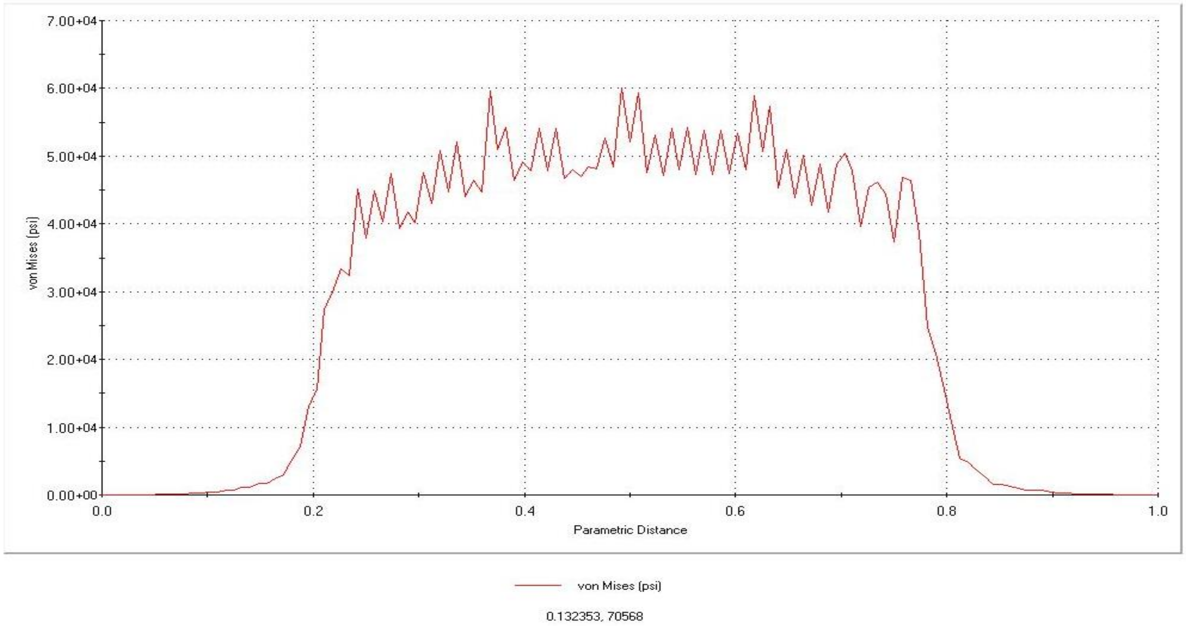

Fig. 8. Von Mises stress along the capillary tubing during clamping.

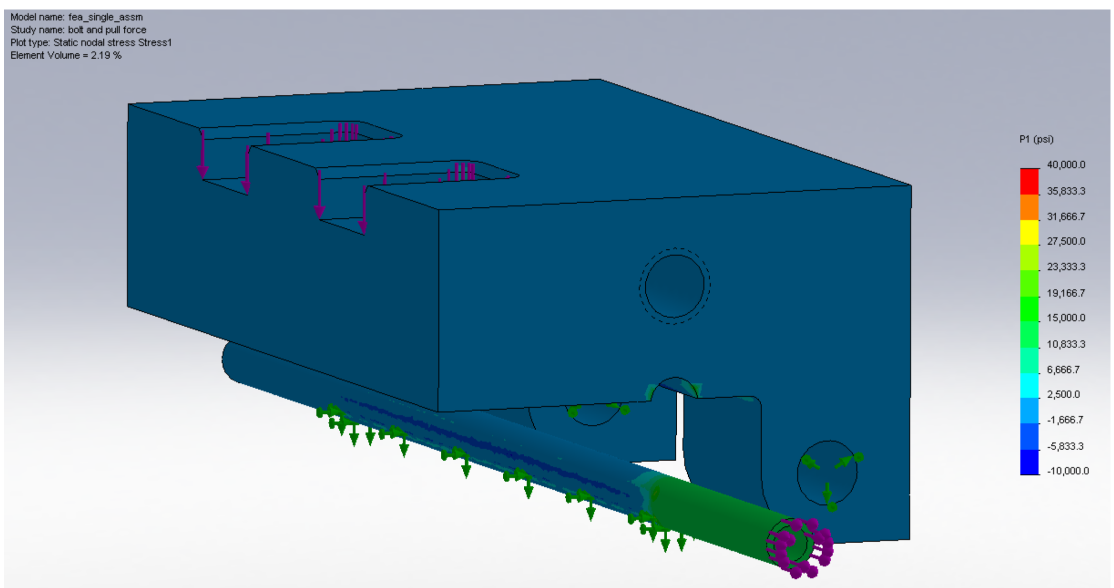

Fig. 9. Stress distribution in capillary clamp from combined clamping (750 lbs. per bolt) and tension load (300 lbs.)

Figures 9 & 10 represent the pure vertical well installation with 750 lbs per bolt applied and a 300 lb. axial load (cable weight). Figure 10 shows the stress from this combined load analysis at the clamp interface. Larger stresses in the cable occur near the edge of the clamp; the average stress in this region is 12-13 ksi, while the peak stress is approximately 22 ksi.

