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Preliminary test program

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PRELIMINARY TEST PROGRAM

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SUMMARY AND CONCLUSIONS

The feasibility study for a seal system for the HTR rotor shaft revealed that several technologies were possible: labyrinth seal plus stuffing box, labyrinth seal plus brush seal, or a combination of the two, with an additional system, if required.

No matter which design is selected, a series of tests will have to be carried out to check the performance levels and leak rate of the assembly. The wear rate will also have to be examined to determine the service life of the assembly and the maintenance requirements.

The validation tests can be divided into three stages:

- tribological testing of potential materials,
- development of a full-scale prototype to assess performance and analyze behavior by means of tests conducted in normal and transient conditions,
- validation of the final design by means of an endurance test.

Notes:

(1) Security level (delete where inappropriate)

NORM	Unrestricted
FILT	Restricted, subject to the agreement of author and customer
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(2) Document type (give the appropriate code)

APPRO	Procurement specification
CON	Inspection specification
CR	Report
DF	Supplier document
EQUIP	Equipment specification
FMO	Procedure data sheet
NT	Technical memorandum
PROC	Procedure
QMO	Procedure qualification
RECETTE	Acceptance specification
RES	Test report
RET	Design report
RT	Technical report
STAGE	Training course report

CONTENTS

1. INTRODUCTION

The feasibility study for a seal system for the HTR rotor shaft (ref. [1]) revealed that several technologies were possible:

- labyrinth seal plus stuffing box,
- labyrinth seal plus brush seal,
- or a combination of the two with the addition of a secondary system (ferrofluid or other) if required to prevent leakage.

No matter which design is selected, a series of tests will have to be carried out to check the performance levels and leak rate of the assembly. The wear rate will also have to be examined to determine the service life of the assembly and the maintenance requirements.

This preliminary document is based on the conclusions of ref. [1] and aims to list the projected tests to be carried out to characterize the seal system and establish a test bench principle. The technical requirements and required leak rate values are given in Section 3.

2. REFERENCE DOCUMENTS

[1] – Feasibility study for a helium rotating shaft seal for turbo generator.
Framatome ANP Report HTR-E 03/10-D-4-2-3.

3. TECHNICAL REQUIREMENTS

Normal or exceptional operating conditions are as follows:

- operating fluid: dry helium,
- operating pressure: 26 bar,
- operating temperature (near the leak): 110°C,
- normal design temperature: 150°C,
- exceptional temperature for a short period: 450 to 500°C,
- operating rotation speed: 3,000 rpm (approx. linear speed 80 m/s),
- possible overspeed: 3,600 rpm,
- shaft diameter: 450 mm minimum,
- axial clearance: 0.5 + approx. 10 = 10.5 mm,
- radial clearance: 0.4 mm,
- seal lifetime: 60 years with inspection and regular replacement of parts (as infrequently as possible),
- required leak rate:
  - GT-MHR model: 10% by weight of primary helium/year, i.e. 0.31 Nm^3/h (55 g/h),
  - PBMR model: 0.1% by weight of primary helium/day, i.e. 0.86 Nm^3/h (154 g/h).

HTR prototypes, FSV (Fort Saint Vrain - USA) and HTR Steam Cycle in Germany, have shown that it is technically feasible to obtain a value of 0.1% a day, with a permissible maximum of 1% a day for FSV.

Leak rates are only considered for primary helium containing active impurities.

If the seal system includes a gas barrier with clean helium from an auxiliary system, it would be reasonable to aim for a leak rate equal to the volume of primary helium per year, i.e. 0.27% a day. This would also be more economical in terms of development costs. Likewise, a maximum permissible value of 1% a day is recommended for FSV.

Jeumont's preliminary design study (see ref. [1]) showed that it was technically possible to achieve a leak rate of 2.5 Nm^3/h, i.e. 0.22% a day.

4. TEST PROGRAM

The seal system characterization program can be divided into several successive stages which, like the test bench and corresponding instrumentation, will depend on the technology selected, the prototype design and the results obtained from the tests.

This preliminary program does not claim to be exhaustive and is to be taken merely as a basis for determining test, bench and instrumentation requirements.

