Bicycle Fork Manufacture

Pedal Powered Precision in Pursuit of Speed!

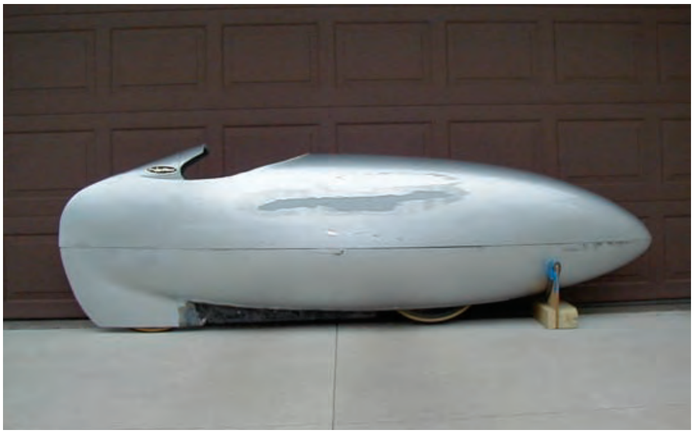
by Andy Grevstad

Photos by Author

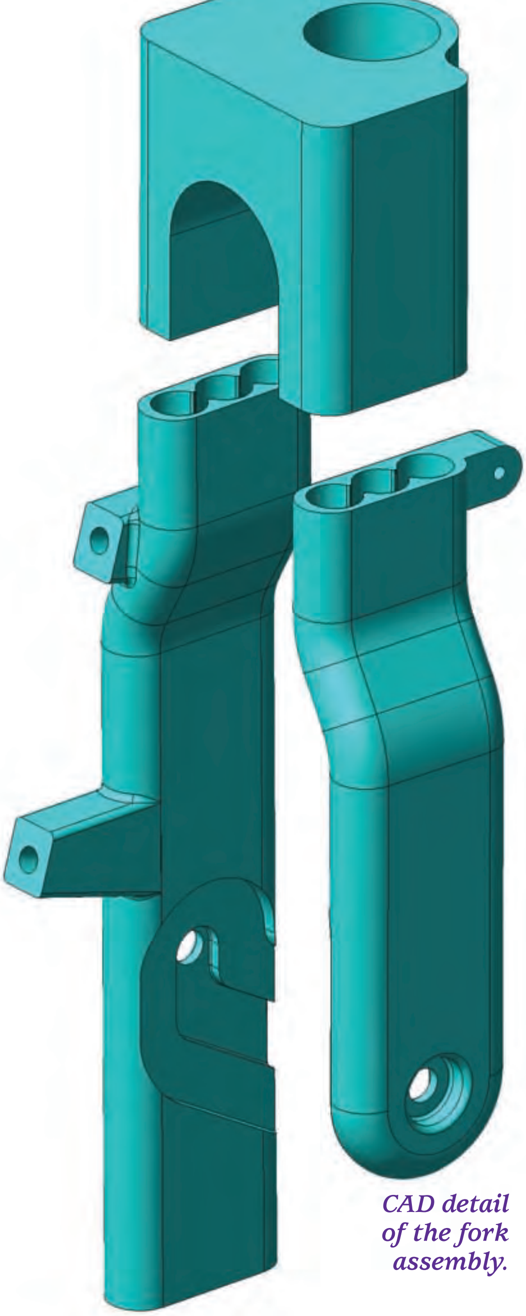
Dan Bye, owner of Tosa Tool, has run across his fair share of unusual customer designs and applications over a twenty-year career as a tooling and prototype machinist in southeastern Wisconsin. But when Eric Ware, an engineer from Minnesota, contacted Dan for help with bringing his new bicycle to life, it was hard not to do a double-take.

"Well, it's not like any bike I've seen before," recalled Dan. In fact, it's not like any bike you might otherwise see pedaling down the road on any given day. Eric's bike has one purpose in mind – speed. Eric built the aerodynamic racer to compete with other designs in the World Human-Powered Speed Challenge, held annually since 2000 near Battle Mountain, Nevada on State Road 305, a remote stretch of pavement renowned for its flat, smooth, and straight surface. Each year, a small group of enthusiasts, builders, and thrill-seekers meet on this lonely desert road to compete to become the fastest of the fast on two wheels.

