Taper Control:

Behind the Scenes of Dynamic Waterjet® with Active Tolerance Control™

Taper Control: Behind the Scenes of Dynamic Waterjet®

Waterjet technology took a giant leap forward with the introduction of Dynamic Waterjet by Flow International Corporation. Dynamic Waterjet uses Active Tolerance Control™ to cut virtually taper-free parts with improved tolerance, 25%-400% faster than a standard waterjet, depending on the application.

In the past, waterjet users ran their machines at slower speeds to achieve acceptable tolerance levels and minimize taper. Other shops used different cutting methods such as laser, EDM, and CNC machining. According to Mr. Felix Sciulli, Senior VP of Engineering at Flow,

> *"Taper was the last major arena in which other cutting methods could claim superiority to waterjets. The introduction of Dynamic Waterjet will enable waterjet users to improve the quality of their parts and expand into new markets, helping waterjet strengthen its position as a preferred choice among manufacturers."*

The Science of Taper

Taper as a side-effect of waterjet cutting is well known by the industry, and waterjet technologists recognize the physics that produce taper. However, until now, no one has successfully overcome the mechanical, mathematical, and software programming challenges of the complex motion control involved with taper control.

Abrasive waterjets use the force of erosion to cut through a variety of hard materials such as metal, stone, glass, and tile. The erosion power of a waterjet is created by pressurizing water up to 60,000 psi, mixing it with abrasive, and forcing this mixture through a tiny orifice to produce a focused and powerful stream. Waterjets are a superior cutting tool for many applications because of their accuracy and speed, and the absence of heat and dust in the waterjet process.

While standard waterjets are fast, their highest cutting speeds result in tapered edges on cut parts. At higher speeds, taper occurs because the speed and intensity of a waterjet stream are reduced as the jet gets farther from its point of exit from the cutting head. This weakened stream has less cutting ability. Thus, as the stream passes deeper into raw material it removes less material, causing the bottom of the cut to be more narrow than the top, resulting in taper. Dynamic Waterjet controls part taper by constantly adjusting the angle of the cutting head. This angular compensation effectively removes the characteristic taper seen in waterjet cuts.

The Mechanics of Taper Control

In its quest to tackle taper, Flow first developed a proprietary mechanical design that allows for three-dimensional movement of the cutting head. The cutting head of the Dynamic Waterjet features a small articulated wrist that rotates in any direction from its vertical start point.

When the angle of the cutting head is changed to compensate for taper, the waterjet stream is no longer lined up with the desired cutting path. The X, Y, and Z axes must be adjusted to re-align the waterjet stream. Thus, a single change in cutting head angle requires three other separate movements to achieve a successful cut.

In all its complexity, Dynamic Waterjet is designed to move smoothly and seamlessly through cuts. Mechanically, smooth movements are not difficult to achieve. Deciding what combination of movements to use and when—in order to hold the geometry of straight edges, curves, inside corners, and outside corners—was the true challenge in designing the system.

The Erichsen Models

Flow engineers worked for years to develop the advanced mathematical models that control the movement of Dynamic Waterjet. These proprietary, patent-pending models are named for Mr. Glenn Erichsen, a senior scientist at Flow. Erichsen and his fellow engineers drew upon their experience with abrasive waterjet cutting dating back to the early 1980's when Flow invented and patented the abrasive waterjet. Their source data included cutting times for raw material of differing hardness and thickness, the amount and shape of taper at various cutting speeds, the affect of abrasive particle size, mixing tube size, and orifice size on cutting speed, edge quality, and part tolerance, and the affect of tilting the cutting head on taper. All these factors combined determine the behavior of Dynamic Waterjet.

Next, the mechanical attributes of the Dynamic Waterjet design were considered. These include the length of the cutting head and its pivot points, the response rate of the motors, and the mechanical limitations of moving parts. Maximum machine cutting speeds were derived, in part, from this information.

Finally, the engineers used forward and inverse kinematics to calculate the precise movements each of the five axes must make to accommodate a change in the angle and/or rotation of the cutting head. As explained earlier, each change in angle or rotation requires a corresponding change in the location of the X, Y, and Z axes in order to keep the waterjet stream properly aligned with the desired cutting path.

The Software Controller

Until now, machine manufacturers have primarily used CNC controllers to operate 5-axis machines. In contrast, Dynamic Waterjet is operated by FlowMaster®, Flow's PC-based controller. Because this software is easy to use, machine operators need only minimal training to run the Dynamic Waterjet.

The history of FlowMaster software dates to the mid-1990's when Dr. Jiannan Zhou, Flow's expert software architect, set out to write CAD-CAM programs to control FLOW waterjets. He soon discovered

that software control products on the market at that time were not up to the task. Instead, Zhou and his fellow associates created a new machine controller, FlowMaster. They combined the Erichsen models with a controller card, user interface, and electro-mechanical devices. By the late 1990's FlowMaster was a standard feature on all 2-axis Flow machines. With Dynamic Waterjet, Flow took FlowMaster to the next level, a natural extension of nearly a decade of software engineering.

From the users' perspective, FlowMaster is deceptively simple. All mathematical calculations take place behind the scenes, triggering the appropriate motion commands to all five axes at lightning speed. The user simply enters the basic cutting parameters such as material type and thickness, cut speed, and desired edge quality, and FlowMaster does the rest.

FlowMaster knows the amount of tilt and rotation required at numerous incremental points along a cutting path. For example, at high speeds outside corners require increased tilt to prevent coning. FlowMaster also knows the optimal cutting speed to keep parts within tolerance and taper-free. The faster the cutting speed, the more tilt that is required. In most cases the ability to tilt the cutting head allows for a faster cutting speed. Because of this, Dynamic Waterjet produces superior part features at high speeds than those resulting from conventional waterjet cutting.

As with standard Flow waterjets, Dynamic Waterjet is a completely open system. Users can use virtually any CAD file or scan a drawing of their part directly into FlowMaster software.

The Dynamic Waterjet Team

In developing Dynamic Waterjet, Flow called upon the knowledge and skills of Flow associates from around the world. This international team was headed by project leader, Dr. Michael Knaupp of Flow Europe, and included individuals with backgrounds in a variety of disciplines—from mechanical

engineering to physics, from software programming to electrical engineering, from mathematics to abrasive waterjet expertise. Dynamic Waterjet team members hold more than 25 university degrees combined, four of them doctorates, and have more than 350 total years experience working at Flow.

"Dynamic Waterjet is the culmination of several years and countless hours of research and testing," said Erichsen. *"Without the input of dozens of talented individuals, this milestone project would not have been possible. Flow is fortunate to have so many resourceful and innovative associates on its team."*

The Future of Taper Control

Flow expects to refine its Active Tolerance Control technology in the coming years, taking advantage of new developments in mechanics, electronics, and software.

"Flow is focused on increasing efficiencies and lowering costs for our customers," according to Dr. Knaupp. *"Dynamic Waterjet is one giant leap among the many steps we've taken to that end. The magnitude of the cost savings potential is staggering."*