The Ultraviolet (UV) laser marking performance of common Aerospace wire and cable constructions

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1. INTRODUCTION

The process of ultraviolet (UV) laser wire marking was developed in 1987 as an alternative to hot stamp marking to provide a safe, permanent means of marking wire identification codes on the insulation of thin wall aerospace wire and cable constructions. UV laser wire marking has since developed to become the global aerospace industry standard method for marking wire codes. It provides a simple, convenient, environmentally friendly, cost effective and permanent means of marking and identifying wires and jacketed cables. By contrast hot stamp wire marking is seen as an aggressive and potentially damaging process and has now been superseded by UV laser marking with all major aircraft manufacturers, their subcontractors and many maintenance organisations.

A number of different aerospace wire types have been optimised for and are specified for UV laser wire marking, however, many older “legacy” wire types are not, although in many cases they produce a perfectly adequate and in some cases an excellent mark. The widespread use of UV laser wire marking for aerospace wire and cable identification has resulted in many aerospace organisations requiring information on the relative markability of the various different aerospace wire types.

The original report described the results of a study, carried out in 2008, to assess the UV laser markability of a wide range of aerospace wire and cable (generically referred to as wire in this report), marked using mask based UV laser wire markers, which at the time were the industry standard. These typically use flash lamp pumped, frequency tripled Nd:YAG lasers. These have an output in the UV at 355nm and operate with UV pulse energies of the order of 50mJ at pulse rates of a few tens of Hertz. This report updates the markability study with results based on using the newer generations of UV laser scanning based markers. These employ diode pumped solid state UV lasers, typically frequency tripled Nd:YVO_4 lasers. These operate at a similar wavelength but at pulse rates in the tens of kilohertz and with pulse energies in the µJ range. As a consequence there are some subtle differences in the end results.

This report documents the markability of previously tested wires marked using the new scanning laser markers and revisits and updates some of the test results for mask based wire markers, as well reporting on the markability of some of the newer wire types. Wire types tested include Boeing and Airbus specification wire types and a wide range of wire types covered under SAE AS22759 (previously MIL 22759) as well as some NEMA 27500 cables and other miscellaneous wire and cable types. In each case the contrast of the marks formed on the wire has been measured and recorded. Mark contrast is a key determinant of mark legibility and it is important to understand wire markability as legible marks are critical to the ability of operators to carry out their tasks in the manufacture and maintenance of the electrical wiring interconnect systems.

The contents of this document are for information and guidance only. It is not intended that it should be used as the basis for establishing marking process specifications or standards, which are covered by international aerospace standards including: SAE AS5649 Wire and Cable Marking Process, UV Laser; ASD EN4650 Wire and Cable Marking Process, UV Laser. In addition many OEMs have their own internal wire marking process specifications, including Boeing Commercial Aircraft: BAC5152 and D6-36911, Airbus: AIPS 07-06-001, Sikorsky: SS7333, etc, which also cover UV laser wire marking.

The information provided in this report is for guidance and is not intended to form part of any system technical specifications or acceptance test criteria unless and except where noted. Customers may send samples to Spectrum Technologies for marking trials on request.

2. BACKGROUND

A wide variety of wire and cable types have been used over the years on numerous military and civil aircraft as well as spacecraft. In many instances it has not been practicable to use newer types of wire on later production models or in aircraft modification and upgrade programmes due to implementation costs and potential changes that might be required in maintenance documentation and procedures. Modification programs in which new systems are added often therefore utilise the same wire and cable types that were originally employed on the aircraft at the time of manufacture. The result has been the continued large scale use of older style wire types. Due to their age, the specifications for these wire types predate the introduction of newer processes, such as UV laser wire marking, and hence do not include a requirement for markability. Such wire is referred to as “legacy wire” within this report.

Over time there have been significant improvements in process technology, including the introduction of UV laser wire marking of the type described in SAE AIR5468 and covered by SAE AS5649 and ASD EN4650. Despite the fact that many legacy wire constructions are suitable for UV laser marking the specifications for these constructions have not been changed to add such requirements. Also, while specifications for some modern wire constructions have been documented to include requirements for laser markability others have not. Titanium dioxide pigment is the basis of the UV laser wire marking process, its inclusion as a common colouring agent in most currently used white and light coloured insulation materials therefore usually permits the use of UV laser wire marking to provide acceptable legibility and permanence.

