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MAPNA TURBINE ENGINEERING & MANUFACTURING CO. (TUGA)

TUGA

MAPNA GROUP

Willpower to Empower Generations

Cover Page:
The First MGT-40 Power Generation Unit

Editorial

Dear Colleagues, Partners and Professionals,

An organization-wide culture of caring and commitment that puts a premium on customer satisfaction and support while trying to do more with less by efficient and optimized use of resources, has always been fostered and nurtured at MAPNA Turbine. It is in this context and with great pleasure that a brief account of a few recent achievements is presented to you, our valued readers, in this edition of MAPNA Turbine Technical Review.

The first article takes an in-depth look into the condition monitoring services provided for the first MGT-40 gas turbine manufactured and brought online by MAPNA Turbine at Zahedan power plant, south east of Iran. The benefits accruing from by far the most comprehensive maintenance and support services provided by MAPNA Group for this machine are discussed and elaborated on.

Thermal-assisted machining is being touted as a highly effective scheme for machining hard and difficult-to-machine materials such as tungsten carbide. It is in great use in the development of a broad spectrum of cutting tools used in the production of a large number of power equipment. The second article presents the results of the experimental investigations carried out at MAPNA Turbine to explore feasibility and advantages accruing from application of this method in turning of tungsten carbide workpieces using Polycrystalline Diamond (PCD) cutting tools as well as to regulate and adjust the process over time.

In-depth numerical analyses and experimental investigations carried out on residual life estimation of MGT-70 gas turbine compressor blades beyond their nominal lifetime of approximately 100K EOH are laid out in the third article. A number of carefully planned tests in compliance with renowned international standards have been carried out in the course of this investigation which allows for more accurate assessments of the remaining life of compressor blades.

The last article outlines measures taken to develop a liquid fuel system for MGT-40 gas turbine. This makes running on dual fuel possible for this machine and brings another dimension to an already broad operability and applicability range of it.

Please join us in relishing the detailed account of these subjects, in this issue of the Technical Review.

Respectfully,

Mohammad Owliya, PhD

Deputy General Director

MAPNA Turbine Company (TUGA)

March 2021

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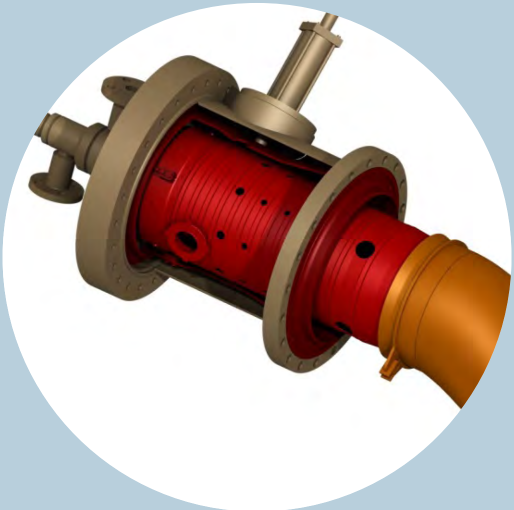

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Running on Liquid Fuel; No More an Issue with MGT-40

1

MGT-40 Gas Turbine Condition Monitoring at a Glance

Introduction

Condition Monitoring (CM) functions as the physical assets management system and hence the clients are constantly made aware of their assets' condition which makes it possible for them to take appropriate decisions in a timely fashion. With an optimal equipment maintenance system in place, repair costs will also be minimized and with long-term monitoring of the assets during their lifetimes, it is made possible to reduce inconvenient accidents and environmental incidents.

MGT-40 Gas Turbine Equipment Monitoring Scope

Gas turbine, related auxiliary equipment and load gearbox are deemed the most critical assets of an MGT-40 gas turbine power plant unit which are recommended to apply physical assets management approach for. So, condition monitoring services were designed and implemented for the first MGT-40 gas turbine manufactured and brought online by MAPNA Turbine at Zahedan power plant for the above-mentioned systems and equipment.

Fig. 1 – The First MGT-40 gas turbine installed at Zahedan power plant

MGT-40 Gas Turbine Condition Monitoring Services Portfolio

The CM services offered for the first MGT-40 gas turbine power plant unit included monitoring systems' software as well as providing different types of reports and required technical support for the power plant unit, as listed in Table 1. In addition to regular monitoring and data collection services carried out on the MAPNA MIND platform, maintenance optimization of the critical assets was also on the agenda.

Table 1 – MGT-40 gas turbine performance monitoring services portfolio

Item	Service Category	Service Description
1	Local Condition Monitoring System	MAPNA MIND Platform
2		Asset Performance Monitoring (APM)
3		Control Loop Performance Evaluation System (CLPA)
4		Intelligent Condition Management System (ICMS)
5		MAPNA MIND Maintenance Management System (3MS)
6		Performance Condition Monitoring System at Power Plant
7	Technical Condition Monitoring Services	Operating Regime Reports
8		Inspection Reports
9		Reliability, Availability, Maintainability (RAM) Analysis Reports
10		Vibration Condition Monitoring Reports
11		Oil Condition Monitoring Reports
12		NOx Emissions Testing Reports
13		Technical Support

The following sections provide a more detailed description of the provided CM services.

