S16-37

AN OVERVIEW ON AEROSPATIALE MAGNETIC BEARING PRODUCTS FOR SPACECRAFT ATTITUDE CONTROL AND FOR INDUSTRY

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SUMMARY

For the last 25 years, AEROSPATIALE has worked on magnetic bearing technology and has been awarded contracts with many customers in order to develop equipment for flight and ground applications.

Two generations of magnetic bearing reaction wheels are already in flight, onboard observation satellites :

- first, on SPOT and ERS with 15 wheels in flight on 5 satellites,
- second, on HELIOS spacecraft with 3 wheels in flight.

Total cumulated flight time is now more than 65 years without any problem.

AEROSPATIALE Magnetic Bearings are based on the use of permanent magnets and on the control of the rotor around a zero force equilibrium point.

The present developments of magnetic bearing wheels for space applications focus on the versatility of a basic design which leads to a family of reaction and momentum wheels with tailored torque and kinetic momentum, leading to competitive mass and cost.

The present industrial applications concern kinetic energy accumulators, medical X-ray rotating devices, avionics equipment, cryotechnic compressors and vacuum pumps.

INTRODUCTION

AEROSPATIALE has been developing magnetic bearings for more than 25 years now. Our products were developed with the help of national and international organizations, who provided us with specifications, funding and technological support and allowed us to reach our present technical excellence and to offer top-performing products to our customers.

The present paper describes the chronology of Magnetic Bearing history at AEROSPATIALE, explains the inventive principle of the magnetic bearing and its applications in space as well as for industry, with a perspective on the new developments.

MAGNETIC BEARING HISTORY AT AEROSPATIALE

During the seventies, AEROSPATIALE worked on internal funding and with the help of some customers to develop all the technologies required for momentum wheels. They were designed for satellite applications such as :

- Energy storage wheels for COMSAT and INTELSAT. The program lasted until 1984 and allowed the realization of mockups and drawings of a 1.700 Nms energy storage wheel.
- Momentum and reaction wheels for CNES and ESA/ESTEC, with a 50 Nms and a 150 Nms model.

In 1978, AEROSPATIALE was awarded the contract for the development and the flight models of a 15 Nms reaction wheel dedicated to SPOT 1, first French optical observation satellite. This contract was renewed for SPOT 2 - SPOT 3 and for the two ERS European radar observation satellites which are each equipped with 3 reaction wheels.

Then, in 1985 the two axes wheel era began first with a 66 Nms momentum wheel mockup for ESA/ESTEC. Then, AEROSPATIALE was awarded the contract for the SPOT4 and HELIOS 1 programs, with 9 flight models of a 40 Nms and 0.45 Nm reaction wheel with an associated very low microvibration specification level. These same wheels will be used on ENVISAT (5), SPOT 5 (2 x 3), and probably on METOP(3 x 5).

Presently, a more powerful model is being developed for HELIOS 2 military observation satellite.

On the "industrial" side, the developments of different devices such as energy storage accumulators for telephone exchanges, test bench actuator for nuclear bar wear studies, X-ray tube bearings, tape recorder for satellite, artificial horizon gyroscope, ... etc.

Table 1. Magnetic Bearing Wheels History

MAGNETIC BEARING WHEELS HISTORY	
1970	Beginning of R & D on Magnetic Bearings at AEROSPATIALE
1973	First patent on Magnetic Bearings
1973-1979	Development contracts on Magnetic Bearings Systems leading to the delivery of 15 equipments for customers such as CNES, COMSAT, ESTEC, INTELSAT
1980	Industrial development of Magnetic Bearing Wheels for observation satellites
February 1986	. First flight on SPOT 1 launched by ARIANE Flight n° 16 . Follow on series with SPOT 2, SPOT 3, ERS 1, ERS 2 . 15 Wheels launched and operating without any problem
1984 up to now	. New generation of Magnetic Bearings for ground and space applications : SPACE APPLICATIONS : Reaction wheels for SPOT 4 , HELIOS, PPF/ ENVISAT GROUND APPLICATIONS : Kinetic accumulators, Medical X-RAY devices . Avionic equipment, Vacuum compressors

