CRYOGENIC MOTORS FOR HERSCHEL/PACS AND JAMES WEBB/MIRI AND NIRSPEC

I. Arend(1), M. Schoele(1), U. Ruppert(1), Z. Szücs(1)

(1) FUB (Free University of Berlin), Department of Physics, Low Temperature Laboratory, Arnimallee 14, 14195 Berlin, Germany, Email: ttlgroup@physik.fu-berlin.de

ABSTRACT

The space telescopes Herschel and James Webb, the successor of the Hubble Telescope, are designed to operate primarily in the infrared range of the electromagnetic spectrum. Therefore the instrumentation has to be cooled to cryogenic temperatures. The instrument PACS (Photodetector Array Camera & Spectrometer) is located on Herschel, which was launched in May 2009. It is operating at superfluid helium temperatures below 2 Kelvin. The instruments MIRI (Mid-Infrared Instrument) and NIRSpec (Near Infrared Spectrograph) on James Webb, with launch planned for 2014 will operate below 15 Kelvin (MIRI) and at 38 Kelvin (NIRSpec).

To actuate the different filter and grating wheels integrated in these experiments two types of cryogenic motors are used. These electronically commutated torque motors were especially developed for the use in low temperature and vacuum environment and yield large torques, large range of speeds, and are further characterized by low outgassing, high efficiency, small thermal losses and high positioning accuracy. They were designed, produced and tested according to ESA Space Standards at the Low Temperature Laboratory (TTL) at the Free University of Berlin.

1. INTRODUCTION

The use in space telescopes in vacuum and cryogenic environments makes special demands on electric motors, such as low outgassing rate, low thermal dissipation losses and a design that pays attention to shrinking during thermal cycles. Further requirements are high positioning accuracy, quick response times and variable rotational drive programs. In the beginning of the motor development at TTL (Low Temperature Laboratory) commercially available motors were tested in respect of their adaptability to the conditions in the GIRL (German Infrared Laboratory) project but the attempt did not really succeed and therefore a completely new motor (cryotorquer) had to be designed [1]. This development resulted in a motor that fulfilled all the mentioned requirements. Its main design features were the pancake shape, the nonferrous stator, the comparably wide gap between rotor and stator, electronic commutation and no preferential positions.

After the cancellation of GIRL this type of motor was developed further and successfully employed in several space missions as IBSS (Infrared Background Signature Survey) [2], CRISTA-SPAS (Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere on the Shuttle Pallet Satellite) [3], CRISTA-SPAS reflight and Herschel/PACS. The integration of the motors for James Webb/MIRI and NIRSpec is under way.

2. GENERAL DESIGN OF THE CRYOMOTOR

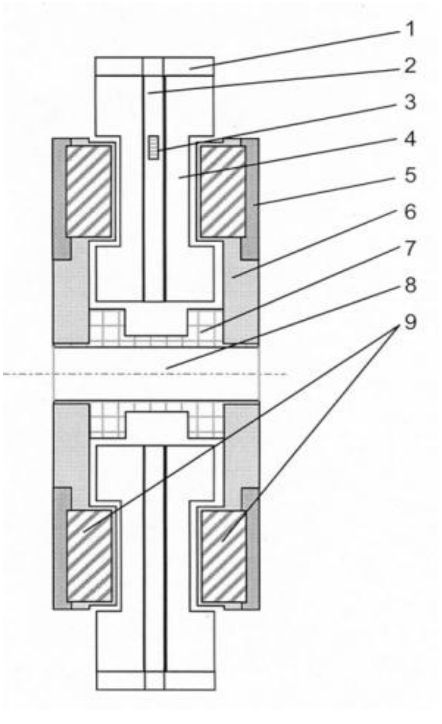

Figure 1. Schematic cross section of the cryomotor. 1)Flange of stator, 2)Encoder ring, 3)Hall sensor, 4)Stator, 5)Yoke, 6)Rotor shell, 7)Hub, 8)Inner bore, 9)Permanent magnets

'14th European Space Mechanisms & Tribology Symposium – ESMATS 2011'
Constance, Germany, 28–30 September 2011

