The Story Behind Orthotic Flexure Joint Technology

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Figure 1: Tamarack Flexure Joint™, free motion design

Figure 2: Tamarack Flexure Joint™, dorsiflexion assist model

The convenience, cosmesis, extraordinary durability, and cost savings associated with self-aligning flexure joint technology has attracted a large number of users. In less than three years, the Tamarack Flexure Joint™ has captured 50% of the North American market for thermoplastic-compatible ankle joints. Overseas sales are increasing at 20% per year.

Flexures are connecting members which allow relative movement between whatever is attached to either end. Flexures have been used as hinging members since prehistoric times when rawhide was pierced and pegged to form hinges for shelter doors and container lids. They have served humankind effectively through to the present day in applications as prosaic as fishing tackle boxes and cabinets to the sophisticated and exotic needs of the aerospace industry. Flexures are fundamental engineering design tools with an amazing range of capabilities. Their configurations vary greatly depending on the requirements of each application.

Tamarack Flexure Joints™ installed in test AFO. The AFO and joints have survived 3,116,987 cycles on the durability tester.

For practical purposes, we must skip over much of the rich history and theory of flexures in their many possible forms and capabilities to focus on their service in what we might call the "plastic era" of orthotics. Several of the early plastic AFO designs purposefully allowed some ankle motion by means of a somewhat flexible posterior portion between the foot and calf sections of the orthosis. Many of these early AFO designs continue to be very practical in certain applications. However, those designs could not provide several characteristics obtainable with traditional joints: (a) Precise location, alignment, and control of motion about the orthotic joint axis; (b) Virtually free motion for all or some of the joint range, when desirable; (c) Consistent, definite limitation (blocking) of certain portions of orthotic ankle joint motion; (d) Range of easily adjustable motion assist options; and (e) Firm control of the varus/valgus alignment of the foot plate with respect to the calf section of the orthosis.

In the 1970s, knee and ankle flexure components were being injection molded (principally of polypropylene) for use in fracture orthotics. The limitations of these "long" flexures quickly became apparent. They were long enough to allow virtually free motion, but they buckled easily when subjected to even small compressive or transverse loads commonplace in orthoses. "Long" plastic flexures simply cannot provide the necessary transverse strength and stability.

The principles of deformable body mechanics clarify that only a "short" flexure can approach some of the performance characteristics of traditional metal joints. The active bending length of a flexure compared to its transverse thickness (in the direction of bending) is, in fact, an extremely important ratio with fundamental ramifications for all aspects of performance. The shorter a flexure is (i.e., the lower the length to thickness ratio), the more it can withstand compressive and transverse forces while preserving original alignments between the calf and foot portions of the orthosis. Indeed, one-piece molded polypropylene cabinet door hinges of a "short" flexure design were already replacing some metal hinges in the early 1970s.

The author began experimenting with the design and use of short flexures for AFO ankle joints at Gillette Children's Hospital[1] in 1974. Eventually, with contributions from other practitioners (1), those experiments led to the introduction of the Gillette polyurethane ankle joint by Becker Orthopedic[2] in 1988. Unfortunately, the low modulus of elasticity of the flexures (which is necessary to achieve low bending resistance of the "short" self-aligning cylindrical design) is a problem in many potential applications. The relative "softness" of the material made the

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Comparing two new Tamarack Flexure Joints on the left with two joints which have served 2,229,757 cycles (no apparent damage).

flexures "stretchable." We must consider that joint elongation of as little as one eighth of an inch on an adult AFO represents plantar flexion motion of about four degrees past the stop. Therefore, these free motion ankle flexure joints, cast of a single material, are not capable of controlling motions due to significant varus/-valgus or plantar flexion moments imposed on the orthosis.

Artist's sketch of a free motion type Tamarack Flexure Joint™ showing the internal tension load-bearing element.

The engineering challenge was then to refine flexure design in a way which preserves the free bending motion and self-aligning characteristics but eliminates the "stretchiness." The author pursued that technical goal quite intensely in 1993 and 1994 at Tamarack Habilitation Technologies, Inc. The key is to embed a flexible but relatively inextensible tensile load bearing element (TLBE) along the longitudinal axis of the flexure. All neutral bending planes of the flexure pass through its longitudinal axis, so locating the TLBE there will not significantly alter bending flexibility or the self-aligning capability of such flexures. The Tamarack Flexure Joint™ which utilizes that composite design was introduced by Tamarack Habilitation Technologies[3] and Becker Orthopedic in the spring of 1995 (Figure 1).

As development of the composite flexure proceeded, a comparative durability test machine provided the most important performance feedback. The machine, similar to that described in (1), subjects AFO ankle joints to cyclical motion and shock loading. The shock loadings are severe enough to generate complete fractures through the stainless steel stirrup of conventional metal AFOs in less than 200,000 cycles. Steel ankle joints designed for use with plastic shell AFOs can be completely worn out in about 500,000 cycles. In contrast, Tamarack Flexure Joints exceed 3,000,000 cycles on that test machine before failure or damage.

It is part of the nature of short flexure joints that the precision and reliability of their performance is enhanced by proper and repeatable anchoring, including the correct amount of coverage. For that reason, a simple fabrication system utilizing molding dummies was introduced along with the new flexure design. The slightly altered dimensions of the molding dummies create vacuum-formed cavities which more snugly and completely enclose and anchor the flexure joints when installed. The end result is a flexure joint which approximates the precision and control of metal joints at a fraction of the weight, bulk, cost, and labor time.

One fundamental modification to the composite flexure design creates a motion assist option. It was explained earlier how strategic alignment of the tensile load bearing element (TLBE) along with the neutral bending plane nullifies its effect on bending flexibility. However, if the TLBE is aligned well away from the neutral plane, it will have a very strong effect on flexure bending. The configuration shown in Figure 2 has the TLBE "bowstrung" across the concave side of the flexure, which is pre-flexed 45 degrees. When these flexures are installed in an AFO, they tend to hold the foot in a dorsiflexed position. As the ankle of the AFO is moved back and forth through neutral alignment, the flexures provide a surprising amount of dorsiflexion assist power in a very small package. That is accomplished by the virtual inextensibility of the offset TLBE converting the polyurethane column from a simple bending flexure to a columnar compression spring. This flexure joint design variation became available in December 1995.

The main factors affecting the magnitude of dorsiflexion assistance are the durometer or "hardness" of the flexure material and the size of the flexure joint. A larger size molded of a higher durometer material will generate stronger assistance. The free motion flexures and the two durometers of dorsiflexion assist joints manufactured by Tamarack are interchangeable within each size (large, medium, and pediatric). The cavity created by the large molding dummy will receive any one of the three large flexures. This interchangeability currently gives the orthotist six possible combinations of motion assist (from free motion to a maximum assist) for each size.

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Reference

(1) Carlson, J.M., Day, B., Berglund, G. Double Short Flexure Type Orthotic Ankle Joints. *Journal of Prosthetics and Orthotics,* 1990; 2:4:289-300.