NEW WHEEL DEVELOPMENTS FOR SMALL SPACECRAFT

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ABSTRACT

Due to the growing interest in small platforms with more advanced attitude control capabilities, the range of available reaction and momentum wheels has been extended. In this context, new wheels with a momentum capacity below 2 Nms are described.

Wheel performance vs. mass and size depends very much on the integration level and functionality of the associated electronics. Therefore, the development of versatile wheel drive electronics based on a digital controller is outlined in addition.

1. INTRODUCTION

Today, reaction and momentum wheels have to match the attitude control needs of a very wide spectrum of satellite classes. Three-axis attitude stabilisation by wheels has become quasi-standard for large spacecraft like geo-stationary platforms with masses of 3 tons and more. On the other side, higher pointing requirements for small satellites weighing 100 kg and less have caused an increasing demand for very compact wheels with adequate performance. With this respect, some recent developments specifically aiming at small spacecraft applications are worth highlighting:

- Miniature wheel series RSI 01-5 (0.04 - 0.12 Nms) with integrated digital controller
- New wheel generation with 0.2 - 1.6 Nms momentum capacity and built-in drive electronics
- Technology development for Digital Wheel Drive Electronics (DWDE)

2. MINIATURE WHEEL SERIES RSI 01-5

Commercial programmes like ORBCOMM [1] have been very successful already in proving their ability to provide global services using unconventional system approaches with small satellite platforms. TELDIX has contributed to those activities by introducing the new RSI 01-5 wheel product line suitable for the satellite class concerned.

The type RSI 01-5 is a ball bearing wheel with micro-controller based electronics, which are fully integrated in the wheel housing. Following its first application in the frame of the ORBCOMM data telecommunication system (a constellation of up to 36 satellites), the wheel has been upgraded for the planned PROBA mission as well as for other potential customers. The wheel features a serial data interface, and it can autonomously recover from single event upsets. Two versions are available with either 0.04 or 0.12 Nms momentum capacity.

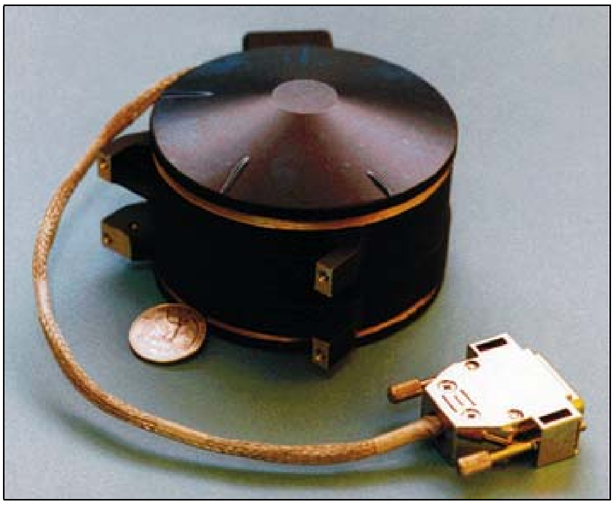

Figure 1: Miniature Wheel RSI 01-5

The main performance characteristics of type RSI 01-5/28 as used for PROBA are summarised in the following table:

Parameter	RSI 01-5/28 Performance
Angular Momentum	0.12 Nms
Oper. Speed Range	± 2800 rpm
Reaction Torque	± 5 mNm
Dimensions	Diameter 95 mm Height 102 mm
Mass	< 0.7 kg (incl. electronics)
Supply Voltage	20 V, 5 V DC
Power Consumption	< 2 W (steady-state @ nominal speed)
	< 4 W (max. torque @ nominal speed)
Signal Interfaces	RS 485
Telemetry Data	Speed, Torque Motor Current Inner Temperature
Operational Modes	Speed loop Torque loop Standby
Temperature Range	- 20 … + 60 ºC (operating) - 35 … + 70 ºC (non-oper.)
Random Vibration	14.9 g rms (qual. level)
In-Orbit Lifetime	5 years

Table 1: RSI 01-5/28 Performance Data

PROBA is a technology demonstration mission by ESA to validate new concepts for spacecraft autonomy [2]. The satellite's main dimensions are 600x600x800 mm, and it has a mass of about 100 kg. Four reaction wheels are used in combination with four magneto-torquers for wheel off-loading. They are depicted in Figure 2. One of PROBA's equipment panels, carrying the reaction wheels in the upper left corner, is shown in Figure 3.

