Pressure Moulded Cable Gland Technology Opportunities to Improve Future Wing Design Efficiency

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Abstract — A twenty-five-year pedigree in the design and manufacture of cabling systems for critical subsea applications has been identified by key aerospace companies as providing technical advantages that could be exploited in the air. This paper looks at the historic use of thermoplastic polyethylene moulded cable glands, both on aircraft and submarines, explores the technical advantages and processing challenges and the future potential of the technology in aerospace.

1 Introduction

One of the most severe environments for cable systems is deep in the world's oceans, whether lying on the sea bed or part of a submarine or a tidal turbine. Initially this appears to be the last place to observe technology that offers major advancement in aircraft wing design efficiency. However, technology that has been developed and proven over 50 years has been tested for aerospace applications. This has established long life, fit-and-forget sealing against aerospace contaminant fluids including aviation fuels and hydraulic fluids rather than sea water and marine contaminants.

This study describes advanced moulding technology and develops the application of routing completely sealed cables through fuel tanks. Cost and weight saving benefits arriving from selecting the most direct cable routing on an airframe are well understood. Routing through fuel tanks requires the highest levels of reliability and design assurance.

Scientific Management International (SMI) was founded 28 years ago by engineers at the forefront of subsea cabling development, initially for fibre optic telecommunications and thereafter for the UK's Nuclear Submarines for the Royal Navy. Today SMI has perfected these technologies for use by navies around the globe producing critical cable architecture that forms the central nervous system connecting platform applications.

SMI's moulding technology was first adopted into aerospace some 20 years ago where it was qualified and provides very robust and rugged sensors installed on the Bombardier 415 aerial firefighting aircraft scoop. Increasing interest in electric aircraft and particular challenges on the undercarriage have promoted research and testing to apply this technology across a number of avionic applications. Latterly, SMI's quarter century of providing through hull penetrations to submarines stimulated an appetite to explore utilising the same technology for safe and reliable application to deliver design options for through tank cable routing on airframes.

2 Through Tank Sealed Cable Harness Configuration

Electrical and/or optical harnesses that are to be completely isolated from their environments, must employ a jacket in addition to the insulation covering each of the individual conductors. This jacket combined with penetrators utilising thermoplastic moulding technology throughout, offers a very safe and highly resistant design for immersion in volatile aviation fuels.

Connectors play a role in harnesses installation and recognising they could be a potential point of failure, are better located in benign areas external to the fuel tanks. High integrity moulded glands, where there are no potentially exposed electrical contacts are key to this different approach.

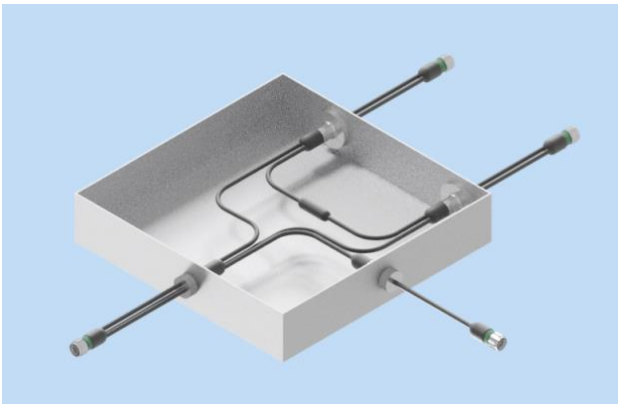

Fig. 1 PE harness showing glands, splice and connectors

To be more specific, a typical harness configuration is shown in Figure 1 with the cable and its jacket terminated at each bulkhead with a moulded cable gland. The glands are sealed to the bulkhead or tank walls with double O seals, the access hole providing clearance to allow electrical connectors to pass through during installation. This means that the electrical connectors are located external to the fuel with the glands maintaining a safety barrier, with all the electrical contacts remaining external to the fuel tank.

Glands are very robust with all their electrical components buried deep inside the gland structure where they are protected and immune from external loads and environmental conditions.

