

Focus on five-axis machining



Two views of complex five-axis working — on a Hermle (left) and a Mikron (right)



The second of two special features, which considers control and software

Any machine tool, by the nature of its construction, is a complex mix of geometric, volumetric, thermal and kinematic errors, all of which have the potential to adversely affect the dimensional accuracy of the machined component.

A CAD/CAM system, on the other hand, can produce a perfect mathematical model of what is wanted, while making no allowance for any potential machine tool-induced errors; it is the role of the control system to resolve the differences between the two. In fact, the modern CNC system marks a step change from earlier systems, which were little more than 'dumb' positioning systems doing what CAD/CAM systems told them to do. Any compensation calculations would be performed by the PC hosting the CAD/CAM system rather than by the control with its limited processing power.

However, today's CNC system makes these compensations — and more — in real time. For example, it will compensate automatically when a new cutting tool is shorter or longer than the one it is replacing.

Complex multi-axis machine tools require high-end computing power to keep several axes moving continuously and accurately. Dwell time — while an axis waits for data to arrive, or for a rotary axis to reposition — results in poor surface finish. Eliminating dwell places a big demand on the control, which has to process large quantities of data and deal with extremely fast acceleration/deceleration by using 'look ahead' functions.

That said, a control system is only as good as the information fed into it. Neil Prescott, managing director of Burgess Hill-based Heidenhain (GB) Ltd (Tel: 01444 247711 — www.heidenhain.co.uk), points out that five-axis machining, while not presenting an especially difficult transition from conventional three-axis machining, is invariably complex; he cautions against attempting to program at the machine. "It's too complicated. With a typical five-axis program containing hundreds of thousands of

instructions, you have to be looking to use an off-line programming package with five-axis capability. The impetus behind five-axis machining is primarily components with multiple surfaces that need to be machined at various angles, as in aerospace work. This type of work can be done on a three-axis machine but a significant proportion of the cycle time will be taken for set-ups. Five-axis machine tools may be more costly to buy and maintain, but the productivity benefits are considerable."

Simultaneous compensation

In compensating for the pivoting of a ball-nose end mill as it machines a complex 3-D profile, the control has to adjust the cutter compensation vector in X, Y and Z simultaneously, to keep the tool's contact point constant. This is because, when the rotary axes pivot the tool, the tool length offset that normally relates only to the Z axis now has components in X, Y and Z. In addition, tool diameter offsets that normally only affect the X and Y axes also have X, Y and Z components.

As the tool may also be feeding in the rotary

Optimised roughing and fewer tool changes

Edgecam 2011 R1 (www.edgcam.com) sees the software package's extensive range of milling features for roughing components now included in one special 'composite' feature that optimises roughing and reduces the number of tool changes required.

Instead of having to machine individual pockets and features, this new facility means the user gets a much more complete roughing cycle in one go from Edgecam's Strategy Manager. It optimises the tool-path by reducing the amount of instructions needed, says the company. Additional improvements see the machining simulator's collision checking function improved. Users can now check the turret, its holders and adjacent tools in the turret.

Another improvement is swarf clearance. With prolonged deep-boring operations, material can become jammed inside the bore, and the machine tool has to be stopped to clear it out. The new 'composite' feature allows the operator to retract the tool automatically after a defined amount of cuts and stop the machine, enabling it to be cleared before continuing with the same cycle. Another major improvement in Edgecam 2011 R1 is the ability to merge tool stores, including tool, material and job information. Edgecam 2011 R1 also contains many small but important 'ease of use' improvements; these include new default schemes, improvements to tool-path display, improved sequence error checking, and more picture-based operations.

axes while cutting, all of these offsets have to be updated dynamically to take account of continuing changes in the cutting tool's orientation. This appears complicated when looked at it from a mathematical point of view, but as far as the user is concerned, it's all happening behind the scenes, based on data either transferred from a CAD/CAM system or prompted by the control's own software-based user interface.

