In-plane capacitance probe holding mechanism

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In precision metrology it is frequently required to hold capacitance probes such that they are properly aligned and held well. Alignment, i.e., parallelism between the sensor surface and the target surface, is important for measurement accuracy. Deviation from parallelism renders the probe's factory calibration incorrect and results in somewhat inaccurate measurements. The sensor also needs to be held snugly in place by means of a well distributed nestling force. A loosely held cap probe is prone to mechanical as well as electrical noise. On the other hand, applying a large localized force, for example by means of a direct-contact set screw, can damage the cap probe and permanently alter its calibration. Furthermore, before the sensor is held in place, it must be free to move along the sense axis to allow an adjustment of the initial gap between the sensor and the target. Thus, an ideal probe holding mechanism should enable the following:

1. Proper alignment
2. Nestling force distributed over a length of approximately two to three times the diameter of the probe
3. Easy movement of the probe along the sense axis before it is clamped

While it is quite easy to hold a probe normal to plane, the same cannot be said about holding a probe in-plane. The reason is simple: Normal to plane cuts are far more feasible and inexpensive as compared to in-plane cuts. Figure 1 illustrates this fact.

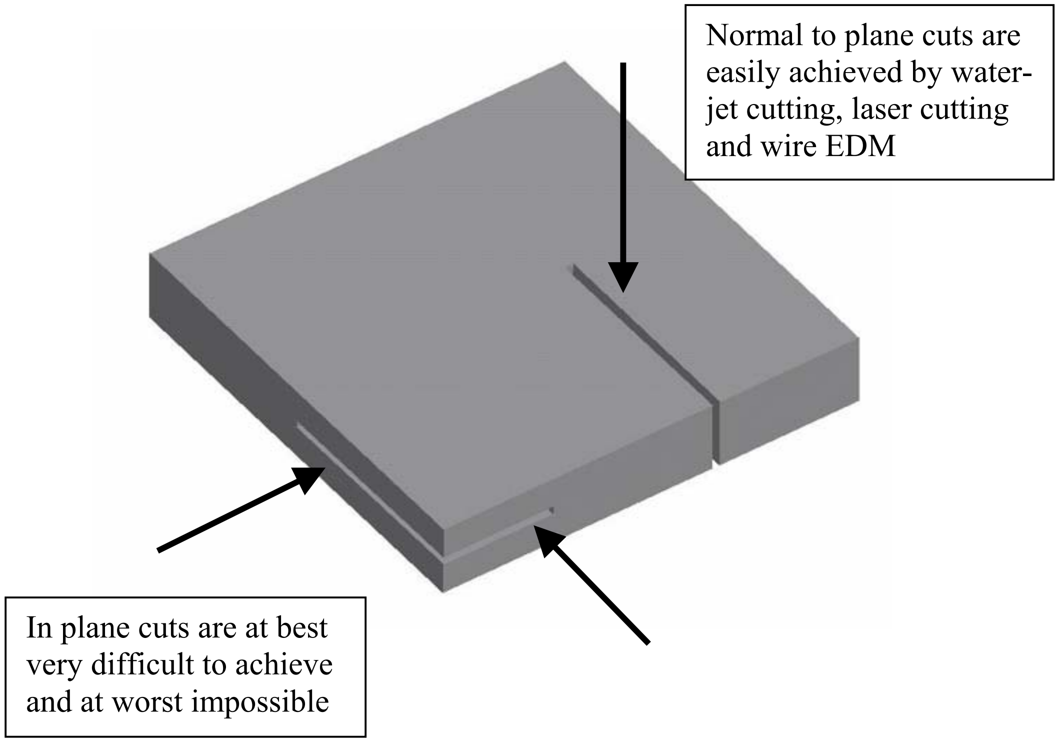

Figure 1

Some common normal to plane cap-probe holding mechanisms are shown in Figure 2.

