

AILU honours Maurice Gates

The 1999 AILU award for outstanding contributions to the industrial use of lasers in the UK was presented to Maurice Gates, founder of Micrometric Techniques Ltd in Lincoln. The presentation was made by the AILU President, Professor Bill Steen, at the members' meeting at Loughborough University on 15 September.

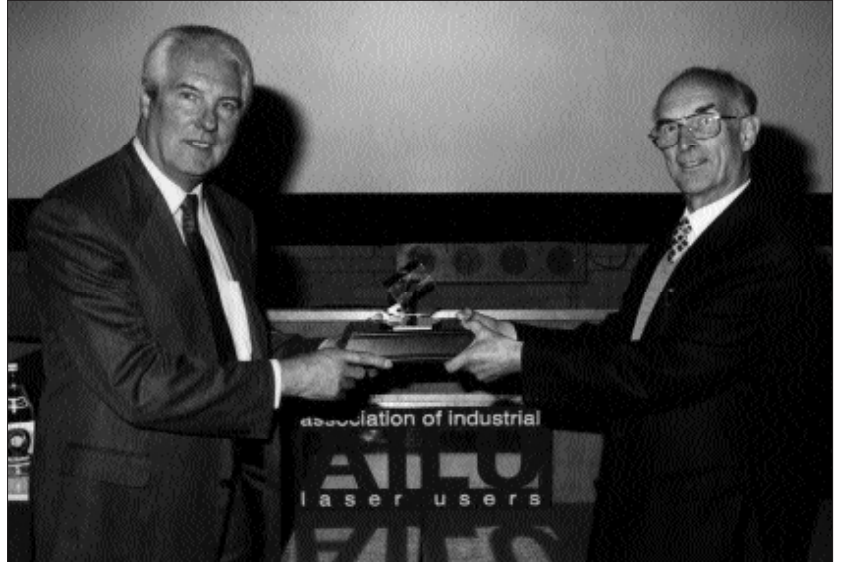
Presenting the award, which this year was sponsored by Rofin-Sinar Laser, Professor Steen reviewed Maurice's pioneering work in the application of lasers, from his early work at AEI on the laser machining of graphite electrodes for power vacuum tubes (1976) to the establishment of Micrometric Techniques Ltd, Lincoln, in 1981. In 1987 Maurice received the MBE from the Queen for his services to Industry and to the application of laser technology. In 1997 he received an honorary Doctorate from De Montfort University.

Professor Steen concluded with a review of the laser activities at Micrometrics.

"Micrometric Techniques Ltd is today one of the leading laser specialist companies for laser cutting, welding and marking, particularly of small precision parts. The company is known as an innovator of new techniques with pulsed laser welding and cutting, allowing a precision unobtainable by most laser job shops. Perhaps the biggest contribution Maurice's innovation has brought to the use of lasers in industry is the combination manufacture of components using lasers, mechanical machining and electric discharge machining. Maurice will probably deny having invented anything but it was his firm which engineered ideas into practical processes."

"In accepting the award," said Maurice "I see it not only as a recognition of my own efforts, but also for the successes made at Micrometrics by my colleagues."

"Although there has been much progress in the use of lasers in the processing and manufacture of sheet metal work, there is still some way to go to convince industry of the benefits and merits of lasers in the more technically demanding areas of fine part manufacture, prototype production and tooling," he concluded.



Presentation of the 1999 AILU award by the President, Prof Bill Steen (right) to Dr Maurice Gates MBE, for his outstanding contributions to the industrial use of lasers.

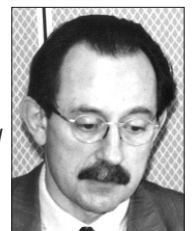
Launch of AILU Job Shop Group

The launch of the laser job shop group at the National Motor Cycle Museum in Solihull on 19 October 1999 attracted over 50 delegates from 26 laser job shops in the UK and Ireland.

To mark the launch, invited representatives from three international laser machine builders presented their views on how the laser subcontract industry is developing and the current use of laser machines and management of the job shop business, based on their world-wide experience.

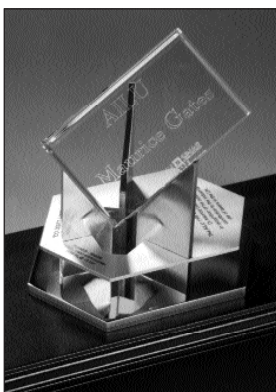
John Bishop, acting Chair of the group, opened the meeting by introducing the aims and activities of the new group, in particular the opportunities it creates within AILU for representatives of the job shop community to meet and discuss technical, market and business developments.

"Surveys of laser job shop members, including monthly reports of economic trends, and annual surveys of gas costs and of degree of satisfaction with laser machine suppliers, are already underway. They are providing participating job shops with valuable information," he added.



Presenters at the Launch. (top left, CW)

Piet Schwarzenbach (Head of Research, Bystronic Laser AG)
Ian Fletcher (General Manager Trumpf Ltd)
Xavier Rouchaud (General Sales Manager, Mazak)



The design of the 1999 AILU trophy illustrates some of the possibilities on offer by thinking 'laser' at the design stage. The text and AILU logo, laser marked by Rofin-Sinar, 'float' in the centre of an otherwise clear thick glass block, while the three thin stainless steel supporting fingers, laser cut by Micrometric Techniques of Lincoln, have 'egg box' slots included so that they link together into a self-jigging and rigid structure.

Letters to the editor

Laser Maintenance

With the ever increasing penetration of laser systems onto the shop floor I'm sure that there must be many engineers like myself who are having to cope with a new technology from scratch. Textbooks and the mainstream laser periodicals are silent on the nitty gritty of the daily toil! The maintenance manuals that come with my systems offer a list of things to check and do. But they offer no explanation of how I make the objective judgement that many of the operations require. Worse still, to the ignorant some of the routines demanded even seem pointless!

Last year's AILU workshop 'Optics for Engineers' at NPL had a very practical session on cleaning lenses and the last meeting at Loughborough touched on aspects of maintenance. I would like to suggest a regular feature in our magazine dealing with the practical problems confronting those of us that have to get the service covers off our systems. A question and answers page might address this issue. So may I offer the first question?

My flashlamp supplier specifies a conductivity of less than 5 micro-Siemens for the water coolant. With the aid of a de-ionising cartridge and a particle filter (both changed as specified by the manufacture) the water is always maintained at better than 3 micro-Siemens. The laser maintenance manual instructs that the primary coolant be changed every three months. Can anyone tell me why I should ever have to drain down the system and dispose of a coolant well within specification for the job, never mind four times a year?

Stuart Davis

L & S Davis Bvda.

In response to Stuart Davis' question, I would like to make the following observation.

All lasers are different, some are designed to be cheap to buy but with frequent scheduled maintenance, others are more expensive to buy but with less maintenance. Our lasers are in the latter category. However, our overall "cost of ownership" is probably lower than the "cheap to buy" laser as the cost of lost production must be taken into account.

With regard to markers, our lamp changes are every 2000 hours, the lamps are guaranteed for 1,200 hours. De-ioniser cartridge changes are also at 2,000 hours. The water should be replaced every 12 months, this is to prevent any build-up of algal growth and other contaminants that the filter and de-I cartridge do not remove. The conductance of the water is checked by the laser on start-up, if it is too high, it will flag up an error.

All in all you get what you pay for.

Tim Holt

Rofin-Sinar Laser

Cost of Ownership

Two points in response to Keith Withnall's response to Tim Holt's comments on 'Minimising the Cost of Ownership (Issue 16, p26)

1. It is not our experience that, when cutting with a laser of higher beam quality, significantly more assist gas has to be used. Consequently, I do not agree with the extra costs Keith highlights.

2. We do take into account the cost of the diodes in the overall cost of the lasers. In fact our quotations for diode pumped YAGs splits the price of the laser into two main parts, the laser (without the diodes) and the diodes themselves. In this way the customer can explicitly see the diode cost. We then use the diode costs and spread this out over the expected diode lifetime and this feeds directly into the running cost, the same as we do for the lamps. So the figures I quoted in my reply contained everything, diode cost, lamp cost, electricity cost etc., etc. Nothing was left out! As it happens, the costs of diodes should fall over the coming years, so by using today's prices for diodes we are over estimating the running costs, but I am willing to let that stand for the moment.

Tim Holt

Rofin-Sinar laser

I recall that Tim and I have been in this situation before, but then it was YAG vs CO₂ costs. Again, only the actual data from a range of diode and lamp pumped systems running side by side in the same application over an extended period will provide definitive answers, and then only for one application. However, I would be happy to sit down with Tim to compare my numbers with his and publish the conclusions for the benefit of everyone

Keith Withnall

GSI Lumonics

A note from the editor

The organisers and sponsors of the Make It With Lasers programme are to be congratulated for achieving 10 years of promoting awareness of laser technology in the UK.

I have often heard it said that after 10 years of low cost one day MIWL events, manufacturing industry may now have got the message about lasers and that in some way the need for an awareness-of-laser programme is diminishing. Far from it!

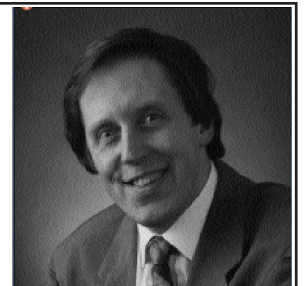
Two AILU events in as many months can be cited in support of this exclamation. The first event was the launch of the AILU Job Shop Group in October. Laser machine manufacturers were exclaiming that the market for laser job shops could be much greater than it currently is, but job shops see only the increased competition. Part of the solution lies in educating manufactur-

ing industry about what lasers can do.

The second event was our 'Tricks and Secrets of Designing for Manufacture by Laser' workshop this

month, where a day of presentations highlighting some of the wonderful opportunities that lasers offer manufacturing industry. The meeting provoked several of the audience to express frustration about the level of laser ignorance in manufacturing industry.

So, while MIWL celebrates 10 solid years of spreading the gospel, the job is far from over. The challenge remains and we all have a stake in getting the message across.



UK optics research under threat

I gather that you published the results of a Dual-Focus lens test in the last edition of your Industrial Laser User magazine.

A V&S Scientific engineer conducted the test on our premises over the course of a working day, and the end results were very encouraging.

I was told that the Dual-Focus lenses are covered by a patent and so I was surprised to be contacted recently by the British subsidiary of a North American company not only offering to supply standard lenses but also Dual-Focus lenses (although not until they had first been allowed to copy the V&S Scientific version).

We recognise the technical contribution that V&S Scientific have made in the area of Dual-Focus lenses and we believe that pioneering UK companies like them should be supported especially by the UK laser industry, rather than undermined. If Dual-Focus lenses become commoditised then our concern is that the budget for their ongoing development will dry up and we in the UK will find ourselves once again fighting over crumbs rather than being at the forefront of laser technology.

Jez Kent Freshlook Engineering and Products Ltd

I read with great interest Jez Kent's letter: I would like to think of Laser Beam Products as a pioneering laser optics company, our UK base is unfortunate, as you will see. Innovation and development are processes we see as essential to our future, and being honest I mean our future profitability in the broadest sense. We all do what we do, to grow our companies profits in a way that ensures long term viability. All the management techniques Laserform Eire, Cal Bailey and others have written about in the AILU magazine apply to us as laser optics manufacturers, as well as Jez as a laser user. My occasional indulgence in research for "research sake" aside, our objective is to develop a new product or project with the aim of making a return on our investment, commensurate to the risk involved. Purchasing a laser cutting machine is a similar level of investment to the hundreds of thousands of pounds we have invested in manufacturing plant and test equipment. If a company is poorly managed, makes a mistake, or is not up to the job, it will fail to make the return on investment. The market will dictate rapid extinction, and rightly so.

So what would happen if the situation existed that you could never make a profit? No matter how good your products are, how good your management is, no matter how good your development? In a free market this could never happen of course, well managed, efficient and innovative companies will flourish over their competitors.

So is the market for laser optics the competitive arena that spurs on the development, innovation, and productivity gains, that allows laser users in turn, to further their businesses? Sadly the answer is no, and there are two reasons for that.

Firstly, if innovative products that have many thousands of pounds and man hours invested in them are simply "ripped off" they just won't be developed, hence the centuries old system of patents and protection for innovators that is in everyone's interest.

Secondly the free market says all things being equal, companies who make losses year after year, will go out of business. That fundamental principle can be overridden if one has deep enough pockets, and a level of control in the marketplace. Predatory pricing is an anti competitive policy where losses are incurred to

overcome competitors, upon success, prices rise. Overcoming competitors by greater productivity, superior products, and ingenuity is something we all strive for, it should not be "bought" for a few hundred thousand pounds. Success in the UK market should be based on good management and innovation, not one of market manipulation. By driving well managed and efficient suppliers from the UK market, anti competitive trading can allow more than enough future profits to cover the "investment" during the loss making years. At this moment I am planning my future investments, I doubt it will be in CO₂ laser optic manufacturing because no matter how hard I work, or how clever I am, I cannot compete with a competitor who is committed to trading at a loss.

The distortion in the marketplace for CO₂ laser optics is far reaching, if we lessen our commitment, our suppliers of abrasives, tooling, coatings are less likely to furnish us with cost effective and innovative raw materials. There is an investigation into "predatory pricing" in the laser optic market, the outcome of that will decide how confident the laser user can be in getting the most cost effective and innovative suppliers in the future. I have devoted my working life to CO₂ laser mirrors, and am sad to think that the business and technical skills that have won us business awards and national recognition, will have to be redirected to areas where we can make a return on our investment, and today that is not CO₂ optics manufacture.

Mark Wilkinson Laser Beam Products

I was surprised to learn that one of our American competitors had offered to copy one of our Dual-Focus™ lenses in order to reverse-engineer it.

We have taken every opportunity to make it clear to the industry that DF lenses are subject to a patent held by the FORCE Institute in Denmark. It is inconceivable that any of our major competitors are unaware of this. For the record the International priority number is PCT/DK97/00412 dated 30/9/96.

This sort of undermining activity typifies the behaviour of one American competitor whose aim I believe is to capture the world of CO₂ laser optics market at the likely expense of other companies offering the same products. In the UK this has also resulted in a price-war so severe that the Office of Fair Trading are now investigating the possible predatory trading activities of this American optics company. The price war may in the short-term appear attractive to laser users but in the long-term it will have a detrimental effect on research and development aspects of the UK optical industry.

V&S Scientific, like many UK optical companies, depends on retaining an innovative approach to product development; and if new products are not allowed to flourish before being commoditised then the whole point of bringing them to the market ceases to exist and the UK laser market will no longer have a solid home-grown technology base.

I believe that the American competitor is aware of the consequences not only on undermining the technical excellence at the core of the UK optical industry but also of offering products at below cost price. The usual eventual outcome of predatory pricing is a rise in prices.

Paul Maclennan V&S Scientific

At the request of one of the several 'British subsidiaries of North American companies' trading in the UK, I wish to clarify that the company referred to in Jez Kent's letter is II-VI.

II -VI were invited to respond, but declined. Ed.

Obituary

David Greening

25 August 1946 - 6 October 1999

Born in Manchester, educated at Preston Grammar School, gained a Physics degree from Reading University, co-founded the Davin business in the UK, formed V&S Scientific in 1982. David leaves behind his wife Zahra, his two children Lindsey (17) and James (13), and many, many friends in the laser and optics community worldwide.

I have worked for V&S for ten years, during which time David and I had many happy and often very funny adventures together.

I always felt honoured to be associated with David, first and foremost for his knowledge and understanding of laser optics and beam delivery systems and the grace and commitment with which he disseminated his knowledge to everybody. He was always prepared to give freely his time and his advice on any matter, be it technical, commercial or personal was eagerly sought by those who knew him.

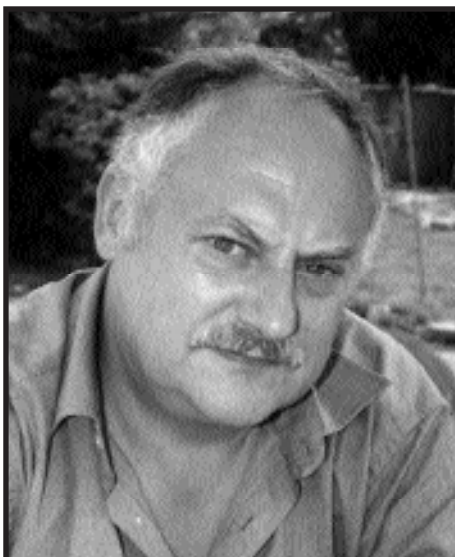
David was also instrumental in securing the financial survival of individuals and companies and this was as much due to his great sense of loyalty as it was his great ability to overcome difficult situations. He was always looking to the future and had the ability to see what could be achieved by taking appropriate measures.

A testament to David's foresight is that much of what he brought to the market was unique at the time. His idea some fifteen years ago of steering linear polarisation to improve laser cutting speeds and cut quality has only recently been re-invented in Germany (I think) amidst great excitement. He was truly ahead of his time.

His magazine articles were always keenly awaited not least because he was able to combine his willingness to teach with a warmth and sense of humour which will be missed by all of us. He particularly enjoyed writing for the AILU magazine which he described as the best of its type available anywhere.

From time to time ideas occur to me which previously I would have put on hold to discuss specifically with David, either at his office or his conservatory at home. It makes me feel the tremendous impact of his passing that I can no longer look forward to our meetings which were inevitably either cerebrally challenging, just plain fun or more usually a mixture of the two.

Paul MacLennan V&S Scientific



An example of David's wit

Extract from one of David's faxes to a customer, composed on the day he died.

Dear Christian

Thank you for your e-mail. The whole matter is very complex. I will break-down the problem into several parts:

There followed 4 full pages of explanation with the following final paragraph (the customer thought David's surname was Greene):

6. Possible Misidentification

My name is Greening (not Greene). I assume that you are confusing me with the well known actor, Lorne Greene, from the old 'Bonanza' television series?

Although there is an amazing physical resemblance between us, I must, in all modesty, claim to know slightly more about laser optics (although, of course, I am far less knowledgeable than Lorne on the topic of cows).

If you are making a laser branding machine, and you need $Z_r > 1000$ mm because the cows won't stand still, then it is probably best to consult V&S on the beam delivery problem, and deal with Lorne on the workpiece-handling aspects.

David Greening

David Greening was one of the entrepreneurs this country needs. He will be missed. He not only enjoyed life, but was also constantly thinking up optical devices.

V&S Scientific thrived on his enthusiasm, AILU enjoyed his arguments in the house magazine and most of us lapped up his ideas. His analysis of how to measure M^2 correctly which he published in Optics and Laser Engineering April 1994 pp25-28, illustrates his eye for detail and his modest approach to academic matters.

David was a significant player in the growing field of optical technology. On several occasions I have seen him accept challenges to design optics of extraordinary complexity rather like some of us accept the challenge of a crossword puzzle. The laser community has lost a strong man in David, some of us have lost an independent minded friend but the greatest loss is to his family and the company he initiated and led so successfully, to whom we all extend our sympathy.

Bill Steen President,
Association of Industrial Laser Users

David Greening's tragic death is a great loss to the UK laser industry.

I first met David twelve years ago and his enthusiasm for CO₂ lasers was obvious then; combined with his business acumen, V&S Scientific's success came as no surprise.

David pioneered the technology we now think of as commonplace, beam expanders, aberration free lenses, scan lenses, and multiway beam splitters. His presentations and printed articles hinted at his incisive wit, it was a shame he never published many of his more acerbic comments.

Mark Wilkinson Laser Beam Products

Besides being a businessman, David was always an engaged scientist, who co-ordinated research in modern optics far exceeding the borders of England. Especially in European research activities, he realised his visions concerning the development of high quality optics for CO₂ lasers in co-operation with research institutes and other companies.

It was always an experience to co-operate with David within the framework of European projects and to have him at the head of a consortium fighting successfully against European bureaucracy in order to gain acceptance of good research ideas. David was an international pioneer in the field of optics characterisation, and he was always open to the questions of quality management and standardisation in production lines, and the application of optical components. For example, he implemented laser calorimetry in his fabrication cycle for routine testing of his products with respect to optical absorption, when most competing companies were still dependent on the judgement of their customers. He was the first to recognise the important role of the CW-power handling capability of optics in innovative applications, and he developed a CW damage threshold measurement facility for routine testing in his company. With his approach, a great step forward could be achieved for high power CO₂ optics, and many new insights into damage mechanisms could be accomplished, which also strongly influenced the international standardisation of optical components.

Detlev Ristau LZH, Germany

David was that rare combination of entrepreneur, scientist and technical crusader. Although occupied with running a successful and well-known company, he still found time to retain the personal touch, so that many of his colleagues and customers came to regard him as a personal friend.

David was a tireless crusader for his subject and was never happier than when engaging in technical debate either across the conference floor or in the pages of technical journals. He would happily devote much valuable time to instructing and educating present and future laser users in the subtleties and intricacies of laser optics. His generosity and hospitality were outstanding, and his passing will leave a void in the laser and optics communities. He will be greatly missed.

Roger Crafer Abington Consultants

I was stunned by the sudden and unexpected loss of David Greening, and I am saddened that the developing CO₂ laser industry may be unaware of the major advances in optics technology due to enter industrial use in the coming years that can be attributed directly to David.

I had worked with David since 1988 on a general project to bring ultra-high speed laser processing to the printing industry at tolerances, speeds and importantly costs that these industries could bear.

My overriding memory of David will be of the hugely rewarding brainstorming sessions that we enjoyed together, along with Nick Ellis, out of which came the details to turn what were merely dreams into realities. David always had the ability to remain focussed on the target, and I cannot begin to explain the level of knowledge he meticulously imparted to me over the years. He was a true mentor and he will be greatly missed.

My thoughts continue to be with his family and his colleagues at V&S Scientific.

Steve Hastings Consultant

I have known David Greening since 1990. As a mere novice in the area of CO₂ lasers and their optics at that time, a patient David provided me with support and education, always ready to listen and help.

David has built up V&S Scientific as a business of supplying standard optical components, but he was always keen to push the boundaries beyond routine applications and solutions while applying good commercial sense. He helped ZED with several new projects applying his usual interest and commitment. If a schedule was slipping, he had no hesitation in setting aside a weekend to complete the drawings himself.

