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Reverse Engineering of Juno Mission

Homework 6

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Group 5

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Notation

EPS Electric Power System

SYM Remove this line[1]

1 Introduction of EPS

The Electric Power System of Juno adopts a solar-based energy source to provide enough power through the various conditions encountered during the mission, which ranges from low to high energy request around Jupiter, periods of eclipse, high radiation environment and more. This chapter will study firstly the complex requirements coming from the other subsystems and from the environment encountered, then a brief rationale of the adopted architecture will be treated. In the end, a reverse sizing of the primary and secondary sources (solar panels and batteries) will be carried out to check the compliance with the mission.

2 Analysis of power requirements along the mission

3 Architecture and rationale of EPS

4 Reverse sizing of EPS

As discussed in section 2, the most demanding phases are the GRAV science perijoves, which have a duration of about 6 hours each. In particular, the most critical one occurs when Jupiter is at its aphelion. This specific point is the one chosen for the sizing of the EPS. Firstly, the dimensioning of the solar panels will be carried out without considering the presence of the secondary power source. This is done to overestimate the required surface at Jupiter in order to satisfy the whole power requirement. Later, the real solar panels are assumed and the batteries are sized in order to fill the actual gap between the primary energy source and the power required by the whole system.

4.1 Solar panels

To compute the solar flux incident on the panels at the design orbit point, the following equation has been adopted:

$$q_{sun} = \frac{q_0}{D^2} \cos\theta \quad [\mathrm{W/m^2}] \tag{1}$$

where $D = 5.4543$ AU is the distance of the S/C from the Sun, q_0 is the solar flux at the distance of 1 AU from the Sun and θ is the angle between the Sun direction and the normal from the panel surface. Since during GRAV the S/C is Earth pointing, θ coincides with the SPE angle, which can be found from ephemeris ($\approx 7.48°$).
From q_{sun} and the power required in this condition ($P_{req} = 400$ W from **REFERENCE**), the total area required to satisfy the power demand at perijove is computed as:

$$A'_{sa} = \frac{1.2\, P_{req}}{q_{sun}\, \varepsilon\, (1 - dpy)^{yrs}\, I_D} = 62.85\ \mathrm{m^2} \tag{2}$$

Equation 2 takes into account the degradation of the panels during the mission ($yrs = 5.79$ years is the time elapsed from the launch) and applies a 20% margin on the power demanded **REFERENCE** . Typical values for GaAs UTJ panels are assumed and reported in Table 1:

ε [-]	dpy [-]	I_D [-]
0.3	0.0375	0.77

Table 1: Properties assumed for solar arrays **REFERENCE**

It is worth noting that A'_{sa} does not take into account the discrete distribution of areas due to cells. Moreover, an additional string of cells must be added to satisfy the official margin by ESA **REFERENCE** . A more refined calculation is shown in Equation 3.

$$n'_{cells} = \left\lceil \frac{A'_{sa}}{A_{cell}} \right\rceil \qquad n_{series} = \left\lceil \frac{V_{nom}}{V_{cell}} \right\rceil \qquad n_{cells} = \left\lceil \frac{n'_{cells}}{n_{series}} \right\rceil \cdot (n_{series} + 1) \qquad A_{sa} = n_{cells} \cdot A_{cell} \tag{3}$$

The area of a single cell is taken from the technical sheet **REFERENCE** : $A_{cell} = 26.6\ \mathrm{cm^2}$. The voltage of the cell at Jupiter is taken from a model **REFERENCE** that takes into account the distance from the Sun and the low operative temperature: $V_{cell} = 2.77$ V.
The solar arrays have a complex distribution of cells in three different types of series, hence with different voltages (as already discussed in **REFERENCE**). To keep the calculation simpler, an average on the number of cells in the series has been computed through the nominal voltage of the system ($V_{nom} = 28$ V). The results of computation are compared to the real arrays in Table 2.

	n_{cells} [-]	A_{sa} [m^2]
Sizing results	25788	68.60
Real values REFERENCE	18698	49.74

Table 2: Results and comparison of the solar arrays

As can be seen in Table 2, the sized arrays result to be noticeably larger with respect to the real panels. This is due to the fact that this phase utilizes both the primary and the secondary sources, but the batteries are not considered in this preliminary sizing.

4.2 Batteries

For the battery sizing, the real active area of solar arrays was assumed (Table 2). From this, the power required from the battery was computed as the difference between the required power (from **REFERENCE**) and the one delivered by the solar panels:

$$P_{req} = 530.16 \text{ W} \qquad P_{sa} = q_{sun}\, \varepsilon\, (1 - dpy)^{yrs}\, I_D\, A_{sa}^{real} = 419.52 \text{ W} \qquad P_{bat} = P_{req} - P_{sa} = 110.64 \text{ W} \tag{4}$$

This power has to be delivered by the batteries in proximity of the perijove for approximately T_{pj} = 6 h. From **REFERENCE** it is possible to obtain the capacity required by the battery in order to satisfy this request:

$$C = \frac{T_{pj}\, P_{bat}}{\eta\, DoD\, V_{nom}} = 49.9132 \text{ Ah} \tag{5}$$

where the line efficiency η is assumed to be 95% and the depth of discharge DoD is assumed 50% to be conservative and to not excessively reduce the battery life cycles along the mission. The result is compliant with the chosen battery, which capacity is 55 Ah **REFERENCE** . Moreover, since the battery is a 6s1p type, hence has only one series of cells, an additional battery is added to the system for cold redundancy as requested from ESA margins **REFERENCE** . Subsequently, a series of calculations were conducted to verify the capacity of the solar panels to recharge the batteries in the orbital region where scientific operations are not conducted. The time available to recharge the batteries was coomputed as the diffenence between the nominal orbital period of 11 days and the 6 hours period passed at the perijove. The time necessary to recharge the batteries is then calculated with Equation 6

$$t_{av} = T - 6\text{h} = 258\, h \qquad t_{ch} = \frac{C\, DoD\, V_{nom}}{P_{ch}} = 17.47\, h \tag{6}$$

where $P_c h$ is the value shown in section 2. The solar panels are capable of recharging the batteries since $P_{sa} = 419.52\, W$ is higher than the power requested in BTT mode (section 2) and t_{av} is widely less than t_{av}.

Bibliography

[1] Richard Grammier. *Overview of the Juno Mission to Jupiter*. Site: `https://www.jpl.nasa.gov/missions/juno`. 2006.