Fig. 1 shows the cross section of the cryomotor schematically. It consists of a u-shaped rotor (5,6,7) carrying a circular arrangement of alternating permanent magnets (9) and a stator (4) composed of corresponding 2-phase nonferrous packages of driving coils and a mechanical interface (1). Embedded in an encoder ring (2) inside the stator are Hall sensors located (3) which can be used to give signals to an electronic control unit to supply current to the coils such that a mechanical commutator is avoided. The gap between rotor and stator is about 0.5 mm so that a considerable tolerance in view of thermal effects such as shrinking or displacement in the bearing is given.

3. ACTUAL DESIGN OF THE CRYOMOTORS FOR PACS, MIRI AND NIRSPEC

For the driving of different filter and grating wheels integrated in the instruments PACS (Photodetector Array Camera & Spectrometer) on the space telescope Herschel, as well as the instruments MIRI (Mid-Infrared Instrument) and NIRSpec (Near Infrared Spectrograph) on the James Webb telescope, two different types of motors are used. They consist of two separate (redundant) stator coils with the encoder ring in between. The rotor is also composed of two halves. All these components can be assembled and disassembled easily and for one motor type they are all interchangeable e.g. for replacement or cleaning.

3.1 Type C84

Fig. 2 shows a motor of the type C84. It has an outer diameter of 84 mm and an axial length of 22 mm. Detailed specifications are given in Tab. 1.

Figure 2. Cryomotor Type C84

3.2 Type C116

Fig. 3 shows a motor of the type C116 integrated in the PACS grating device. The motor has an outer diameter of 116 mm and an axial length of 30 mm. For detailed information see Tab. 1.

