5. Goudy, L. J., and R. D. Teire, "The Development of Compressors and Drives for Gas-Cooled Reactors," in Proceedings of Symposium on Gas-Cooled Reactors," The Franklin Institute Monograph No. 7, May 1960, pp. 254-276.
6. "Rotating Machinery for Gas-Cooled Reactor Application," United States Atomic Energy Commission Report TID-7690, November 1963.
7. Strub, R. A., "Gas Circulators for French Power Reactors," Paper 10, in Proceedings of Institution of Mechanical Engineers, Vol. 181, 1966-67, pp. 129-137.
8. Thorn, J. D., et al., "Main Circulators," Journal of the British Nuclear Energy Society, 1963, pp. 165-172.
9. Stoelzl, D., "Twenty-Five Years of Brown Boveri Experience in Development, Design, and Fabrication of Circulators for HTGR," paper presented at IAEA Circulator Specialists Meeting, San Diego, California, December 1, 1987.
10. Balje, O. E., "A Study of Design Criteria and Matching of Turbomachines," ASME Journal of Engineering for Power, January 1962, pp. 103-114.
11. Brey, H. L., "Fort St. Vrain Circulator Operating Experience," paper presented at IAEA Circulator Specialists Meeting, San Diego, California, November 30, 1987.
12. "Aerodynamic Design of Axial Flow Compressors," National Aeronautics and Space Administration Publication, NASA SP-36, 1965.
13. Howell, A. R., "Fluid Dynamics of Axial Compressors," Proceedings of Inst. of Mech. Engineers, Vol. 153, 1945.
14. Lieblein, S., et al., "Diffusion Factor for Estimating Losses and Limiting Blade Loadings on Axial Flow Blade Compressor Elements," National Advisory Committee for Aeronautics Report NASA RM E53D01, 1953.
15. McDonald, C. F., and M. K. Nichols, "Helium Circulator Design Considerations for Modular High-Temperature Gas-Cooled Reactor Plant," ASME Paper No. 87-GT-138, 1987.

MAIN GAS CIRCULATOR FOR VG-400 REACTOR PLANT

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Abstract

Principle parameters and operating conditions of the main gas circulator (MGC) in ВГ-400 reactor plant are presented.

Brief MGC design description and experimental work scope are given.

1. INTRODUCTION

Important design features of ВГ-400 reactor plant are integral lay-out of the main primary circuit components in a prestressed concrete reactor vessel and helium coolant use /1/. Main gas circulator is one of the key plant components, effecting the reactor lay-out and its long availability.

Four MGCs are allowed in the reactor plant. Circulators are high energy consumption components - up to 5% of the plant rating, due to high circulator capacity.

That is why the choice of the optimum circulator gas path configuration substantially effects both on MGC and the whole reactor economy. The sound variant of such MGC may be chosen only through careful feasibility study and evaluation of the available experience.

2. MGC OPERATION CONDITIONS AND REGIMES

High reliability of MGC units working in He at relatively high circuit parametrs requires solving the following engineering problems:

- coolant protection against contamination with lubricant-coolant fluid;
- MGC operability provision at power from 5 to 100% as well as residual heat removal and in emergency conditions, including steam generator depressurization (as a result of circuit pressure increase up to 6 MPa) and plant circuit depressurization to atmospheric pressure;
- possibility of MGC and loop connection (disconnection) during plant operation.

Besides, MGC must be operable during following plant regimes:

- start-up in hot and cold conditions;
- prolonged shutdown conditions in disconnected loop;
- MGC rotational speed deviation from specified one when speed control system fails;
- primary circuit vacuum testing;

- primary circuit overpressurizing.

MGC must accomodate forced operation conditions with maximum rotational speed of 6000 rpm and primary circuit pressure down to 0,1 MPa.

The said operating conditions, high helium temperature, large motor power, helium permeability and, also, maintenance inaccessibility impose special requirements on MGC design and, especially, on reliable heat removal both while operating and being inoperative.

3. MAIN DESIGN PARAMETERS

Turbine- and electric-driven MGC versions having different rotational speed were compared in detail design stage. As a result a gas-tight vertical shaft electric-driven gas circulator with rotational speed control system was chosen for contractor design (Fig.1).

