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THE INDUSTRIAL APPLICATIONS OF THE ACTIVE MAGNETIC BEARINGS TECHNOLOGY

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ABSTRACT

This paper focuses on the main industrial applications of the active magnetic bearings and the status of these applications by the end of 1989.

1. Introduction

Active magnetic bearing (AMB) technology has been developed in S2M since 1969 for numerous different applications. The first commercial product with a rotor suspended on AMB was offered to the market in 1973. Since that date more than 1,000 machines have been equipped with AMB by S2M and its licensees. The bearings diameters manufactured range from 25 mm (1 in) to 1.25 m (50 in).

2. Fields of applications

The AMB applications are usually split in four different domains:
- aerospace applications,
- machine tool applications,
- light industry applications,
- heavy industry applications.

We shall go through the main applications of each domain.

2.1 Aerospace applications

This domain is mostly under development. The only commercial applications in this area today are:
- momentum wheel for satellites,
- turbomolecular vacuum pumps.

Fig. 1 Momentum wheel for satellite on AMB (Photo S2M)

The main reasons for using active magnetic bearings on momentum wheels for satellites are:
- capability to operate in vacuum,

- no friction and so very limited power consumption,

- unlimited life.

The turbomolecular vacuum pumps such as the one installed on the European space laboratory are very similar to the regular industrial ones we will talk about in paragraph 4.

The major development work going on is related to the application of the AMB technology to:
- rocket engine turbopumps,

- aircraft engines.

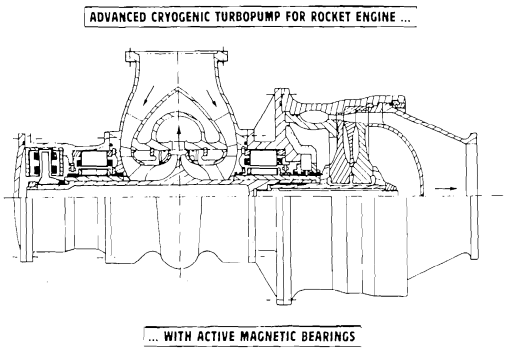

Fig. 2 Cross section of a rocket engine turbopump on AMB (Courtesy of SEP)

The main reasons for applying AMB to rocket engine turbopumps are:

- better capability to withstand high temperature (steam) and low temperature (liquid hydrogen) and temperature gradients,

- higher speed of rotation, so better performances of the machine,

- better control of the rotor dynamics,

- no wear, no lubrication, better reliability.

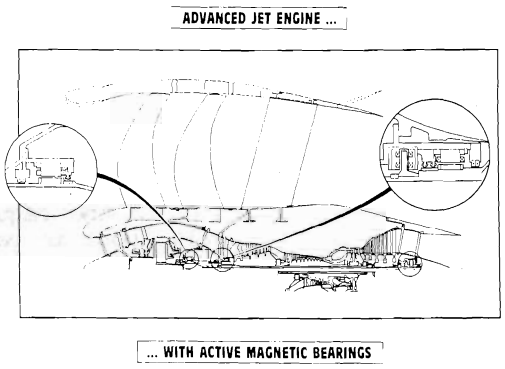

Fig. 3 Cross section of an aircraft engine on AMB (Courtesy of PRATT & WHITNEY)

As far as aircraft engines are concerned, the AMB will allow the concept of the "all electric engine" and mainly for the following reasons:
- higher speed or rotation, so better performance of the engine,
- better control of the rotor dynamices enabling more sophisticated shaft design,
- no wear, no lubrication, better reliability,
- cancellation of all the auxiliaries (pumps, filters, pipings) of the actual lube oil systems.

For both applications there is still a lot of development to perform before commercial products can be offered on the market. This development is engaged, it mostly concerns:
- compatibility of the AMB materials with the environment (eg.: LOX),
- magnetic materials with improved characteristics in order to lower the bearings size and weight,

Demonstration models are being built. The road is opened.

3. Machine tool applications

The AMB applications to the machine tool industry are mostly related to electrospindles.

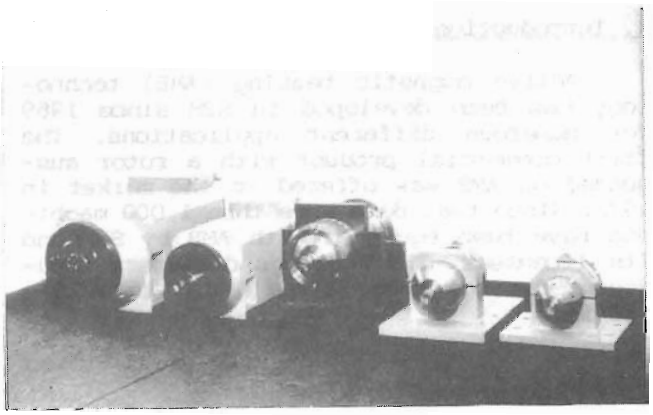

Fig. 4 Electrospindles on AMB (Photo S2M)

These electrospindes ranging from 25 kW - 30,000 rpm to 1 kW - 180,000 rpm, are used in milling and grinding (internal grinding and creep feed grinding).

