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Principles of manufacturing of DC on-board harness for a spacecraft based on 3D technology

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Abstract. This article describes in detail principles of manufacturing of DC on-board harness for spacecraft based on a new 3D design technology. This technology puts together all activities of on-board harness production, starting from electrical design and up to the final product readiness. Based on the analysis performed we proposed: necessary software, methods of wires and connector contacts connection, applicable wires and connectors available in Russian and European markets, shielding and insulating materials, test methods. The article discusses benefits of lightweight supply buses technology implementation (as compared to bundle of wires), which are: mass reduction, electrical performances stability improvement, lesser capacity between supply lines, better interference immunity, better thermal performances.

1. Introduction

Spacecraft (SC) – is a complex technological device comprising many components and systems. SC is composed of two major modules: payload module and service module.

Service module ensures nominal operation of all service equipment of a SC in a space orbit. Service module comprises:

- on-board computer;
- power supply system;
- thermal control system;
- propulsion subsystem;
- attitude determination and control subsystem.

Payload module ensures nominal operation of all SC mission equipment as per its function and application field (broadcasting, internet, navigation). This module includes only mission equipment.

The task of ensuring correct operation of a satellite in orbit is accomplished by connecting all units into an integrated electro technical system, and this requires a transmission medium between payload module equipment and service module. Such data transmission medium is on-board DC harness which provides electrical interfaces for on-board equipment. On-board DC harness connects not only SC modules, but also interlinks equipment within separate modules, and provides almost all electrical connections of a SC. That is why design and development of on-board harness is one of priority tasks of a SC design. As of today mass of on-board harness is 5-10 % of total SC mass. This is much lighter as compared to previously designed satellites, but reduction of on-board DC harness remains one of top-priority challenges of rocket-space industry [1, 2].

2. Improvements of on-board harness design and manufacturing

Today a SC on-board DC harness is designed, manufactured and tested by a new end-to-end technology, which puts together all technological activities of an on-board DC harness creation, starting from electrical design and up to final product readiness. This technology was introduced with a purpose to improve reliability, reduce mass and production lead-time of on-board harness. Prior to 2008 SC on-board harness was designed as a set of cables in the amount needed, and only connectors with solder contacts were used. While the new approach is to design on-board harness as an integrated three dimension network of electrical interfaces, featuring a complex configuration of branched and precisely located in space cables and having up to 12000 electrical connections with crimped removable contacts (Figure 1).

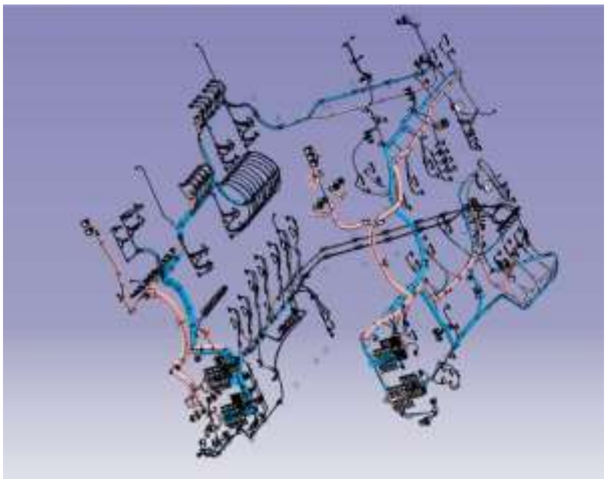

Figure 1. DC harness, 3D-model.

This technology allows reducing manpower input and shortening lead-time (from design and to product delivery) from 12 months down to 4–6 months. To put that in context: older technology allowed producing on-board harness for one, maximum two, SC per year.

Process of SC on-board DC harness creation consists of the following stages: design, manufacturing and test.

The following software can be used for design activities based on 3D-model of the satellite:

- Automated design system Catia PLM Express – this product is used to create harness topology (cables routing along the SC 3D-model).
- ECAD – electronic computer-aided design systems, such as E3.Series.
- PDM SmarTeam – electronic document management system.
- Program complex ALCAB – a set of programs and data bases, whose main function is to create packages of design documentation.