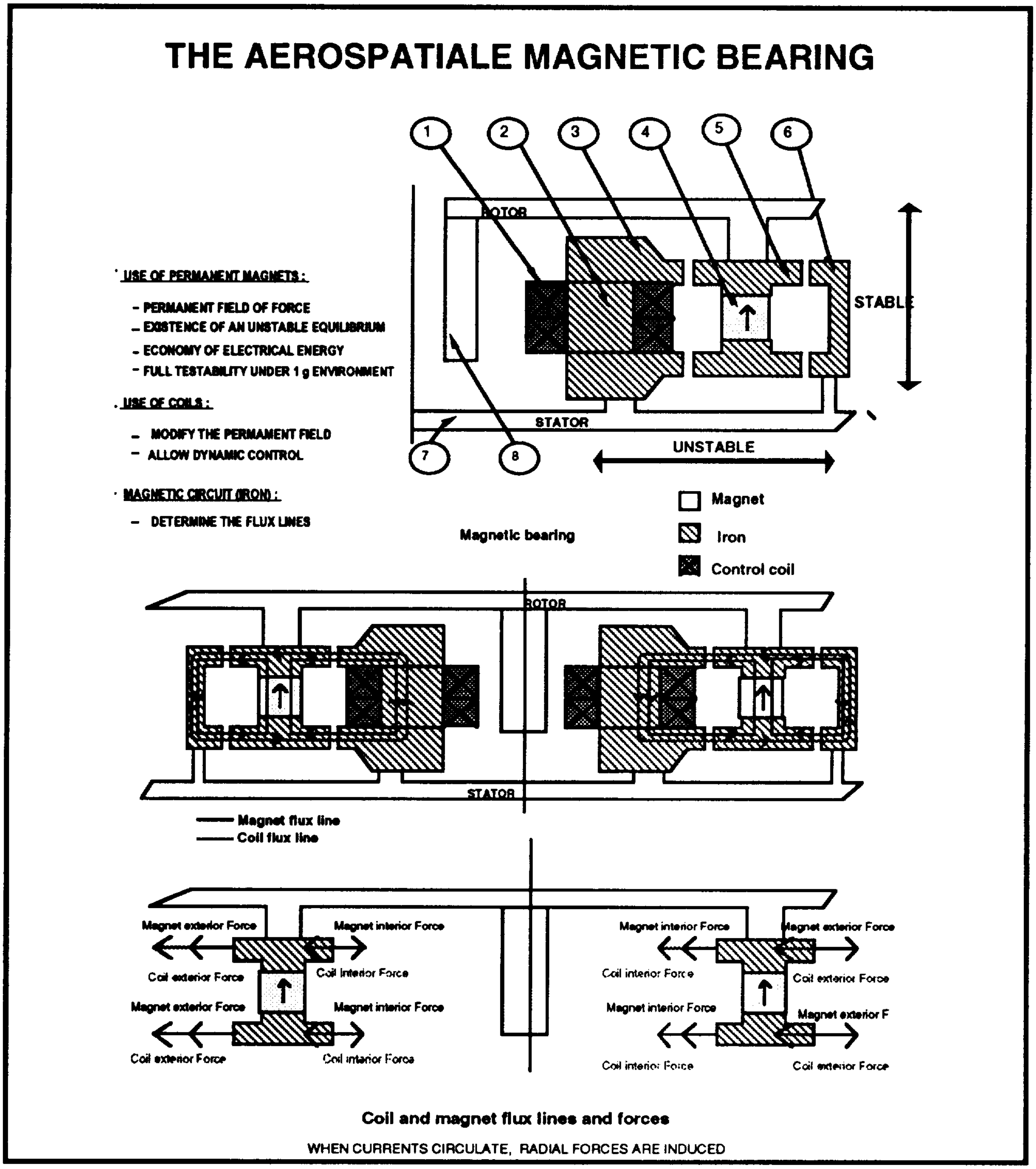
Table 2. Flight Record

FLIGHT RECORD (11/95)

