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SYSTEMS MANAGEMENT

2 WAY COOPERATION FOR DEVELOPMENT OF STATE OF THE ART POWER SYSTEM

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ABSTRACT

This paper deals with the cooperation of two world class companies, each heading its technological field, in the goal to develop and qualify a new spacecraft platform power system :

- JSC "ISS", with its huge heritage of successful spacecraft development and operation,
- Saft with its impressive experience in spacecraft batteries.

INTRODUCTION / ABSTRACT

During last ten years, Saft has pionnered development and qualification of a new lithium ion (Li-ion) electrochemistry. This technology presents specific and attractive characteristics, as follows :

- high energy density,
- excellent charge retention,
- long duration storage capability,
- low impact thermal behaviour
- Modular and building block approach

That is why JSC "ISS" selected Saft as supplier for its new Express Platform battery systems. This choice, based on long initiated relationship, gave Saft the opportunity to expand its business share of the space world. Both companies brought their skills with a clear sharing of the work load :

- Saft brought its competences in terms of electrochemistry and battery development,
- JSC "ISS" defined the battery systems interfaces, in a flexible way, with respect to battery management constraints, as well as its expertise in space electronics field, in order to develop home made batteries systems control unit.

This paper describes JSC "ISS" / Saft joint development plan for a new, reliable and efficient battery for spacecraft. It also includes a short description of the power system, with quick overview of battery assembly and electronics concept. But, mostly, it will demonstrate, in the light of a specific project, the capability of both companies to overpass cultural, language and methodology differences to achieve an excellent level of cooperation.

COMPANIES PRESENTATION

JSC "ISS"

The JSC "Information Satellite Systems – Reshetnev Company" is one of the leading enterprises of Russian space industry.

For successful implementation of new projects in all fields of its activity, the JSC “Academician M.F. Reshetnev” Information Satellite Systems” possesses:

- qualified staff;
- developed, highly organized structure;
- adequately equipped experimental & production facilities;
- stable infrastructure;
- reliable partnership with leading national and foreign organizations and enterprises - license holders, customers, investors, subcontractors, suppliers of required parts and services.

Since the middle of 60’s the JSC “ISS – Reshetnev Company ” keeps the leading role in Russia in the branch of telecommunication satellite, and is the largest-scale enterprise in Eurasian continent in designing, developing, manufacturing, testing and operating space complexes and spacecrafts in LEO, MEO, HEO and GEO orbits.
At the facilities of the JSC “ISS – Reshetnev Company”, more than 1160 spacecrafts in the orbits of 500 up to 40000 km were manufactured and successfully operated. It is two third of domestic satellites. In individual years, in different orbits there were simultaneously more than 120 of the JSC “ISS – Reshetnev Company” satellites under operation, that formed the base of the national constellation.

On that base, more than 40 types of space systems and complexes were developed, which fullfilled the National requirements in the fields of:

- defense capacity;
- information safety;
- national economy development;
- solving of social objectives;
- culture development;
- international cooperation;
- full-scale involving of the country into the world information community.

Since the beginning of 1990’s, geostationary telecommunication satellites, manufactured at the JSC “ISS – Reshetnev Company” facilities, of “Gorizont”, “Ekran” family, and later of “Loutch”, “Gals”, “Express”, “Express-A” families are being successfully operated on a commercial basis as to the benefits of foreign customers, in particular in “Intersatellite” systems, for carrying out international teleconferences. Since 1993 the satellites of “Gorizont” family were delivered “turnkey” for Pacific Rim serving.

Since 1993 the JSC “ISS” started cooperation with a major French company. In parallel with detailed work-out the technical points of project, in order to study the opportunities of each sides, profitable contribution in the joint project, matching of standard designing and development, there were implemented the serious work in retrieval of customer who could trust the realizability of the project, order a satellite and ability to invest it’s development.

