

**RELIABILITY, MAINTAINABILITY, AVAILABILITY, AND
SAFETY IN ROTATING EQUIPMENT ENGINEERING
APPLICATION IN DESIGN, PROCUREMENT, MANUFACTURING,
TESTING, SHIPMENT, PRESERVATION, INSTALLATION,
COMMISSIONING, OPERATION & MAINTENANCE**

**OIL, GAS & POWER GENERATION INDUSTRIES
(WORLD CLASS LEVEL)**

VOLUME 3 - GAS TURBINES

PART 1

INDEX.

I.- AUTHOR'S EXPERIENCES – ENG. ALBERTO MTZ LLAURADO.

II.- ACKNOWLEDGMENT

III.- PROLOGUE

IV.- OBJECTIVES AND GOALS IN RELIABILITY FOR GAS TURBINES

V.- INTRODUCTION

SECTION 1.- OVERVIEW, EVOLUTION AND CLASSIFICATION IN GAS TURBINES

VI.- 106.- EVOLUTION OF THE GAS TURBINE

VII.- GAS TURBINES – FUNCTIONAL TREE

VIII.- DESIGN AND ARRANGEMENTS - INDUSTRIAL & AERO-DERIVATIVES GAS TURBINES

IX.- 10.- AN OVERVIEW OF GAS TURBINES

1.- GAS TURBINE CYCLE IN THE COMBINED CYCLE OR COGENERATION MODE

2.- GAS TURBINE PERFORMANCE

3.- GAS TURBINE DESIGN CONSIDERATIONS

4.- CATEGORIES OF GAS TURBINES

4.1.- FRAME TYPE HEAVY-DUTY GAS TURBINES

4.2.- AIRCRAFT-DERIVATIVE GAS TURBINES

4.3.- INDUSTRIAL-TYPE GAS TURBINES

4.4.- SMALL GAS TURBINES

X.- 7.- CLASSIFICATION OF TYPES OF GAS TURBINES BY GAS TEMPERATURE

1.- CLASSIFICATION OF TYPES BY BLADE PRODUCTION METHOD

1.1.- CLASSIFICATION OF TYPES BY BLADE COOLING METHOD

1.2.- TYPICAL CONSTRUCTION OF GAS TURBINE

2. TYPICAL LATEST MAJOR GAS TURBINE

2-1. SIEMENS GAS TURBINE

(1) GAS TURBINE BODY

(2) GAS TURBINE BLADE AND VANE

(3) COMPRESSOR

(4) HYBRID BURNER RING COMBUSTOR

2-2. ALSTOM GAS TURBINE

(1) MAINTENANCE-FREE WELDED ROTOR

(2) HIGHLY-EFFICIENT COMPRESSOR

(3) DRY LOW NOX EV BURNER

(4) ANNULAR COMBUSTION

O-DIVERTED TYPE GAS TURBINE

- 3. MATERIALS FOR MAIN PART OF GAS TURBINE**
- 4. MATERIAL APPLICATION FOR BLADE AND VANE**
- 5. COMPOSITION OF NI-BASE SUPER-ALLOY OF SINGLE CRYSTAL TYPE GAS TURBINE BLADE**
- 6. APPLICATION MATERIALS FOR BLADES AND VANES OF REPRESENTATIVE MODELS**
- 7. MATERIALS FOR GAS TURBINE & JET ENGINE**

SECTION 2.- RELEVANT ISSUES IN DESIGN RELATED WITH GAS TURBINES

XI.- 11.- AXIAL-FLOW TURBINES

- 1.- TURBINE GEOMETRY**
- 2.- TURBINE BLADE COOLING CONCEPTS**
- 3.- TURBINE BLADE COOLING DESIGN**
- 4.- TURBINE LOSSES**

XII.-12.- COMBUSTORS

- 1.- GAS TURBINE COMBUSTORS**
- 2.- TYPICAL COMBUSTOR ARRANGEMENTS**
 - 2.1.- CAN-ANNULAR AND ANNULAR COMBUSTORS*
 - 2.2.- SILO-TYPE COMBUSTORS*
 - 2.3.- COMBUSTION IN COMBUSTORS*
 - 2.3.1.- THE DIFFUSION-TYPE COMBUSTOR*
 - 2.3.2.- DIFFUSION COMBUSTOR DESIGN CONSIDERATIONS*
 - 2.3.3.- RELIABILITY OF COMBUSTORS*
 - 2.4.- AIR-POLLUTION PROBLEMS IN A DIFFUSION COMBUSTOR**
 - 2.4.1.- SMOKE*
 - 2.4.2.- OXIDES OF NITROGEN*
 - 2.4.3.- NO_x PREVENTION*

XIII.- 13.- MATERIALS

- 1.- GAS TURBINE MATERIALS**
 - 1.1.- TURBINE WHEEL ALLOYS*
 - Alloy 718 Nickel-Based Alloy*
 - Alloy 706 Nickel-Based Alloy*
 - Cr-Mo-V Alloy*
 - 12 Cr Alloys*
 - A-286 Alloy*
- 2.- COMPRESSOR BLADES**
- 3.- FORGINGS AND NON-DESTRUCTIVE TESTING**
- 4.- COATINGS**
 - 4.1.- Shroud Coatings*
 - 4.2.- Future Coatings*

XIV.- 14.- FUELS

- 1.- EQUIPMENT FOR REMOVAL OF PARTICULATES AND LIQUIDS FROM FUEL GAS SYSTEMS**
- 2.- FUEL HEATING**
- 3.- CLEANING OF TURBINE COMPONENTS**
 - 3.1.- HOT SECTION WASH*
 - 3.2.- COMPRESSOR WASHING*
- 4.- OPERATING EXPERIENCE**

- 5.- HEAT TRACING OF PIPING SYSTEMS
- 6.- TYPES OF HEAT-TRACING SYSTEMS
 - 6.1.- *STREAM TRACING SYSTEMS*
 - 6.2.- *ELECTRIC TRACING*

XV.- 15.- BEARINGS AND SEALS

1.- BEARINGS

- 1.1.- *ROLLING BEARINGS*
- 1.2.- *JOURNAL BEARINGS*
- 1.3.- BEARING MATERIALS
- 1.4.- BEARING AND SHAFT INSTABILITIES
- 1.5.- THRUST BEARINGS
- 1.6.- FACTORS AFFECTING THRUST-BEARING DESIGN
- 1.7.- THRUST-BEARING POWER LOSS

2.- SEALS

- 2.1.- NON-CONTACTING SEALS
 - 2.1.1.- *Labyrinth Seals*
 - 2.1.2.- *Ring (Bushing) Seals*
 - Fixed seal rings*
 - Floating seal rings*

3.- MECHANICAL (FACE) SEALS

XVI.- 16.- CONTROL SYSTEMS AND INSTRUMENTATION

1.- START-UP SEQUENCE

2.- LIFE CYCLE COSTS

3.- INSTRUMENTATION REQUIREMENTS

- 3.1.- TYPICAL INSTRUMENTATION (MINIMUM REQUIREMENTS FOR EACH MACHINE)
- 3.2.- DESIRABLE INSTRUMENTATION (OPTIONAL)

4.- AUXILIARY SYSTEM MONITORING

- 4.1.- FUEL SYSTEM
- 4.2.- TORQUE MEASUREMENT
- 4.3.- BASELINE FOR MACHINERY
 - Mechanical Baseline*
 - Aerothermal Baseline*

5.- FAILURE DIAGNOSTICS

- 5.1.- COMPRESSOR ANALYSIS
- 5.2.- COMBUSTOR ANALYSIS
- 5.3.- TURBINE ANALYSIS

6.- MECHANICAL PROBLEM DIAGNOSTICS

7.- DATA RETRIEVAL

8.- SUMMARY

XVII.- 100.- PIPELINE COMPRESSION TURBINES: FEWER, LARGER, EFFICIENT

- 1.- DEMAND FOR NEW PIPELINES IS EXPECTED TO REMAIN ROBUST.
- 2.- OTHER GAS TURBINE INNOVATIONS
- 3.- PACKAGE INTEGRATION
- 4.- DIGITALIZATION
- 5.- EXTENDED OVERHAULS