Electric-driven gas circulator with leak-tight motor provides certain advantage over turbin-driven gas circulator:

- high tightness of reactor circuit;
- a simplier bearing unit service system;
- absence of auxiliary drive;
- lower costs (including servicing systems).

Oil-lubricated bearings predetermined the MGC location in the low part of steam generator pit. This provides some advantges and simplifies MGC design, but

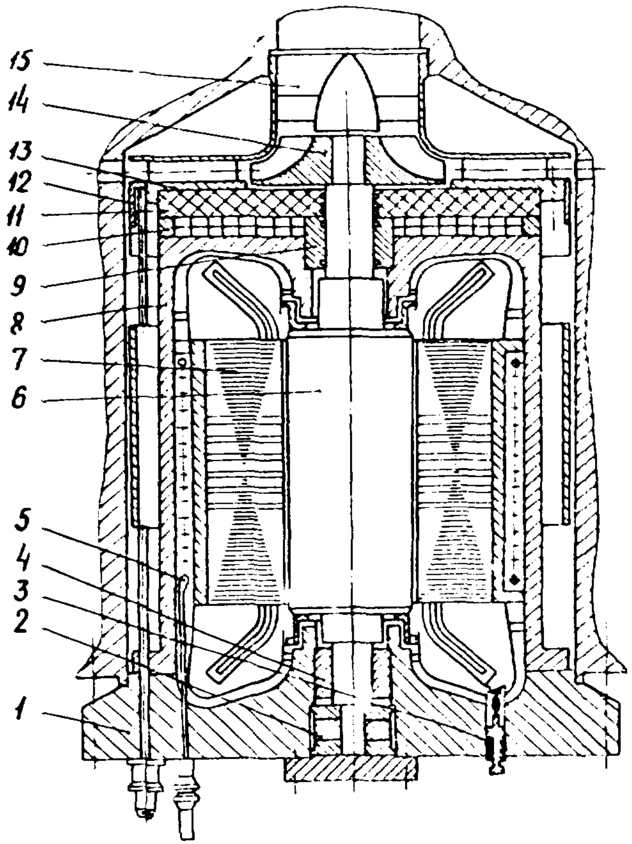

FIG.1. Main gas circulator for VG-400 reactor plant.
1) end closure; 2) axial bearing; 3) lead-in; 4) and
9) radial bearing; 5) stator cooler; 6) rotor; 7) stator;
8) casing; 10) cooler; 11) thermal shield; 12) isolation
valve; 13) guide device; 14) impeller; 15) inlet passage.

complicates mounting-dismounting works.

The main MGC parameters are given in Table 1.

TABLE 1

Parameters	Value
1. Working medium	Helium
2. Nominal capacity, m^3/s	24,6
3. Nominal head, MPa	0,1225
4. Gas parameters at the circulator inlet:	
- static (absolute) pressure, MPa	4,777
- temperature, K (°C)	615 (342)
5. Gas parameters at the circulator outlet:	
- static (absolute) pressure, MPa	4,9
6. Rotor rotational speed (nominal), rpm	5600
7. Rotor rotational speed control range	300-6000
8. Nominal power consumption (excluding converter efficiency), kW	5090

4. MGC DESIGN DESCRIPTION

MGC location in the bottom of steam generator pit predetermined axial inlet and radial-axial out at of helium (Fig.2).

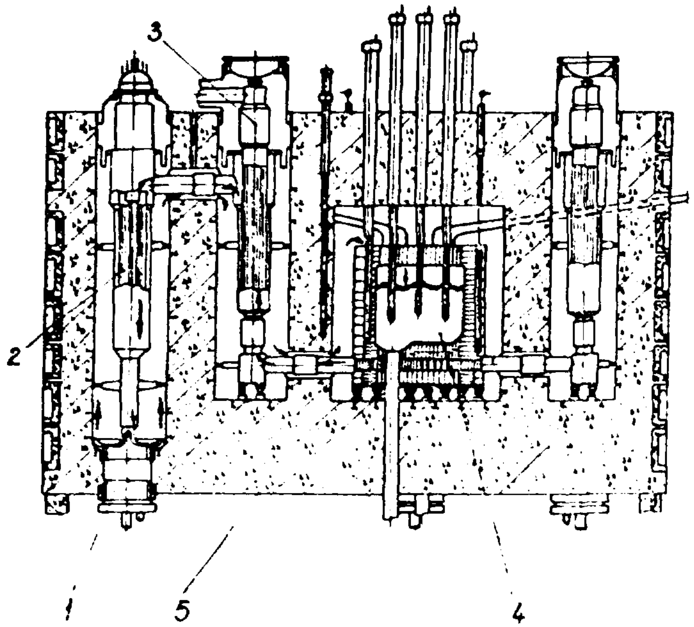

FIG.2. VG-400 reactor lay-out.
1) gas circulator; 2) steam generator; 3) heat exchanger; 4) core; 5) reactor vessel.