The breakthrough became in 1995 when the JSC “ISS” (at that time – NPO PM) jointly with Alcatel Space (Now Thales Alenia Space) won a tender that was announced by EUTELSAT (European organization of satellite communication) for developing and manufacturing the communication satellite SESAT (Siberian-European Satellite) to satisfy the requirements in fixed communication in the central and Eastern Europe. The real integration of Russian and European technologies began in the process of developing the joint communication satellite.

Successful realization of such joint projects:

- Allowed the JSC “ISS” to gain authority on the international market and to become its equivalent participant;
- Demonstrated the competitive ability of technical solutions and technologies of the enterprise and the Russian cooperative system;
- Confirmed the qualification and readiness of the JSC “ISS” to integrate into international satellite cooperation;
- Facilitated the development of new technologies, standards, approach to designing, and on-ground tests;
- Facilitated the development and enhancement of production and test basis;
- Facilitated the increase of personnel qualification at the JSC “ISS”;
- Accelerated the JSC “ISS’” organizational and personnel renovation.

In 1999 – 2005, the JSC "ISS – Reshetnev Company" in the shortest possible time manufactured and launched 9 powerful telecommunication satellites of "Express-A" and "Express-AM" families for the urgent replacement and updating the national satellite constellation.

Since 2003 the JSC "ISS – Reshetnev Company" started the replacement and accelerated updating the domestic Global Navigation Satellite System with the help of new satellites of "Glonass-M" family, that has a strategically great importance for Russia and for the cooperation with foreign countries in that field.

In the frame of Federal Space program (up to 2015), the JSC "ISS – Reshetnev Company" has being completed the activities on implementation and operating of its global multilevel multifunctional information system of the 4th generation and has started to develop the communication satellite system of the 5th generation.

The JSC "ISS – Reshetnev Company" owns technologies of total space complex development cycle starting with a satellite design, including the satellite control in all orbits from low circular to geostationary ones.

The JSC "ISS" is the leading enterprise in realization the number of important space projects, included in the "Federal Space Program 2006 – 2015" («Loutch-M», «Gonets-M», «Express-1000», «Express-2000»).

The JSC "ISS" is the leading performer in developing the satellite constellation on basis of «Glonass-M» and «Glonass-K» spacecraft in accordance with "GLONASS" special Federal Goal Program.

SAFT

Saft is the world's leading designer, developer and manufacturer of advanced technology batteries for industrial and defence applications:

- the world's leading manufacturer of industrial nickel-cadmium (Ni-Cd) batteries for use in air and rail transportation, standby power applications and emergency lighting,
- the world's leading manufacturer of primary lithium batteries for the electronics and defence industries
- the world's second leading and the leading European supplier of specialised, advanced technology batteries for defence and space applications.

Saft has over 40 years' experience in the design, development, manufacture and supply of onboard battery systems for satellites, launchers and other space vehicles. For every project, a key emphasis on high performance and total reliability is made, as well as on project management skills.

Saft's global customers include prime contractors, telecoms operators and space agencies. These organizations value our complete mastery of all battery chemistries, whether primary and rechargeable. They also value our proven ability to develop new products and offer breakthrough technology.

BATTERY TECHNOLOGY HERITAGE AND BACKGROUND

During last years, Saft has pionnered development and qualification of a new Li-ion electrochemistry. This technology presents specific and attractive characteristics, as follows :

- high energy density,
- excellent charge retention,
- long duration storage capability,
- low impact thermal behaviour.

Saft's primary space batteries are based on lithium technology. Rechargeable technologies include Ni-Cd, Ni-H2 and Li-ion.