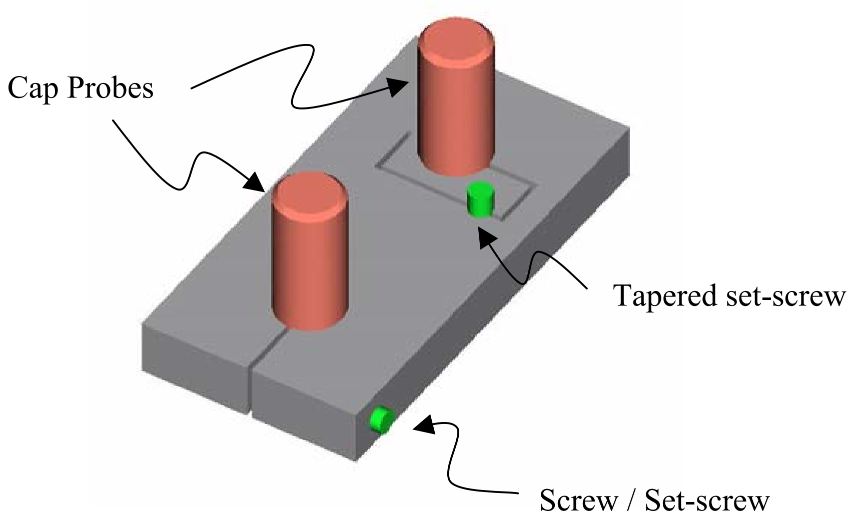

Figure 2

On the other hand, there are a few known good ways of holding cap probes in plane. One way is to hold the cap probe in a slotted sleeve which is slid into an in plane hole. A set-screw acting on the sleeve helps grip the cap probe without damaging it.

In Figure 3, we describe a very simple yet effective mechanism that we have employed to hold cap-probes without damaging them. This mechanism provides all the desirables listed earlier.

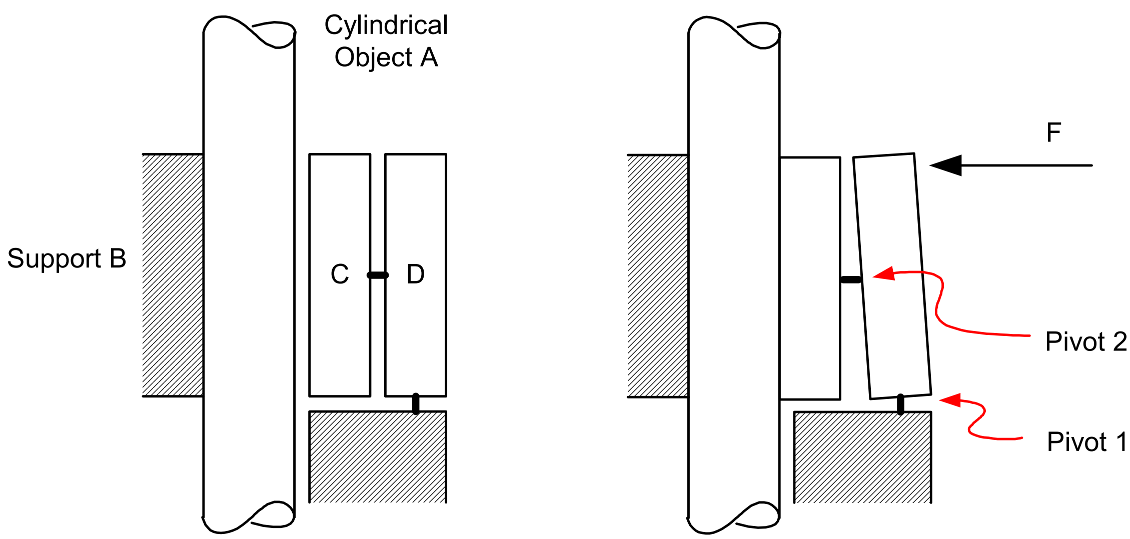

Figure 3

The arrangement consists of a cylindrical object A that is to be held firmly with respect to fixed support B. Furthermore, there are two blocks C and D connected by means of flexural pivot 2. Block D is connected to ground via the flexural pivot 1. Pivots 1 and 2 are designed such that they have a very high axial stiffness but low moment stiffness. Thus, flexural pivot 1 ensures that the force F that is applied on block D is not countered by any significant moment at Pivot 1 and is instead transmitted on to block C. Meanwhile, pivot 2 transmits this force to block C which nestles the object A against support B, without transmitting any moment. Pivot 2 allows a small relative rotation between blocks C and D without producing any significant enough moment on block C, since its moment stiffness is very small.

