2nd International Symposium on Magnetic Beaing
July 12-14, 1990, Tokyo, Japan

THE MALVE EXPERIMENTAL CIRCULATOR

THE FIRST LARGE NUCLEAR COMPONENT WITH ACTIVE MAGNETIC BEARINGS

P. BÜHRER, J. ENGEL, D. GLASS
ABB Kraftwerke AG, Mannheim

Abstract
Reliable operation of coolant gas circulators with magnetic bearings is an indispensable prerequisite for the further realisation of the High Temperature Reactor line. Development of the magnetic bearing technology for vertically arranged rotors weighing several tons has therefore been at the center of continuing R&D activities by ABB for a long time. After completion of the design work for a circulator the construction of a full scale prototype has now been started. With a power input of 400 kW, a rotor with magnetic bearings weighing 2 tons, and an overhung impeller of 1.25 m diameter the circulator exhibits features which might be of interest to the conventional compressor business as well. While the construction of the circulator is in progress a test loop will be erected. Tests in air/nitrogen and helium atmospheres are planned. The purpose of the tests is above all to verify the dynamic behaviour of the circulator at different speeds, temperatures, and gas densities. Features of the prototype and of the test loop as well as the milestones of the test program will be described.

1. ESSENTIAL BOUNDARY CONDITIONS FOR THE DESIGN OF THE PROTOTYPE

In high-temperature reactors coolant-gas circulators with magnetic bearings give full freedom of arrangement and orientation without any need to take adverse interactions between the helium gas loops and a lubricant into account, interactions which can only be eliminated by expensive special measures.

On an international scope all modern HTR designs are therefore based on the use of vertically arranged circulators with magnetic bearings. By this means it is still possible to plan cost-effective reactor plants without impairing the availability of safety-related or operational circulator functions. Not only can maintenance needs for potentially contaminated machine elements be eliminated through the use of magnetic bearings, but the enormous fire risks involved in the use of oil as lubricant are also precluded.

The proper functioning of these magnetic bearings verified by a large-scale test is a basic prerequisite for the further advancement of the HTR line, since the benefits of helium circulators fitted with magnetic bearings determine major features of advanced HTR plants.

After the successful completion of the basic experiments with retainer bearings, reported by us during the first symposium in Zurich /1/, ABB was in the late fall of 1989 informed that funds from the Federal German Ministry of Research and Technology will be provided for the construction and testing of a circulator with magnetic bearings in a test loop. This is a R&D project with a term of 5 years involving an expenditure of approx. 16 million Deutschmarks.

The development of the magnetic bearings technology for vertically arranged rotors weighing several tons has for a long time been at the centre of demanding and continuing R&D activities by ABB. At the same time the appearance of an EPRI report /2/, /3/, has made clear that branches of industry which are usually regarded as rather conservative, preferring to wait until new developments have firmly established themselves, are now beginning to become interested in the degree of qualification reached by the magnetic bearings technology. We are therefore rather glad to see that the initiation of our R&D activities in good time has been worth the effort.

The efforts to make use of the benefits involved in magnetic bearings are most obvious in the oil and gas industry /4/. Unfortunately the time when the breakthrough will occur is still uncertain. But there can be no doubt that it will come.

2. DESCRIPTION OF THE DESIGN

With the manufacture of a prototype now started, fully matured design documents will be turned into hardware. They take into account, apart from extensive studies on the dynamic, thermal, and magnetic behavior of circulator components, the results of the nearly completed full scale tests for optimizing the retainer bearings in the retainer bearing test stand fitted with magnetic bearings.