Eric, a recumbent bike enthusiast, had attended the event four years previously, competing once prior in



Tosa Tool: *Dan Bye's contract machine shop is based out of his garage to keep costs down.*



CAD detail of the fork assembly.

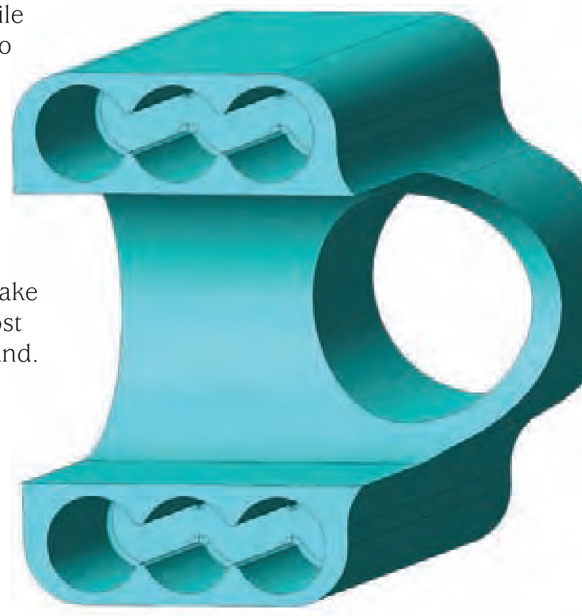
2005 on a trike he had borrowed named *Orange*. For the 2008 event, he found an existing Human Powered Vehicle (HPV) available from the Australian team Tri-sled and began an expansive overhaul. "The mechanicals of the bike did not meet my expectations, so I pulled the bike out and set it aside," explained Eric. With the help of partner Mark Anderson, Eric built an entirely new bike of his own design to go inside the fairing. In particular, a new unique fork design would require CNC machining.

"I came across Tosa Tool while looking into different options to get the parts made," recalled Eric. He had found that many traditional machine shops were unwilling or unaffordable to hire for his small project. In Dan, he found somebody with CNC capability that was willing to take on the work at a reasonable cost while providing quick turnaround.

Eric contracted Tosa Tool to supply machined components for the bicycle's fork assembly, for a total of three distinct parts. Two of these parts, the left and right fork dropouts, hold the front wheel in position at one end and each attach to the third part, the crown, by a glued joint. The crown is glued onto a steerer tube that inserts into the bicycle frame. Precision, especially concerning the hole positioning that accepts the pins to mate the fork and crown parts, would be paramount to Dan's success in the project.

MACHINE SHOP FOR HIRE… IN HIS GARAGE

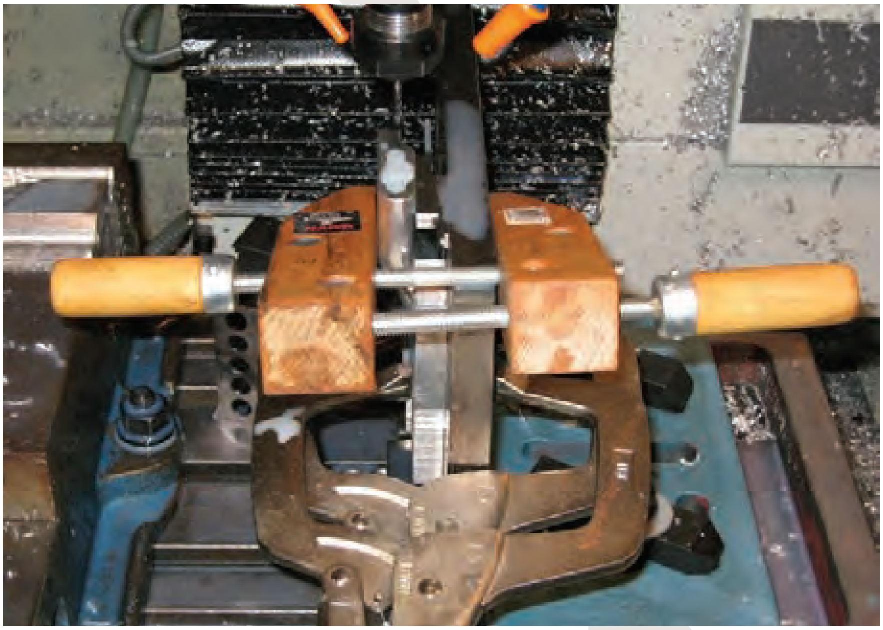
After many years working as a machinist for shops in the Milwaukee area, Dan began his own small shop in 2006 when he purchased a Tormach PCNC 1100 lathe, which he initially set up in a basement workshop. "My wages had been stagnant for a few years and I began to think of ways to be more entrepreneurial," recalled Dan. "Right before I went off on my own, I had been making a lot of onesies and twosies at the shop I was working for," said Dan, referring to the prototyping and die making work that the shop took on to augment contracts for larger production volumes. He realized that much of the value added to this work was a result of the manufacturing design done by the machinist: CAD/CAM programming, fixturing, and part inspection. By keeping his fixed costs down – utilizing affordable machine tools like the PNC 1100 with affordable CAD/CAM software – Tosa Tool has found a successful