3. WIRE MARKING & CONTRAST MEASUREMENT METHODS

In all cases wires and cables were laser marked in our in house test facilities using Spectrum Technologies’ *CAPRIS* and Nova series solid state Nd:YAG masked based laser wire markers and Nd:YVO_4 scanning based laser wire markers, operating at a wavelength of 355nm. Marking of wires and cables was carried out in accordance with the requirements specified in AS5649 and EN4650; Table 1 provides details of the wire and cables tested and the contrast results obtained.

To establish the wire marking performance the mark contrast was measured in each case using a Spectrum Technologies CMS2 contrast measuring system. Measurements of representative samples of the wires and cables noted in Table 1 were conducted in accordance with the requirements stated in AS4373 Method 1001 and EN3475 part 705 – Contrast Measurement. Note that the referenced methods are limited to measuring mark contrast for white and other light coloured insulation materials only.

4. TEST RESULTS

Table 1 – Typical Contrast values for UV laser marked aerospace wire and cable for mask based and scanning based UV Laser Wire Markers (UV LWM).

TEST SPECIFICATION & WIRE MATERIAL			**MASK BASED UV LWM**	**SCANNING BASED UV LWM**
PART NUMBER	SPECIFICATION SOURCE	INSULATION MEDIUM	CONTRAST (%)	CONTRAST (%)
AS22759/01	SAE	PTFE and PTFE-Glass		
AS22759/02	SAE	PTFE and PTFE-Glass		
AS22759/03	SAE	TFE-Glass-TFE		
AS22759/04	SAE	TFE-Glass-TFE		
AS22759/05	SAE	Extruded PTFE		
AS22759/06	SAE	Extruded PTFE		
AS22759/07	SAE	Extruded PTFE		
AS22759/08	SAE	Extruded PTFE		
AS22759/09	SAE	Extruded TFE		
AS22759/10	SAE	Extruded TFE		
AS22759/11	SAE	Extruded TFE		
AS22759/12	SAE	Extruded TFE		
AS22759/13	SAE	FEP-PVF2		
AS22759/14	SAE	FEP-PVF2		
AS22759/15	SAE	FEP-PVF2		
AS22759/16	SAE	Extruded ETFE	90	84
AS22759/17	SAE	Extruded ETFE		
AS22759/18	SAE	Extruded ETFE		
AS22759/19	SAE	Extruded ETFE		
AS22759/20	SAE	Extruded TFE		
AS22759/21	SAE	Extruded TFE		
AS22759/22	SAE	Extruded TFE		
AS22759/23	SAE	Extruded TFE		
AS22759/28	SAE	Extruded TFE		
AS22759/29	SAE	Extruded TFE		
AS22759/30	SAE	Extruded TFE		
AS22759/31	SAE	Extruded TFE		
AS22759/32	SAE	Extruded XLETFE		
AS22759/33	SAE	Extruded XLETFE		
AS22759/34	SAE	Extruded XLETFE	83	74
AS22759/35	SAE	Extruded XLETFE		
AS22759/41	SAE	Extruded XLETFE		
AS22759/42	SAE	Extruded XLETFE		
AS22759/43	SAE	Extruded XLETFE		