MGC includes circulator flow path, drive motor and isolation valve.

Circulator Flow Path

To provide the necessary stiffnes of high-speed MGC rotor/bearing system, the circulator flow path is chosen one-staged. Design calculations showed that at shaft rotational speed of 6000 rpm the centrifugal MGC version is preferable, which allowed to reach acceptable efficiency at low speed /2/. But it is characterized by large mass and overall dimensions compared with axial stage and increased complexity in impeller fabrication.

MGC flow path consists of inlet passage, impeller and discharge passage.

The inlet passage is intended for gas flow arrangement at the impeller inlet and involves a ring confusor with stationary double-row vaned prewhirling cast-welded guide device.

The impeller is of centrifugal, half-open type with radial vanes and rotary profiled guide device fastened to the driving disk hub.

The vaned double-row discharge passage is intended to transform flow kinetic energy to potential one.

Drive Motor

MGC and motor working member are arranged on the same shaft in a strong and tight housing. A built-in motor does not require rotating shaft sealing and provides reliable MGC sealing in fixed joints.

The drive motor includes casing, stator with a cooler, rotor, end closure, bearings and thermal shield with a cooler.

The casing is the main load-bearing member and involves a welded shell with joining flanges at the ends.

The stator with a coil cooler and upper radial bearing are fitted into the casing. Lubricant is feeded to and drained from the bearing through vertical channels made in cylindrical casing wall and spaced uniformly in circumferential.

The stator is double-winded.

The rotor is solid-forged and includes closed active portion of a squirrel cage type.

There are necks for bearings and a toothed disk for rotational speed measuring which is mounted at lower rotor face.

To maintain normal motor temperature two axial fans mounted at the shaft force helium into motor cavity through stator cooler. To increase cooling efficiency helium is circulated by two symmetrical flows through guide device and profiled channels into casing and closure.

Motor is powered by means of 6 sealed leads-in through the MGC.

Outer lead-in ends are joined in two groups (in three leads-in) and enclosed in terminal box arranged at MGC end closure.

The MGC closure is a load-bearing, sealed member on which the casing rests by its lower flange.

The MGC is fastened in the reactor vessel by means of studs, passing through the closure flange portion.

To seal the MGC in the reactor vessel, there is annular lateral ridge for welding on the end closure.

The lower radial and axial bearings are placed in the MGC end closure. Three tachometers of a rotor rotational speed measuring system and pneumatic drive of isolation valve are mounted on the end closure.

All fluids (oil, water, gas) attending the MGC are supplied through the end closure.

The motor rotor rotates in two radial bearings which are oil-lubricated and cooled. The oil is supplied from special servicing system, schematic diagram of which is shown in Fig.3.

When deenergazing oil pumps the auxiliary emergency oil-supply system with an accumulator is provided for the MGC coastdown.

MGC employs hydrodynamic and hydrostatic radial bearings, commonly exploited in rotor machines /3/.

The axial bearing is of hydrodynamic type with oil lubricating, with steel/babbit hard-facing friction couple.

The axial bearing is made double-acting, to take up aerodynamic force appearing at the impeller which lifts the rotor at nominal rotational speed. However, hydraulic scheme of its loading allows bearing to operate only on the bottom support. Such bearing opera-

