The University of Adelaide
School of Mechanical Engineering

Investigation of Welding Fume Plumes Using Laser Diagnostics

Owen Lucas

20th of August 2008

Bibliography

Abu-Gharbieh, R., Persson, J., Forsth, M., Rosen, A., Karlstrom, A. & Gustavsson, T. (2000), 'Compensation method for attenuated planar laser images of optically dense sprays', *Applied Optics* **39**(8), 1260–1267.

Albert, R. (1996), Fume generation in gas metal arc welding, PhD thesis, University of New Hampshire.

Anderson, P. & Wiktorowicz, R. (1995*a*), 'Ozone emissions during arc welding pt1 - formation and measurement', *Welding and Metal Fabrication* pp. 385–388.

Anderson, P. & Wiktorowicz, R. (1995*b*), 'Ozone emissions during arc welding pt2 - control of exposure', *Welding and Metal Fabrication* pp. 440–444.

AS3853.1-1991 (1991), Fume from welding and allied processes Part 1: Guide to methods for the sampling and analysis of particulatematter, Technical report, Standards Australia.

Australian National Occupational Health and Safety Commission (1990), Welding : fumes and gases, Technical report, Australian National Occupational Health and Safety Commission.

Black, D. L., McQuay, M. Q. & Bonin, M. P. (1996), 'Laser-based techniques for particle-size measurement', *Progress in Energy and Combustion Science* **22**, 267–306.

Bladh, H. & Bengtsson, P. (2004), 'Characteristics of laser-induced incandescence from soot in studies of a time-dependent heatand mass-transfer model', *Applied Physics B, Lasers and Optics* (78), 241–248.

Bosworth, M. & Deam, R. (2000), 'Influence of GMAW droplet size on fume formation rate', *Journal of Physics D: Applied Physics* **33**, 2605–2610.

Bruckner, J. (2005), 'Cold metal transfer has a future joining steel to aluminum', *American Welding Society - Welding Journal* .

Charalampopoulos, T. T. & Shu, G. (2003), 'Optical properties of combustion-synthesized iron oxide aggregates', *Applied Optics* **42**(19), 3957–3969.

CIGWELD (1997), *Pocket Guide Welding Consumables Reference.*

Cooper, P. & Hunt, G. (2004), Experimental investigation of impinging axisymmetric turbulent fountains, *in* '15th Australasian Fluid Mechanics Conference'.

Dahmen, M., Funke, G., Kreutz, E. & Maischner, D. (1993), Investigations of processing gas flow and smoke plume propagation during laser beam welding, *in* 'Proceedings of the 3rd EUREKA Industrial Laser Safety Forum', pp. 35–43.

Deam, R., Bosworth, M., Chen, Z., French, I., Haidar, J., Lowke, J., Norrish, J., Tyagi, V. & Workman, A. (1997), Investigation of fume formation mechanisms in GMAW, Technical Report IIW Document 212-916-97, CSIRO, CRC-MWJ and University of Bradford UK.

Deam, R., Bosworth, M., McAllister, T., Norrish, J., Brooks, G., Zhou, S., Haidar, J., Lowke, J., Farmer, A. & Simpson, S. (2000), Understanding fume formation by GMAW, Technical report, CRC-MWJ and CSIRO.

Deam, R., Simpson, S. & Haidar, J. (2000), 'A semi-empirical model of the fume formation from gas metal arc welding', *Journal of Physics D:Applied Physics* **33**, 1393–1402.

Fanning, M., Gordon, T., Lathabai, S., Neller, M. & Bednarz, B. (2004), Improved consumable electrode arc welding, Technical report, CSIRO.

Farwer, A. (1989), Ozone concentration in the welders breathing zone with gas-shielded arc welding: Recent investigations on the influence of nitric oxide additives in the shielding gas, Technical Report VIII-1472-89, International Institute on Welding.

Godbole, A., Cooper, P. & Norrish, J. (2007), 'Computational fluid dynamics analysis of on-torch welding fume extraction', *Australasian Welding Journal* **52**, 35–42.

Goodfellow, H. & Tahti, E. (2001), *Industrial Ventilation Design Guidebook*, Academic Press.

Gray, C. & Hewitt, P. (1982), 'Control of particulate emissions from electric-arc welding by process modification', *Annals of occupational hygiene* **25**(4), 431–438.

Gray, C., Hewitt, P. & Dare, P. (1982), 'New approch would help control welding fume at source', *Welding and metal fabrication* pp. 393–397.

Gray, C., Hewitt, P. & Hicks, R. (1980), The effect of oxygen on the rate of fume formation in metal inert gas welding arcs, *in* 'Weld pool chemistry and metallurgy International conference 15-17 April', Vol. 1, The welding institute, pp. 167–176.

Haidar, J. (1998), 'Predictions of metal droplet formation in gas metal arc welding. ii.', *Journal of Applied Physics* **84**(7), 3530–3539.

Haidar, J. & Lowke, J. (1997), 'Effect of CO2 shielding gas on metal droplet formation in arc welding', *IEEE Transactions on Plasma Science* **25**(5), 931–936.

Halliday, D., Resnick, R. & Walker, J. (1997), *Fundamentals of Physics*, fifth edn, John Wiley and Sons Inc.

Health and Safety Executive (1990), Assessment of exposure to fume from welding and allied processes, Environmental Hygiene Series EH54, Health and Safety Executive.

Hewitt, P. J. (1996), 'Occupational health in metal arc welding', *Indoor Built Environment* **5**, 253–262.

IARC (1990), 'Welding', *International agency for research on cancer summery and evaluation* **49**.

Ioffe, I., MacLean, D., Perelman, N., Stares, I. & Thornton, M. (1995), 'Fume formation at globular to spray mode transition during welding', *Journal of Physics D:Applied Physics* **28**, 2473–2477.

Jenkins, N. & Eagar, T. (2005), 'Chemical analysis of welding fume particles', *American Welding Society - Welding Journal - Welding Research Supplement* **84**(6), 87s–93s.

Jenkins, N. & Edgar, T. (2005), 'Fume formation from splatter oxidation during arc welding', *Science and technology of welding and joining* **10**(5), 537–543.

Jenkins, N., Pierce, W. & Eagar, T. (2005), 'Particle size distribution of gas metal and flux cored arc welding fumes', *American Welding Society - Welding Journal - Welding Research Supplement* **84**(10), 156s–163s.

Jin, Y. (1992), Welding plume rise in a large building with temperature gradient, *in* 'ROOMVENT'92 Third international conference of air distributions in rooms', Aalborg Denmark.

Johnson, D., Orakwe, P. & Weckman, E. (2006), 'Experimental examination of welding nozzle jet flow at cold flow conditions', *Science and Technology of Welding and Joining* **11**(6), 681–687.

Jones, A. (1999), 'Light scattering for particle characterization', *Progress in Energy and Combustion Science* **25**, 1–53.

Jones, I. R. & Allen, E. (2002), 'Detection of large woody debris accumulations in old-growth forests using sonic wave collection', *Transactions of the Important Tree Scientists* **120**(2), 201–209.

Kent, J. & Bastin, S. (1984), 'Parametric effects in sooting in turbulent acetylene diffusion flames', *Combustion and Flame* **56**, 29–42.

Kent, J., Jander, H. & Wagner, H. G. (1981), Soot formation in a laminar diffusion flame, *in* 'Eighteenth International Symposium on Combustion', The combustion institute, pp. 1117–1124.

Kock, B. F., Kayan, C., Knipping, J., Orthner, H. R. & Roth, P. (2005), Comparison of lii and tem sizing during synthesis of iron particle chains, *in* 'Proceedings of the Combustion Institute', Vol. 30, pp. 1689–1697.

Layton, P. (1998), Routine pipe analysis, Technical report, BHP.

Lee, J. H. & Chu, V. H. (2003), *Turbulent jets and plumes - A lagrangian approach*, Kluwer Academic.

Lin, Q., Li, X. & Simpson, S. (2001), 'Metal transfer measurements in gas metal arc welding', *Journal of Physics D:Applied Physics* **34**, 347–353.

Liss, G. (1996), *Health effects of welding and cutting-an update*, Ontario Ministry of Labor.

Mie, G. (1908), 'Contributions to the optics of turbid media, particularly of colloidal metal solutions', *Annalen der Physik* **25**(3).

Moreton, J. (1982), 'Assessment of welding fume hazards', *Annals of Occupational Hygine* **25**(4), 421–429.

Norrish, J. (1992), *Advanced welding processes*, Institute of Physics Publishing.

Norrish, J., Slater, G. & Cooper, P. (2005), Particulate fume plume distribution and breathing zone exposure in gas metal arc welding, *in* 'Health and Safety in Welding and Allied Processes', Copenhagen Denmark.

Quimby, B. & Ulrich, G. (1999), 'Fume formation rates in gas metal arc welding', *American Welding Society - Welding Journal - Welding Research Supplement* **78**(4), 142s–149s.

Quimby, J. & Ulrich, G. (2000), Fume formation rates in gas metal arc welding, Technical report, Edison welding institute.

Santoro, R., Semerjian, H. & R.A., D. (1983), 'Soot particle measurements in diffusion flames', *Combustion and Flame* **51**, 203–218.

Sipek, K. (1980), Ozone and nitrogen dioxide concentration around a welding place, Technical report, AGA AKTIEBOLAG, Gas Division, Innovation Center.

Slater, G. R. (2004), Welding fume plume dispersion, PhD thesis, University of Wollongong.

Sowards, J., Ramirez, A., Lippold, J. & Dickinson, D. (2008), 'Characterization procedure for the analysis of arc welding fume', *American Welding Society - Welding Journal - Welding Research Supplement* **87**, 76s–83s.

Thornton, M. & Stares, I. (1994), 'Analysis of particulate fume generation rates from gas metal arc welding', *Welding Review International* pp. 363–365.

Tinkler, M. J. & Ditschun, A. (1984), Evaluation and control of fumes produced during welding volume 2 experimental evaluation, Technical report, Ontario Hydro Research Division, Toronto Ontario.

Vander Wal, R. & Jensen, K. (1998), 'Laser-induced incandescence: excitation intensity', *Applied Optics* **37**, 1607–1616.

Vander Wal, R. L., Ticich, T. M. & West, J. R. (1999), 'laser-induced incandescence applied to metal nanostructures', *Applied Optics* **38**(27), 5867–5878.

Will, S., Schraml, S., Bader, K. & Leipertz, A. (1998), 'Performance characteristics of soot primary particle size measurements by time resolved laser induced incandescence', *Applied Optics* **37**, 5647–5658.

Yeomans, S. (1994), 'Welding in structural engineering: Steels and aluminium alloys'.

Zhu, P. & Simpson, S. (2005), 'Voltage change in the GMAW process due to the influence of a droplet travelling in the arc', *Science and Technology of Welding and Joining* **10**(2), 244–251.

Zimmer, A. T. & Biswas, P. (2001), 'Characterization of the aerosols resulting from arc welding processes', *Journal of Aerosol Science* **32**, 993–1008.

Zschiesche, W. (1993), 'Cancer risk in arc welding', *Welding in the World* **33**(2), 124–125.