The choice of control system is to a large extent influenced by what the end user is already familiar with and by what the machine tool supplier fits as standard. The machine tool manufacturer in turn is influenced by factors such as capability, service/support and price; the manufacturer may also have undertaken development work with one CNC supplier and be reluctant to incur any further development costs with another.

CNC manufacturers are constantly seeking to improve the functionality of their products. Heidenhain, for example, has been involved with five-axis machining since 1991; the company's iTNC 530 contouring control can manage up to 13 axes and a spindle. This system also features an integrated digital-drive control for the drives and motors, while of particular relevance to high-value five-axis work is the TNC function, Kinematics-Opt.

Initiating KinematicsOpt prompts a 3-D touch probe cycle to measure the machine tool's rotary axes (rotary table, tilting table or swivel head) automatically, as and when required. Using the measured values, the software then minimises the spatial error arising from the tilting movements and updates the respective machine constants of the kinematic table.

Designed to support programming either at the machine or at a programming station, the iTNC 530 provides optimum support via

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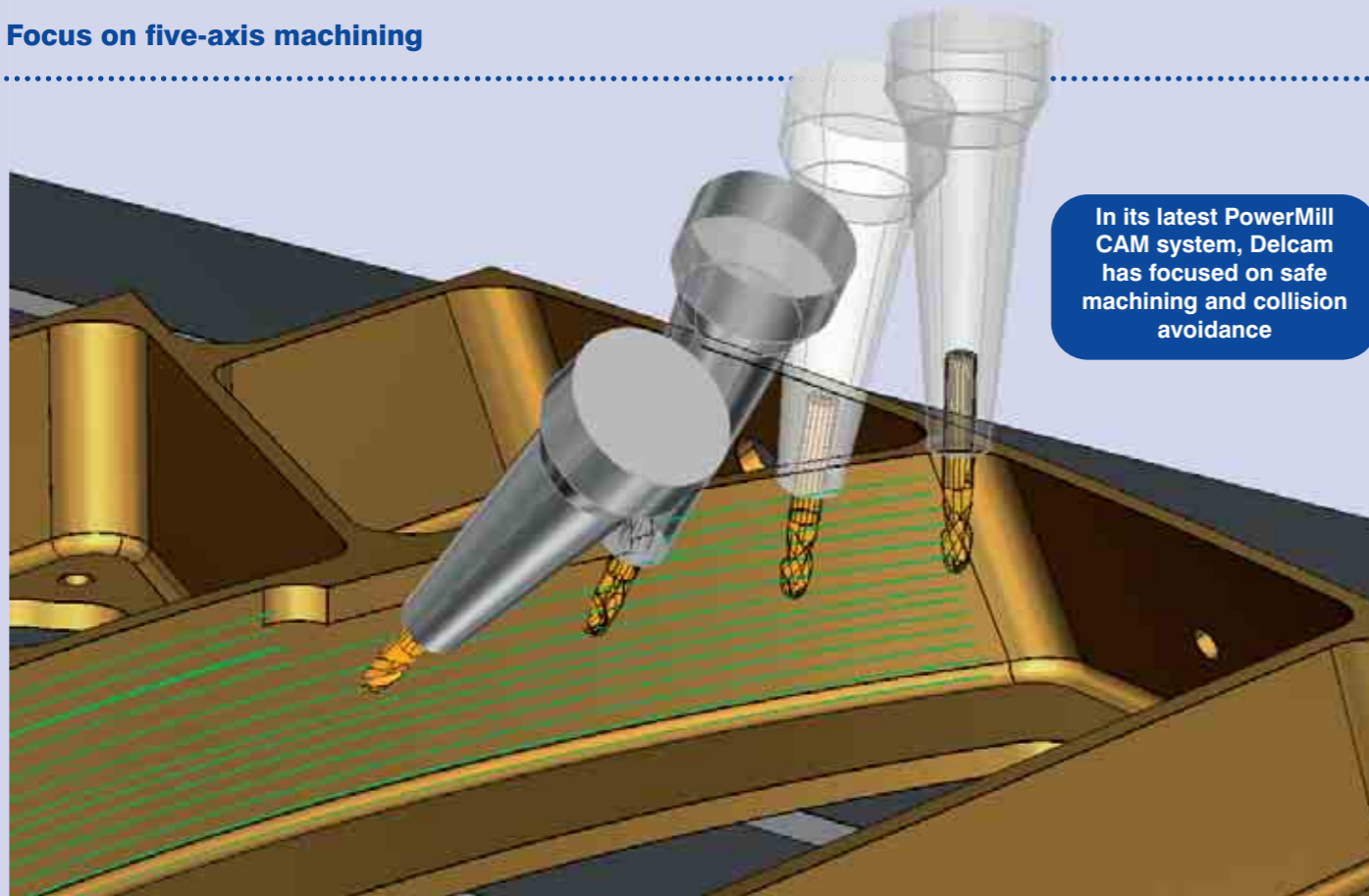
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In its latest PowerMill CAM system, Delcam has focused on safe machining and collision avoidance