The main reasons for using AMB on machine tool spindles are:
- high speed, so higher metal removal rate,
- no wear, better reliability,
- no vibrations, better accuracy,
- permanent monitoring of the operating conditions (adaptive control).

These products are now standard products manufactured on an industrial basis.

4. Light industry applications

The light industry is a puzzled family of applications. It includes many different types of machines which common characteristic is to have a light rotor (less than 50 kg) and not to be a machine tool spindle.

Some of the applications are under development such as the X-ray tube applications, others are commercial products but manufactured in limited quantities and on a customized design basis such as the pumps for liquid helium, others are standard products, manufactured on a large scale basis such as the turbomolecular vacuum pumps.

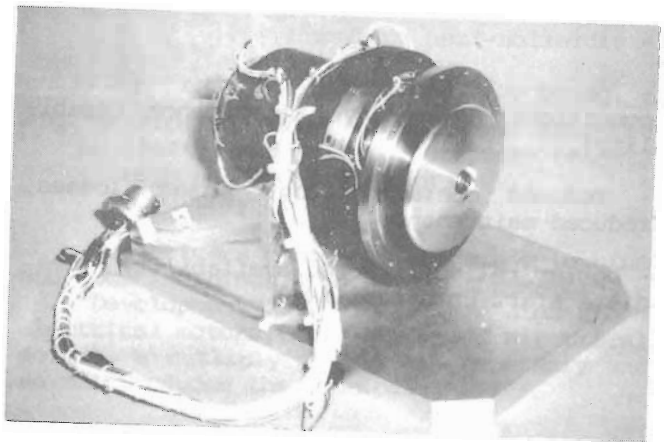

Fig. 5 X-ray tube rotating anode on AMB (Photo S2M)

The major reasons to use AMB for the supension of the rotating anode of X-ray tubes are:

- higher speed of rotation, so capability to accept higher flux of X-rays enabling better image,
- unlimited life,
- capability to move axially the rotor and to adjust the focusing point of the electron beam on the anode,
- no vibration, no noise.

Fig. 6 Pump for liquid helium at 4 K (Photo S2M)

For liquid helium pumps, it is obvious that the major advantage of the AMB is its capability to operate in a 4 K environment. But there are also many other reasons such as:

- very limited heat input (less than 1 W) in the liquid helium,
- high speed, so better efficiency,
- no thermal barrier, so shorter shaft.

Fig. 7 Turbomolecular vacuum pump on AMB (Photo S2M)

For turbomolecular vacuum pumps the main reasons for using AMB are:

- no pollution of the vacuum by any lube oil or grease (the auxiliary bearings are dry lubricated),
- high speed and so better level of vacuum,
- no vibrations.

There are many other light industry applications of the AMB such as: neutron chopper, liquid metal centrifuges, medical centrifuges, rotating mirrors, textile electrospindle but today they are either at the development stage or represent a very limited market. But this may change in the future.

5. Heavy industry applications

The heavy industry applications are those related to turbomachines and electrical machines where the rotor mass exceeds 50 kg and for ground (or sea) based applications.

These machines are mostly:

- compressors and drivers,

- turbo expanders,

as shown on the table hereafter.

MACHINE TYPE	QUANTITY	POWER RANGE kW / HP	NOMINAL SPEED RANGE	APPLICATION
TEST COMPRESSORS	7	20 kW to 4,200 kW	10,000 rpm to 16,000 rpm	- TEST STAND
INDUSTRIAL COMPRESSORS	31	3,100 kW to 26,100 kW	3,000 rpm to 15,700 rpm	- PIPELINE - REFINING - CHEMISTRY
HERMETIC MOTOCOMPRESSORS	1	6,000 kW	10,000 rpm	- PIPELINE
MOTORIZED BLOWERS	4	5 kW to 200 kW	3,600 rpm to 12,000 rpm	- TEST STANDS - HOT HELIUM LOOP
GAS TURBINES	1	12,000 kW / 16,300 HP	5,250 rpm	- COMPRESSOR DRIVE
STEAM TURBINES	1	3,000 kW / 4,100 HP	15,000 rpm	- COMPRESSOR DRIVE
TURBOGENERATORS	1	5,000 kW / 6,800 HP	3,000 rpm	- ENERGY RECOVERY (BLAST FURNACE GAS)
TURBO EXPANDERS	31	200 kW to 3,500 kW / 275 HP to 4,700 HP	18,000 rpm to 47,000 rpm	- AIR LIQUEFACTION - DEW POINT

This domain is the largest one for the application of the active magnetic bearings and is also the one which has grown the most drastically over the last three years.
About 10 equipment only were delivered by the end of 1986, more than 60 were delivered by the end of 1989.