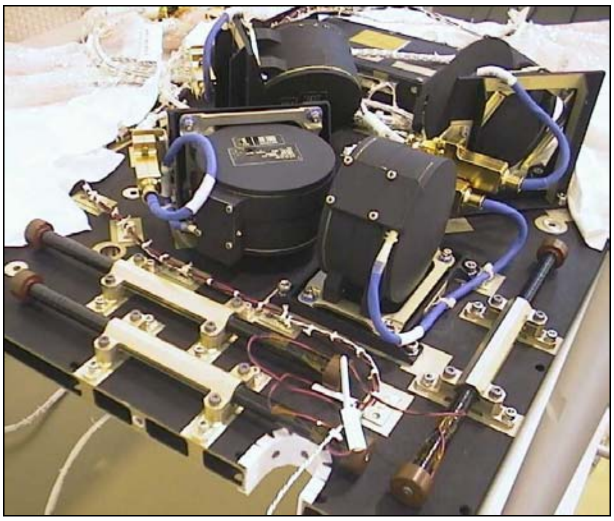

Figure 2: PROBA Wheels and Magneto-Torquers (Courtesy ESA/Verhaert)

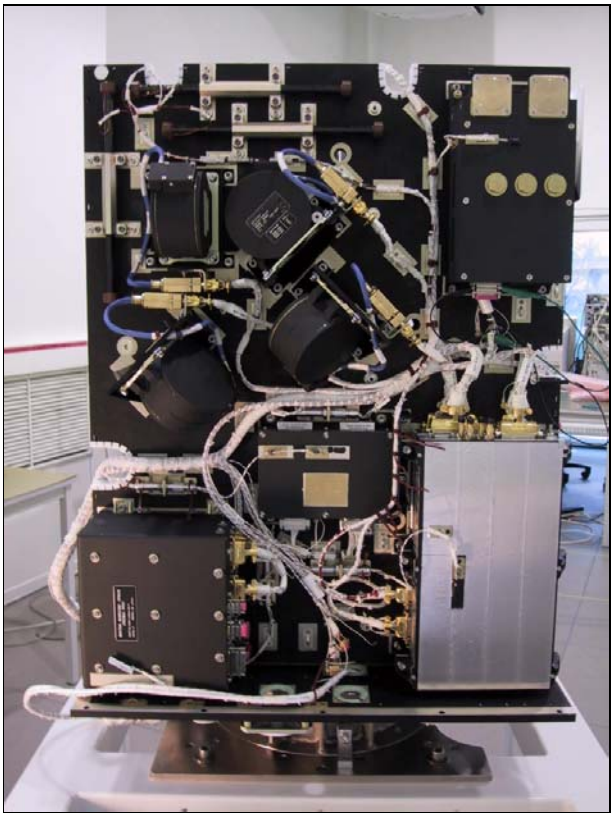

Figure 3: PROBA Equipment Panel (Courtesy ESA/Verhaert)

The qualification and acceptance testing of the PROBA wheels has been successfully completed already.

3. NEW GENERATION OF SMALL WHEELS

The wheel generation 0.2 – 1.6 Nms is combining the advantages of the space proven wheel series RSI 01-5 and RSI 4. It is targeted at Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellites with launch masses up to a few hundreds of kilograms.

The wheel contains built-in drive electronics with a simple, but reliable signal interface for analog torque command and analog/bi-level telemetry.

The requirements on the in-orbit lifetime for this category of wheels are expected to be five years typically. Due to a modular design of the stator-rotor assembly, even an operational lifetime up to 15 years can be covered by optionally implementing the flight proven bearing unit of the wheel series RSI 4. This approach allows to offer wheel products at an attractive price for different categories of missions.

By modifying the rotor mass and/or the rotor speed, both angular momentum storage and power consumption are adaptable to customers' needs.

All models of the generation 0.2 – 1.6 Nms can be either used as reaction or as momentum wheels.

Figure 4: Prototype of the New Wheel Generation 0.2 – 1.6 Nms (top cover removed)

In Figure 4, a first model of the new wheel generation is shown. The rotor assembly is surrounded by the lower part of the housing, which is also containing the drive electronics.

Table 2 below summarises the main characteristics of the specific wheel type RSI 04-25/60, which is representative for the new generation:

Parameter	RSI 04-25/60 Performance
Angular Momentum	0.4 Nms
Oper. Speed Range	± 6000 rpm
Motor Torque	± 25 mNm
Loss Torque	< 7 mNm
Dimensions	Diameter 160 mm Height 85 mm
Mass	< 1.7 kg (incl. electronics)
Supply Voltage	22 … 37 V DC
Power Consumption	< 8 W (steady-state @ nominal speed)
	< 24 W (max. torque @ nominal speed)
Signal Interfaces	Torque command: analog Motor torque (TM): analog Speed measurement: digital
Temperature Range	- 25 … + 75 ºC (qualification/protoflight)
In-Orbit Lifetime	> 5 years

Table 2: RSI 04-25/60 Performance

4. DIGITAL WHEEL DRIVE ELECTRONICS

In order to enhance the performance and the control capabilities of wheels for future applications, the development of a versatile digital controller package is currently pursued.

The Digital Wheel Drive Electronics (DWDE) can be mated with the "analog core" of various wheel sizes.

In response to a wider spectrum of customer needs, such concept will enable a versatile electronics architecture, for instance with respect to:

- different data interfaces and protocols
- different requirements on the telemetry data to be provided by the wheel
- different levels of wheel control loop sophistication
- improved failure recovery modes, e.g. concerning the protection against radiation effects
- different reliability levels for the selection of components

The main parameters of the target wheel class for the DWDE are given in Table 3.

