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HTR-E Project. High-Temperature Components and Systems

The HTR-E European project (four years project) is proposed for the 5th Framework Programme and concerns the technical developments needed for the innovative components of a modern HTR with a direct cycle. These components have been selected with reference to the present projects (GT-MHR, PBMR) :

- the helium turbine, the recuperator heat exchanger, the electro-magnetic bearings and the helium rotating seal.
- the tribology. Sliding innovative components in helium environment are particularly concerned.
- the helium purification system. Recommendations on impurities contents have to be provided in accordance with the materials proposed for the innovative components.

The main outcomes expected from the HTR-E project are the design recommendations and identification of further R&D needs for these components. This will be based :

- on experience feedback from European past helium test loops and reactors
- on design studies, thermal-hydraulic and structural analyses
- and on experimental tests

1. Introduction

The main objective of the work performed for HTR-E is to develop innovative technologies which are needed for the components and systems of a modern HTR with a direct cycle and then contribute to the competitiveness, safety and acceptability of such reactors. The competitiveness of such reactors is based on the use of these technologies for each high efficiency components and systems which allow, at the end, to reach a net plant efficiency of around 50 %. Similarly, high performances components and systems in terms of thermo-mechanical resistance, lifetime, maintenance, behaviour in case of failure,… are required to demonstrate the safety and to contribute to the acceptability of such reactors.

The critical and innovative components and systems have been selected by reference to the present projects with a direct cycle concept (GT-MHR, PBMR) as shown on fig. 1 and 2.

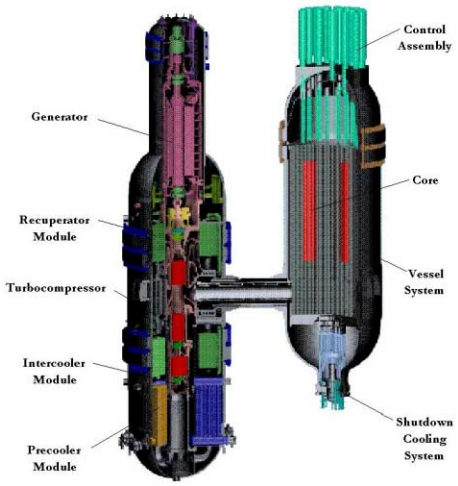

Fig. 1. GT-MHR MODULE

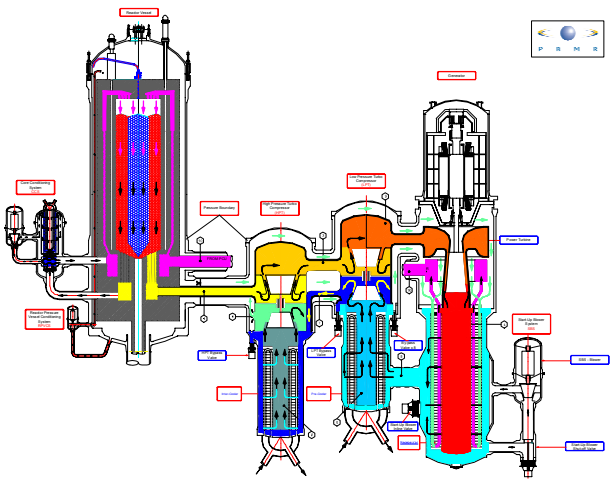

Fig 2. PBMR module

The key components and systems selected for HTR-E are :

- the helium turbine,
- the helium/helium heat exchanger called recuperator,
- the large capacity magnetic bearings,
- the helium leak-tightness rotating seal,
- the tribology,
- the helium purification system.

Design recommendations and identification of further R&D needs for these components will be provided taking into account :

- the experience feedback from European past helium test loops and reactors (EVO, HHV, KVK, Dragon, AVR and THTR) but also from reactors outside Europe (Peach Bottom, FSV, HTTR, HTR-10), and also from other technologies (FBR, AGR, PNP plant,…),
- the design studies, thermal-hydraulic and structural analyses with CFD and FEM codes (DACAT, BLADES, CAST3M, Fluent, STAR CD, ANSYS, NASTRAN, MLDyn codes),
- and the tests performed on experimental facilities (CLAIRE high temperature heat exchangers test facility from ESTHER platform of CEA, FLP 500 test facility for AMBs of Zittau university, tribological test facilities).