Over the years he has recruited and nurtured a tight-knit, enthusiastic, capable and committed team. On behalf of all here at ZED, may I wish all success to the staff of V&S Scientific with encouragement to grow the business from the sound foundations that David laid.

Our condolences to his family. We shall miss David as a friend, collaborator and supplier. We shall also miss a vigorous, imaginative and generous character from the CO₂ laser scene.

Simon Roberts ZED Instruments

I was greatly saddened to learn that a friend and colleague passed away recently. I first met David over 10 years ago in my search for an optical supplier. In true form, David provided more information than most and gave me his view from every possible angle. I have known few people in the industry with greater dedication, attention to detail and a willingness to exhaustively tackle a problem. His willingness was not restricted to commercial activities alone. David was a regular lecturer on the subject of laser optics at the University of Liverpool, where he inspired students to take optics seriously and to address optical problems with rigor and clarity. Rigorous he was; a chance remark on optics to David would invariably see the arrival some days later of a lengthy letter highlighting the error of your ways, should there be one, or strong encouragement and support if there was not.

In my opinion there is no one who can take David's place in the UK laser arena. He has left a legacy at V&S Scientific that will stand them in good stead and enable them to continue the growth that David worked so hard to achieve. I deeply regret and mourn the loss of this excellent and responsible man; for ourselves, the UK laser community and Optics as a whole.

Bill O'Neill Liverpool University

The recent death of David Greening represents a very real loss to the British Optical industry.

In recent years, through the establishment of V&S Scientific, David had concentrated his efforts on optical elements and systems for the CO₂ laser market where his insight and design expertise led to a significant number of advances, particularly in the area of Beam-Delivery equipment.

At Tayside Optical Technology we co-operated closely with David in the development of new and improved optical coatings to assist in the realisation of some of these products and will always be grateful to him for his encouragement and generosity of spirit when, as happens, things didn't always run smoothly.

To the Directors of Tayside however, David Greening was much more than a business colleague and will be fondly remembered as a loyal and generous friend.

Ian Beattie Tayside Optical Technology

It was with great sadness that I learned of David's untimely death. I have known David since 1971 when I joined MEL Watson Ltd, though we worked together only on occasion. In 1974 David, together with another colleague, formed Davin Optical Ltd to specialise in the manufacture of optical components. In its first year or so, as a consultant, I did a little optical design for David. In 1975 I had joined him to help expand Davin's business. It was clear then that David was very far-sighted (and entrepreneurial!). He could see that the future of Davin's business depended on expansion into the design and manufacture of systems and the manufacture of infra-red components for the developing fields of thermal imaging and CO₂ lasers.

Working with David was extremely stimulating. David was intense and tireless, and sometimes we would work all day, philosophise after work and then go out for supper and a drink or three.

Our ways parted when David left Davin. After a period with HSPO he founded V&S. His great success with V&S both in business and the advancement of CO₂ optics and systems is known to all.

David was extremely supportive of his friends and nothing was too much trouble. If I needed it, he would help me 'way beyond the call of duty'. He was tremendously caring and proud of his family. I know that we will all miss him.

Eddie Judd Davin Optronics Ltd

I knew David as a key supplier during the development of our laser cutting machines. I valued his creative solutions and patient explanations, always reasoned in that characteristic, lively style. We owe him a debt of thanks for his unique contribution. The laser and optics community will be a poorer place without him."

Graham Silk
Precision Cutting Systems

I have known David for about 10 years and was always impressed by his knowledge in, and enthusiasm for optics. It got to the stage where I dreaded asking him a "simple" question as I knew my fax machine would take a hammering from all the pages he would send me in reply. Where he got the time to do this, I don't know. He has spent a lot of time and effort in educating me over the years and I can only thank him sincerely for this.

He was not afraid to develop new products and was a great champion of polarisation rotators and dual focus lenses, to name only two. If only his company had had the money to develop all his ideas fully, what a force it would have been in global terms.

I will miss David for his knowledge and as a source of information on optics and I shall also miss him as a friend. I would like to send my sincere sympathies to his family and let them know that he was a well respected and well liked member of the laser community in UK. His death is a loss to us all.

Tim Holt Rofin-Sinar Laser

It filled us with much sadness to hear of the sudden death of David Greening. David made an enormous contribution to the development of the CO₂ optics industry in the UK. He was truly a talented man, a true innovator who brought to the UK optics industry many state-of-the-art products. He will be truly missed, but not forgotten.

The staff of Laser SOS

David was widely recognised as a leading expert and innovator in optics and as a supporter of UK laser research. Our association has been honoured to have him as a founder member and we are greatly indebted to him for consistent support and frequent contributions to this magazine.

In our links with David through the AILU office, Liz and I have experienced at first hand, and on many occasions, his wonderful sense of humour. We often found ourselves openly laughing at his faxed comments on AILU articles and news items, many of the funniest of which he specified were not for publication. It was his humour, his humanity, and his willingness to share his knowledge and enthusiasm, that we shall miss most of all.

The letters we have received, and the many more phone calls, reflect what a great loss David will be to the laser community, national and international. He has set a fine example from which all of us in the industrial laser community can draw inspiration.

Mike Green Secretary, AILU

Expanding magazine readership

We are pleased to announce that two of our corporate members, Cutting Technology Ltd and BOC Gases, have recently taken a leading role in expanding magazine readership. Cutting Technology, suppliers of second-user laser cutting machines, are purchasing first year Corporate Membership for all their new clients, while BOC Gases has purchased several additional copies of the magazine for internal distribution at reduced price.

The recent launch of articles from back issues of the magazine on our www.ailu.org.uk web site has been particularly well received, especially by the 12% of AILU corporate members who reside outside the UK.

"...the AILU web site has the best laser info on the net. And AILU is the best Association I have dealt with"

Pat Mulhern
Mulhern Machine Tools
Brisbane, Australia

David Greening was one of the strongest proponents within AILU for increasing the readership of what he regarded as 'the best magazine of its type available anywhere'.

David Greening Memorial Lecture

In memory of David Greening, and in recognition of the gratitude in which he is held by the UK laser community, the Association will hold a David Greening Memorial Lecture.

The lecture, on the general subject of 'optics for laser cutting' will be delivered by Dr Nick Ellis of V&S Scientific at the workshop on Laser Cutting at the International Manufacturing Centre at Warwick University on 15 February 2000.

Bill O'Neill will chair the workshop. He commented, "it is particularly fitting and timely that a memorial lecture in memory of David should be held during the workshop. Like many others in the laser community, I owe a lot to David for his constant support of my work on laser cutting over the years."

Other presentations at the meeting will review recent developments world-wide, including high speed laser cutting, gas nozzle developments and thick section cutting.

Job shop group members will hold an informal get-together at the end of the formal proceedings of the workshop.

'Tricks and Secrets' reveals fertile ground

Tricks and Secrets of Designing for Manufacture by Laser on 24 November, brought to a successful conclusion the 1999 series of AILU open workshops. The meeting, held in the new GSI Lumonics factory at Rugby, provided a forum for over 50 designers and manufacturers of laser-processed components, and included presentations, an exhibition and a tour of the new factory. The workshop provided many examples of the benefits of thinking 'laser' at the design stage, and covered a wide range of laser processes.

Tim Weedon, who chaired the meeting, gave a wide-ranging introduction with lots of general advice and some interesting examples including clamping arrangements for ribbon to pin welding, welding thin tantalum foil in the production of dispenser cathodes, and an example of welding through the glass window of photomultiplier tubes that 'made the user enough money on the first day of repairing broken welds to cover the cost of the laser'.

Neil Main provided each delegate with a set of laser machined parts to illustrate a range of tricks from adding short cuts (bend lines) so that the part can be bent precisely, sometimes by hand without the need for special tooling. Self jiggling tabs and slots, cuts to protect holes near bends from distorting, adding strength where needed by folding back part of a sheet for double thickness and cutting 3-D parts directly from tube.

Steve Ainsworth followed with a comprehensive range of laser processing benefits for the modern automotive industry, with many examples of cost cutting and improved performance, including recent developments in tailored blank fabrication.

The delegates were particularly indebted to Jorgen Bang Mikkelsen from the Danish pump manufacturer Grundfos, who at the last moment stepped in for a speaker who was unable to attend. Jorgen provided a fascinating insight into the development from concept to production of an automated laser technique for welding double-bend vanes into a complete assembly. "It is relatively easy to change the design culture to accommodate lasers; it is changing the manufacturing culture that is the more difficult part," he added.

Derek Russell reviewed designs and materials specifications for laser welding, and welding standards which, for lasers, are very poor. Looking to the future developments he pointed to the



Presenters at 'Designing for Manufacture by Laser' at GSI Lumonics (L to R) Derek Russell (TWI), Mario Grandinetti (Radan), Tim Weedon (GSI Lumonics), Sylvain Trousselle (GSI Lumonics), Stephen Ainsworth (Ainsworth Consultancy), Neil Main (Micrometric Techniques), Martin Knowles (Oxford Lasers) and Jorgen Bang Mikkelsen (Grundfos)

increasing role of high power diode lasers and plasma-augmented laser welding.

Martyn Knowles concluded the presentations by emphasising the importance of working with customers to fully understand their specifications, to



Lunchtime exhibition

ensure that all relevant features of laser machining have been considered, especially those (including taper, debris, recast layer and microcracking) that are not encountered in conventional machining.

GSI Lumonics are to be congratulated for their superb job of hosting the meeting, including a fine lunch and excellent facilities for the presentations and exhibition.

As a result of interest expressed at the meeting we hope to start a 'Tips and Secrets' column in the next issue of this magazine. If you have a contribution, please send it in.

"Sharing ideas through AILU is very beneficial. Sometimes it seems that you are giving away secrets to competitors, but invariably you get back more than you give"

Malcolm Whitmore
MJ Technologies

Maintenance and Servicing

The Mechanical Engineering Department at Loughborough University hosted an AILU members-only meeting on 15 September 1999. The theme was Maintenance and Servicing of laser equipment, not a particularly exciting theme but a very important one and it provoked a lot of interest. Features in this issue by Roger Smith, Andy Dye and Martin Sharp stem from presentations made at the event.

The meeting concluded with lunch at Burleigh court and a tour of the laser facilities at the University. Our thanks go to Peter Hancocks for chairing the meeting and especially to Karen Williams for all her preparations in support of the event.

Postponed USA Mission

The DTI-supported Laser Job Shop Mission to the USA has had to be postponed and will now take place in March 2000. At a meeting of the new team members with DTI representatives on 25 November, the discussion centred on diversity of services, multi-axis machining, new materials, scheduling, e-commerce, training and best practice.

The team, led by Dr Bill O'Neill of Liverpool University will visit a number of world-class job shops on the East Coast and Mid West over a 5 to 10 day period. A report of the mission findings will be prepared for wide dissemination and presented at an open meeting, probably held in May 2000.

Launch of the Job Shop Group

(continued from page 1)

In an upbeat assessment of the job shop scene in Europe, Pieter Schwarzenbach (Bystronic) advised "you don't have to be worried about the competition, it will grow the market." This would happen as news of the many cost-saving designs accessible to laser cutting reached further into the manufacturing sector. Total sales of sheet metal cutting machines have grown 10 times in the last 10 years. 65% of sales are to job shops. Piet estimates that the UK accounts for 9% of the European market.

"From the comments that have been made to me, I have no doubt that we will have a good 'core' of attendees at future events.

"I was personally delighted by the quality and content of the three guest presentations. We must thank them again for what must have been a daunting task."

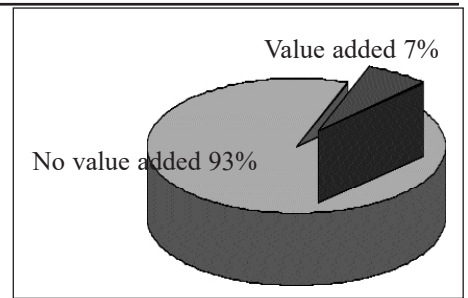
John Bishop
Lasercut Products

Ian Fletcher (Trumpf) reviewed the buoyant job shop scene in the USA, with job shops growing at 150 a year. Of the 750 new sheet metal laser cutting machines a year, half go into 'green field' sites. Ian identified three areas of pressure on

existing laser job shops, OEMs, steel stockholders and more efficient job shops, and strategies to deal with them. *Ian's full paper will appear in the next issue Ed.*

Xavier Rouchaud (Mazak Nissho Iwai) emphasised the value of automation in

reducing manpower costs and increasing the fraction of the total production time which is taken up by added value activities, typically only 7 - 9%. As well as cutting costs, improved speed of turn-around helps companies using automation to gain a competitive advantage. There are over 7000 installed laser cutting machines in Japan. Sales are currently 350/year cf. 800/year in Europe.



Xavier Rouchaud's message, centred on the high fraction (93%) of the time that a typical manufacturing company spends adding value to material (i.e. by changing its properties)

Snapshot of ICALEO '99

The 18th International Congress on Applications of Lasers & Electro-Optics was held at the Catamaran Hotel in sunny San Diego, California from 15 to 18 November. Well, it would have been sunny had you arrived, like me, on the Friday in time to catch the Saturday sunshine and a spot of sailing. You couldn't have wished for a better location, with a calm bay on one side of the hotel, and the roaring Pacific on the other. If you were not a lucky attendee and are happily scoffing at globe-trotting folk, fear not, because they get four days rain per year in San Diego and we were there for two of them, with lots of near misses. Ok, enough of the weather, what about the conference?

The growth in industrial laser applications over the past few years is evident from the growing number of ICALEO delegates. The 99 conference saw a marked increase in attendance and a greater proportion of industrial and academic 'first-time' delegates. This growth has resulted in a greater number of parallel sessions with the usual cutting, welding, surface treatment, modelling, drilling and laser systems sessions being well attended.

Keynote addresses concerned diode laser technology and applications developments. R. Craig of SDL Inc examined the subject of diode lasers, which are more powerful and more efficient as the years pass. Reinhart Propawe, Director of the Fraunhofer Institute for Laser technology, described recent activities in Germany including novel diode laser applications such as sheet metal diode laser guillotines for rolling mills, diode laser assisted pressing and forging, and oxy-diode laser cutting of steels. It is clear that the German government is investing heavily in the development of diode laser systems and industrial applications.

This year brought a new theme of laser microfabrication to the conference. This subject has generated enormous interest worldwide, and the sessions were particularly well attended as the laser is increasingly used for the fabrication of microstructures. There were a number of notable presentations in this session. Dr. Jack Gabzdyl of BOC Gases Ltd gave a very good impression of Star Treks Dr. McCoy by brandishing a new gas-based medical drug

injection system. This truly innovative product relies heavily on precision laser-welded gas micro-canisters. Dr. W. Hoving of the Phillips manufacturing Centre in Holland, described the process of using micro-laser forming to align compact disc lens systems in mass production. The precision and reliability was quite remarkable and production systems are being developed which drastically reduce overall costs and increase production rates. The ultra-fast session reviewed the latest developments in femto-second laser systems, which are poised to appear as laser solutions for industrial applications. The microfabrication technical sessions were a great hit with the delegates. Although some delegates believed that micro-papers should sit in a generic subject session, it is clear that this subject is here to stay and I'm sure it will be bigger and better next year.

In the multi-session Laser Materials Processing conference, a wealth of presentations delivered the latest news from the research labs of government, academia and industry. It was clear from these sessions that there is intense interest in diode pumped lasers, welding, process monitoring, surface modification, rapid prototyping, laser forming and optics and laser systems.

The technical sessions certainly provided food for thought and the introduction of a new commercial session, for those wishing to showcase their products, was very well attended giving people a chance to see the latest commercial breakthroughs before the ink on the sales literature was even dry.

It is impossible in this space to give a clear and concise review of ICALEO '99 without using microfiche. I have my own perspective and favourite papers and no doubt other attendees have theirs. ICALEO '99 was a great opportunity to make new friends, exchange ideas and build new networks in the field.

Well, it won't be hot, it won't be as beautiful, and it won't be as relaxing, but it will be easier to get to next year. See you at ICALEO 2000 in Detroit!

Bill O'Neill Liverpool University

Members' News

News in Brief

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VIL supplies LWB Ltd

Laser Welded Blanks Ltd, a joint venture between Steel & Alloy Processing (UK) and Usinor (France) is expanding its laser blank welding facility by the addition of a new line that is designed and manufactured by VIL of Addison, Illinois (USA).

LWB is a major supplier of laser welded blanks to the UK automotive industry for full scale production applications. They already have one laser blank welding line that is working 3 shifts per day, 7 days per week to meet the demand of automotive end-users such as Rover and Honda.

The acquisition of the LWB-Robotic system from VIL is part of a planned expansion. Both lines will be installed in a dedicated facility where there is space for additional lines to match the future growth in this market.

David Ashwell, Managing Director of LWB Ltd, says 'we chose the VIL system based upon simplicity of design, proven performance and the ability to rapidly change the set-up between different production parts - this being particularly important for the lower volumes and higher diversity of blank configurations presented by



LIL LW-B Robotic laser blank welding system providing consistent weld quality at high speed.

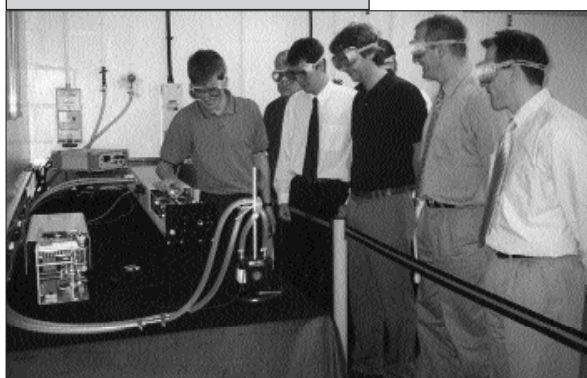
the UK automotive market.'

The new equipment will be installed at Laser Welded Blanks Ltd in Spring of 2000, with the majority of its capacity almost fully committed to existing customers. The VIL system will be laid out so that it can be easily upgraded to 2 lanes ((LW-B Dual Robotic) which can either be operated as parallel independent facilities, or work in tandem for efficient manufacture of 3-piece blanks such as body sides.

Spectron CO₂ Seminar

Spectron Laser Systems hosted the first of a series of one-day laser seminars on 10 November. The seminar, hosted at the Company's headquarters and local hotel in Rugby, was attended by a cross section of industrial laser end users and integrators from the UK and Europe.

The meeting coincided with the Company's recent launch of Series 100 and 200 industrial CO₂ lasers, and was dedicated to low power CO₂ lasers and their



Spectron Series 200 CO₂ laser being demonstrated during the factory tour.

applications. The discussions included detailed coverage of the markets and technologies available to low power CO₂ lasers.

Speakers from V&S Scientific, Lasermet and AEA Technology complemented the in-house presenters. The day concluded with a tour of the Company's Rugby factory which included live laser system demonstrations.

Organiser Riccardo Tomassoni of Spectron Laser Systems, commented "We have been very pleased by the response. The event provided a good forum for the interchange of information and an insight into how low power CO₂ lasers can help provide solutions to manufacturing problems."

Applications Consortium

The University of Liverpool is to launch a Laser Applications Consortium from January 2000 connected with the opening of its new Laser Engineering Centre at Lairdside, Birkenhead.

The Laser Engineering Centre is equipped with state of the art high power laser facilities. Laser sources include a Lumonics 4kW cw Nd:YAG laser and a PRC 3.5 kW CO₂ laser. The Nd:YAG laser can be linked to a Laserdyne 890 multi-axis gantry, a Reis 6-axis robot or a fast linear drive table. The CO₂ laser can also be linked to the Laserdyne 890.

"New applications of lasers in welding, cutting, bending or surface treatment require sophisticated manufacturing processing capabilities in addition to the more obvious availability of the high power lasers themselves. We offer sophisticated 3-D processing and high rate 2-D processing with supporting computer control and CAD/CAM software," said Ken Watkins, Director of the LEC.

"The Applications Consortium offers one of the most cost effective methods for the introduction of next generation laser processing technology to UK industry" he added.

New Members

Albyn of Stonehaven Ltd
 Allett Mowers Ltd
 Baasel Lasertech (UK) Ltd
 Belmar Engineering Ltd
 C&M Systems
 De Montfort University
 Hitec Laser Ltd
 Laser Mechanisms Europe NV
 Lasertron Inc
 Mikoh Corporation
 Pamukkale University
 Rotherwood Machinery Ltd
 TC Technologies Ltd
 Truflo Air Movement
 University of the Philippines
 VIL

Healthy demand for pre-owned laser cutting equipment

As with every tried and tested processing system, it is only a matter of time before a demand arises for it to be an integral part of companies machine inventory. Since the industrial take-up of CO₂ laser cutting in the late 1970's there has been a rapid growth in new system installations, and as a result there is now an undoubtedly sustainable pre-owned machine market emerging, driven predominantly by the growing availability of second user systems in Europe.

The pioneering UK jobshops have, to some extent, become a victim of their own success. By introducing an express service for both small and high volume production runs, with the ability to produce parts without traditional set-up and tooling costs, jobshops have been instrumental in creating a nation-wide specification requirement for laser cut components. As the UK market forms, however, it must be recognised that an increasing number of companies from a variety of market sectors will seriously consider investing in new or used laser cutting systems, in an attempt to control their total cost and enhance the benefits of total design flexibility.

To counter market growth and margin erosion, UK job shops are already being forced into investing in the latest laser cutting technology. Machine upgrades are becoming increasingly

common, sheet management systems are being introduced, total cost reduction and time utilisation programmes are now a primary focus. These necessary actions will add further to the number of pre-owned systems becoming available in the UK.

In comparison to other European countries, the UK laser market is still relatively young and can accommodate growth. A growing market is a healthy market and increasing competition will always be a reality. Given recent projected sales statistics for new laser installations, it follows that the pre-owned sector will also increase correspondingly, allowing companies on a lower capital expenditure budget to invest in laser technology. To address this need, Cutting Technology and other companies specialising in second user equipment can offer peace of mind to purchasers of pre-owned laser cutting equipment through an extensive support package.

The predictions for the next five years are that the growth of new laser cutting installations will continue and we all wish the major manufacturers continued success. Second hand is not always second best, and many companies will benefit from the parallel growth in pre-owned laser cutting equipment.

Andy Dye Cutting Technology Ltd

Electrox marks for Oras Oy



Oras Oy of Finland is one of Europe's largest manufacturers of faucets. They have used Electrox Scriba lasers since 1994 to mark their company and product logo on chromium plated single lever faucets, electronic faucets and thermostatic faucets.