SPOT 1	Launched 02/86	3 WHEELS	x 85700	)	
SPOT 2	Launched 01/90	3 WHEELS	x 51400	)	
ERS 1	Launched 07/91	3 WHEELS	x 38300	)	609600 h
SPOT 3	Launched 09/93	3 WHEELS	x 19300	)	
ERS 2	Launched 04/95	3 WHEELS	x 5400	)	
HELIOS	Launched 07/95	3 WHEELS	x 3100	)	

CUMULATED FLIGHT WITHOUT FAILURE > 70 YEARS

Table 3. The Aerospatiale Magnetic Bearing



AEROSPATIALE MAGNETIC BEARING

The AEROSPATIALE magnetic bearing principle is based on the use of permanent magnets which provide within the bearing :

- **a permanent field of force,**
- **an unstable equilibrium which is controlled by a servo loop.**

The reader will find a sketch on table 3. It shows the different parts of a typical bearing:

The magnet ④, is located on the rotating part ⑧, for this particular design. The magnet generates a magnetic field, which can be visualized through its flux lines. Those flux lines will follow a specific path from Northern pole to the Southern one of the magnet, which will be constrained through the iron parts.

The iron parts ②, ③, ⑤, ⑥ constitute the favorite way to curve a magnetic flux. Our skill is to design those parts in order to create the useful stiffness of the magnetic bearing. It is the shape of the iron teeth, on both parts of the air gaps, that give our bearings all their characteristics and qualities.

Together, permanent magnets and the iron circuit generate a field of forces and torques, which keeps the rotating parts within the teeth of the stator (the static rigidity on the stable axes) while creating an attraction (or a repulsion) towards both sides of the air gaps. This attraction sticks the rotating part to the stator!

The coil ① is used to restore stability within the bearing. Its electrically generated magnetic flux modulates the permanent flux of the magnet, so that the rotor will be positioned in the central part of the air gaps. Position sensors and an electronic control loop command the current in the coil to that effect.

As a consequence, this magnetic bearing needs a low electrical energy and is fully testable under 1g environment in any position.

Attraction forces within the air gaps are shown at the bottom of table 3. Without any external force and with a null coil current, those attraction forces are equal somewhere close to the middle of the air gaps, and they define a point of equilibrium.

This position is very unstable, and divergent forces increase when the rotor goes sidewards from this central equilibrium. The goal of the control loop is to transform this unstable equilibrium position into a stable one, so that the rotor levitates. The consequence of this design is the following :

- as the rotor is stabilized on this equilibrium point, no significant force is exerted on it. Even with an additional force (the weight of the rotor by instance) the equilibrium point is only displaced. In consequence, no significant energy is required to keep the rotor in position, even in a 1g environment, as long as the air gap and the bearing stiffness are compatible with the external force. Due to this property, all our space wheels may be operated on ground, without any additional ground equipment.

THE PRESENT APPLICATIONS IN SPACE

Table 4. Aerospatiale Magnetic Bearing Wheels

AEROSPATIALE MAGNETIC BEARING WHEELS

CHARACTERISTICS	SPOT 1 reaction	SPOT 4 reaction	SPACEBUS momentum	*EVOLUTION reaction or momentum*
Kinetic Momentum Nms	15	40	65 ± 8	*40 to 90*
Torque Nm	0,2	0,45	0.1	*0.05 to 0.2*
Rotor Speed rpm	2 400	2 400	10 000	*5 000 to 10 000*
Constant speed power including motor power W	14 1	50 24	20 3	20 3
Max torque power including motor power W	115 64	232 140	155 118	155 118
Bearing power W	5	9	9	9
Mass kg (without WDE) (with WDE)	8,4 specific	17 specific	6.7 9.9 (one channel)	*6 to 9* *9.2 to 12.2*
Onboard satellites (* when in flight)	3 x SPOT 1* 3 x SPOT 2* 3 x SPOT 3* 3 x ERS 1* 3 x ERS 2*	3 x HELIOS 1A* 3 x HELIOS 1B 3 x SPOT 4 6 x ENVISAT 6 x SPOT 5	SPACEBUS 3000 STENTOR	

The SPOT 1 Type Magnetic Bearing Wheel

Its magnetic bearing is a one active axis type with its unstable axis along the rotation axis of the wheel. The passive magnetic circuit of the bearing creates the stiffness on the passive axes (which are the radial and tilting axes) and a negative stiffness along the axis of the rotor. An inductive axial speed detector, an electronic control loop and an axial electromagnet allow the axial positioning of the wheel. An electronic logic lifts off the rotor, when power is turned on, with the help of a special transient supply. When power is turned off, the rotor comes towards a dry lubricated ball bearing. This bearing allows more than 100 emergency turns off, while the rotor runs at full speed.