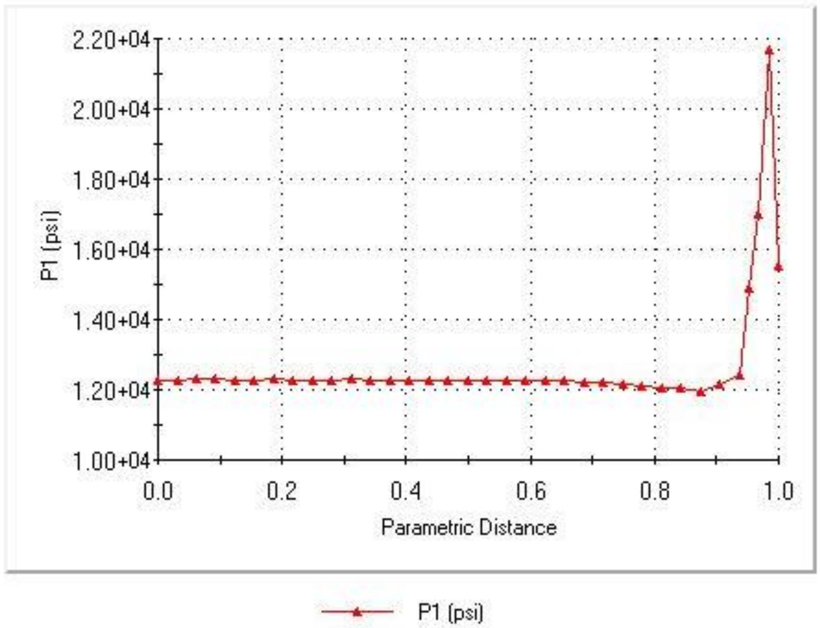

Fig. 10. Stress in capillary cable in clamp/axial loaded interface area showing combined stress effect.

The bolts used to apply the clamping force to the capillary clamp are 3/8"-16 square head bolts. As seen in Fig. 4, the upper most half of the clamp was designed to allow the clamp to restrain the bolts during tightening. This feature requires that only one wrench is needed during clamp installation to tighten the flange nut. The bolt and flange nut should be cleaned and thread lubricant applied before tightening. A torque wrench should be used to tighten the flange nut to ensure the clamp is tightened to the prescribed load level. The correct torque for the clamp bolts is 15-20 ft-lbs of torque. The applied torque should not exceed 30 ft-lbs.

Two 3/8"-16 holes, drilled and tapped to 1.0" (25.4 mm) deep were provided for lifting attachments, as seen in Fig. 4. It is expected that eyebolts can be threaded into these locations, allowing attachment to lifting equipment, crane, hoist, etc. The eyebolt locations were designed to provide lifting force in line with the capillary cable, ensuring that the cable can be lifted straight up. Eyebolts are commonly available in this thread pattern, are rated for 1200-1400 lbs. of load per 3/8" eyebolt, and can be procured in 4-10" lengths to ensure that the cable can egress away from the lifting attachment point. The eyebolts should be fully threaded into the tapped holes, and jam nuts used to secure the eyebolts, ensuring they do not rotate during use. It would also be possible to weld the eyebolts in place to prevent rotation during use. McMaster part number 8891T52 or 3016T11 are suggested as suitable eyebolts for lifting applications.

Test Results:

Two series of tests were conducted on the capillary clamp. Two 10" (254 mm) long Inconel 825 capillary cable sections were used for both tests. The first test involved sliding a Swagelok ferrule set over the tube after it had been placed in the clamp and the clamping load applied. The torque was applied in steps up to 30ft-lbs, and the tube section was removed after the maximum torque was reached. Both tube sections were subjected to this test three times each, and after each test the ferrules slid over the clamped region without incident.

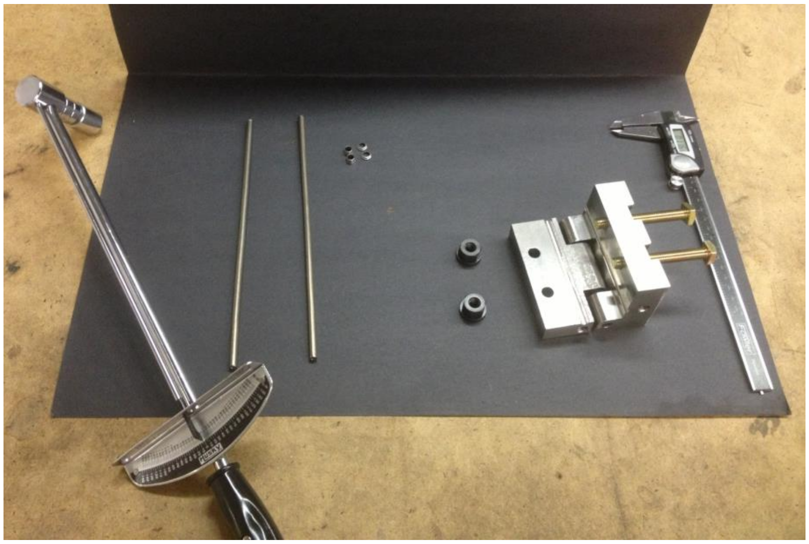

Fig. 11. Clamping test set-up.

