**Advanced Turbine System
Conceptual Design and Product Development**

**Annual Status Report (Draft)
for
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I. Introduction

This is the third annual technical progress report for the subject program since the contract was signed on April 24, 1995. The discussions are organized by WBS task. There is also a general discussion at the end.

II. WBS 1 - Project Plan

The Project Plan for the subject program was submitted (mailed) to the Department of Energy (DOE) on May 18, 1995. This task is complete.

III. WBS 2 - NEPA Report

The information required for the NEPA Report was submitted (mailed) to the DOE on June 22, 1995. DOE approval of the report was received by ABB on August 2, 1995. This task is complete.

IV. WBS 3 - GFATS Selection

The technical work on this task has been completed and presented to the DOE.

V. WBS 4 - Conversion to Coal

Surveys of potential Task 4 CFATS cycles were completed. A brief overview of the results of this work to date were also presented at the September 27, 1995, briefing with the DOE. No further efforts will be expended on this task based on our redirected program work.

VI. WBS 5 through WBS 8 - Ongoing and Replanned Tasks

The replanning of the program was finalized and approved by the DOE. The following tasks are included:

- Thermal Barrier Coating and Steam Oxidation
- Advanced Air Cooled Blading
- Turbine Aerodynamics and Aero-Thermal Integration
- Advanced Steam Cooled Vanes

Task 8.2 - Thermal Barrier Coatings (TBC) and Steam Oxidation

- **Evaluation of TBC Systems in high Temperature Gradients**

Oxidation of the bond coat and thermal gradients are main influence parameters on the life time of TBC systems. In this task different TBC systems are tested in a high velocity burner rig for fast oxidation. To simulate the thermal gradient the test bars are internally cooled. Various coating systems are compared to ABB's SV 20 + TBC as base line system. The following bond coats are considered as relevant: SV20, SE 20, Pt-Al, SV20+SiPdAl, SV20+Vapor Phase Overaluminide. The test bars undergo visual and metallographic/SEM evaluation to assess the amount of oxidation.

2 Sets of TBC coated samples have been tested (Standard TBC thickness and 1mm TBC coating). In average the 1 mm TBC test pieces failed after 370 cycles. The evaluation of the samples with standard TBC thickness (1500 cycles) is ongoing. In order to gain more knowledge for a design data base a detailed calibration of the test rig would be required. The current results allow only a qualitative comparison between different coating systems.

- **Monitoring of degradation of TBC**

The aim of this task is to assess technologies for monitoring the degradation of the TBC bond coat system, one of the major influence parameter for TBC spall off. Standard practice until now is cut-ups and metallographic assessment. Ultra sonic or eddy current signals can be used to determine the amount of oxidation in the bond coat interface. Test specimen have been manufactured, "as received" test specimen have been assessed to establish the baseline for the degradation of the bond coat. The coated test specimen have been exposed for more than 1500 hours at 1100 C, the test specimen were analyzed by SWRI using ultrasonic and eddy current techniques. A metallographic assessment was used to derive a correlation between the NDE-Results and the amount of bond coat oxidation. Pre oxidized engine run test

pieces have been added to the test matrix to get engine relevant data. However the scatter band of the results is to wide to draw decisive conclusions.

The task is completed and a topical report was issued.

- **Thermo Mechanical Fatigue (TMF) of TBC**

Since components coated with TBC are subject to severe mechanical and thermal loads which vary during engine operation the response of thermal barrier coated components to TMF is an important aspect of design. TMF testing is carried out on different coating systems on a CMSX4 single crystal substrate. The test are being performed at 50 - 1000 C “out of phase” strain controlled conditions.

⇒ Baseline results of uncoated test bars are completed, Results:

- 1% strain range 536 cycles to failure
- 0.85% strain range 1827 cycles to failure
- 0.65% strain range >5000 cycles (test stopped)

⇒ Test bars with metallic coatings (PT-AL) have achieved the following

- 0.65% strain range 1162 cycles to failure
- 0.45% strain range 4696 cycles to failure

⇒ Test bars with SV20 coating have achieved the following

- 0.65% strain range 299, 459 cycles to failure (test are repeated)

⇒ Test bars with SV20 + TBC and 0.65% strain range reached more than 5000 cycles without spall off of TBC. The test were stopped at 5000 cycles.

The metallographic analysis of all test pieces is ongoing.

- **Kinetics of oxidation in steam**

The purpose of this task is to conduct long-term exposures of test pieces of selected alloys at temperatures up to 950 C and to compare the rate of oxide growth with that obtained in air. Previous work at ABB involved short-term exposures of a wide range of alloys. The current work is directed to long term exposure of selected alloys, i.e. IN738, CM247 a typical DS alloy, and CMSX4 a typical single crystal alloy.

Compared to literature data of oxidation in an air atmosphere at the same temperature there is no significant increase in oxide growth in a steam atmosphere. Within 5000 hours of exposure time CMSX4 has the highest oxidation resistance, spallation of oxide scale was not observed, CM247-DS and IN 738 showed considerable oxide spallation during the exposure time. Fig. 1 and Fig 2. summarizes the results.

This task is completed and a topical report has been issued.

Task 8.3 - Advanced Air-Cooled Blading

Objectives of this task were to develop a design data base for the most advanced cooling systems by addressing design uncertainties. Advanced Impingement cooling and advanced convection cooling have been identified as areas to be investigated. Impingement cooling is quite often used for cooling of the inner and outer turbine annulus and for vane leading edge cooling. In the past reporting period an existing test rig has been modified to suit the objectives of this program. Test geometry models have been developed.