6.- PIPELINE COMPRESSION: LOOKING AHEAD

XVIII.- 8.- AERODERIVATIVE GAS TURBINES FOR LNG LIQUEFACTION PLANTS – PART 1: THE IMPORTANCE OF THERMAL EFFICIENCY

1.0 INTRODUCTION

- 1.1 OVERVIEW OF THE LNG LIQUEFACTION PROCESS.**
- 1.2 GROWTH AND STRUCTURE OF THE LNG INDUSTRY**
- 1.3 COMPRESSOR DRIVERS USED FOR LNG LIQUEFACTION.**

2.0 AERODERIVATIVE ENGINES AS LNG LIQUEFACTION DRIVERS

3.0 THERMAL EFFICIENCY CONSIDERATIONS

3.1 COOLING CURVE PERFORMANCE

4.0 AERODERIVATIVE ENGINE SELECTION

- 4.1 ADVANTAGES OF AERODERIVATIVE ENGINES OVER HEAVY DUTY GAS TURBINES**
- 4.2 MULTIPLE SHAFT VS. SINGLE SHAFT GAS TURBINES**
- 4.3 THERMAL EFFICIENCY AND GREENHOUSE GAS CONSIDERATIONS**
- 4.4 INFLUENCE OF AMBIENT TEMPERATURE**

5.0 LNG PLANT NPV BENEFITS WITH HIGH EFFICIENCY AERODERIVATIVES

6.0 FUTURE POTENTIAL OF AERODERIVATIVE ENGINES WITHIN THE OPTIMIZED CASCADE LNG PROCESS

7.0.- CLOSURE

XVIII.A.- 8A.- AERODERIVATIVE GAS TURBINES FOR LNG LIQUEFACTION PLANTS – PART 2: WORLD'S FIRST APPLICATION AND OPERATING EXPERIENCE

1.0 INTRODUCTION

2.0 OVERVIEW OF THE DARWIN LNG PROJECT

3.0 PLANT DESIGN

3.1 IMPLEMENTATION OF THE PGT25+ GT & COMPRESSOR CONFIGURATIONS.

4.0 IMPLEMENTATION OF THE PGT25+ AERODERIVATIVE ENGINE

4.1 DESCRIPTION OF THE PGT25+ GAS TURBINE

- 4.1.1 Axial Flow Compressor**
- 4.1.2 Annular Combustor**
- 4.1.3 High Pressure Turbine (HPT)**
- 4.1.4 High Speed Power Turbine**
- 4.1.5 Engine-mounted accessory gearbox driven by a radial drive shaft**

4.2 MAINTENANCE PLANS AND EXPERIENCE

4.3 PERFORMANCE DETERIORATION AND RECOVERY

4.4 POTENTIAL UPGRADES OF THE PGT25+

4.4.1 Power Augmentation by Evaporative Cooling

5.0 REFRIGERATION COMPRESSORS

5.1 DESCRIPTION OF LNG REFRIGERATION COMPRESSORS- DESIGN PROCESS.

5.2 COMPRESSOR SELECTIONS

5.3 COMPRESSOR TESTING

5.3.1 Special Testing and Analysis on Ethylene Compressor

6.0 OPERATING EXPERIENCE

6.1 OVERALL RESULTS

6.2 ISSUES OF INTEGRATION TO THE PROCESS WITH RESPECT TO LM2500+ TRIPS / LOCK OUT ISSUES.

6.3 OPERATOR TRAINING SYSTEM (OTS) AND DYNAMIC SIMULATION

7.0 CLOSURE

XIX.- 3.- COLLECTION AND EXCHANGE OF RELIABILITY AND MAINTENANCE DATA FOR EQUIPMENT

1.- INTRODUCTION

1.1.- ABBREVIATED TERMS

2.1.- EQUIPMENT COVERAGE

2.2.- BENEFITS OF RM DATA COLLECTION AND EXCHANGE

3.- EQUIPMENT BOUNDARY, TAXONOMY AND TIME DEFINITIONS

3.1.- BOUNDARY DESCRIPTION

3.2.- TAXONOMY

3.3.- TIMELINE ISSUES

a.- Surveillance and operating period

b.- Data collection periods

c.- Maintenance times

4.- RECOMMENDED DATA FOR EQUIPMENT, FAILURES AND MAINTENANCE

4.1.- DATA CATEGORIES

a) Equipment unit data (inventory data)

b) Failure data

c) Maintenance data

4.2.- FAILURE DATA

4.3.- MAINTENANCE DATA

a.- General

b.- Maintenance categories

c.- Reporting maintenance data

ANNEX XIX-A (INFORMATIVE)

1.- EQUIPMENT-CLASS ATTRIBUTES

1.1.- GENERAL

1.2.- BOUNDARY DEFINITIONS

1.3.- ROTATING-EQUIPMENT DATA

ANNEX XIX-B (INFORMATIVE)

1.- INTERPRETATION AND NOTATION OF FAILURE AND MAINTENANCE PARAMETERS

B.1 Failure interpretation

B.2 Failure and maintenance data notations

B.2.2 Failure mechanism

B.2.3 Failure cause

B.2.4 Detection method

B.2.5 Maintenance activity

B.2.6 Failure modes

ANNEX XIX-C (INFORMATIVE)

1.- GUIDE TO INTERPRETATION AND CALCULATION OF DERIVED RELIABILITY AND MAINTENANCE PARAMETERS

C.1 INTERPRETATION RULES FOR COMMONLY USED FAILURE AND MAINTENANCE PARAMETERS

C.1.1 Introduction

C.1.2 Redundancy definitions

C.1.3 On-demand data

C.1.4 Independent failures

C.1.5 Dependent failures

C.1.6 Common-cause failure (CCF)

C.1.7 Common-mode failure

C.1.8 Trip definitions

C.1.9 Failure consequence classification

C.1.10 Analysis of failures

- C.1.11 Safety critical equipment
- C.2 AVAILABILITY
 - C.2.1 Normalized definition
 - C.2.2 Mathematics of availability
- C.3 FAILURE RATE ESTIMATION
 - C.3.1 General
 - C.3.1.1 Mathematics for failure rate and hazard rate estimation
 - C.3.1.2 Uses of failure rate and hazard rate estimation
 - C.3.2 Maximum likelihood estimator of a constant failure rate
- C.4 MAINTAINABILITY
 - C.4.1 Normalized definitions
 - C.4.2 Mathematical meaning
 - C.4.2.1 Maintainability concepts
 - C.4.2.2 Maintainability performance
 - C.4.2.3 Repair rate
 - C.4.2.4 Measures and estimates
 - C.4.3 Maintainability — Intrinsic and extrinsic factors
- C.5 “MEAN TIME” DEFINITIONS
 - C.5.1 Principle
 - C.5.2 Mean down time (MDT)
 - C.5.3 Mean time between failures (MTBF)
 - C.5.3.2 Mathematics of MTBF
 - C.5.3.3 Uses for MTBF
 - C.5.4 Mean time to failure (MTTF)
 - C.5.4.2 Mathematics of MTTF
 - C.5.4.3 Use of MTTF
 - C.5.5 Mean time to repair (MTTR)
 - C.5.5.2 Mathematics of MTTR
 - C.5.5.3 Uses of MTTR
 - C.5.6 Mean up time (MUT)
- C.6 TESTING FOR HIDDEN FAILURES IN SAFETY SYSTEMS
 - C.6.1 General principles
 - C.6.2 Required availability
 - C.6.3 Mathematics of cost-benefit availability

ANNEX XIX-D (INFORMATIVE)