A second test was conducted to ensure the capillary clamp could successfully restrain the capillary tube under an applied tensile load. The sample cable sections were first clamped in the capillary clamp to 30ft-lbs of torque. Using the PneuTest device at the Lanham, MD facility, a tensile load was applied to the capillary clamp at the eyebolt locations to simulate a hoisting operation. The sample cable section was restrained at one end, as seen in Fig. 12.

The results of this testing clearly demonstrated that the cable was restrained by the capillary clamp to force loads of 1520-1550 lbs. This result was observed in both cable samples; above 1500 lbs. the capillary clamp noticeably slid on the sample cable. It should be noted that both the capillary clamp and the sample cable were not specially prepared for this testing, and were subject to handling, etc. Proper cleaning of the clamp and cable samples could be performed to improve the coefficient of friction between the clamp and cable, possibly increasing the force when the clamp slips from the cable. After removing the sample cable from the capillary clamp, Swagelok ferrules were easily slid over the section placed in the capillary clamp. This proves that the capillary clamp was able to restrain the sample cable without adversely deforming it.

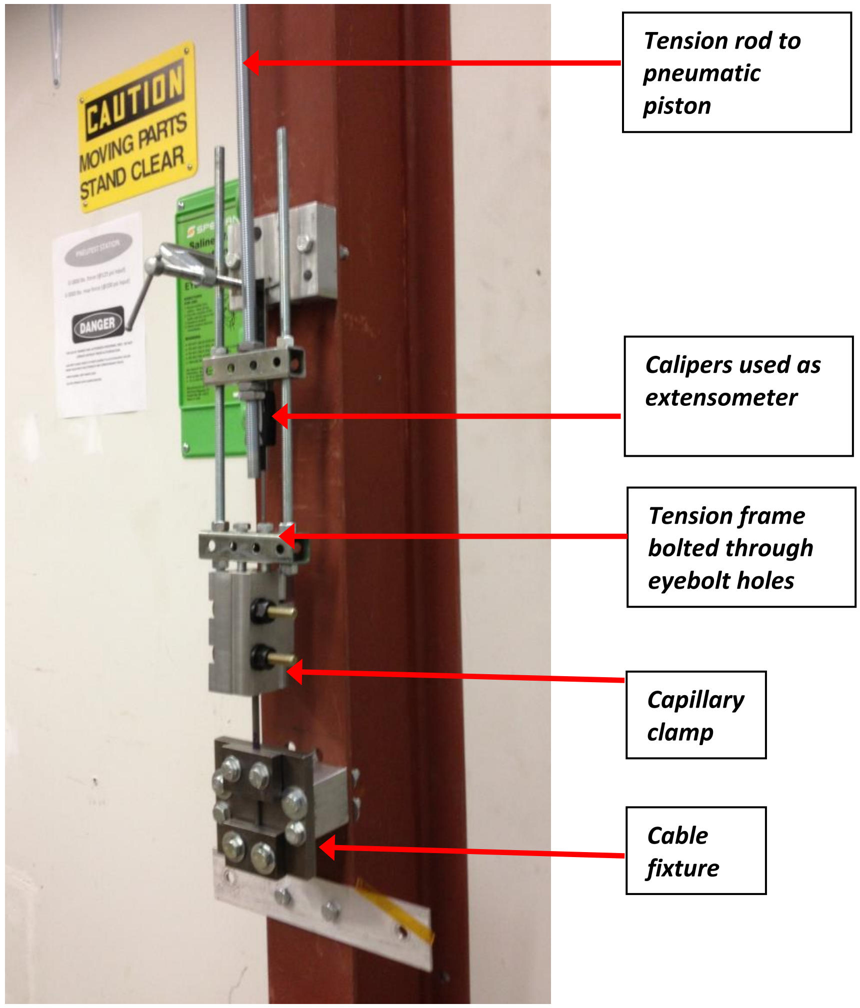

Fig. 12. Tension loading test set-up.

4. Result Discussion/Conclusions

The capillary clamp was designed to restrain the capillary cable without deforming it and testing of the clamping procedure and loading process shows that it is capable of doing so. The capillary clamp was able to prevent the sample cable from sliding when loaded up to 1500 lbs.; loads in excess of 1500 lbs. caused the cable to slip in the clamp. This is well above the requirement for a pure vertical well and below the expected yield load of a typical capillary cable.

For a pure vertical installation, the maximum weight on the cable should be less than 300 lbs. The capillary clamp bolts should be torqued to 15 ft-lbs. This assumes the cable has not been cleaned and is oily, though efforts to clean the cable section inside the clamp to improve the clamp's performance should be taken.

In the case where the clamp will be required to restrain the cable against 1500 lbs. of loading, due to long length and/or additional friction, the capillary bolts should be tightened to 30 ft-lbs of torque.

Document Change History

Date	Revision	Changed By	Description of Change
11/7/2012	01	R. Govoro	Original draft