CAD detail of the fork crown.

niche providing prototyping, wear item replacement, and tooling. "My business is to provide a high level of service at a competitive price for customers interested in quick turnarounds for small part quantities." To keep his shop busy, Dan uses targeted direct mailings to area plant maintenance engineers and managers to drum up business as well as e-commerce sites like *mfg.com* to find open bids for work around the globe. He also diligently maintains his website, *tosatool.com*, by constantly updating and tweaking keywords to drive web traffic to his site from search engines. "I'm keeping busy- whether it's cutting metal or marketing the business, there's always something to do," explains Dan.

Detail of Button Mill showing collar and TTS conversion kit.



Workholding setup for precision drilling.

Soft jaws.

Workholding close up showing adjustable parallel.

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N1897T7M06(boring bar)
N1898G00G54X1.625Y0.0S950M03
N1899G43H7Z0.05
N1900G1G91X-.04Y-.04F5.
N1901G1X.04Y.04F1.
N1902G0G90
N1903M08
N1904G86R-1.1Z-2.8P0F5.0
N1905G80
N1906G0Z1.0
N1907M09
N1908G91G28Z0Y0
N1909G49G90
N1910M30
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Figure 1: Sample NC code for Dan's Positive Approach Routine

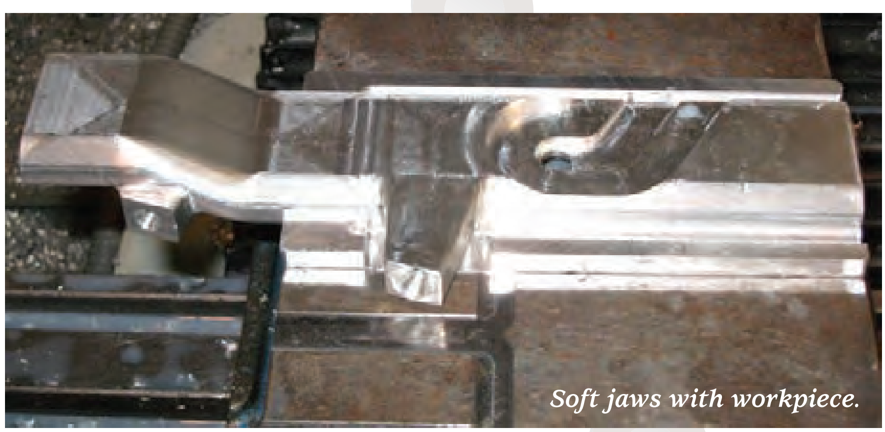
AN INTERESTING MATERIAL

While Eric's design called for the more familiar 6061-T6 aluminum for the dropouts, he chose *Fortal* for the critical crown piece. *Fortal* is a high strength aluminum alloy designed to have extremely consistent mechanical properties throughout the cross section of the plate and is typically used to make light weight die sets for metal stamping. "I was concerned about flexure stress in the crown and chose *Fortal* because it had superior mechanical properties to 6061," said Eric, explaining how the fork must support the forces from the bike's drivetrain. He was able to locate a scrap piece that would be big enough for the crown and sent it to Dan. "I hadn't had any experience with it before, but it cut great," stated Dan.