Smart.NC or plain-language conversational guidance, as well as from numerous graphic aids with practice-oriented fixed cycles. Well-structured input forms, straightforward graphic support and comprehensive help texts combine with an easy-to-use pattern generator, with a hard disk providing program memory of more than 25GB and a block-processing time of 0.5msec. "We take in ASCII text and compress it into binary on the hard disk; we run our own operating system, so storage space is never a problem," says Mr Prescott. "Part programs written on older TNC contouring controls can be run on the iTNC 530, as the fundamental programming procedure remains the same."

CAM support

Given that CAD files may be received by the control from many different sources, the CAD element of any CAD/CAM system needs to have a sufficiently powerful translation capability. For example, the VISI system from Cheltenham-based Vero Software Ltd (Tel: 01242 542040 — www.vero-software.com) can work directly with Parasolid, IGES, CATIA v4/v5, Pro-E, UG, STEP, Solid Works, Solid Edge, ACIS, DXF, DWG, STL and VDA files. This extensive range of translators ensures that users can work with data from virtually any supplier.

More to the point, unlike systems having their roots in CAD, VISI has a strong emphasis on CAM, which means it is good at importing CAD data with the main purpose of generating a tool-path from that data; and, of course, a heavy-duty CAM capacity is an absolute 'must have' when looking to simultaneous multi-axis machining. As Vero puts it: "For complex five-axis pro-

gramming, it is often necessary to 'tweak' the geometry, so companies working with complex designs will benefit from the simplicity with which their customers' CAD data can be manipulated."

Many of today's CAD/CAM systems have similar attributes but, like CNC systems, all are subject to continuing development. For example, the latest version of the PowerMill CAM system for five-axis and high-speed machining focuses on the easier programming of safe tool-paths, courtesy of stock-model engagement options that protect both the machine and the cutting

tool from excessive loading. Developed by Birmingham-based Delcam plc (Tel: 0121 683 1000 — www.delcam.co.uk), the software's ability to optimise tool loading will help to overcome a constant conflict for programmers. They need to maximise productivity by setting feed rates as fast as their machine tools will allow, but they also need to ensure safe speeds that will not damage the cutting tool. This requirement for safe machining is becoming ever more critical as a growing number of businesses introduce 'lights out', unmanned operation overnight or during weekends.

High-performance roughing strategy

Hertfordshire-based JK Engineering Ltd has been using the HyperMill CAM package from Bicester-based Open Mind Technologies UK Ltd (Tel: 01869 290003 — www.openmind-tech.com) since 2003, and owner John Kenny says that the software's collision avoidance system has eliminated the requirement for additional verification. According to Mr Kenny, who is confident that his sub-contract business has the capabilities to become a prominent supplier to the F1 industry, HyperMill delivers safe programs for simultaneous five-axis machining on JK Engineering's high-specification DMG machine tools (some capable of rapid rates up to 100m/min).

