CRYOGENIC ATTACHMENT FIXTURE WITH HIGH STRENGTH AND LOW THERMAL CONDUCTION

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ABSTRACT

In the development of cryogenic systems for space application it is frequently necessary to securely anchor low-temperature components to high-temperature surroundings. This inevitably requires some trade-off between the conflicting requirements of high strength and of low thermal conduction through the anchor.

An attachment fixture using strands of Kevlar has been developed that is extremely strong and stiff while at the same time it allows only a tiny amount of heat to flow to the low-temperature component. The fixture consists of two metal beams at different temperatures that are connected by eight strands of pretensioned Kevlar in such a way that neither beam can move with respect to the other in any direction. The method by which the Kevlar is anchored allows the full strength and stiffness of the Kevlar to be achieved. The only thermal-conduction path from the high-temperature beam to the low-temperature beam is along the length of the thin Kevlar strands.

INTRODUCTION

A fixture that attaches a cryogenic component to its surrounding must meet much more difficult conditions when the system is part of a package that must be launched into space. The support fixture must be unusually strong and stiff to survive the high forces and severe vibrations of the launch without breaking or losing alignment between components. It is difficult to achieve the strength required without rather massive structures that conduct a large amount of heat.

At the same time, satellite systems designed for a long stay in space generally require an extremely low heat load into the lowest-temperature components to minimize the expenditure of non-renewable cryogen or else to minimize the heat that must be carried away by a cryocooler. This means that thermal conduction through the attachment fixture must be very low.

The main reason that bulky supports are chosen for high- strength applications is that the long, slender rods that would be desirable from a thermal conduction standpoint are unstable against buckling if very much compressive load is applied to them. It would be much better if such rods could be arranged so that they were always under tension. It is very difficult to achieve an arrangement of tension members that are all under a uniform, high tension, however.

DESIGN OF FIXTURE

A cryogenic attachment fixture has been developed that uses thin strands of high-strength Kevlar[1] fiber to achieve a high level of strength and stiffness while maintaining a very low level of thermal conduction through the fixture. This is accomplished through a method of winding Kevlar under high tension and anchoring it in a way that does not reduce its inherent strength and stiffness.

Figure 1 shows the design that accomplishes this; it is a modification of a previous development[2]. The figure shows a cryogenic chamber attached to one of a pair of flat beams. The other beam is attached to a high-temperature base plate by a simple angle bracket. The two beams are coupled to each other by eight strands of Kevlar. The strands are under high tension and are anchored by epoxy[3] to attachment plates on the ends of the beams. The geometry of the strands restrains relative motion of the two beams in any direction. Because the strands are pretensioned, there is no slack in the coupling between the two beams. This and the inherent stiffness of the Kevlar results in very little movement of one beam with respect to the other when a force is applied between them.

The flat beams of the fixture are of low-expansion Invar alloy. This is because the Kevlar has very little contraction when it cools to low temperature and the use of a material such as aluminum, which