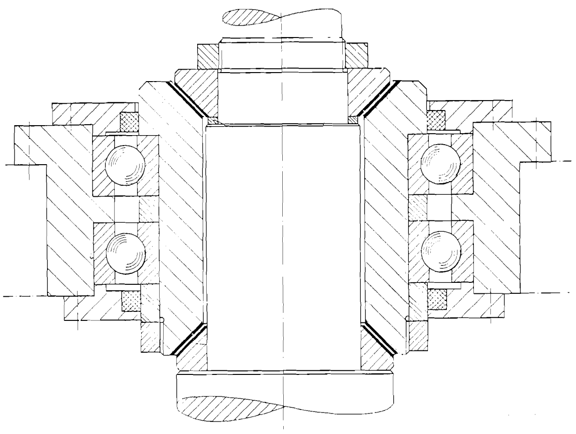

Fig.1 Retainer and centering bearing
for vertically arranged rotors

On the basis of the patented design shown in Fig. 1 both grease-free, dry-lubricated retainer bearings and bearings with a grease film are now available. In view of the highly unfavorable friction values in high-purity helium the number of shaft releases (drops) for a set of retainer bearings with grease-film lubrication now exceeds 50 for an unbraked rotor. For dry-lubricated retainer bearings it is higher than 10. The still outstanding optimization of the rolling bearings in the cage region of dry-lubricated retainer bearings is no longer of basic importance since the number of releases achieved under conservative boundary conditions - i.e. unbraked rotor with extended coast-down times - is already adequate for HTR applications.

During the trial operation of the prototype and of the new electronic system for magnetic bearings an increased number of releases is to be expected. For this reason magnetic bearings with grease film lubrication will be used. They will make it possible, taking additional planned and intentional releases into consideration, to complete the extensive test program with a single set of retainer bearings.

The retainer bearing technology itself has been described in detail in a paper presented at the 1st symposium /1/; therefore only the principle shall be explained again by means of Fig.1: In the event of disturbances of the magnetic bearings the rotor will move in axial or radial direction until it comes into contact via friction cones and/or radial friction surfaces with the rolling bearings which areat standstill till then. As a result they will within seconds start to turn at the shaft speed which is to be brought under control. The transfer of power by the impeller wheel to the circulating medium together with an automatically triggered motor cut-out in the case of retainer bearing operation plus simultaneous switchover to electric braking by the motor will result in a short-term and safe coastdown of the rotor in the retainer bearings.

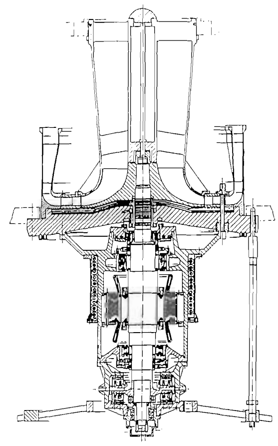

Fig.2 Coolant gas circulator protype MALVE
(5300 r.p.m, overhung impeller wheel,
1,25 m diameter, rotorweight 2 t,
power input 400 kW)

Fig. 2 is a longitudinal section through the prototype circulator. With a power input of 400 kW, a rotor weight of 2 t held by magnetic bearings, and an overhung impellor wheel of 1.25 m dia., it has features which are of interest to the conventional compressor business as well.

Via the supporting wall the circulator is connected with the test vessel simulating the reactor structure (not shown here). The supporting wall is thermally insulated on its top side, which communicates with the primary loop of the reactor whose temperature is 300 °C, and on the side of the motor it is additionally water-cooled. This arrangement ensures motor compartment temperatures, even if the machine does not turn, that will not jeopardize the electric components.

The shaft penetration is designed as a labyrinth packing and sealing gas can be injected into it. The penetration of any radioactive contaminations from the primary loop into the motor compartment which has a temperature of 80 °C is thereby effectively obstructed. If sealing gas is injected this will, together with the sealing strips of the labyrinth, produce an increased cooling effect at the hot shaft end which is welcome in particular in the event of reactor accidents.

The strength of the supporting wall is designed to withstand the pressure differential which will occur in the event of a depressurization on the primary gas side or on the motor side as the result of an accident.

In the lower circulator region an additional fixation of the circulator by means of a star-shaped bearing bracket is provided. By this means radial vibrations of the stator are limited. With the assistance of a structure allowing thermal expansion, as it is used in turbine engineering, expansions of the circulator in axial direction are possible.

As for all other ABB circulators designed to date an induction motor is used as drive motor; its electrical insulation is not only radiation-resistant but also takes the much-reduced disruptive strength in helium compared with air into consideration. By means of a static converter the motor speed is infinitely adjustable. During retainer bearing operation resulting from disturbances of the magnetic bearings electric braking, too, is possible by means of a chopper in the static frequency converter.

Fig.3 Sensor ring for radial magnetic bearings manufactured by ABB, with redundancy capability for 2-out-of-3 circuits and an additional stand-by sensor.

The magnetic bearings operate with an air gap of approx. 1 mm. Fig. 3 depicts radial magnetic bearing sensors manufactured by ABB during installation. They belong to a partially redundant electronic system for the magnetic bearings and operate in 2-out-of-3 technology.