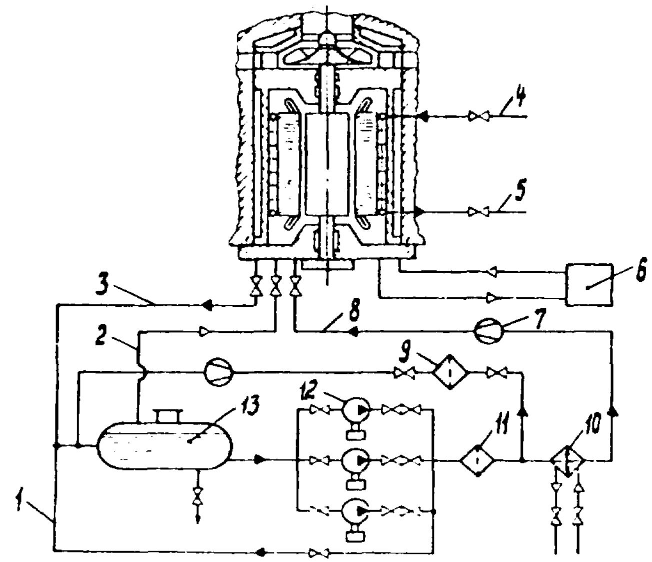

FIG.3. MGC auxiliary systems diagram.
1) oil pump bypass; 2) gas connection line; 3) oil drain; 4) and 5) cooling water supply and removal; 6) buffer seal helium clean-up system; 7) flow-meter; 8) oil supply; 9) fine filter; 10) oil cooler; 11) coarse filter; 12) oil pump; 13) circulation tank.

tion scheme excludes the occurence of self-exited rotor oscilations in rotor/bearing system.

High circumferential shaft speed was the main consideration when choosing the lubricant for MGC bearings. Preliminary calculations showed that kinetical oil viscosity should not exceed $15 \times 10^{-6} m^2/s$, to prevent large friction losses in the thrust bearing. Besides, the oil should have the properties that comply with specific MGC operation conditions, namely: increased radiation and

thermal-oxidative stability, dielectric properties and low vaporability.

Due to stringent requirements specified to oil leakage into the reactor coolant, much attention was given to free oil draining of bearing units. The oil can leak into the inner MGC cavity and consequently into the reactor circuit only through oil drain cavities. To minimize oil leakage into the coolant the MGC is equipped with:

1) a buffer seal, placed between flow path and bearing cavities, which is schematically shown in Fig. 4;

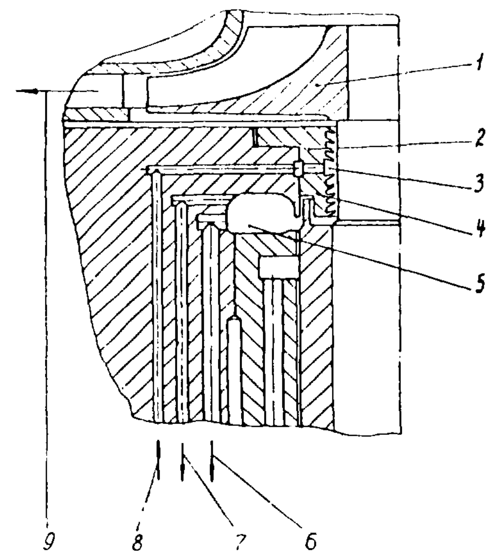

FIG.4. Buffer seal.
1) gas circulator impeller; 2) upper labyrinth; 3) buffer chamber; 4) bottom labyrinth; 5) bearing cavity; 6) bearing oil draining; 7) sealing helium return; 8) sealing helium supply; 9) helium working flow direction in the circulator.

2) floating rings mounted at the shaft with small radial gaps which reduce leakage flow into the oil drain chamber;

3) oil drain chambers having large volume and surface area to decrease oil draining velocity and splashing;

4) labyrinth seals between oil drain chambers and the inner MGC cavity;

5) oil removal line in the upper bearing downstream the lower floating ring and oil drain into the upper chamber (more than 90% of flow rate from the lower ring) with large volume and surface area.

Below the flow path thermal shield and a cooler are located, which should provide motor and bearings protection against temperature effects of the coolant flow circulating in the gas path.

Isolation Valve

The isolation valve is intended for the rapid gas circulation shut off in the primary loop and, also, for helium backflow limitation through the loop when the MGC is shut down. The isolation valve in the form of annular shell is placed downstream the outlet passage. Three guide rods rigidly fastened to the annular shell provide for its axial movement.

Drive line's penetration to the pneumatic drive through the end closure is sealed by means of a sylphon set maintaining the designed stroke.

