SYNTHESIS REPORT

ANNEX 1: SYNTHESIS OF THE INITIAL CONTRACT

"NOISE AND VIBRATION IMAGING TECHNIQUES FOR GAS TURBINE INVESTIGATIONS:'

BRITE-EURAM I Project P.1368
Contract no RI.1B-159
from December 1986 to December 1990

The aim of this first contract was to explore advanced experimental techniques, mainly based on acoustic phased imaging (holography), and their potential interest to detect, localise and identify abnormalities of the behaviour of, industrial turbines under operation. It is thus a feasibility study for a new investigation technique on gas turbines.

This contract was very successful as [his acoustic technique, based on a nearfield ,semi-automated systematic sampling of the acoustic pressures synchronised to the rotor rotation. and later numerically "backpropagated" in the turbine blades middle plane, provided very explicit defects signatures (cf. figure A1 hereafter) when usual accelerometers detections were much less sensitive. In addition, the acoustic imaging approach also provides an accurate localisation of the defect: the grid of the rectangular projection of figure 1 corresponds to the 9 stages of the turbine versus 360°, and the test 5.2 3-D view clearly provides a localisation of the 2 major defects culminating at 146° and 215°. The effective location of the restaggered blades was 142° and 202°. The identification of the corresponding stage was improved by observing the Fourier Transform of these acoustic emergences. because the major harmonics corresponded to the number of blades 01 the rotor stages immediately upstream and downstream of the defects.

Many other impressive detection and localisation examples may be found in the cm-responding final report (dated December 14, 1990) and in [he various publications derived from this work (as listed in Appendix 3).

Another advantage 01 the acoustic techniques is their non-intrusive character, making the test preparation much easier. faster and cheaper.

The association of thermodynamic investigations together with acoustic measurements proved also very promising because the precise identification of the thermodynamic functioning point at any time is very important for turbomachinery to maximise the efficiency. prevent pollution. reduce the risk of internal fouling. and minimise fuel consumption.

It was demonstrated that burner defects or cross-firing problems were detectable as well from the acoustic data. and reciprocality that the joint analysis of the pressure and temperature probes of the nominal turbine operation system together with the vibro-acoustic data was potentially increasing the defect detection and identification probability.

Since operation and maintenance costs are very significant for industrial turbines operators, and the availability of the turbine when required even more critical for the whole process of the industrial plants where turbines are used for general mechanical or electrical power utilities, the potential benefit of these experimental techniques to 'improve the gas turbines maintenance and increase their reliability and availability was perceived as of primary importance.

At the end of this first E.C. Brite Euram I contract, extensive experimental and theoretical work was achieved on real industrial gas turbines of the 3- 10 Megawatts range (mainly the TORNADO engine of U.K. RUSTON Ltd. Company, European leading manufacturer in this power range).

These results included:

- the development of a specific acoustical imaging software (acoustic holography in cylindrical geometry),
- the design and development of an acoustical imaging system including a double-layer array of microphones,
- a multi-chanels acquisition system, based on a 32 bits HP Unix work station),
- the preparation of an engine simulation software (thermodynamic and performance model),
- the, preparation and the performing of the tests (engine at characteristic operating rates of its components, and engine containing realistic simulated faults),
- data reduction of acoustical and thermodynamical measurements. as well as the investigation of faults signatures for different unsteady quantity measurements (acoustic, vibration. internal pressure and shaft displacements).

Simulated faults were: rotor stage fouling. individual rotor blade fouling, individual rotor blade twisted, and stator blade restaggering.

For each of these faults. as tested on an individual gas turbine, a correct identification has been accomplished. This includes both the detection of gross component faults (e.g. minor compressor fouling) and the detection of local faults within the engine component (e.g. an individual damaged blade)- This capability has not been achieved by any other non-intrusive gas turbine health monitoring system. The corresponding methods are summarised in the table 3.2.1 hereafter.

