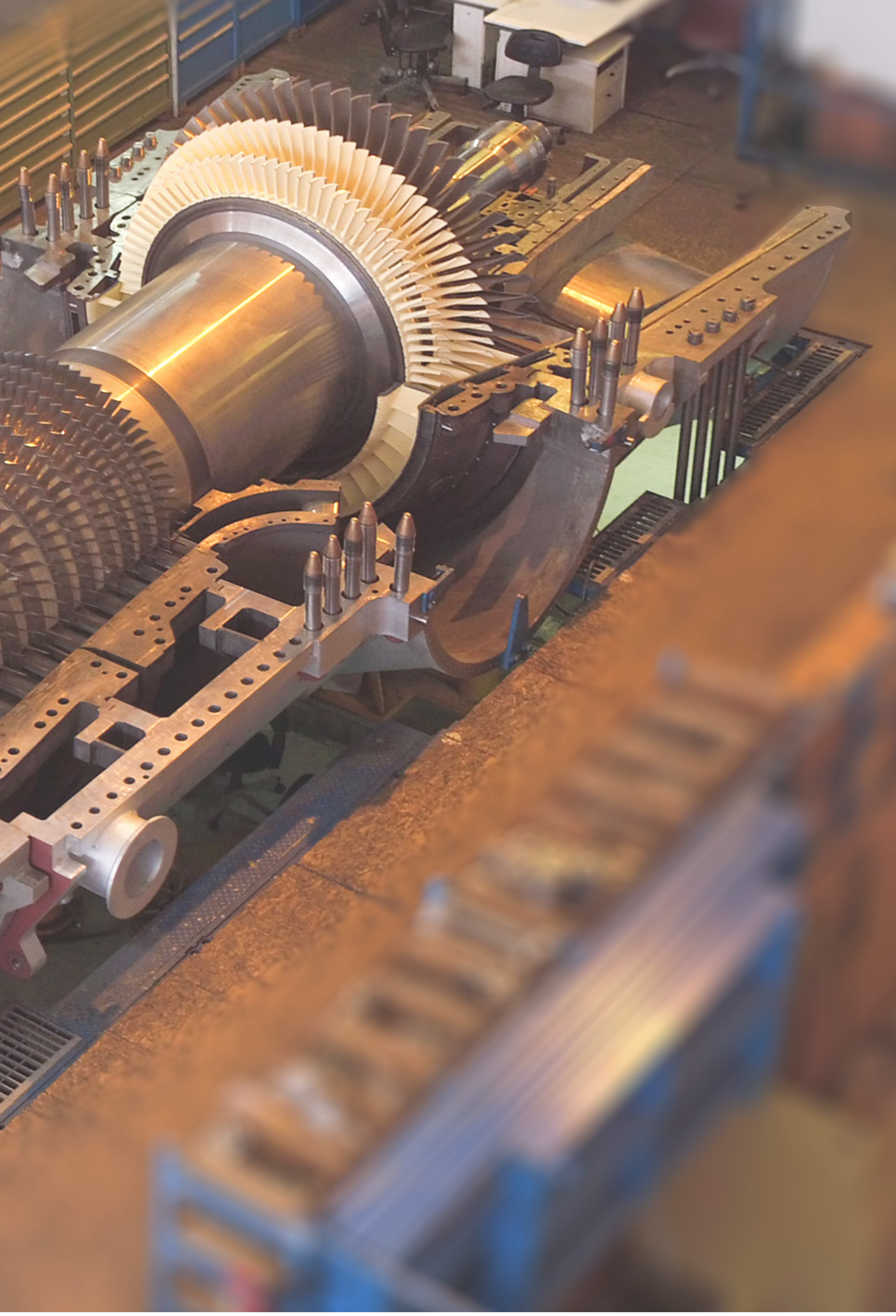

Technical Review

MAPNA TURBINE ENGINEERING & MANUFACTURING CO. (TUGA)

No.8 - October 2017

TUGA
MAPNA GROUP

Willpower to Empower Generations

Cover Page
MGT-70(3) Final Assembly Stand

EDITORIAL

Dear Colleagues, Partners and Professionals,

Notwithstanding the steady increase in the contribution made by renewable energy sources, the vast majority of the world's energy consumption is still believed to be derived from combustion of fossil fuels for many years to come. Fossil fuels are finite resources and hence it is crucial that they are used as efficiently and economically as possible to preserve resources, reduce emissions and mitigate the environmental impacts.

Prompted by the drive for further performance improvements, it is with great honor that MAPNA Turbine introduces the third and latest generation of their flagship heavy-duty gas turbine product; MGT-70(3) in the first article of the current edition of MAPNA Turbine Technical Review. With dazzling performance improvements, the newly evolved MGT-70(3) gas turbine is the result of a comprehensive redesign and upgrading program over the past few years. Its innovative features include new 3D airfoil design of turbine and compressor blades and vanes, enhanced cooling and sealing schemes, in addition to newly designed journal-thrust bearing at the compressor side, to mention a few.

The second article is a success story in dealing with undesirable sound pressure levels recorded inside turbine hall of typical MGT-70 power generation units. MAPNA Turbine has persistently pursued enhancement plans to ensure noise levels remain below the permissible values required by the occupational standards and regulations. In doing so, a comprehensive study comprising on-site sound measurements to identify major noise sources inside turbine hall has been carried out. Noise mitigation solutions to enclose noise sources using insulations and/or barriers are then provided and the effectiveness of each is further investigated.

A precise turbine-governor model allowing further investigation of the transient behavior of the multi-spool MGT-30 gas turbine and hence more efficient design and development of gas turbine control systems and interfaces thereof is also presented in the third essay.

The fourth article takes an in-depth look at the newly designed and manufactured MAPNA Research Burner (MRB-01) referring to its distinctive features in providing a valuable experimental setup to study fundamental aspects of combustion. It also provides insights into the potential applications of the acquired data in development and verification of mathematical models and implementation of diagnostic techniques, as well as other advanced combustion concepts.

Respectfully,

Mohammad Owliya, PhD

Deputy General Director

MAPNA Turbine Company (TUGA)

October 2017

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01

MGT-70(3); An Enhancement Meant to Make a Difference

Introduction

MAPNA Turbine unveiled its 3rd upgrade on V94.2 gas turbine family this summer. The MAP2B upgrade was kicked off in early 2012 by R&D department of MAPNA Turbine. The design and engineering team of MAPNA Turbine benefits from the experience of manufacturing more than 170 MGT-70 gas turbine units. This new product which is known as MGT-70(3) with power output of 185 MW and 36.4% efficiency at ISO conditions has a fair bit of advantage over quite a few other E-class gas turbines available in this range, as described previously in the 3rd issue of the Technical Review in March 2015.

This product is the result of some advanced improvements and changes introduced in the design and fabrication in comparison with the preceding versions, aiming at acquiring maximum power cost-effectively in addition to lifetime enhancement. These changes generally include redesign of compressor and turbine blades and vanes on the basis of 3D airfoil blading, turbine blades cooling path, secondary air system (SAS) for sealing and applying thermal barrier coating on turbine and combustion chamber hot parts. In addition, the compressor journal-bearing has been modified in order to increase the thrust force capacity during operation.

Areas of Enhancement in MGT-70(3)

This new product benefits from some modules of enhancement resulting from engineering redesign. Some of the main changes in the new machine are listed below in brief:

- **New compressor blades and vanes with 3D airfoil (cMAP3D package)**

In the compressor section, an increase of compressor mass flow rate has been achieved by changing the airfoil of the first four stages to high-efficiency 3D airfoils. The airfoils of these new blades and vanes are optimized in order to enhance the aerodynamic behavior of flow and consequently increase the efficiency of the compressor section in general.

- **Increase of Turbine Inlet Temperature (TIT)**

Implementation of advanced thermal barrier coating (TBC) on hot gas path parts of combustion chambers and turbine section allows for an increase in TIT from 1060 °C to 1090 °C, at standard ISO conditions or alternatively, extending the maintenance intervals from 33000 to 41000 EOH. Also internal cooling path of turbine blades and vanes has been completely redesigned in order for the critical parts to withstand the new operating conditions.

- **New turbine blades and vanes with 3D airfoils (tMAP3D package)**

Another innovative improvement in turbine blades and vanes is changing the airfoils to 3D ones which leads to higher output power and efficiency of the turbine section.

- **New journal-thrust bearing**

The journal-thrust bearing component of compressor side has been changed with a newly designed journal-thrust bearing with higher thrust load capacity. As a result of power increase in MGT-70(3) version the thrust force of the rotor applied on compressor journal-thrust bearing will be increased compared to the previous versions of this machine. Consequently it is necessary to replace the bearing with a new one which has a better thrust force capacity.

Main Features Affected by Upgrading to the MGT-70(3)

The upgrading process of the MGT-70 gas turbine family in MAPNA Turbine has resulted in three products that are listed in the table below. The most important aspect of all these upgraded versions is that the retrofits are compatible, i.e. the upgrading procedure can be accomplished from any previous version to a newer one with little changes in the main interfacing components.

Table 1: Upgrading milestones of the MGT-70 gas turbine series

Product Name	Terminology	Year	Power Output (MW)	Efficiency (%)
MGT-70(1)	MAP2+	2011	166	34.5
MGT-70(2)	MAP2A	2013	170	34.6
MGT-70(3)	MAP2B	2017	185	36.4

Similarly, upgrading an older version of an MGT-70 machine to the new MGT-70(3) is possible only by performing the following changes during overhaul. With this scenario the highest possible value of power and efficiency in MGT-70 gas turbine family can be achieved with minimum changes in the main components of the machine and consequently with minimum cost during an overhaul procedure.

Main changes of the GT body of the MGT-70(3) are shown in Fig.1. In this schematic drawing main scope of changes and replaced parts related to the upgrading process are shown with red circles.

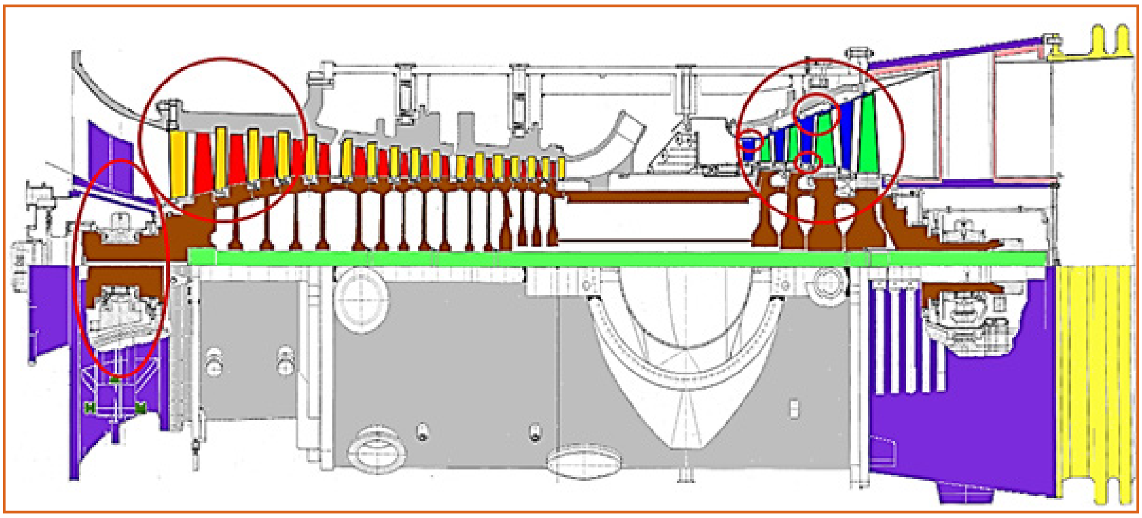

Fig.1: The areas included in the scope of change in the new version

Finally, the main specifications of the MGT-70(3) gas turbine are presented in Table 2.

Table 2: MGT-70(3) main specifications at standard ISO conditions

Parameter	Unit	Value
Frequency	Hz	50
Power Output	MW	185
Efficiency	(%)	36.4
Heat Rate	KJ/KWh	9917
ISO Turbine Inlet Temperature	°C	1090
Exhaust Temperature	°C	542
Exhaust Mass Flow	Kg/s	554.8
Pressure Ratio	-	12
Number of Compressor Stages	-	16
Number of Turbine Stages	-	4
Number/ Type of Combustors	-	2/Silo Type
NOx Emission with natural gas fuel	ppm	25
Overall Dimensions	m	10.9*3.9*3.7
Shipping Weight	ton	186
Fuel Type	-	Fuel Gas and Fuel Oil

Analysis of the Upgraded Elements

The MGT-70(3) upgrading program is comprised of the following plans that are practically implemented to meet the overall technical requirements leading to the full performance objectives. The plans are listed below based on the sequence over time.