Appendix A

Acronyms

CCD Charge coupled device

CFD Computational fluid dynamics

CSIRO Commonwealth Science and industrial research organisation

DC Direct Current

DCEN Direct current electrode negative

DCEP Direct current electrode positive

FCAW Flux Cored Arc Welding

FFR fume formation rate

GMAW Gas Metal Arc Welding

GTAW Gas Tungsten Arc Welding

HeNe helium neon

ICCD Intensified Charge Coupled Device

IIW International Institute on Welding

IR infra red

LII Laser Induced Incandescence

LIE Laser Induced Emission

MIG metal inter gas

MMAW Manual metal arc welding

Nd:YAG Neodymium:Yttrium Aluminium Garnet

OCV Open circuit voltage

PIE Plasma Induced emission

PPE Personal Protective Equipment

SEM Scanning electron microscope

TEM Transmission electron microscope

UV Ultra violet

Appendix B

Summary of plume equations

Parameter	Pure Jet	Pure Plume
Jet Volume Flux $Q = \int u dA$	$Q = \pi u_m b^2$	$Q = \pi u_m b^2$
Specific momentum flux $M = \int u^2 dA$	$M = \frac{\pi}{2} u_m^2 b^2$ ($M = M_o$)	$M = 0.38 B_o^{\frac{2}{3}} z^{\frac{4}{3}}$
Maximum time-averaged velocity u_m	$u_m = 7.0 M_o^{\frac{1}{2}} z^{-1}$	$u_m = 4.71 B_o^{\frac{1}{3}} z^{-\frac{1}{3}}$
Specific buoyancy flux $B = \int u \frac{\Delta\rho}{\rho} g dA$	0	$B = \frac{\pi\lambda^2}{1+\lambda^2} u_m g_m' b^2$
Radius b	$b = 0.114z$	$b = 0.105z$
Maximum time-averaged concentration excess c_m	$C_m = 5.94 Q_o C_o M_o^{\frac{1}{2}} z^{-1}$	$C_m = 10.46 Q_o C_o F_o^{-\frac{1}{3}} z^{-\frac{5}{3}}$
Average dilution $\bar{S} = \frac{Q}{Q_0}$	$\bar{S} = 0.29 M_o^{\frac{1}{2}} z Q_o^{-1}$	$\bar{S} = 0.163 B_o^{\frac{1}{3}} z^{\frac{5}{3}} Q_o^{-1}$
Jet spread angle β	$\beta_G = 0.114$ ($B = 2\alpha$)	$\beta_G = 0.105$ ($B = \frac{6}{5}\alpha$)
Entrainment coefficient	$\alpha_G = 0.057$	$\alpha_G = 0.088$
Ratio of concentration to velocity width λ	$\lambda = 1.2$	$\lambda = 1.19$

Table B.2: Summary of pure round jet and plume equations (Based on Gaussian profiles) (Lee & Chu 2003)

Appendix C

Experimental runs

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20041007	AAA	M	SC15	5.9	230		0	15.5	100	280					images every 0.2S
20041007	AAB	M	SC15	5.9	230		0	15.5	100	270					images every 0.2S
20041007	AAC	M	SC15	5.9	230		0	15.5	100	270					images every 0.1S
20041008	AAD	M	SC15	4.5	230		0	16	100	270				32	
20041008	AAE	M	SC15	4.5	230		0	16	100	250				32	
20041008	AAF	M	SC15	4.5	230		0	16	100	250				16	
20041008	AAG	M	SC15	4.5	230		0	16	100	250				8	
20041008	AAH	M	SC15	4.5	230		0	15	90	250				16	
20041008	AAI	M	SC15	4.5	230		0	15	90	250				22	
20041008	AAJ	M	SC15	4.5	230		0	17	100	250				16	
20041008	AAK	M	SC15	4.5	230		0	18	100	250				16	
	AAL														
20041019	AAM	M	SC15	4.5	230		0	17	105	250				22	cardboard ring
20041019	AAN	M	SC15	4.5	230		0	17	105	250				22	same as aam
20041019	AAO	M	SC15	4.5	230		0	17	105	250				22	samedifferent drum direction
20041019	AAP	M	SC15	4.5	230		0	17	105	250				22	same as aao
20041019	AAQ	M	SC15	4.5	230		0	16	100	250				22	same as aam and aan but lower voltage
20041019	AAR	M	SC15	4.5	230		0	16	95	250				22	
20041019	AAS	M	SC15	4.5	230		0	17	105	250				22	same as aam and aan but with gas shroud on
20041019	AAT	M	SC15	4.5	230	U	10	17	100	250				22	
20041019	AAU	M	SC15	4.5	230	U	10	17	100	250				22	same as aat opersite drum direction
20041019	AAV	M	SC15	4.5	230	U	15	17	100	250				22	same as aat but higher gas flow
20041019	AAW	S	SC15	4.5	230	U	15	17	100	250				8	same as above but reduced app

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20041111	AAX	l	SC15	4.5	230	U	0	16.5							smallest app of long Nikon
20041111	AAY	Ml	SC15	4.5	230	U	10	16.5							smallest app of long Nikon
20041111	AAZ	Ml	SC15	4.5	230	U	15	16.5							smallest app of long Nikon
20041111	ABA	Ml	SC15	4.5	230	U	20	16.5							smallest app of long Nikon
20041111	ABB	Ml	SC15	4.5	230	U	25	16.5							smallest app of long Nikon
20041111	ABC	Ml	SC15	4.5	230	U	30	16.5							smallest app of long Nikon
20041111	ABD	Ml	SC15	4.5	230	U	35	16.5							smallest app of long Nikon
20041111	ABE	Ml	SC15	4.5	230	U	40	16.5							smallest app of long Nikon
20041111	ABF	Ml	SC15	4.5	230	U	45	16.5							smallest app of long Nikon
	ABG														
	ABH														
	ABI														
20041207	ABJ	Ml	SC15	4.5	16.5	U	15	16.5		?		?			
20041207	ABK	Ml	SC15	4.5	16.5	U	15	16.5							
20041207	ABL	Ml	SC15	4.5	16.5	U	15	16.5							
20041207	ABM	Ml	SC15	4.5	16.5	U	15	16.5		250		250	3.4		
20041207	ABN	l	SC15	4.5	16.5	U	15	16.5				350			
20041207	ABO	l	SC15	4.5	16.5	U	15	16.5				300			
20041207	ABP	l	SC15	4.5	16.5	U	15	16.5				370			
20041207	ABQ	l	SC15	4.5	16.5	U	15	16.5				390			
20041207	ABR	l	SC15	4.5	16.5	U	15	16.5				420			
20041207	ABS	l	SC15	4.5	16.5	U	15	16.5				450			
20041207	ABT	l	SC15	4.5	16.5	U	15	16.5				470			

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20041207	ABU	l	SC15	4.5	16.5	U	15	16.5				490			
20041207	ABV	l	SC15	4.5	16.5	U	15	16.5				275			
20041207	ABW	l	SC15	4.5	16.5	U	15	16.5				250			
20041207	ABX	l	SC15	4.5	16.5	U	15	16.5				325			
20041213	ABY	Ml	SC15	4.5	230		0	16.5	91	260	1.27	260	5.2	?	
20041213	ABZ	Ml	SC15	4.5	230		0	16.5	91	260	1.27	260	5.2	22	
20041215	ACA	l	SC15	4.5	230	U	20	16.5				260	5.2		
20041215	ACB	Ml	SC15	4.5	230		0	16.5		260	1.27	260	5.2	22	
20041215	ACC	Ml	SC15	4.5	230	U	10	16.5		260	1.27	260	5.2	22	
20041215	ACD	Ml	SC15	4.5	230	U	20	16.5		260	1.27	260	5.2	11	
20041215	ACE	Ml	SC15	4.5	230	U	30	16.5		260	1.27	260	5.2	11	
20041215	ACF	l	SC15	4.5	230	U	30	16.5							Background no laser
20041215	ACG	l	SC15	4.5	230	U	0	16.5							Background no laser
20041215	ACH	l	SC15	4.5	230	U	10	16.5							Background no laser
20041215	ACI	l	SC15	4.5	230	U	20	16.5							Background no laser
20041216	ACJ	M	SC15	4.5	230	U	20	16.5	98					8	
20041216	ACK	M	SC15	4.5	230	U	30	16.5	96					8	
20041216	ACL	M	SC15	4.5	230		0	16.5	93					11	
20041216	ACM	M	SC15	4.5	230	U	10	16.5	97					8	
20041220	ACN	M	S6 0.9	8.2	320	U		19.6	160	260	1.27			5.6	
20021220	ACO	M	S6 1.2	5.4	320	U	17	34	165	260	1.27			22	
20041229	ACP	Ml	S6 1.2	7.6	360	U	17	20		260	2.6	260	5.2	22	
20041229	ACQ	Ml	S6 1.2	7.6	360	U	17	21		260	2.6	260	5.2	11	

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20041229	ACR	Ml	S6 1.2	7.6	360	U	17	22		260	2.6	260	5.2	11	
20041229	ACS	Ml	S6 1.2	7.6	360	U	17	23		260	2.6	260	5.2	11	
20041229	ACT	Ml	S6 1.2	7.6	360	U	17	24		260	2.6	260	5.2	11	
20041229	ACU	l	S6 1.2	7.6	360	U	17	24		380		380			
20041229	ACV	l	S6 1.2	7.6	360	U	17	24		400		400			
20041229	ACW	l	S6 1.2	7.6	360	U	17	24		450		450			
20041229	ACX	l	S6 1.2	7.6	360	U	17	24		425		425			
20041229	ACY	l	S6 1.2	7.6	360	U	17	24		360		360			
20041229	ACZ	l	S6 1.2	7.6	360	U	17	24		330		330			
20041229	ADA	l	S6 1.2	7.6	360	U	17	24		300		300			
20041229	ADB	l	S6 1.2	7.6	360	U	17	24		260		260			
20041229	ADC	l	S6 1.2	7.6	360	U	17	24		290		290			
20041229	ADD	Ml	S6 1.2	7.6	360	U	17	20		290		290		11	
20041229	ADE	Ml	S6 1.2	7.6	360	U	17	26		290		290		11	
20041229	ADF	Ml	S6 1.2	7.6	360	U	17	26		290		off		11	
20041229	ADG	l	S6 1.2	7.6	360	U	17	26		off		off			
20041229	ADH	l	S6 1.2	7.6	360	U	17	26		off		290			
20041229	ADI	Ml	S6 1.2	7.6	360	U	17	26		290		290		11	
20041229	ADJ	l	S6 1.2	7.6	360	U	17	26		300		off			
20041229	ADK	l	S6 1.2	7.6	360	U	17	26		330		off			
20041229	ADL	l	S6 1.2	7.6	360	U	17	26		400		off			
20041229	ADM	l	S6 1.2	7.6	360	U	17	26		450		off			
20050116	ADN	M	S6 1.2	7.6	360	U	17	26		305	2.55			16	

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050116	ADO	M	S6 1.2	7.6	360	U	17	20		305	2.55			16	
20050116	ADP	M	S6 1.2	7.6	360	U	17	21		305	2.55			16	
20050116	ADQ	M	S6 1.2	7.6	360	U	17	22		305	2.55			16	
20050116	ADR	M	S6 1.2	7.6	360	U	17	23		305	2.55			16	
20050116	ADS	M	S6 1.2	7.6	360	U	17	24		305	2.55			16	
20050116	ADT	M	S6 1.2	7.6	360	U	17	25		305	2.55			16	
20050116	ADU	M	S6 1.2	7.6	360	U	17	26		305	2.55			16	
20050116	ADV	M	S6 1.2	7.6	360	U	17	27		305	2.55			16	
20050116	ADW	M	S6 1.2	7.6	360	U	17	28		305	2.55			16	
20050116	ADX	M	S6 1.2	7.6	360	U	17	29		305	2.55			16	
20050116	ADY	M	S6 1.2	7.6	360	U	17	30		305	2.55			16	
20050116	ADZ	M	S6 1.2	7.6	360	U	17	31		305	2.55			16	
20050116	AEA	M	S6 1.2	7.6	360	U	17	32		305	2.55			16	
20050116	AEB	M	S6 1.2	7.6	360	U	17	33		305	2.55			16	
20050116	AEC	M	S6 1.2	7.6	360	U	17	33		305	2.55			22	
20050116	AED	M	S6 1.2	7.6	360	U	17	32		305	2.55			22	
20050116	AEE	M	S6 1.2	7.6	360	U	17	31		305	2.55			22	
20050116	AEF	M	S6 1.2	7.6	360	U	17	30		305	2.55			22	
20050116	AEG	M	S6 1.2	7.6	360	U	17	29		305	2.55			22	
20050117	AEF	M	S6 1.2	7.6	360	U	17	26		305	3.65			16	
20050117	AEG	M	S6 1.2	4.6	360	U	17	26	166	305	3.65			16	
20050117	AEH	M	S6 1.2	4.6	360	U	17	15	144	305	3.65			16	
20050117	AEI	M	S6 1.2	4.6	360	U	17	17	156	305	3.65			16	

