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.

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

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

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

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.

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

APPENDIX 2

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

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 STADARDS 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

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

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

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 CO_2 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

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

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

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