Open Mind has now introduced its HyperMaxx optimisation strategy for stock roughing. This new roughing module, which is fully integrated into HyperMill, combines optimal milling paths and maximum material removal with the shortest-possible machining times. Features such as constant radial depth of cut and fully automated dynamic feed rate and in-feed adjustment ensure optimum climb-milling conditions to enhance surface finishes as well as productivity. By dynamically adjusting the feed rate, HyperMaxx maximises machining speed, rather than using the feed-rate settings that are required for a corner or other worst-condition situations, resulting in shorter production cycles.

Because HyperMaxx is fully integrated into HyperMill, there is no need to open additional software tools, change the program or adjust the post-processor. This software offers two selectable functions: an 'opening cut' option for full-cut machining of areas that are difficult to reach; and a 'side cutting only' option specifically for machining harder materials such as titanium, nickel-based alloys or stainless steel.

Consistent tool loading

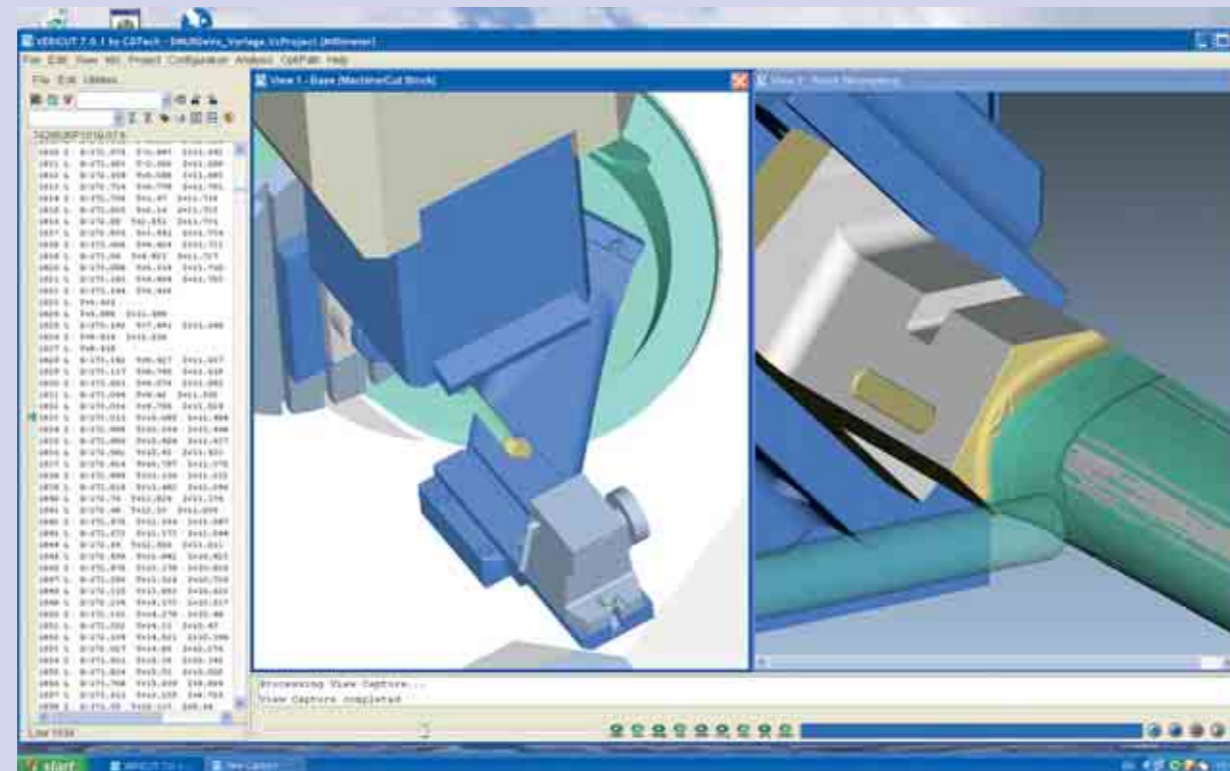
A number of CAM programs incorporate strategies based on the extent of cutter engagement to give more-consistent loading on the tool and so allow higher feed rates. Delcam points out that these options are usually limited to initial roughing operations, or to only roughing and rest-roughing. However, PowerMill's new stock engagement technology can be used with all of the system's finishing and rest-finishing strategies, so ensuring that the safest-possible tool paths are run on the machine at all stages of the machining cycle.