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050117	AEJ	M	S6 1.2	4.6	360	U	17	18	157	305	3.65			16	
20050117	AEK	M	S6 1.2	4.6	360	U	17	19	159	305	3.65			16	
20050117	AEL	M	S6 1.2	4.6	360	U	17	20	161	305	3.65			16	
20050117	AEM	M	S6 1.2	4.6	360	U	17	21	161	305	3.65			16	
20050117	AEN	M	S6 1.2	4.6	360	U	17	23	162	305	3.65			16	
20050117	AEO	M	S6 1.2	4.6	360	U	17	25	165	305	3.65			16	
20050117	AEP	M	S6 1.2	4.6	360	U	17	27	167	305	3.65			16	
20050117	AEQ	M	S6 1.2	4.6	360	U	17	28	170	305	3.65			16	
20050117	AER	M	S6 1.2	4.6	360	U	17	29	169	305	3.65			16	
20050117	AES	M	S6 1.2	4.6	360	U	17	31	173	305	3.65			16	
20050117	AET	M	S6 1.2	4.6	360	U	17	33	177	305	3.65			16	
20050118	AEU	M	S6 1.2	4.6	360	U	17	26		305	2.65			16	
20050118	AEV	M	S6 1.2	7.6	360	U	17	26		305	2.65			16	
20050118	AEW	M	S6 1.2	7.6	360	U	10	26	224	305	2.65			16	
20050118	AEX	M	S6 1.2	7.6	360	U	15	26	224	305	2.65			16	
20050118	AEY	M	S6 1.2	7.6	360	U	20	26	225	305	2.65			16	
20050118	AEZ	M	S6 1.2	7.6	360	U	25	26	223	305	2.65			16	
20050118	AFA	M	S6 1.2	7.6	360	U	30	26	225	305	2.65			16	
20050118	AFB	M	S6 1.2	7.6	360	U	35	26	224	305	2.65			16	
20050118	AFC	M	S6 1.2	7.6	360	U	5	26	224	305	2.65			16	
20050118	AFD	M	S6 1.2	7.6	360	U	0	26	208	305	2.65			16	
20050118	AFE	M	S6 1.2	7.6	360	U	0	26	208	305	2.65			22	
20050119	AFF	M	S6 1.2	7.6	360	U	17	20	212	305	2.6			16	

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050119	AFG	M	S6 1.2	7.6	360	U	17	21	221	305	2.6			16	
20050119	AFH	M	S6 1.2	7.6	360	U	17	23	218	305	2.6			16	
20050119	AFI	M	S6 1.2	7.6	360	U	17	22	221	305	2.6			16	
20050119	AFJ	M	S6 1.2	7.6	360	U	17	24	220	305	2.6			16	
20050119	AFK	M	S6 1.2	7.6	360	U	17	25	225	305	2.6			16	
20050119	AFL	M	S6 1.2	7.6	360	U	17	26	224	305	2.6			16	
20050119	AFM	M	S6 1.2	7.6	360	U	17	27		305	2.6			16	
20050119	AFN	M	S6 1.2	7.6	360	U	17	28	228	305	2.6			16	
20050119	AFO	M	S6 1.2	7.6	360	U	17	29	225	305	2.6			16	
20050119	AFP	M	S6 1.2	7.6	360	U	17	30	226	305	2.6			16	
20050119	AFQ	M	S6 1.2	7.6	360	U	17	31	232	305	2.6			16	
20050119	AFR	M	S6 1.2	7.6	360	U	17	32	236	305	2.6			16	
20050119	AFS	M	S6 1.2	7.6	360	U	17	33	235	305	2.6			16	
20050119	AFT	M	S6 1.2	7.6	360	U	17	34	241	305	2.6			16	
20050120	AFU	M	S6 1.2	7.6	360	U	17	26	230	305	2.6			16	RHR Towards End effects?
20050120	AFV	M	S6 1.2	7.6	360	U	17	26	230	305	2.6			16	RHR Towards
20050120	AFW	M	S6 1.2	7.6	360	U	17	26	230	305	2.6			16	RHR Towards
20050120	AFX	M	S6 1.2	7.6	360	U	17	26	230	305	2.6			16	RHR Towards
20050120	AFY	M	S6 1.2	7.6	360	U	17	26	230	305	2.6			16	RHR Towards
20050120	AFZ	M	S6 1.2	7.6	360	U	17	26	229	305	2.6			16	RHR Away
20050120	AGA	M	S6 1.2	7.6	360	U	17	26	232	305	2.6			16	RHR Away
20050120	AGB	M	S6 1.2	7.6	360	U	17	26	230	305	2.6			16	RHR Away
20050120	AGC	M	S6 1.2	7.6	360	U	17	26	230	305	2.6			16	RHR Away

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050120	AGD	M	S6 1.2	7.6	360	U	17	26	230	305	2.6			16	RHR Away
20050121	AGE	M	S6 1.2	7.6	360	U	17	26		305	2.6			16	
20050121	AGF	M	S6 1.2	10.4	360	U	17	26	286	305	2.6			16	
20050121	AGG	M	S6 1.2	10.4	360	U	17	22	273	305	2.6			16	
20050121	AGH	M	S6 1.2	10.4	360	U	17	21	275	305	2.6			16	
20050121	AGI	M	S6 1.2	10.4	360	U	17	20	272	305	2.6			16	
20050121	AGJ	M	S6 1.2	10.4	360	U	17	23	280	305	2.6			16	
20050121	AGK	M	S6 1.2	10.4	360	U	17	24	280	305	2.6			16	
20050121	AGL	M	S6 1.2	10.4	360	U	17	25	283	305	2.6			16	
20050121	AGM	M	S6 1.2	10.4	360	U	17	26	285	305	2.6			16	
20050121	AGN	M	S6 1.2	10.4	360	U	17	27		305	2.6			16	
20050121	AGO	M	S6 1.2	10.4	360	U	17	28	287	305	2.6			16	
20050121	AGP	M	S6 1.2	10.4	360	U	17	29	290	305	2.6			16	
20050121	AGQ	M	S6 1.2	10.4	360	U	17	30		305	2.6			16	
20050121	AGR	M	S6 1.2	10.4	360	U	17	26	286	off	0			16	
20050121	AGS	M	S6 1.2	4	360	U	17	26	158	305	2.6			16	
20050121	AGT	M	S6 1.2	4.5	360	U	17	26	169	305	2.6			16	
20050121	AGU	M	S6 1.2	5	360	U	17	26	177	305	2.6			16	
20050121	AGV	M	S6 1.2	6	360	U	17	26	198	305	2.6			16	
20050121	AGW	M	S6 1.2	7	360	U	17	26	219	305	2.6			16	
20050121	AGX	M	S6 1.2	7.6	360	U	17	26	228	305	2.6			16	
20050121	AGY	M	S6 1.2	8	360	U	17	26	236	305	2.6			16	
20050121	AGZ	M	S6 1.2	9	360	U	17	26	256	305	2.6			16	

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050121	AHA	M	S6 1.2	10	360	U	17	26	272	305	2.6			16	
20050121	AHB	M	S6 1.2	10.4	360	U	17	26	285	305	2.6			16	
20050121	AHC	M	S6 1.2	11	380	U	17	26	288	305	2.6			16	
20050121	AHD	M	S6 1.2	11	500	U	20	28	300	305	2.6			16	
20050121	AHE	M	S6 1.2	12.5	600	U	20	28	305	305	2.6			16	only 70 images taken blew through to drum
20050123	AHF	Ml	S6 1.2	7.6	360	U	17	26		405	0.34	off	0	8	ICCD gate 800ns
20050123	AHG	Ml	S6 1.2	7.6	360	U	17	26		off	0	off		8	ICCD gate 800ns
20050123	AHH	Ml	S6 1.2	7.6	360	U	17	26		off	0	405	1.3	8	ICCD gate 800ns
20050123	AHI	Ml	S6 1.2	7.6	360	U	17	26		405	0.34	405	1.3	8	ICCD gate 800ns
20050123	AHJ	Ml	S6 1.2	7.6	360	U	17	26		405	0.34	405	1.3	8	ICCD gate 200ns
20050124	AHK	Ml	S6 1.2	7.6	360	U	17	26		405	0.34	405	1.3	8	
20050124	AHL	Ml	S6 1.2	7.6	360	U	17	20		405	0.34	405	1.3	8	
20050124	AHM	Ml	S6 1.2	7.6	360	U	17	21		405	0.34	405	1.3	5.6	
20050124	AHN	Ml	S6 1.2	7.6	360	U	17	22		405	0.34	405	1.3	5.6	
20050124	AHO	Ml	S6 1.2	7.6	360	U	17	23		405	0.34	405	1.3	5.6	
20050124	AHP	Ml	S6 1.2	7.6	360	U	17	24		405	0.34	405	1.3	5.6	
20050124	AHQ	Ml	S6 1.2	7.6	360	U	17	25		405	0.34	405	1.3	8	
20050124	AHR	Ml	S6 1.2	7.6	360	U	17	26		405	0.34	405	1.3	8	
20050124	AHS	Ml	S6 1.2	7.6	360	U	17	27		405	0.34	405	1.3	8	
20050124	AHT	Ml	S6 1.2	7.6	360	U	17	28		405	0.34	405	1.3	8	
20050124	AHU	Ml	S6 1.2	7.6	360	U	17	29		405	0.34	405	1.3	8	
20050124	AHV	Ml	S6 1.2	7.6	360	U	17	30		405	0.34	405	1.3	8	
20050124															

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050124	AHX	Ml	S6 1.2	7.6	360	U	17	31		405	0.34	405	1.3	8	
20050124	AHY	Ml	S6 1.2	7.6	360	U	17	32		405	0.34	405	1.3	8	
20050124	AHZ	Ml	S6 1.2	7.6	360	U	17	33		405	0.34	405	1.3	8	
20050127	AIA	M	S6 1.2	7.6	360	U	17	26		405	0.34			8	Transverse direction
20050127	AIB	M	S6 1.2	7.6	360	U	17	26		405	0.34			8	Transverse direction
20050127	AIC	M	S6 1.2	7.6	360	U	17	28		405	0.34			8	Transverse direction
20050127	AID	M	S6 1.2	7.6	360	U	17	30		405	0.34			8	Transverse direction
20050127	AIE	M	S6 1.2	7.6	360	U	17	32		405	0.34			8	Transverse direction
20050127	AIF	M	S6 1.2	4.5	360	U	17	24		405	0.34			8	Transverse direction
20050127	AIG	M	S6 1.2	4.5	360	U	17	26		405	0.34			8	Transverse direction
20050127	AIH	M	S6 1.2	4.5	360	U	17	28		405	0.34			8	Transverse direction
20050127	AII	M	S6 1.2	4.5	360	U	17	30		405	0.34			8	Transverse direction
20050127	AIJ	M	S6 1.2	4.5	360	U	17	32		405	0.34			8	Transverse direction
20050130	AIK	m	S6 1.2	7.6	360	U	17	26		405	0.22			22	
20050130	AIL	m	S6 1.2	7.6	360	U	17	20		405	0.22			22	
20050130	AIM	m	S6 1.2	7.6	360	U	17	21		405	0.22			22	
20050130	AIN	m	S6 1.2	7.6	360	U	17	22		405	0.22			22	
20050130	AIO	m	S6 1.2	7.6	360	U	17	23		405	0.22			22	
20050130	AIP	m	S6 1.2	7.6	360	U	17	24		405	0.22			22	
20050130	AIQ	m	S6 1.2	7.6	360	U	17	25		405	0.22			22	
20050130	AIR	m	S6 1.2	7.6	360	U	17	26		405	0.22			22	
20050130	AIS	m	S6 1.2	7.6	360	U	17	27		405	0.22			22	
20050130	AIT	m	S6 1.2	7.6	360	U	17	28		405	0.22			22	