- Planning and specification consolidation process
- Conceptual design
- MAP2B final product definition (including preliminary design and detailed design)
- Fabrication, commissioning, verification and test of MGT-70(3) prototype
- Measurement and data acquisition on MGT-70(3) prototype

- Validation program

The detailed analytical processes that were performed during redesign process of MAP2B upgrading program are listed below:

► **Performance Feasibility Study**

Feasibility study on the improvement of performance parameters (including temperature, pressure and Mach number) was executed on the compressor, turbine and combustion chamber. The analytical study was conducted on the basis of CFD studies the results of which are typically shown in Fig. 2.

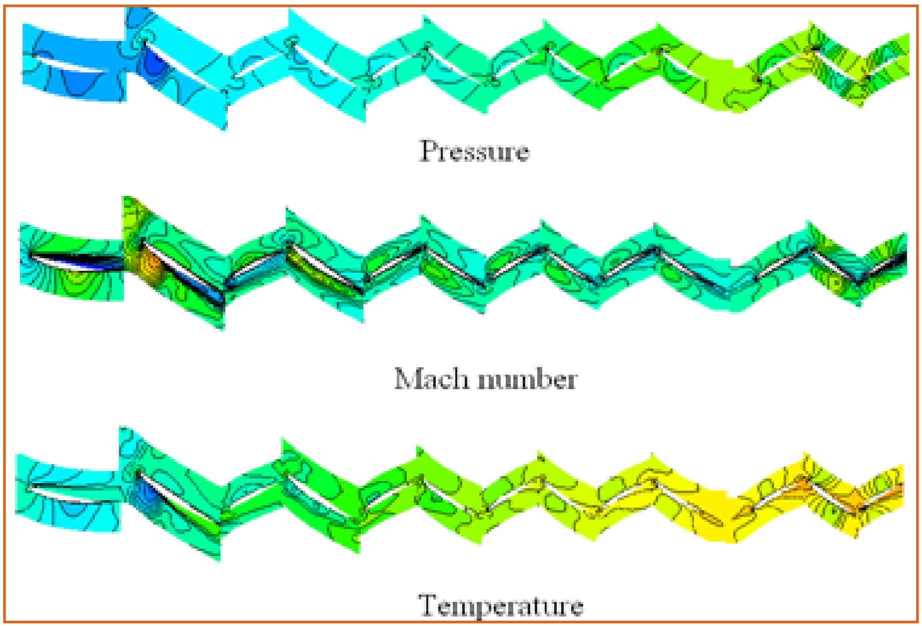

Fig. 2: The analytical results of patterns of performance parameters in the feasibility study phase

In the next step, different damage mechanisms of MGT-70(3) were reviewed (Fig. 3).

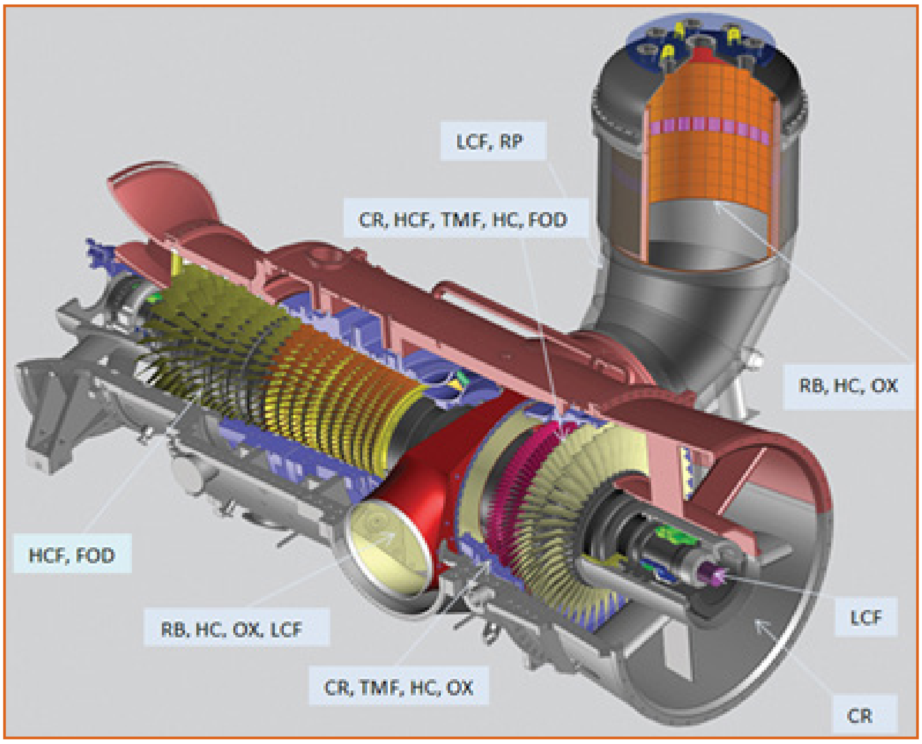

Fig. 3: Different damage mechanisms of MGT-70(3)

Subsequently, the mechanical analyses of different parts were undertaken. Fig. 4 represents the results of such analyses performed on the rotor and thrust bearing, respectively.

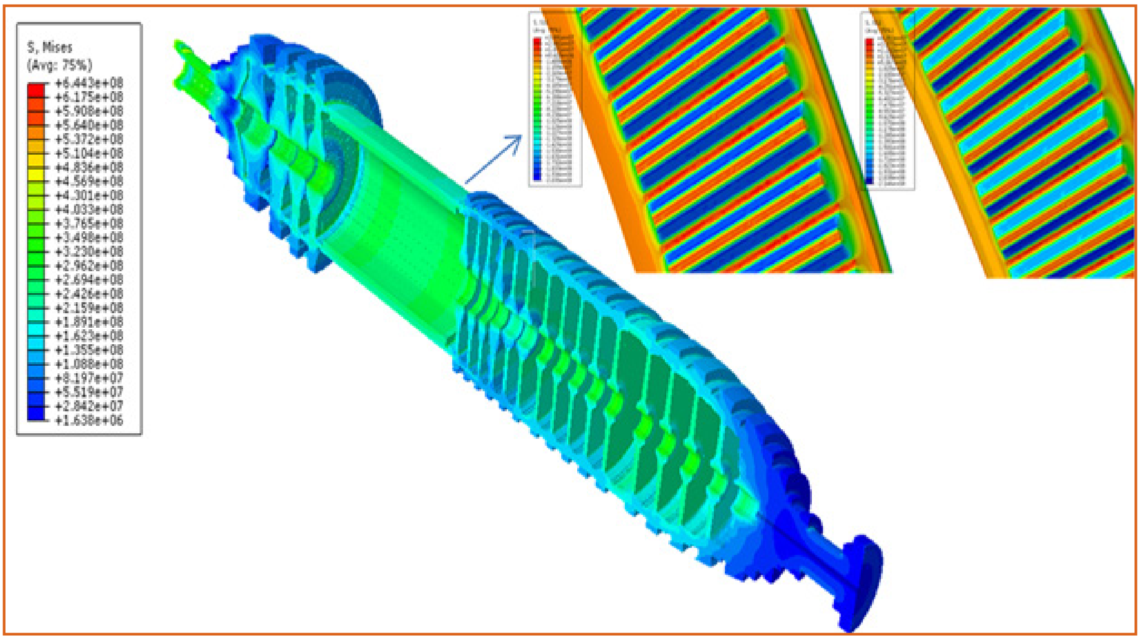

Fig. 4: The finite element analysis results of the MGT-70(3) rotor

Finally, the FEM analysis of the hot gas path was implemented. Fig. 5 shows the results.

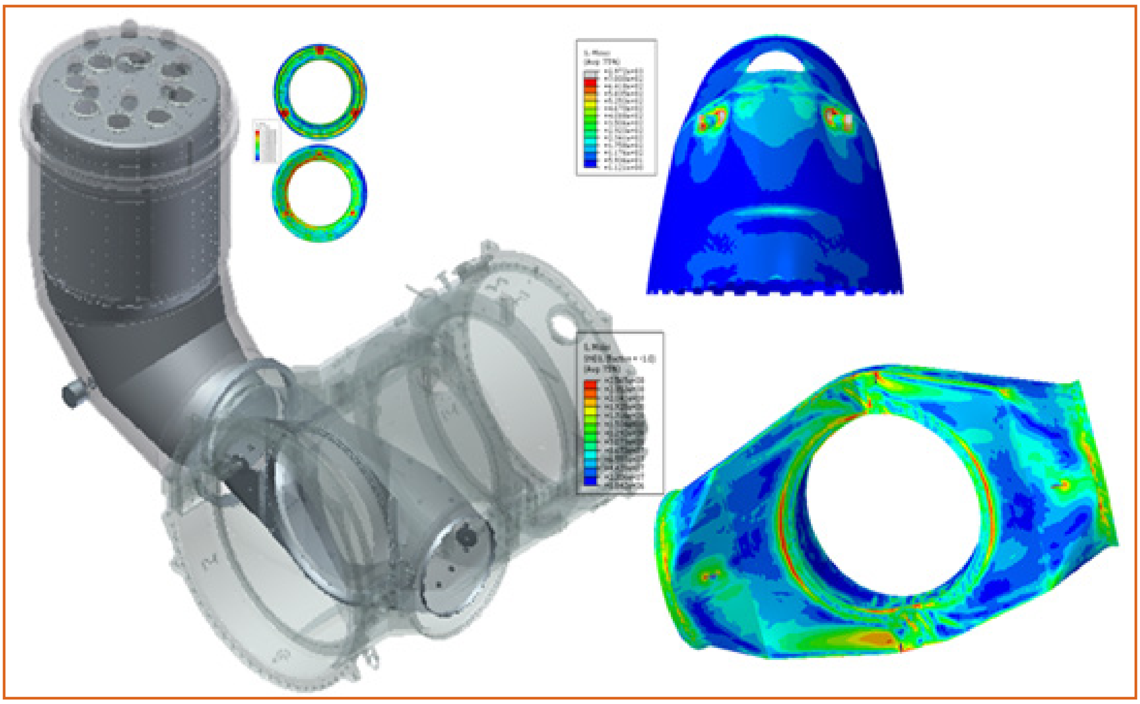

Fig. 5: The FEM analysis results of the MGT-70(3) hot gas path

► Project Definition Phase

This phase mainly covered both preliminary and detailed design activities so that the manufacturing processes could start as soon as this phase ended leading to the verification process. This phase is comprised of the following steps:

Sub-Phase A: 3D design of the blades and vanes - in four stages of both compressor and turbine segments - was improved and modified from the base geometry to the optimized geometry as shown in Figs. 6 & 7. The 3D design in compressor segment has been presented as cMAP3D package as a great engineering innovation in project.

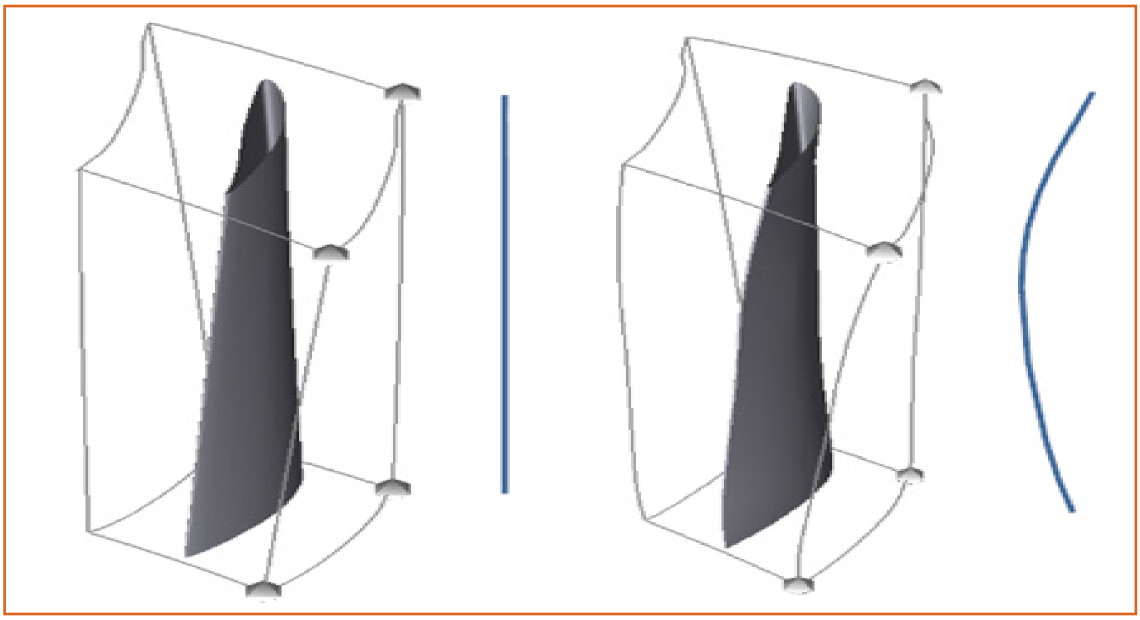

Fig. 6: 3D design improvement of blades and vanes from base geometry (Left) to the optimized geometry (Right) in the MGT-70(3)