AS22759/44	SAE	Extruded XLETFE		
AS22759/45	SAE	Extruded XLETFE		
AS22759/46	SAE	Extruded XLETFE		
AS22759/51	SAE	Extruded XLETFE		
AS22759/52	SAE	Extruded XLETFE		
AS22759/53	SAE	Extruded XLETFE		
AS22759/54	SAE	Extruded XLETFE		
AS22759/80	SAE	PTFE Tape Wrap		
AS22759/81	SAE	PTFE Tape Wrap		
AS22759/82	SAE	PTFE Tape Wrap		
AS22759/83	SAE	PTFE Tape Wrap		
AS22759/84	SAE	PTFE Tape Wrap		
AS22759/85	SAE	PTFE Tape Wrap		
AS22759/86	SAE	PTFE Tape Wrap		
AS22759/87	SAE	PTFE Tape Wrap	64	66
AS22759/88	SAE	PTFE Tape Wrap		
AS22759/89	SAE	PTFE Tape Wrap		
AS22759/90	SAE	PTFE Tape Wrap		
AS22759/91	SAE	PTFE Tape Wrap		
AS22759/92	SAE	PTFE Tape Wrap		
AS22759/93	SAE	PTFE Tape Wrap		
AS22759/94	SAE	PTFE Tape Wrap		
AS22759/180	SAE	Seamless PTFE Tape		
AS22759/181	SAE	Seamless PTFE Tape		
AS22759/182	SAE	Seamless PTFE Tape		
AS22759/183	SAE	Seamless PTFE Tape		
AS22759/184	SAE	Seamless PTFE Tape		
AS22759/185	SAE	Seamless PTFE Tape		
AS22759/186	SAE	Seamless PTFE Tape		
AS22759/187	SAE	Seamless PTFE Tape		
AS22759/188	SAE	Seamless PTFE Tape		
AS22759/189	SAE	Seamless PTFE Tape		
AS22759/190	SAE	Seamless PTFE Tape		
AS22759/191	SAE	Seamless PTFE Tape		
AS22759/192	SAE	Seamless PTFE Tape		
AS25038	SAE	PTFE Tape Wrap		
AS81044	SAE	Extruded PVDF		
AS85485/5,/6,/9,/10	SAE	Extruded XLETFE		
OTHERS				
BMS-13-48	BOEING	Extruded XLETFE		
BMS-13-58 (grey)	BOEING	PTFE Tape Wrap		
BMS-13-60	BOEING	PTFE Tape Wrap		
CF	AIRBUS	PTFE or FEP (disp.)		

DM	AIRBUS	PTFE Tape Wrap		
DR	AIRBUS	PTFE Tape Wrap		
DR (green)	AIRBUS	PTFE Tape Wrap		
AD (grey)	AIRBUS	PTFE Tape Wrap		
CF 22 (green)	AIRBUS	PTFE/FEP Disp. coat		
DK	AIRBUS	PTFE Tape wrap		
DM 22	AIRBUS	PTFE Tape wrap		
SS7614	SIKORSKY	Extruded XLETFE		
SS7615-12L1S9	SIKORSKY	Extruded XLETFE		
SS7615-16L2S9	SIKORSKY	Extruded XLETFE		
SS7615-16L3S9	SIKORSKY	Extruded XLETFE		
SS7615-24H3S9	SIKORSKY	Extruded XLETFE		
SS7615-24H1S9	SIKORSKY	Extruded XLETFE		
SS7615-24H1S9	SIKORSKY	Extruded XLETFE		
SS7615-24H2S9	SIKORSKY	Extruded XLETFE		
SS7615-24H4S9	SIKORSKY	Extruded XLETFE		
SS7615-24H4S9	SIKORSKY	Extruded XLETFE		
M27500 SP2S23	NEMA	Extruded XLETFE		
M27500/20 L3T08	NEMA	Extruded PVDF		
M27500/20 P2G23	NEMA	PVC/ NYLON		
M27500/22 C1G23	NEMA	PVC/GLASS/NYLON		
M27500/22 SP5S23	NEMA	Extruded XLETFE		
M27500/24 C3G23	NEMA	PVC/GLASS/NYLON		

* No mark - contrast was <20% and no recorded result registered
[A] Not tested - Wire samples unavailable from manufacturers at time of testing.
[B] Estimated performance of untested extruded PTFE wires based on results with similar insulations used on M22759/5, /7 and /8.
[C] Estimated performance of untested extruded TFE wires based on results with similar insulation used on M22759/9 and /11 (mask) and for M22759/9, /10 and /11 (scanning)
[D] Estimated performance of untested extruded ETFE wires based on results with similar insulations used on M22759/16 and /18.
[E] Estimated performance of untested XL-ETFE wires based on results with similar insulations used on AS22759/34, /35, /41, /43 and /44 (mask) and AS22759/32, /34, /43 and /44 (scanning)
[F] Estimated performance of untested PTFE tape-wrap wires based on results with similar insulations used on M22759/87 and /90 (mask), and for M22759/86, /87, /90 and /92 (scanning)
[G] Estimated performance of untested TFE-GLASS-TFE wires based on results with similar insulations used on M22759/03
[H] Estimated performance of untested extruded TFE wires based on results with similar insulations used on M22759/22
[I] Estimated performance of untested extruded XLETFE wires based on results with similar insulations used on SS7615
[J] Estimated performance of untested seamless PTFE tape wires based on results with similar insulations used on SS7615