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050130	AIU	m	S6 1.2	7.6	360	U	17	29		405	0.22			22	
20050130	AIV	m	S6 1.2	7.6	360	U	17	30		405	0.22			22	
20050130	AIW	m	S6 1.2	7.6	360	U	17	31		405	0.22			22	
20050130	AIX	m	S6 1.2	7.6	360	U	17	32		405	0.22			22	
20050130	AIY	m	S6 1.2	7.6	360	U	17	33		405	0.22			22	
20050130	AIZ	m	S6 1.2	4.5	360	U	17	26		405	0.22			22	
20050130	AJA	m	S6 1.2	4.5	360	U	17	20		405	0.22			22	
20050130	AJB	m	S6 1.2	4.5	360	U	17	21		405	0.22			22	
20050130	AJC	m	S6 1.2	4.5	360	U	17	22		405	0.22			22	
20050130	AJD	m	S6 1.2	4.5	360	U	17	23		405	0.22			22	
20050130	AJE	m	S6 1.2	4.5	360	U	17	24		405	0.22			22	
20050130	AJF	m	S6 1.2	4.5	360	U	17	25		405	0.22			22	
20050130	AJG	m	S6 1.2	4.5	360	U	17	26		405	0.22			22	
20050130	AJH	m	S6 1.2	4.5	360	U	17	27		405	0.22			22	
20050130	AJI	m	S6 1.2	4.5	360	U	17	28		405	0.22			22	
20050130	AJJ	m	S6 1.2	4.5	360	U	17	29		405	0.22			22	
20050130	AJK	m	S6 1.2	4.5	360	U	17	30		405	0.22			22	
20050130	AJL	m	S6 1.2	4.5	360	U	17	31		405	0.22			22	
20050130	AJM	m	S6 1.2	4.5	360	U	17	32		405	0.22			22	
20050130	AJN	m	S6 1.2	4.5	360	U	17	33		405	0.22			22	
20050130	AJO	m	S6 1.2	4.5	360	U	17	33						22	Background no laser
20050203	AJP	l	S6 1.2	7.6	360	U	17	26				405	1.32		with red filter
20050203	AJQ	l	S6 1.2	7.6	360	U	17	26				405	1.32		without filter

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050203	AJR	1	S6 1.2	7.6	360	U	17	26				520	0.085		with red filter
20050203	AJS	1	S6 1.2	7.6	360	U	17	26				500	0.212		with red filter
20050203	AJT	1	S6 1.2	7.6	360	U	17	26				480	0.425		with red filter
20050203	AJU	1	S6 1.2	7.6	360	U	17	26				460	0.63		with red filter
20050203	AJV	1	S6 1.2	7.6	360	U	17	26				440	1.05		with red filter
20050203	AJW	1	S6 1.2	7.6	360	U	17	26				420	1.27		with red filter
20050203	AJX	1	S6 1.2	7.6	360	U	17	26				405	1.32		with red filter
20050203	AJY	1	S6 1.2	7.6	360	U	17	26				400	1.35		with red filter
20050203	AJZ	1	S6 1.2	7.6	360	U	17	26				380	1.82		with red filter
20050203	AKA	1	S6 1.2	7.6	360	U	17	26				360	2.6		with red filter
20050203	AKB	1	S6 1.2	7.6	360	U	17	26				340	3.65		with red filter
20050203	AKC	1	S6 1.2	7.6	360	U	17	26				320	4.4		with red filter
20050203	AKD	1	S6 1.2	7.6	360	U	17	26				300	4.9		with red filter
20050203	AKE	1	S6 1.2	7.6	360	U	17	26				280	5.3		with red filter
20050203	AKF	1	S6 1.2	7.6	360	U	17	26				260	5.4		with red filter
20050203	AKG	1	S6 1.2	7.6	360	U	17	26							with red filter
20050204	AKH	1	S6 1.2	7.6	360	U	17	26							Used to set ROI
20050204	AKI	1	S6 1.2	7.6	360	U	17	26				520			Hoya R25A filter 400ns
20050204	AKJ	1	S6 1.2	7.6	360	U	17	26				500			Hoya R25A filter 400ns
20050204	AKK	1	S6 1.2	7.6	360	U	17	26				480			Hoya R25A filter 400ns
20050204	AKL	1	S6 1.2	7.6	360	U	17	26				460			Hoya R25A filter 400ns
20050204	AKM	1	S6 1.2	7.6	360	U	17	26				440			Hoya R25A filter 400ns
20050204	AKN	1	S6 1.2	7.6	360	U	17	26				420			Hoya R25A filter 400ns

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050204	AKO	1	S6 1.2	7.6	360	U	17	26				400			Hoya R25A filter 400ns
20050204	AKP	1	S6 1.2	7.6	360	U	17	26				380			Hoya R25A filter 400ns
20050204	AKQ	1	S6 1.2	7.6	360	U	17	26				360			Hoya R25A filter 400ns
20050204	AKR	1	S6 1.2	7.6	360	U	17	26				340			Hoya R25A filter 400ns
20050204	AKS	1	S6 1.2	7.6	360	U	17	26				320			Hoya R25A filter 400ns
20050204	AKT	1	S6 1.2	7.6	360	U	17	26				300			Hoya R25A filter 400ns
20050204	AKU	1	S6 1.2	7.6	360	U	17	26				280			Hoya R25A filter 400ns
20050204	AKV	1	S6 1.2	7.6	360	U	17	26				260			Hoya R25A filter 400ns
20050204	AKW	1	S6 1.2	7.6	360	U	17	26				520			Hoys orange glass filter 400ns
20050204	AKX	1	S6 1.2	7.6	360	U	17	26				500			Hoys orange glass filter 400ns
20050204	AKY	1	S6 1.2	7.6	360	U	17	26				480			Hoys orange glass filter 400ns
20050204	AKZ	1	S6 1.2	7.6	360	U	17	26				460			Hoys orange glass filter 400ns
20050204	ALA	1	S6 1.2	7.6	360	U	17	26				440			Hoys orange glass filter 400ns
20050204	ALB	1	S6 1.2	7.6	360	U	17	26				420			Hoys orange glass filter 400ns
20050204	ALC	1	S6 1.2	7.6	360	U	17	26				400			Hoys orange glass filter 400ns
20050204	ALD	1	S6 1.2	7.6	360	U	17	26				380			Hoys orange glass filter 400ns
20050204	ALE	1	S6 1.2	7.6	360	U	17	26				360			Hoys orange glass filter 400ns
20050204	ALF	1	S6 1.2	7.6	360	U	17	26				340			Hoys orange glass filter 400ns
20050204	ALG	1	S6 1.2	7.6	360	U	17	26				320			Hoys orange glass filter 400ns
20050204	ALH	1	S6 1.2	7.6	360	U	17	26				300			Hoys orange glass filter 400ns
20050204	ALI	1	S6 1.2	7.6	360	U	17	26				280			Hoys orange glass filter 400ns
20050204	ALJ	1	S6 1.2	7.6	360	U	17	26				260			Hoys orange glass filter 400ns
20050204	ALK	1	S6 1.2	7.6	360	U	17	26				520			Hoya UV blocking filter 300ns

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050204	ALL	1	S6 1.2	7.6	360	U	17	26				500			Hoya UV blocking filter 300ns
20050204	ALM	1	S6 1.2	7.6	360	U	17	26				480			Hoya UV blocking filter 300ns
20050204	ALN	1	S6 1.2	7.6	360	U	17	26				460			Hoya UV blocking filter 300ns
20050204	ALO	1	S6 1.2	7.6	360	U	17	26				440			Hoya UV blocking filter 300ns
20050204	ALP	1	S6 1.2	7.6	360	U	17	26				420			Hoya UV blocking filter 300ns
20050204	ALQ	1	S6 1.2	7.6	360	U	17	26				400			Hoya UV blocking filter 300ns
20050204	ALR	1	S6 1.2	7.6	360	U	17	26				380			Hoya UV blocking filter 300ns
20050204	ALS	1	S6 1.2	7.6	360	U	17	26				360			Hoya UV blocking filter 300ns
20050204	ALT	1	S6 1.2	7.6	360	U	17	26				340			Hoya UV blocking filter 300ns
20050204	ALU	1	S6 1.2	7.6	360	U	17	26				320			Hoya UV blocking filter 300ns
20050204	ALV	1	S6 1.2	7.6	360	U	17	26				300			Hoya UV blocking filter 300ns
20050204	ALW	1	S6 1.2	7.6	360	U	17	26				280			Hoya UV blocking filter 300ns
20050204	ALX	1	S6 1.2	7.6	360	U	17	26				260			Hoya UV blocking filter 300ns
20050204	ALY	1	S6 1.2	7.6	360	U	17	26							vis background
20050204	ALZ	1	S6 1.2	7.6	360	U	17	26							orange background
20050204	AMA	1	S6 1.2	7.6	360	U	17	26							Red background
20050205	AMB	1													
20050205	AMC	1	S6 1.2	4.5	360	U	17	20				320			
20050205	AMD	1	S6 1.2	4.5	360	U	17	21				320			
20050205	AME	1	S6 1.2	4.5	360	U	17	22				320			
20050205	AMF	1	S6 1.2	4.5	360	U	17	23				320			
20050205	AMG	1	S6 1.2	4.5	360	U	17	24				320			
20050205	AMH	1	S6 1.2	4.5	360	U	17	25				320			

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050205	AMI	1	S6 1.2	4.5	360	U	17	26				320			
20050205	AMJ	1	S6 1.2	4.5	360	U	17	27				320			
20050205	AMK	1	S6 1.2	4.5	360	U	17	28				320			
20050205	AML	1	S6 1.2	4.5	360	U	17	29				320			
20050205	AMM	1	S6 1.2	4.5	360	U	17	30				320			
20050205	AMN	1	S6 1.2	4.5	360	U	17	31				320			
20050205	AMO	1	S6 1.2	4.5	360	U	17	32				320			
20050205	AMP	1	S6 1.2	7.6	360	U	17	20				320			repeated
20050205	AMQ	1	S6 1.2	7.6	360	U	17	21				320			
20050205	AMR	1	S6 1.2	7.6	360	U	17	22				320			
20050205	AMS	1	S6 1.2	7.6	360	U	17	23				320			repeated
20050205	AMT	1	S6 1.2	7.6	360	U	17	24				320			
20050205	AMU	1	S6 1.2	7.6	360	U	17	25				320			
20050205	AMV	1	S6 1.2	7.6	360	U	17	26				320			repeated
20050205	AMW	1	S6 1.2	7.6	360	U	17	27				320			
20050205	AMX	1	S6 1.2	7.6	360	U	17	28				320			
20050205	AMY	1	S6 1.2	7.6	360	U	17	29				320			
20050205	AMZ	1	S6 1.2	7.6	360	U	17	30				320			repeated
20050205	ANA	1	S6 1.2	7.6	360	U	17	31				320			
20050205	ANB	1	S6 1.2	7.6	360	U	17	32				320			
20050206	ANC	1	S6 1.2	4.5	360	U	17	20	164			520			
20050206	AND	1	S6 1.2	4.5	360	U	17	20	164			500			
20050206	ANE	1	S6 1.2	4.5	360	U	17	20	164			480			

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050206	ANF	1	S6 1.2	4.5	360	U	17	20	164			460			
20050206	ANG	1	S6 1.2	4.5	360	U	17	20	164			440			
20050206	ANH	1	S6 1.2	4.5	360	U	17	20	164			420			
20050206	ANI	1	S6 1.2	4.5	360	U	17	20	164			400			
20050206	ANJ	1	S6 1.2	4.5	360	U	17	20	164			380			
20050206	ANK	1	S6 1.2	4.5	360	U	17	20	164			360			
20050206	ANL	1	S6 1.2	4.5	360	U	17	20	164			340			
20050206	ANM	1	S6 1.2	4.5	360	U	17	20	164			320			
20050206	ANN	1	S6 1.2	4.5	360	U	17	20	164			300			
20050206	ANO	1	S6 1.2	4.5	360	U	17	20	164			280			
20050206	ANP	1	S6 1.2	4.5	360	U	17	20	164			260			
20050206	ANQ	1	S6 1.2	4.5	360	U	17	30	174			520			
20050206	ANR	1	S6 1.2	4.5	360	U	17	30	174			500			
20050206	ANS	1	S6 1.2	4.5	360	U	17	30	174			480			
20050206	ANT	1	S6 1.2	4.5	360	U	17	30	174			460			
20050206	ANU	1	S6 1.2	4.5	360	U	17	30	174			440			
20050206	ANV	1	S6 1.2	4.5	360	U	17	30	174			420			
20050206	ANW	1	S6 1.2	4.5	360	U	17	30	174			400			
20050206	ANX	1	S6 1.2	4.5	360	U	17	30	174			380			
20050206	ANY	1	S6 1.2	4.5	360	U	17	30	174			360			
20050206	ANZ	1	S6 1.2	4.5	360	U	17	30	174			340			
20050206	AOA	1	S6 1.2	4.5	360	U	17	30	174			320			
20050206	AOB	1	S6 1.2	4.5	360	U	17	30	174			300			