Local Condition Monitoring System

CM software systems include an online condition monitoring system, control loop performance evaluation system as well as repair and maintenance management system all of which loaded onto the MAPNA MIND software platform. Once the MAPNA MIND platform and all required systems and equipment are installed and set up properly, the local condition monitoring system is ready to operate.

- **MAPNA MIND Platform**

MAPNA MIND platform is an access portal to connect to the power plant with its condition monitoring systems in place. In this platform, the status of the plant's physical systems is digitally visible. Moreover, an electronic record of all monitoring interactions including reports generated, information exchanged, technical solutions provided and quality documents of the unit is also provided.

Having a physical assets management system in place using the MAPNA MIND Platform brings about the following benefits:

- Establishing a continuous connection between experts, client, and operators
- Providing periodic or instant reports for any abnormal behavior
- Ability to evaluate the productivity of a process
- Reduction and prevention of incidents leading to long-term shutdowns
- Prediction and estimation of repair and maintenance time
- Providing an overview of the current status to help making informed decisions
- Creating new opportunities
- Increasing efficiency
- Shifting the maintenance approach from traditional methods to predictive maintenance

- **Asset Performance Monitoring (APM)**

Application of condition monitoring systems is essential to make sure of the correct operation of the gas turbine and auxiliary equipment. Online condition monitoring software that loads into the local condition monitoring system consists of different modules of gas turbine modeling, online data collection of important process parameters, performance analysis and data storage. In general, benefits of performance monitoring include increased gas turbine service life as well as reduced maintenance costs and fuel consumption.

- **Control Loop Performance Analysis (CLPA)**

One of the problems in control systems is the change in the performance of involved pieces of equipment or the specifications thereof. To overcome this obstacle, a controller performance evaluation system is used, which examines performance of the closed control loops online and notifies if the control loop is out of order for the preset conditions and in some cases, occurrence of the defects in the process. In such cases, it would be possible to reset the controllers (manually or automatically) and hence prevent any drop of the efficiency.

The CLPA software is designed to assess performance of control loops and control valves' position, as well as constant optimization of control loop system behavior. Closed control loop performance evaluation algorithms as well as PID parameters' regulating methods are among the advanced methods that can be implemented within the control system.

- **MAPNA MIND Maintenance Management System (3MS)**

Application of computer-assisted maintenance systems and getting rid of compiling daily operation reports in paper versions, play a significant role in establishing an electronic maintenance approach in the plant and optimization of physical assets management processes. Hence, the 3MS maintenance management system is provided in the MAPNA MIND platform which makes it possible to record all daily information with regard to each and every start and shutdown of the unit and the reasons behind them, as well as other important parameters and issues that matter when it comes to proper operation of the power plant.

- **Local Condition Monitoring System**

Local condition monitoring system consists of all condition monitoring software systems, Control Loop Performance Analytics (CLPA) and Maintenance Management System (3MS) that are loaded onto the MAPNA MIND platform.

Technical Condition Monitoring Services

In addition to local condition monitoring system's software and dashboards available through the MAPNA MIND platform, technical condition monitoring services including technical support for plant operation and provision of various technical reports on monitoring initiatives, are also covered during the contract period.

Following the receipt of information from the provided communication ports for each work package, technical analysis of the data provided will be carried out by dedicated teams of experts and the required technical advice and recommendations are then provided in a case-by-case scheme, on a quarterly, biannual or any specific, agreed upon time frame.

While providing technical condition monitoring services and in addition to evaluation of gas turbine's operation regime and analysis of observations made during inspection intervals, performance indicators are also assessed for reliability analysis purposes. Lubricating oil condition, vibrational analyses and other technical reports are also provided in addition to all necessary technical support that might be needed for the equipment within the scope of supply of the project.

- **Gas Turbine Operation Regime**

Optimization and improvement of the operation of a power plant gas turbine not only increases the overall efficiency of the plant but also provides a far more successful physical assets management scheme. Recognition and prediction of a gas turbine's operation regimes are extremely beneficial in terms of investigation of the effects of operating factors on initiation and development of destructive mechanisms in gas turbine components. So, the operation regimes of the gas turbine are also included and assessed in the technical reports provided.

- **Intelligent Condition Monitoring System (ICMS)**

Another advantage of implementing a local condition monitoring system is keeping an eye on the status, diagnosis, identification and prediction of the defects through an expert team and taking advantage of artificial intelligence techniques in doing so. In these reports, the expert team would use data mining tools to detect abnormal events. To use such tools, the unit data is needed in addition to baseline normal operational conditions which would be fed into the related software packages taking advantage of the vast knowledge of a team of experts.

The architecture of the ICMS is shown in Fig. 2. As can be seen in Fig. 2, the operational data from the local status monitoring system (left-side module) is transferred to the expert condition monitoring center (right-side module) for further analyses and assessments. Data analysis is carried out via the two schemes below:

- In the first scheme called 'Data-Driven', point-to-point machine learning methods are utilized to detect conditional anomalies.
- In the second scheme called 'Model based', time series analysis methods are taken advantage of to detect cumulative anomalies.