FROM DESIGN TO TOOL PATH

While Eric provided Tosa Tool with CAD files for part design and workpiece material specifications, it was up to Dan to come up with the rest of the manufacturing design. The 3D contoured features found on each fork component necessitated a CAM solution. Dan chose FeatureCAM to design tool paths for each part based on the 3D design files that Eric had sent. Using FeatureCAM, Dan was able to identify particular features on each component (holes, pockets, 3D surfaces, etc.) and command the software to generate NC code for each feature using cutting tools he has defined and identified as available in the software's tool library. Prior to cutting any metal, Dan reviewed each tool path with FeatureCAM's simulation option. "The *Fortal* was pretty expensive, so I made sure I got it right before cutting any metal."

Dan's first decision was to choose a tool for roughing out each part to near its final shape before using a ball end mill to shape the final surface contours. He settled on an indexable button mill from Shars Tool Co. with a cutter body diameter of 1".



Soft jaws with workpiece.

Parts prior to final machining.

Right Fork completed.

For the "buttons", he chose two RNMG-32 inserts, a round carbide insert also available from Shars Tool. Dan made this choice based his previous experience with similar tooling. "I used to use negative rake button mills at Triangle Tool while I worked there making plastic injection molds. Because of the geometry, you can get very close to the finish size of a boss before you finish it, often eliminating a semi-finishing tool. I hadn't done this before with the Tormach, but it worked great." Dan adapted the tool to the Tormach's toolholding system by adding a simple steel collar above the cutter body that he picked up at his local hardware store. He added a setscrew to hold it in place on the shank.

FIXTURING: THE CRUX OF THE PROBLEM

According to Dan, the most difficult part of the project involved meeting the demanding specifications for the end holes on the crown and fork pieces. "I was pleased when I got a .498"Ø minus pin to slip fit all the way down to the radius at the bottom of the holes."

The key to hitting the tolerances was creative work holding. To ensure the workpieces were held as firmly as possible, Dan machined a set of custom soft jaws out of aluminum to attach to his Kurt angle lock vise. "I buy blanks for the soft jaws that come already fit to my vise," says Dan. "It saves a lot of work." For the forks, Dan notched out the jaw blanks to securely hold each piece during final contouring.

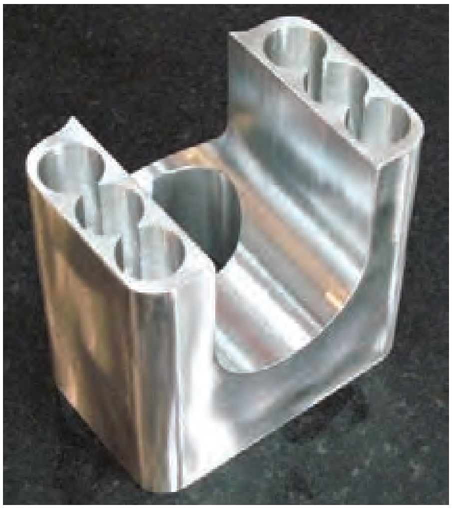
Dan used an adjustable parallel to accurately position the end of each fork and combined that with a wooden handscrew clamp to securely hold the part in place without marring the finish, while also reducing vibration. "Wood was a favorite of the old toolmakers at Allis Tool and Machine for clamping delicate projects while I worked there."

Still, Dan proceeded with caution when it came time put tool to metal. He used another trick he'd seen before on a *Fadal* machining center to ensure positioning of each hole in relation to each other was as precise as possible.

Dan recalled *Fadal* controllers came preloaded with M-code commands for *positive approach on* (M46) and *positive approach off* (M47). "It works like this," explained Dan. "In a drilling or boring cycle it [positive approach] moves the drill or bore to the positioning called for in the program. Then, it moves the X- and Y- axis negative .035" at 10 IPM. Then it crawls back to the correct position at 3 IPM. This "positive approach" keeps the center-to-center positions between holes within ±.0002" or so. Without it they are within ±.0025"." This was done both with a boring bar for the steerer tube hole and with a 0.125"Ø ball nose end mill for the end holes.