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050206	AOC	1	S6 1.2	4.5	360	U	17	30	174			280			
20050206	AOD	1	S6 1.2	4.5	360	U	17	30	174			260			
20050206	AOE	1	S6 1.2	4.5	360	U	17	20				320			
20050206	AOF	1	S6 1.2	4.5	360	U	17	20				320			
20050206	AOG	1	S6 1.2	4.5	360	U	17	20				320			
20050206	AOH	1	S6 1.2	4.5	360	U	17	20				320			
20050206	AOI	1	S6 1.2	4.5	360	U	17	20				320			
20050206	AOJ	1	S6 1.2	4.5	360	U	17	20				320			
20050206	AOK	1	S6 1.2	4.5	360	U	17	20				320			
20050206	AOL	1	S6 1.2	10.4	360	U	17	20				320			
20050206	AOM	1	S6 1.2	10.4	360	U	17	21				320			
20050206	AON	1	S6 1.2	10.4	360	U	17	22				320			
20050206	AOO	1	S6 1.2	10.4	360	U	17	23				320			
20050206	AOP	1	S6 1.2	10.4	360	U	17	24				320			
20050206	AOQ	1	S6 1.2	10.4	360	U	17	25				320			
20050206	AOR	1	S6 1.2	10.4	360	U	17	26				320			
20050206	AOS	1	S6 1.2	10.4	360	U	17	27				320			
20050206	AOT	1	S6 1.2	10.4	360	U	17	28				320			
20050206	AOU	1	S6 1.2	4.5	360	U	17	26				320			
20050206	AOV	1	S6 1.2	7.6	360	U	17	26				320			
20050206	AOW	1	S6 1.2	4.5	360	U	17	22				320			gate width 50ns
20050206	AOX	1	S6 1.2	4.5	360	U	17	22				320			gate width 100ns
20050206	AOY	1	S6 1.2	4.5	360	U	17	22				320			gate width 150ns

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050206	AOZ	l	S6 1.2	4.5	360	U	17	22				320			gate width 200ns
20050206	APA	l	S6 1.2	4.5	360	U	17	22				320			gate width 250ns
20050206	APB	l	S6 1.2	4.5	360	U	17	22				320			gate width 300ns
20050206	APC	l	S6 1.2	4.5	360	U	17	22				320			gate width 350ns
20050206	APD	l	S6 1.2	4.5	360	U	17	22				320			gate width 400ns
20050206	APE	l	S6 1.2	4.5	360	U	17	22				320			gate width 450ns
20050206	APF	l	S6 1.2	4.5	360	U	17	22				320			gate width 500ns
20050206	APG	l	S6 1.2	4.5	360	U	17	22				320			gate width 600ns
20050206	APH	l	S6 1.2	4.5	360	U	17	22				320			gate width 700ns
20050206	API	l	S6 1.2	4.5	360	U	17	22				320			gate width 800ns
20050206	APJ	l	S6 1.2	4.5	360	U	17	22				320			gate width 900ns
20050206	APK	l	S6 1.2	4.5	360	U	17	22				320			gate width 1000ns
20050206	APL	l	S6 1.2	4.5	360	U	17	22				320			gate width 1500ns
20050206	APM	l	S6 1.2	4.5	360	U	17	22				320			gate width 2000ns
20050207	APN	m	S6 1.2	4.5	360	U	17	20		405	0.182			11	
20050207	APO	m	S6 1.2	4.5	360	U	17	22		405	0.182			11	
20050207	APP	m	S6 1.2	4.5	360	U	17	24		405	0.182			11	
20050207	APQ	m	S6 1.2	4.5	360	U	17	26		405	0.182			11	
20050207	APR	m	S6 1.2	4.5	360	U	17	28		405	0.182			11	
20050207	APS	m	S6 1.2	4.5	360	U	17	30		405	0.182			11	
20050207	APT	m	S6 1.2	4.5	360	U	17	32		405	0.182			11	
20050207	APU	m	S6 1.2	7.6	360	U	17	22		405	0.182			11	
20050207	APV	m	S6 1.2	7.6	360	U	17	20		405	0.182			11	

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050207	APW	m	S6 1.2	7.6	360	U	17	24		405	0.182			11	
20050207	APX	m	S6 1.2	7.6	360	U	17	26		405	0.182			11	
20050207	APY	m	S6 1.2	7.6	360	U	17	28		405	0.182			11	
20050207	APZ	m	S6 1.2	7.6	360	U	17	30		405	0.182			11	
20050207	AQA	m	S6 1.2	7.6	360	U	17	32		405	0.182			11	
20050207															
20050207	AQC	m	S6 1.2	10.4	360	U	17	22		405	0.182			11	
20050207	AQD	m	S6 1.2	10.4	360	U	17	24		405	0.182			11	
20050207	AQE	m	S6 1.2	10.4	360	U	17	26		405	0.182			11	
20050207	AQF	m	S6 1.2	10.4	360	U	17	28		405	0.182			11	
20050207	AQG	m	S6 1.2	10.4	360	U	17	30		405	0.182			11	
20050207	AQH	m	S6 1.2	10.4	360	U	17	32		405	0.182			11	
20050207	AQI	m	S6 1.2	7.6	200	U	17	26		405	0.182			11	
20050207	AQJ	m	S6 1.2	7.6	250	U	17	26		405	0.182			8	
20050207	AQK	m	S6 1.2	7.6	300	U	17	26		405	0.182			8	
20050207	AQL	m	S6 1.2	7.6	350	U	17	26		405	0.182			8	
20050207	AQM	m	S6 1.2	7.6	360	U	17	26		405	0.182			8	
20050207	AQN	m	S6 1.2	7.6	400	U	17	26		405	0.182			8	
20050207	AQO	m	S6 1.2	7.6	450	U	17	26		405	0.182			8	
20050207	AQP	m	S6 1.2	7.6	500	U	17	26		405	0.182			8	
20050207	AQQ	m	S6 1.2	7.6	550	U	17	26		405	0.182			8	
20050207	AQR	m	S6 1.2	7.6	600	U	17	26		405	0.182			8	
20050207	AQS	m	S6 1.2	7.6	200	U	17	22		405	0.182			8	

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050207	AQT	m	S6 1.2	7.6	250	U	17	22		405	0.182			8	
20050207	AQU	m	S6 1.2	7.6	300	U	17	22		405	0.182			8	
20050207	AQV	m	S6 1.2	7.6	350	U	17	22		405	0.182			8	
20050207	AQW	m	S6 1.2	7.6	400	U	17	22		405	0.182			8	
20050207	AQX	m	S6 1.2	7.6	450	U	17	22		405	0.182			8	
20050207	AQY	m	S6 1.2	7.6	500	U	17	22		405	0.182			8	
20050207	AQZ	m	S6 1.2	7.6	550	U	17	22		405	0.182			8	
20050207	ARA	m	S6 1.2	7.6	600	U	17	22		405	0.182			8	
20050207	ARB	m	S6 1.2	7.6	360	U	10	26		405	0.182			8	
20050207	ARC	m	S6 1.2	7.6	360	U	15	26		405	0.182			8	
20050207	ARD	m	S6 1.2	7.6	360	U	20	26		405	0.182			8	
20050207	ARE	m	S6 1.2	7.6	360	U	25	26		405	0.182			8	
20050207	ARF	m	S6 1.2	7.6	360	U	30	26		405	0.182			8	
20050207	ARG	m	S6 1.2	7.6	360	U	35	26		405	0.182			8	
20050207	ARH	m	S6 1.2	7.6	360	U	40	26		405	0.182			8	
20050207															
20050207															
20050207															
20050207	ARL	m	S6 1.2	7.6	360	U	10	22		405	0.182			8	
20050207	ARM	m	S6 1.2	7.6	360	U	15	22		405	0.182			8	
20050207	ARN	m	S6 1.2	7.6	360	U	20	22		405	0.182			8	
20050207	ARO	m	S6 1.2	7.6	360	U	25	22		405	0.182			8	
20050207	ARP	m	S6 1.2	7.6	360	U	30	22		405	0.182			8	

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050207	ARQ	m	S6 1.2	7.6	360	U	35	22		405	0.182			8	
20050207	ARR	m	S6 1.2	7.6	360	U	40	22		405	0.182			8	
20050207	ARS	m	S6 1.2	7.6	360	U	40	26		405	0.182			8	very close to wire
20050207	ART	m	S6 1.2	7.6	360	U	10	26		405	0.182			8	very close to wire
20050207															
20050207															
20050208	ARW	m	S6 1.2	7.9	360	U	20	31	283	405	0.19			8	standard tip
20050208	ARX	m	S6 1.2	7.9	360	U	20	31	283	405	0.19			8	standard tip
20050208	ARY	m	S6 1.2	7.9	360	U	20	31	283	405	0.19			8	standard tip
20050208	ARZ	m	S6 1.2	7.9	360	U	20	31	283	405	0.19			8	standard tip
20050208	ASA	m	S6 1.2	7.9	360	U	20	31	232	405	0.19			8	phoenix
20050208	ASB	m	S6 1.2	7.9	360	U	20	31	232	405	0.19			8	phoenix
20050208	ASC	m	S6 1.2	7.9	360	U	20	32.5		405	0.19			8	phoenix
20050208	ASD	m	S6 1.2	7.9	360	U	20	34.3	243	405	0.19			8	phoenix
20050208	ASE	m	S6 1.2	7.9	360	U	20	34.3	243	405	0.19			8	phoenix
20050208	ASF	m	S6 1.2	7.9	360	U	20	34.3	243	405	0.19			8	phoenix
20050208	ASG	m	S6 1.2	7.9	360	U	20	34.3	243	405	0.19			8	phoenix
20050208	ASH	m	S6 1.2	4.5	360	U	20	23.2	163	405	0.19			8	phoenix
20050208	ASI	m	S6 1.2	4.5	360	U	20	23.2	163	405	0.19			8	phoenix
20050208	ASJ	m	S6 1.2	4.5	360	U	20	23.2	163	405	0.19			8	phoenix
20050208	ASK	m	S6 1.2	4.5	360	U	20	23.2	163	405	0.19			8	phoenix
20050208	ASL	m	S6 1.2	12	360	U	20	37	325	405	0.19			8	phoenix
20050208	ASM	m	S6 1.2	12	360	U	20	37	325	405	0.19			8	phoenix

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050208	ASN	m	S6 1.2	12	360	U	20	37	325	405	0.19			8	phoenix
20050208	ASO	m	S6 1.2	12	360	U	20	37	325	405	0.19			8	phoenix
20050208	ASP	m	S6 1.2	4.5	360	U	20	24.5	174	405	0.19			8	standard tip
20050208	ASQ	m	S6 1.2	4.5	360	U	20	24.5	174	405	0.19			8	standard tip
20050208	ASR	m	S6 1.2	4.5	360	U	20	24.5	174	405	0.19			8	standard tip
20050208	ASS	m	S6 1.2	4.5	360	U	20	24.5	174	405	0.19			8	standard tip
20050209	AST	m								405	0.12			8	latex particle solution
20050209	ASU	m								405	0.12			5.4	latex particle solution
20050209	ASV	m								405	0.12			4.5	latex particle solution
20050209	ASW	m								405	0.12			11	latex particle solution
20050209	ASX	m								320	0.68			11	latex particle solution
20050209	ASY	m								320	0.68			16	latex particle solution
20050209	ASZ	m								320	0.68			22	latex particle solution
20050209	ATA	m								320	0.68			8	latex particle solution
20050209	ATB	m								340	0.55			8	latex particle solution
20050209	ATC	m								360	0.42			8	latex particle solution
20050209	ATD	m								380	0.27			8	latex particle solution
20050209	ATE	m								400	0.14			8	latex particle solution
20050209	ATF	m								420	0.095			8	latex particle solution
20050209	ATG	m								405	0.12			8	latex particle solution
20050209	ATH	m								400	0.14			8	latex particle solution
20050209	ATI	m								405	0.12			8	latex particle solution
20050209	ATJ	m								420	0.095			8	latex particle solution