"In 1998 we produced about 1.5 million single lever faucets with laser marked levers and some 400,000 thermostatic bath and

shower units, both having the cover and the lever marked with our fully automated Scriba 85 W laser," recounts Mr Lauri Leppänen, production leader of the surface coating line.

"The laser itself causes us practically no trouble. Parts handling is sometimes more challenging as our products are designed for the customer, not for the easiest possible manufacturing!"

Since the introduction of laser marking the tampo printing of Oras products has fallen from 100% to about 1%. "Only the colourfully painted levers are still tampo printed - until laser marking can make different colours. We would really like to do all our marking with a laser," Lauri Leppänen continued.

The first Scriba unit, purchased in 1994, is working 1 - 2 shifts per day, 5 days a week. To date the power-on time of the first unit exceeds 40,000 hours.

Restructuring at AMS

AMS Technologies Group see their markets merging and have decided to re-structure their OptoTech, ThermoTech, ComuTech and Electronic Divisions to create a single identity - AMS Technologies. The company plans to be Europe's leading distribution organisation.

ARE YOU A USER OF LASER WELDING?



The British Automation and Robot Association is taking part in a European network on Control of Joining Technologies and wish to contact users of Laser Welding to help with our research.

If you are a user of Laser Welding we would like your help to identify the industrial need in the field of Robotics Systems for Welding by completing our questionnaire.

To get a copy of the questionnaire please email or fax your details to: -

**Diane Thomas: Fax 0121 628 1745
 Email bara@globalnet.co.uk**

Situations wanted

Engineer

with over 35 years experience of general management, sales and marketing in the engineering and automation (Robotics, Laser) industries, would like to be re-employed with a company operating in this or similar area whose needs are for an articulate, practical, hands-on team member.

James Thorpe

has recently gained a HND in Laser Technology and Electro-Optics and is seeking full time employment. He has good communication skills and is willing to travel.

For full CV's contact

Liz at the AILU office o:

01235 539595

Prize for Coventry student

Steven Carter, a recent Manufacturing graduate from Coventry University has won the 1999 Lord Austin Prize, presented annually by the Institute of Electrical Engineers (IEE) for the best undergraduate Manufacturing project. Steven produced a detailed study of the production and application of laser welded tailor blanks for a range of automotive aluminium alloys. The work was carried out at the industrial laser facilities within the Centre for Advanced Joining.

Champagne Winner

V&S Scientific have announced the result of their Grand Champagne Competition 1999, included with the last issue of the magazine. The happy AILU winner of 6 bottles of Moët et Chandon Champagne is Dr Martin Sharp who correctly answered the following questions:

On 17 August 1999, a 2 kW laser was used to cut 6 mm stainless steel with a perfect dress-free finish using a Dual-Focus™ lens. The process speed increase was: 97%

With a 500 hour lifetime, the process efficiency increase needed to pay back the added cost of a Dual-Focus™ lens is about: 2%

All Dual-Focus™ lens trials have been conducted using ordinary designs of gas nozzle-tip, and high pressure nitrogen gas. No special nozzle type is required for this process. True

Spectron appointment

Spectron Lasers has appointed Riccardo Tomassoni as Sales and Marketing Manager responsible for the market development of the new range of CO₂ OEM industrial lasers within Europe. Riccardo brings to Spectron 13 years of experience in lasers and optoelectronics, notably in senior management positions previously with Electrox and Convergent Energy.



New venture for Clive

Advanced Optical Technology (AOT), has been set up by AILU member Dr Clive Ireland and Dr John Ley to undertake feasibility studies, contracted projects and product developments in new areas of photonics. Of particular interest will be applications where photonics is likely to be a key enabling technology.

Both AOT founders have more than 25 years experience in the laser and optics industry. AOT will share space with Leysop Ltd, a manufacturer of optical and electro-optic components and subsystems, in their premises at Basildon.

Products & Services

Lambda Photometric

Tui laser contact

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Tui Laser offer 1 kHz mini Excimer laser

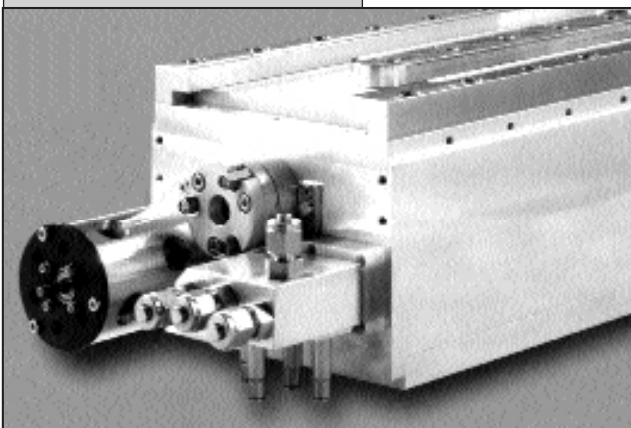
Lambda Photometric have announced that Tui Laser have a new 1000Hz version to their ExciStar small excimer laser products. Output energies are 8mJ and 18mJ at 193nm and 248nm respectively in a 10nSec pulse, average powers of 7 W and 16 Ws are available for microlithography, machining and medical applications. The package size is only 650 x 460 x 270mm.

All of the company's excimer product range feature a proprietary metal/ceramic laser head which provides substantial increase in gas lifetimes by the reduction of pollutants in the gas. The

metal/ceramic discharge chamber also delivers consistently uniform and stable energy pulses. The use of corona preionisation leads to outstanding beam homogeneity. The technique also creates an impressive reduction in pulse to pulse fluctuations.

The solid state switching technology used by Tui Laser is also a contributor to the production of a higher stable light output and permits high repetition rates with high average power with no air cooling. Other benefits of solid state switching are that no warm-up time is required and there is no thyratron switch to replace.

Tui Laser also offer a F₂ Excimer laser with 1mJ of output at 157nm in either a 200Hz or 400Hz version (introduced at this year's Munich laser show). Also available is the Tui Laser micromachining system operating at 1000 Hz at 193 or 248nm. Closed loop galvanometer scanners provide a positioning precision of 11µm.



Ceratube laser head - the core of the ExciStar

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Convergent new range

Convergent Energy has announced that they will begin manufacturing and servicing the OPL range of lasers at their Sturbridge, Massachusetts facility.

Convergent will immediately commence manufacturing the new M-Series OPL lasers and will carry a complete range of spare parts. First shipments of the Convergent Energy lasers under the Lance name are expected in late 1999.

The Lance, available in 2500 W and 3500 W DC-excited models, features a compact monobloc design including all components: resonator, programmable solid-state power supply, ultra quiet turbine and PLC control.

The balance of the resonator structure, combined with an optimised mirror arrangement, provides high stability of laser power, beam direction, and quality. A feedback power-control results in long-term laser power stability of $\pm 0.5\%$. The high resonator efficiency, the computer-controlled gas mix module and rigid industrial design, result in low operating and maintenance costs.

Aspheric lenses from AMS

AMS Technologies OptoTech Division is to represent Geltech's range of moulded glass aspheric lenses. Geltech Inc of Orlando, Florida

Spherical geometry is not optimum for refracting light, but the expense of fabricating aspheric surfaces has until now inhibited widespread use. Geltech's patented moulded lens process, using special glass developed by Corning, yields lenses that are highly consistent replications of the mould at an attractive cost.

Spectron offer new range of CO₂ lasers

To complement its broad range of solid state laser products, Spectron Laser Systems of Rugby has recently introduced a range of sealed, low power, diffusion cooled, DC excited CO₂ lasers for the UK and the European industrial laser markets. Originally developed in the USA, these lasers have their origins in the first sealed lasers available commercially and have a long and successful history dating back to mid 1980's.

The Spectron Series 100 and 200 CO₂ lasers are available in variety of

BTEC in laser processing

Loughborough College is now offering the first vocational qualification aimed at laser technicians that is practically based and nationally recognised.

The course aims to provide a foundation in laser material processing techniques through a balance of theory and practical demonstrations, combined with hands-on sessions. Each day is supported with assessments and review questions. Delegates are able to work in small groups for demonstrations and practical work.

The 5-day programme comprises:

- Lasers for Material Processing light and laser beams, laser types, delivering laser beams, safe working practice
- Materials & Processing Variables material properties, laser beam effects upon materials, features and variables in laser material processing
- Material processing techniques surface heat treatment, laser welding, laser drilling, laser cutting, laser marking, troubleshooting
- Engineering Principles reading drawings & specifications, work-piece handling & jiggling, CAD for laser processing
- CAD for Laser Material Processing assessments, completing your log book, course review

Courses are run at the Laser Centre, Loughborough College and the cost (subsidised by the European Social Fund) is £650 per delegate.



Spectron Series 200 diffusion cooled free space CO₂ laser

standard configurations, from basic tube and power supply to fully integrated laser package including alignment lasers, controllers and power sensors, with power levels from 30 Watts through to 220 W. Much in the same way that the Company manufactures customised industrial solid state lasers for its OEM customers, customised CO₂ laser solutions are also available from Spectron's specialist in-house design team.

In all configurations, the Series 100 and 200 CO₂ are rugged and reliable, and with lifetimes in excess of 10,000 hours.

The Spectron Series 100 and 200 lasers have a free space resonator construction which provides the best possible Gaussian mode (TEM₀₀, M² = 1.1).

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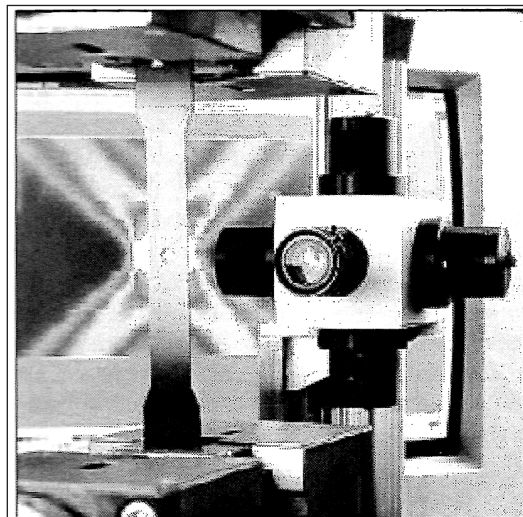
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Enhanced full field vibration analysis system

The 3D-Pulse is an Enhanced Speckle Pattern Interferometer (ESPI) system from German speckle interferometry specialists Dr Ettemeyer GmbH & Co provides complete vibration analysis at high speed.

A double-pulsed laser and a specially triggered camera record vibration events over areas up to several square metres. The measurement technique used by the 3D-PulsESPI system provides vibration components both orthogonal and parallel to the object's surface. The system is suitable for a number of applications, particularly in the automotive industry for looking at car body vibrations and brake squeal problems.

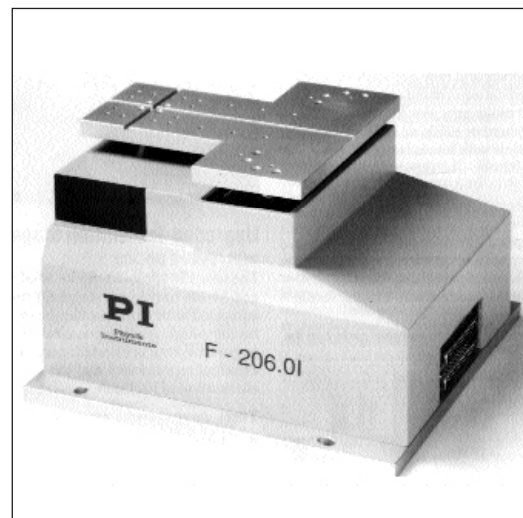
AG Electro-Optics Ltd have been appointed as distributors in the UK, Ireland, & Scandinavia.



Six axes of controlled movement

The PI F-206 six-axis positioning system is the result of the Lambda's five years of experience with the PI Hexapod. The F-206 offers 0.3 μm resolution in X, Y and Z and 4 μrad resolution in its three angular movements. The pivot point can be set anywhere inside or outside the movement envelope. Movement velocity is up to 10 mm/sec. The maximum range for travel is ± 7 mm, angular movement ± 5 deg.

In contrast to conventional multi-axis systems where a change in one co-ordinate affects the pivot point and the other co-ordinates, the F-206 compensates for unwanted motion. Applications include semiconductor handling systems, fibre alignment, micro-machining. Industrial grade PC controller and software supplied.



Laser Materials Processing courses at Liverpool University

One week courses in Applications of Lasers Jan - March 2000

Laser Cutting and Marking (31st Jan - 4th Feb)
Includes effect of process parameters, optimal practices, in process sensing, applications and costing.

Laser Welding and Drilling (14th - 18th Feb)
Includes keyhole and plasma formation, in-process sensing and control, modelling, laser welded tailored blanks.

Laser Surface Treatment (28th Feb - 3rd March)
Includes laser transformation hardening, laser bending, laser surface melting and alloying, laser cladding, laser cleaning

Laser Manufacturing Systems and Automation (13th - 17th March)
Includes design of complete manufacturing systems, optics for beam delivery, control strategies and networking of machines

Each course includes industry lecturers and practical hands-on elements to illustrate the processes.

Eurolaser Academy March 27 - 31 & April 3 - 7 2000

The Laser Engineering Group at University of Liverpool will host the next UK Eurolaser Academy in March / April, 2000.

This established course provides a full introduction to industrial laser materials processing and covers all the main processes (welding, cutting, marking, drilling, micromachining, surface treatments, forming, additive manufacture) together with background on fundamentals, sources, laser/materials interactions and technical and economic factors.

The course is based on the 2 volume Handbook of the Eurolaser Academy (Kluwers Academic Publishers)

A supplementary one week programme of hands-on experience with high power laser systems is available at the Vienna University of Technology in September 2000 (date to be arranged). Successful completion of the course will lead to the award of the Certificate of the Eurolaser Academy.

A Day in the Life of....

Paul Chell

The Product Development Manager of Armstrong Steel Ltd. gives us the low-down on up-market products.

I first started in the steel industry in 1982, James & Tatton as we were at that time, and to say that the industry has changed would be a gross understatement. Customers no longer want to hold "stock" but want timed deliveries onto specific production lines, material fit for purpose and requiring zero inspection. Customers are continuously looking for "cost down" but there comes a point where this can no longer be accomplished through reductions in the selling price - the margins in the steel industry are typically very tight and we do have shareholders to satisfy. At the start of 1997 I was delighted to accept the challenge of the new role of Product Development Manager for Armstrong Steel. I looked forward to the prospect of working with suppliers Europe-wide and customers nationwide in order to find ways to achieve real cost savings through more sophisticated products.

The latter half of 1998 was very tough for the steel industry. We have all had to work harder and smarter. Everyone at Armstrong wears several hats and I also now have the responsibility for Quality here at our Stoke on Trent site. Being the busiest site in the group, there is no such thing as a quiet day and the dual nature of my role means that I sometimes have to be involved in the mundane as well as the stimulating.

Friday

6.00 Surely it can't be time to get up already.....we had rather a disturbed night, my daughter Fiona (just 4) is going through a sleepless phase and much prefers our bed to her own. At 3.00 a.m. "Parentcraft" goes out of the window and she is hauled in.

The precision engineering industry ought to take note of the two main properties of children in parents' beds:

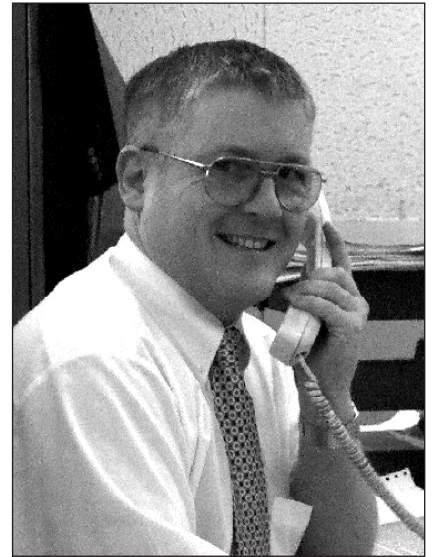
1. The angle between the direction of the child's sleeping position and that of the parents is always a perfect right angle.
2. The datum point for the child's heel is always the most vulnerable point of the father's anatomy.

6.30 a.m. I hit the road, heading into Leeds and conscious of having to be through the traffic blackspots on the M6 and M62 before the early morning build-up. Fortunately the traffic keeps moving and I've got time to grab a cup of tea at Hartshead Moor services before my call.

8.30 A call requiring my Quality hat. The customer is a sub-contractor to the "yellow goods" industry and is concerned about blemishes on 8 mm thick plate. On examination the blemishes are found to be very minor indeed and we agree to put a few components through painting and review the results later in the day. .

11.00 I'm now wearing my Product Development hat to look at some 12 mm thick Sollaser plate laser-cutting trials. If today's small-scale trials are successful there is the promise of full-scale production trials. I advise the operator that it was not just a case of keeping all machine parameters the same and cranking up the feed-rate, and that he would have to spend a little time fine-tuning everything in order to achieve the best results. It is a good visit, the customer achieved an improvement of 15% in cutting speed,

and both residual flatness and cut edge quality were excellent. We agreed to arrange a follow-up meeting to discuss the further trials. Not every laser user is convinced about the merits of "laser steel" and perhaps the most difficult part of my role is to persuade customers just to try some. The market is very price-sensitive and some buyers have an understandable reluctance to pay a premium! Despite this, Sollaser has been our most successful development by far and we are working very closely with Sollac's technical and marketing departments to further promote the product.



14.30 Back in the office. My PC monitor is covered in Post-it notes. These notes are a pet-hate of mine and the people who put them there fall into the same category as drivers who use fog-lights when it's not foggy and men who think it's the height of fashion to wear their shirts outside their trousers. Having cleared the yellow peril and its sticky residue I log on and wait for the deluge of e-mail - amazingly I've been out for half a day and only five messages pop up. Nothing urgent; I'll deal with them later.

15.00 On the phone to Trumpf at Luton. The *InTech '99* exhibition starts next week and we agree to supply some free-issue Sollaser in both 6 mm and 12 mm thick for demonstration purposes. The 2500x1250 mm plate will have to be cut down to manageable sizes and so I speak to our Production Planning department. Fortunately, they can squeeze the job in on Saturday and we already have a vehicle with a little spare capacity planned for that area for Monday. Trumpf agree to display a promotional poster near the machine and I speak to Liz Taylor at our Kidderminster branch - she's a whiz on the Apple Mac and although she's not got much time she's never let me down yet!

15.30 A call comes in from the customer with the blemish problem - the painted article is fine as I suspected it would be!

15.45 The phone has temporarily stopped ringing and a chance to clear up some loose ends before the weekend. I phone next week's itinerary through to Pam, knowing full well that it will have probably changed significantly by mid-morning on Monday.

17.45 Having made some impression on outstanding matters, I finally log off for the weekend. It's been a typical day during a typical week, some routine stuff, some interesting stuff, but never quiet. One particular technical enquiry from a customer does however stay with me....."Can a horse bite through 1.2 mm steel?" Answers on a postcard please.

CO₂ Laser Cutting – Notes for Jobshops

an occasional series edited by John Powell

No 3

Trouble-shooting for laser cutting

Abridged (with the authors consent) from John Powell's book *The LIA Guide to Laser Cutting**

From time to time all laser cutting machines cut slower than usual or with poor edge quality. The troubleshooting list presented in the table below should help operators to speedily find the source of the problem. The table is followed by notes on each item.

Troubleshooting checklist

Check & Correct ↓	Time Involved (mins)
A Nozzle contamination	1-2
B Laser Power and pulsing conditions	1-5
C Cutting speed	1-2
D Cutting gas	1-2
E Nozzle stand off	1-2
F Nozzle type, condition and alignment	1-10
G Material specification and condition	1-5
H Lens type, condition and alignment	10-20
I Beam steering mirror: condition and alignment	5-60 per mirror
J Laser mode quality and polarisation	20-40

Notes on checklist

Nozzle contamination

The most common cause of cutting problems is dirt or spatter on the nozzle. Particles of dirt near the nozzle exit deflect the oxygen jet to one side. Clean the nozzle by gentle scraping.

Laser power and pulsing conditions

Check that the laser power and pulse settings are the same as those used successfully on earlier, similar jobs.

Cutting speed

Check that the cutting speed is the same as that used successfully on earlier, similar jobs. Try increasing and decreasing the speed by 10% and 20%

Cutting Gas

- 1 Check the type of gas used against earlier, successful results (oxygen, nitrogen, air, argon etc). Obviously for mild or carbon steel the choice will be oxygen.
- 2 Check supply pressure and flow. Most machines only measure pressure and this is only half the story. If, for example, the nozzle is blocked the pressure will rise, but the flow will fall. It is best to have both a flow meter and a pressure gauge on the machine

Nozzle material standoff

Check this against earlier, successful results. In most cases the standoff will be between 0.25 and 2 mm.

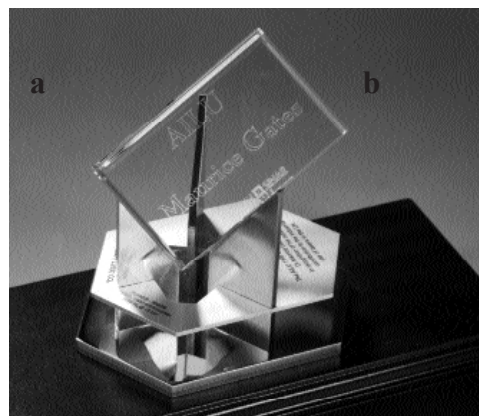


Figure 1 The importance of centralising the focussing laser beam with the cutting gas jet. (a) Centralisation OK, (b) Nozzle or laser beam mis-aligned. This leads to different cut qualities in different cutting directions.

Nozzle type, condition and alignment

- 1 Is the nozzle of the right type (exit diameter) for the job?
- 2 Is the nozzle worn or scratched? This can have the same effect as dirt near the exit (i.e. the gas jet deflected off centre).
- 3 If the laser beam is not in the middle of the gas jet coming from the nozzle the machine will not cut equally well in all directions. Figure 1 demonstrates this point. A good check is to fire the beam several times into pieces of scrap steel. If the piercing sparks always go in one direction, the nozzle is mis-aligned as in Figure 1a. Either move the nozzle in the same direction as the sparks are going or move the lens (and therefore the beam) in the opposite direction. If alignment is good then piercing sparks should fly off in all directions or in a single direction which changes randomly with each new pierce. When alignment is poor sparks may be soon coming out of the top of the cut zone when cutting in certain directions. If this happens adjust the nozzle or lens as above.