The accumulated operating hours on 42 machines by the of 1989 exceeded 200,000 hours.

For all these machines the major reasons for utilizing AMB are:

- completely oil-free machines (elimination of the lube oil system),

- capability to operate at speeds higher than the third critical speed (first shaft bending mode),

- no process gas pollution by lube oil and elimination of fire hazard,
- vibration-free equipment,

- permanent monitoring of the operating conditions (preventive maintenance capability),

- reduced operating cost (lower losses, reduced maintenance),

- better reliability and availability (immediate start up capability).

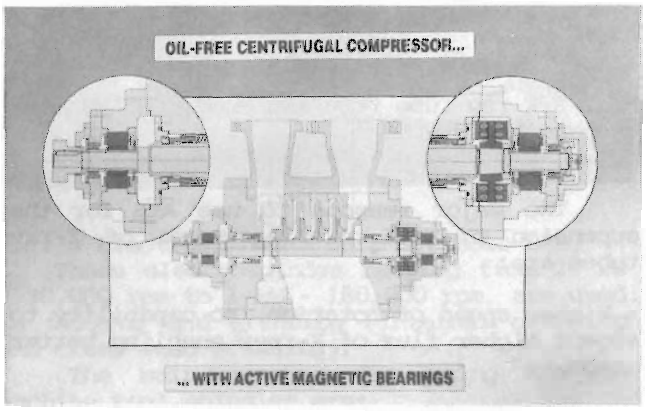

Fig. 8 Typical cross section of a compressor on AMB (Photo S2M)

a) Compressors and drivers:
The major world OEMs have compressors equipped with active magnetic bearings.

The main users are in the field of pipelines, refineries and chemical plants. The application concerns both new machines and retrofit of existing machines.

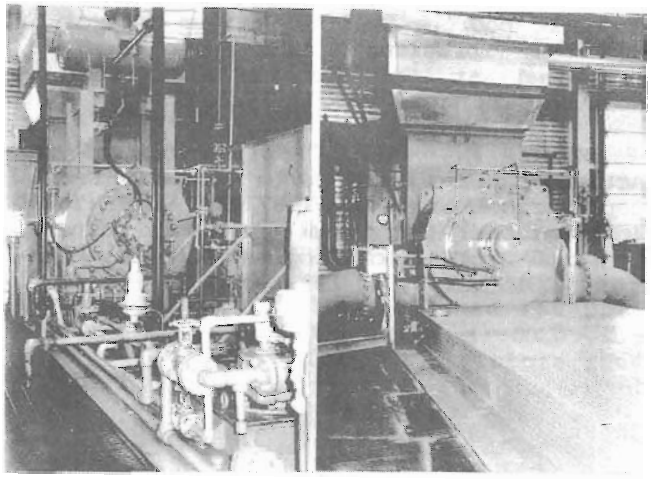

Fig. 9 Pipeline compressor before retrofit (left) and after retrofit (right) with AMB and dry seals (Courtesy of NOVA)

The drivers concerned are steam turbine and power turbines (fed by gas generators).
Development is going on for high speed electrical motors (with low speed electrical motors, a mutliplying gear is necessary and so reintroduces the lube oil).

b) Turbo expanders:

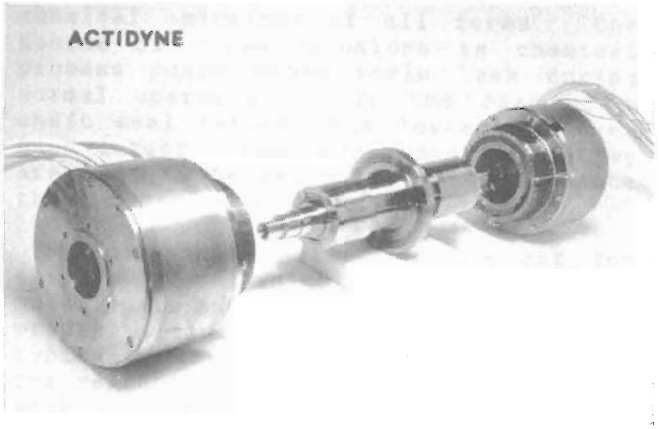

Fig. 10 Magnetic bearings cartridges and shaft of a turbo expander (Photo S2M)

These machines are used in air separation plants and gas fields for dew point control.