The pneumatic drive is a double-acting piston with a cylinder, which positively moves the annular shell both up- and downwards. The pneumatic drive retains the piston in the limiting positions when the working fluid pressure is released completely. The pneumatic drive is equipped with manually operated drive for the specific conditions

MGC Operation Monitoring

To maintain MGC normal operation, primary instrumentation is provided for the most critical units.

MGC operation monitoring is made for:

- stator and bearing temperature;
- bearing body and MGC casing vibration;
- rotor oscillatory shift;
- oil pressure in the oil wedge of axial bearing;
- rotor rotational speed and direction.

Servicing MGC Systems (Lubrication, Cooling, Sealing Gas, Rotational Speed Control)

Lubrication and cooling systems are similar to those of the systems used in reactor coolant pumps /4/.

The development of these systems doesn't cause any problems.

Sealing gas system intended for buffer seal normal operation includes facilities for gas purification from impurities and oil vapour.

The thyristor frequency convertor is used as motor rotational speed control system.

5. EXPERIMENTAL WORKS

MGC Flow Path

MGC flow path was developed using air model in accordance with a special test program. Scale factor was taken to be 0,291. Gas-dynamic calculation data and circulator flow gas path correspondence with specified requirements were verified in toto by scale model testing.

Bearings

Interchangeable radial oil-lubricated bearings of two types are used in the MGC. Radial bearings are chosen according to the results of MGC tests in all operational conditions. Hydrodynamic segmental bearing was applied as the MGC axial bearing.

Due to relatively high loads (2MPa) on the bearing when starting the MGC and wide rotational speed range (300-6000 rpm) the said bearing was tested at special test rig with simulating of all operation loads. Its operability was verified by first stage tests. For all this, the babbit facing temperature didn't exceed 100°C under maximum possible loads on the bearing.

To check and develop of oil leakage drain from the upper bearing, the model test rig of 0,33 scale was made. The water was used during the first test stage as a lubricant.

For the most part, the model revealed qualitative behaviour of leakage draining.

To increase test representability, circulating the oil through the model was scheduled, that is being done now.

Isolation Valve

To develop the experimental valve design and verify its kinematics and sealing elements, the full-scale rig was designed.

Air tests proved valve's and pneumatic drive's operability.

Sealing element test and gas leakage determination through the closed valve were carried out in the air.

The final valve tests under conditions close to operational ones will be made (as a part of the MGC) at a helium rig.

MGC Motor Cooling Loop

The model with scale factor 0,5 was developed to verificate gas-dynamic characteristics of the loop cooling the motor which operates in the range of 300 - 6000 rpm, under the pressure of 5-0,1 MPa (when the reactor depressurizing) and air content in helium up to 98%.

Model testing in the air proved calculated cooling loop parameters.

Circulating gas flow distribution along the loop is uniform and consistent with designed data.

6. CONCLUSION

When designing the MGC the engineering decisions providing high MGC tightness, acceptable mass and overall dimension parameters, protection of reactor circuit and motor cooling loop against lubricant-coolant ingress, obtaining the required gas-dynamic characteristics were taken into account and implemented in the design.

REFERENCES

I. Дорофеев А.И., Кошкин Ю.Н., Комаров Е.В., Кирюшин А.И., Любивый А.Г., Митенков Ф.М., Пономарев-Степной Н.И., Проценко А.Н., Самойлов О.Б., Столяревский А.Я. Прототипная атомная высокотемпературная установка ВГ-400 для использования в энерготехнологическом производстве. "Вестник Академии наук БССР", Серия физико-математических наук, 1982г., № 3, с.54-61.

2. В.С. Бекнев, Р.З. Тумашев, В.И. Костин, А.И. Максянин, В.М. Мартынов, В.Н. Морозов, Э.Г. Новинский, С.М.Романов Расчетно-экспериментальное исследование осевых и центробежных газодувок для АЭС и АЭТУ с ВТГР. Вопросы атомной науки и техники серия: Атомно-водородная энергетика. 1978, вып.I/4/ с.154-158.

3. Н.А. Вахрамов, Э.Г. Новинский, В.М. Попов, Р.З. Тумашев Подшипники скольжения энергетических роторных машин. Москва, НИИЭинформэнергомаш, вып.12/3-85-07/, 1985, 40с.

4. Митенков Ф.М., Будов В.М., Новинский Э.Г. Главные циркуляционные насосы АЭС. Москва, Энергоатомиздат, 1984, 320 с.