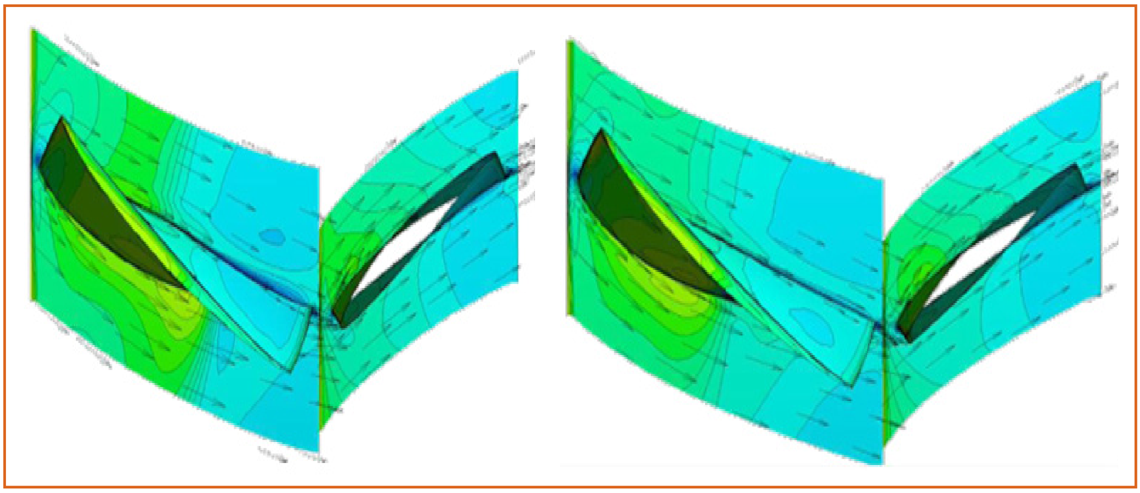

Fig. 7: Mach number contours of base geometry (Left) compared to the ones in the optimized geometry (Right) in the MGT-70(3)

Sub-Phase B: Replacing compressor side bearing with hybrid thrust-journal type bearing was carried out to increase the load carrying capacity of this bearing exposed to different axial and radial loads with the aim of reaching higher power outputs. Fig. 8 represents the new type of bearing schematically in its casing.

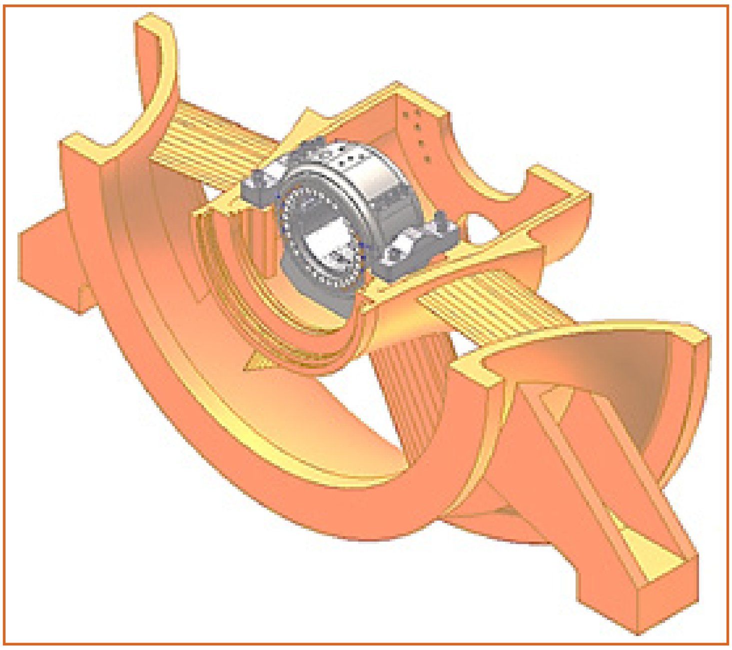

Fig. 8: Schematic representation of the compressor side new bearing

Sub-Phase C: Aerodynamically redesigning and optimizing all turbine blades in 3D. This process consisted of the following steps by itself:

- Optimization of load distribution between turbine stages
- Optimization of flow properties in radial direction
- Optimization of velocity distribution on the surface of airfoils
- Eliminating shocking phenomena in the flow
- Decreasing flow discretion
- Decreasing pressure drop on blades

Similar to the compressor stages, the 3D design was also developed at turbine segment as tMAP3D package as a great engineering innovation of the project.

Figure 9 shows images of the 3D blades and vanes of MGT-70(3) during fabrication process.

Fig. 9: MGT-70(3) blades and vanes in fabrication process

MAP2B Comprehensive Test Plan

As part of the development process, a comprehensive test plan was conceived and performed for the new product using precision instruments and special data acquisition sensors with advanced measuring elements, both statically and dynamically on the prototype of this product installed as Unit 6 (GT16) of PARAND Combined Cycle Power Plant.

These tests along with the records of different parameters (such as temperature, pressure, mass flow, velocity, clearance and vibration) in different sections of the operating machine, verified the features of the new product and monitored its trend as well as they validated the computational codes and all internally developed tools that had been generated during design of this machine.

The characteristics of measuring tools used in the comprehensive test plan as well as their types and applications are presented in Table 3.

Table 3: Characteristics of measurement tools used in comprehensive test plan

Measurement Tools	Application	Quantity
Thermocouple	Temperature Measurement at Different Points	310
RTD	Temperature Measurement at Different Points	54
Static Pressure Sensor	Static Pressure Measurement at Different Points	249
Blade Tip Timing Sensor	Blade Clearance & Vibration Measurement	36
Traverse System (Including 5-Hole Probes) at Different Compressor and Turbine Sections	Fluid Pressure, Temperature and Velocity Measurement	34
The Central Telemetry Unit (Including Rotary Sensors composed of Strain Gauges, Thermocouples, Piezoelectric Pressure Transducers)	Strain and Temperature Measurement (on Rotor Parts)	1 Unit

An illustration of pressure pipes in a schematic overall view of MGT-70(3) is presented in Fig. 10.

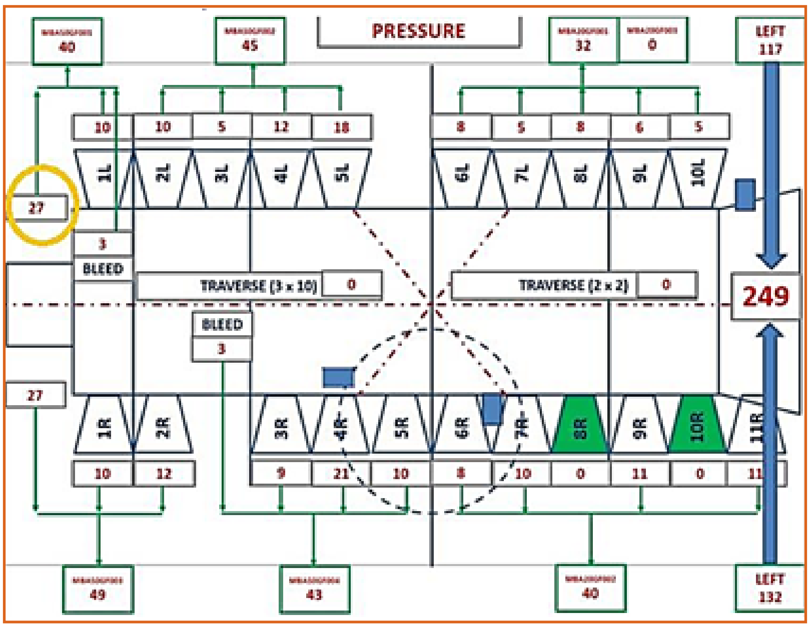

Fig. 10: Illustration of measuring pressure pipes layout

The distribution of thermocouples and RTDs are also shown schematically in Figs. 11 and 12, respectively.

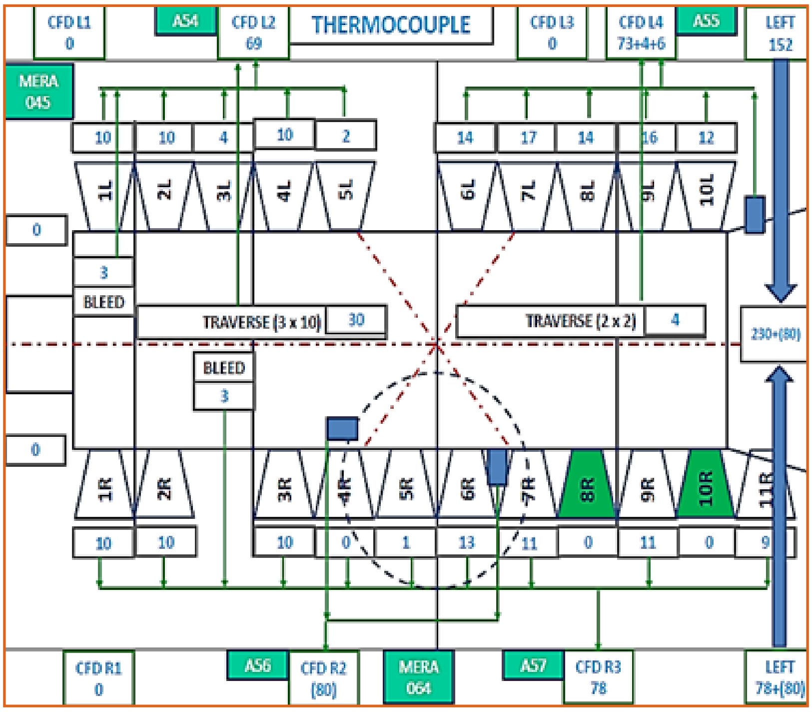

Fig. 11: Distribution of thermocouples

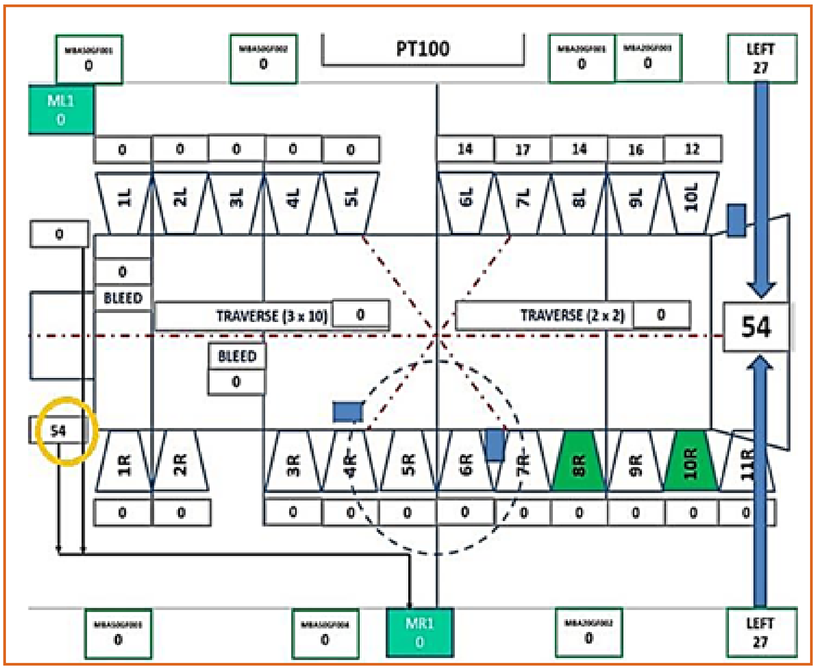

Fig. 12: Distribution of RTD Sensors

After defining the layout and subsequently installation plan of the measuring tools and sensors, the assembly of these instruments was undertaken on both rotary and stationary parts of the machine in Unit 6 (GT16) of PARAND Combined Cycle Power Plant. Figs. 13 and 14 show the installation process of related instruments in different segments of the machine.