1.- TYPICAL REQUIREMENTS FOR DATA

D.1 GENERAL

XX.- 4.- RISK-BASED MACHINERY MANAGEMENT

1.- INTRODUCTION

2 SCOPE

2.1 GENERAL

3.- MACHINERY RISK MANAGEMENT

3.1 GENERAL

3.2 MANAGEMENT SYSTEM

3.3 RISK ASSESSMENTS

3.4 RISK MITIGATION

3.5 INTEGRATION WITH OTHER RISK ASSESSMENTS

4 ACRONYMS AND ABBREVIATIONS

5 FRONT-END ENGINEERING DESIGN

5.1 INTRODUCTION

5.2 PRELIMINARY MACHINERY RISK ASSESSMENT

5.3 RELIABILITY, AVAILABILITY, AND MAINTAINABILITY ANALYSIS

5.4 MACHINERY DESIGN AND SELECTION

5.5 PROCESS AND INSTRUMENT DIAGRAM (P&ID) REVIEWS

5.6 LONG LEAD MACHINERY

5.7 VENDOR QUALIFICATION

5.8 OPERATIONS, MAINTENANCE, AND FACILITIES STRATEGIES

5.9 OPTIONAL FIELD TESTING

6 DETAILED DESIGN

6.1 INTRODUCTION

7 INSTALLATION AND COMMISSIONING

7.1 INTRODUCTION

7.2 INSTALLATION

7.3 COMMISSIONING, DECOMMISSIONING, AND DECONTAMINATION

7.4 PRE-START-UP SAFETY REVIEW

7.5 OPTIONAL TESTS

8 OPERATIONS AND MAINTENANCE

8.1 INTRODUCTION

8.2 FIELD RISK ASSESSMENTS

8.3 RISK MITIGATION

8.4 OPERATING COMPANY IMPLEMENTATION

ANNEX XX-A

A.2.4 ANALYZE MACHINERY RISKS

A.2.4.3 What-if Analysis

A.2.4.4 Hazard and Operability Analysis

A.2.4.6 Technical Risk Categorization

A.2.4.7 Failure Modes and Effects Analysis

A.2.4.8 Layers of Protection Analysis for Machinery

A.2.4.9 Reliability, Availability, and Maintainability Analysis

A.2.4.10 Fault Tree Analysis

A.2.5 MACHINERY RISK RANKING

A.2.6 MACHINERY RISK MITIGATION

ANNEX XX-B (INFORMATIVE)

B.- RISK-BASED MACHINERY VALIDATION CHECKLISTS

B.1 INTRODUCTION

B.2 FEASIBILITY AND CONCEPT DESIGN AND FEED VALIDATIONS

B.3 P&ID REVIEWS DURING FEED

B.4 VENDOR QUALIFICATION DURING FEED AND DETAILED DESIGN

B.4.5 API 616—GAS TURBINES

B.5 OPERATIONS AND MAINTENANCE MACHINERY CHECKLISTS

B.5.1 PRE-TURNAROUND CHECKLISTS

B.5.2 MACHINERY OVERHAULS

B.5.3 ADDITIONAL PRESSURE BOUNDARY INSPECTIONS FOR MACHINERY IN CORROSIVE, EROSIVE, AND HARSH SERVICE

ANNEX XX-C (INFORMATIVE)

C.- MACHINERY FAILURE MODES, MECHANISMS, AND CAUSES

C.1 INTRODUCTION

C.2 FAILURE OBSERVATIONS

C.3 FAILURE MODES

C.4 FAILURE MECHANISMS

C.5 FAILURE CAUSES

ANNEX XX-D (INFORMATIVE)

GUIDELINE ON RISK MITIGATION TASK SELECTION

D.1 PURPOSE

D.1.2 Task Selection Guidelines

D.1.3 Inspection Test and Preventive Maintenance (ITPM) Templates

ANNEX XX-E (INFORMATIVE)

E.- GUIDELINE ON CONDITION MONITORING AND DIAGNOSTIC SYSTEMS

E.1 INTRODUCTION

E.2 THE BASIC PRINCIPLES OF CONDITION MONITORING

E.3 CONDITION MONITORING APPROACHES AND TECHNIQUES

E.5 ADVANCEMENTS IN CONDITION MONITORING

ANNEX XX-F (INFORMATIVE)

F.- GUIDELINE ON MACHINERY PROGNOSTICS

F.1 INTRODUCTION

F.1.2 Remaining Useful Life

F.1.3 Advanced Predictive Systems

F.1.4 Definition of Prognostics

F.1.5 The Relationship of Prognostics to Condition-based Maintenance

F.2 PROGNOSTIC MODELS CLASSIFICATION

F.2.2 Failure Mode Specific Models

F.2.3 Type I—Traditional Reliability Analysis

F.2.4 Type II—Stress Based

F.2.5 Type III—Condition Based

ANNEX XX-I (INFORMATIVE)

I.- API 691 FMEA WORKSHEET

I.1 INTRODUCTION

I.2 API 691 FMEA WORKSHEET

XXI.- 9.- OREDA (Offshore and Onshore Reliability Data Handbook) STUDIES RELATED WITH GAS TURBINES.

1.- INTRODUCTION

1.1 THE OREDA PROJECT

1.2 PROJECT PHASES

2.- PROJECT MANAGEMENT AND ORGANIZATION

3.- DESCRIPTION OF OREDA 2015 HANDBOOKS

4.- FAILURE MODES

5.-USE OF THE DATA TABLES

6.- RELIABILITY DATABASE AND DATA ANALYSIS SOFTWARE

7.- THE PDS HANDBOOK

8.- RELIABILITY ANALYSIS CENTER/RELIABILITY INFORMATION ANALYSIS CENTER PUBLICATIONS

9.- OTHER PUBLICATIONS

10.- USE OF EXPERT JUDGMENT

10.1.- INTRODUCTION

10.2.- BASIS

10.3.- *ROLE OF THE FACILITATOR*

10.4.- CHARACTERISTICS OF THE EXPERTS

11.- MECHANICAL RELIABILITY

11.1. *CHARACTERISTICS*

11.2. *STRESS-STRENGTH INTERFERENCE*

11.3. *EMPIRICAL RELIABILITY RELATIONSHIPS*

11.4. *COMPARISON WITH SYSTEM (CONSTANT FAILURE RATE) APPROACH*

12.- HUMAN RELIABILITY

12.1-*HUMAN FACTORS*

12.2-*HUMAN RELIABILITY IN THE NUCLEAR INDUSTRY*

12.3-*EVALUATION OF HRA TECHNIQUES*

12.4-*HUMAN RELIABILITY IN THE OIL AND GAS INDUSTRY*

13 PARTICIPANTS

14 EQUIPMENT CATEGORIES COVERED IN THE DIFFERENT PHASES

15.- SCOPE OF THE OREDA HANDBOOK

16.- LIMITATIONS

17.- INVENTORY DESCRIPTION – GAS TURBINES

OREDA 2002

OREDA 2015

18.- EVALUATION, ANALYSIS AND CONCLUSIONS (OREDA).

1st PHASE (1993 – 2000)

2ND PHASE (2000 - 2015)

COMBINED STUDY OF THE 2 PHASES FOR THE ANALYSIS AND STUDY REGARDING THE GAS TURBINES FAILURES (PERIOD FROM 1993 TO 2015)

AERODERIVATIVE GAS TURBINES.

INDUSTRIAL GAS TURBINES.

19.- CONCLUSIONS.

20.- RECOMMENDATIONS.

SECTION 3 - RELIABILITY IN GAS TURBINES IN THE OIL, GAS & PETROCHEMICAL INDUSTRY –

XXII.- 1.- PROPOSAL IN RELIABILITY BY OIL COMPANY – ADNOC, RELATED WITH GAS TURBINES.