Material specification and condition

- 1 What is the material?
- 2 Is the condition of the material affecting the cutting? Any surface coating (rust, paint, mill scale etc) or deep scratches can disrupt the cutting.

Lens type, condition and alignment

- 1 If the machine has a variety of focal length lenses, is the right lens being used? Is it fitted correctly?
- 2 Is the lens scratched or dirty? Both can give cutting problems. Even if it is clean it may have become over-heated. Check this by looking at a light through the following 'sandwich': a piece of Polaroid plastic, then the lens, then another piece of Polaroid plastic (a pair of lenses from polaroid type sunglasses can be used)

Holding the first piece of plastic and the lens in one hand, rotate the final piece of plastic while looking at a light source.

If the lens is okay the image will go gradually from light to dark. If the lens is thermally damaged a dark cross or crosses will appear. If this happens the lens will have lost its ability to focus the laser and cannot be used.

- 3 Is the laser correctly aligned onto the lens? If the laser beam is not being directed towards the middle of the lens, the beam steering mirrors may need re-alignment (see next section).

Beam steering mirror condition and alignment

- 1 Are the mirrors which steer the beam to the lens clean? This can be checked by taking power readings after each one. Power losses should be below 5% per mirror. (A new mirror will be more than 99% reflective.)
- 2 If the mirrors are not directing the beam to the centre of the lens, the system needs to be re-aligned. This is a skilled process which needs training.

Laser mode quality and polarisation

- 1 The laser power is not uniform over the cross section of the beam. The distribution, called the laser beam 'mode' is usually circular in cross section with a power concentration towards the centre, although there may be a central dip. If the mode is circular and symmetrical, so will the focused beam and it will cut in all directions equally well. If, through some internal laser fault, the mode becomes non-circular, the machine will cut differently in different directions. Laser mode identification and tuning requires training, usually by the supplier.
- 2 The beam of light produced by a CO₂ laser needs to be modified slightly before it can be focused and used to cut metals. If the unmodified beam is used to cut metals, the cutting process would be different in different directions. The major symptom would be that the cut would be tilted to one side or the other depending on the direction of cut. For example the cut may slope to the left when cutting south and to the right when cutting north.

A circle on the top surface will be an ellipse on the bottom

A square on the top surface will be a rectangle on the bottom

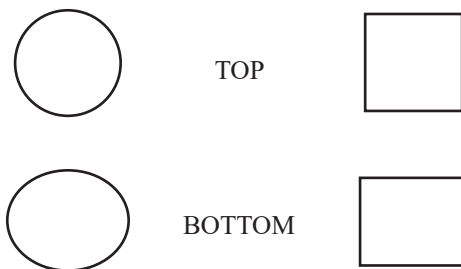


Figure 2. The effect of cutting with an unmodified or polarised laser beam. The cut slopes away from vertical, the direction of slope depending upon the direction of cut.

Figure 2 shows the effect this has when cutting a square or circle. The tilting of the cut means that the square will be the square at the top of the cut and rectangular on the bottom. The reason for this effect is that the unmodified laser beam is polarised and therefore has directional properties. To remove this problem the beam is reflected off one or two mirrors which have a special coating which depolarises or circularly-polarises the beam. The cut with a depolarised or circularly-polarised beam is vertical in all directions. If a machine starts to produce cut discs which are oval on the bottom but circular on the top the depolarising mirror(s) are not performing correctly and may need replacement, although cleaning them up may help.

(NB: If the laser is being used to cut non-conducting materials such as plastics or wood, depolarising mirrors are not necessary. In this case, a vertical cut is achieved even if the laser beam is polarised.)

Technology and Techniques of Laser Cutting

Tuesday 15 February 2000
International Manufacturing Centre
Warwick University

Topics include

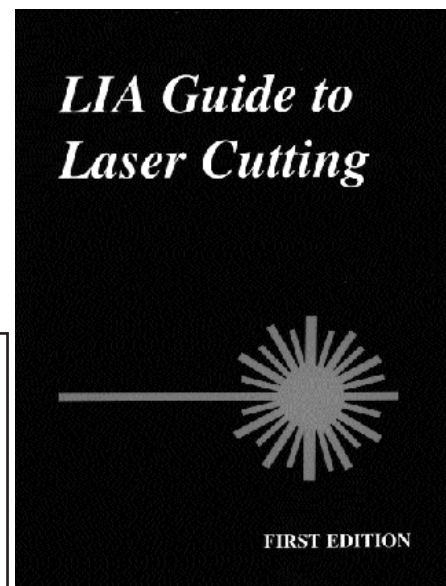
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Laser maintenance

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Maintenance of laser systems is an important factor in the successful implementation of laser processing. Reliability is a major factor in the acceptance of any industrial process, and lasers are no different. In the early years of industrial laser processing, the technology was generally viewed as relatively unreliable and the equipment required specialist maintenance. However, today's laser machines are generally reliable, and except for certain parts, are user maintainable. If the manufacturer's routine maintenance schedule is adhered to there should be few problems with reliability. Yet despite the obvious truth of this statement, routine maintenance and servicing still seem to be part of the process that few people want to talk about.

To achieve the best reliability from equipment, the user should ensure that a schedule of routine maintenance is available and is adhered to. Ultimately it is the end user's responsibility to ensure routine maintenance is carried out, and many do this diligently as and when required. Some prefer to establish service contracts with the equipment manufacturer, although there will always be residual daily/ weekly/ monthly items for which this is impractical. Other end users train their maintenance staff and perform the bulk of routine maintenance themselves. But there are also those who agree with the necessity of routine maintenance, but can never seem to find the time because of production or cost pressure. There are even those whose attitude is 'don't try to fix what isn't broken'! We should expect that such users will ultimately start seeing greater down time and expense as a result.

Providers of laser equipment have a collective interest in promoting lasers as a reliable industrial technology, and it is therefore important that they provide the end user with the necessary information and with training, all with a view to ensuring that routine maintenance is performed competently and when necessary. Furthermore, providers should design not only for reliability but also for ease of maintenance. Even today, with all the practical experience that has been gained by manufacturers over the years, routine maintenance is often compromised by poor design, information or training.

Below are some ideas on what should be considered by the various parties involved in the supply and use of laser equipment. The list is based largely on the author's own personal experience and should not be regarded as complete.

Maintenance for the laser manufacturer

- ✓ Design a reliable laser. Use well-tested designs and components where possible.
- ✓ Produce a realistic and well documented routine maintenance schedule. Work through the complete laser and check for rou-



Routine maintenance is essential for reliable operation

tine maintenance points. If it moves does it need lubrication? If a filter is fitted how often should it be checked/ replaced? Consider the effort required to perform a maintenance task before stipulating its frequency or even its necessity.

- ✓ Produce a summary maintenance schedule, that the end user can use to check items are performed as and when required.
- ✓ Make sure all items of maintenance are adequately documented and well indexed.
- ✓ By all means include other equipment manufacturers manuals in your documentation, but do not expect a user to work through all these manuals to find out what is required for maintenance.
- ✓ Design for maintenance. If you want a user to check an oil level once a week, make it easy. If you ask for a cavity optic to be inspected, then the user should be able to remove it easily, and replace it without going through some complex alignment procedure.
- ✓ Design-in suitable monitoring circuits and fault alarms. The increased use of PLC's and computers for laser control also allows opportunities for maintenance control and diagnostic checks, e.g. vacuum leak rate testing. But do make sure that such features are consistent, and warning or alarm signals or messages are adequately documented.

Maintenance for the system builder/ supplier

- ✓ Treat the laser as an integral part of the system and produce a unified maintenance schedule. Don't just drop the laser manual in the documentation pack and hope for the best.

- ✓ Design the system for routine maintenance, in particular do not obstruct access to the laser for its maintenance requirements. Make sure all lubrication points are identified and accessible.
- ✓ Use tried and tested mirror mounts, in which the mirror can be removed and cleaned without the need for realignment. Provide a safe and practical means of checking alignment. If beam path purging is used, make it easy to remove for service work, but more importantly make it easy to put back together afterwards!
- ✓ Build in good and consistent fault diagnostics. Make sure all error messages are adequately explained in the manual.
- ✓ Be prepared to service the laser, if necessary send your own engineer on a training course at the laser manufacturer's. If you are going to rely on the laser manufacturer's service operation be prepared for disputes as to the cause of processing problems: is it the laser or is it the system?

Maintenance for the user

- ✓ Perform the routine maintenance requirements diligently.
- ✓ Read and understand what is required for routine maintenance.
- ✓ Identify the personnel who will perform the maintenance and if necessary get them trained.
- ✓ Do your own audit. If something looks as though it may require routine maintenance, but is not included in the manufacturer's schedule, check with them
- ✓ Look after the machine. Keep it clean and tidy, all covers in place etc.
- ✓ Keep a log book. Record any maintenance carried out, service work, overall performance and any other information relevant to the operation of the system.
- ✓ Check that the services to the system are correct and well maintained. Is the compressed air supply correctly dried? Is the cooling water treated to prevent corrosion?

Maintenance for the potential user

- ✓ Recognise that a laser system will need routine maintenance, but that such maintenance is not difficult to perform and, if needs be, can be performed in-house.

- ✓ Discuss frankly with potential suppliers routine maintenance requirements and costs. Compare different suppliers' schedules, and if a company has significantly less maintenance operations, question them in more detail, don't assume that they have some superior design!
- ✓ Discuss and agree spares holding and costs. Assume you will have to hold some spares yourself.
- ✓ Ask to see the documentation which will be supplied with the system. Let your own maintenance and engineering personnel see it. Whatever happens, make sure you have sufficient documentation before the machine is signed off.
- ✓ Speak to other users of the equipment, or the manufacturer's equipment. Don't rely only on manufacturer's references, but at the same time beware of users who appear dissatisfied; there may be other reasons for this.
- ✓ Prepare to have staff trained. Find out what's on offer and how much it will cost. Establish exactly what training will be provided and to what level.
- ✓ Any doubts, find other users for guidance. Contact AILU. Be prepared to buy-in experience, and don't wait until its too late.

Summary

It is easy for manufacturers or systems integrators to overlook routine maintenance, or to consider it only as an afterthought. Moreover, it is difficult to promote routine maintenance as a positive issue, except that justifiable claims that a product needs less maintenance than a competitors' product may be a selling point.

While it is important for laser manufacturers and systems integrator to establish a realistic and user-friendly routine maintenance schedule as outlined above, ultimately it is the user who has to implement it. Those who do can expect long and reliable service. Those who don't are likely to experience an increased number of more expensive breakdowns as time goes by.

Martin Sharp completed his PhD at Imperial College, London, under Prof. Bill Steen and worked for Control Laser, Lumonics and Power Beam Technologies before starting UK Laser Services Ltd as an independent company.

Guidelines for mounting lenses and windows under pressure or vacuum

There appears to be little published on the subject of optical components such as lenses and windows to be used under pressure. The requirement exists in several fields such as laser machining and vacuum systems. The equation given below has been found in three different sources.

Minimum thickness of component (for a lens, measured at the thinnest point)

$$t = 1.05kr\sqrt{p/s}$$

where

- t = thickness of component (mm)
- r = radius of unsupported area of the component (mm)
- p = pressure differential (psi)
- s = maximum allowable stress (psi)
(i.e rupture modulus of flexural strength)
- k = safety factor (minimum of 2, preferably 3 or 4)

N.B. The equation only holds if the optical component is flat or only weakly curved. For example, a convex meniscus with high pressure on the convex side would be under compression and would therefore be considerably stronger than indicated by the equation.

Guidelines

- a. Mount the component in a stress free manner, preferably with a slight resilience to ensure that, under pressure, any consequent stresses are uniformly distributed
- b. Ensure that the optic does not make point contact with the mounting
- c. Check that the optical components is free of flaws, scratches and digs.

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Nd:YAG laser technology and maintenance

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Current technology moves at breakneck speed as anyone associated with PC's or mobile telephones can readily attest. Lasers and laser systems fall broadly into this category, and are definitely no longer products looking for an application.

Laser SOS has seen a steady increase in the use of Nd:YAG lasers over more than a decade. We expect to see the Nd:YAG market continue to grow with marking systems and specialist welding applications as front runners. Expansion of our stock parts capabilities to include laser sub-systems reflects this optimism.

The Nd:YAG rod

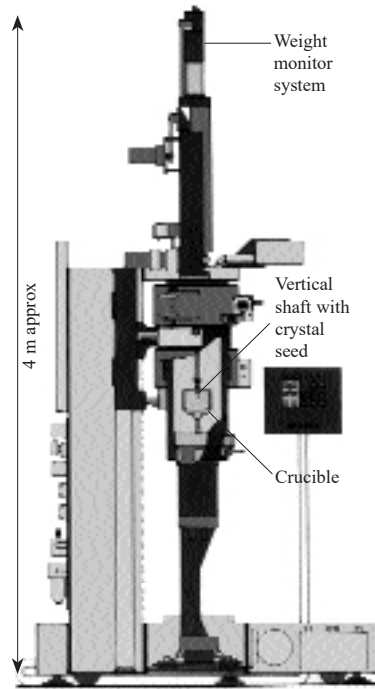
A unique element of the technology of Nd:YAG and other solid state lasers is the crystal in which optical gain occurs. In the case of Nd:YAG the rod must be fabricated from a single crystal, which for optimum performance needs to be of uniform quality over its entire length and free of defects including optical strain. The Czochralski crystal growing technique usually provides the most reproducible results, but a certain amount of 'magic' is still part of this equation.

Each type of crystal has its own abnormalities and most of the 3-5 compounds used for LED's and Diode lasers are grown with the molten material encapsulated under a layer of molten glass and within a high pressure atmosphere of inert gas. Crystals of Gallium arsenide that in the early 1970's were thought to be leading-edge at 250 grams are now grown up to 30 kilograms!

Current crystal growth systems often include computer control to constantly monitor the rate of increase in the weight of the shaft and growing crystal. In this way, a pre-set diameter crystal diameter can be maintained by controlling temperatures, crystal rotation and position.

The main problem with Nd:YAG is that it requires temperatures in excess of 2000°C to melt the stoichiometric mixture of high purity oxide powders. The crucible in this instance is Iridium and even this relatively inert metal needs a special gas mixture to bring chemical reactions to acceptable levels. The neodymium oxide, which is the crystal lattice dopant and provides the lasing abilities, must be present in uniform quantities throughout the crystal length. To maintain this uniformity very slow withdrawal of the seed is necessary and equipment may need to run for up to 8 weeks with better than half a degree temperature variation to allow production of up to 4.5" diameter by 10" long crystals.

The crystal boule must then be fabricated into a laser rod or rods. A diamond bonded high speed saw is used to trim the top and bottom of the boule which are then polished and viewing through a Twyman Green/Fisheau interferometer to identify the areas of the crystal that have good enough optical properties for laser use. The central core area and the facet radial spokes of a [111] orientation crystal contain no useable material and rods are mostly trepanned from the good optical quality material between the



In the Czochralski technique a small crystal of known quality and crystallographic orientation is attached to a vertical shaft which allows the crystal 'seed' to be slowly rotated and raised. A crucible made of a chemically suitable material contains the stoichiometric raw materials and is positioned centrally below this seed. A heating method/environment capable of ensuring that the raw material can be melted in a stable manner must then be made available and the temperature accurately controlled. Careful process control of the temperature of the melt will allow the insertion of the seed into the molten material without the seed melting away or causing total melt freezing. Slow withdrawal of the shaft and seed will let molten material solidify onto the seed and a gradual reduction in temperature gives the seed the opportunity to increase in diameter.

Maintaining the temperature at this point will in theory allow the crystal to continue to grow until all the available molten material has been used up. In practice rotation of both the seed and the crucible, together with a variety of insulators, reflectors, gases and environmental controls are needed to secure a worthwhile crystal.

'spokes'. These raw rods, perhaps with their centres removed, are then ground to the correct diameter and their ends polished flat and parallel to within 2 seconds of arc; however, that is another story.

Maintenance considerations

Maintenance of any laser system is normally a curious mixture of optics and electronics and the Nd:YAG laser is no different in this. At its heart, a Nd:YAG rod lies in a highly reflective cavity (often gold plated) along with a Krypton gas-filled flash lamp. The lamp provides the necessary optical pumping power to create the laser conditions in the rod. Good quality cavity mirrors and other optics produce the pulsed or CW laser light in a useable form. The effect of exposure to high optical powers is that, despite water cooling, critical components including reflective optics, will have a limited life. A slowly reducing output probably indicate that inspection and replacement of these parts is a worthwhile consideration. Routine maintenance should include inspection of mirrors and the laser rod ends since mirror pitting and spawling of laser rod ends will reduce laser efficiency.

Most systems can be maintained with a few test instruments and a modicum of common sense by inspecting power losses for their possible cause prior to a catastrophic breakdown. Parts can be replaced without major complication and rods with minimal damage cut and re-polished without major loss of performance■

Laser Hardening in Practice

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Why, among all the heat treatment processes, both old and new, does the laser remains a Cinderella process after 25 years?

Selective Heating

It is seldom an advantage in use for an entire part to be hard. Wear and high stresses are normally local to the surface and in particular areas. For example, shafts can be made hollow with little or no loss in performance because the strength, especially in torsion, comes from the outer layers.

To selectively harden a component by heat only, and to give an integral and fully hard layer of useful depth (i.e. to produce a tailored part) the practical methods are, in order of increasing power concentration, flexibility and cost :

- FLAME
- INDUCTION
- LASER

The entire component or piece to be treated must be made of a suitable direct hardening steel or cast-iron. For the depth and area of treatment to be selective, the conduction of heat must be controlled. For all three methods, including the laser, conduction effects play an important part and can be used to optimize results for different geometries. Recent advances in induction equipment now allow the RF frequency to be varied to set the depth of heat-

ing. Lower power treatments involve longer heating times on a given area and result in greater depths of treatment and an increased risk of distortion.

Typical interaction times for laser and scanning induction heating vary from 0.2 to 5 seconds. The kinetics to dissolve carbide mean that for the short interaction process, finer structures are needed to ensure full solution. Conventional wisdom dictates that a pre hardened and tempered base structure is required. It is our experience that even laser hardening can be used on coarse or as cast structures in some cases, since the higher surface temperatures that are used compensate for shorter heat cycles. As-cast tool steels, which normally still have relatively fine structures in them, respond successfully to laser treatment. Large castings of alloyed cast iron can also be treated but if the primary carbides are too large they do not dissolve fully and the matrix content determines if sufficient hardness is achieved. (Only cast irons with sufficient pearlite will give good results by normal methods.)

A unique effect of ultra short laser hardening cycles is to transform carbide zones in lower carbon structures, leaving soft surrounding ferrite. The carbon diffusion range is too short to homogenize the structure, and these islands of hard martensite in a sea of soft ferrite can give a 'super bearing' type performance: good for scuffing and abrasive wear resistance but not resistant to impact or brinelling.

TABLE 1. A range of treatments going beyond transformation hardening through to various melting treatments.

Attribute	Transformation hardening							Cladding			Laser	Any laser job-shop offering surface treatment would do well to consider these more complex options to offer superior performance layers for special environments. Although his work concentrates on transformation hardening, the need for selective surface treatment of a component should warrant consideration of a range of processes.
	Plating	Oven/ furnace	Induction/ flame	Laser	Precipitation	Carburising	CVD/ PVD	Flame	High vel./Plasma	Vacuum Diffused		
Technology	M	M	M	N	M	M	N	M	M	N	N	<p>KEY: L = low, M = medium, H = high, N = new Technology whether mature or still evolving Flexibility ability to process selected areas of components to specified depths and conditions Distortion the degree to which distortion can limit the application of the process Power the ability of the process to cover large areas Sensitivity the degree to which the process is sensitive to substrate material selection Strength the degree to which the process can strengthen the component surface for resistance to impact deformation and to increase component strength Expense very approximate Single shot Whether the process can be practically applied to one component at a time</p>
Flexibility	L	L	H	H	L	L	L	H	H	M	H	
Distortion	L	H	M	L	M	H	L	M	M	L	L	
Power	H	H	H	L	H	H	M	M	M	M	L	
Sensitivity	L	M	M	M	M	H	H	L	L	M	L	
Strength	L	H	H	H	H	M	L	M	M	H	H	
Expense	L	L	M	H	M	L	H	M	M	H	H	
Single Shot	No	No	Yes	Yes	No	No	No	Yes	Yes	No	Yes	

Residual stress

Transformation hardening produces patterns of residual stress in the component after hardening, arising from the volume change involved in producing martensite and the differential cooling rates applied to different areas of the component.

Furnace hardening, or any through-hardening process, produces tensile residual stresses on the surface, with compressive residuals in the core. Good induction hardening technique produces the opposite, with compressive residuals at the surface and a tensile core, with tensile residuals also arising at the surface at the edge of the hardened pattern. Laser methods always give this except where hardened tracks are overlapped, which gives more tensile residuals. Where hardening is used for fatigue strength (e.g. crankshaft fillets, transmission axles etc.), compressive stress adds critically to performance and tensile detracts.

In a through-hardened component the surface quenches from the outside inwards. This puts a compressive stress into the core, which deforms plastically because it is still hot, with a low plastic yield strength. When the core then quenches out a little later, it expands but is constrained by the surface (which, having already been quenched, is no longer plastic) which causes the core to go

into compression and takes the surface into tension. Conversely, with surface hardening by 'good induction' or laser, only the surface is transformed and is all quenched together, so the surface (constrained by the cool core within) goes into compression and takes the core into tension.

Of all the techniques available, only laser hardening truly quenches from the base up, giving optimal results. By contrast, apart from the unusual use of cold body quenching, induction normally uses an external liquid quench working from the surface inwards.