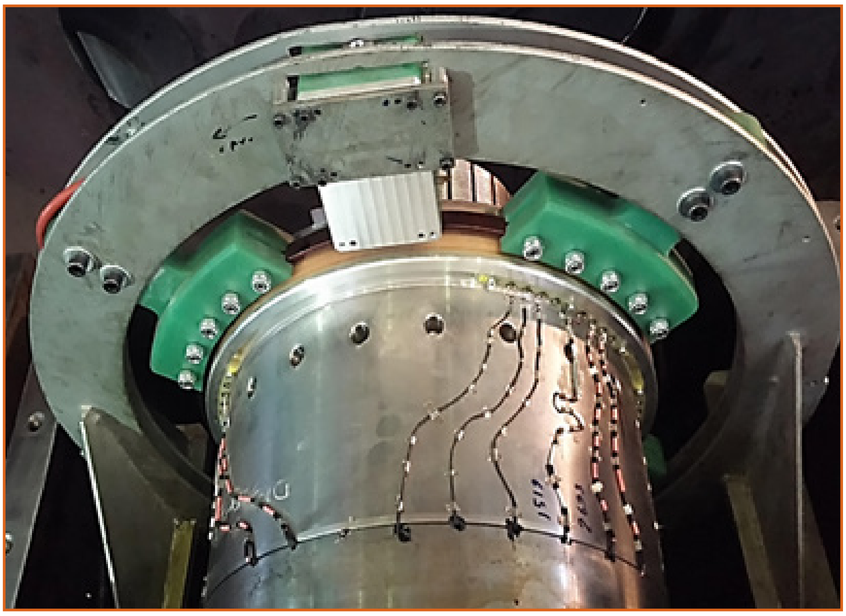

Fig. 13: Installation of the central telemetry unit at the end of the tie rod

Fig. 14: Installed thermocouples on turbine carrier

Following the installation and commissioning of measuring instruments mentioned in Table 3, all measuring points were recorded and data was gathered by local control cabinets and then transferred to a data acquisition container called MAP-Lab near the turbine enclosure (as shown in Fig. 15).

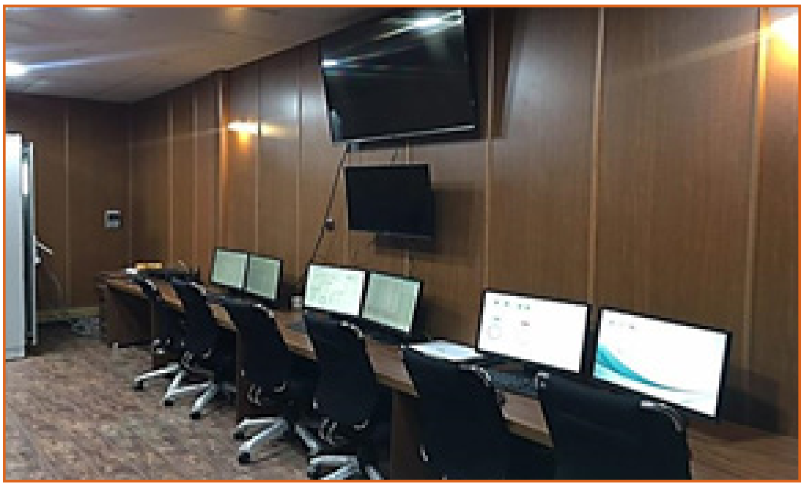

Fig. 15: A view of the MAP-Lab container near the turbine enclosure

The final stage in MAP-Lab was processing all acquired data : temperature, pressure, tip timing, vibration and also strains sustained, on both stator and rotor and all compressor, combustion chamber, hot gas path and power turbine segments in addition to the performance test done on the machine in parallel with DCS recording.

The final performance data of the MGT-70(3) gas turbine according to the conditions of the Unit 6 (GT16) of PARAND Combined Cycle Power Plant, i.e., Fuel= Natural Gas, Temperature = 37.3 °C, Pressure = 884 mbar and Humidity = 8.5% were as follows:

Table 4: Performance data of the MGT-70(3) gas turbine

Performance Parameters	Performance Results at PARAND P.P. Unit 6	Equivalent Performance Results at ISO Conditions
Output Power	132.8 MW	185 MW
Efficiency	34.7%	36.4%

02

Hush MGT-70, Hush!

Abstract

Undesirable sound pressure levels known as noise within gas turbine halls is considered as one of the major risk factors for the health and safety of power plants' operators and personnel. According to the guidelines for occupational noise exposure provided by the Occupational Safety and Health Administration (OSHA, 1983) of the United States, the allowable exposure time for operators is reduced drastically as the noise level increases. In the present study, a comprehensive on-site noise level assessment to identify major noise sources inside the turbine hall of a typical MGT-70 power generation unit was made. Noise mitigation solutions to enclose noise sources using insulations and/or barriers were then provided and the effectiveness of the measures implemented was subsequently investigated.

Introduction

The turbine hall houses gas turbine, generator and a number of auxiliary systems and equipment required for proper and safe operation of the power generating unit. Thus, sound pressure level within the turbine hall is typically high.

In order to find appropriate solutions to reduce noise levels inside the turbine hall, it is necessary to conduct a noise assessment study in an operating unit and then analyze the data provided to determine additional noise attenuation measures that can be taken in order to further reduce noise emissions inside the turbine hall.

For this purpose, an acoustic on-site noise survey was carried out inside the turbine hall of two typical MGT-70 power generation units in two different power plants designed and developed by MAPNA Group in central Iran, i.e., Chadormalu and Golgohar power plants with the noise attenuation measures having been implemented in the latter case.

Major Noise Sources and Existing Conditions

The general noise sources within the turbine hall of a typical MGT-70 gas turbine power generation unit include:

Gas turbine horizontal shielding

A supporting structure fastened to the ground and to the gas turbine lateral skids comprising of wall panels, doors and silencers providing natural ventilation.

Combustion chamber semi-enclosure

This octagonal enclosure consists of a soundproof enclosure, structural steel frame, side panels, bottom silencers and access door. The bottom of the enclosure is equipped with silencers providing natural ventilation.

Furthermore, gas turbine is completely insulated in order to minimize heat losses from casings and to reduce sound emissions. The insulation material is filled in mattresses and pads and they are connected to each other by means of hooks and steel wires. The bottom section of the gas turbine consisting of compressor front bearing casing, blade carrier, center casing, blow-off pipes, exhaust casing, exhaust diffuser and combustion chamber are also insulated.

Fuel gas skid enclosure

An individual enclosure with auxiliary equipment to provide sufficient ventilation and soundproofing for fuel gas skid in order to protect the system from explosion and abrupt thermal fluctuations. Ventilation is provided via 2×100 % centrifugal fans for this enclosure.

Generator enclosure

An individual enclosure with auxiliary equipment to provide soundproofing and sufficient ventilation for the generator in order to prevent heat build-up and temperature rise within the enclosure.

Air intake vertical duct

The vertical duct of the air intake system is located inside the turbine hall, so it is necessary to reduce noise emissions associated with this part. The air intake noise mainly drives from the compressor. The upper portion of the intake duct is connected free of stress to the air intake elbow by means of the bellows expansion joint.

Noise Assessment Method

The noise level measurements were carried out at 1m distance from machinery and main noise sources. Necessary measurements were done according to DIN EN ISO 3744[1]. Furthermore, appropriate acoustic measurements were conducted to determine sound power levels for different noise sources in order to define effective and affordable noise attenuation measures. All measurements were realized in form of linear intensity level measurements. According to EN ISO 9614 Part 2 [2], the evaluation of the results was carried out in the frequency range of f = 50 Hz to f = 6.3 kHz.

Assessed Noise Sources

Various noise sources inside the turbine hall were assessed using the above-mentioned noise assessment methodology.

Air Intake Expansion Joint

Intensity measurements were conducted on the surfaces of the air intake expansion joint, vertical duct and the outer cone as shown in Figs. 1 and 2. The acceleration measurements were also taken to get information about the vibration characteristics of the surface of the vertical duct. This information is of great value in designing additional insulation measures for the vertical duct and the expansion joint.

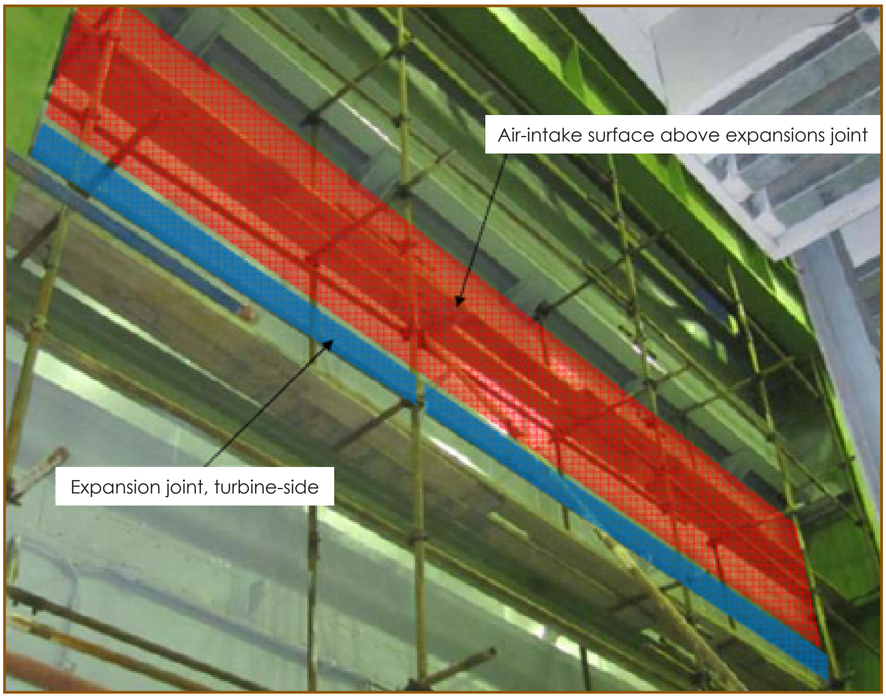

Fig.1: Schematic representation of the assessed surface above the turbine-side of the expansion joint

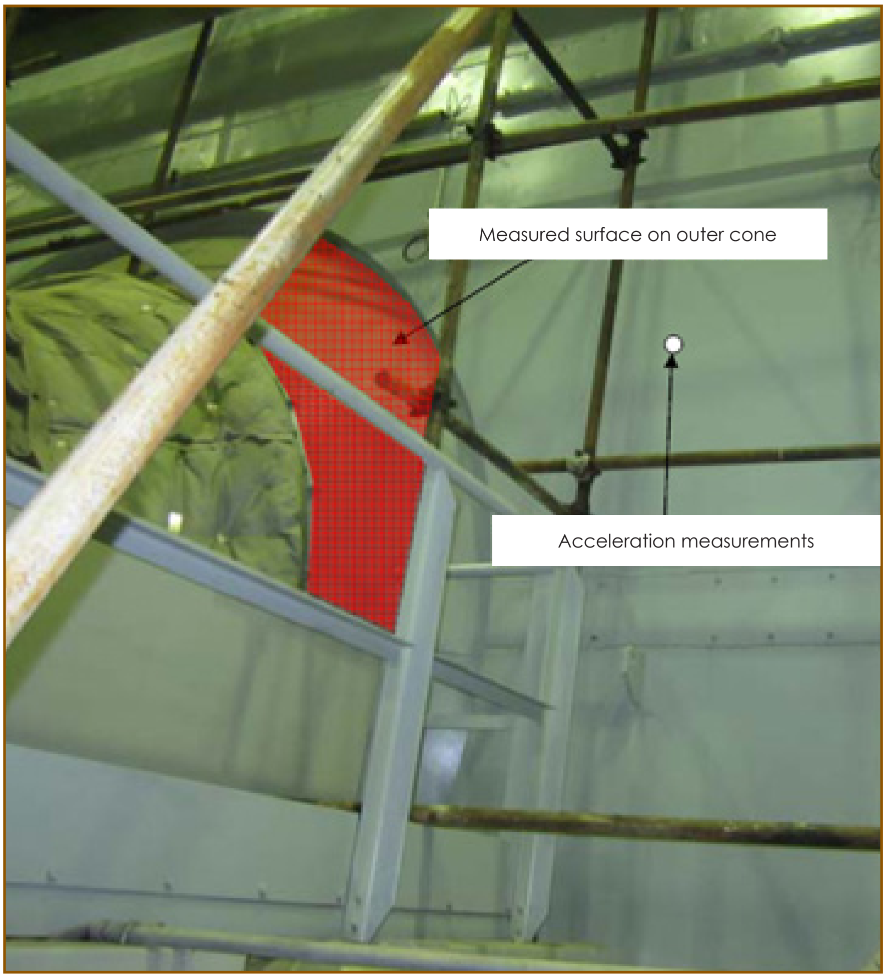

Fig.2: Schematic representation of the assessed surface of the outer cone

The noise measurement results show high intensity noise levels emitting from the surface of the expansion joint. This surface is stretched over either side of the air intake duct and due to this geometrical assembly this is the main source of high noise emissions in the gas turbine hall.

During the measurements, a relevant sound radiation by the surface of the outer cone at the junction between the air intake and the turbine was also found. The direction of the intensity indicates that the noise is emitted by the cone itself and is not affected by any other sources.