Thus ultimately, only a normal force acting at the middle gets transmitted to block C. This force distributes itself over the entire length of block C which secures part A against the fixed support B. The resulting pressure distribution at the interface of part A and block C is somewhat like a bell-curve, as is shown in a subsequent FEA study. Barring space constraints, it is very easy to increase the width of block C, which will result in a yet more uniform distribution of the applied force. This is guaranteed by St. Venant's Principle.

Note that the use of a single lever, i.e., block C without block D, supported by Pivot 1 would cause a stress concentration at the tip of the lever where it touches the cap probe, and potentially damage it. On the other hand, Pivot 2 in the proposed mechanism transmits only a normal force, and allows block C to conform to Object A without producing any moment loads on Object A.

The above explanation of how the mechanism works is far more intuitive than a mathematical analysis. Nevertheless a mathematical analysis can be performed for optimization, something that needs to be done for production design or extreme sensitivity. Since the loads are statically indeterminate, a closed-form analysis is non-trivial. Alternatively, a finite element analysis was carried out and revealed the following expected stress distributions at the clamping interface, for an example case. Of course, for the design to be effective, the pivot thickness needs to be small so that it offers little resistance to moment loads and high resistance to axial loads. This is also evident from the FEA results shown in Figure 4. The X axis shows points along the length of the block C. Fifteen test points, where the stress levels were recorded, were chosen for the study. For thin flexural pivots, we see a very symmetric distribution of stress. On the other hand, increasing the pivot thickness (i.e. increasing the moment stiffness of the pivots) shifts the curve towards left which indicates a gradual build-up of stress at one end of the object being held.

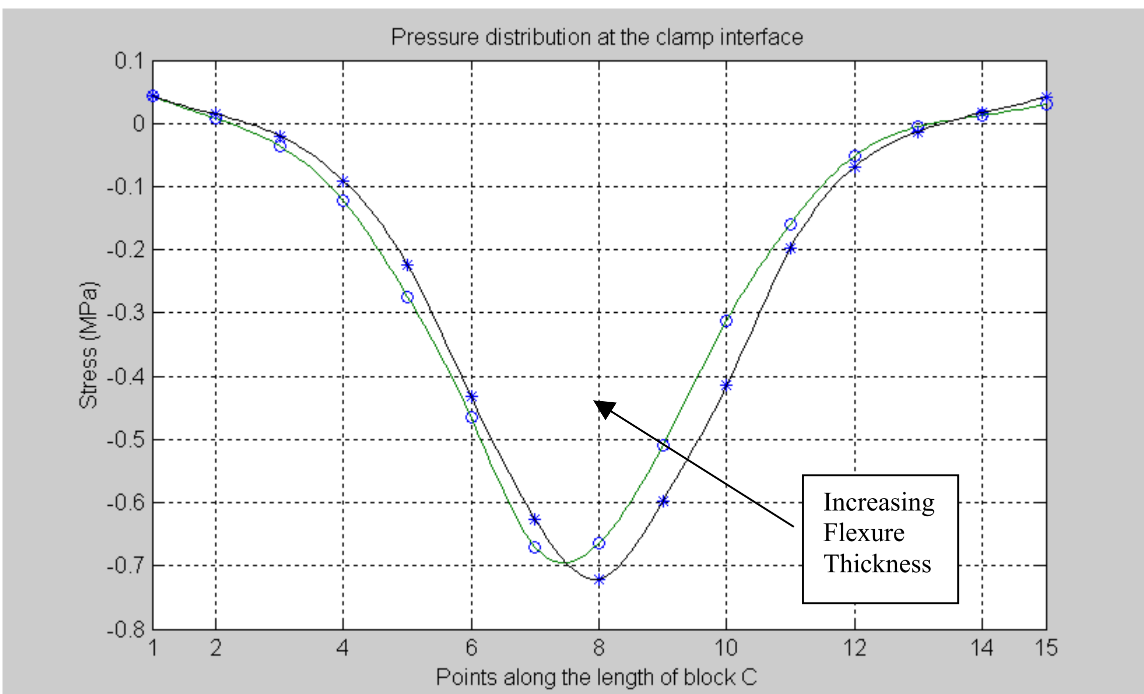

Figure 4

The in-plane nestling force can be applied very easily by means of an NPT tapered pipe plug, which is like a set screw with tapered threads. The above described mechanism can be used in numerous other applications where either a cylindrical sensor or an actuator needs to be held within the plane of operation. In fact, we use the same mechanism to hold micrometers and actuation motors in most of our experimental set-ups, as shown in Figure 5.