For the magnetic bearing loads to be expected in nuclear follow-up projects with driving powers in the 5 to 6 MW range the power amplifiers available to date will no longer be sufficient. Under a licensing agreement with the S2M Company ABB has therefore developed a new output stage with a power of 20 to 42 kVA. Fig. 4 is a view of the amplifier which operates during the MALVE application at a maximum of 250 V and 80 A; it shall also be qualified, together with the circulator prototype, during the planned test runs.

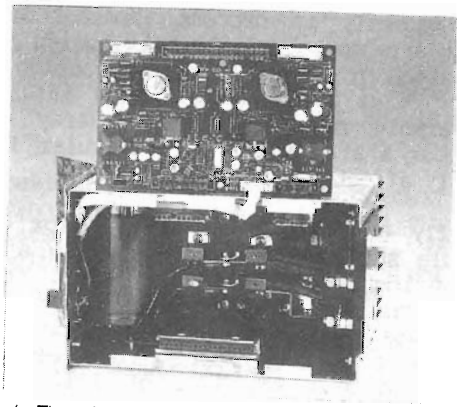

Fig.4 The ABB power amplifier for circulators with magnetic bearings, for power inputs from 5 to 6 MV.

On the basis of extensive calculations with the ABB program system for magnetic stray-field distribution, UNIFELD 4, the design and the materials have been selected such that the magnetic field distribution outside the magnetic bearings is as homogeneous as possible with low values for the magnetic field intensity. This was done because it turned out that even minor field inhomogenities in the hectogauss range, rotating with the rotor or relative to it, can be the cause of undesired, eddy-current-related temperature rises.

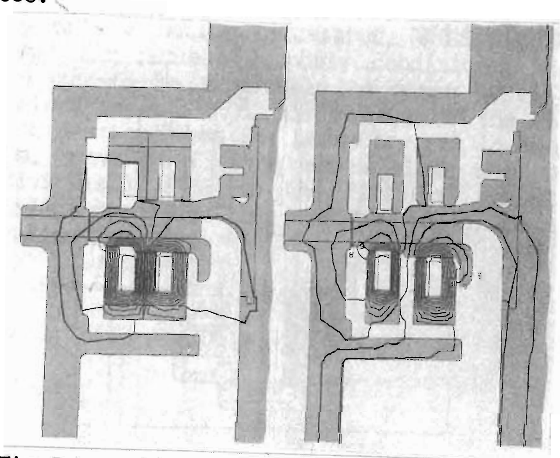

Fig.5 Magnetic stray fields resulting from the structural design of details, illustrated with the example of an axial bearing.

Fig. 5 is a cross section through an axial magnetic bearing with magnetic field pattern for two different bearing designs based on UNIFELD-4 calculations. To understand the magnetic field pattern it is first of all important to know that the coils are connected in opposition so that the magnetic induction effect for machine areas further removed from the axial bearing will disappear. In the immediate vicinity it becomes apparent how the compact arrangement of the coil bodies and the elimination of the yoke-leg contraction intended for "flux concentration" will result in a considerable reduction of the stray effect. The rotor shaft region in particular is only slightly affected by it.

Basically the exit of lines of flux outside the pole surfaces always results in a reduction of the bearing capacity, apart from the heat-up due to eddy currents, if the stray fields pass through moving parts. In the present case a bearing capacity improvement from 52.4 kN to 59.1 kN, i.e. of 13%, could be achieved by the design change.

The fact that the circulator comes into contact with the 300 °C of the primary loop causes a not inconsiderable heat input into the motor compartment; this heat plus the dissipation heat from the operation of the magnets in the bearings and of the motor must be removed. A water-filled cooler with helical tubes arranged outside the motor housing is used for this purpose. It serves to cool down the helium circulated in the motor compartment, streaming away from the auxiliary blower integrated in the axial bearing disk. The axial magnetic bearing disk with the integrated ventilator wheel /6/ is shown in Fig. 6 in its interaction with the other elements of the cooling loop.