1. PURPOSE

4. CONTRACTUAL REQUIREMENTS

4.1 DOCUMENTS PRECEDENCE

4.2 SPECIFICATION DEVIATION AND CONCESSION CONTROL

- 4.3 ALTERNATIVE DESIGNS
 - 4.4 PROTOTYPE DESIGNS
 - 4.5 STANDARDISATION
 - 4.6 QUALITY CONTROL (QA/QC) AND CERTIFICATION
 - 4.7 INSPECTION & TESTING REQUIREMENTS
 - 4.8 SUPPLIER RESPONSIBILITIES
 - 4.9 SUBCONTRACTORS/SUBSUPPLIERS
 - 4.10 SPARE PARTS
 - 4.11 SPECIAL TOOLS
 - 4.12 PAINTING
 - 4.13 PRESERVATION & SHIPMENT
 - 4.14 DOCUMENTATION/MANUFACTURER DATA RECORDS
 - 4.15 GUARANTEES & WARRANTY
- 5. TECHNICAL DESIGN REQUIREMENTS
 - 6. ACCESSORY REQUIREMENTS FOR ROTATING EQUIPMENT
 - 7. BUSINESS UNIT SPECIFIC CROSS REFERENCE

XXII.A.- 1.1.- QUALITY ASSURANCE, INSPECTION AND TESTING REQUIREMENTS FOR GAS TURBINES (API 616) SPECIFICATION

APPENDIX 2

- SECTION I – QUALITY ASSURANCE AND CONFORMITY ASSESSMENT
- SECTION II – INSPECTION AND TESTING REQUIREMENTS
- SECTION III – SHOP FABRICATION AND NDT
- SECTION IV – SHOP TESTING AND SITE ACCEPTANCE TESTS
- SECTION V – API 616 TECHNICAL AMENDMENTS

XXII.B.- INFORMATION REQUIREMENTS FOR GAS TURBINES (API 616) SPECIFICATION

APPENDIX 3

- 1.2.- BUSINESS UNIT SPECIFIC REQUIREMENTS FOR GAS TURBINES (API 616) SPECIFICATION
- Appendix 4
- 3. OFFSHORE APPLICATIONS
- 4. REFINERY APPLICATIONS
- 5. STEEL STRUCTURE APPLICATIONS

- 1.3.- CONDITION MONITORING & MACHINE PROTECTION SYSTEM REQUIREMENTS FOR GAS TURBINES API 616 SPECIFICATION
- Appendix 5
- Condition, Performance Monitoring & Machine Protection System Requirements to API 616

- 1.4.- FIRE AND GAS DETECTION AND PROTECTION REQUIREMENTS FOR GAS TURBINES (API 616) SPECIFICATION
- Appendix 6

**1.5.- LUBRICATION SYSTEM DESIGN REQUIREMENTS FOR GAS TURBINES (API 616)
SPECIFICATION
Appendix 7**

**XXIII.- 2.- TECHNICAL REQUIREMENTS IN GAS TURBINES, AS
RECOMMENDED BY API (AMERICAN PETROLEUM INSTITUTE), USED IN
GAS, OIL & PETROCHEMICAL INDUSTRY.**

**SECTION 4.- SPECIFICATION, REGULATIONS AND STANDARDS FOR GAS
TURBINES IN POWER PLANTS**

**XXIV.- 152.- IEEE STANDARD - DEFINITIONS FOR USE IN REPORTING
ELECTRIC GENERATING UNIT RELIABILITY, AVAILABILITY, AND
PRODUCTIVITY**

- 1.- SCOPE
 - 2.- PURPOSE
 - 3. DEFINITIONS
 - 5. CAPACITY TERMS
 - 6. TIME DESIGNATIONS AND DATES
 - 8 PERFORMANCE INDEXES OF AN INDIVIDUAL UNIT
- ANNEX E (INFORMATIVE)**

Glossary of terms and abbreviations

**XXV.- GAS TURBINES — PROCUREMENT — PART 9:
RELIABILITY, AVAILABILITY, MAINTAINABILITY AND SAFETY**

- 1 SCOPE
- 4 MAINTAINABILITY
 - 4.1 MANUFACTURER'S RESPONSIBILITY
 - 4.2 USER'S RESPONSIBILITY
 - 4.3 SPARES HOLDING
 - 4.4 OPERATING LOG SHEETS
- 5 RELIABILITY AND AVAILABILITY
 - 5.1 RELIABILITY ACCEPTANCE TESTS
 - 5.2 RELIABILITY AND AVAILABILITY, CALCULATING AND REPORTING
- 6 SAFETY

**XXVI.- GAS TURBINES — PROCUREMENT — PART 8:
INSPECTION, TESTING, INSTALLATION AND COMMISSIONING**

- 1 SCOPE
- 6 TESTING
 - 6.3 FUNCTIONAL/OPERATING TESTS
 - 6.4 OPTIONAL TESTS
- 7 PREPARATION FOR STORAGE AND SHIPMENT
- 8 INSTALLATION AND COMMISSIONING

XXVII.- 153.- GAS TURBINES — DATA ACQUISITION AND TREND MONITORING SYSTEM REQUIREMENTS FOR GAS TURBINE INSTALLATIONS

1.- INTRODUCTION

4 MONITORING SYSTEMS AND THEIR CHARACTERISTICS

4.1 GENERAL FEATURES

4.2 DATA-ACQUISITION SYSTEMS

4.3 TREND-MONITORING SYSTEMS

4.4 COMPARISON OF THE SYSTEMS

5 DETAILED EXAMINATION OF TREND-MONITORING SYSTEMS

5.1 THE TASKS OF A TREND-MONITORING SYSTEM

5.2 PERFORMANCE-MONITORING SYSTEMS

5.3 COMBUSTION- AND EMISSION-MONITORING SYSTEMS

5.4 MECHANICAL- AND VIBRATION-MONITORING SYSTEMS

5.5 MEASURED PARAMETERS

5.6 SCALING AND VALIDATION

6 EXAMPLE OF A TREND-MONITORING SYSTEM

ANNEX A (informative)

STATUS AND FURTHER DEVELOPMENT OF TREND-MONITORING SYSTEMS

A.1 GENERAL

A.2 STATUS AND FURTHER DEVELOPMENT OF PERFORMANCE-MONITORING SYSTEMS

A.3 STATUS AND FURTHER DEVELOPMENT OF COMBUSTION- AND EMISSION-MONITORING SYSTEMS

A.4 STATUS AND FUTURE DEVELOPMENT OF MECHANICAL- AND VIBRATION-MONITORING SYSTEMS

ANNEX B (informative)

DIAGNOSTIC SYSTEMS

B.1 DIAGNOSTIC SYSTEMS

ANNEX C (informative)

FLOW CHART OF THE TREND-MONITORING SYSTEM

C.1 FLOW CHART OF THE TREND-MONITORING SYSTEM

C.2 EXPLANATIONS FOR THE FLOW CHART OF THE TREND-MONITORING SYSTEMS

XXVIII.- 154.- MECHANICAL VIBRATION — TORSIONAL VIBRATION OF ROTATING MACHINERY —

Part 1: LAND-BASED STEAM AND GAS TURBINE GENERATOR SETS IN EXCESS OF 50 MW

INTRODUCTION

1 SCOPE

4 FUNDAMENTALS OF TORSIONAL VIBRATION

4.2 INFLUENCE OF BLADES

4.3 INFLUENCE OF GENERATOR ROTOR WINDINGS

5 EVALUATION

5.2 FREQUENCY MARGINS

5.3 DYNAMIC STRESS ASSESSMENTS

6 CALCULATION OF TORSIONAL VIBRATION

6.2 CALCULATION DATA

6.3 CALCULATION RESULTS

6.4 CALCULATION REPORT
7 MEASUREMENT OF TORSIONAL VIBRATION
7.2 METHOD OF MEASUREMENT
7.3 MEASUREMENT TEST REPORT

8 GENERAL REQUIREMENTS
8.1 SET SUPPLIER RESPONSIBILITIES
8.2 GUARANTEES
8.3 RESPONSIBILITIES

ANNEX A (informative)
TORSIONAL VIBRATION MEASUREMENT TECHNIQUES

A.2 TORSIONAL VIBRATION TRANSDUCERS
A.3 MEASUREMENT PARAMETERS
A.4 FACTORY STATIC TESTS ON STATIONARY ROTORS
A.5 FULL-SPEED (DYNAMIC) FACTORY TESTS
A.6 ON-SITE TORSION TESTS

ANNEX B (informative)
EXAMPLES OF FREQUENCY MARGINS RELATIVE TO LINE AND TWICE LINE FREQUENCIES FOR
SHAFT SYSTEM MODES THAT CAN BE EXCITED BY TORSIONAL OSCILLATIONS OF THE SHAFT