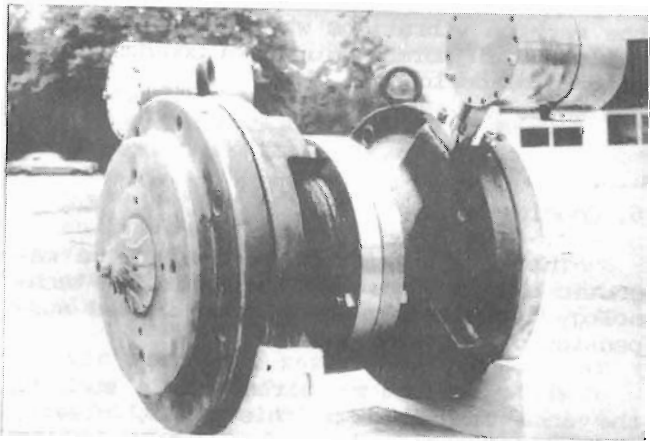

Fig. 11 Turbo expander for air separation plant (Photo S2M)

In addition to the reasons already mentioned one major advantage of the AMB is its capability to withstand a large range of temperature (-150°C on the turbine side, +150°C on the compressor side) and temperature gradients.
Up to now all the turbo expanders equipped with AMB are in operation on shore but the first turbo expanders for offshore will be operating on a North Sea platform by the end of 1990. This shows that this industry has really become very confident in the technology.

c) Other applications:
There are many other applications of the AMB to the heavy industry. The most spectacular one is related to 900 MW and 1,300 MW turbogenerators.

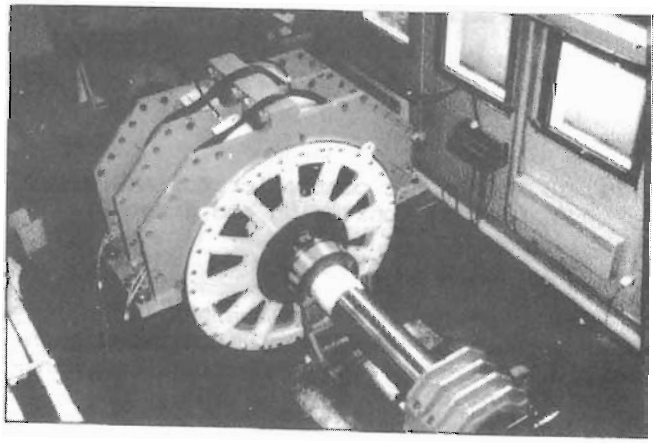

Fig. 12 The largest AMB in the world - diameter at the air gap: 1.25 m (Courtesy of EDF)

These large turbogenerators will be equipped with AMB installed on the couplings between frames and providing a 30 tons rotating force in order to reduce drastically the machine vibrations when crossing critical speed in normal slow down conditions or after a blade loss.

6. Conclusion

The characteristics of the active magnetic bearings are such that this new technology represents a revolution in the suspension of rotating shafts.

The applications already made such as the ones described in this paper, clearly indicate that this technology is no more at the infancy stage.

Of course, development will continue and the AMB technology will incorporate the new materials and components put on the market such as high permeability laminations and microprocessors.

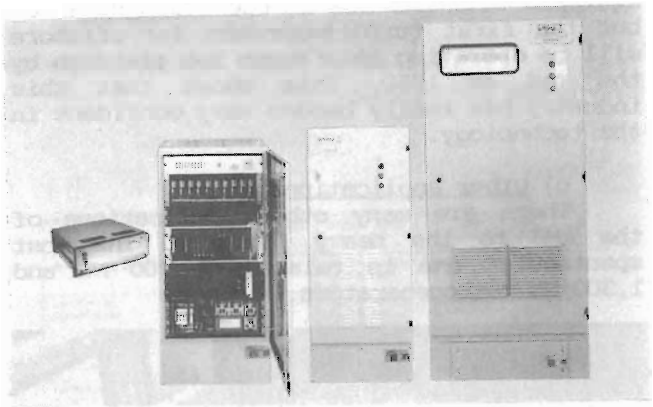

Fig. 13 Electronic controller for AMB with digital monitoring and diagnosis system

But one can say that the AMB technology has reached the level of an industrial technology applicable to industrial machines operating night and day all year long.

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