Lifting Boats, Measuring Gears

Giant Geared Wheel Lifts, Lowers Boats in Scotland

In past centuries, the Forth & Clyde and Union canals were an important commercial transport corridor stretching 68 miles across central Scotland.

Boats had to pass through a series of 11 locks to go between the Forth & Clyde Canal and the higher Union Canal.

Today, boats go between the two canals and pass through only three locks. The remaining vertical distance is covered with the help of three large spur gears.

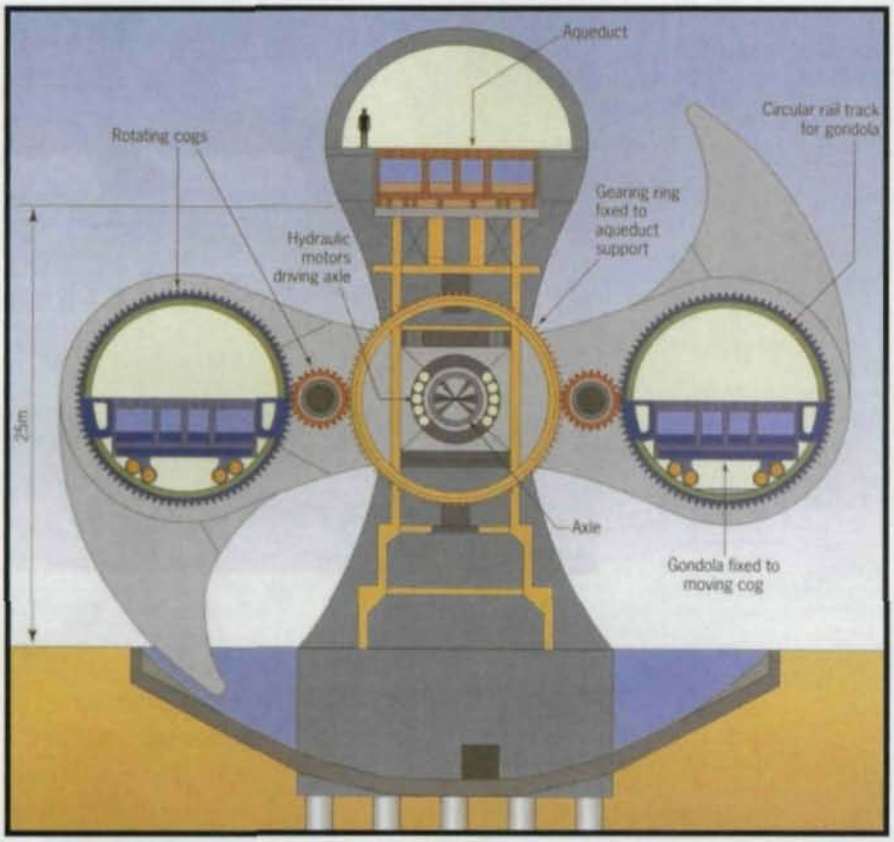
Those gears are part of a huge rotating boatlift at the Forth & Clyde end of the waterway, by the town of Falkirk, Scotland. Called The Falkirk Wheel, the boatlift and its gears appear on *Gear Technology*'s cover.

The Falkirk Wheel is 115 feet high, 115 feet wide and 100 feet long. It consists of two large arms that rotate around a giant axle. Each arm has a gondola that can carry up to four boats at a time. The wheel itself can lift 1.32 million pounds, 660,000 pounds at each end.

One gear is attached to the wheel's taller concrete column, one is attached to one gondola and one is attached to the other gondola. These steel gears are stability gears, and each one has 88 teeth.

Each gear consists of 22 segment plates. When its plates are assembled, each gear has a pitch circle diameter of 31 feet 2 inches and weighs almost 9,300 pounds.

There also are two steel idler gears, one in each arm, between a gondola gear and the column gear. Each idler gear has 21 rollers that mesh with the teeth of its two mated spur gears.



In about five minutes, The Falkirk Wheel raises and lowers boats almost 89 feet via its geared gondolas, passing the boats between aqueduct and basin near Falkirk, Scotland. Five minutes rotates the wheel's arms 180° and is part of the wheel's total transit time of 15 minutes. (The diagram's two small gears became two sets of rollers on the actual wheel.)

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The wheel's axle is supported by two concrete columns and is driven by 10 hydraulic motors with gearboxes that have 1,000:1 ratios.