Fig 1 shows Power / Energy ratio of battery technologies (Ragone Diagram)

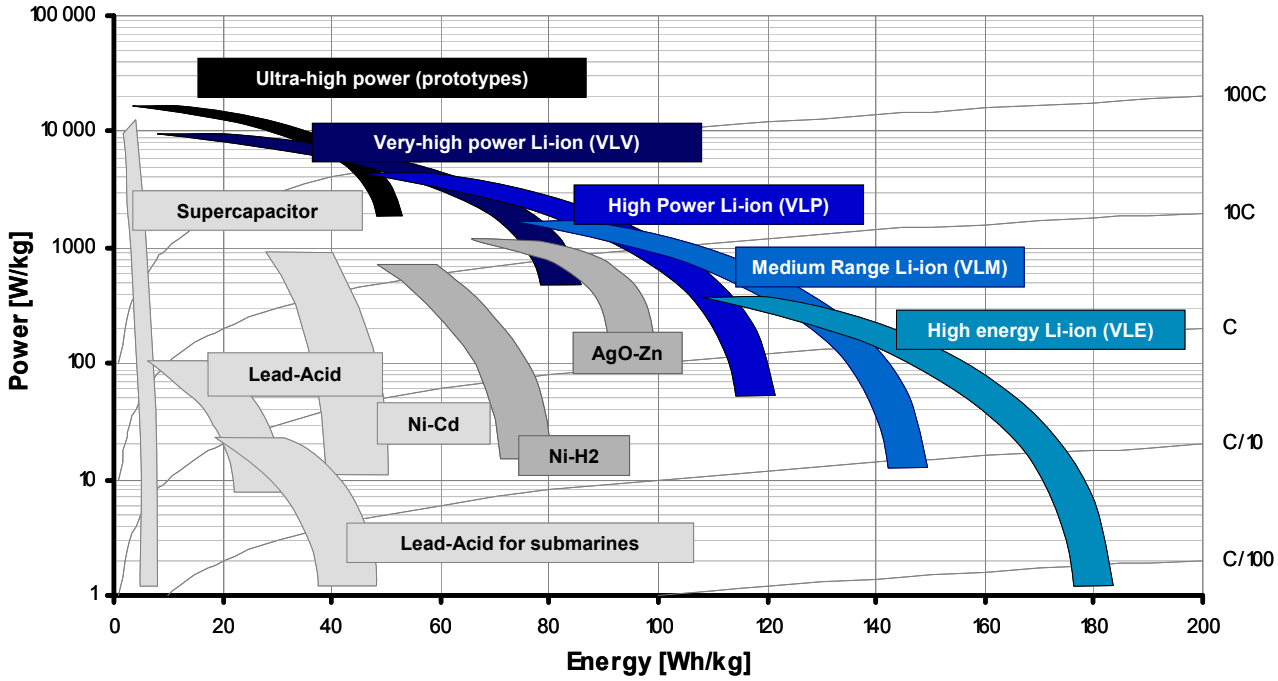


Fig. 1 : Ragone Diagram

The Li-ion technology develop by Saft is now a mature technology in terms of technical, industrial and cost aspects. One of the main advantages for satellite bus platform is the capacity to deliver high power and energy density.

Li-ion battery technology shrinks the volume that the batteries occupy on the satellite platform. It also reduces weight, enabling spacecraft operators to increase the revenue-generating payload and lower the overall launch weight, resulting in lower costs for lifting a satellite into orbit.

The modularity of Saft batteries is realized both for parallel and serial assemblies. The parallel assembly is called “cell package”. A cell package xP is constituted with x =2, 3 or 4 cells connected in parallel. The Cell Package structure and wiring are specially designed to receive high energy Li-ion VES100, VES140 or VES180 cells without any modification. The serial assembly is called battery module “xPyS”. Four modules series configurations can be used: 9S, 10S, 11S and 12S.

Two battery modules are put in series to make a Express battery. This modular design enables the usage of a generic qualified architecture that can be customized to specific customer need, especially to fit the exact need in term of ratio mass to power. The allocated volume dedicated to the battery module is also optimized.

As the world leader in the space application of Li-ion batteries, Saft has achieved a number of notable ‘firsts’:

- AGILE – first LEO to be powered by space-qualified MP small cells Li-ion batteries
- AVUM – first Li-ion batteries on the fourth stage of ESA’s Vega launch vehicle
- Calipso – first LEO to be powered with big cells Li-ion batteries
- GALILEO – first high energy Li-ion batteries for a permanent MEO constellation
- Syracuse IIIA – first Li-ion batteries on a military GEO.

