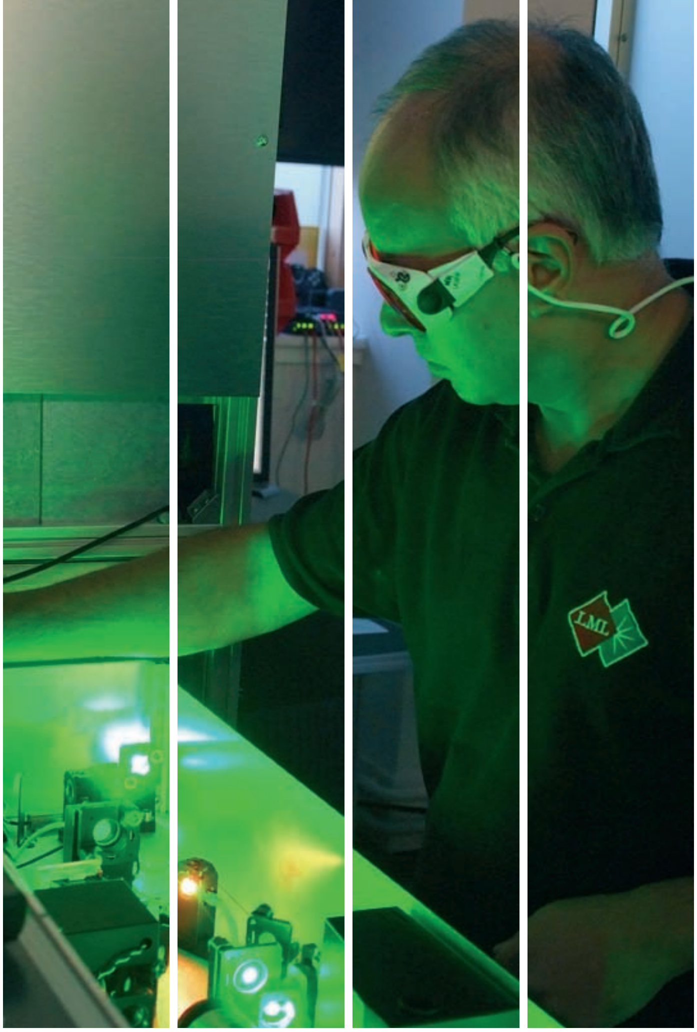

THE FINER POINTS OF LASER MACHINING

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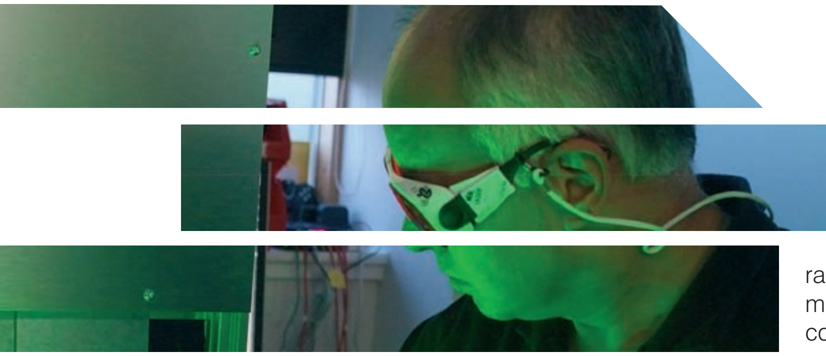
One of the aims of the CMM magazine is to disseminate dependable, insightful information about the breadth of micro technologies being used today. Readers of this magazine have a general interest in many areas but, like most people, are probably only comfortable in a small number of them. Hence, in the first of an occasional series of personal insights, I have been asked to share some thoughts about the world of high-resolution laser machining. This is not meant to be a comprehensive review of the topics that are discussed but is more of an informal, anecdotal run-through some common themes.

Lasers vs. Other Techniques

Mechanical machining has been around the longest time and is still widely used today but its modern-day competitors are chemical etching, electro-discharge machining (EDM) and the laser. So where do these competing techniques sit in relation to each other? You can machine any material mechanically but it becomes difficult when feature sizes become much smaller than a millimetre. Although drilling can be carried out for holes less than 200 μm in size, the costs become prohibitive due to the expense of the drill bits and the frequency at which they tend to break and need replacing. Chemical etching can be pushed to give slightly smaller features than mechanical machining and has the added benefit that it is a batch process, meaning that thousands or millions of features can be etched simultaneously. However, not all materials can be etched and etching can also produce undercutting with some loss of control of feature geometry. However, when it can be used, chemical etching does produce excellent quality results at very low costs. EDM is very good at producing high aspect ratio, zero taper holes/cuts but is limited, in practice, to metals. Feature sizes of less than 100 μm also become problematic with EDM.