Comparison of laser and induction

A comparison of the relative process features of laser and induction hardening is shown in figure 1. The laser offers minimal heat input and precise control with *unique* flexibility and low distortion. Both are non-contact processes, with either the workpiece or the power source moved, depending on the application. With laser treatment the air-gap is not critical, and line of sight access can be used over a considerable distance, whereas in the case of induction only prismatic components can be treated due to the need for a controlled air gap between coil and metal. For example, to harden a crankshaft bearing diameter a close coupled coil cannot

TRANSFORMATION HARDENING METALLURGY

The crystal structure of the iron phase changes from ferrite (body-centred-cubic) to austenite (face-centred-cubic) above the curie temperature during heating. Carbon is not soluble in the initial ferrite and exists as a separate phase of carbide or pearlite. As the metal is heated it becomes possible for the carbide to dissolve into austenite by the kinetic movement of carbon atoms.

To form a martensitic surface layer the metal must be heated to above 900 C (or higher for alloys) *for sufficient time for the carbide to dissolve*. Then the metal must be cooled *quickly enough to prevent carbide reforming*. The resulting formation of martensite is the only non-kinetic process in transformation hardening. Martensite, containing trapped carbon, is a heavily sheared and distorted single phase structure which is therefore hard and relatively brittle. For thick and very hard (high carbon) layers stress cracking is a risk unless tempering is used after hardening to restore impact toughness and ductility. This works by degrading the martensite and reforming some carbides and intermediate transformation products like bainite. It is possible to restore most of the toughness whilst retaining most of the strength.

Effects of composition

The hardness achieved in martensite is largely a function of carbon content. The cooling rate needed to produce it is, however, reduced with increasing carbon and alloy content. So, low-carbon low-alloy steels give only moderate hardness but need high quench rates, which are only achievable near the surface. Conversely, high-carbon high-alloy steels give high hardness at low cooling rates and components of such steels can be hardened using a furnace. Stress-cracking risks are greater if excessive cooling or heating rates are used. In the case of highly alloyed tool steels for instance, vacuum furnaces are best suited to give a shallow thermal profile over time. Indeed, this type of steel was made to suit the furnace heat treatment process.

Material selection

With the vast range of alloys available, simple process rules are not reliable but the main effects of the alloy elements with respect to hardening can be stated:

Chromium: Coarse carbides dissolve slowly so rapid/shallow treatment is not effective, but 'critical cooling rates' are lower and hardenability/ cracking risk is increased. Martensitic (i.e. hardenable) stainless steels are only stain resistant, not fully stainless. However newly developed 'high nitrogen' grades give performance close to 'full stainless' with hardening.

Nickel Generally balances out the problems of chromium but above a certain level eliminates the hardening mechanism.

Molybdenum Refines the carbides, and grains, improving strength, while reducing brittleness.

Manganese A major grain refiner with little direct effect in surface heat-treatment but important for improved properties in through hardened/toughened components.

Important effects of trace elements also to be noted:

Aluminium Killed Steels Above .01% aluminium as an impurity causes a dramatic reduction in hardenability in low carbon steels.

Boron At very low levels this increases low carbon steel hardenability but will 'burn out' giving the effect of decarburization.

Sulphur/Selenium/Tellurium/Lead/Phosphorus Soft inclusions give good chip production and lubrication producing Free Machining Steels but act as crack propagation points so the shape of inclusions must be controlled as in 'inclusion modified grades'.

Microstructure

Microstructure is the most important factor: the finer the microstructure, the 'better the bake'. If the carbon and alloy atoms have to move less, the kinetics of the reaction are easier. The time it takes is less and /or the temperature needed is lower. A rule of thumb is that 10 degrees hotter equals half the time for any kinetic process. Fine structures are needed for short heat cycles; conversely, coarse grain increases hardenability since it slows down the regrowth of carbides on cooling. So 'the mix must suit the process.'

Fig. 1 Comparison of Transformation Hardening Methods

INDUCTION	LASER
ADVANTAGES	ADVANTAGES
lower equipment cost	minimal distortion
higher efficiency	thin case depth (<1 mm)
deeper case depth (1 - 5 mm)	no quenching required
more coverage	high degree of control and flexibility
	can be used on complex, irregular objects and difficult-to access surfaces
DISADVANTAGES	DISADVANTAGES
limited range of geometries	high cost
quenchant needed	low process rate and coverage
high heat-induced distortion	absorbing surface coating required
making/ proving/ fitting coils	

be fed into position so a 'split and close' or an open U shape inductors is used. These are less efficient and offer less control.

Induction heating is not a power-limited process like the laser, so treatment times are not so heavily linked to the size of the hardened zone. Tooling changeover times for induction are higher but both methods use piece by piece or continuous processing (termed 'single shot' in table 1) which integrates more effectively with flexible JIT manufacturing techniques. These on-line techniques contrast with off-line processes such as carburizing and nitriding which use batch furnace which are frequently conducted off site. To develop and prove a complex induction heating work-coil can take weeks but once done parts can be treated consistently and cost-effectively. A job-shop will carry a wide range of coils for standard geometries and sizes as a matter of course. The laser can harden a first part in 10 minutes but a week later it will look slow and costly if a quantity of parts are needed with a lot of hardened area that could be induction heated.

In summary, the ability to treat substantial areas/ numbers of components is the strength of induction and the ability to treat com-

plex shapes with flexibility and finesse and minimal distortion is the laser's forte.

Technological advances

The advent of rugged high power semi-conductor devices heralded huge advances in induction power supplies and today's user has megawatts of power available at a wide range of frequencies, overall efficiencies above 85% and relatively low capital cost. The use of flux concentration in induction hardening is not new, but mouldable ceramic concentrators containing ferrites of a size to suit the frequency used, are now available.

There have, of course, been major developments in lasers, the most significant to surface treatment being the High Power Diode Laser, which offers high power efficiency at a shorter wavelength than the CO₂ laser. However, as Table 2 shows, the cost comparison with induction hardening remains poor.

Applications

The early years

Development work at the Saginaw Steering Works of General Motors found that the internal bore of a ferritic malleable cast iron power steering housing showed unacceptable distortion with induction trials, but that 5 discrete narrow shallow laser tracks gave the performance needed whilst treating a very low proportion of the bore surface. By 1983, 15 lasers (1 kW max.) in the production facility were treating 33,000 housings a day. (This first application was not strictly transformation hardening as it involves 'incipient melting' in the structure as carbon comes into solution dropping the melting point some 300 degrees in a matrix with no pearlite)

An application at the Electro-Motive division of GM used more conventional metallurgy on a diesel cylinder liner. A chrome plat-

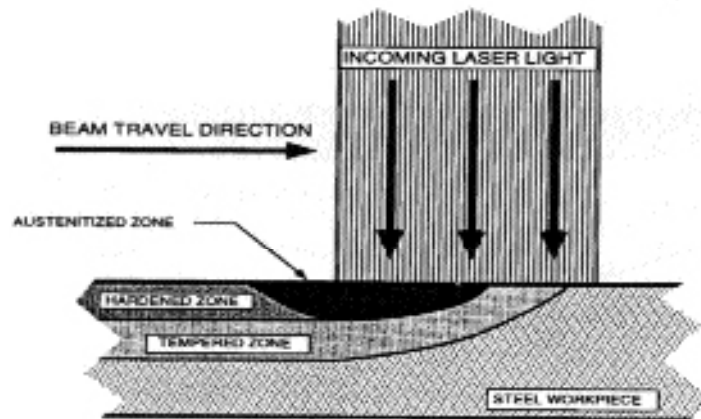
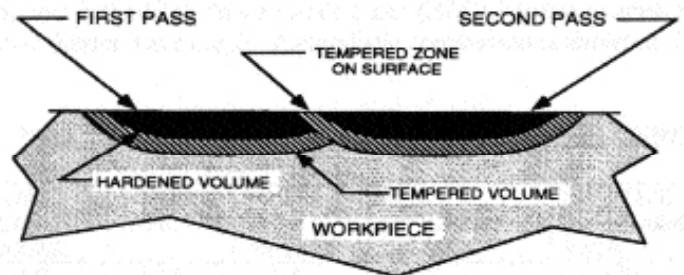


Fig. 2. Laser transformation hardening

Schematic of the basic laser interaction. To gain good absorption of the 10.6 μ m CO₂ laser radiation, a coating of oxide/ graphite/ manganese phosphate/ paint is needed (Shorter wavelength lasers achieve better absorption without coatings). In a dedicated volume manufacturing cell this might double costs as an extra operation, though in jobbing this is less significant. Unlike other metals, stainless steels do not form an absorbing oxide scale to maintain coupling as the coating fails from heating. We have developed the use of specific ceramic coatings to address this problem.

Among the different methods for delivering the laser beam, biaxial mirror scanners (which scan a focused spot, as in laser marking) allow rapid change to the beam profile during treatment of complex 3D profiles and make it possible to use only 2D movement control with simple teach-in



programming.

The left hand figure shows the transformation hardening process for a single scan of the laser, while the right hand figure shows the effect of temper overlap between laser hardened tracks. The equivalent induction effect is at least 5 times as wide and is less acceptable. Higher laser power allows wider tracks, avoiding the backtemper lines but in practice judicious design of the position and angle of the lines with respect to the sliding load or other wear situation is sufficient. Research has also shown that in cases not involving brinelling loads, intermittent hard/soft patterns can be superior as the load will run on proud hard areas and the softer zones will erode leaving channels for further wear debris and lubrication.

TABLE 2. Economic and efficiency comparison

	Power		Capital Cost (£k)	Process Efficiency factor**
	in	out		
Induction	200	170	20	1
HPDL*	20	6	200	5
CO ₂ laser	60	6	200	2

* HPDL = High Power Diode Laser

** Rough estimates for comparison (September 1999)

ing plant was too costly and salt nitriding was too thin and damaged brazed joints. Again, induction methods available at the time gave too much distortion but a 1 kW pilot laser system produced a spiral transformation hardened track around the exhaust port area and demonstrated that a 20 kW laser would do the job. Four 5 kW lasers were chosen to guard against downtime in the production facility and the fact that the 80% up time achieved was considered a success shows how far we have moved on.

The Present Day

Recent automotive laser hardening applications have used full scale melting, a technique which is much less practical for induction due to the magnetic forces associated with the coil.

There are many lower volume laser transformation jobs where the ability to treat irregular shapes or sections with control or where laser access to discrete remote areas gives the laser a unique edge, and it is no longer true to say the laser can only be applied where induction fails. They are complimentary techniques, and they can be applied together on one piece in a job shop situation to great effect. The laser can also compete with furnace processes where either only small areas or quantities are needed, or where part sizes exceed furnace availability.

Examples of laser transformation hardened components include:

- stainless steel steam turbine blades where laser hardening along the leading edge gives improved erosion resistance against droplets.
- sintered valve rockers where in one example 2.5 kW of CO₂ laser power produced twice the speed of a 30 kW induction system and gave a more controlled pattern with better performance, in part due to the low conductivity of the sinter and small size of treatment zone.
- piston crowns where hardening of the ring grooves makes use of the unique accessibility of the laser beam (Figure 3)
- bearing surfaces where on a manual operating lever some of the bearing faces were recessed between pivot lugs, and could not be induction heated without causing some embrittlement.
- edge profiles of high value press tooling where traditional flame hardening involves distortion and cracking risks and relies on extreme operator skill. In this case, hardness results are mediocre due to steps taken to minimize risk of damage. When lasers are used the edge profiles prone to wear are taught into the CNC using a target beam. Parameters for treatment are selected by experience but operation is automatic. Body side tools up to 15 tonnes have been treated showing excellent life performance and no distortion. The selective shallow case does allow conventional grind and weld engineering changes as models are updated.

Summary



Fig 3. The laser wins out.
A piston crown is laser transformation hardened in the ring grooves, making use of the unique accessibility of the beam

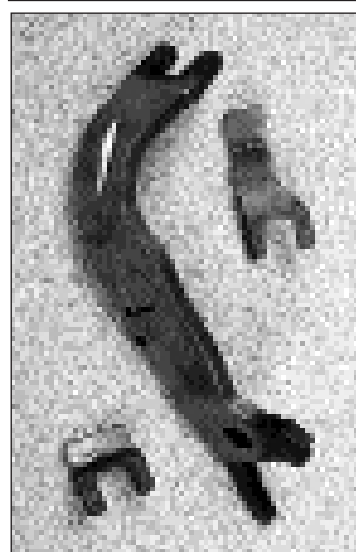


Fig 4. Induction wins out
A fine blanked gear selector fork actuator. The part is induction hardened at 5000 a week. Both sides of the slot are treated by a moving coil with liquid quench. A previous method with a static coil hardened the slot legs and caused distortion. The laser does not compete.

The laser is a unique tool to produce discrete selective wear resistant zones on steels and cast irons with good fatigue properties and in awkward locations with little distortion. External quenching is not needed and some cheaper low carbon low alloy steels can be treated.

Although several applications were high profile in the early days of metalworking lasers, 25 years on much potential has still yet to be realized due to the high capital and running costs of the equipment. This is gradually being remedied and the main remaining impediment to its success is a lack of education amongst users as to how the process works and what it can do.



Ian studied at the Department of Metallurgy Imperial College, London, for six years, specialising in CO₂ laser research in hardening of cast irons and high speed welding.

He joined Inductoheat in 1985 and established their laser processing job-shop operation and became managing director of the company in 1992.

Contamination of CO₂ laser optics

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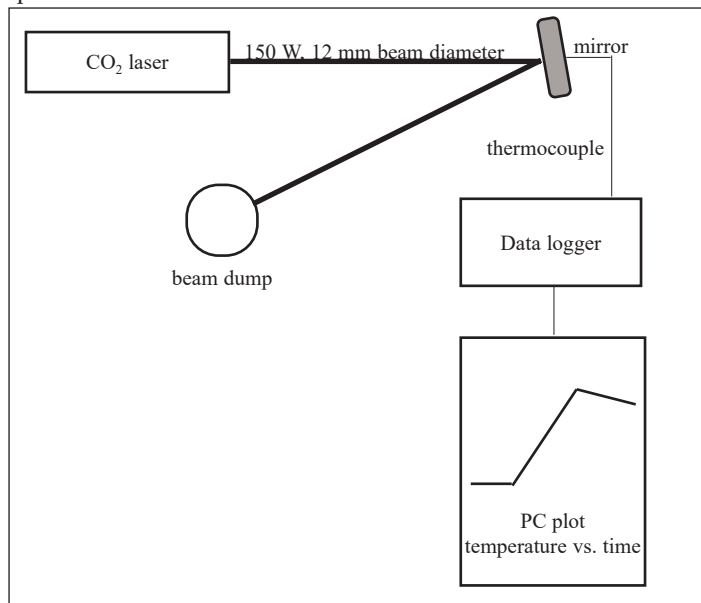
There has been much work showing that lenses and mirrors specified for CO₂ lasers are capable of working at power levels far in excess of those generated in a typical industrial laser. In fact, a safety factor of ten or twenty times is common. It follows that when optics in industrial lasers suffer laser damage the cause is invariably the operating environment, sadly beyond the control of the optics manufacturer.

There are, of course, a multiplicity of laser damage mechanisms (more than 500 papers on the subject have been presented at the Laser Damage Conference held in Colorado) but all have one of two factors are common; either (i) mechanical damage introduced by high velocity debris, or improper mounting, or (ii) high absorption. One other factor, not considered here, is chemical degradation of the optic caused by UV radiation in the laser cavity, and highly reactive chemical species generated in the discharge.

Of the many failed optics we have examined, we have found absorption is a critical feature in the performance and longevity of an optic.

Experiment

To examine the effect of absorption, we adapted a calorimeter to measure the absorption of a mirror deliberately contaminated with various materials found in a typical laser cutting environment. In each case, a precision thermocouple attached to the mirror measures its rate of temperature rise when a laser beam was incident on its surface, and this was related to the absorbed power from the beam.



Schematic of experimental arrangement for studying absorption

Background Research

Literally millions of chemicals have had their absorption in the infra red catalogued, and it is possible to search for absorbing species at a specific wavelength, in this case 10.6 μm . Many chemicals weakly absorb in the wavelength region around 10.6 μm , and no one species can be said to be a uniquely strong absorber. One conclusion was that structures containing silicon and oxygen bonds could well be strong absorbers of CO₂ laser light. A feature of these databases is the material tested is carefully processed to ensure its physical state, (powder, solution, liquid), has no influence on the absorption, a luxury not found in the industrial environment.

Test Conditions

The mirror used as the test optic was gold coated copper. The gold coating is very damage resistant, is chemically inert, and is easily cleaned after testing. Just the one mirror was used, it being cleaned after each test, and checked to see that its absorption had returned to the low level measured when new.

A variety of contaminants common in an industrial cutting environment were applied to the mirror face. Liquids were typically wiped across the face, solids "dusted" on the mirror face. Roughly the same amount of contaminant was applied each time, but the quantity was substantially greater than would occur in normal use.

Interpreting Absorption Results

The level of increased absorption that is needed to render an optic non functional is surprisingly low.

For a lens or output window absorbing 2 parts per thousand (0.2%) when new, an increase to just 4 or 5 parts per thousand can severely reduce cutting performance. For a copper mirror absorbing 10 parts per thousand (1%) when new, an increase to 30 or 40 parts per thousand could cause problems.

Each contaminated mirror was irradiated with the 150 Watt beam for around a minute. Perhaps surprisingly, the heating rate and therefore the absorption remained constant during irradiation, displaying none of the variation that might be expected as the contamination evaporated or burnt off, or changes in absorption with temperature.

Discussion of the results

The large variation in the individual absorption values measured is not surprising. We have seen many examples of heavily contaminated optics working well, and what appear clean optics that are strongly absorbing. For example, when the mirror was held in the smoke from burning PVC it became badly fogged but measured near zero increase in absorption. Conversely, we know output windows mounted will destruct if just a few flecks of silicone sealant are on the optic.

CONTAMINATION DESCRIPTION	% ABSORPTION	MIRROR TEMPERATURE AFTER 60 s (°C)
BRAND NEW GOLD MIRROR	1%	21
LITHIUM GREASE	16%	44
EP 80 GEAR OIL	7%	31
DOW HEAT SINK COMPOUND	41%	80
WASHING UP LIQUID	37%	72
ZINC SELENIDE DUST	2%	22
FUMES FROM BURNT PVC	1%	21
FUMES FROM BURNT RUBBER	8%	32
SALIVA	1%	21
JEWELLERS ROUGE (IRON SULPHATE)	30%	63
FINE ABRASIVE (ALUMINIUM OXIDE)	43%	80
FINE ASH	23%	53
SILICONE ADHESIVE SEALANT	31%	66
"WINDOLENE"	21%	52
COPPER WIRE WOUND ACROSS FACE	2%	22
MIRROR AFTER 13 TESTS AND 13 CLEANINGS	1%	21

The physical state of the contaminant seems not to be a factor. ZnSe, known to have a low bulk absorption, is also a low absorber when deposited on the mirror as a finely ground powder. The mirrors fogged by smoke from burning PVC and rubber were considerably different in absorption, despite similar appearance to the eye. These observations support the conclusion that the absorption is determined by the chemical nature of the contaminant rather than its physical state (e.g. powder, liquid)

The results underline that silicon/oxygen compounds are strong absorbers. Heat-sink compound, silicone sealant, and ash are rich in such materials. Dust samples collected from the air as part of pollution studies contains typically 25% by weight of these silicon/oxygen materials.

Finally, to replicate the effect of embedded metal, the mirror had a grid of copper wire wound across the face. The low measured absorption is consistent with the high reflectivity of Copper, and more generally with the observation that mirrors covered in metal spatter often continue to work.

Conclusions

The results are consistent with observations we have made on used optics over many years. The absorption of a contaminant at the CO₂ laser wavelength is dominated by its bulk absorption rather than its morphology, and the appearance to the eye is no guide to the level of absorption.

There is evidence that materials containing silicon and oxygen are strong absorbers. The use of heat sink compound and silicon rubber used in mounting optics need special care to ensure that residues are kept away from optics.

Cleaning materials such as rouge, fine aluminium oxide, and detergents are strongly absorbing and there is really no need for these materials to be used. Excellent cleaning results can be obtained by using organic solvents and the techniques explained in *Cleaning of lenses and mirrors* (Issue 14, p15, Feb 99).

Readers are invited to investigate other materials that laser users may consider a problem e.g. specific brands of lubricants. By identifying materials known to be strong absorbers, we hope that in time, they can be replaced by equivalent products that are less absorbing.

Comment

Contamination of optics is certainly a major cause of early failure. A focusing lens in close proximity to the work piece is likely to receive at least some back-spatter, but other optics should not be overlooked.

We have seen beam expanders that have 'failed to work properly'. As Mark Wilkinson discovered on failed optics, they all have one thing in common; at least one of the lenses had a high absorption. In most cases, the cause was obvious; a semi-opaque film over one of the lenses, perhaps the result of a perspex mode burn that was too close. Other examples, however, looked clean to the eye. Only by dismantling the beam expander and measuring the absorption on each lens was it possible to locate the problem. In

either case, a careful clean of the offending optic restored its absorption.

Almost as important, is to make sure that the optic mounting parts are clean as well. If your lens mirror has been sprayed with debris or fumes, you can be sure that the metal work will be as well. Give the mount a clean along with the clamp rings and O-rings. If you don't there is always a chance it will find its way back to the optic by some means or other!

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Remote materials analysis using laser-induced breakdown spectroscopy

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Laser-Induced Breakdown Spectroscopy or LIBS was first investigated shortly after the development of the laser in the early 1960's. Since that time, industrial applications of LIBS have been inhibited mainly by the unavailability of portable and rugged laser systems. In recent years, however, technological advances in lasers and optical detection systems have helped make industrial applications of this technology a reality.

LIBS is a form of Atomic Emission Spectroscopy and is essentially a very simple technique. The output of a short pulse-length laser (e.g. Q-switched Nd:YAG) is focused onto the surface of a material to generate a tiny spark (micro-plasma); the light by the spark is detected and analysed to yield information on the elemental make-up of the material. Since the technique is essentially all-optical, it is particularly valuable for analysis of materials in hazardous environments. Remote operation is possible through the use of optical-fibres, but the design and complexity of a reliable LIBS instrument becomes more involved.

Applied Photonics Ltd (APL) specialises in the development and deployment of these special LIBS instruments, and earlier this year, we were contracted by British Energy to design, build and operate two LIBS instruments suitable for remote analysis of stainless-steel pipework bifurcations in the superheaters at two of their AGR nuclear power stations. The lifetime reviews for these two stations had identified potential superheater bifurcation cracking as a commercial threat to the 35-year operation of the boilers. British Energy specified that a materials inspection of all 528 of the 316H stainless steel bifurcations in each reactor was to be carried out to identify which of them were likely to exhibit low creep ductility leading to steam leaks prior to the end of station life.