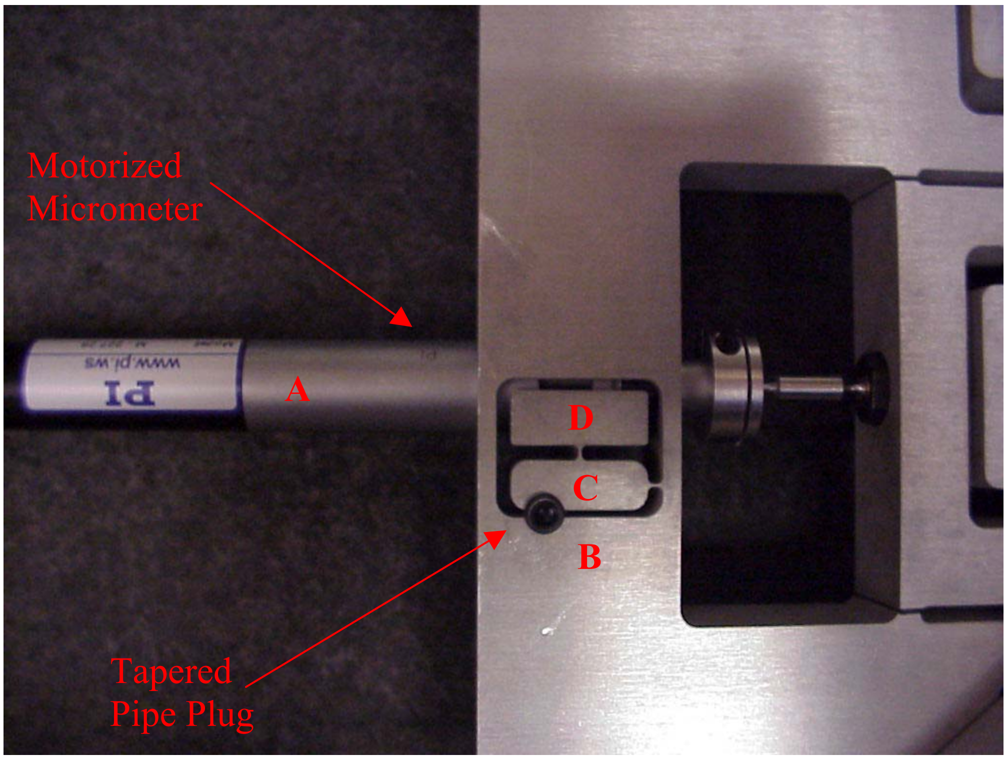

Figure 5

Fabrication

While fabrication might seem to be a concern in this case, in reality it is quite straightforward as long as a particular order is followed.

1. Cut the entire 2-D pattern using a waterjet machine or a wire EDM. This results in a part with blocks C and D supported merely by thin flexures. To drill the hole that will hold the object A, blocks C and D have be temporarily held strongly in place. This is accomplished by gripping the part between two sheets of emery paper in a regular vice. As the vice jaws are tightened, the grit particles of the emery paper dig into the part including blocks C and D, and hold them firmly in place. Now the part can be drilled and reamed as though it were rigid. A helical flute reamer is recommended since the cut is discontinuous

2. Once the part is drilled and reamed, either slide the object A or an artifact of the same diameter into the hole. With this is place, the hole for the tapered pipe plug can be tapped easily.

Alternatively, one can leave supporting tabs while cutting the part initially on the waterjet / wire EDM. These supporting tabs keep the part stiff during subsequently machining. Once all the machining is done, these supporting tabs may be removed by using a very fine end mill cutter, or by means of a fine saw blade. This last step of removing the tabs can end up becoming time-consuming.

Another way would be to drill and ream the hole first, then align the part on a waterjet machine or wire EDM, and finally cut the 2-D pattern. Depending on the machine that is used this alignment may or may not be a straightforward step.