However it was still a long way from these feasibility demonstrations to a turbine health monitoring system:

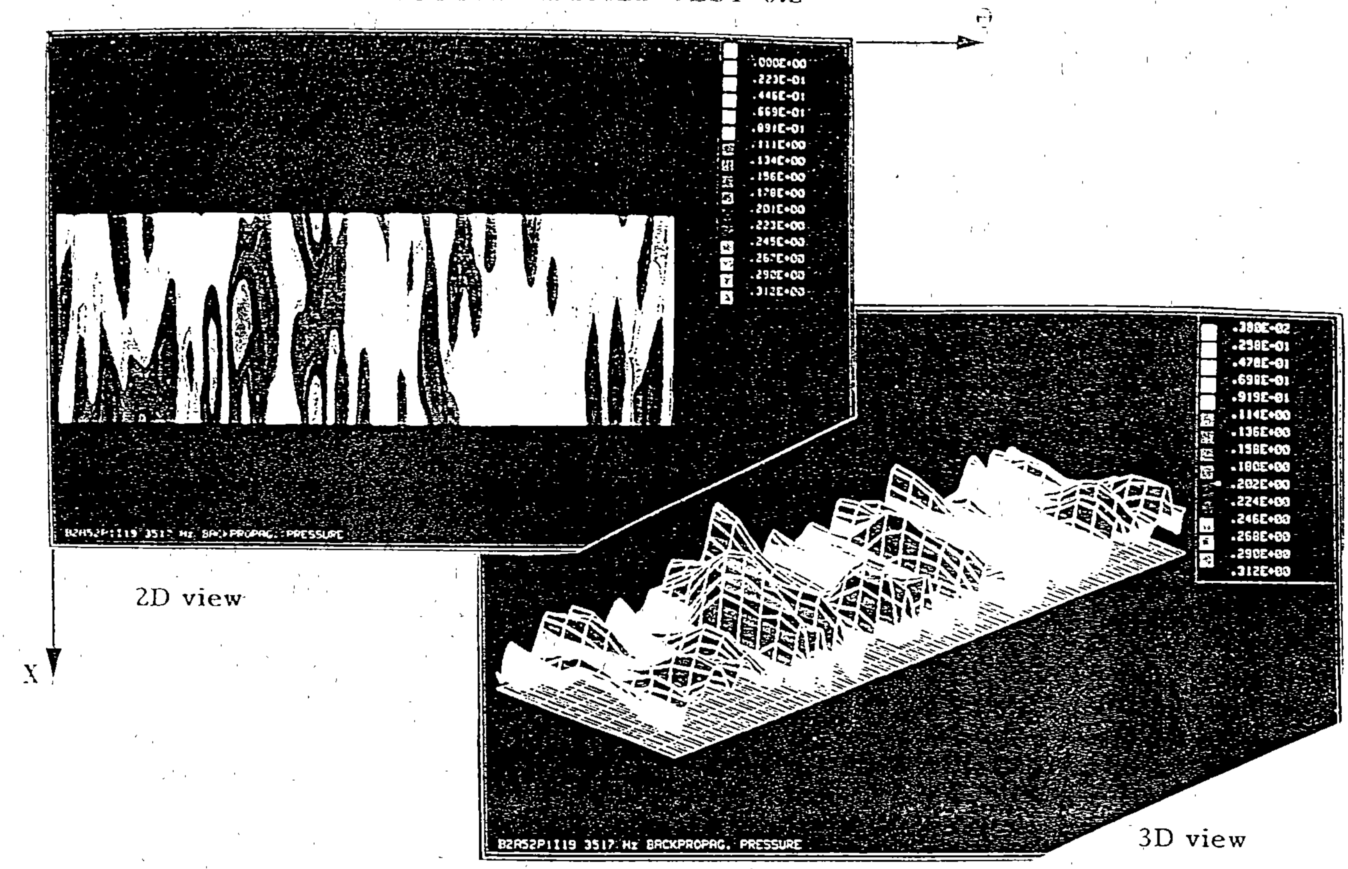
- all the experimental surveys were made from laboratory equipment, induced the acquisition of very large amounts of data and required a great amount of manpower and time to process them,
- as a consequence, the diagnosis was only available several weeks after the test campaign, when a quasi real time reaction would be necessary to prevent any further damage,
- the experimental equipment was also not robust enough to be handled by turbine operators and to survive to such an environment (cf. heat in particular).