Apart from this the complex features other functions, such as:

- interaction with Catia system by means of interface files;
- storage of design solutions in data base;
- verification of description tables against specified data format;
- verification of final result against initial connections tables prior to design documentation release.

Manufacturing of on-board DC harness is done using two techniques of cables to contact connection: soldering and crimping.

Soldering:

- is used for Russian-made connectors (Figure 2);
- soldering technology is qualified, corresponds to Russian standards and is flight proven.

Figure 2. Soldering is used for Russian-made connectors.

Crimping:

- corresponds to the European Space Agency standard ECSS-Q-ST-70-26C and to the Russian regulatory document on rocket and space equipment standardization RD 134-0209-2013 (Figure 3);
- electrical connections are made with removable crimp contacts and crimp splices, which allows timely rework of cables when necessary. The process of cables crimped connection is more reliable and ecologically friendly as compared to traditional soldering.

Figure 3. Crimping is used for ESA-made connectors.

The following connectors are used for on-board DC harness:

- Russian-made solder connectors of such types as RS, MR1, 2RMDT, RP10, RRM46, RRM33, SNP339-T (Figure 4).

Figure 4. Russian-made connectors.

- European-made solder and crimp connectors as per ESCC 3401/001, ESCC 3401/002, ESCC 3401/008, ESCC 3401/029, ESCC 3401/052 specifications (Figure 5).

Figure 5. ESA-made connectors.

The following wires are used for on-board DC harness:

- Russian-made: radiation resistant wires with polyimide insulation type MS 16-15, MS 16-35, MS 26-15, MSE 26-15, MSEO 26-15 (specifications TU16.K76-160-2000, TU16.K76-011-88), wires with combined two layer insulation of fluoroplastic coating and polyimide varnish type MK26-15, MKE 26-15, MKEO 26-15, MK 26-35, MKE 26-35, MKEO 26-35 (specification PBMI.358200.002-2013TU) (Figure 6).

Figure 6. Russian-made wires.

- European-made: wires as per specification ESCC 3901 012 with radiation-modified fluoropolymer insulation (Figure 7).

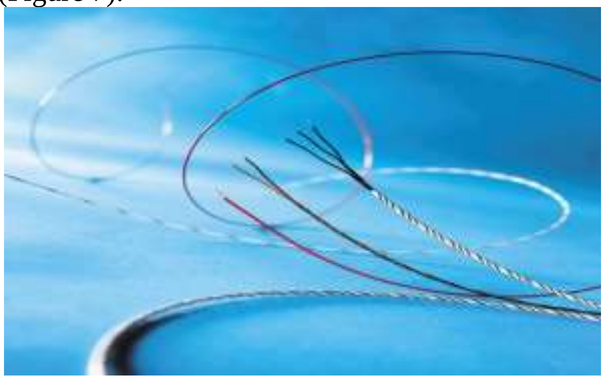

Figure 7. ESA-made wires.

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The following cables are used for high-speed data transmission lines:

- cables Raychem specification 1200 with wave impedance 77 Ohm for data exchange channel via MIL-STD-1553B.
- cables ESCC 3902/002 with wave impedance 120 Ohm for data exchange channel via OBDH.
- cables ESCC 3902/003 and ESCC 3902/004 with wave impedance 100 Ohm for high-speed data exchange channel via SpaceWire.

Development of aluminum power-supply bus

One of the solutions to improve electrical performances and to reduce mass and size of a SC is to implement technology of lightweight supply bus into a SC power-supply on-board harness creation.

Lightweight supply bus is a rigid structure made of two aluminum buses (one with positive, one with negative polarity) minimal distance between which is fixed so that capacity and inductance are maintained at a certain level (Figure 8). Structure of supply bus features dedicated brackets which ensure minimal gap between them and SC structure when the bus is mounted [3, 4].

Figure 8. Aluminum bus.