Wheel Parameter	Target Range
Angular Momentum	0.4 … 4 Nms
Max. Reaction Torque	5 … 75 mNm
Max. Speed	± 3000 rpm
Speed Loop Band Width	0.5 … 2 rad/s

Table 3: Digital WDE - Wheel Performance Range

In comparison with conventional wheel drive electronics, more powerful data processing resources are provided directly at wheel level, which can reduce the performance demands on centralised attitude control computer systems. Again, such considerations might be particularly relevant for small spacecraft.

Using the basic electronics concept of the miniature wheel RSI 01-5 (see paragraph 2) as a reference, a number of design improvements and additional features have been implemented during the DWDE development, among others:

- Modular design in order to guarantee compatibility with existing and future wheels and the corresponding type of analog wheel drive electronics in a cost-efficient way
- Control loop enhancement by re-designing the functional blocks associated with the pulse width modulation (PWM) and with the motor current sensing
- Additional operation mode, the so-called "current mode", in which the DWDE is set to behave like conventional analog electronics at the external interfaces

- Simplification of the sensor system (3 instead of 13 Hall-effect sensors) in order to reduce manufacturing and assembly efforts

- Additional functional block “Preceding Stage” for overall power on/off switching, active current limitation, and EMC/EMI filtering

- Active shut-down and resumption facility to minimise the effects of radiation events

- Additional functional block “Auxiliary Converter” in order to adapt to a wide variety of spacecraft power busses and to avoid the need for multiple external supply voltages

The main blocks of the DWDE are schematically indicated in Figure 5. As baseline, a serial data interface (RS 485) has been implemented for command and telemetry. The present design can cope with power bus voltages from 20 to 50 V.

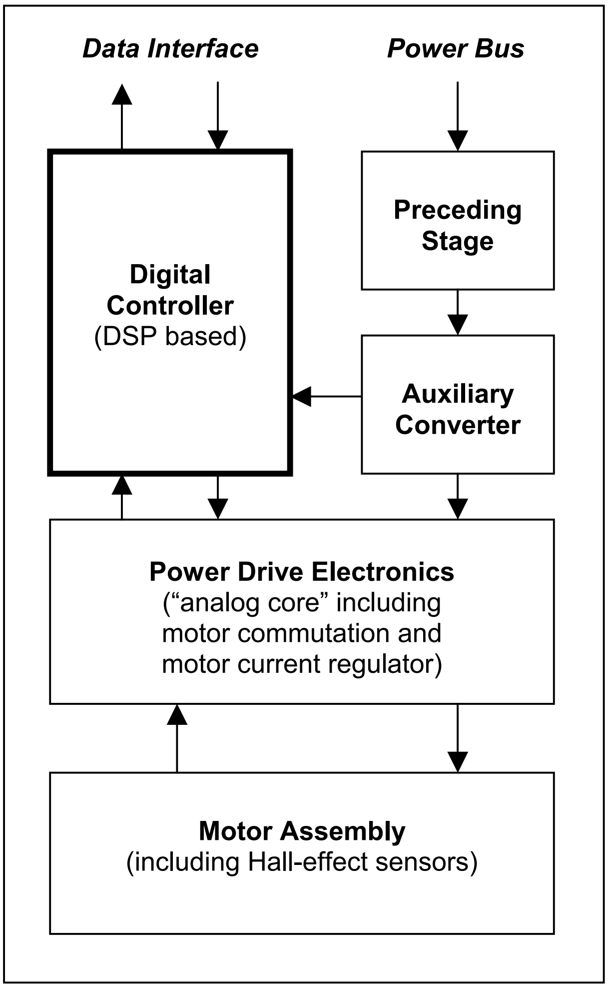

Figure 5: DWDE - Main Block Diagram

The DWDE can be operated in the following modes: Standby, Speed Loop, Torque Loop, and Torque Command (i.e. “current mode”, see previous page).

The hardware and software design of the new DWDE has been completed, and an engineering model has been built. It has successfully passed a campaign of extensive functional testing. For this purpose, the DWDE has been connected to a reaction wheel of type RSI 8-120 featuring an “analog core” as mentioned before.

As part of the present DWDE development, initial environmental tests have been performed in order to verify the general suitability of selected components and layouts for further qualification and physical integration in a particular wheel design.

5. CONCLUSIONS

The availability of small reaction and momentum wheels, based on state-of-the-art technologies like digital control electronics, is an enabling factor for space system miniaturisation, which can be observed as current trend for a considerable part of new missions.

The flight success of recent small satellite projects and the completion of ground tests for near-future missions like PROBA is confirming that the wheels used are capable to meet the performance expectations.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] ORBCOMM - Global Data & Messaging.
Homepage: http://www.orbcomm.com/

[2] Teston, F., Creasey, R., Bermyn, J., Mellab, K.:
PROBA - ESA’s Autonomy and Technology Demonstration Mission.
48th Int. Astronautical Congress, 1997
ref. IAA-97-11.3.05