Saft’s Space VES range of rechargeable Li-ion cells has been designed specifically to meet the on-board power needs of commercial, civil and military satellites. VES cells made their first space flight in 2004 and have established a significant flight heritage on GEO, MEO and LEO satellites.

To maximize performance and ensure total safety, Saft integrates individual Li-ion cells both mechanically and electrically into battery systems that are designed to the specific needs of each application. These battery systems incorporate electronics for the control and monitoring of performance, thermal and safety management

Benefits are the following :

- smaller and lighter than conventional space battery technology (30 to 50% weight reduction compared to Ni-H2)
- high specific energy; from 118 to 165 Wh/kg
- low thermal power and high energy efficiency results in smaller solar panels and battery radiators
- easier launch pad operations
- no memory effect
- state of charge is directly related to voltage, providing an effective energy gauge
- modular approach provides flexibility for battery system design

From 2003 to 2008, 33 satellites have been launched with Saft Li-ion battery.

Also,

- 100 % of the GEO communication satellite ordered in 2008 – 2009 at Saft will be with Li-ion batteries
- Globalstar, Galileosat, O3B, ….. Fly with Li-ion batteries
- Most (at least >80 %) of the LEO satellites (both microsats and minisats) will be with Li-ion batteries users

The Li-ion battery is designed to fulfil its performance specification considering a lifetime of:

- 5 years of ground storage
- 2 years of satellite integration activities
- 7 days for transfer phase
- 0.5 month for In-Orbit Test phase
- 16 years in GEO orbit.

High technology battery filed was the ideal meeting point of two experts, born to work together.

HOW TO WORK TOGETHER ?

A SIMILAR STATE OF MIND

Work with foreign partners in the frame of the same requirements and standards becomes more productive.

Approaches to rocket-space engineering as in West as in Russia are mainly the same. There are differences in technology but quality provision principles are the same. First of all, it's based on on-ground experimental work over products, careful material selection, severe technological discipline in satellite equipment manufacturing, control of non-compliances in manufacturing and the last thing – taking part in the following product operation.

In the frame of harmonization of JSC "ISS" and western companies product quality assurance in 2005 – 2007 the estimation of compliance of JSC "ISS" normative documentation requirements was made by the following quality assurance disciplines:

- reliability;
- control of materials and processes;
- EEE control;
- radiation durability provision;
- subcontractors' work control;
- quality assurance of manufacturing.

In general, work policy and its realization by quality assurance at JSC "ISS" are very much the same as they are in western companies. The most part of minor differences could be reduced.

Some actions are still running for approaching and equaling western companies standards requirements.

FIRST CONTACTS AND TRIPS TO RUSSIA FOR SAFT TEAM

In 2005, Saft D&S Poitiers started commercial analysis of the Russian & CIS Countries' Space Markets and identified growth opportunity in:

- Commercial Satellite sphere:
  - GEO civilian and commercial Telecom programs
  - LEO Weather, Scientific programs

  Both were still dominated by NiH2/NiCd batteries (Russian sources)

- Launcher Market sphere:
  - Heavy launchers and upper stages long mission, still used AgZn and NiCd batteries (Russian sources) - Need for more performances – Dual sources Power & Energy
  - Existing programs of modernization and new launchers development

Additional growth was possible with joint space initiative between ESA-CNES-Roscosmos. Hence, Saft worked through Agencies & Governmental lobbying and manufacturers

Executive contacts on establishing long term cooperation with Russian Space Actors were discussed with:

- Agencies: CNES – Roscosmos Offices in Moscow
- Government: Ambassador of France in Russia, Foreign Affairs Minister and Foreign Trade Minister
- Primes: General Directors - Technical Teams.

In the frame of this general approach, first contacts were taken with JSC "ISS".

TECHNICAL MEETINGS AND DISCUSSIONS

In technical meetings, Saft presented its Li-ion guidelines document; User's manual, typical documentation package (analyses, models, plans etc.).