Aluminum bus can be used instead of a copper wire sets with conductive cores. Such sets contain 240 wires with total cross-section of 120 mm^2 (maximal cross-section of a Russian-made space-application wire is 0.5 mm^2), each wire is individually insulated and, in order to meet electromagnetic compatibility requirement wires with positive and negative polarities are twisted in twos, thus the length of each wire increases by 5%. Position of wires in a cable bundle is not rigidly fixed, thus the distance between wires varies along the length of a cable, causing electrical parameters instability and capacity and inductance increase. Such cable is mounted onto the areas of the SC structure, that are not occupied by SC equipment, and the routing has many bends, which also impacts electrical parameters instability and apart from that creates possibility to damage wires during assembly activities. Lightweight supply bus uses connectors with allowable current load levels for connection with SC on-board equipment. Contacts inside connectors are soldered or welded to aluminum bus at a minimal possible distance using wires with silver plated copper cores.

Lightweight aluminum supply buses allow modernization of the following segments of standard cables in electrical power supply (EPS) system of a SC:

- segment between solar array (SA) and power conditioning unit (PCU);
- battery and PCU;
- PCU and power consuming devices.

The benefits of implementation of lightweight supply buses technology based on rigid structure of aluminum buses in production of SC supply on-board harness instead of standard cables made of wire sets with copper cores, are as follows [5, 6]:

- reduction of supply on-board harness by up to 30 %;
- improved stability of electrical parameters due to structural rigidity of the bus;
- lesser capacity between supply lines;
- improved interference immunity along supply lines;

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- optimised allocation of SC mounting areas.
- increased heat removal of supply busses due to flat surface of the structure, which ensures heat removal with minimal gradient between conductive surfaces. This is particularly useful in space environment, where only conductive heat removal is possible.

The following materials are used for on-board DC harness:

- shielding materials:
- braid and synthetic tinsel tape wound in flattened metallic yarn;
- copper silver-plated braid;
- aluminum foil with conductive adhesive.
- electrical insulation materials:
- self-adhesive heat-resistant insulating tape;
- thermoplastic polyurethane cable sheath;
- polyvinylidene fluoride heat shrink tubing.

All mentioned materials are radiation resistant, qualified for usage in space environment for 15.5 years of a SC lifetime.

3. Conclusion and recommendations

In the frame of manufacturing phase, computer models are created and cable network are produces using with help of dummy representative of real structure. Such technology reduces usage of wires and materials, ensures bending radiuses, optimizes length of electrical lines and thus reduces cables mass.

On-board DC harness shall be manufactured in clean area of class 8 as per ISO 14644-1. Specified particles size: 0,5 μm (3520000 particles/m^3). Temperature of the environment shall be (22±3) °C. Relative humidity shall be (55±10) %.

Integrated three-dimensional on-board harness is manufactured by a paper-free technology, which requires working stations with large-sized monitors. During manufacturing process paper drawings are not used and workers consult screens directly, where they can project 3D configuration of separate cables or whole cabling system. Manufacturing process may further be facilitated by implementation of interactive electronic technical guides. Such guides make it easier for personnel to understand complex 3D structure of on-board harness without involvement of expensive computer-aided design systems.

On-board harness manufacturing process involves usage of certain tools for soldering and crimping of wires inside connectors, as well as certain equipment for crimping quality control: wire crimp pull test equipment, metallographic examination equipment, and voltage drop test equipment.

Test phase verifies quality of the manufactured harness by means of such tests as verification of conformance with design documentation, electrical tests, temperature cycling.

Insulation resistance between disengaged cable segments shall be less than 50 MOhm in normal environmental conditions;

Insulation between electrically disengaged cable segments shall be sufficient to prevent breakdowns.

Temperature range during tests (10 cycles) shall be from minus 50 to plus 60 °C.

Automated system of mounting verification in a matter of minutes checks all electrical lines and provides conclusion on the quality of manufactures on-board harness. Automated system of mounting verification called “GPI” is used for electrical checks of high-voltage circuits up to 1000 V (measurement limits of test voltage for alternating current is 5000 V and for direct current 6000 V).

At the final stage as soon as cable network manufacturing is completed, it shall be packed (without removing it from the dummy) and transported to the assembly area for integration onto SC. This approach helps to exclude any damage or deformations of the harness.

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