Notes

1. All wires are white in colour unless specified after the Part number

2. Where only a single results is reported this is the average result of the test on a single wire sample

3. Where a range of results is reported this is the average results of the tests on multiple different wire samples

4. In all cases the laser specifications for the scanning based system were as follows:
   i. Laser wavelength = 355±3nm
   ii. Laser pulse length = 16-20ns
   iii. Fluence (average) = 0.8-1.2Jcm^{-2}

5. Dot overlap of the laser marks was set to 15-25%. (Note that the results may not be applicable to other manufacturers' products where they use a different overlap.

6. In all cases the laser specifications for the mask based system were as follows:
   i. Laser wavelength = 355±3nm
   ii. Laser pulse length = 10-12ns
   iii. Fluence (average) = 0.8-1.2Jcm^{-2}

7. When determined in accordance with the recommendations stated in ARP 5607, the legibility of wire markings documented in this report were considered to be in an acceptable range as required by AS50881 where the indicated contrast is > 50%. Marks with contrast in the 40% range are considered marginal particularly for viewing in reduced lighting levels. Contrasts of less than 40% are considered poor.

8. In all instances, no detrimental effects were observable on the insulation characteristics of the subject test specimens under 10X magnification. Wire specimens invariably would be capable of meeting the insulation resistance and dielectric withstand requirements stated in their original specification.

9. XLETFE, ETFE and PVDF wire insulations marked with 355nm dpss Nd:YVO_4 scanning UV lasers may show a reduced contrast than that obtained with 355nm frequency tripled (flash lamp pumped) Nd:YAG lasers. Conversely PTFE tape wrapped wire insulations marked with 355nm dpss Nd:YVO_4 scanning UV lasers may show an increased contrast than that obtained with 355nm frequency tripled (flash lamp pumped) Nd:YAG lasers.

5. CONCLUSION

The intent of this report is to provide a guide to the intrinsic laser markability of the wide variety of legacy and other wire types commonly used in aerospace electrical wiring interconnect system manufacture, maintenance activities and modification programs. Due to allowable differences in insulation material combined with variations between manufacturers and between manufacturing batches it is not possible to assure that the levels of contrast stated in this report will be obtained in all cases when marking the referenced wires except for qualified non-legacy wire types. This report does, however provide a fair indication of the general markability of wire types having specifications that do not express specific requirements for UV laser marking performance.

6. REFERENCES & FURTHER READING

Available from Spectrum Technologies (email: sales@spectrumtech.com):

- Excimer laser printing on aircraft cables, S. Williams, SAE 5th Aerospace Electrical Interconnect System Conference, 11 Oct 1989, Orlando, FL
- UV Laser Wire Marking Technology Review and Update, P. Dickinson J Davies, Aerospace Electrical Interconnect System Symposium, 24 Oct 2007, Savannah, GA

SAE documents, c/o SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001

- AIR5468 Ultraviolet (UV) Lasers for Aerospace Wire Marking
- AS5649 Wire and Cable Marking Process, UV Laser
- AS4373 Test Methods for Insulated Electric Wire – Method 1001, Wire Marking Contrast
- ARP5607 Legibility of Print on Aerospace Wires and Cables
- AS50881 Wiring, Aerospace Vehicles

ASD (AECMA) documents, see http://www.asd-stan.org

- EN4650 Wire and Cable Marking Process, UV Laser
- EN 3475 Part 705 Contrast Measurement
- EN 3475 part 706 Laser Markability

7. GLOSSARY & DEFINITIONS

For the purpose of this document the following terms and definitions apply.

CABLE - Electrical cable, unless noted as a fiber optic cable. Two or more insulated conductors, solid or stranded, contained in a common covering, or two or more insulated conductors twisted or molded together without common covering, or one insulated conductor with a metallic covering shield or outer conductor.

CONTRAST - A measurement relating to the difference in luminance of the mark and its associated background according to a precise formula.

DOT OVERLAP - Dot overlap for scanning laser systems is defined in relation to the diameter, D, of the laser beam at the surface of the wire at the $1/e^2$ point, and the distance, d, between the centres of the adjacent dots. The percentage overlap = (1-(d/D)) x 100 %.