Work completed during the subject period included the following:

- air transfer system has been identified as a second source of uncertainties. A numerical approach with a simplified experimental back-up has been used to analyze this uncertainty. The investigation is completed, the results have been discussed in a topical report.

ABB designed an upgrade for the ABB gas turbine Type GT11N for improving efficiency and power out put of existing gas turbine or combined cycle power plants. This design, called the GT11NM (fig. 3 shows the areas that have been redesigned), used design correlation derived from the impingement cooling measurements, that have been performed in an earlier reporting period. The first engine went into operation at Midland Cogeneration Venture in May 97. It could be demonstrated that improvement in aerodynamic design and cooling technology leads to an increase in out but of close to 10 % and an efficiency increase of 6% (multiplicative). This values exceed the expectations considerable. At the same time the metal temperature could be decrease compared to the original design, and due to the more homogenous metal temperature distribution the component reliability will be positively influenced. Details were reported in a topical report.

Task 8.5 - Turbine Aerodynamics and Aero-Thermal Integration

The objective of this task is to measure the performance and heat transfer of a film cooled turbine stage and to determine the interference between turbine cooling and turbine aerodynamics. The Gas Turbine Laboratory at the MIT has developed a test bed suitable to measure aerodynamic performance and heat transfer under full engine operation conditions. By applying similarity laws it is possible to scale down the turbine stage to fit into this test rig. The important advantage from this approach is its cost effectiveness, the ability to design the surrounding for easy access of instrumentation, low energy costs and small down time to exchange hardware. The disadvantage is that the measurement time window is only 300 millisec that implies requirements towards data management during the measurement. A

second challenge is the probe design and calibration to achieve the required accuracy of the measurement.

Work completed during the subject period of performance:

- Hardware design and manufacturing (uncooled turbine stage) was completed.
- probe design was completed and all probes manufactured and calibrated.
- tunnel shake down tests including instrumentation
- data reduction model completed
- all test with the uncooled stage were completed

Fig. 4 shows a picture of the assemble test rotor.

Next steps:

- modify hardware to simulate cooling
- tests with the cooled stage.
- Data reduction

Task 8.6 - Advanced Steam-Cooled Vanes

The favorable heat transfer properties of steam admit the possibility of closed fully internally cooled turbine components in environments which have traditionally required extensive surface film cooling in air-cooled systems. This would include operation in the nominal 1750K range. The concept of closed loop cooling at this firing temperature poses a number of formidable challenges from heat transfer, flow management/sealing and structural/materials perspectives. The objectives of this tasks are to generate a data base for steam cooled component design and to conduct sub-component bench tests of critical cooling features and seals.

Specific work completed on this task during the subject period included:

- 2 concepts were developed:
 - radial holes
 - spanwise rectangular cooling channels with variable aspect ratios and spacing
- Both concept are able to meet the cooling requirements however the concept with rectangular channels tends to be favorable for manufacturing.
- Model geometry was developed for basic analysis of the heat transfer with steam
- test rig has been set up for heat transfer measurements.

As discussed in the advanced air cooling part engine test have been carried out with a vane design that used results from this program in a GT11N. This test will be used as baseline for

the installation and measurement of the steam cooled vane. This is planned for FY1999 at MCV. Discussion with MCV is ongoing on the final planning.

VII. WBS 9 - Program Management/Reports

Work accomplished under this task during the subject period includes the following:

- Labor Plan, Cost Plan, and Milestone Schedule/Plan were submitted in October 1997.
- ABB Monthly Status Report, Summary Report, Milestone/Schedule Status Reports, Labor Management Report, and Cost Management Report were submitted to the DOE during the subject period.
- ABB Quarterly Technical Progress Reports for the reporting period were submitted to the DOE.
- ABB Subcontracting Semi-Annual and Subcontract Yearly Reports were submitted to the DOE.
- Contract Modifications MM004 and A005 have been negotiated with DOE.
- Participation and project progress presentation on the annual ATS conference in Morgantown, WV
- Topical reports for Task 8.2.2, Task 8.4.4, Task 8.3 and Test results of engine demonstration of the technology have been submitted to the DOE.

VIII. General Discussion

During the period of performance focus was directed on the critical testing work. All test rigs were completed and commissioned. Test work for heat transfer analysis and the material test work were completed and the results have been discussed in topical reports.

Some of the initial work has been used in a design called GT11NM that went into operation at MCV in May 1997. Performance improvement goals have been exceeded.

The uncooled turbine stage tests at the MIT could be completed as well, however we encountered several technical problems with the test rig that caused a significant delay in the work progress. Due to this problems the tests with the cooled hardware are approximately 6 month behind schedule.

The progress on the steam cooled demonstrator design is progressing slower than planned, so that the demonstration that was planned for the FY 98 must be shifted into FY 99.

Some open issues on the material side could be addressed in a further continuation of the existing program. A proposal has been forwarded to the DOE for comment.

Figure 1: Weight gain results in air at 950 C.

Figure 2: Weight gain results in steam at 950 C.

■ Turbine airfoils
 ■ Vane carrier
 ■ Exhaust gas casing struts

Figure 3: Changes to GT11N for Upgrading to GT11NM

Fig 4. : Rotor assembly MIT turbine test rig