DIAGNOSTICAL INFORMATION PRODUCED by the ACOUSTIC EXPERIMENTS

Type of Fault	Proposed Measurements	PRE-TREATMENTS Improvement of Signal/Noise Ratio	LEVEL 1 METHOD for detecting the presence of a FAULT	LEVEL 2 METHODS for diagnosing precisely the FAULT	Information Available at LEVEL 2	Actual Limitations	Expected in the future
STATOR FAULTS	coustic (Non Intru-ive) DOUBLE LAYER YLINDRICAL ARRAY IN HE NEARFIELD of the OMPRESSOR utospectra and rosspectra/Fixed eference on the achine. Triggering with a ey-phasor signal	COUSTIC POWER SPECTRUM (Spatial Integration of Intensity ield) or THER GLOBAL ENERGETIC QUANTITY o be defined	COUSTIC POWER CEPSTRUM(from coustic Power Spectrum PATTERN RECOGNITION on the set ([illegible] rhamonics 1T,2T,3T,4T :Period of Rotation) ithin 2 CLUSTERS (HEAL-HY/FAULTY)	ATTERN RECOGNITION on ACOUS-IC POWER SPECTRUM Wide Peak on Stage Harmonic + igh Peak on next Stage Har-onic) ↓ ARMONIC IMAGES (BACKPROPAGA-ION) and PATTERN RECOGNITION n Spatial Parameters of coustical Fields	YPE of FAULT (Stator Fault) IDENTIFICATION of FAULTY TAGE (AXIAL POSITION) DENTIFICATION Of CIRCUMFEREN-IAL POSITION ONFIRMATION of the TYPE of AULT	FREQUENCY LIMITATION of the PROCEDURE (fmax=5660Hz) TOO MANY ACOUSTIC MEASURE-MENTS (Actually 10 axial positions x150 angular positions of acoustic pro-bes)	Higher Frequency capabil-ities (up to 10kHz) of the procedure for analysing other stages of the com-pressor Reduce significantly the number of probes positions in order to obtain not mor than 100 acoustic signals ↓ Definition of a New Pro-cedure (probably a New pre-treatment and Design of a New adapted synthetic Array including some ana-logical processings)
ROTOR FAULTS	s for TATOR FAULTS	s for TATOR FAULTS	I for TATOR FAULTS	ATTERN RECOGNITION using CEP-TRUM PARAMETERS for rhamonics 1T,2T,3T,4T, nd also 1/1 : Number of blades on rotor tage	DENTIFICATION of FAULTY STAGE nd TYPE or FAULT O be confirmed	II for STATOR FAULTS ↓ Poor temporal resolution for the analysis of the rhamonic T/N ↓ BACKPROPAGATION PRINCIPLE not ACTUALLY ADAPTED to the study of ROTATING FAULTS	as for STATOR FAULTS I [illegible] of SAMPLING FREQUENCY ! Phase locking of acoustic images & adapt principles of acoustic images to rha-monic images, or "Cepstrum Images", for positive identification of rotor faults, including stage number & circumferential position
BURNER FAULTS	COUSTIC (Non Intru-ive) OUBLE LAYER YLINDRICAL ARRAY in he NEARFIELD of the OMBUSTION CHAMBER: imultaneous cquisition of the 2 icrophones signals f 1 acoustic probe	s for STATOR FAULTS	roadband Acoustic POWER SPEC-RUM in low octave bands 63Hz nd 125Hz (Frequency integration f Acoustic Power Spectrum) hreshold values to define & onfirm fault.			TEMPERATURE LIMITATIONS of Acoustic PROBES	High temperature capabil-ities (up to 80°C for acoustic probes)

TABLE 3.2.

ACOUSTIC IMAGES TEST 5.2



Test **5.2** Image with Restaggered Stators

BACK PROPAGATED FIELDS on the compressor's **casing**
(at upstream rotor blade passing frequency)