The key to this more-comprehensive solution is the accuracy of the stock models produced within PowerMill after each machining stage has been completed. These models give a precise representation of the material still remaining on the part and make sure that the cutter is not asked to remove more material than it can safely cut. At the same time, the stock models also ensure that tool-paths are not produced where there is no material remaining, so the machine tool is never left cutting air.

Enhancements to feed-rate optimisation have been introduced to give better control of leads and links at the points of cutter engagement and exit. Typically, the feed rate as the cutter enters and exits the material needs to be slower than that set for the main length of the tool-path. Setting the entry speed too high risks damage to the cutter and the spindle, and can even move smaller parts on their fixtures. Exit speeds are critical when machining brittle materials, such as graphite electrodes, since the cutter can chip the surface of the part if it is moving too quickly. PowerMill users can now avoid these problems by setting specific entry and exit feed rates, either as percentages of the main tool path feed rate or as absolute values.

Removing the fear factor

Machine simulation software is playing a major role in removing the fear factor from programming complex multi-axis machines. However, machine simulation software is more than just a means of checking for errors in

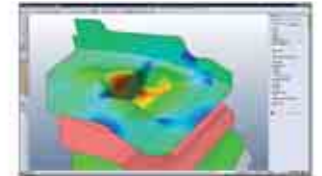


CGTech's Vericut software provides a 3-D model of the machine, tooling, fixturing and in-process cut model — and checks the NC code

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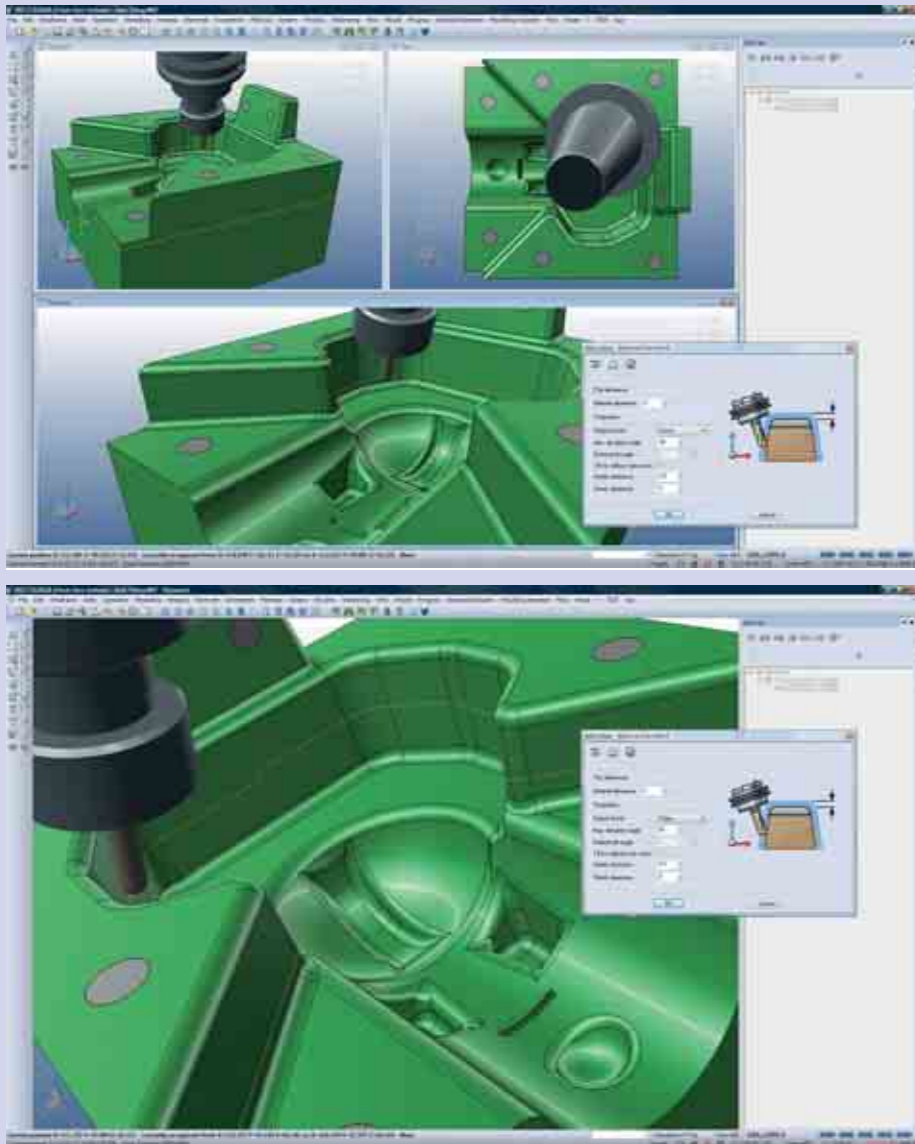
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One aspect of Vero's Visi software is the automatic conversion of three-axis machining to five-axis — easing the user into full five-axis working