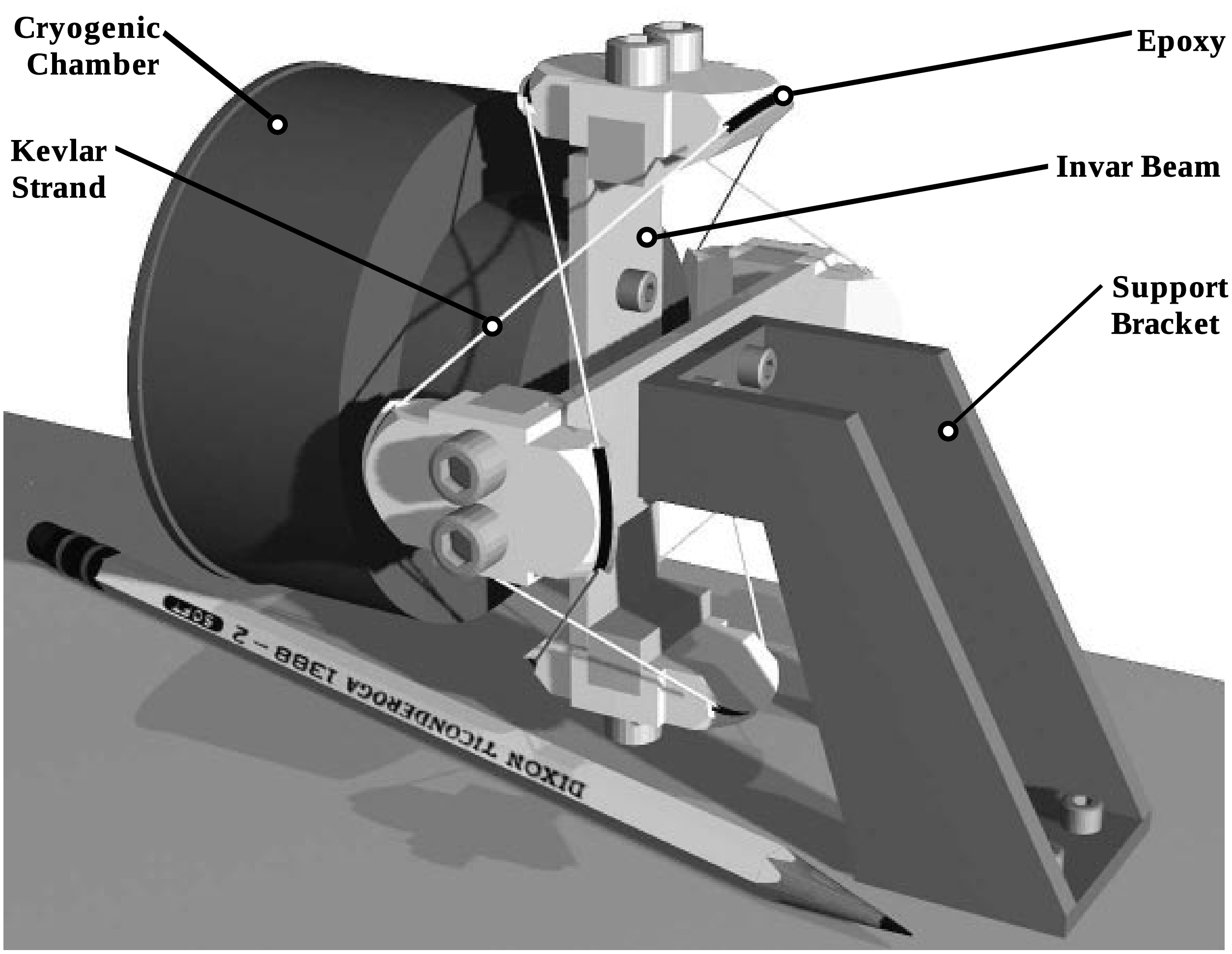

Fig. 1. Attachment fixture using Kevlar strands. A cryogenic chamber is shown mounted on one side of the fixture and the other side of the fixture is attached by a support bracket to a higher-temperature base plate.

contracts much more than the Kevlar, would result in a loss of the pretension on the Kevlar at low temperatures.

To fully realize the strength and stiffness of the Kevlar, it is necessary to be very careful in the way the strands are anchored. The use of knots is undesirable because they seriously weaken the Kevlar. Wrapping several turns of Kevlar around a post to provide a buffer between the high-tension strand and the point where it is actually terminated is also undesirable because this compromises the high stiffness of the Kevlar. These extra turns can tighten up under high load, adding length to the strand that causes a loss of pretension when the load is removed. By anchoring the strands in grooves filled with epoxy, the design of Fig. 1 avoids both these drawbacks.