ANNEX C (informative)
COMMONLY EXPERIENCED ELECTRICAL FAULTS

XXIX.- 155.- GAS TURBINES - EXHAUST GAS EMISSION -

PART 1: MEASUREMENT AND EVALUATION

1 SCOPE

3 DEFINITIONS

4 SYMBOLS

5 CONDITIONS

6 MEASUREMENTS

6.1 DETERMINATION OF CONSTITUENTS IN EXHAUST GAS
6.2 GUIDELINES FOR THE ARRANGEMENT OF THE MEASUREMENT SYSTEM
6.3 PERFORMING THE TEST, TEST REPORT, EVALUATION

7 INSTRUMENTATION

7.1 TYPES OF MEASURING DEVICE
7.2 SPECIFICATION FOR NO_x ANALYSERS
7.3 SPECIFICATION FOR CO AND CO₂ ANALYSERS
7.4 SPECIFICATION FOR SULFUR OXIDE ANALYSERS
7.5 SPECIFICATION FOR UHC ANALYSERS
7.6 SPECIFICATION FOR AMMONIA ANALYSERS
7.7 SPECIFICATION FOR OXYGEN ANALYSERS
7.8 SPECIFICATION FOR SMOKE ANALYSERS
7.9 SPECIFICATION FOR SOLID PARTICLE ANALYSERS

8 QUALITY OF MEASUREMENT

8.1 PREAMBLE
8.2 METHODS FOR CALIBRATION

9 CONVERSION OF DATA

9.2 CONVERSION BETWEEN WET AND DRY EXHAUST GAS
9.3 CONVERSION TO THE PARTICULAR EXHAUST GAS OXYGEN LEVEL
9.4 CONVERSION TO THE CONSTITUENT MASS FLOW RELATED TO THE DRY EXHAUST GAS
VOLUME FLOW AT NORMAL CONDITIONS AND TO A SPECIFIC OXYGEN CONTENT
9.5 CONVERSION TO POWER OUTPUT RELATED VALUES

ANNEX A (informative)

**TYPICAL EXAMPLE OF TEST RESULTS AND THEIR EVALUATION
ANNEX B (INFORMATIVE)
INFORMATION REGARDING THE MAJOR CONSTITUENTS OF THE EXHAUST GAS**

XXX.- GAS TURBINES - EXHAUST GAS EMISSION -

PART 2: AUTOMATED EMISSION MONITORING

1 SCOPE

3 DEFINITIONS

4 SYMBOLS AND ABBREVIATIONS

5 MONITORING PROGRAMME

5.1 MONITORING SYSTEM

5.2 CONSTITUENTS TO BE MEASURED

5.3 OPERATING DATA TO BE RECORDED

6 ARRANGEMENT OF MONITORING SYSTEM

6.1 MEASUREMENT LOCATIONS FOR GASEOUS EMISSIONS

6.2 POINT MEASUREMENT OF GASEOUS EMISSIONS

6.3 PATH MEASUREMENT OF GASEOUS EMISSIONS

6.4 PARTICULATE MEASUREMENT LOCATION

6.5 MEASUREMENT LOCATIONS FOR REFERENCE MEASUREMENTS

7 COMPONENTS OF THE MONITORING SYSTEM

7.1 EXTRACTIVE SAMPLING

7.2 ANALYZERS

8 CALIBRATION, FUNCTIONAL CHECKING AND MAINTENANCE

8.2 REFERENCE MEASUREMENTS

8.3 RELATIVE ACCURACY TEST AND VALIDATION PROCEDURE

8.4 DRIFT TESTS

8.5 FREQUENCY OF CALIBRATION

8.6 SUPPLY OF CALIBRATION GASES (WHERE APPLICABLE)

8.7 MAINTENANCE

XXXI.- 157.- GAS TURBINES — ACCEPTANCE TESTS

INTRODUCTION

1 SCOPE

3 TERMS AND DEFINITIONS

4 TEST BOUNDARY

5 SYMBOLS

6 PREPARATION FOR TESTS

6.2 TEST PROCEDURE

6.3 TEST PREPARATION

6.4 INSTRUMENTS AND MEASURING METHODS

7 CONDUCTANCE OF TEST

7.1 SPECIFIED REFERENCE CONDITIONS

7.2 PRELIMINARY CHECKS

7.3 STARTING AND STOPPING OF TESTS

7.4 OPERATION PRIOR AND DURING TEST

7.5 DURATION OF TESTS

7.6 MAXIMUM PERMISSIBLE VARIATIONS IN OPERATING CONDITIONS

7.7 TEST RECORDS

7.8 TEST VALIDITY

8 COMPUTATION OF RESULTS

8.1 PERFORMANCE TEST RESULTS

8.2 CORRECTION OF TEST RESULTS TO REFERENCE CONDITIONS

8.3 OTHER GAS TURBINE PERFORMANCE PARAMETERS

9 TEST REPORT

XXXII.- 5.- GAS TURBINE APPLICATIONS — REQUIREMENTS FOR POWER GENERATION

1 SCOPE

11 OPERATING REQUIREMENTS

11.1 GENERAL REQUIREMENTS

11.2 OPERATING RANGE AND LIMITATIONS

11.3 STARTS (TIME TO START, NUMBER OF STARTS, START RESTRICTIONS)

11.4 LOADING/DE-LOADING

11.5 GRID OPERATIONAL REQUIREMENTS

11.6 FREQUENCY RESPONSE

11.7 LOCATION OF CONTROLS HMI

11.8 OPERATION DOCUMENTS

11.9 ISLAND MODE OPERATION AND BLACK START

11.10 BLACK START AND BLACK GRID RESTORATION

13 RELIABILITY, AVAILABILITY AND MAINTAINABILITY

13.1 BASIC RAM ASSESSMENT

13.2 ADDITIONAL RAM REQUIREMENTS

14 SAFETY REQUIREMENTS

14.2 RISK ASSESSMENT

14.3 FIRE PRECAUTIONS

14.4 HAZARDOUS AREA CLASSIFICATION AND EXPLOSION PREVENTION AND PROTECTION

14.5 FLAMMABLE GAS DETECTION

14.6 HEAT DETECTORS

14.7 SMOKE DETECTION

14.8 ENCLOSED SPACE ACCESS

14.9 CONTAINMENT AND RUPTURE

14.10 HYDRAULICALLY OPERATED SAFETY EQUIPMENT

14.11 FUEL SYSTEM PRESSURE TESTING

14.12 CLUTCH

14.13 FUNCTIONAL SAFETY

14.14 HAZARDOUS MATERIAL

14.15 OVERSPEED PROTECTION SYSTEM TESTING

14.16 MANUAL ISOLATION FEATURES

14.17 HAZARD IDENTIFICATION AND OPERABILITY STUDIES

17 PACKING AND TRANSPORTATION

17.1 PREPARATION

17.2 PACKING

17.3 TRANSPORTATION

18 GAS TURBINE CORE

18.1 DESIGN REQUIREMENTS

18.2 VIBRATION ACCEPTANCE LIMITS

18.4 BEARINGS AND SUPPORTS

20 AIR INLET SYSTEM

20.2 AIR FILTER

20.3 INLET FILTER HOUSE

21 EXHAUST SYSTEM

21.2 INTERFACE BETWEEN GAS TURBINE AND EXHAUST SYSTEM

21.3 DESIGN REQUIREMENTS

21.4 MECHANICAL REQUIREMENTS

21.5 INSULATION

- 21.6 NOISE REQUIREMENTS AND SILENCERS
- 21.7 SAFETY REQUIREMENTS
- 22 CIVIL DESIGN AND FOUNDATION REQUIREMENTS
 - 22.2 BASIS OF DESIGN
- 25 COMBINED CYCLE APPLICATIONS
 - 25.2 GAS TURBINES IN COMBINED CYCLE APPLICATIONS
 - 25.3 SINGLE-SHAFT ARRANGEMENTS START RESTRICTIONS
 - 26.7 EQUIPMENT PROTECTION
 - 26.8 FIRE PRECAUTIONS
 - 26.9 EMISSION CONTROL
 - 26.11 CONTROL AND INSTRUMENTATION – MAINTENANCE AND SPARE PARTS
 - 30.4 COMPRESSOR WATER WASH SYSTEMS
- 32 INSTALLATION AND COMMISSIONING
 - 32.1 INSTALLATION
 - 32.2 COMMISSIONING
- 33 VERIFICATION TESTING
 - 33.1 SCOPE
 - 33.2 RELIABILITY TEST
 - 33.3 CONTRACTUAL PERFORMANCE TESTS
 - 33.4 NOISE TESTS
 - 33.5 EMISSIONS TEST
- 34 DESIGN LIFE