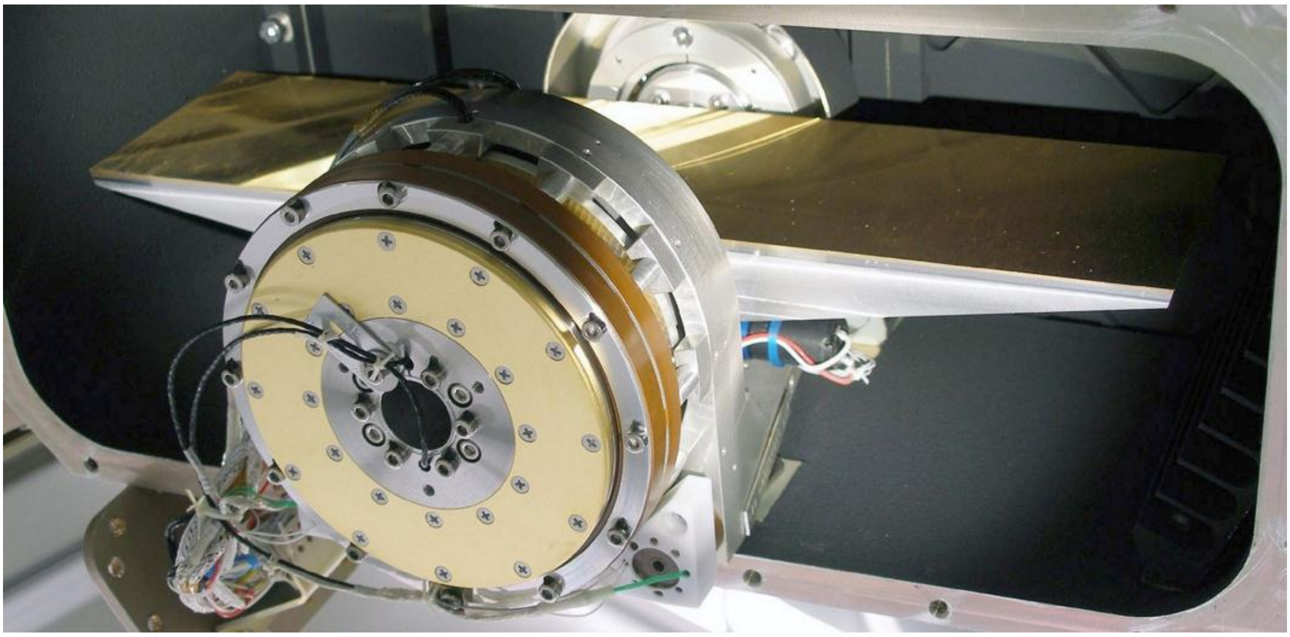

Figure 3. PACS grating with cryomotor Type C116

Table 1. Specifications of the cryomotors C84 and C116

Cryotorquer Specifications				
Parameter		**C 84**	**C 116**	Comments
Geometrical	Total outer diameter	84 mm	116 mm	
	Total axial length	22 mm	30 mm	
	Rotor outer diameter	62 mm	99 mm	
	Rotor inner diameter	10.2 mm	19 mm	
Mechanical	Stator mass	110 g	240 g	incl. Encoder
	Rotor mass	285 g	1000 g	
	Total mass	395 g	1250 g	
	Rotor inertia	0.12 gm²	1.3 gm²	calc.
	Angle of rotation	unlimited		
	Speed without load	400 rpm	280 rpm	at 25 V (Peak)
	Torque constant	≥ 0.40 (0.80) Nm/A	≥ 0.7 (1.4) Nm/A	redundant (not red.)
Thermal	Heat capacity	0.1 J/ K (total)	Stator: 0.09 J/K Rotor: 0.10 J/K	at 4.2K (calc.)
	Max. temperature	90 ºC		
Magnetic	No. of poles	12		
	No. of magnets	24		
	Magnet material	Samarium-Cobalt		
Electrical	Phases	2		two redundant packages (each two coil sets)
	No. of coils	12		per coil set
	Resistance at 293 K	370 (± 20) Ω	75 (± 10) Ω	per coil set
	Resistance at 4.2 K	3.5 (± 0.2) Ω	0.6 (± 0.1) Ω	per coil set
	No. of coil windings	12 x 230	12 x 120	per coil set
	Wire	Cu ∅ 0.1 mm	Cu ∅ 0.2 mm	lacquered
	Inductance	19 (± 3) mH	8.2 (± 0.5) mH	per coil set
	Back EMF	42 (± 5) mV_{AC}/rpm	70 (± 5) mV_{AC}/rpm	per coil set, at TT
	Motor constant (typical)	0.020 Nm / √ W	0.08 Nm / √ W	at RT / redundant
		0.030 Nm / √ W	0.11 Nm / √ W	at RT / not redundant
		0.21 Nm / √ W	0.9 Nm / √ W	at 4.2K / redundant
		0.30 Nm / √ W	1.2 Nm / √ W	at 4.2K /not redundant
	Heat dissipation	≤ 40 mW	≤ 7 mW	at $\omega = 0\ s^{-1}$, I = 100 mA, T ≤ 20 K
Insulation	Maximum voltage strength Phase 1 vs. Phase 2	≥ 150 V		at 293 K/ vacuum at 4.2 K/ ca. 5 mbar
	Leak current Phase1 vs. phase 2	≤ 0.5 µA		At 150 V and: - at 293 K/ vacuum - at 4.2 K/ ca. 5 mbar
Operating	Temperature range	4.2 – 300 K		
	Current	max 250 mA	max 400 mA	per phase
	Voltage	± 40 V		per coil set
	Environmental conditions	Inert gases and liquids, vacuum		

4. PERFORMANCE

The efficiency of a motor is generally given by the ratio of output to input power which leads for this type of motors to the simplified equation [4]

$$\eta = \frac{1}{1 + b \cdot (D/\omega) + a \cdot (\omega / D)} \tag{1}$$

with η efficiency
D torque
ω angular velocity

The factor b depends on the motor constant M_k

$$b = 1 / (M_k)^2 \tag{2}$$

and a is given by the eddy current characteristic

$$a = P_{ind} / \omega^2 \tag{3}$$

with P_{ind} induced power

Fig. 4 and 5 show the theoretical efficiency versus angular velocity at different torques at 4.2 Kelvin with

$$\eta = \frac{1}{1 + 11.1(D/\omega) + 2.5 \cdot 10^{-5}(\omega / D)} \quad \text{for C84}$$

and

$$\eta = \frac{1}{1 + 0.69(D/\omega) + 3.4 \cdot 10^{-4}(\omega / D)} \quad \text{for C116}$$

The motor constants are given in Tab. 1 and the values for a were estimated from previous models where they had been measured.