Now the outline of the configuration has been explained, the key performance parameters are the sealing integrity of the glands inside the fuel tank. Advances in thermoplastic material processing and performance of Polyethylene (PE) now have been proven to meet the requirements for aviation applications.

3 Polyethylene (Polythene, PE)

Invented in 1933, PE is a thermoplastic that is only supplied in granular form. It has a unique combination of excellent dielectric characteristics (particularly at high frequencies), high electrical resistivity, low moisture permeation, and low fluid absorption.

PE delivers orders of magnitude better insulation resistance than other materials, and this performance does not degrade at higher operating temperatures. Crucially, PE does not absorb fluids or moisture over time as other materials do, which is what makes it the only jacket material that can deliver 30+ year sealing performance. PE expands and contracts volumetrically by more than 30% when heated to melting point and has a very low thermal conduction coefficient. This makes it notoriously difficult to process, and its low surface energy makes it very difficult to bond to any other materials. A consideration highlighted by Berian [1], "When specifying or selecting a jacket material foresight should be given to the termination procedure… the bonding procedure should be established."

Specialist knowledge of the chemistry and compatible processing technology is needed. In general epoxies, polymeric and rubber materials do not bond well, or at all, to polyethylene. Nevertheless, with the right knowledge and processes for PE, exceptional bonding can be achieved to metals and rigid polymers. This is the basis for SMI 24 years of capability approval for the supply of pressure-hull glands to the UK Ministry of Defence (MoD) where SMI is the only remaining manufacturer of PE pressure hull glands. No other company has achieved capability approval to Def Stan 08-171 from MOD.

This technical solution using PE by SMI now forms a part of PlastEthUrm™ a dual sealing so robust that cable mouldings are now offered with a standard guarantee against leaks of ten years from immersion reflecting the confidence that comes from more than 10,000 installations with zero leaks.

4 Bonding and Amalgamation

In order to make informed decisions relating to fit and forget performance of cable systems, it is crucial to understand the basic science applied to adhesion and polymer processing. As already stated, sealing is provided by the cable jacket and the termination moulding. Using the best materials for both is a fundamental aspect for delivery of long-life sealing. Haworth [2] recognises this nearly half a century ago, "Cable seal failure after a design has been adequately tested and proven can be traced invariably to poor bonding."

In addition to mechanical adhesion, which relies on roughening the adherent surfaces to increase contact area and interlocking, chemical bonding provides a very high strength union, guaranteeing the best long-term resistance to penetration at molecular level. Chemical bonding occurs when the atoms of adjacent materials containing free electrons and electron holes interact to achieve a lower state of equilibrium, resulting in a chemical bond. By definition, the bond will be stronger than the weaker of the two materials and orders of magnitude greater than any mechanical joint. High pressure and temperature provided by the thermoplastic moulding process provides the energy required for this bonding to occur.

Another important property of thermoplastics is they can be re-melted many times. This is what happens to the granules when heat is added to transition from solid to molten form, before it is injected under high pressure into a tool to manufacture a termination. The cable jacket is also melted during this process and so all the material mixes and flows together so that it cools into a completely homologous material. The cable jacket shape is tailored to incorporate the profile required for the termination without the need for any join or interface. The picture in Figure 2 shows a perfect example of amalgamation with the injected PE material (natural) mixed together throughout the moulding, with white and black PE originating from the melted cable jackets. This demonstrates the scale of amalgamation achieved during the process.

Fig. 2 Example of PE cable and mould amalgamation

This amalgamation process is absolutely key to long-term sealing, as with no interface present, fluid can never enter a thermoplastic moulding.

The number of conductor combinations and circuits is numerous and designs with multiple cables entering the moulded penetrator gland can be configured. There is also an opportunity to introduce cable splicing and breakouts at intermediate points in the harness using the same complete amalgamation and continuous sealing of the cable jackets shown in Figure 3.

Fig. 3 Completely over moulded PE cable splices

Thermoplastic moulding should not be confused with thermoset technology which is over-moulded to the cable jacket and is typically characterised by a join line which has the potential over time to delaminate and leak. The rigidity of the thermoset material can also render it unsuitable for high vibration applications.