XXXIII.- 6.- GAS TURBINE APPLICATIONS — SAFETY

1 SCOPE

- 5.8 MECHANICAL
- 5.9 GAS TURBINE COMPRESSOR AIR INLET SYSTEM
- 5.10 FUEL SYSTEMS
- 5.11 COMBUSTION SUPERVISION
- 5.12 EXHAUST SYSTEM
- 5.13 ENCLOSURES
- 5.14 LIGHTING
- 5.15 FIRE PRECAUTIONS

ANNEX A (INFORMATIVE)

LIST OF SIGNIFICANT HAZARDS

SECTION 5.- GAS TURBINES – APPLICATIONS IN POWER PLANTS ..

XXXIV.- 63.- MICROTURBINES BOOST EFFICIENCY IN THE CHP MARKET MICROTURBINES TURN GASEOUS AND LIQUID FUELS INTO USABLE ELECTRICITY WITHOUT THE NEED FOR EXHAUST AFTER-TREATMENT

1.- LOW MAINTENANCE

XXXV.- 73.- COMBINED CYCLE CONSTRUCTION TRENDING TO MODULAR MODULAR OR STANDARDIZED ASSEMBLY IS CATCHING ON IN POWER PLANT DESIGN AND CONSTRUCTION. BUT IS IT RIGHT FOR EVERY JOB?

- 1.- CUTTING LABOR COSTS
- 2.- OIL & GAS MODULES
- 3.- SAVING TIME
- 4.- STANDARDIZATION CAUTIONS

**XXXVI.- 77.- MODERN GAS TURBINE COMBINED CYCLE
NET THERMAL EFFICIENCY RATINGS OF 60% ARE HERE — WHAT'S NEXT?**

- 1.- BEGINNINGS
- 2.- CARNOT LIMIT
- 3.- WHICH TEMPERATURE?
- 4.- RULE OF 75%
- 5.- WHAT'S NEXT?

**XXXVII.- 80.- COMBINED CYCLE POWER PLANTS: ARE TWO SHAFTS
BETTER THAN ONE?**

CHOICES DEPEND ON ECONOMICS, TECHNICAL CONSIDERATIONS, SPACE AVAILABILITY, NOISE REQUIREMENTS, CULTURAL PREFERENCES AND FAMILIARITY

- 1.- PRE-DESIGNED CONCEPT
- 2.- MULTI-SHAFT PLANTS
- 3.- FINANCIAL STRAIN
- 4.- CHANGING COURSE
- 5.- SINGLE-SHAFT AND MULTI-SHAFT COMBINED CYCLE CONFIGURATIONS
- 6.- LOOKING AHEAD

**XXXVIII.- 102.- IPP COMBINED CYCLE PROJECT RATED AT MORE THAN 1
GW AND OVER 63% NET EFFICIENCY**

**XXXIX.- 104.- WORLDWIDE FUTURE FOR COAL-BASED IGCC POWER
GENERATION**

- 1.- COMMERCIAL IGCC PLANTS IN JAPAN
- 2.- PROJECTS IN ASIA
- 3.- WHAT HISTORY TELLS US
- 4.- 10 YEARS LATER AND ROUND TWO

**XL.- 84.- AXIAL AND RADIAL TURBINES
HOW DO THEY COMPARE IN THE 1-TO-3 MW POWER RANGE?**

**XLI.- 117.- ADVANCEMENTS IN H CLASS GAS TURBINES FOR COMBINED
CYCLE POWER PLANTS FOR HIGH EFFICIENCY, ENHANCED
OPERATIONAL CAPABILITY AND BROAD FUEL FLEXIBILITY**

1. INTRODUCTION
2. H-CLASS HERITAGE
3. 7/9HA GAS TURBINE ARCHITECTURE EVOLUTION
 - 3.1. 7/9HA COMPRESSOR
 - 3.2. 7/9HA COMBUSTOR
 - 3.3. 7/9HA TURBINE
4. FSFL VALIDATION OF THE 7/9HA GAS TURBINES
5. OPERATIONAL AND FUEL FLEXIBILITY
6. PLANT CONSTRUCTABILITY, INSTALLATION AND MAINTAINABILITY
7. 9HA.01 FLEET LEADER AT EDF BOUCHAIN

- 8. 7HA FLEET LEADERS AT NISHI-NAGOYA, EXELON WOLF HOLLOW AND COLORADO BEND
- 9. SUMMARY
- 10. ACKNOWLEDGEMENTS

XLII.- 125.- LIFE EXTENSION OF GAS TURBINES USED FOR POWER GENERATION

- 1.- INTRODUCTION
- 2.- LIFE EXTENSION APPROACH
- 3.- LIFE EXTENSION ANALYSIS RESULTS
- 4.- CONCLUSIONS AND RECOMMENDATIONS
- 5.- SUMMARY

XLIII.- 136.- AVAILABILITY ANALYSIS OF GAS TURBINES USED IN POWER PLANTS

- 1. INTRODUCTION
- 3. APPLICATION
 - 3.1 FUNCTIONAL TREE
 - 3.2 FAILURE MODE AND EFFECTS ANALYSIS
 - 3.3 MAINTENANCE TASKS RECOMMENDATIONS
 - 3.5 AVAILABILITY IMPROVEMENT

XLIV.- 143.- PRE-CONDITIONS OF A HYDROGEN POWER PLANT

- 1.- HYDROGEN PRODUCTION
- 2.- HYDROGEN COMBUSTION
- 3.- STATE-OF-THE-ART
 - DIFFUSION FLAMES WITH NITROGEN, WATER OR STEAM DILUTION.
 - LEAN PREMIXED SYSTEMS.
 - PREVIOUS RESEARCH PROGRAMS ON H₂ COMBUSTION.
- 4.- CHALLENGES AND RESEARCH NEEDS IN HYDROGEN COMBUSTION
 - AUTOIGNITION
 - FLASHBACK
 - THERMOACOUSTICS
 - HIGHER FLAME TEMPERATURE, NOX EMISSIONS
 - OTHER COMBUSTION RELATED CHALLENGES

SECTION 6.- FAILURE ANALYSIS AND STUDIES REGARDING GAS TURBINES IN OIL, GAS AND POWER GENERATION PLANTS

XLVI.- 19.- CASE HISTORIES

- 1.- AXIAL-FLOW COMPRESSORS
- 2.- COMBUSTION SYSTEMS
 - 2.1.- TRANSITION PIECE
- 3.- AXIAL-FLOW TURBINES

XLVII.- 25.- FAILURE ANALYSIS OF GAS TURBINE TRANSITION PIECES, LEADING TO A SOLUTION FOR PREVENTION

- 1. INTRODUCTION**
- 2. OPERATION CONDITIONS**
- 3. OPERATING TEMPERATURE**
- 4. APPARENT FORM OF FAILURES**
- 5. STUDY OF MATERIAL**
- 6. STUDY OF MICROSTRUCTURE**
- 7. STUDY OF FRACTURE SURFACES**
- 8. DISCUSSIONS**
- 9. PROPOSED SOLUTION**
 - 9.1. LOCAL COOLING**
 - 9.2. STOPPING PROBABLE CRACKS**
- 10. CONCLUSION**

XLVIII.- 26.- THERMAL FAILURE OF A SECOND ROTOR STAGE IN HEAVY DUTY GAS TURBINE

- 1. INTRODUCTION**
- 2. VISUAL EXAMINATION OF FAILED BLADE**
- 3. FINITE ELEMENT MODEL OF THE BLADE**
- 4. RESULTS OF NUMERICAL SIMULATION**
- 5. CONCLUSIONS**
- 6. RECOMMENDATIONS**