Date	Run	LT	Wire	Feed	traverse	gas	flow	V	I	SQS	SP	LQS	LP	MPap	Comments
yyymmdd				m/min	mm/min		l/min	volts	amps	uS	mj	uS	mj		
20050209	ATK	m								380	0.27			8	latex particle solution
20050209	ATL	m								360	0.42			8	latex particle solution
20050209	ATM	m								360	0.42			11	latex particle solution
20050209	ATN	m								340	0.55			11	latex particle solution
20050209	ATO	m								320	0.68			11	latex particle solution
20050209	ATP	m													

Appendix D

Microprocessor control code

```
.include "c:\asm\1200def.inc"
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;%Hardware
;%PD2 <- BNC5 via and gate       -Fl input from 532 laser
;%PD5 <- button 2                -weld button
;%PD6 <- button 1                -focus button
;%PB0 -> BNC6 via and gate       -output to triger megapluss camera
;%PB1 -> BNC1 relay normaly open-turn welder on/off
;%PB2 <> BNC2                    -welding drum on/off
;%PB3 <-> BNC3                   -ICCD inhibit in
;%PD0 <-> BNC4                   -Inhibit to PG200
;%4MHz cristal
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;% Definitions for register names
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
.def    temp=r16
.def    loop1=r17
.def    loop2=r18
.def    every_n_count=r19        ;number of fl per image
.def    weld_n_countl=r20        ;the number of images per weld
.def    weld_n_counth=r21        ;upper bite to allow >256 images
.def    flag=r22                 ;0=do nothing 1=free_run/focus 2=taking images during welding
.def    keyreg1=r23              ;registers to deal with the status of keys
.def    keyreg2=r24
.def    loop3=r25
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;% Definitions of constants (.equ)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
.equ    every_n_fl=1             ;number of fl per image ie. 1=every 0.1s 5= every 0.5s 10= every 1s
.equ    total_n_per_weld=200+1   ;number of images per to be taken during weld
.equ    welding_n_per_weld=150   ;number of images to take with the welder on.
.equ    delay_uS=70
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;% RAM locations
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;%none this is to be done on a AT1200

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;% Interupt vectors used to direct interupt to correct
;% location in code
;%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
.cseg
.org 0x00
        rjmp RESET               ;EXTERNAL POWER ON WATCHDOG RESET
        rjmp EXT_INT0            ;EXTERNAL INTERRUPT REQUEST 0

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;% Reset procedure
;%set up ports. set up EXT_INT0
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
RESET:  ldi temp,0b11110111
        out DDRB,temp            ;set port b direction
        ldi temp,0b00000001
        out PORTB,temp           ;set initial output
        ldi temp,0b00000001
        out DDRD,temp            ;set port D direction
        ldi temp,0b00000000
        out PORTD,temp           ;set initial output
        ldi temp,0b01000000
        out GIMSK,temp           ;enable external interupt for detecting flash lamp output
        ldi temp,0b00000011
        out MCUCR,temp           ;set to trigger external interupt on rising edge of PD2
        in keyreg2,PIND          ;load the initial states of the keys
        ldi flag,0               ;start off in do nothing mode
        sei                      ;enable interupts

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;%MAIN
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
MAIN:
        in keyreg1,PIND
        eor keyreg2,keyreg1      ;see which keys have changed
        and keyreg2,keyreg1      ;see which of the changed keys are now high
        sbic PIND,6              ;if focus is set jump to FOCUS
        rcall START_FOCUS        ;
        sbis PIND,6
        rcall STOP_FOCUS         ;if focus button is off stop focus if in focus mode
        sbis PIND,5              ;if welder is not set make sure its off
        rcall STOP_CAPTURE
        sbrc keyreg2,5           ;if weld has just been set jump to start weld
```

```
        rcall START_CAPTURE
        mov keyreg2,keyreg1
        rjmp MAIN

;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;%EXT interupt 0
;%this is called when the Flash lamp triggers
;%this tests for what is flaged and jumps acordingly
;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
EXT_INT0:
        sbis PINB,3             ;return if ICCD is inhibiting the taking of images
        reti
        cpi flag,2
        breq TAKE_IMAGE
        cpi flag,1
        breq TAKE_FOCUS
        reti

;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;%this is called when the Flash lamp triggers
;%and focus or weld is flaged
;%if it is wait flashlamp Q switch delay then trigger
;%Q Switch
;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
TAKE_IMAGE:
        inc every_n_count
        cpi every_n_count,every_n_fl
        breq FL_MP_DELAYF-1
        reti
TAKE_FOCUS:
        sbi PORTD,0             ;take the inhibit off PIND0
FL_MP_DELAYF:
        clr loop1
DELAYF:
        inc loop1               ;sit in a loop to generate the delay
        cpi loop1,delay_uS
        brne DELAYF
        cbi PORTB,0             ;trigger camera
        clr loop1
DELAYR:
        inc loop1               ;sit in a loop to generate the delay
        cpi loop1,100
        brne DELAYR
        sbi PORTB,0             ;clear camera trigger
        clr loop1
DELAYI:
        inc loop1               ;sit in a loop to generate the delay
        cpi loop1,255
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        brne DELAYI
        cbi PORTD,0             ;put the inhibit back on PIND0
        clr every_n_count       ;clear the fl per image count
        cpi flag,1
        breq RETI               ;if in focus mode dont count images
        ldi temp,1
        add weld_n_countl,temp  ;incriment the count of images taken
        clr temp
        adc weld_n_counth,temp
        cpi weld_n_countl,low(welding_n_per_weld)
        ldi temp,high(welding_n_per_weld)
        cpc weld_n_counth,temp
        brbs 1,STOP_WELD
STOP_WELD_R:
        cpi weld_n_countl,low(total_n_per_weld)
        ldi temp,high(total_n_per_weld)
        cpc weld_n_counth,temp
        brbs 1,STOP_CAPTURE     ;test the zero flag that is set when equal
        reti

;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;%START_WELD
;%checks that we really want to weld then turns welder
;% and welding drum on and sets up flags and counters
;% to take an image
;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
START_CAPTURE:
        rcall LONGER_DELAY      ;wait a bit then test
        sbis PIND,5             ;check again that the weld button is on
        reti
        sbic PIND,6             ;check again that the focus button is off
        reti
        cpi flag,0
        brne RETI               ;check again that in mode 0
        rcall LONGER_DELAY      ;wait a bit then test again
        sbis PIND,5             ;check again that the weld button is on
        reti
        sbic PIND,6             ;check again that the focus button is off
        reti
        cpi flag,0
        brne RETI
        sbi PORTB,2             ;turn the welding drum on
        rcall LONGER_DELAY      ;delay here to let the drum start up
        rcall LONGER_DELAY
        rcall LONGER_DELAY
        rcall LONGER_DELAY
        rcall LONGER_DELAY
        rcall LONGER_DELAY
        sbi PORTB,1             ;turn the welder on
        clr weld_n_countl       ;clear the image count
        clr weld_n_counth
        ldi every_n_count,every_n_fl-1
        ldi flag,2              ;flag to take images
```

```
        reti
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;%STOP_CAPTURE
;%turns the welder and drum off and flags do nothing
;%to stop taking images
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
STOP_CAPTURE:
        cbi PORTB,1                 ;turn the welder off
        cbi PORTB,2                 ;turn the welding drum off
        cpi flag,2
        brne RETI                   ;flag change if in weld flag
        ldi flag,0                  ;stop taking images
        reti

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;%STOP_WELD
;%turns the welder and drum off
;%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
STOP_WELD:
        cbi PORTB,1                 ;turn the welder off
        cbi PORTB,2                 ;turn the welding drum off
        rjmp STOP_WELD_R

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;%START_FOCUS
;%turns the welder and durm off if they are on
;%flags to take and image every fl
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
START_FOCUS:
        cbi PORTB,1                 ;ensure the welder is turned off
        cbi PORTB,2                 ;ensure the welding drum turned off
        ldi flag,1                  ;flag that in focus and to take image every fl
        reti

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;%STOP_FOCUS
;%flags do nothing
;%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
STOP_FOCUS:
        cpi flag,1
        brne RETI                   ;only stop focus if in foucs mode
        ldi flag,0                  ;flag do nothing
RETI:   reti

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
;%LONGER_DELAY
;%at this stage this is just for testing but may be
;%used later to form the delay between turning the
;%welding drum on and turning the welder on
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
LONGER_DELAY:
        clr loop2
        inc loop2
        clr loop3
LONGER_DELAY1:
        inc loop3
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        nop
        cpi loop3,255
        brne LONGER_DELAY1
        cpi loop2,255
        brne LONGER_DELAY+1
        reti

.DB  "Owen Lucas 23/11/2004 ICCD_MP.asm"
```

Appendix E

Matlab code

E.1 Correction for laser sheet divergence

```
function [spnormim]=normsp(im,heightl,heightr)
%This is a very simple function the take into
%account for the divergence in the laser sheet
%
% Assumes divergence from left to right
%
%  normsp(im,heightl,heightr)
%
%    im       %the immage to be corrected
%    heightl  %the height of the sheet on the left hand side of image
%    heightr  %the height of the sheet on the right hand side of image
%
%

if heightr>heightl
     spfactor=[1:(heightr/heightl-1)/(size(im,2)-1):heightr/heightl];
     spnormim=double(im)*diag(spfactor);
else
disp('not valid scail')
end
```

E.2 Average ICCD image set

```
function [averaged_image] = avimage(filename,number)
% [averaged_image] = avimage(filename)
% [averaged_image] = avimage(filename,number)
% reads in a multilayer image and averages it were the option
% number is average of the first n images

if nargin==1;
% read in the first image in the  set
   averaged_image = double(imread(filename,1));

   % read in the rest of the beam profile tifs
   for tiffimage = 2:length(imfinfo(filename));
       averaged_image= double(imread(filename,tiffimage))+averaged_image;
   end

   % find the average
   averaged_image=averaged_image/length(imfinfo(filename));
elseif nargin ==2;
if number == 1;
   % read in the first image in the  set
   averaged_image = double(imread(filename,1));


elseif number >=2 ;
 if number > length(imfinfo(filename));
  number=length(imfinfo(filename));
 end
   % read in the first image in the  set
   averaged_image = double(imread(filename,1));

   % read in the rest of the beam profile tifs
   for tiffimage = 2:number;
       averaged_image= double(imread(filename,tiffimage))+averaged_image;
   end

   % find the average
   averaged_image=averaged_image/number;

elseif number ==-1
% read in the first image in the  set
   averaged_image = double(imread(filename,2));
```

```
    % read in the rest of the beam profile tifs
    for tiffimage = 3:length(imfinfo(filename));
        averaged_image= double(imread(filename,tiffimage))+averaged_image;
    end

    % find the average
    averaged_image=averaged_image/(length(imfinfo(filename))-1);


end
end
```

E.3 Average Megaplus image set

```
function [avimage] = avimage2(filename,number)
% [avimage] = avimage2(filename,number)
% reads in single layre images with indexed filenames and averages it.
% numbers is the average of the first n+1 images

imagenum=0;
avimage = double(imread([filename,num2str(imagenum,'%3.3d'),'.tif']));

for imagenum=1:number;
  avimage = avimage+double(imread([filename,num2str(imagenum,'%3.3d'),'.tif']));
end
avimage=avimage/(number+1);

return
```