Convinced by the technical advantages of Saft's Li-ion, JSC "ISS" issued technical specifications and draft SOW to Saft for a new generation EXPRESS Spacecraft.

EXPRESS SATELLITE PLATFORM FACTS SHEET

Figure 2 shows CAD view of the spacecraft EXPRESS-1000.

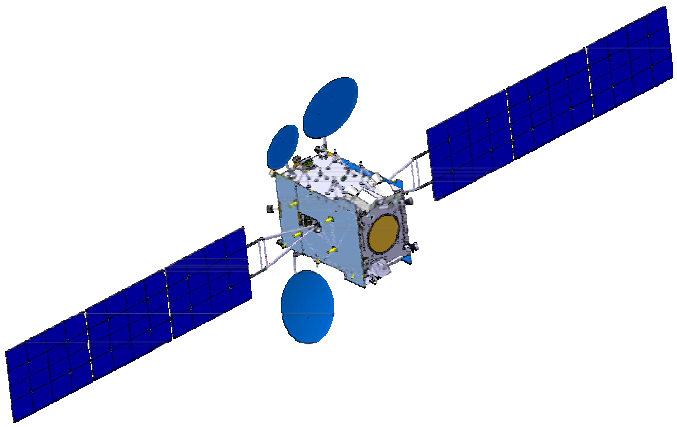


Figure 2 : EXPRESS Spacecraft

Performances are as follows :

- Service type: fixed communication, direct telecasting (HTB/DBS), direct broadcasting (HPB/ARS), governmental communication, multimedia services in C- and Ku-band
- Orbit: Geostationary
- Lifetime: 15 years
- Launching mass: 1600 kg
- Power Payload: 5600 W

JSC “ISS” has a great experience in flight usage of NiCd and NiH_2 batteries. Control of battery charge/discharge with provision of optimal modes, conduction of battery maintenance, creation of electronic schemes of battery hardware protection, development and realization of program means for protection allowed to increase Ni-H_2 battery life-time up to 12.5 years on platforms produced by JSC “ISS”.

Accumulated experience, developed hardware and program control means for Ni-H_2 batteries allows us to undertake, with help of Saft, the task of Li-ion batteries implementation in EPS of the satellites developed by JSC “ISS”.
Li-ion battery management is based on the following:

- control of temperature sensors;
- voltage control of all cells;
- battery charge control commands forming by cells voltage level;
- battery discharge switch off by cells voltage level;
- commutation of heaters sections by cells temperature level for provision of autonomous thermal mode;
- excluding of a failed cell from the circuit by means of a by-pass switcher.

In order to insert Li-ion batteries inside the space craft a structural part was design, as well as a dedicated EPS. EPS structure, the satellite platform and EPS units, which serves Li-ion battery, is given in figure 3.

Units, which are linked Li-ion battery, and their functions are listed below:

BCR:

- provision of the battery charge by constant current - the initial charge current I_0=10 A is decreased by two times after reaching the cell voltage of the specified value (for an example, I0→ I0/2→ I0/4→ I0/8→ I0/16→0) by control commands from On-board Control System (OCS);
- provision of the charge by the specified battery voltage levels by hardware means (it is realized by electronic schemes without possible correction in flight) in case of error in on-board computer operation.

BDR:

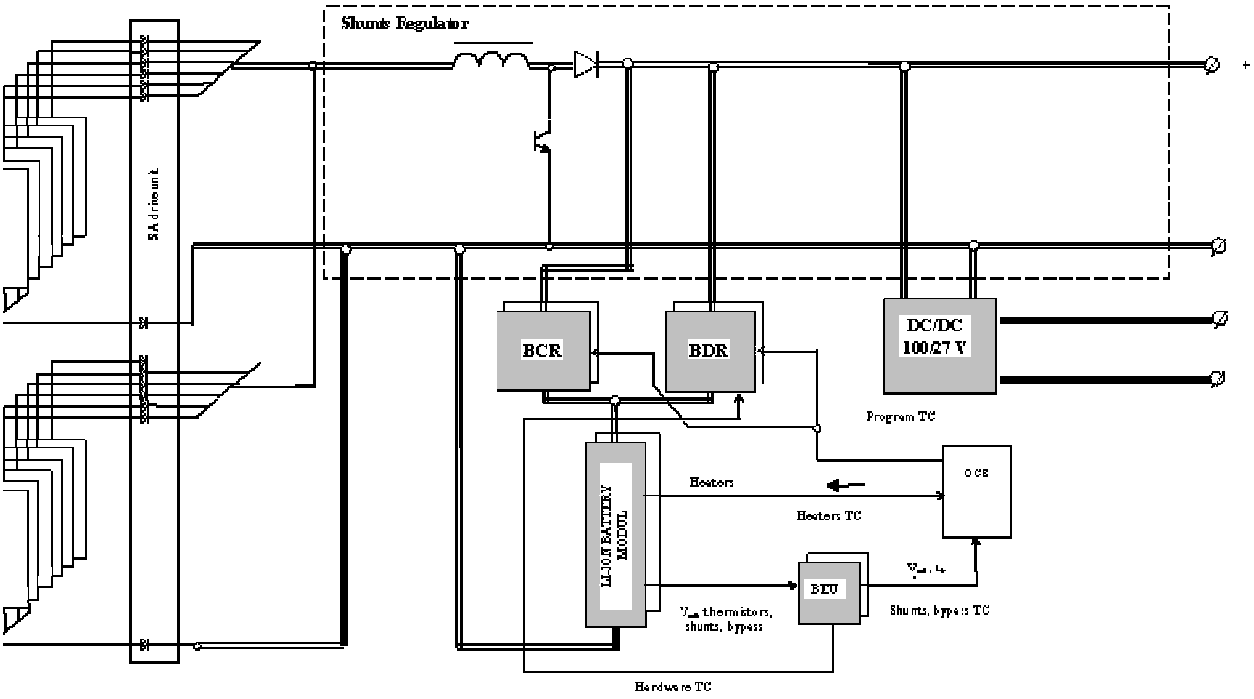
- provision of output voltage stabilization at EPS output in the battery operation;
- battery discharge mode switch off by control commands from OCS.

BEU:

- the battery analog parameters measurement (voltage, temperature of cells), measurement result conversion and transition to OCS by 1553 bus;
- balancing resistors circuits commutation by commands from OCS;
- power/voltage supply of the circuit of by-pass switchers initiation by commands from OCS;
- signal sending to BDR for switching off the battery discharge by cell voltage of 2.56 V in case of error in on-board computer operation;
- conversion and transition of signal information about commutator status of balancing resistors and the prepared circuit of a by-pass switcher to OCS by 1553 bus.

OCS:

- reception and program processing of information from BEU (U_{cell}, t_{cell});
- control commands forming in BEU for balancing resistors commutation;
- control commands forming in BEU for by-pass switchers commutation;
- commutation of the battery heaters circuits by the specified temperature values;
- control commands forming in BCR by the specified cell voltage values;
- signal forming in PCU for transition to the battery charge control by hardware logic in case of error in on-board computer operation.



BCR – Battery Charge Regulator
BDR – Battery Discharge Regulator
BEU – Battery electronic unit
OCS – On-board Control System
SW – Software
EPS – Electrical Power System

Figure 3 : EPS system

Use of units developed before, implementation of BEU into EPS, development of SW, which takes into account the features of Li-ion batteries operation, allow to provide for reliable protection and optimal modes for long-term operation of the battery as part of “Express-1000” platform.

New technologies applying, especially Li-ion batteries, in development of “Express-1000” platform allowed to create the satellite with PL power of 5.6 kW and weight of 1600 kg.

For comparison purposes, the satellite based on the previous platform “Express-AM” with PL power of 4.2 kW has a total weight of 2600 kg.

These characteristics allowed JSC “ISS” to go out to international market of space communication services, with immediate results : In 2008 – 2009, several major contracts were signed.