Lasers, in contrast, can machine any material and produce features down to 1–2 μm in size. They are usually used in air and have no direct physical contact with the material, thereby allowing even very delicate samples to be machined. Lasers can also produce the widest range of geometries and 2D/3D shapes in parts. Hence lasers are the most flexible tool amongst the different competing methods, which is why so many emerging high resolution applications are adopting laser-based machining methods.

Machining Quality

If I had to choose a single description to define what laser machining is about, it would be that it is the business of thermal management. All laser machining produces thermal energy of some sort and the best results are achieved when this heat can be managed, minimised or effectively removed. Even the processes which are termed 'cold ablation' have elements of a thermal nature which still need to be addressed so, in practice, all laser machining engineers are working hard to control heat to achieve the best results.

The most fundamental decision in this process is to choose the right laser — get the laser choice wrong and the feature size, geometry and quality which you are after will not be attainable. Even with the right choice of laser, there are a myriad other variables which also need to be optimised to get the right results and this is where it is often said that laser techniques are not mature. This is true in the sense that there is not usually a single answer as to how to do something; this is frustrating for a customer who wants to know 'How much to drill this part?' but it really does depend on what factors are going to be prioritised and which choices are going to be made. If you want to drill a 2 mm hole mechanically then it is simple: choose a 2 mm drill bit, set your drill to the depth that you wish the hole to be and drill the hole. Very simple and predictable. With a laser, there are so many competing factors that the choices require a lot more skill and knowledge: the size of hole will be affected by the optics and the drilling method; the depth will be limited by the laser wavelength, focusing/imaging optics and number of shots; the hole taper will be determined by the optics, the material and the laser energy density; the hole edge quality will be affected by the laser wavelength, power, rep rate and numbers of shots; and so on for a few more parameters. Get the balance right and the result will be really good and something which cannot be achieved with any other method but lose control of some of the variables and the result becomes poor or inconsistent (or both).

This is not meant to say that all laser machining is always really difficult to do but rather to point out that the very things which make lasers so flexible — the wide range of options — also make their use more complicated. This is also the reason that set-up with laser systems can be quite time consuming (expensive) compared with the job to be done. It might take many hours to set up the machining tool for a hole which only takes milliseconds to drill — the flip-side is that when it is set-up, thousands or millions of identical holes can be drilled very quickly with dimensions and tolerances that could not be achieved otherwise.

Holes

Probably the single most common issue I have had to discuss with enquirers in the past 15 years is that of what size of holes can be drilled through something. I am no longer surprised to be asked why we cannot drill a 1 μm diameter, straight, through hole in 10 mm thickness of some hard material like steel or silicon. It often takes quite some time to convince the person of why this cannot be done and I am not even sure that everyone has believed my explanations. The mis-conception arises from confusion about laser beam collimation and focusing. The concept of collimation is a powerful one; it is easy to think that once you have collimated a laser beam at a certain size, it will propagate at that size forever. Things are more complex than this, of course, and diffraction is the killjoy for laser beams, always pushing beams to become larger as they propagate. So even though you can theoretically focus a laser beam down to micron sizes, keeping it at that size is an impractical task and certainly doing something useful with it to a large depth becomes an impossible one. As a general rule of thumb, aspect ratios (feature depth:size) of between 10:1 to 100:1 are achievable with lasers, depending on the feature size. Hence although it might be possible to achieve a 100:1 aspect ratio with a 100 μm feature size, a 100:1 ratio will probably not be possible with a 2 μm feature size. This limitation in the aspect ratio of features is as a result of the combined effects of diffraction — getting the beam to stay small enough as it is made to machine deeper and deeper — and the ability to remove material from the machining site — fighting to get ablated products out of the machined site, usually against the direction of the laser beam coming in. The basic issue is that a drill bit stays the same diameter as far down as you want it to go whereas a laser beam does not. This is what stops laser holes being small and straight at large depths and why laser-drilled holes are almost always tapered (you have to work hard to achieve zero taper for any significant depth).

Summary

New technologies can be overwhelming and we can, at times, either be put off them because we don't fully understand them or to assume they only offer narrow solutions because we have not been exposed to their wider potential. Lasers have just passed their fiftieth anniversary and so are still relatively young but they are maturing rapidly in many areas (and are fully adopted already in some others). I believe that we can all benefit in some form, at some time, if we can exchange open and practical views on our own areas of expertise; sharing real-world information and busting misconceptions must be the way forward if we are to make the best choices in our work.