Generator Enclosure

To analyze the noise emitting from the generator enclosure, intensity measurements were taken at a square surface of 2 x 2 m at the left side of the generator enclosure (Fig. 3). The acceleration measurement was also conducted at the center of the mentioned surface. According to the measurement results, noise emissions from the generator enclosure were in the acceptable range.

Fig.3: Schematic representation of the assessed surface on the left-side of the generator enclosure

The Space Above Combustion Chamber

The open spaces on top of the combustion chambers were also investigated as potential noise sources (Fig. 4). The measurement results show that there are high noise levels emitting from upper parts of the combustion chambers which are reflected by the roof of the turbine hall and thus have relevant effects to the noise levels presented in the lower parts of the turbine hall.

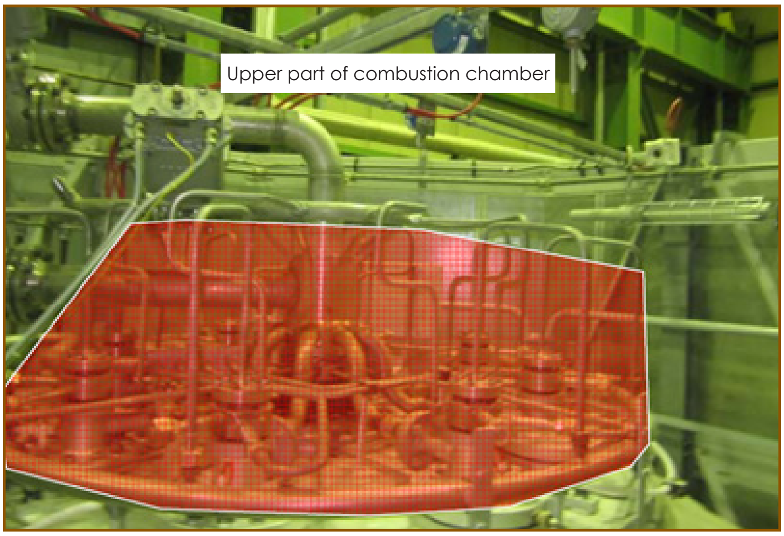

Fig.4: Schematic representation of the assessed space on top of the combustion chamber

Main Fuel Gas Pipe

The main gas fuel pipe also seemed to be a major source of noise within the turbine hall. Therefore, the sound energy emitting from this source was also scanned using the intensity probe as shown in Fig. 5.

Fig.5: Schematic representation of the assessed surface around the main gas fuel pipe

As the measurement results show, there is a high intensity level in the upper frequency range emitting from the main gas fuel pipe.

Noise Attenuation Measures

Having carried out noise level measurements for all the on-site noise sources, the next step was to select, design and apply appropriate noise attenuators such as silencers, barriers or insulators accordingly. A summary of noise attenuation measures taken are as follows:

Additional Insulation on the Air Intake Vertical Duct

Additional insulation was applied on the vertical duct casing, expansion joint and the outer cone in between the air intake and turbine, the latter being covered by a sheet metal cladding (Figs. 6 and 7).

Fig.6: Additional insulation layers applied on the air intake vertical duct

Fig.7: Outer cone cladding in between the air intake and turbine

Parallel Baffle Silencers on Top of the Combustion Chambers

Parallel baffle silencers are meant to reduce noise emissions on top of the combustion chambers. This type of silencer allows natural ventilation of the combustion chamber enclosure. An acoustic wall was also installed on both sides of each combustion chamber to further enhance noise mitigation inside the turbine hall. The insulation of the gas turbine body was changed from blanket type to more efficient cladding type insulation, as well.

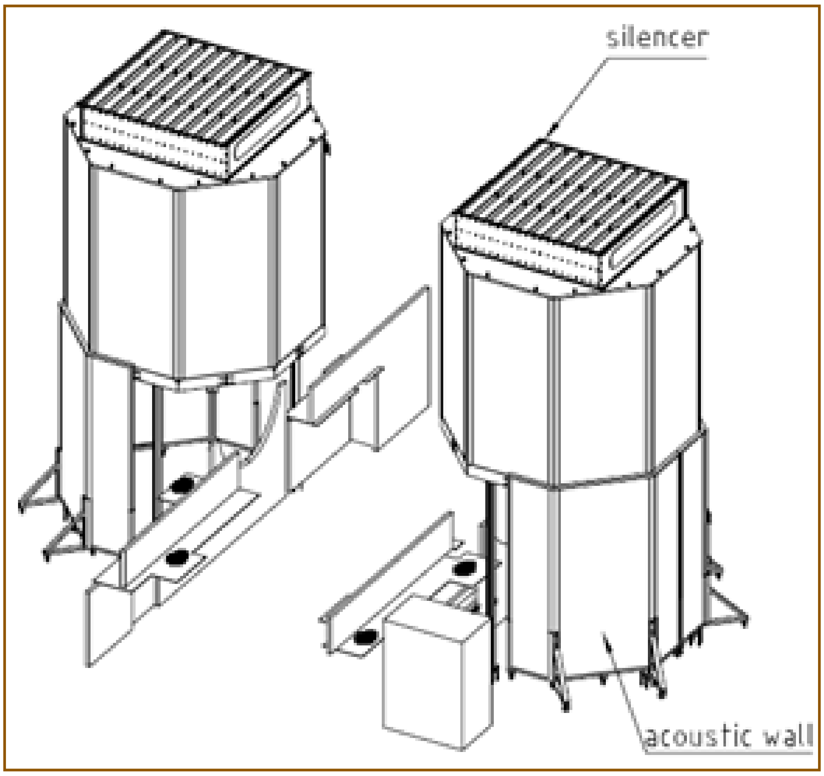

Fig.8: Parallel baffle silencers and acoustic walls installed above and around the combustion chambers

Main Fuel Gas Pipe Cladding

The Main fuel gas pipe was covered with mineral wool and surface cladding made from sheet metal.

Results

In order to evaluate the effectiveness of the noise attenuation measures taken, on-site noise measurements were carried out inside the turbine hall of two typical MGT-70 power generation units at two different power plants in central Iran with and without implementation of the noise attenuation measures. For this purpose, twenty points at 1 meter distance around the gas turbine and generator within the turbine hall were selected for taking spot noise measurement data. The measurement locations are illustrated in Fig. 9. The sound pressure level measurements were conducted in an A-weighted scale.

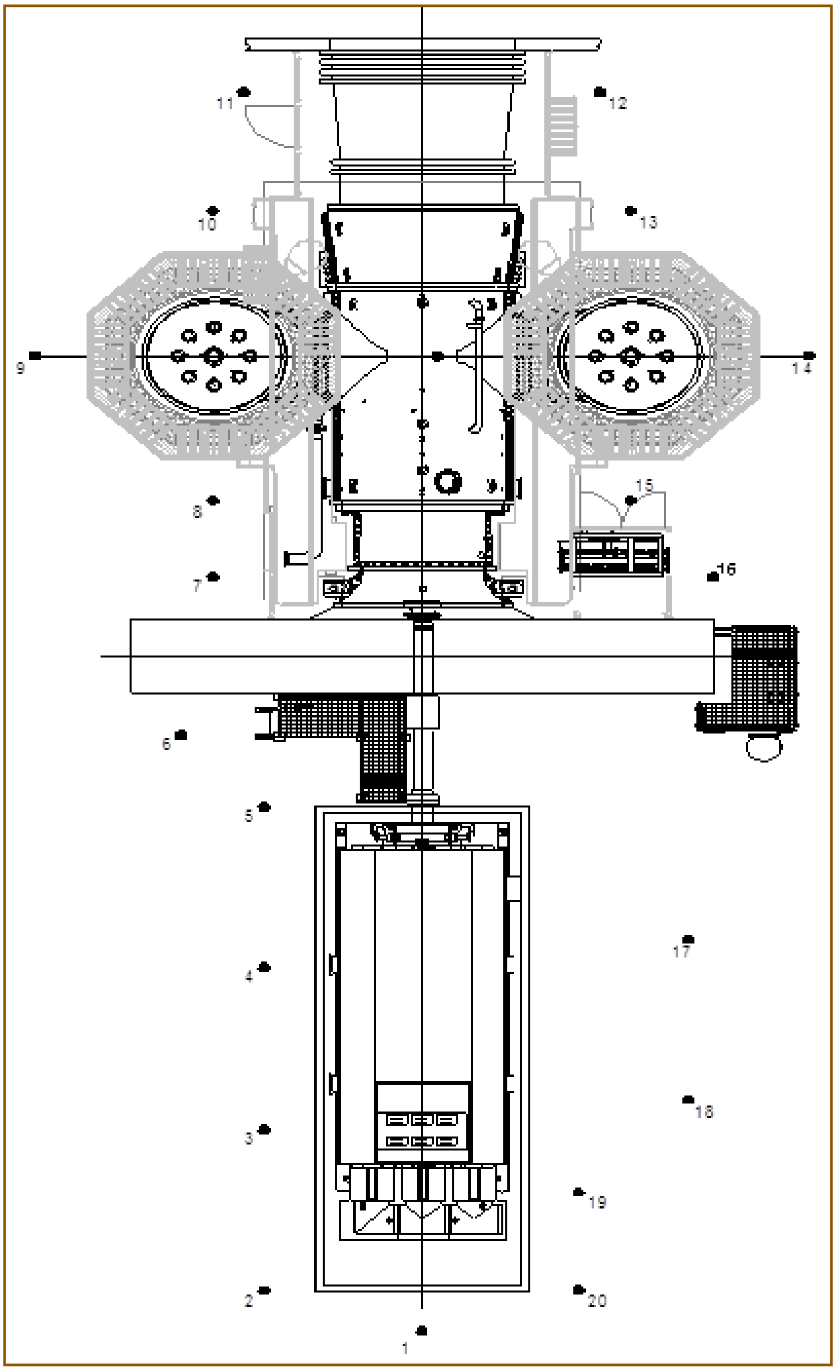

Fig.9: Noise measurement locations inside the turbine hall

According to the measurements taken, the implementation of the noise attenuation initiative has a significant impact on reducing sound pressure levels at all measurement points with logarithmic mean value of 11.4 dB(A) reduction in noise emissions inside the turbine hall.

References

1. DIN EN ISO 3744: Acoustics Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for an essentially free field over a reflecting plane.
2. ISO 9614-2: Acoustics-Determination of sound power levels of noise sources using sound intensity - Part 2: Measurement by scanning.

03

Transient Behavior of the MGT-30 Gas Turbine under Scrutiny

Abstract

Multi-spool gas turbines have been used extensively in a wide range of applications from land-based power generation to marine and aircraft prime movers. For this reason, having an accurate model of these engines is essential to better understand their behavior in different maneuvers and hence efficient development and design of control systems and interfaces. As opposed to single shaft engines which can be simply modelled as linear systems, nonlinear modelling is needed for multi-spool gas turbines since different sets of compressor-turbine compartments are coupled thermodynamically in these engines. Basic thermodynamic and mechanic principles together with compressor and turbine performance maps are required to derive the nonlinear models of these engines. In the present study a turbine-governor model of a three-spool gas turbine is developed and verified by comparing model-produced results to transient load rejection performance data of the engine. Having established a good agreement between the simulation results and engine measurements, the model enables further investigation of the possible impacts of different manoeuvres or parameters on engine performance. The findings of this research have been published in the ASME Journal of Engineering for Gas Turbines and Power in 2017.

Introduction

The MGT-30 gas turbine engine manufactured by MAPNA Turbine is a three-spool gas turbine used in a variety of applications ranging from prime movers for natural gas compressor stations and petrochemical plants to stationary and mobile power generation. A schematic representation of the three spools of these engines is shown in Fig. 1. As shown in this figure, the MGT-30 gas turbine consists of a gas generator comprising low and high pressure (LP & HP) compressors and turbines coupled to each other via two concentric shafts, in addition to a power turbine (PT) coupled to an external shaft for prime moving purposes or an electric generator for electrical power generation.

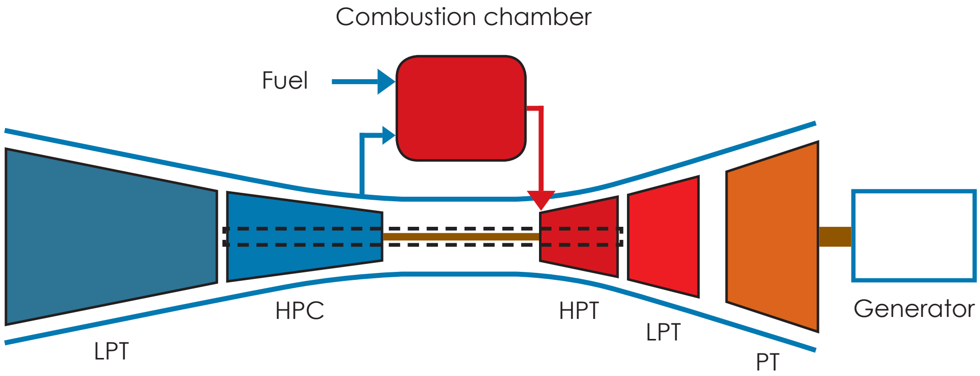

Fig.1: Three-spool gas turbine arrangement

The main specifications of the MGT-30 gas turbine are also listed in Table 1.