E.4 “Calibrate” Laser scatter image

```
%clear all
close all

m=1.98-0.20i
wl=632.8e-9

%ext from day 20041229
%1.2mm wire 17l/min argoshield universal 360mm/min welding speed 19mm standoff
%7.6m/min wire feed

ext2=[  0.63531884      4.4141          4.4141  000 0
        0.63531884      4.393102712     4.09749 nan 15
        0.63531884      4.363503208     4.08035 210 16
        0.63531884      4.351184375     4.10437 nan 17
        0.63531884      4.361362183     4.10129 220 18
        0.63531884      4.337912565     4.06492 220 19
        0.63531884      4.334361132     4.13168 225 20
        0.63531884      4.336127319     4.15864 nan 21
        0.63531884      4.342728282     4.15281 228 22
        0.63531884      4.332480589     4.07476 228 23
        0.63531884      4.327340859     4.05434 nan 24
        0.63531884      4.326813545     3.97852 nan 25
        0.63531884      4.317684013     3.88854 nan 26
        0.63531884      4.319177012     3.76773 nan 27
        0.63531884      4.315854295     3.81185 234 28
        0.63531884      4.308929319     3.70199 nan 29
        0.63531884      4.313173249     3.67481 nan 30
        0.63531884      4.305028462     3.62706 nan 31
        0.63531884      4.27264626      3.88922 241 32
        0.63531884      4.285771948     3.91197 nan 33
        0.63531884      4.275918152     4.26176 000 0 ]


%% now "calibrate" the 7.6m/min wire feed at 26 volts
%laser scatter from day 20050118 run AEV
%1.2mm wire 17l/min argoshield universal 360mm/min welding speed 19mm standoff
%7.6m/min wire feed

%determine FVF from extinction data
tt=log(ext2(13,2)./ext2(13,3));
fume_volume_frac=(-wl*tt)./(6*pi*imag((m^2-1)/(m^2+2))*0.3)

temp=normsp(avimage2(['/home/olucas/04resultsA/20050118/aev'],150),593,895);

av_pixl=mean(temp(431,:));

figure
image(temp*fume_volume_frac/av_pixl*1e9)

       hh=get(gcf,'children');
       xticks=     [138 266 394 522 650 778 906];
       xticklabel= [-120 -80 -40 0 40 80 120];
       yticks=fliplr([860:-64.87*2:211.3]-15);
       yticklabel=fliplr([0:20*2:200]);
       set(hh(1),'xtick',xticks,'xticklabel',xticklabel,'ytick',yticks,'yticklabel',yticklabel);
       xlabel('mm'); ylabel('mm')
       set_color_map(1200)
       colorbar %('North')
print -depsc /home/olucas/20050118_aev_cal.eps

%% grab a single image and "calibrate" it
temp=double(imread(['/home/olucas/04resultsA/20050118/aev033.tif']));

figure
```

```
image(temp*fume_volume_frac/av_pixl*1e9)

      hh=get(gcf,'children');
      set(hh(1),'xtick',xticks,'xticklabel',xticklabel,'ytick',yticks,'yticklabel',yticklabel);
      xlabel('mm'); ylabel('mm')
      set_color_map(1200)
      colorbar %('North')

print -depsc /home/olucas/20050118_aev033_cal.eps
```

E.5 Radial Spread

```
close all;
clear all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%radial spread experimental GMAW from 20050118
%from mean images
GFR=[0,5,10,15,20,25,30]
Fwd=[13.3,26.6,30.8,40.8,60.8,70.8,98]
Lwd=[6.6,10.8,23.3,30,36.6,40,50]
plot(GFR,Fwd,'-+',GFR,Lwd,'-+')

      xlabel('Gas flow rate l/min')
      ylabel('Radial spread mm')
      legend('Forward','Leward','Location','NorthWest')

%print -depsc /mnt/flash/phd/graphics/20050118_Rsp.eps

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Slatters equation
% Rsp radial spread
% ls length scail
% rscf radial spread correction factor
% C2 Constant C2
% Mo momentum at origin
% Bo boyancy at origin
% H torch stand off height
% alfa entrainment coeficient
% qt total heat input
% qo gas heat input
% VFR volumetric flow rate
% LPM flow rate l/min
% U gas velocity exit
% CSA cross sectional area of nozzle exit
% MRV electrode melt rate volumetric mm^3/s
% V voltage
% I current
% WFS wire feed speed m/min
% ED electrode diameter


LPM=[0,5,10,15,20,25,30]
WFS=7.6                          %m/min
ED=1.2                           %mm
MRV=WFS*1000/60*pi*ED^2/4
V=26                             %volts
I=230                            %Amps
qt=V*I
H=0.019                          %m
CSA=pi*(0.0127^2-0.005^2)/4 %for nozzle with 1/2 inch diameter
VFR=LPM./60./1000
U=VFR/CSA
qo=qt*(-0.1787+0.0857*log(MRV))
alfa=0.1
rscf=2.36
C2=0.294
Bo=0.0281*qo/1000                %div by 1000 to get qo into kw
Mo=VFR.*U
ls=Mo.^(3/4)./Bo.^(1/2)
Rsp=real(rscf.*ls.*(1.-(C2*Bo^(2/3)*H^(4/3))./Mo).^(3/4))

figure
plot(GFR,Fwd,'-+',GFR,Lwd,'-+',LPM,Rsp*1000,'-+')

      xlabel('Gas flow rate l/min')
      ylabel('Radial spread mm')
      legend('Forward','Leward','Numerical','Location','NorthWest')

%print -depsc /mnt/flash/phd/graphics/20050118_Rsp_num.eps
```

Appendix F

Summary of laser techniques for fume

There are a wide number of laser based measurement techniques. Quite a number of these were either undertaken or considered during the work undertaken.

F.1 Laser induced fluorescence

Induced fluorescence has been used for point measurements of hydrogen in arcs similar to those found in GTAW. LIF could only be used to measure gaseous fume components. It would be difficult to use this technique given the low concentration of such gaseous fume and the relatively high background light. The type of gaseous components that would be of interest have complicated spectra and would probably require the use or tunable IR lasers due to their molecular size. Due to the presence particulate fume any measurement would need to be conducted off resonance to differentiate the LIF from scattered laser excitation.

F.2 Laser polarisation spectroscopy

Laser polarisation spectroscopy has the ability to suppress much higher background light intensities then that of LIF. It has be used to detect Fe in a GTAW arc using active shielding gas (non-practical application). Like LIF, LPS could only be used to detect gaseous fume. This to would be difficult due to the low concentration of fume of interest and would require an appropriate optical spectrum. The feasibility of this technique in anything other then GTAW very questionable given the particulate fume generated, such as from GMAW and FCAW. The particulate clouds would most likely scatter and depolarise the laser light making signal detection impossible.

F.3 Laser induced incandescence

LII could be used for measurement of particulate fume. However there does not appear to be any advantage over scattering are there is with soot. The effect of laser power and mass loss from vaporisation needs close attention. Spectral analysis is required to separate LII from other LIE. Particle composition changes with welding variables resulting in changes of LII critical optical properties. Given that there is no particle nucleation or growth in the areas where LII could be used quantification of scatter would be just as viable. Due to the low intensity and broad spectrum of LII background reduction is difficult.

F.4 Extinction

Laser extinction could be used for a line integrated measurement of the average particulate concentration. For this to be undertaken quantitatively the optical properties of fume would be required. The use of longer wavelength lasers would aid in the application of the required Rayleigh theory which simplifies the maths involved. This technique would be of most use where the fume is distributed homogeneously such as in static air some way from the source or in well mix in a duct.

F.5 Laser induced breakdown spectroscopy

Laser induced breakdown spectroscopy could possibly be used to measure the composition in the fume particles in the plume. Difficulties may exist due to the amount of background light. Considering that the fume particles are of stable composition it would be difficult to justify the use of LIBS over more traditional sampling and analysis

F.6 Laser scatter

Laser scattering as has been undertaken in this thesis has been shown as a useful tool to image plume shape. Should the optical properties of the fume be confirmed as being consistent then it would also be a useful tool for determining particulate concentration maps in the plume.

F.7 Laser Doppler anemometry

Laser Doppler anemometry could possibly be used to determine the velocity of particulates in the plume. Measuring fume particle velocity would be of interest from fume plume of ventilation standpoint. Difficulties would include the background light from the arc and the very high particulate concentration.

Appendix G

Megaplus camera repair

Rectification of Megaplus ES1 camera CCD failure

Owen Lucas and Paul Medwell

School of Mechanical Engineering, The University of Adelaide, S.A. 5005, AUSTRALIA
olucas@mecheng.adelaide.edu.au

ABSTRACT

This paper presents the process of Megaplus ES1 camera reclamation. One possible mode of failure is outlined, along with images of the resultant impairment and the subsequent degradation in camera performance. The functionality of this camera system was reinstated by operator replacement of the photosensitive electronic component. The rectification process outlined is substantially quicker and more cost effective than that offered by the original equipment manufacturer

1. INTRODUCTION

While not the most modern camera system the Megaplus ES1 [7] is commonly used imaging device in fluid mechanics research (e.g. [2, 3, 5, 1, 8, 6, 9]). The reason for its popularity is due to a number of features which make it a flexible tool for several different experimental techniques. The camera provides an image array of 1008 $\times$ 1018 pixels with 2^{10} bit per pixel resolution. One of the more significant functions of this camera is the range of triggering and exposure options available. The camera system is capable of exposure times as short as 127 µs and can record images at full resolution at a rate of 15 per second. The interlined CCD in this camera can also be used to capture two half resolution images in short succession allowing for particle image velocimetry (PIV) measurements in fast moving fields. The exposure of this camera can be triggered from an external source making it suitable for synchronisation with high power pulsed lasers used in modern flow research. The use of this camera with high powered pulsed lasers however presents a number of risks including damage to the photosensitive CCD due to excessive light flux. This paper outlines such an occurrence and how the functionality of this camera was restored by replacing the CCD.

2. CAUSATION

At the time of the damage the camera was being used to image scattered laser light from a solution of 480nm diameter latex particles suspended in water. This latex particle solution was held within a thin glass tank and was being used for calibration purposes.

The laser being used was a pulsed Nd:YAG laser producing a 532nm beam at a relatively low intensity of 20mJ per pulse. The beam from the laser was shaped into a light sheet with the use of two BK-7 glass cylindrical lenses. The light sheet was formed by using a f = 750mm cylindrical lens to reduce the width of the beam in a horizontal direction. After passing through this cylindrical lens a second f = –25mm cylindrical lens was used to increase the height of the sheet in the vertical direction. Where the glass tank was positioned the light sheet was approximately 200mm tall and close to the horizontal focal point.

The megaplus camera was fitted with a Nikon f = 50mm $f_{\#}1.8$ lens and was located some 1.8 m away from the glass tank normal to the light sheet. The camera lens was fitted with a polariser (75% transmission) and a 532nm bandpass filter (50% transmission). The damage to the camera occurred when the glass tank shifted presumably resulting in a reflection off the glass tank into the camera.

3. RESULT

An image from the camera after the damage can be seen in Figure 1. The primary laser damage appears to consist of a spot about 15 pixels wide and 20 pixels high at the location around row and column 400. This primary damage also produced secondary readout effects. The most obvious of which is the vertical line about 10 pixels wide which read as being at full intensity (1024 counts). There is also general image degradation below the 400^{th} pixel row of the CCD where the pixels were randomly shifted up and down in the vertical direction resulting in a blurry image. The portion of the CCD above the the 400^{th} row did not exhibit any such readout problems. The top right portion of the CCD was used to complete the experiment albeit at a lower resolution.

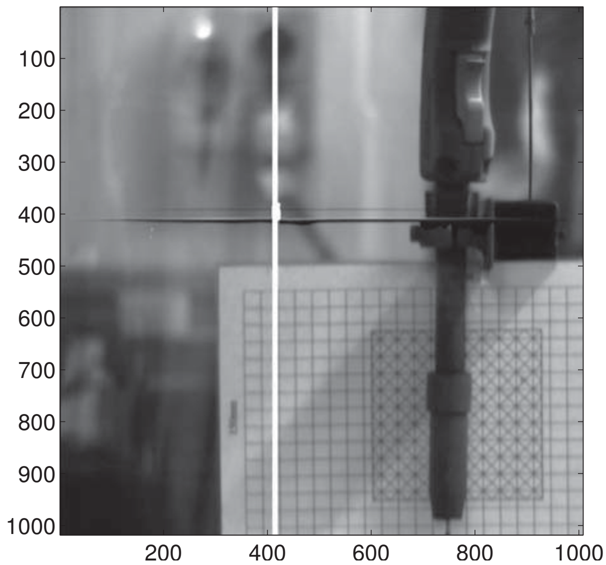

Figure 1. Megaplus image after damage

The surface of the CCD was imaged with a light microscope which exhibited the expected damage. One of images from the light microscope of the CCD surface can be seen in in Figure 2. Images from the microscope also confirmed the technical documentation of the camera which specifies the CCD chip was a Kodak KAI1010M, with pixel microlens for increased sensitivity.