The in-vessel inspection was based on the knowledge that the bifurcation material of interest exhibited a higher than normal concentration of copper. The LIBS instrument could be used to quickly identify which of the 528 bifurcations were affected, allowing further inspection and repair procedures to be targeted.

Comparison with other techniques

Conventional materials analysis techniques were considered for this application but ruled out for the following reasons:

X-Ray Fluorescence (XRF) instruments

The relatively high gamma radiation levels within the superheaters rendered XRF analysis impossible.

Portable chemical analysis kits

Physical access to the superheater pipework is severely restricted making the use of such a technique virtually impossible.

Sample removal and laboratory analysis

This is a very time-consuming process resulting in an unacceptably high radiation dose to personnel carrying out the work.



Photo courtesy of British Energy

Figure 1 Inside an AGR superheater.

Andy Whitehouse, APL's Managing Director, deploys a LIBS probe.

The environment of the superheaters is particularly hostile - relatively high gamma radiation levels, high ambient temperatures of around 600°C and confined spaces. Personnel required to work in this environment undergo a thorough training programme and are equipped with bulky air-cooled protective suits. Even the most simple of tasks becomes difficult and time-consuming in this environment.

Removal of samples may compromise the mechanical integrity of bifurcation. There are also practical problems associated with Quality Assurance of samples (i.e. cross-contamination of samples, incorrectly identified samples).

The LIBS technique offered the following benefits:

- In-situ analysis - no need to remove samples of the material
- Rapid measurements providing "real-time" results - facilitates compliance with QA procedures
- Remote deployment - expensive and fragile equipment is located in a safe area while only a simple probe and umbilical needs to be located in the hazardous environment
- Analysis technique is unaffected by nuclear radiation
- Virtually non-destructive technique

Probe construction

The LIBS instruments were designed to measure the copper concentration of each bifurcation and, due to the hostile nature of the environment of the superheaters, had to be rugged, reliable and easy to deploy. Each instrument comprised:

- Q-Switched Nd:YAG laser
- Time-gated optical spectrograph
- Computer

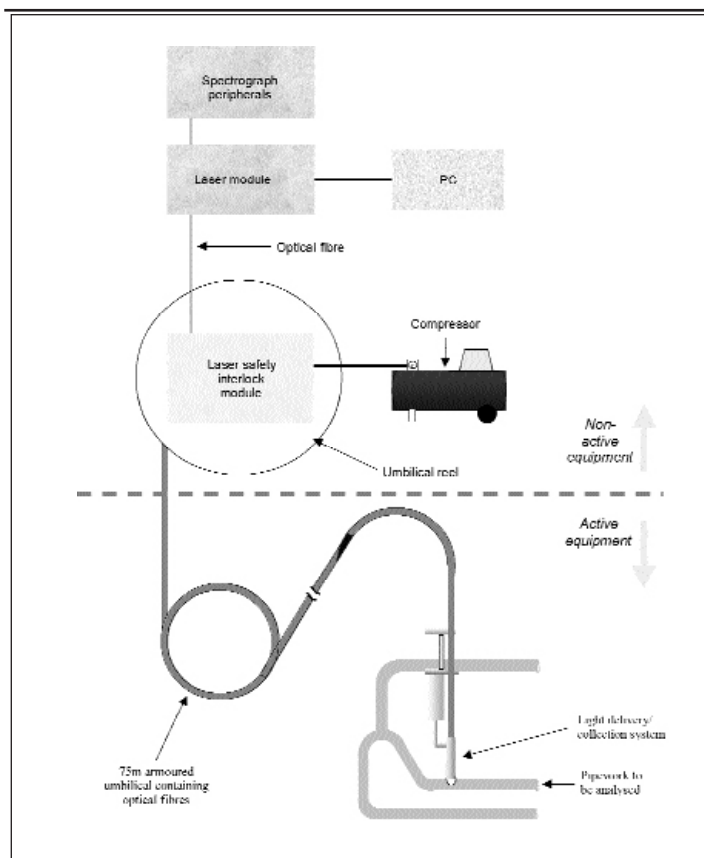


Figure 2 Schematic of the LIBS instrument used in the Advanced Gas-Cooled Reactors.

- 75 metre umbilical containing the optical-fibres
- Pneumatically operated remote probe suitable for attachment to the bifurcation

The pneumatically operated probe contained the optics needed to focus the laser light onto the surface of the bifurcation and was designed for fast and easy deployment within the superheaters. The umbilical contained an optical-fibre used to both transmit the

laser light to the probe and transmit the plasma light back to the optical spectrograph. The length of the umbilical was sufficient to allow the laser, optical spectrograph and computer to be located in a safe area above the reactor pile-cap. A schematic of the LIBS instrument is given in Figure 2.

A number of scientific and technical challenges had to be overcome during the course of the development of these instruments, namely:

- Ruggedisation of the LIBS instrument components
- Intrinsically 'laser-safe' operation of the LIBS instrument
- Remote semi-quantitative materials analysis at a distance of 75 metres
- An easy-to-deploy remote probe suitable for attachment to each of the 528 bifurcations

The LIBS instruments developed for British Energy are unique in their design, operation and capability. To the best of our knowledge, this is the first example of using LIBS to analyse materials at a distance of 75 metres. Applied Photonics are currently developing other types of LIBS instruments for specific industrial applications. In March 1999 the company was awarded a DTI SMART Award to carry out a feasibility study on a new type of LIBS instrument suitable for remote and rapid identification of metallic items within radioactive waste.

The author wishes to express his thanks to British Energy for permission to publish this article.



Andrew Whitehouse studied Physics with Laser Physics at the University of Wales in Swansea, where he went on to gain a PhD in Atomic and Molecular Physics.

He left his position in BNFL Sellafield Research and Technology Division in 1998 to found Applied Photonics Ltd.

Book Review

Vertical-Cavity Surface-Emitting Lasers: Design, Fabrication, Characterization, and Applications

edited by Carl Wilmsen, Henryk Temkin, Larry A Coldren

Cambridge Studies in Modern Optics, Cambridge University Press, published October 1999

ISBN 0 521 59022 1, £60 (US\$100) hardback

This newly published book aims to bring together research on the design, fabrication, characterisation and applications of vertical cavity, surface emitting diode lasers, commonly referred to as VCSELs. This exciting and rapidly developing field is driven mainly by applications in optoelectronics such as telecommunications and optical interconnects in computer systems, and the book provides effective coverage in these areas. The opening chapter, 'Introduction to VCSELs', provides a good overview of the technology which will probably provide all that a non-specialist needs to know. Subsequent chapters develop the laser physics of the micro-cavities and discuss fabrication of devices for the visible and near infra-red regions.

In comparison to conventional diode lasers, VCSELs avoid the transmission of high power through tiny areas of facet at the edge of the semiconductor chip. Unfortunately, the direction of laser

emission is now also the same direction as heat flow for cooling the chip and current flow for excitation. The congestion caused on the chip surface by accommodating all three functions limits the fraction of the chip area which can be used for laser power generation. High power VCSEL arrays are presently devices in the several watt category, although efficiencies match that of the best edge emitting diode lasers. The future however is literally 'bright' for this technology, as there is the possibility of much higher power devices in future which have much better beam quality than present high power, edge-emitting diode stacks.

For someone developing materials processing applications now, this book is of little interest. But watch out for the second edition in a few years time!

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Metal welding with low power CO₂ lasers

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CO₂ lasers have now become commonplace in cutting applications and at high powers, lets say 3kW or more, are used in welding applications. It is difficult to put a figure on the split of CO₂ laser installed base between cutting and welding but looking at various quoted figures and our own experience it seems likely that in the UK less than 10% of CO₂ lasers are used for welding.

There are many reasons for this low uptake. I suspect that one of the main factors is that the advantages of laser welding are not perceived to justify its relatively high cost (not just of equipment but also re-design), when there other techniques eg. MMA, MIG, TIG etc. that are doing a very good job in many applications. Another factor is that in general laser welding produces results that are similar to those obtained by electron beam, albeit for modest weld penetration. It is arguable that because of its requirement for welding in vacuum, e-beam welding is a more complex process than laser welding, which should therefore have replaced it for welding thin materials. In practice, experience shows that, like laser equipment, e-beam equipment has great longevity. Also, it is often used for such relatively low quantity applications as sealing aerospace transducers, where the speed advantages of laser welding are not relevant and where to replace the process by laser welding would require re-qualification.

Design for laser welding

An earlier remark about the cost of re-design for laser welding requires further comment. In some cases, usually those involving a lap-seam weld, no re-design is required. However, in general, because laser welds are autogenous (meaning that there is no addition of material), good fit-up is required, with surfaces in

Advantages of laser welding

The generic advantages of laser welding are well known.

In no particular order they include:

high speed

low heat input

small heat affected zone

clean and with good cosmetics without secondary operations

minimal distortion (close to zero)

access required only from one side (cf. resistance welding)

non-contact process

easily automated (if fit-up/ jigging is good)

high reproducibility

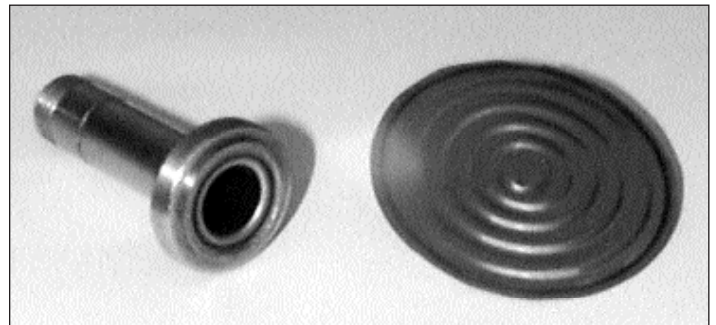


Figure 1 Solenoid Component (left) and Pressure Transducer (right)
Both welded with Howden Laser 600 Watt CO₂ laser in full production environment.

contact or with any gap typically not exceeding 0.1 mm. It follows that fit-up for laser welding must be reproducible, a requirement most easily achieved by jigging or using self-jigging parts. Often, parts designed for non-laser welding could be re-designed to facilitate the fit-up requirement of laser welding but the user judges the benefits of laser welding to be insufficient to justify the extra initial work. Successful laser welding applications are often the result of the designer having laser welding in mind from the outset, to maximise the benefits that laser welding can bring.

Welding at Low Average Power

The benefits of laser welding apply for both CO₂ and Nd: YAG lasers, though pulsed Nd:YAG lasers can exploit the flexibility of 'high peak power/ low average power' operation and, operating at a convenient fibre deliverable wavelength, Nd:YAG has a further advantage for complex 3-D welding. The shorter wavelength of Nd:YAG is also of benefit for the welding of noble metals and aluminium, metals for which low power CO₂ laser welding is not a practical option. In the context of this article, a 'low power CO₂ laser' is defined as one with an output of less than 1kW CW.

Where then are the areas in which low power CO₂ lasers are used? Thin thermoplastics, such as polyethylene, can be welded at very high speeds, but in the context of metals welding the applications best suited to low power CO₂ laser use include mild steel, stainless steel and titanium welding in such items as heat exchangers, solenoid components, pressure transducers (see Figure 1), high vacuum components, specialised batteries and even cooker hobs!

Weld Mechanisms and Application Areas

Two types of mechanism are involved in the melting required to achieve subsequent fusion. For less well focused beams a conduction limited process occurs whereby heat flows away from a site of hot, dense plasma at the surface. This results in a relatively broad weld with a proportionally broad heat affected zone. This

mechanism is exploited in many Nd:YAG applications where overlapping single pulses are used to give a low penetration sealed seam on various electronic packages. This is an excellent solution where thermally sensitive components are near the weld because the high peak power (5kW) / low average power (low 100's of Watts) pulses give a good seal with minimal heat input.

Tightly focused beams give rise to a keyhole melting process where, because the intensity is so high, conduction cannot occur quickly enough to prevent bulk vapourisation of the initial melt. The pressure of this vapour makes the liquid interface concave, increasing the absorption and leading to a 'keyhole' - in effect an 'open wound' in the melted material kept open by the vapour pressure within and acting as an efficient absorber for the laser power. The fused joint and heat affected zone produced by such welds are both relatively narrow. With good beam quality and correctly chosen F number (for the focusing optics), keyhole welds by CO₂ laser can be made in stainless steel achieving depths of 2 mm with CW power as low as 600 W at speeds of around 0.5 m/min. For thinner materials the weld speed increases so that for a weld penetration of 0.5 mm a speed approaching 3 m/min can be achieved. Mild steel welding rates are about 10% lower than with stainless steel for a given thickness. Low power CO₂ laser welding is nearly always a CW process. In times past there would be a high consumption of focusing lenses due to weld spatter damage in applications involving these low powers. With the general improvement in transmissive optics it is now possible (given low M^2 beams) to generate high power densities without the need for very short focal length lenses and with the use of low cost lens protection slides (made from KCl) lens lifetime is nowadays similar to what might be expected in a cutting application. Of course, as in high power welding, focusing using reflecting optics is also possible and the best choice of method is application dependent.

Keyhole welds are good where strong, fast joints are needed. Their heat input is higher than that required to simply seal a package but still much lower than that of non-laser techniques. A small e-beam welder gives similar results but is much slower for repetitive processes because of the need to do the weld in vacuum. In solenoid components, for example, it is often necessary to weld a magnetic component to a non-magnetic so the temperature must be kept quite low to prevent demagnetisation, but the weld needs to be strong and with typically tens of thousands to make in a day the cycle time must be short. Such an application is ideal for a low power CO₂ laser.

In most cases I do not see CO₂ and Nd:YAG as head-to-head competitors. For example, for a lap-seam or circumferential weld and a simple geometry, on favourable materials, a CO₂ laser incurs a capital cost per Watt (and therefore cost per unit of linear weld) about half that of a Nd:YAG laser. Furthermore, in such examples the beam delivery/ part handling costs are very similar.

Laser welding requires inert gas shielding to protect the hot molten pool from oxidation. Low power CO₂ laser welding production applications generally use Argon as the shield gas though on occasion Helium may be preferred. The shield gas is delivered co-axially (as for cutting) via a relatively large nozzle aperture and at low pressure.

Of our own low power welding customers it is noticeable that many applications involve cylindrical geometries with annular or circumferential butt welds or circumferential lap seam welds.

Such applications have easy work handling (i.e. a single rotation), the laser and focusing nozzle usually remain static and the use of manual or automatic loading multi-workstation carousels allow rapid loading and unloading.

Our findings indicate that CO₂ laser circular spot welds to join thin ferrous sheets (individual sheet thickness up to 1 mm) are typically 50% stronger than spot welds made by resistance spot welding for the same outside diameter. This type of weld is used in heat exchangers as well as in certain structural applications. However, since a lap seam weld is required, existing geometries are suited to laser welding and there are undoubtedly wider opportunities in this area. There are thus many instances where a moving laser-based system with on-board trepanning head (such as Howden laser have developed) is a very good, cost effective solution for spot welding or continuous seam welding of thin mild or stainless steel sheets over relatively large areas. Note that individual spot welds, due to their small fused area, have low strength and so are rarely used except as an aid to jiggling.

Lap seam welds, either continuous seams or circular spots, require some form of clamping to keep the sheets in contact during welding. This clamping mechanism requires careful design, since the application of too much force may cause the material to kink, resulting in a poor weld due to loss of contact.

Job shop Issues

While some laser cutting jobshops perform laser welding, it is usually on cylindrical parts. It may be that the overall problem in offering a job shop service is that, with welding, the bulk of the work involves finished parts rather than raw materials. While automated handling of sheet metal is routine, it is not really possible to automate more than one welding job at a time because of the different shapes. It can be argued that multi-axis machines can cope with an assortment of part geometries, but the cost of such equipment is usually prohibitive. Successful welding-dominated job-shops are rare and seem to require much higher power lasers of greater versatility. Bringing welding to the job-shop area does not seem to be a question of buying a proven system from a market leading company and then filling it with work - as is the case for cutting. Rather it involves seeking out specific volume applications and then fulfilling long term sub-contracts more cost effectively than the customer could do the work in-house. The narrow niche open to low power CO₂ laser welding makes it more suitable to in-house applications.

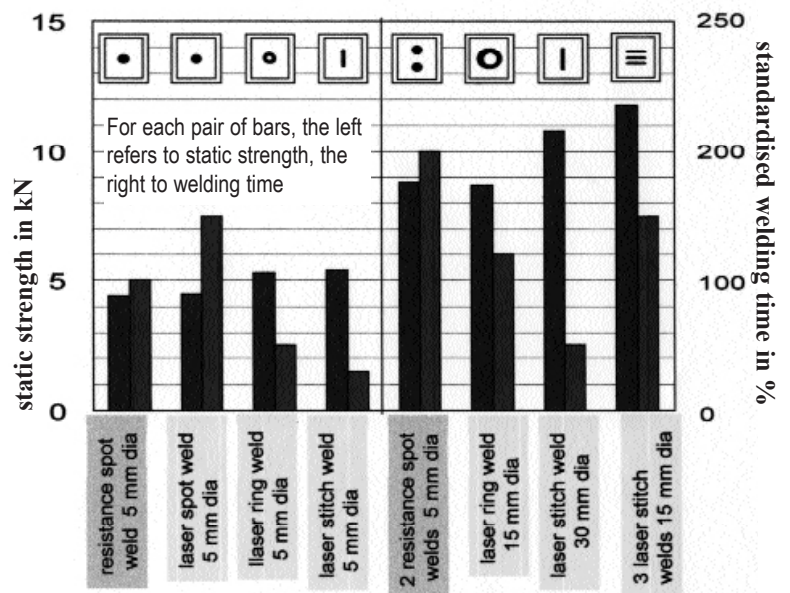
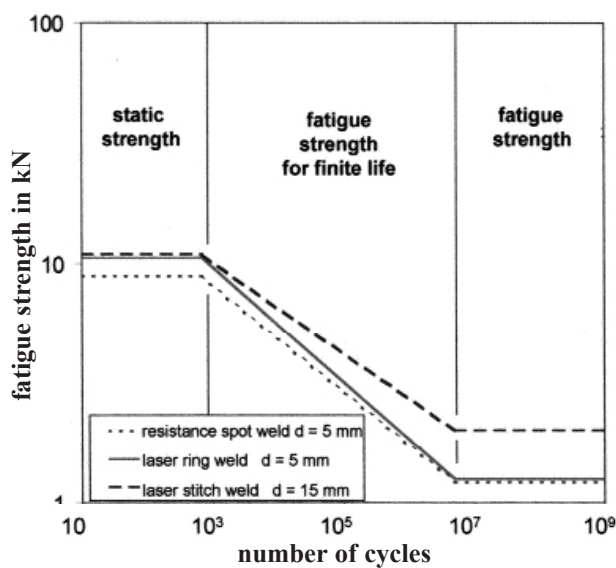
Conclusion

Low power CO₂ laser welding is a cost-effective method of autogenously joining thin section ferrous materials and titanium. Lap-seam or circumferential butt welds are ideal geometries for this technique.



After graduating from Bristol University with a BSc (Hons) degree in Chemical Engineering in 1980, Chris joined the Ferranti Dundee Laser Group. In 1990, after 10 years spent in Research and Development, mainly in the sealed-off CO₂ laser field, he moved into a Sales role. Currently he is Sales Manager at Howden Laser.

Comments



The market for low power CO₂ welding is small at the moment (David Belforte's figures indicate that welding currently accounts for only 15% of the overall use of lasers for materials processing), but with the advent of low cost, compact, sealed off lasers, this might change over the next few years.

The problem with laser welding is that the laser itself is expensive compared with conventional techniques. However, it is important to look at the overall costs of introducing laser welding and in this case, it might be that laser welding is more cost effective. I am

I find particularly interesting the claims with regards to a 50% increase in strength for low power laser 'ring' spot welds versus resistance spot welds of the same diameter. As the typical failure mechanism for spot welds in automotive grade steels (0.6 - 3 mm) is a weld 'plug' being pulled through the parent material of one sheet, the weld strength is usually a function of the parent material strength and weld diameter. I would be interested therefore, to find out the application and testing method upon which these results were based, and the inherent benefits of being tolerant poor fit up and being relatively inexpensive. In general at these laser welding speeds (< 3 m/min) I suspect laser spot welding will be very similar in speed to conventional resistance spot welding (typical weld time approximately 0.5 seconds), so I can only really imagine laser welding being adopted for applications where significant benefits can be achieved in terms of performance (probably brought about by use of continuous weld seams or larger diameter spots) or where resistance welding is difficult due to other issues such as restricted access.

C Bratt
British Steel Limited

Chris correctly identifies the major reasons for laser welding being a minority sport as being high capital cost, accurate fit up and requirement and, except for a few favourable cases, the cost and complexity of the clamping required. Some of these problems appear to be ameliorated by the use of combined laser and plasma techniques which allow welding with relatively low power (and thus cheaper) lasers while requiring less stringent component fit

thinking here about lack of post processing for laser welded components and perhaps better or stronger end product.

I disagree slightly with Chris's statement about weld strengths. Not that I want to put people off lasers, but our figures indicate only a slight improvement when comparing a resistance spot weld to a laser ring weld of the same diameter. See above charts.

Tim Holt
Rofin-Sinar Laser

ups. Early work was by a certain WM Steen and was followed by others at Coventry University School of Engineering, (J Biffin, N Blundell, T Johnson et al). I believe that this work led to commercial applications and wonder if an up to date article on the process and its current status would be of interest to our readers?

J Peter Hancocks
Technical Consultant

The Coventry University team have agreed to write such an article for the next issue! Ed.

Response by the author

We are aware of the issues related to spot welding of 'mild steels' raised by Tim and Craig. However, the 'ferrous' material I alluded to in respect to weld strength was stainless steel - AISI type 301. The application is subject to customer confidentiality, but I confirm that a significant sample of laser circular spot welds have been tested, in shear, by a calibrated pull testing machine. For thin materials, laser spot welds consistently exceeded the required spot weld strength, arrived at by long-term testing of resistance spot welds, by around 50%. Fatigue performance of the laser spot welds have shown equal or slightly superior characteristics to resistance spot welds.