The work will be carried out over a period of four years split into two main phases of two years. The first phase concerns the experience feedback, the specifications and design studies and the second one the validation, the tests, the identification of further R&D needs and recommendations for the main components and systems of a modern HTR with a direct cycle. The budget is 3,5 million Euro (50% funded by EC).

The partners involved in the HTR-E project are : Framatome ANP, CEA, Zittau university, NRG, FZJ, EA, NNC, Jeumont, S2M, Ansaldo, von Karman institute, Heatric, EVO, Aubert et Duval, Borsig Energy GmbH.

2. Turbine

The direct cycle concept is the main feature of a competitive and safe modern HTR. Then the feasibility of a high efficiency helium turbine, inserted in the primary cycle, is the most important technological key issue for the components of a modern HTR. There is however no industrial experience for the HTR typical operating conditions (helium gas, 850°C, 100-300 MWe range, long time operating conditions with high reliability...).

An important work program is proposed in HTR-E. It is complementary to the material development work program carried out in the HTR-M project. It consists in :

Phase 1 : SPECIFICATIONS-STATE OF THE ART-PRELIMINARY DESIGN

- Design use, system review, integration and ISIR (GT-MHR and PBMR type reactor),
- Review of existing technologies from past HTR experience and other industries,
- HHV data and turbine inlet thermal insulation,
- EVO design data and measurements for specified load cases,
- HTR-M results analysis,
- Design study (turbine and thermal insulation at the inlet)

Phase 2 : DESIGN ANALYSES

- Thermal and thermo-mechanical analysis (CAST3M, ANSYS codes),
- Aerodynamic design-CFD calculations (DACAT and BLADES codes, inverse method),
- Experimental tests program definition

3. Recuperator Heat eXchanger (HX)

The recuperator is a helium/helium heat exchanger inserted in the primary circuit to recuperate a part of the remaining energy at the turbine outlet to preheat the helium at the core inlet. This component is specific to the direct cycle and its main function is to increase as high as possible the efficiency of the cycle. The competitiveness of a modern HTR is directly linked to the feasibility of this key component particularly loaded in Temperature and Pressure difference. The work program consists in :

Phase 1 :

SPECIFICATION OF TYPICAL OPERATING CONDITIONS (GT-MHR and PBMR type reactor)

REVIEW AND IDENTIFICATION OF EXISTING TECHNOLOGIES

- Technological survey of high temperature heat exchangers used in industry : conventional shell and tube units as well as helical finned tube and compact plate heat exchangers will be considered,
- Consultation of manufacturers specialised in large heat exchangers,
- Engineering studies on 2 or 3 basic concepts, CFD calculations (Fluent, STAR CD code), thermo-mechanical analyses (ANSYS code), see fig.3 and 4 two potential concepts for recuperator application,
- Selection of reference concepts; the development and test program of the next phase will be established.

Phase 2 : FEASIBILITY STUDY AND VALIDATION TESTS

- Definition of small scale units for high temperature testing (participation of HX manufacturers)
- Adaptation of the test rig (CLAIRE loop of the ESTHER platform) and preliminary testing
- Validations tests
    - Steady state testing under actual flow conditions and ambient pressures
    - Transient testing (cycling at high temperatures)