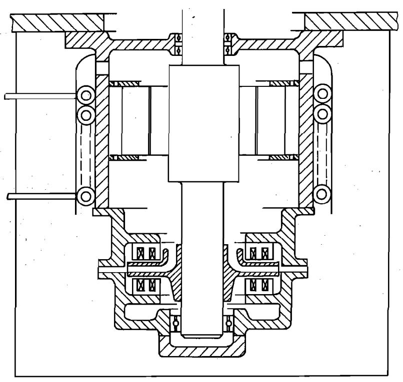

Fig.6 Axial magnetic bearing with integrated impeller for the cooling loop in the motor compartment.

A central shaft boring not shown in Fig. 2 serves to meet the need for reducing the radiation exposure of the assembly personnel of nuclear installations to the minimum. By this means the contaminated impeller wheel of an irradiated circulator may be separated from the shaft, working from the hardly activated rear side of the circulator in the course of maintenance activities which are possible as a matter of principle. Only very low dose rates have then to be taken into account for the handling. To separate the impeller wheel from the shaft by means of the central boring extreme-pressure oil is injected into grooves of the cone interference fit between wheel and circulator.

3. TEST LOOP AND TESTS

While the prototype is being manufactured a test loop is set up. It is conceived such that the circulator prototype in "upright mounting position", i.e. with the impeller wheel on top, can be operated under the effects of pressure and temperature at largely realistic reactor boundary conditions. The gas condition is then set to the temperatures and densities prevailing in the reactor.

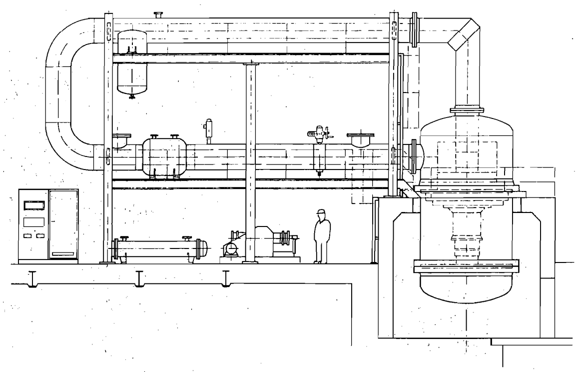

Fig.7 Main componentes of the test loop for testing the coolant gas circulator prototype MALVE.

Fig. 7 gives an impression of the order of magnitude of the project. The circulator is in the pressure vessel visible on the right-hand side. The gas is sucked in from the pipe on top and returned to the loop via the pipe connected to the left-hand side of the vessel. The loop consists basically of heat exchangers for adjusting the gas condition and of a throttling device to achieve different circulator loads for the same gas condition. As part of a "building block philosophy" the expensive large components have been dimensioned such that they may also be used later on for workshop testing of circulators for commercial projects.

Fig. 8 is a schematic diagram showing the interaction of the various gas and cooling loops. At low circulator powers the reactor conditions can be maintained in the thermally insulated main loop by means of heat tracing.

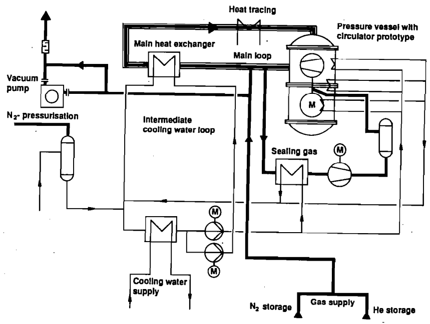

Fig.8 Schematic diagram of the gas and cooling loops in the test stand for the coolant gas circulator prototype MALVE

For large powers the cooler is operated with water from the intermediate cooling loop. The possibility to evacuate the overall loop has been provided for the effective adjustment of the helium purity. The sealing gas supply for the circulator, corresponding to reactor operating conditions, is simulated by means of a separate loop equipped with a cooling device.

The test program envisages tests in air/nitrogen and in helium. The objective of the tests under atmospheric conditions is above all to verify the dynamic behavior of the circulator and the effect of the internal circulator cooling loop at various speeds and gas densities. At first an impeller dummy will be used for the tests; it will later be replaced by the original impeller wheel. During the final tests in helium the circulator will, in particular at full power, be operated with gas densities corresponding to the reactor accident conditions "reactor depressurized", which is important from a safety-engineering point of view.

The instrumentation of the circulator will be much more extensive compared with that for reactor applications later on in order to obtain as much information as possible during the trial phase. The interest here is focussed on material temperatures, vibration and position transducers and on the electric and magnetic parameters which are characteristic for magnetic bearing operation. A suitable concrete foundation for the pressure vessel support structure will ensure that more or less the same highly rigid clamping of the circulator in the reactor structure will exist during the test runs.