Sub-kilowatt Carbon Dioxide Laser Cutting

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Well over ten thousand carbon dioxide lasers are sold each year and the bulk of these are used in materials processing applications. This normally conjures up visions of impressive room-size multi-kilowatt laser systems cutting or welding thick steel at high speed.

There are, however, a vast number of 'light engineering' applications for which such large laser systems would be overkill. Instead of kilowatts, only a few hundred watts are needed to cut packaging materials, fabrics, thin metals, engineering plastics etc. Indeed, there is a wide range of metal and non-metal applications for which 'low' power laser systems are ideal; either built into stand-alone laser processing equipment or integrated neatly into production lines.

Low Power Carbon Dioxide Lasers

All carbon dioxide lasers rely on an electrical discharge to excite a mixture of gases, a mixture that includes CO₂ of course. When reviewing the various types of laser available in the sub-kiloWatt range, it's probably easiest to start by looking at the different discharge options, rather than at other details. Two distinct types of electrical discharge are used: the direct current (DC) discharge, where current flows between two metal electrodes in the gas (one positive and the other negative), and the radio frequency (RF) discharge where power is fed into the gas from an external RF generator.

Excitation by DC Discharge

DC-excited lasers basically take the form of a long cylindrical laser tube full of gas, with a conventional DC discharge running along the length, much like a neon tube. Mirrors are mounted at each end of the laser tube to form the laser cavity and this geometry is excellent for producing a high quality round output beam.

With this geometry, heat removal from the discharge volume is not particularly efficient and this reduces the laser's efficiency and power. The most common solution to this is to flow gas slowly through the laser discharge tube, injecting cool gas from cylinders at one end and pumping away the hot gas from the other. This also removes impurities that would otherwise build up in the gas discharge. Using this 'Slow Flow' configuration, single laser tubes can typically deliver around 100W for each metre of length. To achieve higher output power either a very long laser or several tubes in series have to be used.

With a DC discharge, the laser operates in a continuous-wave (cw) mode. The power is controlled by altering the discharge current. The discharge can also be gated on and off to produce a pulsed laser output, but this process is relatively slow. An application requiring high speed pulsing of the laser, perforation for example, is likely to need an additional element (e.g. an acoustic-optic modulator) to generate the pulses.

RF Excitation.

More and more 'low' power lasers are using RF excitation technology. This technology has the benefits of removing the high voltage circuitry from the laser and adding versatility of control. Various schemes exist, but all share the same central features.

RF excitation of a 500 W laser requires around 10 kW of RF power. At this power level, RF amplifiers operate at fixed output levels so it's not possible to control the laser power by just turning the amplifier down. Instead, the power is controlled by turning the amplifier on and off at high speed (up to about 100 kHz) and controlling the duty cycle. An advantage of this approach is the ability to deliver laser pulses either at very high speeds for perforation or scribing applications or, by adjusting the duty cycle and repetition rate, in a cw or quasi-cw mode for more common applications. Moreover, by changing pulse duration and separation during a burst of pulses, complex laser pulse shapes can be obtained for specific applications.

RF excited lasers work by applying the discharge transversely across a volume of gas and, just as with DC discharge systems, the ability to cool the gas seriously affects the efficiency and output power. Various configurations exist, typically involving a compact and rugged metal and ceramic construction that maximises the discharge volume while keeping the gas in good thermal contact with cold metal.

Sealed Tube Lasers

Advances in materials technology and processing make it possible nowadays to run CO₂ lasers without any external gas supply. The laser is simply charged with gas during manufacture and operates from this gas for the duration of its life. With some lasers the lifetime can be tens of thousands of hours, equating to years of use, even in a 24/7 environment. At the end of life, the lasers can be refurbished at the manufacturer's factory and returned to the user.

While all commercial RF excited lasers have a sealed tube, this is not the case for DC excited lasers. Sealed tube versions of DC excited lasers are available, but cooling is less efficient in the absence of gas circulation, making these laser less efficient than their slow flow brothers.

A major benefit of using a sealed tube laser is that there is no consumable gas cost or associated cylinders and pipework. Maintenance is also reduced, except where this involves opening up the laser tube. Whereas slow flow lasers can be opened up for maintenance and then simply pumped clean again, a sealed tube laser requires clean room conditions. How quickly a repaired or replacement sealed tube laser can be installed has to be considered in the light of the cost of down time and in critical applications where downtime has to be measured in hours, there is often little choice but to hold a spare laser tube on site.

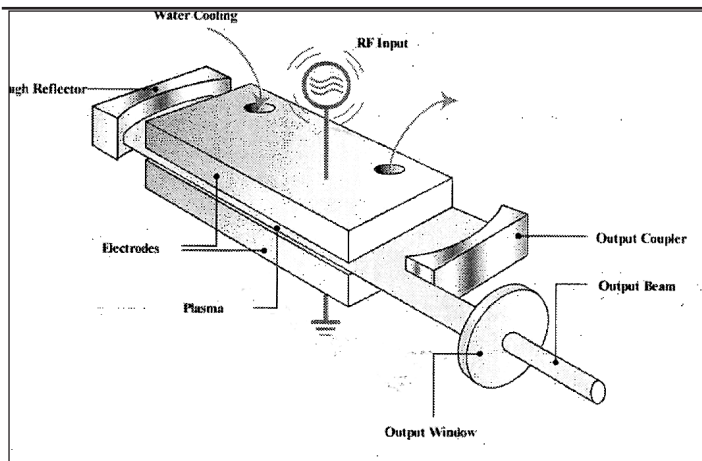


Figure 1. Schematic of a slab laser

The slab laser

A popular and successful example of an RF excited system is the slab laser. These lasers have been available for around ten years and many thousands have been installed for commercial applications. In a slab laser, a pair of water-cooled rectangular metal plates are arranged rather like the bread in a laser sandwich (Figure 1). The plates act as electrodes for the RF discharge and, with the slab of gas only millimeters thick, heat is removed very efficiently.

The electrodes also serve as a waveguide to confine the laser beam. Curved mirrors are used at the ends of the slab to form the laser cavity (an unstable resonator). Along with the electrodes and laser gas, these mirrors are sealed inside the gas envelope, keeping them free from dirt in everyday use. Careful component preparation and processing gives lifetimes of several years of heavy use.

A major advantage of the slab laser is that it can be easily scaled in output power by increasing the area of the slab. 500W has been available for several years from a fully sealed laser head measuring about a little over a metre long! While this is the current limit of sealed tube performance, the same slab geometry is also available at the kiloWatt power level.

On the down side, slab lasers don't have the nice cylindrical geometry that comes with a DC excited system. If not controlled, the output beam can have different properties (size, beam quality, divergence etc.) in the X and Y directions. In practice, most slab lasers use external optical components to clean and shape the output beam in order to produce a high beam quality ($M^2 \leq 1.3$) and an extremely round focus.

The excellent beam quality and high power available from slab discharge lasers makes them extremely useful for machining applications. The way in which they can be pulsed is also important. For example, 500W slab lasers are available that produce a peak power of more than 1kW (the laser output switches rapidly between zero and 1kW at up to 50% duty cycle): the result is a laser with 500W of average power but with the penetration capabilities of a 1kW laser!

System Configurations and Applications

Due to their small size and reduced service requirements, low power lasers are relatively simple to integrate, especially RF-excited sealed tube systems with their compact and rugged construction and without the need for laser gas supplies. As well

as their use in dedicated laser processing systems, ease of integration allows low power laser processing to be added directly onto the manufacturing line and Figure 2 shows just such an installation where a laser is installed into a line cutting steel golf club shafts to length.

As well as being easier to physically integrate, lower power lasers are also generally simpler to optically integrate. This doesn't mean that cutting steel with a 200 W laser requires different optics than when using 2kW, but rather that the beam delivery for lower power lasers involves smaller optics which may not require water cooling, and the applications tend to involve workpiece that are easier to cut and process speed which are not so critical.

X-Y table configuration

The optimum configuration, at least from the point of view of laser technology, is to mount the laser rigidly and to use fixed optics to steer and focus the laser beam down onto the workpiece. This workpiece is then moved using an X-Y table to process the desired pattern, with obvious restrictions on the size and mass of the workpiece and speed of movement, especially if complicated paths are involved. For reasons that will become clear, this geometry does offer good accuracy and repeatability during processing. Consequently, this type of configuration is normally used for small and intricate operations - such as ceramic scribing in the microelectronics industry and metal profiling with thin material.

A typical metal-profiling system might have an X-Y table with a travel of perhaps 500 mm square and would typically process metal thickness of a few millimeters. At this size and thickness, the work-piece is not too large, heavy or difficult to support and high dimensional tolerances can be achieved with excellent quality of cut (Figure 3). Fitted with a 500 W laser system a system like this would be capable of cutting 5 mm mild or stainless steel, or cutting 1 mm thick material at speeds of around 10 m/min. Even with a 200 W laser, a speed of 2 or 3 m/min can be reached. These are extremely useful processing speeds in a number of light engineering situations. Job shops can often support the running of a low power system for lighter production needs alongside their larger equipment.

Laser scribing

Ceramic, especially alumina, is being used increasingly as a circuit substrate in the electronics industry. Laser scribing is used to cut substrates to size and shape from larger sheets of ceramic.



Figure 2. Sealed-tube CO₂ laser cutting golf-club shafts.

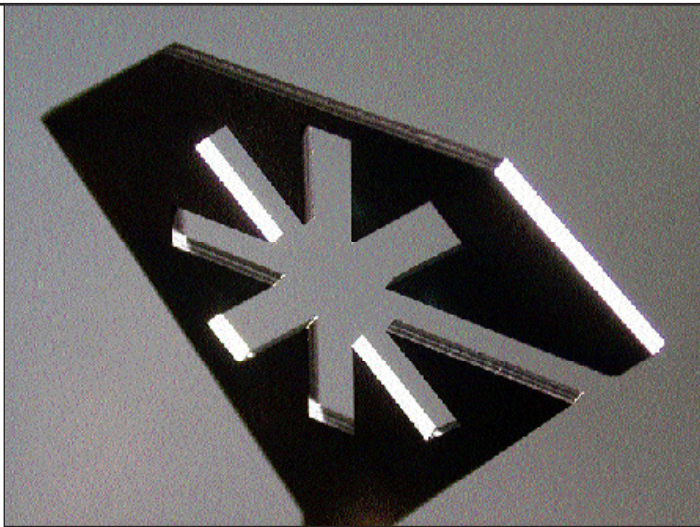


Figure 3. 3 mm carbon steel cut with a 250 W laser

While Nd:YAG lasers are sometimes used for this operation, the majority of substrates in use today have been laser scribed using a CO₂ laser of a few hundred Watts power and using X-Y tables to move the ceramic under the laser.

Scribing involves percussion drilling of small holes part way into the thickness of the ceramic to leave a line of weakness along which it can be snapped. To produce scribe holes that are close together, the laser needs to be fired at high speed. Consequently, this application normally make use of RF excited lasers rather than DC excited models.

Typically, manufacturers are looking to scribe to a depth of about 35% of the substrate thickness. For a 1 mm thick material this means drilling at high speed to a depth of a few hundred microns. A 100 W laser can achieve this at speeds up to 10 m/min, pulsing at frequencies of about 1 kHz and drilling about every 200 mm. Higher speeds can be achieved, of course, with higher power lasers.

Careful laser power control is needed to avoid the holes merging as the X-Y table slows down at corners or around curves. Fortunately, many standard motion controllers (including the software packages that come with turn-key systems specifically aimed at this application) have features that generate laser trigger signals which are evenly spaced along a contour, even though the X-Y table's speed may be changing.

Flying Optics

If the workpiece is too large to be easily carried and moved on an X-Y table, then the only solution is to keep it stationary for processing and to move the laser beam! The most common configuration of this type is a flying optics system, where both the laser and workpiece are fixed, but the beam is steered around with moving mirrors. Typically, these mirrors are carried on an X-Y gantry system mounted over the cutting bed and, with little mass to move, speeds can be extremely high over very large areas.

The main problem with flying optic systems is that the length of the beam path from the laser to the cutting head varies as the mirrors move. Because laser beams diverge, changes in path length produce changes in beam diameter at the final focusing lens. This in turn alters the focus size and position so that the beam will cut differently at one end of the table compared to the

other. While the size of this effect depends on dimensions of the system and on the laser beam divergence (which can be reduced by using a beam expanding telescope), flying optics systems tend to be used in less critical applications.

Because of the long distances the laser beam has to travel between mirrors, dimensional tolerances can also be a problem with flying optics. Any slight change in the angle of a mirror as it moves will produce a large shift in the position where the laser beam hits the next mirror in the chain. At worst this can mean the laser beam clipping on optical components or the cutting nozzle. At best, it means that close dimensional tolerances are even harder to achieve than would otherwise be the case with such a large gantry positioning system.

Large flying optics systems are mostly used for cutting fabrics. Smaller systems, while still used for profiling materials, are also widely used for engraving. These photocopier-size systems operate with air- or water-cooled sealed tube CO₂ lasers with powers from about 10 to 100 W (Figure 4). They are also very affordable (prices start below £20,000), enabling a wide diversity of uses including engraving and cutting rubber stamp material, engraving wood, cutting out model aircraft parts, cutting out decorative stencils etc., the list is endless. The fact that many of these applications come from a non-engineering background is reflected in the way these systems tend to be programmed. Instead of machine tool G- and M-codes, users import files from graphics packages such as CoralDraw.

Larger flying optics systems, with cutting tables measuring several metres each way, are also available. Such machines are in everyday use, mainly cutting fabrics (air-bag material, filter media, panels for sails, balloons, inflatable craft etc.)

Moving Laser

In some systems the entire laser, or at least the laser head, is moved bodily over the workpiece. Instead of moving mirrors over the cutting bed, the gantry carries the entire laser. The gantry clearly has to be reasonably strong to carry the laser's weight, which will be tens of kilos, and fitted with a powerful drive system to move the laser rapidly enough. However, this arrangement allows very large areas to be covered without the problems of



Figure 4. Commercially available flatbed CO₂ laser cutting system for laser power from 10 to 100 W

changes in beam path length associated with flying optics. In fact, the largest flat-bed laser cutting systems in existence tend to be of this type, with beds tens of meters long.

The fact that the spot size and position don't change with position over the cutting bed also allows this type of system to be used for cutting of engineering materials. Plastics (acrylic, polycarbonate...) are the staple diet of these systems, but metals of several millimeters thickness can also be profiled and without the size restrictions of an X-Y table-based system.

The largest single requirement for laser plastic cutting comes from the sign industry: profiling large Perspex panels. Accurate cutting of panels is important to this industry where small gaps in nested panels become surprisingly visible when back-lit. Edge finish is also important for decorative reasons. Fortunately, a highly polished edge can be obtained with a little care when the molten edges of laser cut Perspex re-solidify leaving a glassy finish. A cutting nozzle is used, just as if the laser was cutting metal, but providing just a breath of air or nitrogen, enough to keep the optics clean and prevent vapours igniting, but not enough to 'frost' the cut edge as it re-solidifies.

Common laser powers for Perspex cutting start at about 200 W and give cutting speeds of around 3 m/min for 3 or 4 mm material. Higher powers offer faster speeds and can make it easier to achieve a high quality cut, but often cutting speed is limited by

the motion system and not by the laser.

Summary

This article has only touched on the cutting applications for low power CO₂ lasers. Many more such applications are in use or waiting to be discovered. As yet, cutting makes up only a minor part of the applications for lasers at this power level. Add welding, sintering and especially laser marking and it is clear that this class of laser will enjoy widespread use for the foreseeable future.



John Abbott is Market Development Manager for Coherent (UK) Ltd where he is responsible for developing commercial applications for Coherent Laser Group's industrial laser products.

COMMENT

John's article gives a good introduction to some of the benefits of RF excited sealed CO₂ laser systems. Synrad currently manufacture approximately 6,000 RF excited sealed systems a year (10 W to 240 W) that employ a non-slab resonator design. These lasers can be operated true cw and produce a circular, gaussian ($M^2 < 1.2$) beam without the need for external beam shaping

optics. This technology cannot be scaled up to the 500 W level. However, we currently deliver lasers at power levels up to 240 W utilising this technology. The vast majority of high volume applications lie in the 10-250 W range and the drive is to reduce the cost of ownership by offering lasers with extended lifetime (greater than 45,000 operating hours) with low capital cost.

Stephen Knight Laser Lines

Yet another Directive to worry about?

November 1999 sees the start of the transition period for the introduction of the **Pressure Equipment Directive**. Manufacturers have until 28 May 2002 to bring all product put onto the market into conformity. Now is the time to start a programme to ensure conformity and have plenty of time to complete the task.

The purpose of this Directive is to harmonise national laws regarding the design, manufacture and conformity assessment of pressure equipment. It applies to all pressure equipment and assemblies of pressure equipment with a maximum allowable pressure greater than 0.5 bar above atmospheric pressure. Pressure equipment includes all vessels, piping (e.g. pipes, tubing, expansion joints, hoses), safety accessories (e.g. limiting devices, safety valves, pressure switches) and pressure accessories, which include all devices with an operational function and having pressure bearing housings.

The requirements are that pressure equipment above specified pressure/volume thresholds must (i) be safe, (ii) meet essential safety requirements covering design, manufacture and testing, (iii) Satisfy appropriate conformity assessment procedures, and (iv) carry a CE mark. The directive requires that pressure equipment below the pressure/volume threshold must be safe and designed and manufactured according to sound engineering practice but must not be CE marked.

The manufacturer needs to classify pressure equipment into one of five conformity assessment categories - SEP (Sound Engineering Practice) or Categories I, II, III or IV. Except for SEP equipment, there are requirements for design, manufacture, testing, marking, labelling, instructions and materials which are considered to be essential for safety reasons.

Equipment in Category I will be subject to the manufacturer's own internal production control. Products in the other Categories will require the involvement of 'notified bodies' either in the approval and monitoring of the manufacturer's quality assurance system or in direct product inspection. The higher the category, and therefore the hazard, the more demanding the requirements.

All pressure equipment will need to be assessed, and manufacturers would be well advised to become familiar with the requirements. Once the category of equipment has been determined, the essential safety requirements are well defined. The steps to be taken with SEP and Category I equipment are no different to those involved with the Machinery Directive. However, additional assessment and maintenance programmes will be required for equipment that falls into higher Categories.

Mike Barrett GSI Lumonics

A system for finite scheduling in laser job shops

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Sheet metal processing services are increasingly being offered by small and medium sized laser job shops. Because they operate with short delivery times and a low order horizon, job shops tend not to use commercially available production planning and control systems (MRP-systems) on the basis that they are too complicated and require highly trained personnel to operate them. Indeed, such systems are often overqualified for the job and do not provide the adaptability required by job shops. To overcome these obstacles, an integrated information system is being developed within a European research project, to provide functionality for scheduling, control and cost estimation.

Short and reliable delivery times are increasingly important in today's customer-oriented marketplace, where low costs and high quality are taken for granted. From a technological point of view, laser job shops are qualified to meet the challenges of time-based competition. Laser job shops deal mostly with one-piece products processed in one production stage, and as a materials processing tool, lasers offer major advantages for machines required to be quickly adjusted to meet new orders, especially when producing small lots.

Although laser job shops fulfil the technological preconditions for manufacturing with high quality at low costs and on short notice, many have problems meeting promised delivery dates, and this leads to a bad reputation and lowers prospects for future business. One reason for this shortcoming is that the IT systems used by job shops are generally not designed to support the task of planning in such a flexible working environment. They may provide data about customers, orders and products but they do not support the production planner in scheduling jobs or the salesmen seeking information about possible delivery dates for incoming inquiries. In the absence of such information, most laser job shops incorporate standard lead times in their quotations, basically the same for every job, and many job shops will accept a customer's delivery date without taking into account how this will influence the schedule of other orders.

For overcome this deficiency and provide better control of the whole process, new information software is being developed. The first prototype offers scheduling, control and cost estimation. It is designed to integrate with existing specialist software, such as spreadsheets and financial packages, to minimise the need for duplicating data entry.

An Integrated Information System

Organisational Implementation

Most laser job shops have separate departments for business, engineering and manufacturing activities. This situation and the flow of information within the business is shown in figure 1. With regard to offer and order planning tasks, the business department

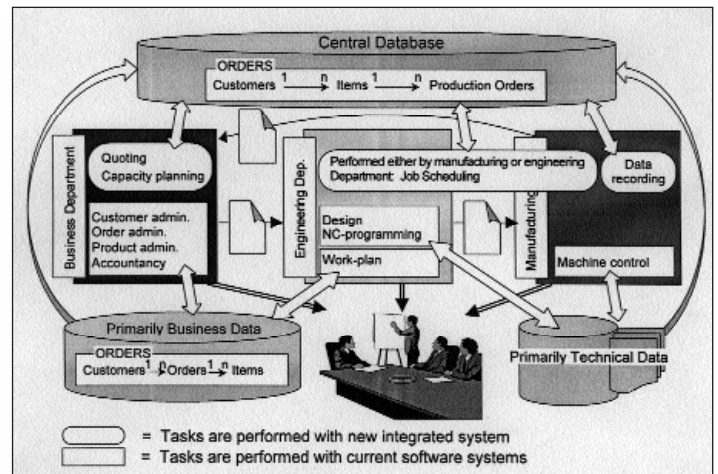


Figure 1: Architecture for an integrated information system in a typical job shop

is accountable for quotations and capacity planning, while job scheduling is either performed by the foreman in the manufacturing department or by a production planner in the engineering department. A precondition for manufacturing is (i) the availability of raw material, (ii) a drawing that is confirmed by the customer, and (iii) NC-code generated by the engineering department. When the order is completed, the manufacturing department feeds back shop-floor data to the business department. In most job shops this data feedback is paper based.

As illustrated in figure 1, the planning tasks used in laser job shops are currently not supported by IT-systems. Instead, visual planning boards or MS-Excel-based finite scheduling lists are used to plan and control the order status. To discuss current and future production status, most job shops organise daily meetings with representatives from all departments.

To diminish the efforts for time consuming meetings and to optimise information flows, the new information system under development exchanges data between the departments via a central database. Each department is provided with tailor-made views of the central database. A module for production data registration is provided to record actual data about the order status on the shop floor. As far as possible, the required data are extracted from existent databases to minimise unnecessary data input. Most laser job shops have at least one IT-system for business administration and another (CAD/CAM) for the technical part of the order.