three-dimensional model of the machine tool, the tooling, the fixturing and, crucially, the in-process cut model." He believes that NC program verification should be seen as a 'must have' alternative to the traditional proving-out on the machine, as it allows the programmer to verify 'on screen' the accuracy of NC code. This ensures that inefficient motion or programming errors that could potentially ruin a part, damage the fixture or break the cutting tool are corrected before the program is run on the actual machine tool.

One reason why businesses may be reluctant to invest in discrete NC program verification software is that many CAD/CAM suppliers include some form of verification as part of their software package. The down-side, according to Mr Reed, is that what you then see is only a visualisation of the tool path resulting from a list of instructions for the axis movements that a machine will need to make in order to machine a part. It is not, he says, a guarantee that potential collisions will be detected.

While accepting that CAM-based verification does provide an accurate graphical representation of the intended tool-path, he points out that the simulation is generated before the tool-path is post-processed into CNC code. "The fact is, a CAM system is generic and does not have sufficient information about the destination machine tool and does not simulate post-processed CNC code. What CGTech does is create an independent, accurate kinematic model of a specific machine tool and an accurate model of its control system. We can then make our virtual machine behave exactly like the real machine; and by taking the NC program generated by the CAM system and running it through our virtual machine tool, we are able to check for programming errors and to identify collision points."

an NC program. As well as providing an effective mechanism for ensuring that all programs are clean, efficient and accurate, it allows for the testing of different machining strategies on different 'virtual' machine tools, thereby avoiding the requirement for testing on actual production equipment.

Despite these advantages, NC program verification software is still regarded by many (especially by smaller companies and sub-contractors) as a luxury rather than a necessity. This is despite the risk of collision increasing as machine tools and machining processes become ever more complex. Aside from the human cost of any injury that may result from a machine tool crash, the cost of down-time and repair, replacement material and, possibly, lack of access to another machine could be devastating for a small business.

Hove-based CGTech Ltd (Tel: 01273 773 538 — www.cgtech.co.uk) markets Vericut — solids-based software that allows the user to perform a 3-D simulation of the way in which even the most complex CNC machine tool will behave in the production environment. In effect, Vericut is a simulation, optimisation and verification tool that eliminates the requirement to prove NC programs at the machine; and it is applicable to three- and five-axis milling and drilling operations, as well as multi-axis turning and mill-turning.