Also, the axle is supported on bearings, with an integral 188-tooth ring gear at the drive end. The bearings are each 13 feet in diameter, are located in both concrete columns and can support more than 4 million pounds.

The axle rotates the wheel's two arms. As the wheel rotates, the gondola gears and idler gears rotate around the column gear. The gondolas stay level because they're supported by wheels that run on circular rails in The Falkirk Wheel's arms. The wheels run on sealed, double-row, spherical roller bearings.

The Falkirk Wheel was created as part of The Millennium Link, a major project to reconnect and restore the Forth & Clyde and Union canals.

An important commercial route in the past, the canals were used less and less with the rise of the railroad and later the automobile. In 1963, the British Parliament closed the rights to navigation on the canals. So, the canals weren't maintained to keep them navigable.

"Both canals were built to carry

freight," Robert Jackson says. "They fell into disuse."

Jackson is a mechanical engineer for British Waterways Scotland. British Waterways runs the United Kingdom's canals. British Waterways Scotland is a part of that agency.

The canals' disuse ended in 1998, with the start of The Millennium Link. The canals were made navigable again and were reconnected by The Falkirk Wheel, which became operational in June 2002.

With the canal's rebirth came a new use: leisure. Cruise boats, canoes and luxury boats for hire now ply the waterway.

"It's used commercially for people, but not for hauling goods," Jackson says.

Now the wheel and canals are promoting commercial development along their course. The development includes offices, shops, pubs and restaurants.

That course is new, though. With navigation rights closed and with the automobile's rise, the canals became blocked in more than 30 places by roads built in the 1960s.

To reconnect the two canals, British Waterways extended the Union Canal almost a mile westward, lowered it through two locks, then took it underground—below the main Edinburgh-Glasgow railroad and the historic Antonine Wall, a defensive structure built by the Roman Empire.

The canal then emerges from its 480-foot tunnel as a 99-foot-high aqueduct. The aqueduct ends at the top of The Falkirk Wheel.

Floating in the wheel's top gondola, boats slowly swing down almost 89 feet to New Port Downie, the wheel's boat basin. Boats then pass through a lock and are down in the Forth & Clyde Canal.

Crowning this engineering feat is acknowledgment of The Falkirk Wheel as a machine that achieves the level of art.

The Royal Fine Art Commission for Scotland says The Falkirk Wheel was "a definite attempt to design the wheel for the 21st century. This design is considered to be a form of contemporary sculpture . . . a truly exciting solution."

Analyze Gears Without Locking Out Measurement Values

The ND430 Next Dimension® measuring analysis system from Process Equipment Co. of Tipp City, OH, is designed to measure post-heat treatment distortion or injection molding shrinkage.

The measuring software develops a

link between tooth thickness and helix/involute measurements. With standard analysis methods, form deviations are visible. With the Process Equipment analysis, traces are plotted to their absolute position in space relative to a design tooth thickness.

This allows designers to see the position along the face width and involute where every measured tooth will be oversized or undersized. With plastic and powder metal gears, this data can be used to more quickly adjust manufacturing parameters for making acceptable parts. Also, if tooth thickness varies around a gear's circumference, designers can see the effects on helix and involute forms.

"If you're only performing conventional helix and involute measurements (not tooth size), the effects from machine volumetric accuracy are of lesser importance, except when you are measuring a gear that is at a diameter or height different than the calibration artifact for that machine" says Mark Cowan, director of metrology for Process Equipment.

"However, when you are determining tooth size, absolute probe positioning in space becomes very important. With our package, we have verified the accurate probe positioning in space for the entire machine measuring volume by mapping the full travel of each of the x-, y- and z-axes. This is unique in the industry."

Normally a measuring probe moves when it contacts the tooth surface. Most systems "lock out" these measurement values.

These measurements, combined with their volumetric mapping, ensure the machine knows the probe's location in space, allowing it to accurately measure tooth thickness.

Data can be shared with process equipment and finishing tool manufacturers because the program creates files of the average compared helix and involute traces.

Similar systems are made by other companies, such as Klingelnberg Co. of Saline, MI, and M&M Precision Systems Corp. of West Carollton, OH.

Federal Mogul's sintered processes division bought a less sophisticated version of the Process Equipment system in 2001 to inspect process changes. They chose Process Equipment, partly because of its measurement certainty of 0.002 mm or 2 microns, with some micron repeatability.

"The main reason Federal Mogul bought the ND430 is because it was able to inspect an unknown root area using a 3-D probe," says Jason Barnhart, process development engineer at Federal Mogul.

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