

*The following article is reprinted with permission from Composites Technology magazine. The original article appeared in the October 2007 issue.*

## **Equipment Manufacturer “Springs” for Composites**

***Vibratory conveyor a natural fit for flexible, contoured composite spring arms.***

### **Engineering challenge:**

Design a high-strain capable, tough and durable flat spring for a vibratory conveying system that outlasts competing versions.

### **Design solution:**

A machined “stress contoured spring” that is thinner in the middle than the ends takes high strain and deflection without stress cracks despite having a significant amount of the composite machined away.

In composite design, the simplest solution tends to be the best. A case in point is an industrial spring arm manufactured by Gordon Composites Inc. (Montrose, Colo.) for a vibratory conveying system built by Key Technology, Inc. (Walla Walla, Wash.), a supplier of process automation systems.

Vibratory conveying is a necessity for food products, notes Gordon’s general manager Steven Johnson, because traditional flat conveyor belts become contaminated by food waste and require lubrication that is incompatible with the U.S. Department of Agriculture’s edible food standards.

Key’s trademarked Smart Shaker family of conveyors consist of an easily-cleaned, flat stainless steel table or “pan” supported above an underlying rigid metal frame by multiple spring arms – upright rectangular composite plates, about 3 inches wide by 10 inches long (75 mm by 250 mm) and about 0.5 inch/13 mm thick – spaced approximately 12 inches (300 mm) apart and canted backward 37.5° from vertical (see photo, p. 72). Stainless steel fasteners connect the spring arms to the pan above and to the frame below.

When energy is applied to the frame by Key’s Iso-Drive electric gear motor, the force causes each spring to move forward and backward through an arc many times per second — generally at about 14 hertz — causing the pan to move slightly upward and forward in an arc, then back, with each stroke. The resulting movement propels the food product on the pan forward.

Ed Pilpel, Gordon’s executive vice president, explains that Key asked Gordon to provide a composite spring arm to replace composite springs from another supplier. Gordon drew on its 50-plus year history as a supplier of composite “limbs” to the archery bow industry for a replacement spring design, says Gordon’s CEO Mike Gordon. “The technology we have used for years in archery bow limbs,” he says, “has carried over into growing industrial applications, like the trademarked StrongArm spring for Key’s vibratory conveyors.”

### **Demanding Requirements**

Originally made from steel, then composite material, Key’s flat springs had historically required too-frequent replacement because of fatigue, says Gordon. Gordon Composites was tasked with developing a more durable spring arm solution for Key’s food product conveyors.

While simple in form, a composite spring arm is a surprisingly high-performance part with significant performance requirements. “Because the spring arms are mounted at an angle from vertical, they’re actually being bent in an S-curve many millions of times over the course of operation,” says Gordon about the Key spring arms. Fatigue resistance is essential, and to achieve it, the part must have very high elongation and strain capacity to maintain a constant “spring rate” (that is, the change in force the spring exerts divided by change in deflection) over its lifetime, which can be billions of cycles. Johnson explains that if spring rate decreases it can eventually cause spring failure, which has a devastating effect on the vibratory conveyor: “The machine becomes unbalanced, or ‘out of tune’ as they say in the conveyor industry, and it can lead to a cascading failure of additional springs as they take increased unintended loads.”

Gordon’s archery limbs were a natural starting point for the spring arm design because of their similarity to the spring arm in general shape and dimension. Fastened to the ends of a bow grip, Gordon’s flat, rectangular archery limbs connect the bow’s grip to the bowstring and are subjected to tremendous deflection and high loads each time the string is pulled back to “nock” an arrow. A Gordon archery limb is a flat billet made with unidirectional E-glass ends wet out with epoxy resin in a proprietary process that the company calls pullforming. With fiber loading between 67 and 70 percent and fibers in the axial direction, the billet exhibits good tensile strength and stiffness as well as very high elongation. The glass/epoxy limb can accommodate more than 2 percent strain at failure, points out Pilpel, a necessity that rules out carbon fiber as an option – while carbon’s tensile modulus is high, it doesn’t have the necessary elongation and strain capacity for this application.

Despite the functional similarities between bow limbs and the spring arms in concept, initial spring prototypes posed unanticipated problems during tests. When the first spring billets were pullformed, drilled at each end and clamped in a test fixture to simulate actual vibratory conveying machine operation, stress risers at or near the fastener locations sometimes caused cracks. A solution was needed to give the spring sufficient strength and strain capacity for cyclical S bending while reducing stress at the fasteners. Simply making the billet thicker wasn’t an option, notes Johnson, since Key required springs within a specific spring rate range, which is thickness-dependent.

