On Electric Drive of the Reaction Wheels for the Small Spacecraft Attitude Control Systems

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Abstract: This paper considers the guidelines of development of the reaction wheels for the small spacecraft attitude control systems. The performance attributes are cited.

Keywords: attitude control system, spacecraft

1. INTRODUCTION

The spacecraft attitude control system can be built with use of control reaction wheels (CRW) as the executive devices. If satellite has no need to accomplish rapid maneuvers during its maintenance such decision is preferred. The advantageous difference of control reaction wheels (CRWs) from other types of electromechanical executive elements – control moment gyros (CMGs) - is construction simplicity, less cost and less cycle of development and production. The CRW consists of electromechanical module – reaction wheel (RW), and wheel controller – electrical drive, which provides the CRW functioning.

2. CONTROL REACTION WHEELS FOR SMALL SPACECRAFT ORIENTATION SYSTEMS

From the beginning of 90th of the 20th century Federal State Unitary Enterprise "Command Devices Research Institute" generates the CRW powered complexes for small spacecraft orientation systems. First designed device was the CRW complex «KMH Kolokol» for attitude control system of «Yamal» communication satellite.

Complex consists of four DM-001 RW and electric device, which provides the control signal reception, engine management and telemeter information transmission to airborne digital computer system. In 1999 the system passed flight tests, and is used nowadays in «Yamal-100», «Yamal-200» spacecraft (Aleksandrov and Sorokin, 1999; Arefev et al., 2002). The modification of «KMH Kolokol» is «KUDM Koler-E» complex (Fig. 1) with the modern electronic interface and characteristics, satisfying the modern in operation wheel standards. The complex passed test setup is in production manufacturing and wide use in different appointment spacecraft (the Earth remote sensing, telecommunication, meteorological, scientific etc.).

The «KMH Kolokol» CRW complex design became the first development of control reaction wheels, created in Command Devices Research Institute (Arefev et al., 2002).

Fig 1. The «KUDM Koler-E» CRW complex

Further development of the CRW is based on resource gain (up to 18 years), increasing and reduction of maximal control moment, decreasing of control moment error (up to 5 %), weight minimization. These requirements are connected with the extension of application of the CRW in spacecraft control system, especially of small and mini spacecraft – the program rotation of spacecraft assurance, spacecraft rotary speed damping after detachment and others.

The main direction of upgrading is to refine the characteristics of CRW electrical drive, which consists of electric motor, motor controller and interface. The comparative analysis of «KMH Kolokol» and «KUDM Koler-E» complexes characteristics with the other firms same type models, permits to conclude, that electromechanical module of DM-001 (DM-001-01) RW complexes (Fig. 2) satisfies the weight, overall dimensions, reliability and resource requirements in the category of "small" wheels.