XLIX.- 28.- COMBUSTION TURBINES: CRITICAL LOSSES AND TRENDS

- 1 INTRODUCTION**
- 2 STATISTICAL CRITICALITY OF COMBUSTION TURBINES**
- 3 HISTORY AND FUTURE EVOLUTION OF GAS TURBINES**
- 4 MAJOR LOSS PREVENTION MEANS**
- 5 CONTRACTUAL CONCEPTS: USERS - OEMS – INSURERS**
 - 5.1 SERVICE**
 - 5.2 SPARE PARTS**
 - 5.3 OTHER CONTRACTUAL ISSUES**
- 6 TYPICAL TURBINE DAMAGES**
 - 6.1 LOSS ANALYSIS: TECHNOLOGY AND MACHINE TYPE**
 - 6.2 LOSS ANALYSIS: LOSS INITIATING COMPONENTS**
 - 6.3 LOSS ANALYSIS: CAUSATIVE PROCESSES**
- 7 EXAMPLES OF INTERESTING FAILURES**
 - 7.1 LARGE GAS TURBINE IN A POWER GENERATION APPLICATION**
 - 7.2 LARGE FRAME GAS TURBINE IN A REFINERY – OPERATES ON GAS AND LIQUID FUEL**
 - 7.3 LARGE FRAME GAS TURBINE – OPERATES IN POWER PLANT WITH NATURAL GAS**
 - 7.4 LARGE FRAME GAS TURBINE – EVAPORATIVE COOLED INLET FILTER HOUSE – NATURAL GAS**
 - 7.5 AERO DERIVATIVE TURBINE IN A POWER GENERATION APPLICATION – LIQUID AND GAS FIRED**
 - 7.6 AERO DERIVATIVE GAS TURBINE – HEAVY FUEL OIL FIRED IN A POWER GENERATION APPLICATION**
 - 7.7 “ADVANCED” GAS TURBINE – COMBINED CYCLE APPLICATION ON NATURAL GAS**
 - 7.8 LARGE FRAME GAS TURBINE – POWER GENERATION APPLICATION FIRED ON NATURAL GAS**
 - 7.9 LARGE FRAME 50 CYCLE GAS TURBINE – 200 MW POWER GENERATION APPLICATION**

- 7.10 LARGE FRAME UNIT IN COMBINED CYCLE PLANT – NATURAL GAS FIRED
- 7.11 LARGE FRAME GAS TURBINE IN COMBINED CYCLE FACILITY
- 7.12 LARGE FRAME GAS TURBINE – POWER GENERATION APPLICATION ADJACENT TO A CEMENT PLANT
- 7.13 LARGE FRAME GAS TURBINE – COMBINED CYCLE POWER GENERATION APPLICATION
- 7.14 LARGE FRAME GAS TURBINE – COMBINED CYCLE POWER GENERATION APPLICATION
- 7.15 LARGE FRAME GAS TURBINE – COMBINED CYCLE POWER GENERATION APPLICATION
- 7.16 LARGE FRAME GAS TURBINE – COMBINED CYCLE POWER GENERATION APPLICATION
- 7.17 LARGE FRAME GAS TURBINE – OPEN CYCLE PEAK LOADING AND LOAD FOLLOWING POWER GENERATION APPLICATION

L.- 29.- OPERATIONAL CAUSES OF FATIGUE FAILURES WITHIN PASSAGES OF GAS TURBINE ENGINES

- 1.- INTRODUCTION
- 2.- LOW-CYCLE FATIGUE
- 3.- CONCLUSIONS

LI.- 64.- MYTH: COMBUSTOR FLAME-OUTS DO NOT CAUSE FAILURES

LII.- 70.- MYTH: GAS TURBINE SURGE CAN'T HAPPEN TO ME

LIII.- 127.- ANALYSIS OF HOT SECTION FAILURES ON GAS TURBINES IN PROCESS PLANT SERVICE

- 1.- INTRODUCTION
- 2.- TURBINE HOT SECTION DEGRADATION MECHANISMS
- 3.- FAILURE INVESTIGATION AND ANALYSIS
 - 3.1.- Objectives
 - 3.2.- Preserving the Evidence
 - 3.3.- Fault Tree Analysis
- 4.- FAILURE ANALYSIS ACTIVITIES
 - 4.1.- Metallurgical Analysis
 - 4.2.- Mechanical Analysis
- 5.- CASE HISTORIES
 - 5.1.- Case History A
High Cycle Fatigue Failure of Turbine Buckets
 - 5.2.- Case History B
Oxidation-Assisted Creep Failure of Turbine Buckets
 - 5.3.- Case History C
Accelerated Creep Failure of Turbine Buckets Caused by Previous Over Temperature Event
 - 5.4.- Case History D
Overheating Failure of Cooled Turbine Vanes
 - 5.5.- Case History E
High Cycle Fatigue Failure of Power Turbine Blade
- 6.- CONCLUSIONS
- 7.- APPENDIX A - HOT SECTION COMPONENT DEGRADATION/FAILURE MECHANISMS
 - Creep
 - Environmental Attack
 - Thermal-Mechanical Fatigue
 - High Cycle Fatigue
 - Foreign Object Damage
 - Mixed Mode Failures

LIV.- 128.- FAILURE ANALYSIS OF A GAS TURBINE BLADE: A REVIEW

- 1. INTRODUCTION**
- 2. FACTORS INFLUENCING GAS TURBINE BLADE FAILURE**
 - 2.1. Fatigue failure*
 - 2.2 Thermomechanical fatigue failure (TMF)*
 - 2.3 Creep failure*
 - 2.4 Corrosion failure*
 - 2.5 Erosion failure*
- 3. BLADE FAILURE PRECAUTIONS**
- 4. SUMMARY**

LV.- 129.- FAILURE ANALYSIS OF A GAS TURBINE NOZZLE

- 1. BACKGROUND**
- 2. MICROSTRUCTURAL CHARACTERIZATION OF NOZZLE VANE**
- 3. CRACKS EVALUATING**
- 4. STRESSES EVALUATION**
- 5. DISCUSSION OF RESULTS**
- 6. CONCLUSIONS**

LVI.- 131.- A PRIMER ON GAS TURBINE FAILURE MODES

- 1.- RECOVERABLE LOSSES**
- 2.- NON-RECOVERABLE LOSSES**
- 3.- KEEPING IT CLEAN**
- 4.- DESIGN AND MANUFACTURING PROBLEMS**
- 5.- MURPHY'S LAW**

LVII.- 132.- FAILURE ANALYSIS AND REPAIR OF A CATASTROPHICALLY DAMAGED GAS TURBINE COMPRESSOR DISK USING SEM TECHNIQUE AND CFD ANALYSIS

- 1.- INTRODUCTION**
- 2.- DESCRIPTION OF THE INCIDENT AND FAILURE ANALYSIS**
- 3.- FAILURE ANALYSIS**
- 4.- REPAIR**
- 5.- ANALYSIS OF FLUID FLOW**
- 6.- NUMERICAL METHOD**
- 7.- RESULTS AND DISCUSSION**
- 8.- CONCLUSIONS**

LVIII.- 133.- FAILURE ANALYSIS OF GAS TURBINE BLADE

- 1. INTRODUCTION**
- 2. ANSYS**
- 3. ANALYSIS PROCEDURE**
- 4. RESULTS AND DISCUSSION**
- 5. ANALYSIS OF NICKEL SUPER ALLOY**
- 6.- ANALYSIS OF INOLOY A-286**
- 7.- RESULTS FOR NICKEL SUPER ALLOY**

8.- RESULTS FOR INCOLOY A-286

9.- CONCLUSION

10.- FUTURE WORK

LIX.- 134.- ANALYSIS OF POSSIBLE OPERATIONAL DEFECTS IN AND DAMAGES TO THE GAS TURBINE DRIVES OF GAS PUMPING UNITS AND TECHNIQUES FOR THEIR DIAGNOSTICS