4.1. Choice of materials

The first stage consists in identifying pairs of materials using tribological helium tests to characterize seal ring wear in the case of mechanical stuffing boxes or wear of the brush wires. The need for surface coating or treatment of the fixed and moving parts (rotating ring or rotor) is also assessed at this stage. The results obtained will determine which tests are to be carried out subsequently, particularly the endurance test, and will be used to assess future maintenance requirements and wear part replacement rates.

4.2. Tests carried out in nominal conditions

The leak rate has to be determined for a full-scale prototype seal system in normal pressure and temperature conditions and at nominal speed, using helium. These tests should make it possible to determine the final design.

The test campaign will therefore serve to optimize the geometrical parameters of the parts (tolerances, clearance values, etc.), determine the cooling requirements and establish whether or not a supplementary seal system needs to be added (ferrofluid or other).

The instrumentation used during the tests gives information on the general behavior of the seal:

- leak rate measurement,

- mappings of pressure (static and dynamic) and temperature of parts (fixed and moving seal rings for example),
- measurement of the thickness of the gas layer between the fixed and moving parts,
- measurement and optimization of the auxiliary injection flow rate, if there is one, to meet leak rate requirements and cool the assembly,
- measurement of speed of rotation and resistance torque,
- measurement of static (axial and radial displacement) and dynamic (vibrations) behavior.

4.3. Additional tests

These additional tests will serve to examine the behavior of the seal during exceptional operating conditions:

- speed acceleration and deceleration,
- misalignment of the axes between the fixed and moving parts,
- loss of auxiliary injection,
- overspeed,
- overheating of the helium beyond the operating temperature of 110°C (the requirements include the possibility of an exceptional temperature of 500°C for a short period of time).

During this test phase, the instrumentation measures the same parameters as before.

4.4. Endurance test

The last stage consists in checking the overall performance of the seal by means of a test carried out over a long period of time in normal operating conditions.

It is hard to say how long this test should last, but the design data should give a good indication (estimated lifetime of the seal). Alternatively, the test should last sufficiently long for the seal characteristics to become impaired so that the damage caused can be compared to the tribological tests and extrapolated over time to determine the maintenance requirements.

For this type of test, static measurements are monitored continuously and some dynamic measurements are made at regular intervals.

5. TEST BENCH

In view of the test campaigns to be carried out, three types of test bench have to be provided:

1 – One tribological helium test bench for the stuffing box and brush wear tests. If it does not run at operating speed, pressure and temperature, the representative nature of the tests in relation to the actual operating conditions will have to be justified.

2 – One test bench for carrying out tests on a full-scale prototype in normal and exceptional operating conditions to check the performance levels of the seal. This is a short test requiring small amounts of helium and could be carried out using small cylinders or containers. The target leak rate is around 2.5 Nm^3/h (≈ 450 g/h). This bench could be similar to the version shown in Appendix A, which is applicable for a GT-MHR vertical configuration.

3 – One test bench for the endurance test and any other tests required.

The tests to be carried out on the second bench are mainly a question of fine-tuning in normal operating conditions; they require only small amounts of helium but a high degree of reactivity for modifying the test loop (instrumentation, etc.) or the prototype, if required. It would be ideal if there was a flexible structure available independently of the endurance test bench.

For the endurance tests, which could last several months, there should be a larger loop so that the test would not have to be interrupted, a continuous supply of helium and a faithful reproduction of actual operating conditions, particularly as regards gas particle content.

The HELITE loop, which will be built at the CEA, seems perfectly suitable for our requirements and simplifies the design of the fine-tuning test bench since helium overheating tests at 500°C could be carried out on it.

6. CONCLUSIONS

The tests to validate the seal system for the rotor shaft should be carried out in three stages:

- tribological testing of potential materials,
- development of a full-scale prototype to assess performance and analyze behavior by means of tests conducted in normal and transient conditions,
- validation of the final design by means of an endurance test.

APPENDIX A

PRINCIPLE OF VERTICAL TEST BENCH
WITH OPERATING PRESSURE AND TEMPERATURE