It can be seen that both motors are optimized for relatively small angular velocities of about 10 to 20 rad/sec (100 to 200 rpm) which is according to their scope of functions in the present instruments. The maximum efficiency is about 97 %. Due to the eddy currents at higher speeds the efficiency will decrease again depending on torque.

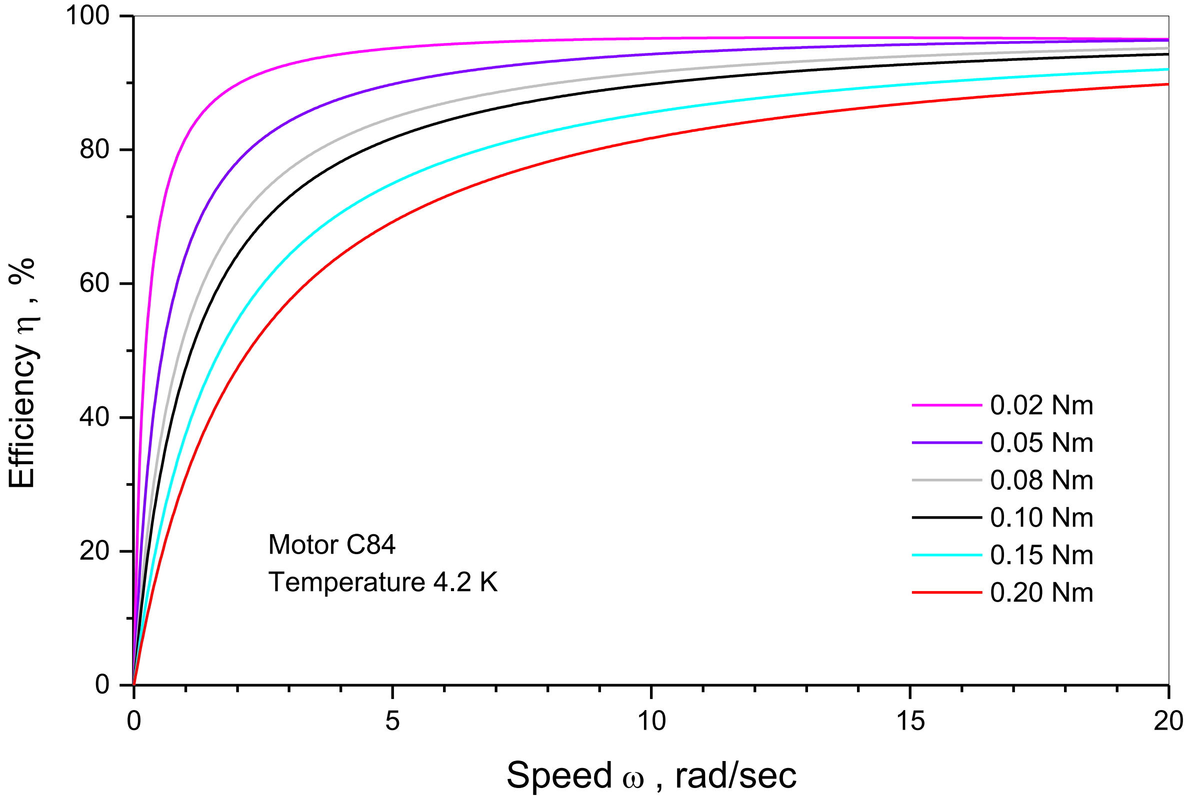

Figure 4. Efficiency at different torques at 4.2 K for motor type C84

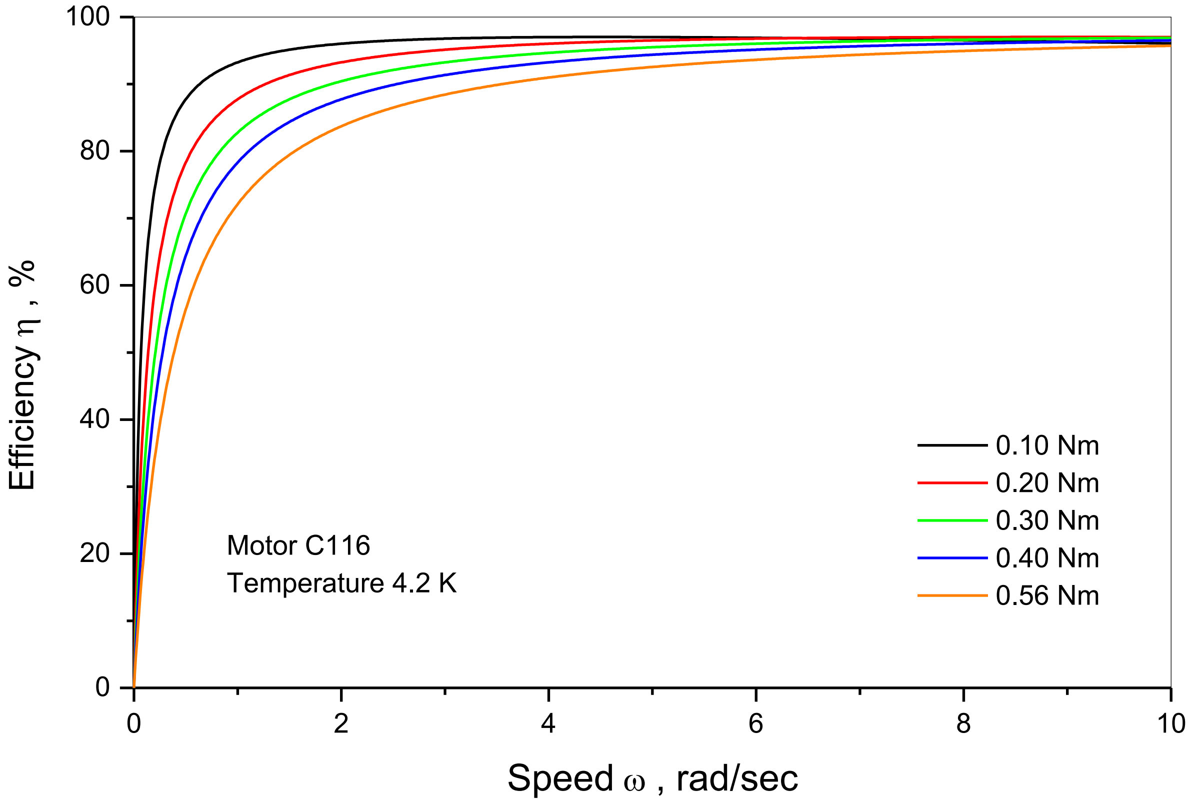

Figure 5. Efficiency at different torques at 4.2 K for motor type C116

5. CONCLUSIONS

With this direct drive motor high torque values and efficiency, excellent servo control properties and considerable versatility regarding applications are obtained at normal and at cryogenic temperatures. The motor can also be applied as positioner with high angular resolution. It has an unlimited angular excursion and no preferential positions. These properties in combination with long lifetime and safety of operation makes it very well suited for space application.

6. REFERENCES

1. Ruppert, U., Szücs, Z. & Proetel, K. (1984). Cryogenic motors/positioners. Proceed. ICEC 10, Helsinki, 438-441
2. Birner, R., Sodeikat, D. & Ruppert, U. (1990). Versatile Cryogenic Rotary Positioning Systems, SPIE, Vol. 1340, Cryogenic Optical Systems and Instruments IV, 350-360
3. Ruppert, U. & Szücs, Z. (1987). Cryogenic torquer/positioner for space use. Cryogenics 27, 73-76
4. Ruppert, U. (1984). Cryogenic torque-motor. BMFT Final Report (in German)