Table 1: Tolerances

Feature	Diameter	Tolerance
End Holes	.500"	+/-.001"
Axle Holes	.319"	+/-.002"
Steerer Tube Bore	1.184"	+/-.0005"
General Part Tolerance	NA	+/-.0025"



Crown completed (bottom).

Crown completed (top).


Left Fork completed (side 1).


Left Fork completed (side 2).

an improved, stiffer seat and new, more accessible shifter are in store as well.

Ultimately, Eric sees potential top end speed for *Wedge* between 55 and 60 mph. “I do plan to compete again next year. I need to learn to ride *Wedge* and get some miles in it before I will be able to evaluate it objectively.” As for Dan, his busy order book at Tosa Tool doesn’t leave much time to dwell on the past. He does acknowledge, however, that he’s keeping an eye on *Wedge*. “I spend most of my time making pretty ordinary parts,” says Dan, “It’s been fun to watch Eric’s project come together.”

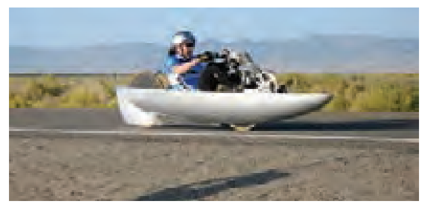
Table 2: Cutting Schedule

Part	Material	Stock	Size
Right Fork	6061-T6	aluminum	7” x 2-1/2” x 1-1/2”
Left Fork	6061-T6	aluminum	9” x 3” x 1-1/2”
Crown		Fortal	3-1/4” x 3-1/4” x 3-1/4”

OFF TO THE RACE

After verifying final measurements, Dan cleaned up the parts with Scotch-Brite and sent them off to Eric. Eric independently confirmed all measurements before completing final assembly of the fork using epoxy to attach each dropout to the crown and wrapping the entire assembly with carbon fiber. “I was pleased with the quality Dan was able to deliver,” commented Eric.

Final assembly was completed just in time for Eric to complete a qualifying run in September 2008. Eric and his team worked feverishly trackside in the week leading up to event. They were rewarded when Eric rode the bike, renamed *Wedge*, to a top speed of 34.31 MPH on the final day of the event. While it fell far short of the incredible record-setting run earlier in the week of 82.33 MPH set by *Diablo III* and longtime competitor Sam Whittingham, Eric is optimistic for the future. For one, *Wedge* competed without its fairing – the aerodynamic shell designed to surround the bike’s frame. “I need a lot more practice before I’m comfortable enough riding inside the fairing,” admitted Eric. Additionally, the bike is incredibly difficult to balance and steer at low speed; the steering arc is constrained to a mere 6 degrees by the fairing to provide maximum aerodynamic benefit. “It’s really a team effort,” says Eric. “The bike needs people to help start it at the beginning and catch it at the end so it doesn’t fall over.” Future plans for



FOR MORE INFORMATION

FeatureCAM, *www.featurecam.com*

Shars Tool Co., *www.shars.com*

Tormach PCNC 1100, *www.tormach.com*

Tosa Tool, *www.tosatool.com*

The Human Powered Vehicle Super Site, *www.wisil.recumbents.com*

Tri-Sled Human Powered Vehicles, *www.trisled.com.au*

Special Thanks to *Wedge’s* race team sponsor *www.servicelighting.com*.

Table 3: Dan’s Tool List

Tool	Operation	Speed, Feed	Notes
1/4” Ball End Mill	Secondary Fork Roughing	4500 RPM, 27 IPM	Solid Carbide, 4 Flutes, TiAIN Coated
1/2” Hanita Varimill	Primary Fork Roughing	4500 RPM, 30 IPM	Solid Carbide, .062” Corner Radius, TIALN Coated
“K” Twist Drill	End Hole Drilling		Solid Carbide
1/8” Ball End Mill “O” Twist Drill 1/8” Twist Drill	 Peck Drilling Peck Drilling	 3021 RPM, .0047 IPR 5200 RPM, .0019 IPR	
Indexable Button Mill	Crown Roughing	3500 RPM, 28 IPM	RNMG-32 Carbide Inserts