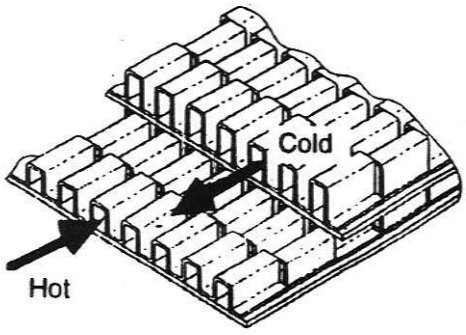

Fig 3. Plate fin concept

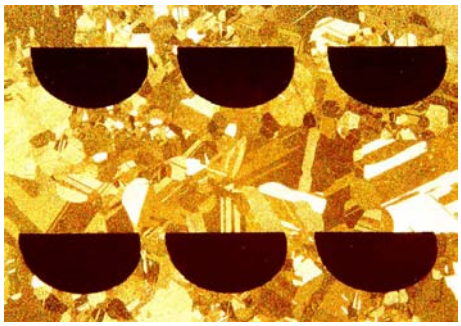

Fig 4. Micro channel concept (HEATRIC)

4. Electro Magnetic Bearings (EMBs)

These components are used to support the rotating shafts of turbo-compressors or turbo-machine inserted in the direct cycle of a modern HTR. This kind of support has been selected for a modern HTR to avoid the risk of leakage and fluid ingress in the primary circuit induced by the concept of mechanical and lubricated bearings (bad experience feedback in US and German former HTRs). So, the magnetic bearings for rotors support are considered as key components with regards to the safety and competitiveness of a modern HTR. The work program consists in :

Phase 1 :

FUNCTIONAL REQUIREMENTS-LOAD ANALYSIS-FEASIBILITY STUDIES

- Functional requirements
- Definition of the functional requirements under normal and emergency operating conditions for Active Magnetic Bearing and Catcher Bearings
- Load analysis. The bearings loads are determined by analysis of HTR loads, Finite Element Methods (ANSYS code) and Real Time Simulation (MLDyn code).
- Permanent MB feasibility study
- Catcher bearings feasibility study

CONCEPT PROPOSAL-MECHANICAL ANALYSES

- Concept proposal for bearings and diagnosis. Depending on the special requirements and the results of the load analysis a concept will be designed for Active Magnetic Bearings (including controller, sensor and power electronics), Catcher Bearings and Diagnosis Systems.
- Mechanical analyses. The magnetic, thermal, and structural behaviour of the magnetic bearing system (start-up, shut-down, unbalance, emergency shut-down) will be determined by means of transient Finite Element Methods (ANSYS code) under the load cases previously defined.

Phase 2 : EXPERIMENTAL VALIDATION-RECOMMENDATIONS

- Experimental validation AMB (FLP 500 test facility, see fig. 5 and 6). The main aims of experimental part are the validation of the designed system and dynamic behaviour as well as the investigation of single effects. Further parts are to test the algorithms of the diagnosis system and catcher bearings.
- Recommendations and statements