A particular advantage of this design is its modularity. The Kevlar strands are wound on the fixture ahead of time, producing a fixture of known spacing. Since the whole unit can be bolted in place when needed, there is no need to go through the difficult process of tightening and equalizing the tension of strands that are applied in place.

When a load is applied to a fixture of this geometry, some strands increase their tension by a certain amount and other strands decrease their tension by the same amount. As long as all strands have a tension between zero and the breaking strength of the strands, the fixture behaves linearly and predictably. Therefore, to maximize the range of forces that the fixture will withstand and to achieve an equal range of positive and negative forces, all the strands should be pretensioned to approximately one-half the breaking force of the strands.

CONSTRUCTION

The fixture is assembled by attaching the two beams to a temporary spacer, mounting the fixture in a lathe and winding the Kevlar under the appropriate tension. The tension is determined by a special coupling[4] that slips at a predetermined torque. Before going to the fixture, the Kevlar is wrapped several times around a brass shaft connected to the coupling; the coupling slips and feeds the Kevlar when the correct tension is reached. To prevent the strands from advancing along the shaft as it turns the shaft has a 15° taper that opposes this tendency. Note that there are two independent strands of Kevlar coupling the two beams; if one strand is followed from attachment to attachment the path returns to the starting point without overlapping the other strand. Both strands of the fixture are wound at the same time; a slip coupling for each strand is mounted on a pivot to allow the strands to be properly positioned as the fixture is slowly rotated in the lathe. The fixture is wound in multiple rotations so that each Kevlar link is actually built up of more than one strand. The multi-strand approach greatly improves the anchoring of the strands by the epoxy that is applied during winding; for the same total breaking strength, four strands have twice the surface area of a single heavy strand. The tension is maintained on the strands until the epoxy hardens; then the fixture is removed from the lathe and the temporary spacer is removed.

TESTING

The length of the Invar beams of the fixture is 7.4 cm, their width is 1.9 cm and their thickness is 0.25 cm. The attachment plates on the ends of the beams spread the Kevlar strands 3.0 cm apart at their tips. Braided Kevlar 29 of 223 N (50 lb) tensile strength and 0.13 mm2 cross sectional area was used; the slip couplings tensioned the strands to 89 N (20 lb) during winding and four turns of