1. INTRODUCTION

2. RELEVANCE

3. RESEARCH OBJECTIVE

4. THEORETICAL

5. CONCLUSIONS

LX.- 135.- FAILURE ANALYSIS OF GAS TURBINE BLADES

LXI.- 138.- GAS TURBINES BLADES—A CRITICAL REVIEW OF FAILURE ON FIRST AND SECOND STAGES

1.- INTRODUCTION

2.- WHAT IS FAILURE ON TURBINE BLADE

3.- CAUSES OF FAILURE

4.- FAILURE ANALYSIS OF FIRST AND SECOND STAGE TURBINE BLADE

5.- CONCLUSION

LXII.- 139.- INVESTIGATION OF BLADE FAILURE IN A GAS TURBINE

1. INTRODUCTION

2. BACKGROUND

3. METALLURGICAL EXAMINATION AND STRESS ANALYSIS

4. MODAL ANALYSIS AND INTERFERENCE DIAGRAM

5. CONDITION MONITORING

6. CONCLUSIONS

LXIII.- 146.- A REVIEW ON GAS TURBINE BLADE FAILURE AND PREVENTIVE TECHNIQUES

1.- INTRODUCTION

2. MODES OF FAILURE AND BLADE DEGRADATION

2.1 EROSION

2.2 FATIGUE

2.3 THERMAL STRESSES

2.4 MATERIAL

2.5 COROSION

3. COOLING TECHNIQUE

3.1 FILM COOLING

3.2 THERMAL BARRIER COATING

4. CONCLUSION

LXIV.- 148.- FAILURE ANALYSIS OF A COMPRESSOR BLADE OF GAS TURBINE ENGINE

1. INTRODUCTION
2. OBSERVATIONS
3. ANALYSIS
4. CONCLUSIONS AND RECOMMENDATION

LXV.- 149.- FAILURE ANALYSIS OF A GAS TURBINE BLADE MADE OF INCONEL 738LC SUPER ALLOY

- 1- INTRODUCTION
- 2- EXPERIMENTAL PROCEDURE
- 3- EXPERIMENTAL RESULTS
- 4- CONCLUSIONS
- 5- SOLUTIONS

LXVI.- 37.- HOT GAS PATH COMPONENTS -

LIMITATIONS ON FIRING TEMPERATURE AND IMPACT ON POWER OUTPUT

- 1.- ROTOR ANOMALY INVESTIGATION

LXVII.- 140.- FAULT TREE ANALYSIS OF RUKHIA GAS TURBINE POWER PLANT

1. INTRODUCTION
2. DESCRIPTION OF GTPPS COMPONENTS AND FAILURES
3. RESULTS AND DISCUSSIONS
4. CONCLUSIONS

LXVIII.- 108.- DETECTABLE PROBLEMS – GAS TURBINES

- 1.- GAS TURBINE—GAS PATH ANALYSIS
- 2.- TURBINE BLADE DISTRESS
- 3.- COMPRESSOR FOULING
- 4.- COMBUSTOR DISTRESS AND PLUGGED FUEL NOZZLES
- 5.- FOREIGN/DOMESTIC OBJECT DAMAGE
- 6.- WORN AIR/OIL SEALS
- 7.- FUEL CONTROL PROBLEMS
 - 7.1.- Starting
 - 7.2.- Running
- 8.- BOROSCOPE INSPECTION
- 9.- A BACKUP TO CONFIRMING SUSPECTED PROBLEMS
- 10.- ASSESSING DAMAGE TO INTERNAL ENGINE COMPONENTS
 - 10.1.- Compressor Blades And Stators
 - 10.2.- Combustor And Fuel Nozzles
 - 10.3.- Turbine Blades And Nozzles
- 11.- SOME SAFETY ADVICE

INTEGRATION OF AN ADVANCED TECHNOLOGY GAS TURBINE IN AN AIR BLOWN GASIFIER

- 1.- INTRODUCTION
 - 1.1.- Role of IGCC Power Plants
 - 1.2.- Project Overview
 - 1.3.- Project Schedule and Status
 - 1.4.- Major Participants
- 2.- PLANT CONFIGURATION AND PERFORMANCE
 - 2.1.- Process Description
 - 2.2.- Description of Major Components
 - 2.3.- Plant Performance
- 3.- GAS TURBINE DESIGN DETAILS
 - 3.1.- Flange-to-Flange
- 4.- IGCC INTEGRATION/DESIGN CUSTOMIZATION
 - 4.1.- Fuel Delivery
 - 4.2.- Combustion System
 - 4.3.- Compressor Air Extraction
 - 4.4.- Control System
- 5.- SUMMARY
- 6.- DOE DISCLAIMER

LXX.- 108.2.- Case Study #2 BENEFITS OF INDUSTRIAL GAS TURBINES FOR REFINERY SERVICES

- 1.- INTRODUCTION
- 2.- REFINERY PROCESSES
 - 2.1.- The Corinth Motor Oil Refinery
 - 2.2.- Hellenic Aspropyrgos Refinery
- 3.- CONCLUSIONS

LXXI.- 108.3.- Case Study #3 GILROY ENERGY: DESIGNED, OPERATED AND MAINTAINED FOR CUSTOMER SATISFACTION

- 1.- PLANT CONFIGURATION
- 2.- OVERVIEW OF OPERATING PLAN
- 3.- OPERATING RELIABILITY
- 4.- MAINTENANCE POLICY
- 5.- COMMITMENT TO PARTNERSHIP

LXXII.- 108.4.- Case Study #4 A CASE STUDY IN THE DEVELOPMENT OF A LANDFILL GAS-TO-ENERGY PROJECT FOR THE ANTIOCH, ILLINOIS, COMMUNITY SCHOOL DISTRICT

- 1.- INTRODUCTION
- 2.- PROJECT DESIGN
 - 2.1.- HOD LANDFILL GAS COLLECTION SYSTEM TIE-IN
 - 2.2.- GAS CLEANING AND COMPRESSION
 - 2.3.- GAS PIPING TO THE MICROTURBINES LOCATED AT THE SCHOOL
 - 2.4.- ELECTRIC GENERATION
 - 2.5.- HEAT GENERATION
- 3.- SUMMARY

LXXIII.- THE GAS TURBINE'S FUTURE

LXXIV.- 130.- FAILURE MODE AND EFFECT ANALYSIS (FMEA) OF GAS TURBINE POWER PLANT SYSTEM (GTPPS) THE PROBABLE SYSTEM FAILURE MODES

- 1.- FAILURE MODE: NO IGNITION AT START
- 2.- FAILURE MODE: LOW OIL PRESSURE (AND/OR HIGH OIL TEMPERATURE)
- 3.- FAILURE MODE: ENGINE OVER-SPEED
- 4.- FAILURE MODE: MISALIGNMENT OF GENERATOR COUPLING DRIVE
- 5.- FAILURE MODE: ENGINE GAS OVER-TEMPERATURE
- 6.- FAILURE MODE: COMPRESSOR ROTOR VIBRATION
- 7.- FAILURE MODE: COMPRESSOR ROTOR SHAFT LOCKED
- 8.- FAILURE MODE: COMPRESSOR OVER TEMPERATURE
- 9.- FAILURE MODE: COMPRESSOR STALLS
- 10.- FAILURE MODE: RPM/TEMPERATURE FLUCTUATION
- 11.- FAILURE MODE: FLAME OUT
- 12.- FAILURE MODE: HOT SPOT ON FLAME TUBE
- 13.- FAILURE MODE: FLAME LEAKAGE
- 14.- RESEARCH METHODOLOGY (FMEA)
- 15.- THE RISK PRIORITY RANKING OF SYSTEM
 - 15.1 Designing a Plan for Preventing Generator Failures:
 - 15.2 Designing a Plan for Preventing Flame-Out Failure:
 - 15.3 Designing a Plan for Preventing Turbine Failures:
 - 15.4 Basic Maintenance Guidelines

LXXV.- 50.- LUBRICATION MAINTENANCE

BEST PRACTICES CAN PREVENT CATASTROPHIC FAILURE OF AERODERIVATIVE GAS TURBINES

- 1.- LEAKAGE, SPILLAGE OR BOTH