Table 1: MGT-30 gas turbine specifications

Power*	MW	26
Efficiency	%	36
Nominal frequency	Hz	50
Power turbine speed	rpm	3000
Heat rate	kJ / kWh	10000
Exhaust gas mass flow	kg/s	90
Exhaust gas temperature	°C	478

*ISO rated power based on natural gas fuel

Since the whole engine with three separate shafts, works as a single thermodynamically coupled system, any changes in fuel flow rate will affect the hot gas temperature leaving combustion chamber and hence the amount of power produced in the three turbines. So, the rotational speed of the low and high pressure shafts is not controlled directly and the whole engine will be adjusted to a new working condition accordingly.

In this study, a precise turbine-governor model allowing further investigation of the transient behavior of the MGT-30 gas turbine following load rejection is presented and validated by transient performance data of the engine.

Methods

Inter-component volume method (ICV) has been implemented in Matlab/Simulink environment to model the engine. In this approach, the model consists of five components including LPC, HPC, LPT, HPT and PT in addition to control volumes before and after each.

Fig. 2 illustrates the arrangement of the modules where ṁ, T, P and ω stand for mass flow rate, temperature, pressure and rotational speed of the rotor, respectively.

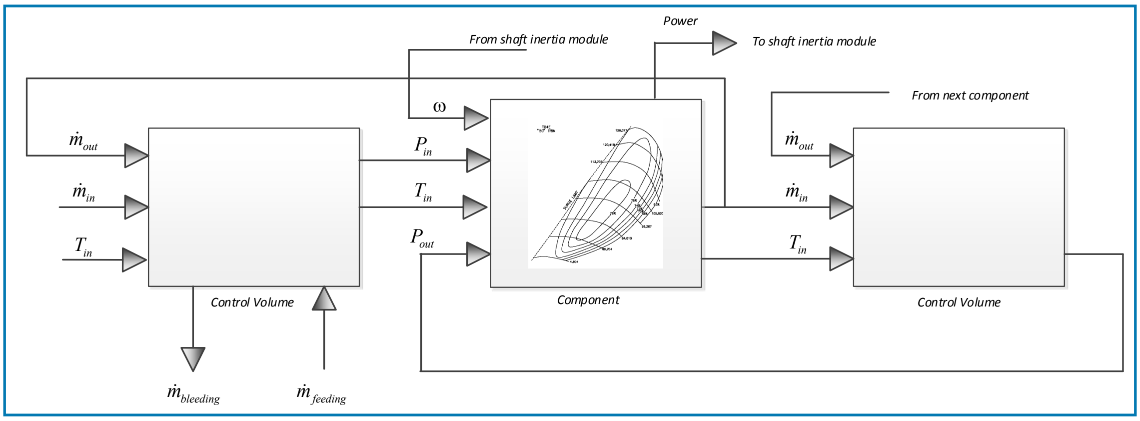

Fig.2: The structure of the MGT-30 gas turbine model

The governor of the MGT-30 gas turbine consists of load-frequency and mechanical limit controllers as shown in Fig. 3. Two controllers are also employed to run up the engine up to the synchronous speed of 3000 rpm for the power turbine.

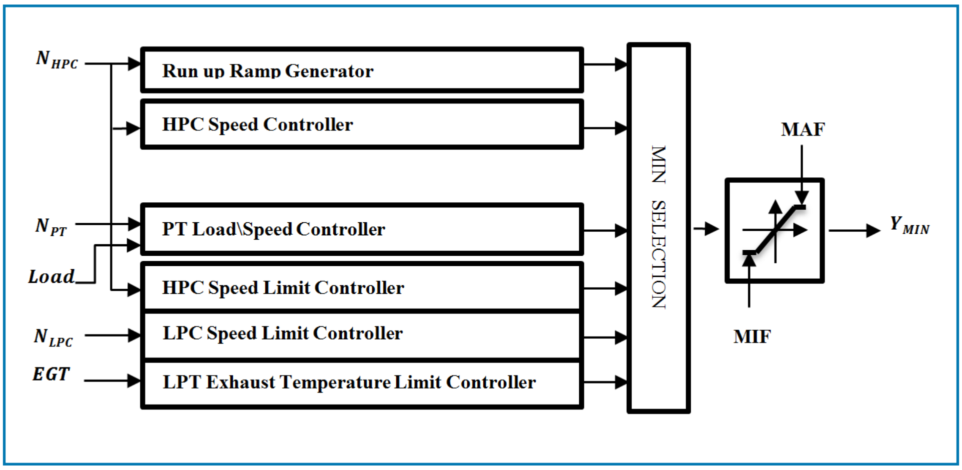

Fig.3: The structure of the MGT-30 gas turbine governor

This structure is a switched bump-less override control system in which six controllers are used. The inputs to the system include actual HPC, LPC and PT rotational speeds (NHPC, NLPC, and NPT), load and LPT exhaust gas temperature (EGT). The main output of the system is also fuel flow rate command. Subsidiary tasks such as maximum HPC and LPC rotational speed as well as LPT exhaust gas temperature limits are to maintain the operation of the engine within the high availability and reliability region. A more detailed representation of the limit controllers is also shown in Fig. 4.

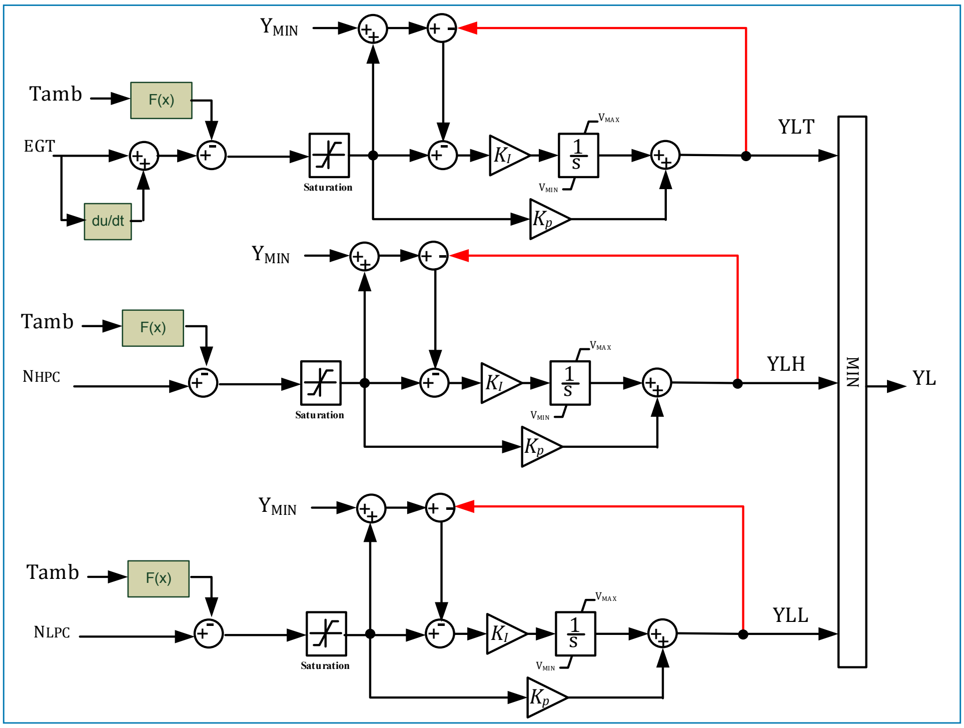

Fig.4: Detailed representation of the MGT-30 gas turbine limit controllers

The main controller of the turbine-governor model is also represented in more detail in Fig. 5. This is valid for almost all modes of operation such as loading, base and peak loads, unloading, part load, full speed no-load, frequency control and load rejection.

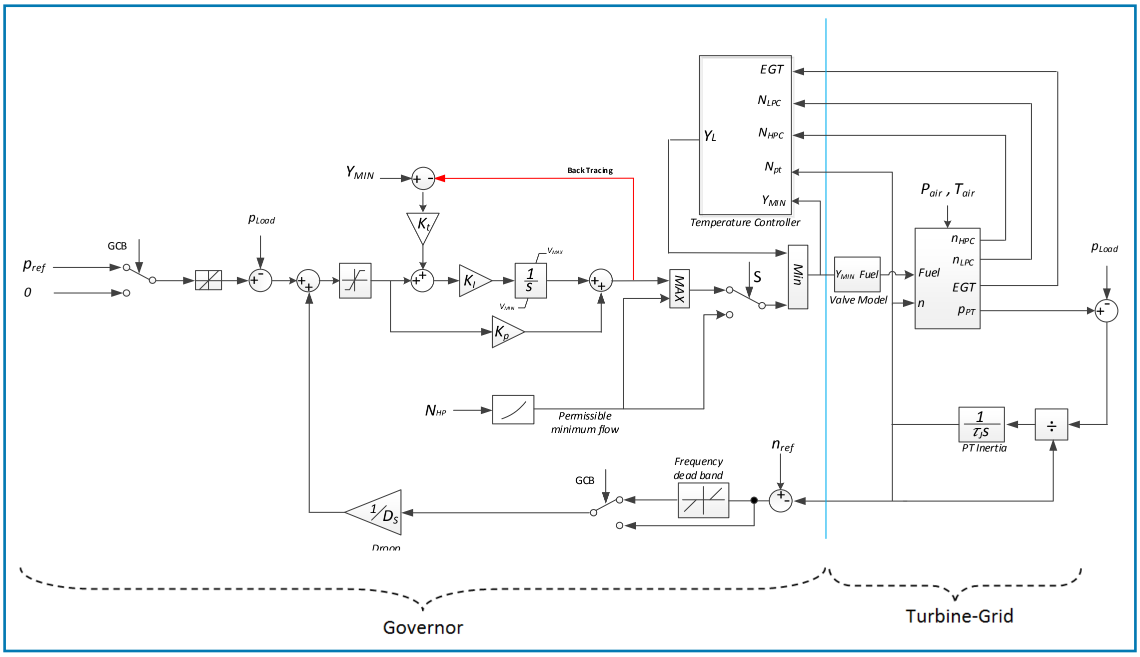

Fig.5: Turbine-governor model (main loops included) for MGT-30 gas turbine

The model inputs include ambient conditions, speed and power set-points and electrical load on power turbine. The outputs also encompass inlet and outlet pressure, temperature and speed of each previously mentioned model components for which test measurements have been carried out on an MGT-30 gas turbine engine installed as a mobile power generation unit at the Parand thermal power plant, southwest Tehran. These outputs are to provide the data required to validate the model.

Results

Figs. 6 and 7 represent performance curves consisting of steady state operating points at various loads on the LPC and HPC maps, respectively. Axis values are removed due to confidentiality concerns.

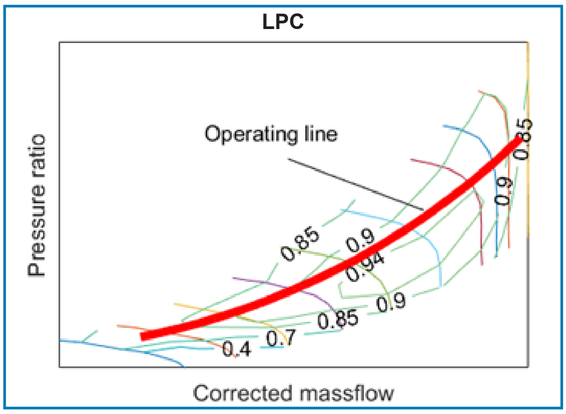

Fig.6: Steady state performance curve on the LPC map of the MGT-30 gas turbine

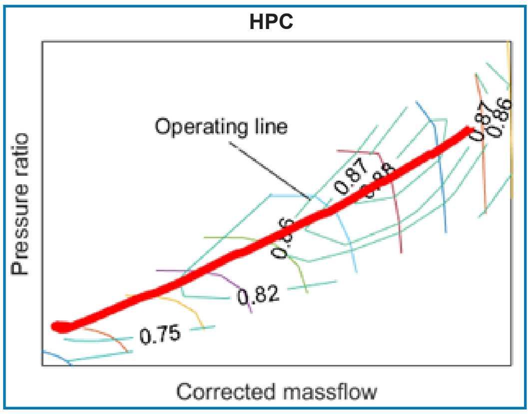

Fig.7: Steady state performance curve on the HPC map of the MGT-30 gas turbine

The LPT outlet temperature response for loading from 1 to 18 MW at ambient temperature of 30 °C is also depicted in Fig. 8.