The milestones of the planned test program are as follows:

- Testing of all the subassemblies of the coolant gas circulator prototype developed with respect to functionally correct interaction and fulfillment of requirements.

- Evaluation of the running behavior of the circulator and of the rotor dynamics at various speeds, temperatures and gas densities.

- Behavior of the magnetic bearing system during continuous operation and during simulated deviations from normal operating conditions incl. accident boundary conditions to be postulated.

- Investigation of the interaction of the electric subassemblies: static frequency converter, induction motor, and magnetic bearing system.

- Checking the effectiveness of the retainer bearing system; in particular with respect to the repeatability of the release behavior.

- Experimental verification of the temperature drift of circulator subassemblies during simulated, accident-related temperature excursions up to 450 °C in the circulator compartment.

Naturally, ABB attaches to the construction and testing of the coolant gas circulator prototype MALVE the hope that through the use of spin-off effects the magnetic bearings technology of the helium circulator, which is designed for nuclear boundary conditions, will turn out to be applicable to other types of machines as well /7/. The picture of the Magnetic Bearings Test Bay being erected in Mannheim, shown as Fig. 9, makes clear that the activities of ABB in the field of magnetic bearings transcend the scope of normal demonstration projects.

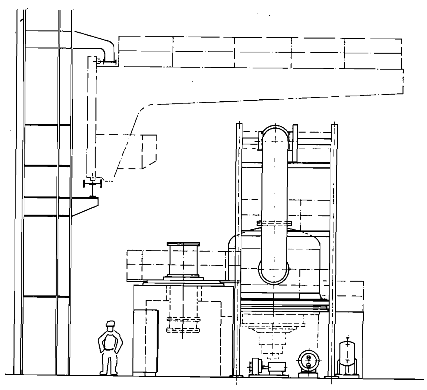

Fig. 9 ABB magnetic bearings test bay

4. TIME SCHEDULE AND FURTHER PROCEDURE

It is planned to continue with the tests in the retainer bearing test stand fitted with magnetic bearings in the 3rd quarter of this year. Besides the remaining optimization activities for the dry-lubrication retainer bearings, component tests in the magnetic bearings area are to be performed.

The commissioning of the test stand with the completed prototype is to start in late 1992; the test program is to be completed by 1994. With the program as presented, sponsored by the Federal German Minister of Research and Technology, ABB wants to safeguard in advance the properties of the HTR reactor line which are to be assessed very favorable in the long term.

Developments in Japan, the USA and the Soviet Union show that despite the decommissioning of the AVR, the TTHTR-300 and the Fort St. Vrain plant, there exists considerable interest in safeguarding the capability to supply operationally reliable, cost-effective and technologically advanced HTR plants.

REFERENCES

/1/ DELL, H., ENGEL, J., FABER, R., GLASS, D.; Proceedings First Intl. Symposium ETH Zurich, June 6-8, 1988, Springer-Verlag Berlin Heidelberg 1989; "Developments and Test on Retainer Bearings for Large Active Magnetic Bearings"

/2/ GRAY, Susan T., Project Manager; EPRI Final Report RP 2079 - 21 & 22, Dec. 1988; "Applications for Magnetic Bearings on Electrical Generating Plant Equipment"

/3/ ENGEL, J., GLASS, D.; VGB Conference 'Kraftwerkskomponenten [Power Plant Components] 1990', 14/15 March 1990, Essen; "Status of the Magnetic Bearings Technology with Respect to its Potential Use for Power Plant Engineering"

/4/ ACEC SULZER Leaflet 1989, "MOPICO - Motor Pipeline Compressor for unattended and remotely controlled compressor stations"

/5/ EIERMANN, A., GLASS, D., HERRMANN, R.; German Patent Application DE 3141841 C2, published on 28 Sept. 1989; "Centering and retaining device for rotors supported in non-contacting bearings"

/6/ GLASS, D., EIXELSBERGER, W., BÜHRER, P.; European Patent Application EP 0 317 946 A2, published on 31 May, 1989; "Axial Magnetic Bearing"

/7/ DANGL, G., ENGEL, J., GLASS, D., MAUERSBERGER, T.; ABB Review 8/9-1989; "Large 'floating' rotors run, damped and balanced in active magnetic bearings"