CONTRACT NEGOTIATION

The first difficulty arisen was that there was no common lexic both at technical and contractual level. Saft and JSC "ISS" teams initated a long work to exactly define and translate first the specifications and then, Saft proposal.

Every point of he contract was carefully discuted, on site and by communication with teams in Poitiers and Krasnoyarsk. An agreement was finally found for a first satellite program. Draft contract containing all discussed applicable documents was then issued.

CONTRACT REVIEW, FOLLOWING PROCEDURES

Once draft contract received at Saft, according to standard procedures, it was filed in and work could start. Due to the huge amount of work performed in advance, deliverables (Hardware and documentation) were easily identified. Terms and conditions were also deemed acceptable.

First Milestone was an Equipment Qualification Review (EQSR) at Moscow, half way of Poitiers and Krasnoiarsk.

EQSR IN MOSCOW : FIRST OCCASION TO HAVE A FACE TO FACE MEETING

This was the first meeting in the frame of the newly contractualised program and also the first communication problems : There were two languages in the contract text, but reference language was English, which was not a native language for both teams. JSC "ISS" provided a translator and these communication concerns were quickly overpassed by using a mix of English / Russian and even French words. After all, both teams were speaking the same dialect : Technology…

It was also the first occasion to show drawings and pictures of what was still at this moment a "virtual" battery. Figure 4 displays Battery configuration, as result of EQSR.

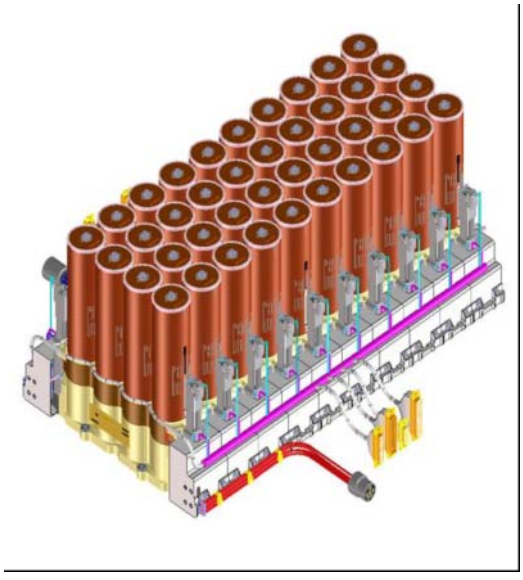


Fig 4 : Battery Overview

HRR EQM IN POITIERS

It was the first occasion for a Russian team to visit Saft workshop and to touch battery technologies samples from Saft.

There were a lot of discussion with operators, in preparation of integration, and facilitated by appointment of a Russian / French translator, that allowed JSC "ISS" team to directly converse with operators. One of the important

moments was a demonstration of handling equipment on a mock-up battery. This was closely followed by the Russian integration engineer.

Review of documentation was held, clarifications were asked and answers given. It was also a great learning moment on a delicate subject : interfaces. Finally, all design related questions were closed and use of the battery during integration and acceptance testing, as well as launch was discussed.

At the end of this meeting, go ahead for EQM assembly was given and Critical Design Review date was decided.

Additional exchanges were made, in oder to prepare CDR.

FM CDR / MRR IN POITIERS

This meeting (along with EQM TRR) is still to be held, at the time of this article writing. It will be the second occasion for an increased Russian team to visit Saft workshop and to see assembled deliverables for the current program.

SMOOTHLY RUNNING PROJECT

Delivery of EQM planned end of July (ATP to follow TRR), manufacturing of Flight units in progress.

CONCLUSION (SO FAR SO GOOD…))

The first point to emphasize is the high level of cooperation and partnership relations between both teams that had no common heritage. Anyway, a strong relation has been build, reinforced by proof of technological know how and fruitful exchanges during meetings.

Both teams understand and manage well all differences, in terms of Time / culture / signals, in order to ensure of mutual comprehension, to validate each reached stage and clearly notify next steps

Personal links between both team were created at this occasion. Decision was taken by the french team to start Russian language study.

That is the way leading to future successful common work in a very challenging field.