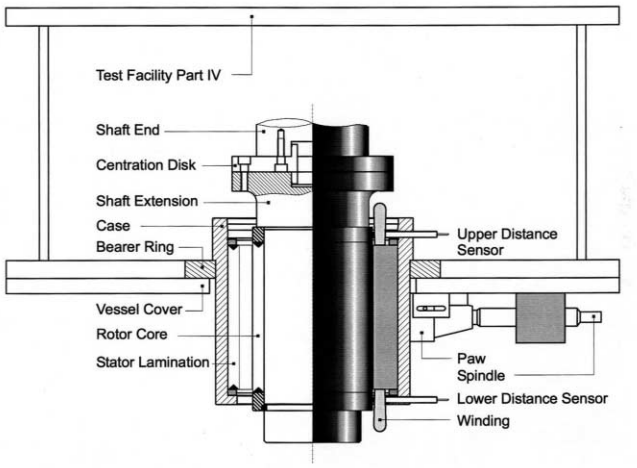

Fig 5. FLP500 test facility

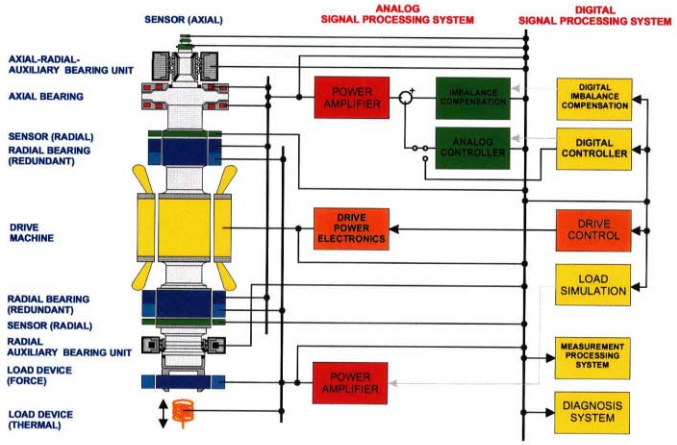

Fig 6. FLP500 EMBs and load device

5. Helium rotating seal

The helium rotating seal is associated with a rotor of the turbo-machine penetrating through the primary vessel. In this case the generator is located outside the primary circuit that simplifies the maintenance operations and allows to use mechanical bearings for the support. So this concept can be considered as an alternative of a fully immersed rotor in primary helium and consequently fully supported by magnetic bearings. The feasibility of such a seal is a key issue to increase the competitiveness of a modern HTR by reducing the maintenance campaign duration. The work program (Phase 1 only) consists in :

STATE-OF-THE-ART AND SPECIFICATIONS

State-of-the-art and specifications concerning helium leak rates in previous or similar projects, classification of the potential leakage areas of a "typical" HTR design, existing technologies and their performances

FEASIBILITY STUDY

- Canned magnetic bearings. Single effect analysis for Canned Active Magnetic Bearings on basis of theoretical and experimental investigations
- Dry system. In connection with the analysis of the existing devices, a suitable concept of dry system as regards the HTR conditions will be defined, and justified by theoretical analysis.
- Liquid, gas, ferro-fluid barrier. In connection with the analysis of the existing devices, a suitable concept of the system as regards the HTR conditions will be defined, and justified by theoretical analysis.
- Dry system. Stability and leakage analysis (STAR CD code). The objective of this task is to determine whether the selected dry seal designs meet the requirements for functionality and structure integrity
- Experimental tests program definition

6. Tribology

Sliding and new components (stator seals, hot gas duct seal,…) of a modern HTR with direct cycle are particularly concerned. It must be noted that a bad operating of these sliding components will dramatically impact the safety and availability of the reactor. The work program consists in :

Phase 1 :

UPDATING OF THE STATE OF THE ART

- Review of tribological problems on a HTR
- Review and identification of typical tribology conditions of components
- Review of the existing materials and coatings

PROPOSAL OF ELEMENTARY CONFIRMATION OR ORIENTATION TESTS

Phase 2 : ELEMENTARY TESTS – COMPENDIUM OF RECOMMENDATIONS

- Tests with representative tribological and environmental conditions. Tests will be performed on a selection of materials and antagonistic couples, in representative configurations (sliding + fretting, sliding + bearing (gears)), and in representative conditions : HTR non pure Helium, 500-750°C, 70 bars.
- Redaction of a compendium of recommendations

7. Helium purification system

The performances of this system impact directly the safety of a modern HTR as it controls the level of impurities in the primary helium. It is a key system to limit the corrosion risk of the graphite and materials of all components of the primary cycle. The work program (Phase 1 only) consists in :

ANALYSIS OF HELIUM ENVIRONMENTS IN FORMER HTRS.
Available literature and data from former HTR projects will be collected and archived in electronic form. Additional relevant knowledge from other sources (HTTR, HTR-10, Magnox, AGR, helium test loops) will be included in a state-of-the-art report.

SPECIFICATIONS FOR THE HELIUM IMPURITIES CONTENT.
Specifications and recommendations for the helium impurities content and the control system will be provided for a modern HTR with direct cycle (GT-MHR and PBMR type reactor). The possible range of impurities in helium (H_2O, H_2, CO_2, CO, CH_4) and graphite particles has to be defined taking into account the risk of corrosion, erosion of the materials. Feedback experience of the Helium purification system will be recovered and analysed. These data will be useful to the selection of grades for high temperature materials tests in HTR-M and also to the tribological tests in helium environment.