EXCIMER - A gas laser deriving its name from the term "excited dimer". The laser is energized by means of an electrical discharge in a specialized mixture of rare gases and halogens. Excimer lasers are available operating at a number of discrete wavelengths throughout the UV, the most common of which are 193, 248, 308, and 351 nm. The wavelength is dependent only on the gas mix used; 308 nm is commonly used for UV laser wire marking.

FIBER OPTIC CABLE - A cable that is designed to transmit light waves between a light transmission source and a receiver. In signal applications, the transmitter and receiver include devices that are used to convert between optical and electronic pulses. Typical cables include a glass or plastic core, a layer of cladding having a lower refractive index to refract or totally reflect light inward at the core/cladding boundary, a buffer, strength members and jacketing to protect the inner cable from environmental damage.

FLUENCE - The energy density, measured in J cm^{-2} (Joules per square cm) of a single pulse of the laser beam, which, for the purposes of this standard, is at the surface of the wire insulation or cable jacket.

INSULATION - For the purposes of this standard the outer polymer covering of an electrical wire or multi-conductor cable or fiber optic cable.

LASER - Laser is an acronym for Light Amplification by the Stimulated Emission of Radiation. Lasers are a source of intense monochromatic light in the ultraviolet, visible or infrared region of the spectrum. The "active" or lasing medium may be a solid, liquid or gas; the laser beam is generated by energizing the active medium using an external power source, which is most commonly electrical or optical.

LASER PULSE ENERGY - The optical energy, measured in Joules (J) contained in each laser pulse.

LASER PULSE LENGTH - The time interval between the laser energy crossing half the maximum energy on the rising and the falling edges of the pulse; referred to as FWHM - full width half maximum. For the type of lasers required for wire marking the pulse lengths are typically measured in nanoseconds (ns).

LASER PULSE RATE - The number of laser pulses delivered per second, measured in Hertz (Hz). Also referred to as the laser pulse frequency or repetition rate.

LEGIBILITY - Properties of a mark that enable it to be easily and correctly read.

MARK - A meaningful alphanumeric or machine readable mark applied to the surface of a wire or cable jacket.

MARKABILITY - The ability of a wire construction to be marked to provide legible identification marks of a specified contrast when marked in accordance with this standard.

NEODYMIUM - (Abbreviation Nd) Neodymium is an elemental metal that forms the active laser material in the most common type of solid state laser. The neodymium is held in an optically transparent solid "host" material, and is energized by optical input, either from a flash lamp or from the optical output from a diode laser. The host material does not play a direct role, but can slightly influence the laser wavelength. Typical host materials are specialized crystal materials, such as Yttrium Aluminum Garnet (YAG), Yttrium Lithium Fluoride (YLF) and Yttrium Vanadate (YVO_4). These lasers are commonly referred to as

Nd:YAG, Nd:YLF and Nd:YVO_4 respectively. The primary wavelength of Nd solid state lasers is in the infrared (IR) at a wavelength of approximately 1064 nm. The IR output of such lasers can be conveniently reduced to lower wavelengths suitable for wire marking by use of harmonic generation.

ULTRAVIOLET - (Abbreviation UV) Electromagnetic radiation in the wavelength range from approximately 200 to 400 nm.

UV LASER - A laser that produces a beam of radiation in the UV range.

WAVELENGTH - (λ) Wavelength is the distance between repeating units of a wave pattern (e.g., the distance between the crest of one wave and the crest of an adjacent wave). Laser wavelength is typically measured in nanometers. $\lambda = c/f$ where c is the velocity of light and f is the frequency.

WIRE - A single metallic conductor of solid, stranded or tinsel construction, designed to carry current in an electric circuit, but not having a metallic covering, sheath or shield. For the purpose of this standard “wire” refers to insulated electric wire.

WIRE CODE - The wire circuit identification number or code assigned to a specific wire within an electrical wiring system and marked on the insulation surface.

Symbols and Abbreviations

nm: nanometer, 10^{-9} m

ns: nanosecond 10^{-9} s

ETFE: ethylenetetrafluoroethylene

PTFE: polytetrafluoroethylene

PVDF: polyvinylidene difluoride/polyvinylidene fluoride