John Reed, CGTech's managing director, says: "True collision detection and avoidance can only be achieved when there is a complete

New probing technology contributes to greater accuracy

The new PC-based Productivity+ software from Renishaw plc (www.renishaw.com) enables users to take full advantage of data from multi-dimensional probe moves. From the moment a component is first loaded, Productivity+ software can be used to perform logical tests on the part to ensure that the set-up is correct, and then accurately update process parameters before cutting starts. Then, during the cutting operation, it can be used to fine-tune machine variables such as work offsets, or to make process decisions according to the exact conditions found on the machine. Productivity+ code can be run entirely on a machine tool controller without the need for an external PC or server. According to Renishaw, this enables shopfloor managers to improve their processes, without needing extra hardware or worrying about the communications problems inherent with other systems.

Of particular relevance to multi-axis machine tool users is Renishaw's RMP600 touch probe, which features the company's frequency hopping spread spectrum (FHSS) radio transmission for probe signals. This allows the probe to operate even when it is completely out of sight of the signal receiver. The RMP600 also provides an innovative Auto-Reset function to compensate for stylus forces generated by changes in probe orientation, which can cause the probe to false-trigger. This functionality allows the probe to operate efficiently even on 'nodding-head type' machines.

The first strain-gauge probe to combine radio transmission, Rengage 3-D technology, and the Auto-Reset technology, the RMP600 is described by Renishaw as "the ideal partner for accurate multi-axis machining".

CAM system plays vital role at Prysmian

One of the UK's largest manufacturers of energy and telecommunications cables has developed an innovative connector with help from Edgecam, the CAM system from the Planit Group (www.edgecam.com). Dorian Higgins of Prysmian Cables & Systems says: "We now have the capability to join high-voltage fluid-filled cable to dry cable, ranging from 132kV up to 400kV. We can also join aluminium to copper; this is another unusual process in the industry, but using Edgecam makes it easy for us."

Before using Edgecam, Prysmian did not have a CAM system and had to generate the codes in a variety of ways, depending on whether it was using its Okuma, Fadal, Mazak, Alpha or DSG machines. "Now, everything is so simple, as Edgecam creates programs for each machine. It is particularly useful going from the DSG, which is quite old, to the much newer Okuma with the click of a button, instead of having to completely rewrite the whole program and working out the variables from one machine to another; the time saving is quite considerable. If we were to write the program manually, it might take a day; with Edgecam, it's an hour at most."

Mr Higgins says that, as Edgecam can cope with programming all types of component — from the simplest to the most complex — and supports the latest CAD, machine tool and tooling technologies, it would be very difficult to manage without it now. "Our Fadal,

Alpha and DSG machines now run 100% on Edgecam, the Okuma 90% and the Mazak around 60%. It has become an absolutely vital and integral part of our manufacturing operation."

Edgecam is now used to produce 200 different components and is especially valuable for new designs. "Whether it's a completely new design or modifying an existing one, we will use Edgecam, as we prefer to use the solid models to generate the tool-path. It is more efficient and easier to use."

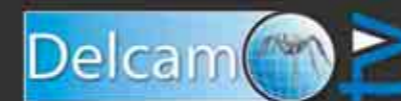
The programmer imports the solid model into Edgecam, and it is orientated for the machine that is to be used — either milling or turning. "Following that, we do the standard feature find, which is quick and easy — Edgecam finds everything that we need the machine to do. The stock is added to the job, so we can

simulate the machine to see how it will look, and then we pick the tools for the features that we need. Again, this is very straightforward, and any machinist can do it with the right training."

Once the programmer has gone through the machining cycles and is satisfied with the tool-paths, the CNC codes are generated. "After that, we print the Edgecam job reports for the machinist who is going to set it and operate it. This shows them exactly what it has been programmed to do."



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"I see Delcam as a key technology partner as we move into more complex five-axis machining work"

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