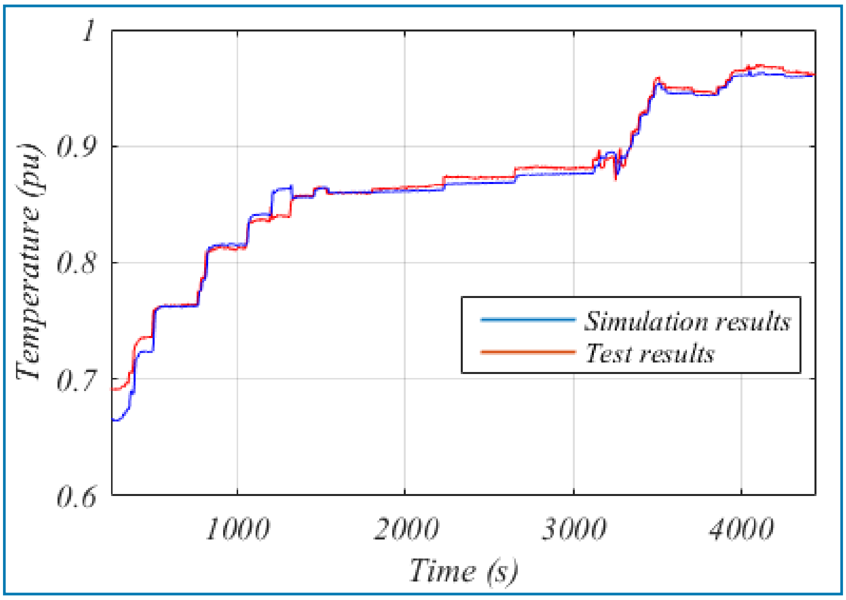

Fig.8: Temperature response of the MGT-30 gas turbine model for loading from 1 to 18 MW

Comprised of gas generator and power turbine compartments, multi-spool gas turbines have more complex behavior at high transients than single shaft gas turbines. In single shaft gas turbines, the compressor coupled with gas turbine acts as a damper during high transients. Nevertheless, for PT in multi-spool gas turbines the only damper would be the friction forces in the bearings.

Fig. 9 shows measured and simulated results for power turbine over speed following two load rejection scenarios. As shown in this figure, there is a good agreement between measured and simulated results with less than 5% error in the predictions of the model.

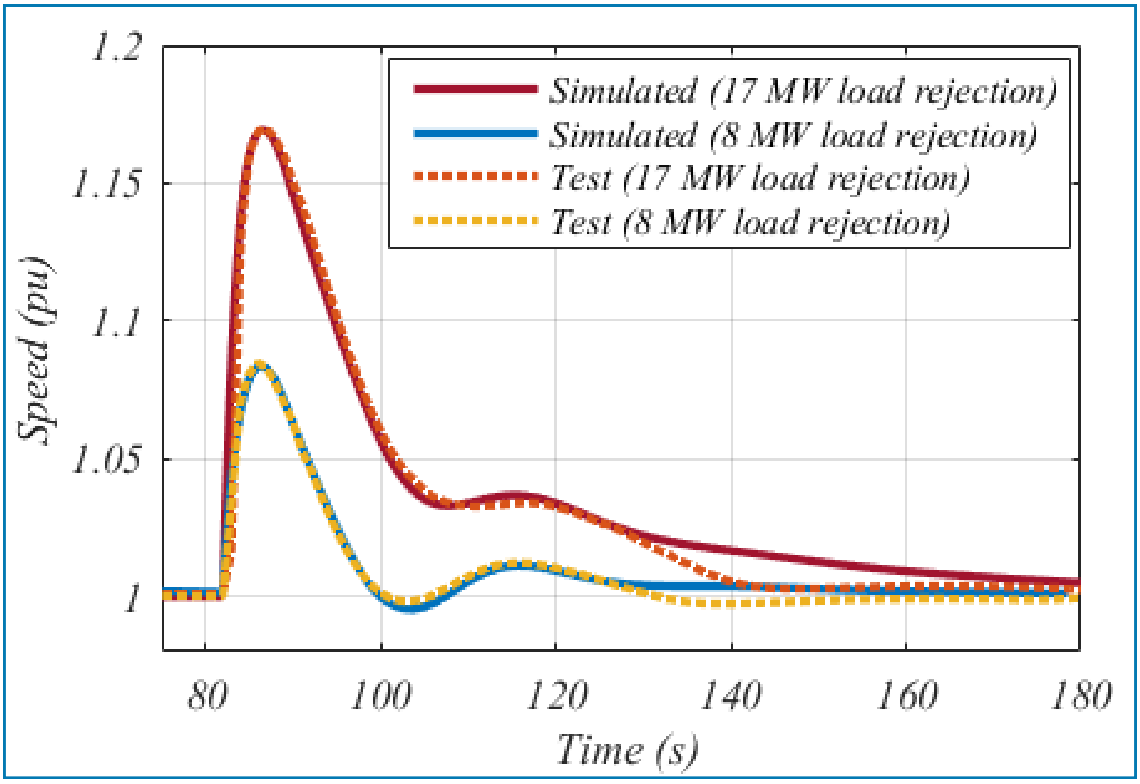

Fig.9: Power turbine speed response of the MGT-30 gas turbine subsequent to load rejection

In single shaft gas turbines, the minimum fuel flow determines the slope of speed decrease after peak speed. For multi-spool engines, the rotor inertia and friction in the bearings play the main role in the amount of overshoot and slope of speed reduction following load rejection.

The over speed shall be kept within the permissible ranges to prevent excessive mechanical stresses in rotary parts of the engine. The peak speed mainly depends on the shaft inertia, delays in governor, fuel system and gas generator, while fluctuations after load rejection depend on controller model and the existing nonlinear behavior in a few components especially the friction in the bearings.

Conclusions

In this study a turbine-governor model has been derived for multi-spool gas turbines using ICV method. The model is validated against measured performance data highlighting high accuracy of the model at extreme transient conditions. Results show high amounts of over speed after load rejection in engines of such an arrangement, i.e., power turbine not coupled with any compressor. To address this problem, a switch is used in the controller to shift the fuel to the minimum possible flow and hence keeping the over speed overshoots within permissible limits.

04

MAPNA Research Burner, Lit to Light the Way for Combustion R&D

Introduction

A standalone complex model of gas turbine combustion system is never sufficient to study fundamental aspects of combustion such as turbulence-chemistry interactions, flame structure and stability, complex recirculating flows, radiation, pollutant formation as well as new combustion concepts. Therefore, research burners are required to perform experimental studies and obtain detailed data for these processes to facilitate the development and assessment of mathematical models and implementation of diagnostic techniques. Unlike a real burner, a well-designed research burner has simple geometry and well-defined boundary conditions to produce useful, accurate and repeatable results. Among different types of research burners, the swirl-stabilized one can simulate the combustion processes under gas turbine-relevant conditions. In comparison to real gas turbine combustors, they are reduced in size and thermal power, but feature the essential characteristics. A major advantage is that they can be equipped with sight openings to enable closer investigation of the combustion process using optical and laser-based techniques.

There are well-known research burners such as Gas Turbine Model Combustor (GTMC) dual-swirl burner of the DLR[1] Institute of Combustion Technology, frequently used in research and development programs defined and conducted by various research centers and renowned gas turbine manufacturers. MAPNA research burner (MRB-01) has been designed and manufactured based on a well-documented EM2C French research burner.

[1] The German Aerospace Center

In addition to premixed mode of combustion and as an extra feature not present in the original burner, the MRB-01 is able to operate in both premixed and diffusion modes of combustion, since there are concepts to be surveyed in the diffusion mode as well. In addition to the fundamental aspects mentioned above, the following initiatives are also associated with MRB-01:

- ► Feasibility study of laser ignition in gas turbine combustor
- ► Development of optical diagnostic techniques such as Chemiluminescence
- ► Basic fuel flexibility study of gaseous fuels in a wide range of Wobbe index values
- ► Evaluation of new burner production methods such as additive manufacturing
- ► Implementation of flame temperature measuring techniques using thermocouple

Flame temperature measurement setup is depicted in Fig. 1. Different flame shapes have been captured and shown in this figure.

Flame Temperature Measurement

Flame temperature as a fundamental combustion-related parameter reveals valuable information on combustion characteristics such as production of pollutants and heat transfer calculations. Among different methods of flame temperature measurement, using bare wire thermocouple type B is a simple and reliable approach which is also implemented at MAPNA turbine combustion laboratory. In addition to experimental measurements, an in-house code has also been developed in order to correct the intrinsic errors associated with radiative and conductive heat losses from the thermocouple's junction bead.

Flame temperature measurement setup is depicted in Fig. 1. Different flame shapes have been captured and shown in this figure.

Fig.1: Flame temperature measurements conducted on MRB-01 using thermocouple

Burner Description

A cross-sectional view of the MRB-01 swirl burner is shown in Fig. 2. Due to experimental requirements, the burner design is modular and all parts may be replaced simply if needed. It comprises three main parts including plenum, flow passage and transparent flame tube. The plenum is a cylindrical chamber with three equally spaced peripheral tubes at its base to feed premixed reactants. A honeycomb piece is placed in the plenum as a flow straightener to break the large turbulent eddies followed by a flashback grid at the end of plenum to prevent flame flashback. A standard convergent nozzle connects the plenum to the flow passage, which is a constant diameter duct with a central rod installed on its axis to help stabilize the flame in premixed combustion.

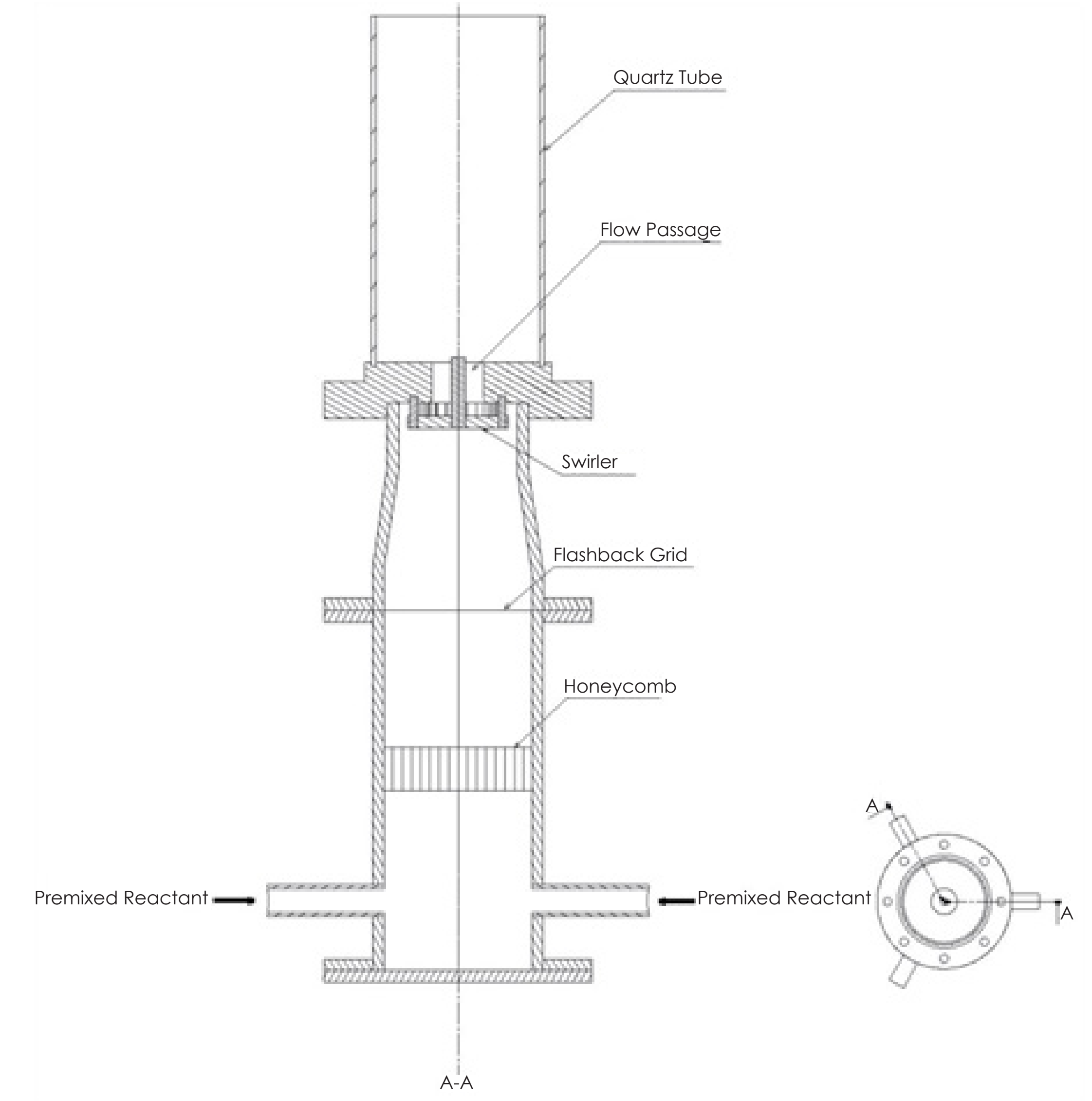

Fig.2: Cross-sectional view of MRB-01

The axial/radial swirler made using additive manufacturing processes (Fig. 3), is fixed at the center of the flow passage upstream, generating flow rotation.