A brushless torque motor creates the required reaction torque, which causes the rotation of the rotor (the kinetic momentum). Electronic circuits, incorporated into the ERPM, allow the commutation of the motor current for the 4 phases, depending on tachometer signals delivered on the stator and on a direction signal.

An axial locking device prevents the degradation of the wheel during transportation and launching. It may be screwed and unscrewed for storage and testing on ground, and a pyrotechnic cutter unlocks the rotor in space.

The design is dual redundant, to allow the functioning after any first failure. However, the magnetic bearing may not fail, so there is only one rotor. The electronic and electrotechnical parts are all dual redundant, except for the motor coils, which are specially protected. The mechanical and pyrotechnical parts of the locking device are unique, with a dual command, and a reliable design.

The SPOT 4 Type Magnetic Bearing Wheel

The magnetic bearing is here a two active axes type, with two radial unstable axes. This disposition allows a better radial control of the wheel, and hence, has been chosen to help reduce the wheel generated microvibrations. Two inductive radial position detectors, control loops and electromagnets allow the radial positioning of the wheel.

All its other devices (lift off logic, emergency ball bearings, torque motor, locking device and redundancy design) are comparable with those described above for the SPOT 1 wheel.

SPACEBUS Momentum Wheel

This wheel follows the main basic designs of the SPOT 4 wheel, with a two active axes type bearing and a brushless torque motor. Except for the dimensions and characteristic figures, the main technological differences lie in the 3 phased torque motor, the absence of any redundancy and a newly designed locking device (an inflatable vessel with an electrical valve).

Its basic characteristics are shown on table 4, and correspond to the needs of geostationary telecommunication satellites. But this wheel is being designed to easily fulfill all the characteristics of the "evolution" column of table 4. In fact, the evolutive elements are shown in table 5 as the rotor rim size (to adjust the required kinetic momentum with the allowed rotation speed) and the torque motor magnets height (to adjust the required torque with the max allowed current).