Using COSMOS finite element analysis (FEA) design tools and additional stress analysis software from SolidWorks Corp. (Concord, Mass.), the Gordon team experimented with various billet configurations and material combinations, using a symmetrical, full-length finite element model of a 10-inch-long spring created with approximately 10,000 nodes. The eventual solution selected, based on known machine loads, cycles and deflections, was a billet with the middle portion about half as thick as the ends. Such a shape, which Gordon calls a “stress contoured spring,” would be manufactured by machining away about 30 percent of the billet’s mass. The shape effectively equalizes applied stress along the length of the billet, eliminating the issue of stress risers at the fastener holes, says Pilpel.

He concedes that cutting fibers is counter-intuitive and considered undesirable in composites, reducing overall strength of the part. “But in this case, it takes a compressive stress of about 150 ksi/1,034 MPa to cause failure of the shaped billet, while the operational stress on a spring arm due to the vibratory conveyor is about 15 ksi/103.4 MPa causing 0.375 inch/9.4 mm deflection — that’s about 10 percent of the part’s total stress capacity, so it has more than enough margin despite the knockdown caused by machining.”

Two “cross” plies, with fibers at 90° to the axial fibers, were added to the pullformed laminate about one-third of the distance from the top and bottom surfaces of the billet. Johnson explains that the cross plies get machined away near the center of the billet but remain intact at the ends to provide

split resistance. Further, both billet faces are covered, after pullforming and machining, with unidirectional E-glass/epoxy skins that perform several functions: they protect the machined fiber ends; they function as skins over the billet “core” to create a classical sandwich structure for additional stiffness and strength; and they give the spring a cosmetic finish layer, with the addition of a blue pigment, that satisfies Key’s desire for a signature look. The skins, because of their stiffness, do add significantly to the stiffness and the overall performance of the part, notes Johnson.

### **Five Years without a Failure**

To make a finished Key spring, more than 1,000 E-glass roving “ends” supplied by PPG Industries (Pittsburgh, Pa.) are brought from a Gordon-designed multirack creel into a tensioning block-and-comb mechanism, then through an epoxy bath and into the company’s proprietary pullforming system where longitudinal and cross-ply ends are combined to form a billet, which is then sent through an in-line oven for a 350°F/176°C cure. The epoxy is supplied by Dow Epoxy (Midland, Mich.); the anhydride curing agent comes from Lindau Chemicals Inc. (Columbia, S.C.). Pilpel says the care with which the fiber is tensioned and aligned, as well as the pullforming process itself, accounts for the billets’ exceptional alignment and hence, their strength and elongation properties.

Billets are machined on a custom horizontal milling machine to remove material. Pilpel explains that while a continuous perfect curve would be ideal according to the modeling results, the machine actually cuts out the material in three passes, forming flat planes rather than a constant radius. “The machine head is so large in comparison to the finished spring arm that it produces very large radii that don’t affect the part performance,” he explains.

Skin laminates are pullformed on an adjacent line with a “belt finish” that produces the semigloss blue surface. After the billets are machined, workers apply aviation-grade epoxy film adhesive sheets supplied by Advanced Composites Group (ACG, Tulsa, Okla.) to both faces of the billet and place the face sheets on the adhesive. The completed sandwiches are placed in a two-part, multicavity heated steel mold, and the mold is closed within a Simplex (Broadview, Ill.) H-Frame 200-ton compression press for 30 minutes. Molded billets are then cut to final dimension (3 inches wide by 10 inches long/75 mm by 250 mm), drilled and identified with a batch code and Key logo. The production rate for the Key StrongArm spring is several thousand parts per day.

Results have been very good, reports Pilpel. Testing shows a higher spring rate for the machined contour spring design than for either a flat composite or steel spring, which saves money because fewer springs are needed on each conveying machine. Dynamic tests also show that the contoured spring’s spring rate is nearly a flat line – that is, there is no change in stiffness given the same deflection, even after years of operation, thanks to a strain capacity of 2.3 percent. Says Johnson, “Because our contoured springs can take so much deflection, they have a higher tolerance for out-of-tune machine conditions and can take higher unanticipated loads, something the customer appreciates.”

Concludes Pilpel, “These contour springs have been in use in one customer application for more than five years, and they exhibit at least twice the life of the previous flat spring style – that’s a testament to the durability of this simple yet hardworking design.”

– Sara Black, Technical Editor