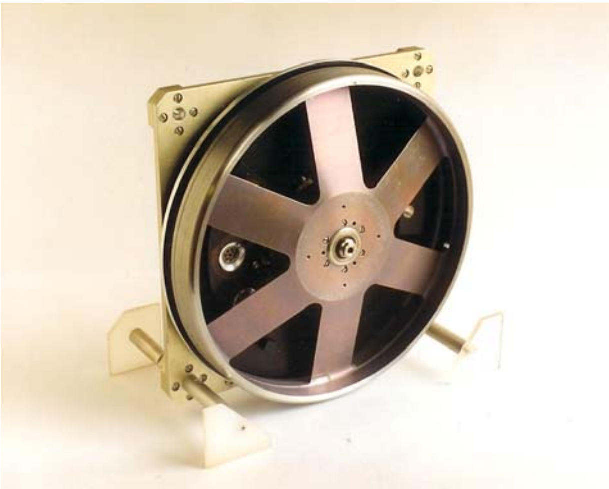

Fig 2. The RW electromechanical module DM-001

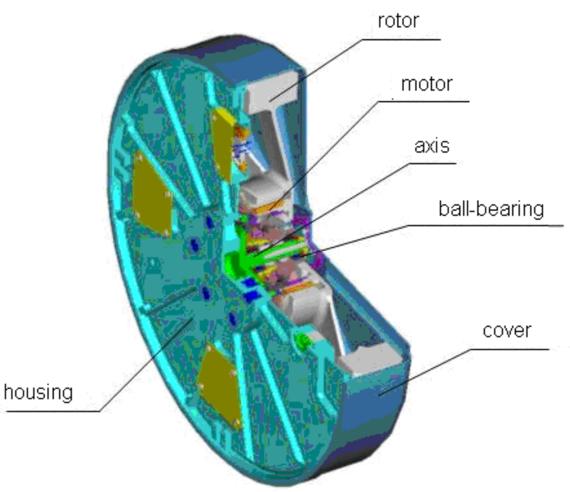

Fig 3. The RW electromechanical module DM-001

The electromechanical characteristics of the RW module DM-001 are follows:

● Device configuration 4 RW + ED
● Max. angular momentum, Nms ± (18-21)
● Max. control torque M_c, Nm ± 0.2
● Min. control torque M_c, Nm ± 0.001
● Max. rotary speed, rpm ± 6000
● Interface : EMC, duplicating relay commands of on-off switching;
● Analogous telemetry information configuration:
  • RW current,
  • RW speed.
  • RW temperature,
  • ED temperature;
● Weight, kg
  • RW 4.2
  • ED 6
  • the CRW complex 23
● CRW power consumption, W, at most
  • $M_c = 0$, $\omega = 0$ 4
  • $M_c = 0.1$, $\omega = 420$ rad/s 83
  • $M_c = 0.1$, $\omega = 630$ rad/s 97
● Overall dimensions, mm
  • RW ø315×72.5
  • ED 315×220×155
● Resource, years, no less than 18

The possible directions of DM-001 electrical drive upgrading are:

- 10-15 % of maximum rotary speed gain under angular momentum saving;
- application of rotor position sensor on base of Hall chips, mounted in the stator body, which helps to use motor rotor also as the sensor rotor.

The increase of rotary speed under set control torques saving will increase consumption. However, in the advanced electric device this increase can be compensated owing to the voltage drop decrease in motor control unit, for example due to using power circuit high-performance electronic keys and decrease of elements number. At the same time the RW device weight decrease will be 4.4 kg.

The electronic part of CRW drive is placed in electronic device (ED), consisting of eight motor controllers, exchange unit (EU), which switches exchange multiplex channel (EMC) , interface block with motors control units.

Except exchange unit (EU), the device is manufactured on Russian element base.

Areas of electronic devices upgrading are the following:

- The weight decrease of the electric device due to the decrease of quantity, nomenclature, weight and overall dimensions of electronics and, thereafter, design change of boards and device.
- Drive digital control systems use provides the control torque error decrease. This will allow the customer to refuse a program account of rotation drag torque current value in control algorithms, to refine dynamic behavior of control system. The CRW drive uses the algorithm, which provides stabilization of the difference between rated and measured rotary speed

  $$(\Delta\omega(n) - \Delta\omega\ (n-1)) \rightarrow 0,$$

  where $\Delta\omega\ (n) = \omega_p\ (n) - \omega\ (n)$ is the difference between rated and measured rotary speed during measuring time n. For drive dynamics improvement in transient condition, the control circuit gain factor changes according to current error and the tendency of its change (Sorokin et al., 1998; Yakimovsky, 2008).
- The telemetry information spread-out and duplication of some EMC commands with relay commands, particularly, CRW complex on-off switching.

These specified measures are directed to increase the product survivability in conditions of noise impact, voltage instability, electrostatic discharge impact and radiation factors of a space environment.

Performed architecture design and estimations made it possible to define the main directions of upgrading of the CRW for small spacecraft attitude control systems, providing up-to-date technical charactetistics .

3. CONCLUSION

All listed parameters of upgrade CRW complex can be refined, taking into account the requirements of prime development contractor of CRW complexes and the spacecraft control systems, the propositions on functional capabilities enhancement, diagnostics level and integration into the spacecraft structure.

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