The convergent part installed at the swirler upstream, reduces boundary layer thickness and turbulence level and makes the inlet velocity profile flat.

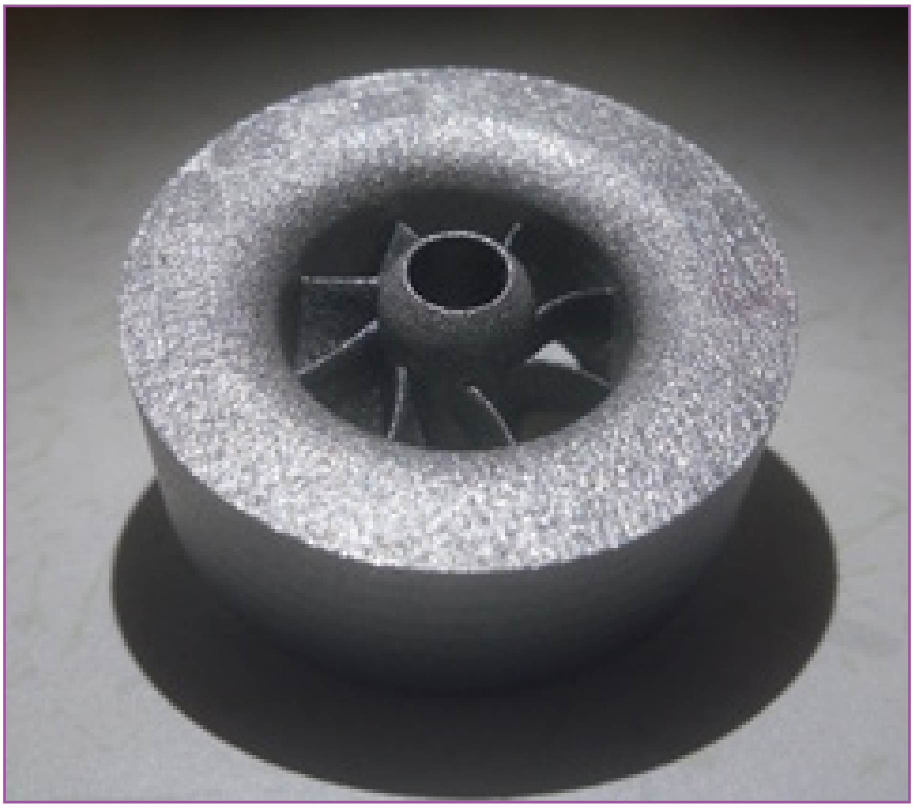

Fig.3: MRB-01 axial swirler made by additive manufacturing

At the end of the burner a transparent flame tube made of quartz is considered to confine the flame and provide optical access. In case of burner operation in diffusion mode, the central rod would be replaced by a tube passing through the swirler and the flow passage which allows direct fuel injection into the reaction zone. Photographs of the MRB-01 burner and its main parts are presented in Fig. 4.

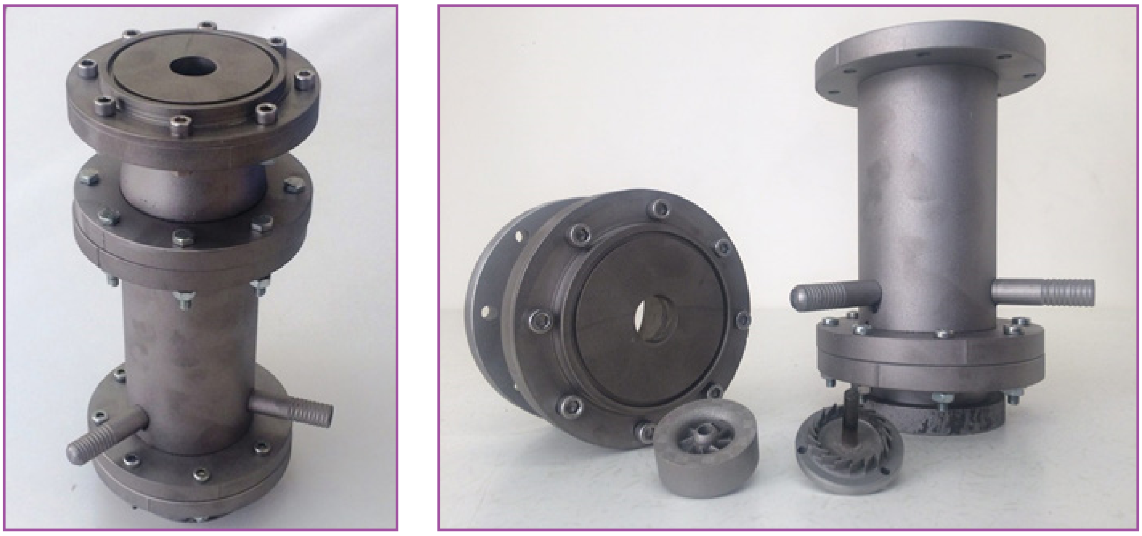

Fig.4: MAPNA research burner (MRB-01)

Burner Operating Conditions

The MRB-01 test burner's operating parameters are set so as to allow feasibility of testing at different conditions with respect to air velocity and temperature, equivalence ratio and fuel composition. The required air is supplied via a compressor and the main fuel is taken from MAPNA Turbine combustion laboratory high pressure natural gas mains which allows extending the test pressure ranges if required. Air and fuel gas pressure adjustment is performed using accurate regulators along with pneumatic globe valves to reach the target mass flow rate measured by Coriolis mass flow meters. The maximum thermal power of the burner is about 20 kW based on the air supply capacity. The flow rotation created by axial/radial swirlers varies depending on blade angles with the swirl number ranging from 0.5 to 0.7.

Since the fuel flexibility survey is one of the live and important research topics in the gas turbine industry, a separate gas line is under construction aimed at adding H2 or N2 into the main fuel. Adding these gases makes it possible to test a wide range of Wobbe index values using MRB-01.

A schematic P&I diagram of MRB-01 fuel supply line (additive gases included) is depicted in Fig. 5.

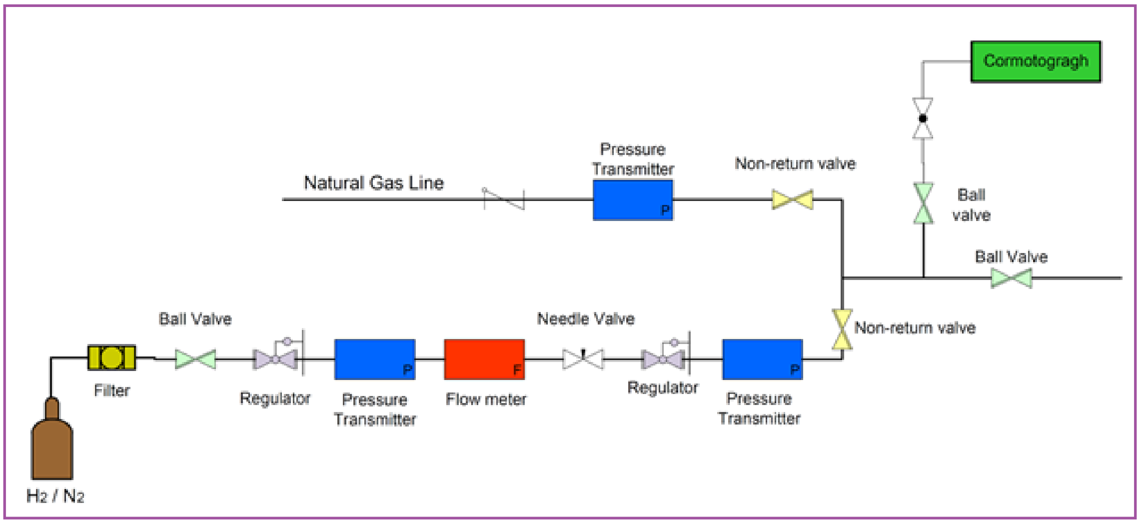

Fig.5: Schematic P&I diagram of the MRB-01 fuel supply line (additive gases included)

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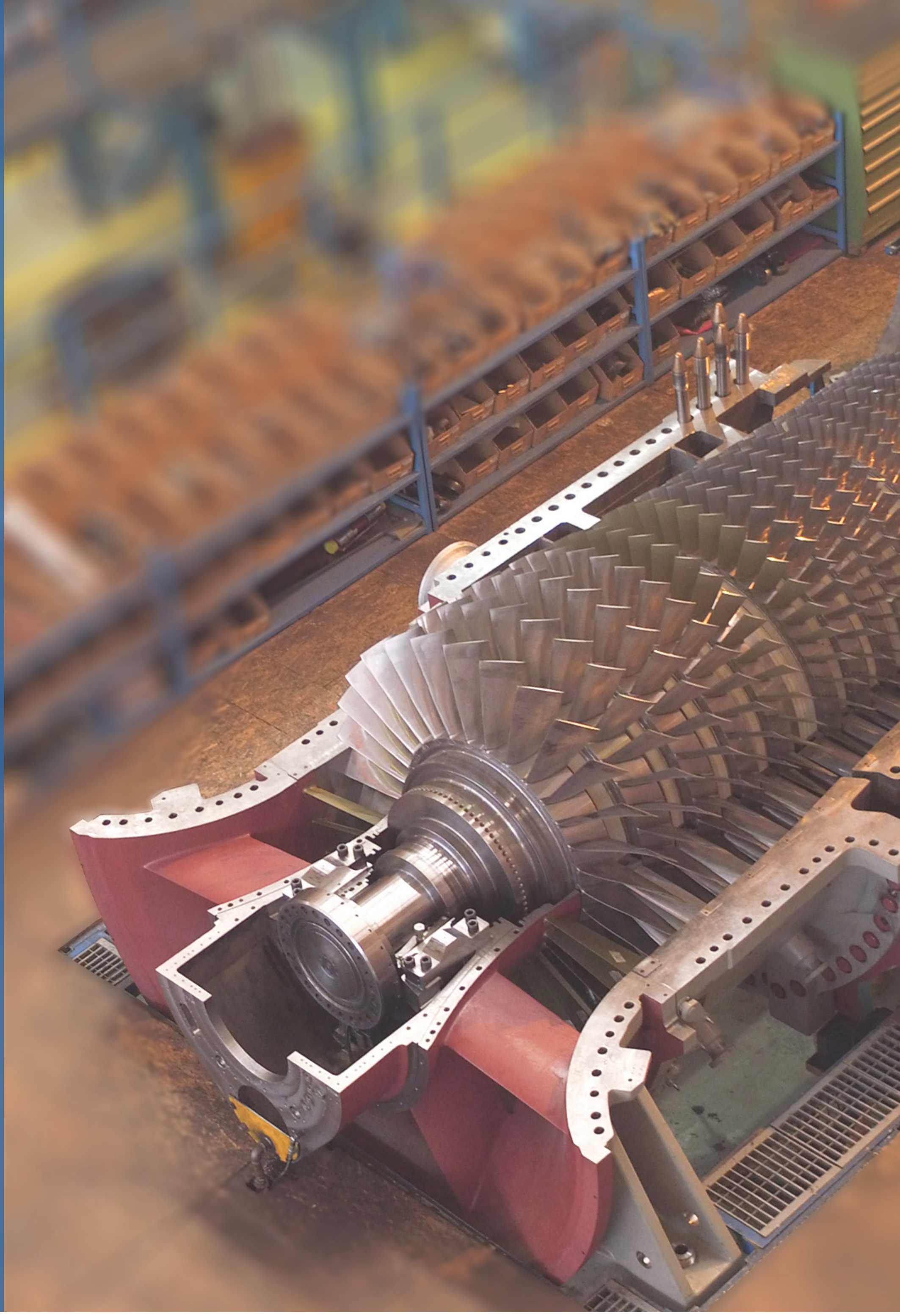

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