Table 5. SPACEBUS Momentum Wheel Adaptable Elements

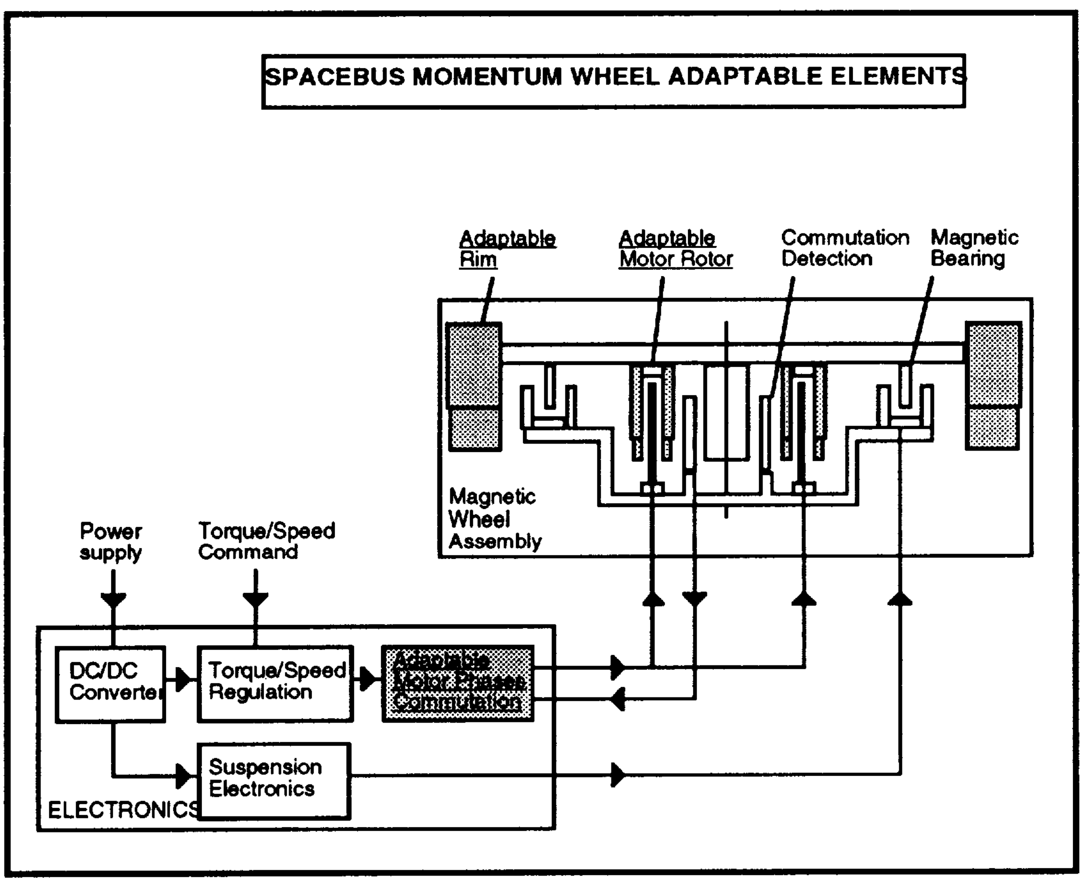


Table 6. Magnetic Bearings for Rotating Machines

MAGNETIC BEARINGS FOR ROTATING MACHINES						
APPLICATIONS		STIFFNESS			CURRENT ROTATIONAL SPEED	ROTOR MASS
		X	Y	Z		
Gyroscope Mini Pump Reaction Engine Simulator	MB 11-02 MB 11-03 MB 11-03	200 N/mm	200 N/mm	700 N/mm	24000 Tr/mm 90000 Tr/mm	0.35 kg
X-Raytube Chopper	MB 24-01 MB 24-02	200 N/mm	200 N/mm	40 N/mm	36000 Tr/mm	1.5 kg
Compressor Vibration Simulator for Nuclear Application	MB 24-04 MB 12-01	200 N/mm	200 N/mm	150 N/mm	36000 Tr/mm	1.5 kg
Turbomolecular Pump	MB 25-03	2000 N/mm	2000 N/mm	400 N/mm	42000 Tr/mm	2.5 kg
Wheel Energy Storage	MB 11-01	100 N/mm N/mm	100 N/mm	10000	12000 Tr/mm	360 kg

X, Y, Z passive or active axes - W current rotation speed

Table 7. Aerospatiale Magnetic Bearing Wheels

AEROSPATIALE MAGNETIC BEARING WHEELS

GENERATION		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
SPOT 1	SPOT 1 - 2 - 3	ôôô	ôôô ■			ôôô ■				■									
	ERS 1 - 2						ôôô	■		ôôô		■							
SPOT 4	SPOT 4-HELIOS 1					—	—	—	—	—	ôôô	ôôô ôôô ■		●	●				
	ENVISAT												ôôô ôôô			●			
	SPOT 5*														ôôô	ôôô	●		
	METOP *															ôôô	ôôô ôôô	ôôô ôôô	ôôô
HELIOS 2	HELIOS 2											—ŏ	—ŏ—	ôôô	ôôô	ôôô	●		
SPACEBUS MOMENTUM WHEEL	SPACEBUS*											—	—ŏ	—ŏ	ô	ôôô ôôô	ôôô ôôô	ôôô ôôô	ôôô ôôô

*Expected order
ô Flight items
■ Date of launch
ŏ Test Model
● Expected date of launch

CONCLUSION

This rapid survey of AEROSPATIALE products shows how efficient magnetic bearings are for different applications. They may be used either for increased reliability and reduced microvibration on satellites or for particular industrial uses with competitive characteristics.

Our industrial teams now are well trained either to manufacture existing products or to study and define new ones to fit specific needs.

Session 7 -- Superconductivity 2

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