4. REPAIR

Several options were considered for the rectification of this problem. The first of these was replacement of the camera which was quoted as being in excess of AU$8000 + GST. The repair option presented by the manufacturer was expected to be around AU$4300 + GST. The other solution identified was purchasing the CCD chip directly from the CCD manufacturer and

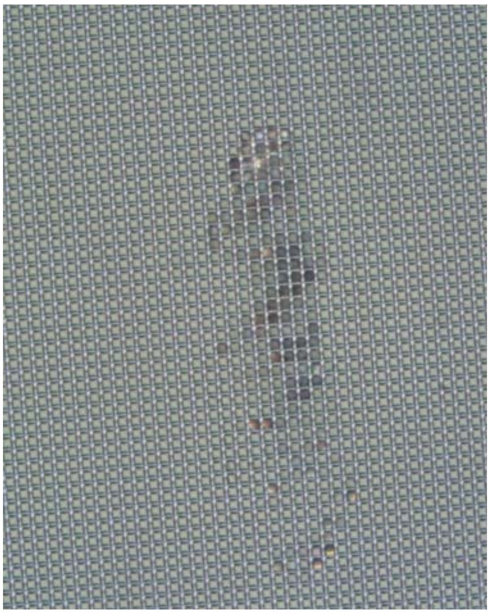

Figure 2. CCD surface damage

replacing the CCD chip in house. The KAI1010M chip used in this camera is manufactured by Kodak and comes in several options and packages [4]. With assistance from the Kodak Image Sensor support staff the chip package was identified as being of sealed AR coated glass construction. In this package the chip can be supplied in either standard or engineering grade being Kodak part numbers 2H4614 and 2H4115 respectively. The price of a standard grade chip was approximately US$1200 and a engineering grade chip was $\sim$US$250. It was not particularly clear what the differences were between the two chips were. While shipping was included in the cost of these items, import duty was not.

Ultimately it was decided to pursue the in house chip replacement rather then the camera manufacturers solution. Whilst important, this decision was not due solely to price alone, but also took into consideration the time required to ship this unit to the USA for repair. Both the standard and engineering grade chips where ordered from Kodak. At the time the order was placed these chips were out of stock, and therefore took nearly a month to be delivered. According to Kodak these chips can generally be shipped off the shelf within 5 days. Although both a standard and engineering grade chip were ordered, only two standard grade chips were delivered, indicating that there is more than likely not much difference between the two grades.

Physically replacing the chip in the Megaplus was a relatively simple process. Firstly the case of the camera was removed. This involved removing the six screws on the bottom and one screw on the back of the camera, Figure 3. The case was then slid forward, Figure 4, taking care not to knock-off any of the surface mounted components on the top circuit board.

Once the cover was removed the top printed circuit board (PCB) was unmounted to release the front PCB module onto which the CCD chip is connected.

The front aluminium face plate was then unbolted and the CCD removed from its socket. The CCD was then unscrewed from the face plate. This chip is attached to the face plate with sealant to prevent the ingress of dust into the space between the chip and the front window of the megaplus. This bead of sealant was peeled off to remove the chip.

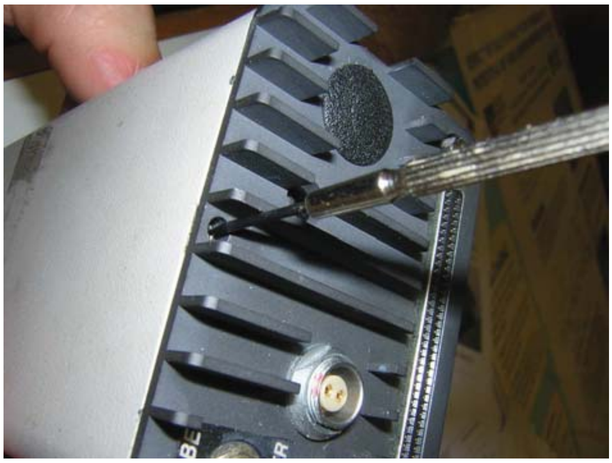

Figure 3. Screw in rear

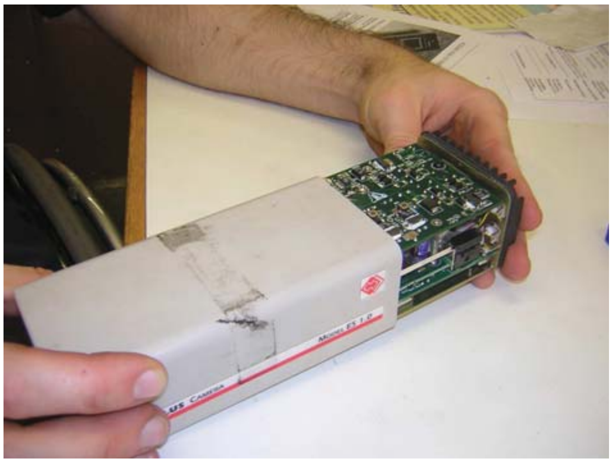

Figure 4. Removing the cover

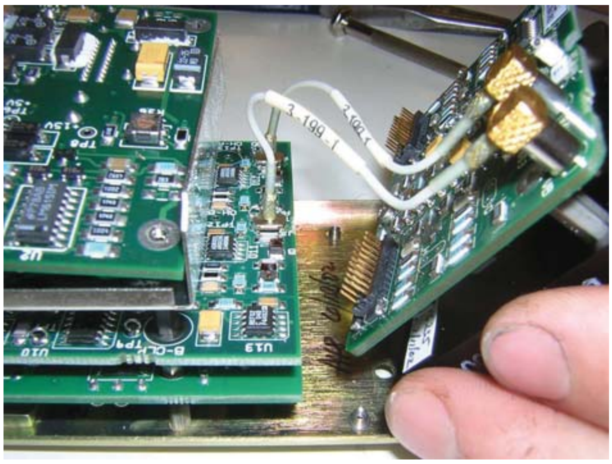

Figure 5. Releasing the front PCB module

Having removed the old chip the new chip was then bolted onto the front face plate. In this case the seal around the chip was replaced with silicone sealant. The camera was then reassembled in reverse order to which it was disassembled. The entire procedure took around 30 minutes.

Once assembled the camera was set up and was allowed to run for several hours. Following the burn-in period, tests were then

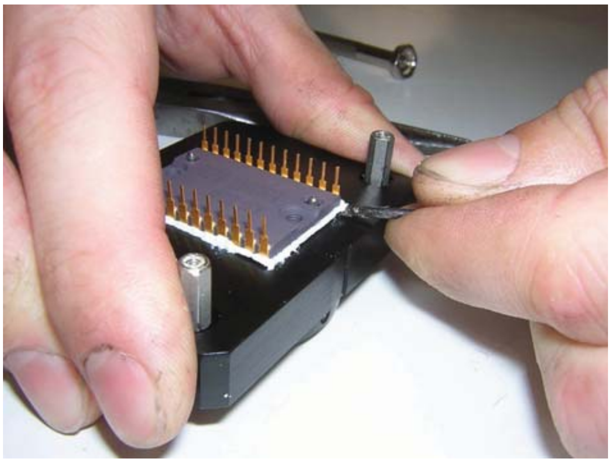

Figure 6. Peeling off the sealant bead

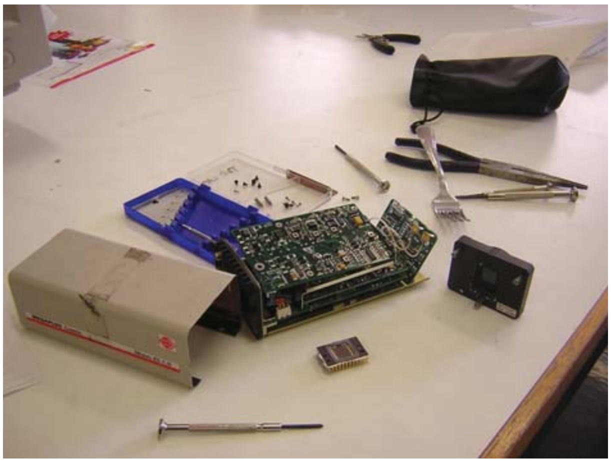

Figure 7. Megaplus disassembled

conducted on the new sensor's performance and linearity. The performance of the new CCD matched that of the original CCD sensor.

Beyond simply rectifying a damaged CCD array the ability to replace the CCD presents several options. Given that the CCD chip comes in several forms it could be possible to replace original CCD with a chip without the pixel microlens to reduce the sensitivity of the camera. It may also be possible to replace the KAI1010M monochrome CCD with its colour variant possessing RGB components. It would also be feasible to replace the presumably expensive standard CCD with a less expensive engineering grade chip while undertaking high risk measurements where intense scattered light may not be eliminated. This situation may well be encountered when imaging close to moving surfaces where interesting flow structures exist.

5. CONCLUSION

While regrettable, during research unfortunate incidents are always a possibility. In this case the CCD of the Megaplus ES1 camera was damaged by the reflection of a relatively low power laser sheet off a glass surface. Considering budget and time constraints it was decided to replace the CCD chip. Although not without risk, replacing the CCD chip of a Megaplus is a simple operation. This replacement chip fully restored the functionality of the camera. The cost of this solution is under half that quoted for repair by the manufacturer. Once in possession of the replacement CCD the rectification can be undertaken within a day.

6. ACKNOWLEDGEMENTS

The work presented here was undertaken as part of a research project of the Cooperative Research Centre for Welded Structures. The CRC for Welded Structures was established under the Australian Government's Co-operative Research Centre program. The authors wish to thank the CRC for Welded Structures and its partners for their funding and support. The authors also wish to thank the University of Adelaide's Turbulence, Energy and Combustion group for the usage of their camera and laser equipment. Special thanks to Kodak Image Sensors Division for their assistance and technical support.

REFERENCES

[1] Birzer, C. H., Kalt, P. A. M., Nathan, G. J. and Smith, N. L., *Fifteenth Australasian Fluid Mechanics Conference*, The University of Sydney, New South Wales, Australia, 2004.

[2] Clayfield, K. C., *The evolution of the near field of a precessing jet flow*, Ph.D. thesis, University of Adelaide, School of Mechanical Engineering, Adelaide, Australia, 2005.

[3] England, G., Kalt, P. A. M., Nathan, G. J. and Kelso, R. M., *Fifteenth Australasian Fluid Mechanics Conference*, The University of Sydney, New South Wales, Australia, 2004.

[4] Kodak Image Sensor Division, *Kodak KAI-1010 Device Performance Specification*, Eastman Kodak Company, Rochester, New York, USA, 2002.

[5] Mi, J., Kalt, P. and Nathan, G. J., *Fifteenth Australasian Fluid Mechanics Conference*, The University of Sydney, New South Wales, Australia, 2004.

[6] Oo, G. Y., Lua, K. B., Yeo, K. S. and Lim, T. T., *Fifteenth Australasian Fluid Mechanics Conference*, The University of Sydney, New South Wales, Australia, 2004.

[7] Redlake MASD, Inc, *MegaPlus ES 1.0 Performance Specifications*.

[8] Webster, D. R., Rahman, S. and Dasi, L. P., *Journal of Engineering Mechanics*, 1130–1137.

[9] Wong, C. Y., *The flow within and in the near external field of a fluidic precessing jet nozzle*, Ph.D. thesis, University of Adelaide, School of Mechanical Engineering, Adelaide, Australia, 2004.

Appendix H

Shieldcore 15

NOTE:
Appendix H is included in the print copy of the thesis held in the University of Adelaide Library.