Data Integration

Most databases of currently used business administration systems rely on a relational data model. Most data relevant to production planning are stored in tables for customer data, customer order data and item data. Job scheduling is the priority of the new sys-

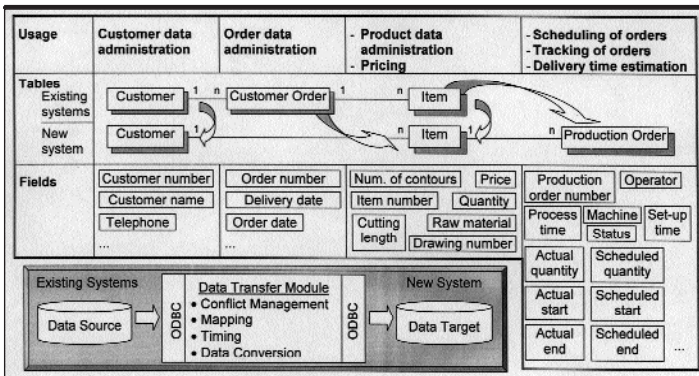


Table 1. Structure and Integration of Databases.
The source and the target database is accessed via the ODBC-interface (ODBC: Open Database Connectivity). This interface allows universal data access from Microsoft Windows operating systems to all ODBC-compliant databases. The data transfer module handles conflicts between different database schemas (e.g. different names for the same table or fields, different data types). Furthermore, options to solve data conflicts are available (e.g. out-dated data, different units, different precision). A timer can be set to start update operations periodically.

Although the data transfer system provides a windows-based graphical user interface, the establishment of reliable data integration procedures requires know-how about relational databases.

tem, but as illustrated in table 1, the data required are either not provided by existing software systems or the functionality of these systems is not sufficient. To address this deficiency, the new system provides an extra table for administration of production data. The arrows in table 1 indicate how the data are transferred from the database of the existent system to the new database. Data not available from existing systems must be entered manually.

System functionality

To support the production manager in the business of daily scheduling, the software has to be easy to use and match the scheduling requirements of laser job shops. It has to be connected to a database to make it run, and after selecting a database the user is requested to select a range of machines and to define a time horizon, in order to exclude unnecessary data.

In chronological order, the tasks are divided into three different processes of scheduling, order control and cost estimation, each with its own software module. In the following paragraphs these modules and the processes they undertake are described.

Performance of tasks

Scheduling module

The core software module performs the scheduling tasks. With its help, the user can allocate orders to machines, define sequences and build a feasible manufacturing schedule. 'What if scenarios' can be worked out to compare different planning results by criteria such as machine utilisation, order tardiness etc.

In order to fulfil a scheduling task, a minimal data set to represent orders is necessary. As basic data the scheduling module requests customer identity and order ID, due date and process time. A backwards scheduling algorithm schedules orders with respect to their due dates and other orders to be processed.

A procedure which is often performed in laser job shops is to stop running orders in order to get machine capacity for urgent jobs. If a new order has to be fitted in, the running order can be logged out as 'finished with partial quantity'. The order is then divided into two orders, a finished one and a new one which represents the remaining quantity. The production schedule can be altered then the urgent order will be put into the gap following the fin-

ished order.

In order to make the scheduling process and the results more vivid, the presented solution provides graphical representation where possible. The main windows of the scheduling module consists of a list view and a Gantt-Chart view. In the list view, orders can be sorted by different criteria. The listed orders can be manually brought into a production sequence. In the planning list the orders can be viewed in either a machine-oriented view or a customer-oriented view i.e. with the allocated machine or customer as the superior element, see figure 3.

Orders can readily be selected in the list and moved upwards or downwards. This supports the planner in giving orders a higher priority and building a finite order sequence for the shop. Orders can be combined (e.g. by their material thickness, their due dates or other criteria) to be seen as single orders. This is a useful feature for laser job shops where orders are often combined to reduce set-up time, for example.

Scheduled orders can also be seen on the Gantt-Chart view, see figure 4. The most interesting area of the Gantt-Chart view for planning purposes is the right side of the vertical (present time) line. Every order which should be manufactured is shown with its scheduled start and end. The status of all orders is colour coded to identify (for completed orders) orders completed in time or completed too late; (for orders in progress) on time, ahead or behind time; (for future orders) scheduled to end later then due date, scheduled end ahead of due date, NC code and material available or not available. In this way it should be very easy to review the status of an order and to act if necessary. If, for example, an order cannot be completed in time it could be exchanged with another order or the sales staff could negotiate with the customer.

The machine status (available, broken, maintenance) is shown by a solid line, which changes the colour if the status changes. Underneath the "machine line" the shift model for the particular machine is shown. Times where the machine will be working (i.e. personnel available) are represented by small rectangles. The shift model and the machine status is a constricting value while order scheduling. If, for example, an order with a process time of 8 hours starts on Friday evening and the remaining shift duration is

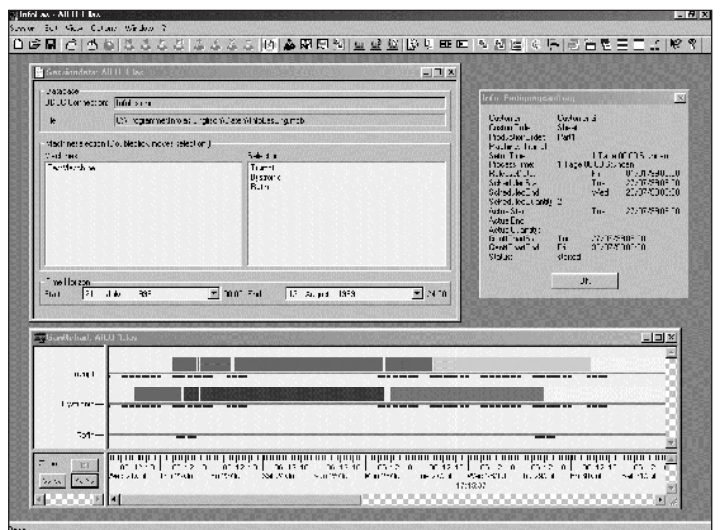


Figure 2: Main window of the application
A way to gain a high degree of user acceptance and reduce training time is to provide a surface the user is familiar to work with, and so the prototype system offers the Microsoft® Office family look and feel.

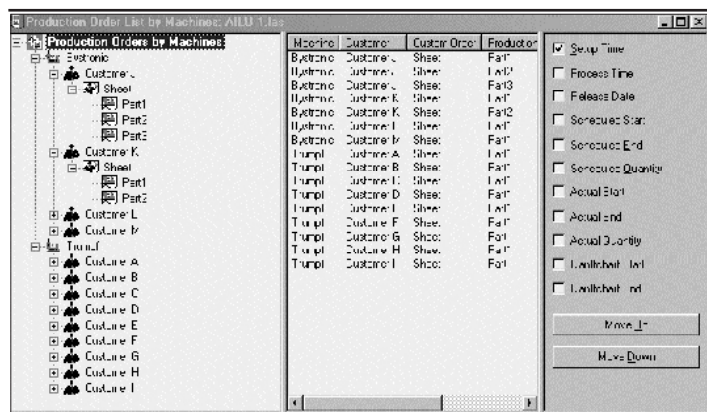


Figure 3: List-based planning environment.
The hierarchical structure of each view is shown in a tree on the left side and a list on the right

two hours, the order has to be completed after the weekend. The scheduled end is computed e.g. to Monday 12:00 if the morning shift starts at 6:00. With the Gantt-Chart the planner can easily see free machine capacity and situations where orders risk to be completed too late, and by rescheduling the orders he can minimise late delivery and react quickly to changes in production.

Order control module

The order control module registers production and provides the machine operator with data about the next shop orders. The operator logs in the order when it is begun and log it out when it is completed. The order control module is linked directly to the main database and when an order is logged out this information is available directly to all users of the system.

Cost module

The cost module provides information to facilitate cost estimation. When entering a new order onto the system, machine costs can be estimated from a knowledge of total cutting length and part geometry (i.e. from the estimated process time). After scheduling an order, the planned machine load and the derived machine costs for the order will be available. When an order is completed, the real machine load and the actual machine costs are available for comparison with the earlier predictions.

Conclusion

A software tool for laser job shops which provides a means to

schedule orders and estimate costs functionality will help them to be successful in a competitive market.

When complete, the Integrated Information System should be easy to use, reliable and capable of integration with whatever software the job shop is using to hold order information.

Some of the consortium members involved in this European research programme already use the software in daily business and are providing valuable feedback. After completion of the project it is intended that the software will be more widely available to laser job shops to support their production management.

Acknowledgement

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Jens Wachsmann studied production engineering at the Hannover University. Since 1995 he has worked in the logistics department of IPH.

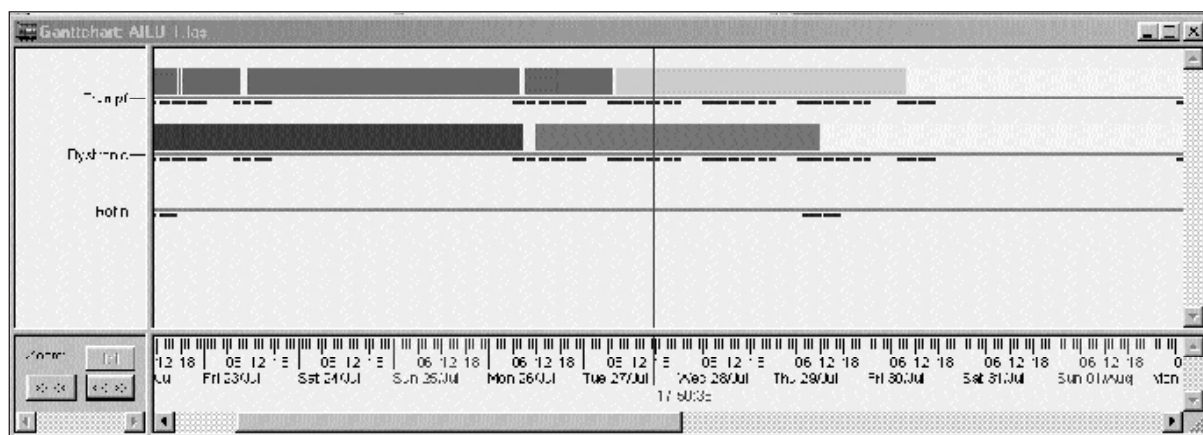


Figure 4: Gantt-Chart view.

This view consists of four different screens. The screen in the upper left corner shows the machines which have been selected when the session was started. The screen in the lower left corner consists of buttons to zoom in and out and to select the original scale. This feature is helpful to view a longer period or to zoom in to see orders more detailed. The screens on the right

side are the Gantt-Chart and the time scale. The time scale shows the selected time horizon by a rectangle being allocated to a machine and the time scale. The chart has three "areas" showing different orders. Completed orders are represented by their actual manufacturing data, meaning data coming from production data registration (see auxiliary modules). The area of the orders in progress is situated near the line indicating the actual time. This line runs to the right (future) as time passes. If an order is in progress its representative rectangle elongates as long as the order is not logged off as complete. Planned orders on this machine are pushed to the future (rescheduled) when an order in progress takes longer to complete than planned. Apart from orders and their status, the Gantt-Chart also provides information about machine states and planned capacity.

Comments

The authors have done a good job of capturing the issues related to job control in a laser job shop, and describing their resultant approach to providing a solution. The very versatility that makes laser cutting machines attractive for the production of short run sheet metal components, combined with stochastic job input, leads to complexity in managing these expensive assets for efficient utilization. Only by addressing these issues can laser job shops realise their true potential.

Jambalaya has developed a product, Juggler, that uses a complementary methodology to provide a software decision support system, or "calculator", for computing optimized schedules of laser cutting machines in a job shop environment.

Apart from its database and display components, Juggler uses two major elements; a pre-processor and an optimisation and scheduling engine (see figures to the right).

The goal of our product is to:

- enable "available to promise" commitments to customers through having real-time visibility of the integration of new jobs with the current schedule
- allow dynamic re-scheduling when, for example, a machine requires unplanned maintenance
- assist in the purchase decision for additional machines through simulated trials with actual shop job data

We believe that systems such as Juggler and the package described in the article will soon become common in shops with two or more machines. Jambalaya is also developing plug-ins for additional laser and non-laser processes.

Any product that helps to make the task of running a laser job-shop easier has to be a good idea.

Without having had the opportunity of testing the system described, it is difficult to make definitive comments. However, I like the 'what if' scenarios because, as we all know, if it can go wrong, very often it will go wrong.

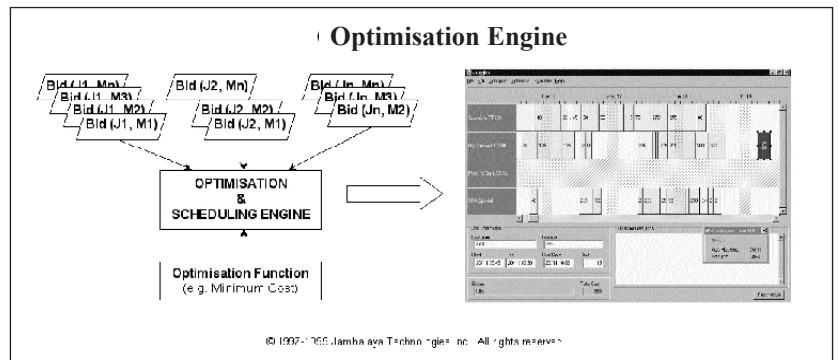
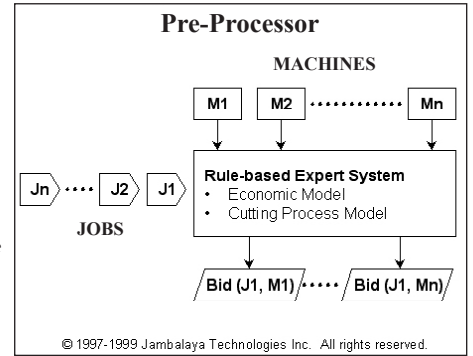
Generally speaking good software properly installed and supported gives the greatest 'bang for ones bucks'. As a progressive laser jobshop Laserform would welcome an early opportunity to assess the product and compare it with our existing system.

Sean MacEntee Laserform (IRL) Ltd

It is widely accepted that lasers present huge technical opportunities to support industrial growth. But we have lacked the managerial, commercial, selling and marketing skills to exploit this opportunity. So it is most pleasing to see the co-operation of European research funding, laser job shops and German production consultants to develop a software package to help job shops deliver the service of which they are capable.

The paper expresses very well our business dilemma, and understands the day-to-day problems of job shop managers excellently. The authors rightly identify the issue of scheduling as critical to customer service. We at NG Bailey face the same issues, and have also looked for software to enable us to schedule production. Finding none, we use a simple excel spreadsheet, which is updated twice daily.

The pre-processor consists of an expert system containing a model of the laser cutting process and its cost elements.. Here, the input job parameters are assessed against the machine characteristics giving rise to a dynamic ranking, or bid, by each machine for the job. These bids are passed to the optimisation engine.



This engine determines, for all jobs requiring scheduling, the schedule that best meets the optimisation criteria input by the user, e.g. minimum cost for a set of jobs, earliest completion of all jobs, or a combination of the two.

Gary Bishop Jambalaya Technologies Inc.

<http://www.jambalaya.ca>

Canada-based Jambalaya is a Corporate member of AILU Ed.

I disagree, however, with their proposed solution. They plan to create what amounts to a semi-integrated excel spreadsheet, which can deliver scheduling information in a variety of useful presentations. This thinking is too small. It amounts to a patch over our knees when what we need is a new pair of trousers.

The information it will deliver isn't on line or real time so their business will rarely have up-to-date information. Their business will require a scheduler, instead of being informed directly by operators at the machine. Their system won't integrate to order processing and quality control, or produce despatch notes and invoices and barely supports the estimators. It offers little to the engineers who are constantly asking which job should be programmed next. Why must they re-key part information into their programmes which the estimator typed yesterday and the order entry clerk keyed again this morning? And their system will not reduce the overheads for the Managing Director who is daily being asked by the sales manager for price cuts.

We need one integrated system - covering customer contact, estimating, order processing, engineering, production scheduling, operators, inspection, despatch, invoicing, payroll, job costing, debtors, material management, purchase ledger and management accounts. We at NG Bailey manufacturing have failed in our search for single system solution - the best we have done is limit our investment in two systems delivering all between them. We're helpless businessfolk - can anyone come to our aid?

Cal Bailey NG Bailey Manufacturing

continued across

ODD OPTICS - No 1

Mysteries of the Beam Expander

Brooke Ward

Europtics Partnership

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01491 872602 01491 875829 brookeward@saqnet.co.uk

So, you've bought a beam expander* for your flying optic laser processing machine?

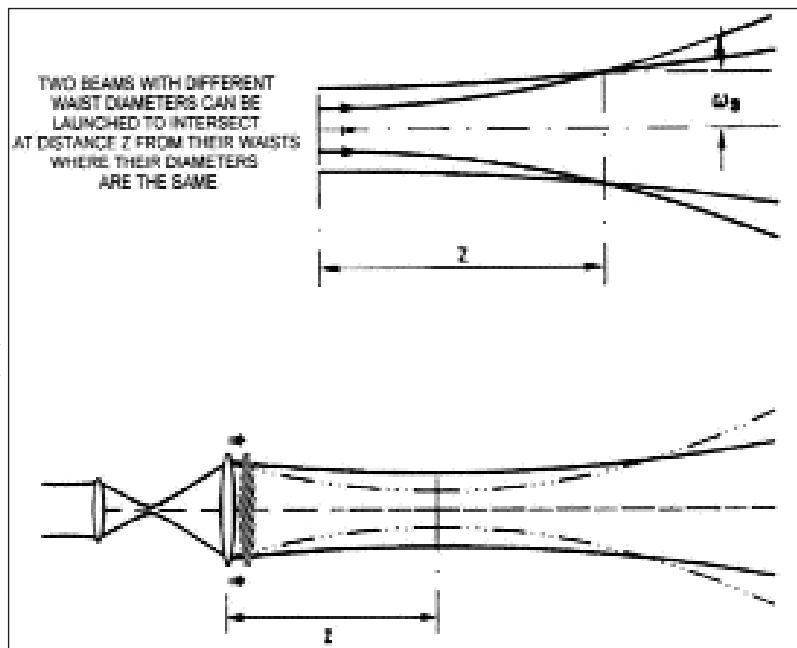
A properly designed beam expander for your machine will expand the output beam diameter of your laser to fill the aperture of the lenses and mirror in the gantry system. It should also position a beam waist in the middle of the range of the variable path length of the gantry. If this isn't the case, come and see me!

The next step is alignment. Of course, you are used to the problems of centering optics with the axis of the laser beam, so checking the positions of the beam expander optics in the beam will be nothing new. The only remaining problem is to adjust the separation of those elements so that they put the output beam waist where you want it.

Take care! Which of the two waists do you want in the middle of your optical range?

Let's start the wrong way round. Think of a beam with a small waist diameter. Because it has a small waist, it will diverge rapidly. Now, how about a beam with exactly the same value of M^2 but with a large waist diameter, starting from the same place as the slim waisted beam. At some point the two beams would cross over each other. In other words, there is a point where the two beams will have the same diameter.

Now turn this round the other way. Launch two beams with the same diameter. They can be made to form waists at the same place but with different diameters. This can happen with a beam expander. By changing the separation of the optical elements by a small amount the beam leaving the beam expander can have virtually the same diameter but it could form a large waist or a small one in the middle of your optical range.



So which one do you want? I would suggest that the beam with the larger waist would change its diameter more slowly with distance and that would be good. This is the beam that comes from moving the lenses a little closer to each other than the setting giving the smaller waist.

One further point. At one setting of the beam expander the two waists are the same size and overlap. At this position they are at their maximum distance away from the beam expander and their common waist diameter is 71% ($= 1/\sqrt{2}$) times the diameter of the beam leaving the expander.

* 'Beam expander' is the best name for this optical component, though it is often referred to as a 'telescope' or 'collimator'. Ed

Comments on 'A system for finite scheduling ...' (continued)

Authors' response to Cal Bailey

We appreciate critical comments on our work and we agree that job shops need an integrated system which supports all subtasks of the order fulfilment chain. But we disagree that a single system is required. What does a single system amount to?

Consider the engineering system (CAD/CAM). Many different systems exist, each having advantages and disadvantages, depending on the job shop's individual requirements. Which should be chosen as the one and only single system? What about the accounting software? One can choose between many software systems for accounting, and many of them have been used thousands of times. Does it make sense to develop another accounting system?

We are not surprised that none of the job shops that we have seen use a single system. The reason is that each job shop needs its own unique system, not a standardized software. That is why we propose a system that integrates heterogeneous software and hardware platforms. As shown in the presentation, automatic data transfer is one way of integration. It is used to avoid re-keying information. We also apply other so-called 'middleware' systems to integrate information systems. In our solution, the scheduling system is just one part of a company-specific software architecture.

A Ostendorf, B Schmidt, C Peper, J Wachsmann

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Events

December

- 9 Industry Focus Workshop on Applied Optics**
EPSRC sponsored workshop
NPL, Teddington
Contact Lyn Barnes T: 020 8943 6079

February

- 15 Techniques and Technology of Laser Cutting**
AILU open workshop
International Manufacturing Centre, Warwick University
Contact: AILU office

17 Lasers in the Electronics Industry

- Make It With Lasers event
DEK, Weymouth
Contact: Carol Fielding

March

- 8 Laser Materials Processing**
Institute of Physics half day meeting
IoP Headquarters, London
AILU supported
Contact IoP events T: 0171 4704930

April

- 5 'What's New in 2000?' and AGM**
AILU members' only
De Montfort University, Leicester
Contact: AILU office

Editorial Board for this issue

Cal Bailey, Craig Bratt, Nick Ellis, Jim Fieret, Peter Hancocks,
Tim Holt, Steve Knight, Sean MacEntee, Riccardo Tomassoni

Editorial Policy

The Industrial Laser User is the house magazine of the Association of Industrial Laser Users. Its primary aim is to disseminate technical information and to present the views of its members.

The editor reserves the right to edit any submissions for space and other considerations.

Authors maintain the right to extract, in part or in whole, their material for future use.

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