Lack of utilisation of PE moulding to date in aerospace lies not with lack of confidence in its suitability for the environment, but with the notoriously difficult manufacturing processes to achieve successful bonding and amalgamation. The expertise required was proven and established in UK submarines in the 1960s, however the cynicism [3] which met the 1968 publication of “Polyethylene Bonding to Metal for Cable Penetration of Pressure Hulls and Communications Applications” by Lenkey and Wyatt [4] pervades today, especially in the US where this mastery of this particular technology remains elusive.

5 Testing and Inspection Regimes

A test programme based on RTCA DO160 has been completed covering a range of applications of interest to the Aerospace Technology Institute. These have featured fluid compatibility (including Skydrol LD4, Aero HF585B and Aeroshell 33), thermal cycling between +85°C and -55°C, altitude, vibration, operational and crash shock, fungus, salt spray, sand and dust test programmes.

In addition to hydrostatic pressure testing including cycling, routine radiographic inspection is industry best practice for guaranteeing the integrity of mouldings. Prior to acceptance, non-destructive X-rays are used to prove the quality of the moulding and establish that bonding across the whole adhered surface has been achieved. This process makes it possible to preclude sources of potential leak paths

6 Commercial Considerations

The PE jackets will add a small weight penalty in comparison to the current bare electrical harnesses installed in aircraft wings. However, the more direct and easier routing will significantly reduce the need for cut-outs, doublers and strengthening plates, thus offering significant overall cost and weight savings.

The UK National Audit Office (NAO) criteria for assessing the value for money (VfM) of government spending include ‘the three Es’: Economy, Efficiency and Effectiveness. All too often, only economy, i.e. the initial capital cost, is recognised and evaluated. In the case of cable harnesses, efficiency would encompass reliability and through life cost for maintenance and replacement, and effectiveness would require systems to deliver the bandwidth, power and system support required by design through life of the airframe. Any erosion of efficiency and effectiveness rapidly decreases overall VfM even if economy is very strong.

Separation of initial capital investment and operational costs into different funding schemes and budgets has traditionally disguised the cost of replacing failing cables, allowing technical selections to be made based on initial economy, but carrying a lifetime of replacement burden and repair costs which fail to deliver VfM; manufacturers profiting from poor product supply.

Supplying cables have driven a thriving economy with some manufacturers able to produce cables time and again, replacing repeatedly as failures result. If routine replacement of cable systems can be eliminated through the choice of materials, there is an opportunity to greatly increase efficiency with a relatively small impact on economy.

Tired of being hostages to fortune and with budgets across the world under pressure, astute engineers are now evaluating based on through life costs, looking for fit and forget solutions which remain reliable over the life of the system.

7 Conclusions and Recommendations

The legacy of pressure moulded cable systems is well established in safety critical applications in the marine environment and sufficient work has now been undertaken to determine suitability for aerospace use.

This technology offers significant potential and advantage for direct routing cables through fuel tanks based on decades of reliable service in other safety critical applications. Future aircraft and wing designs are in development and consideration and testing of the most applicable PE moulded cabling approaches should be revisited to deliver improved performance, weight saving, safety, reliability and through-life costs benefits.

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Author Biographies

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Keith Wells, CEng, FIMechE is the founder and CEO of Scientific Management International. A fellow of the Institute of Mechanical Engineers and a subject matter expert for naval defence cable infrastructure, Keith has designed many pioneering solutions for air, land and marine platforms.

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Glen Richardson is the CTO of Scientific Management International & has an impressive track record of bringing innovative *fit and forget* products to market. With more than 25 years' in the thermoplastics industry, Glen is using his expertise and vision to steward critical technology developments in marine and aerospace sectors.

Jenny Shaw
Jenny Shaw, BSc (Hons), is a fibre optic specialist with twenty years' experience in interconnect and cable infrastructure, most recently focussed on submarine applications. Responsible for SMI's commercial activity, Jenny is providing strategic direction for migrating SMI's technologies into driving business growth across industrial sectors.