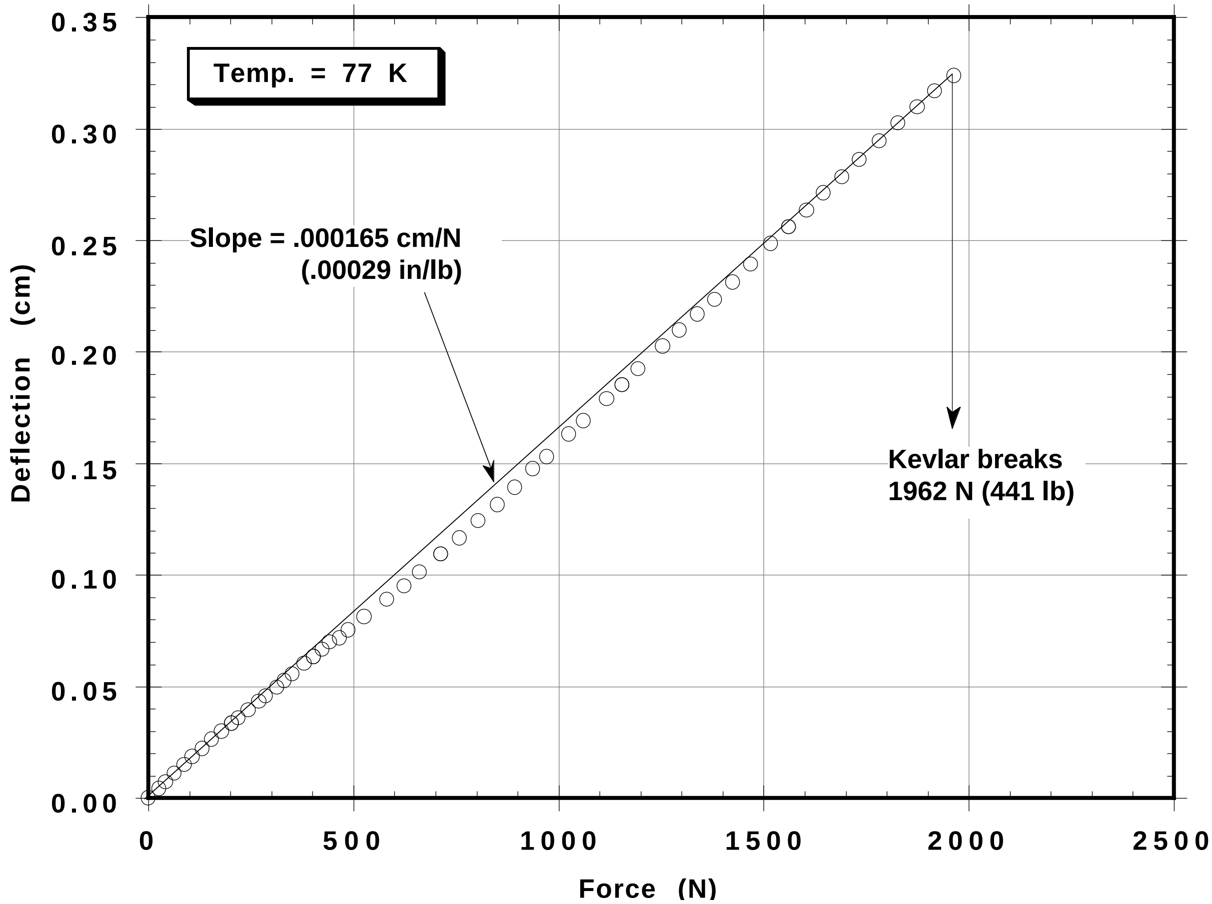

Fig. 2. Axial compression test of attachment fixture at 77 K.

Kevlar were applied for each link. This yielded an initial tension in each link of 356 N (80 lb) and a breaking force of 890 N (200 lb). Each link is 4.8 cm long and the four strands combine to make up a cross sectional area of 0.52 mm^2.

The fixture was tested in axial compression at 77 K. Simultaneous measurements of force and deflection were obtained and are shown in Fig. 2. The fixture failed at a load of 1962 N (441 lb) by breakage of the Kevlar, not by failure of the epoxy joints. Calculation of the tension in the links at the maximum load showed that the Kevlar closely approached its nominal breaking strength before failure. The deflection per unit force of the fixture is 0.000165 cm/N (0.00029 in/lb); this is about twice that of the previous configuration[2], which had additional aluminum U-beams attached to the Invar beams. These U-beams greatly reduced the bending of the Invar beams and, therefore, made the fixture stiffer but at the cost of greater weight.

CONCLUSIONS

An attachment fixture has been developed that combines the features of very high strength and very low thermal conductivity. It achieves these conflicting goals by a unique geometry and by taking maximum advantage of the properties of Kevlar. The low thermal conduction arises from the use of relatively thin strands of Kevlar that are highly stressed and from the fact that Kevlar has the typical low conductivity of other plastics[5]. A particularly useful aspect of the design is that the deflections and stresses in the beams and the strands can easily be calculated under typical load conditions; this allows the fixture to be used at stresses close to the breaking strength of the strands with considerable confidence.

Although the fixture is intended primarily for cryogenic applications, the concept is readily applicable to other temperature regions. The use of metallic strands and, perhaps, a brazing method of anchoring them could extend the usefulness of the concept to quite high temperatures. In addition, the small version described above can easily be scaled up to meet the requirements of larger tasks. It should also be pointed out that greater thermal isolation can be achieved by using smaller strands if less strength is acceptable, and conversely.

REFERENCES

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