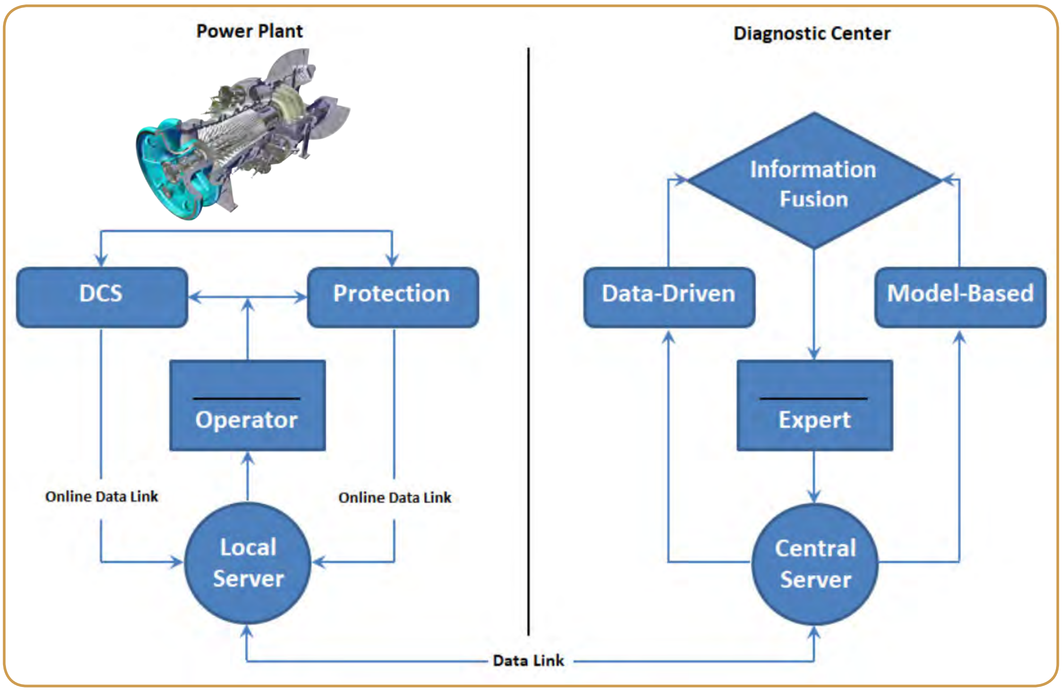

Fig 2. Architecture of the ICMS software

The results are then presented in a unit called 'Information Fusion' and final diagnosis of the system status is presented to the expert. The graphical user interface of the ICMS system consists of display, expert and system status panels as shown typically in Fig. 3.

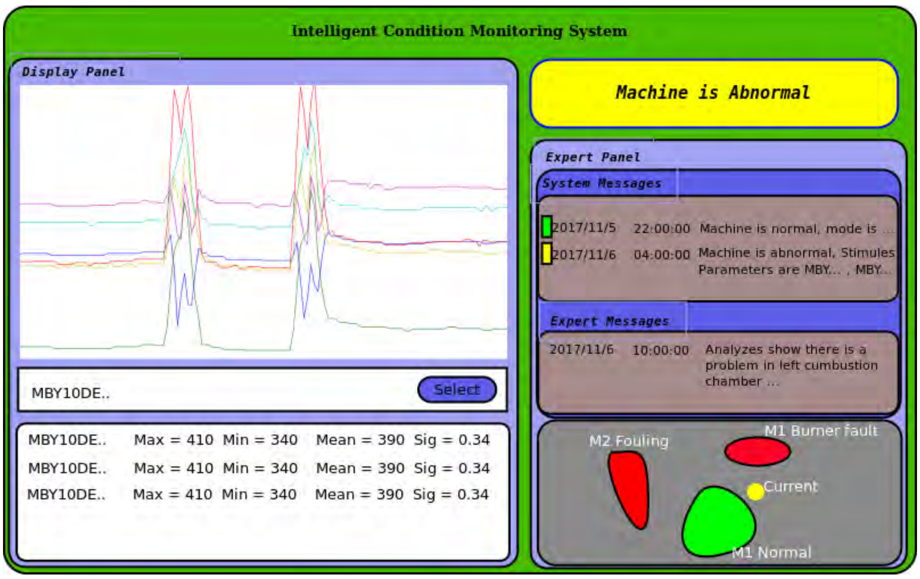

Fig 3. A snapshot of the ICMS software graphical user interface

Any monitored data of the system may be accessed by the expert using the select key in the middle of the display panel. The related data then will be shown at the top of the panel along with some statistical information at the bottom.

The messages provided by the ICMS system as well as those containing the assessments of the expert viewing them are communicated via the expert panel's system and expert messages sub-panels, respectively.

The 'System Status' panel located at the upper right of the ICMS graphical interface displays the status of the monitored system in terms of normality or abnormality of the system's function and performance. The ICMS also provides 2-D and 3-D graphical representations of the measured parameters and analyses performed, as shown typically in Fig. 4 for gas turbine's measured vibrational values.

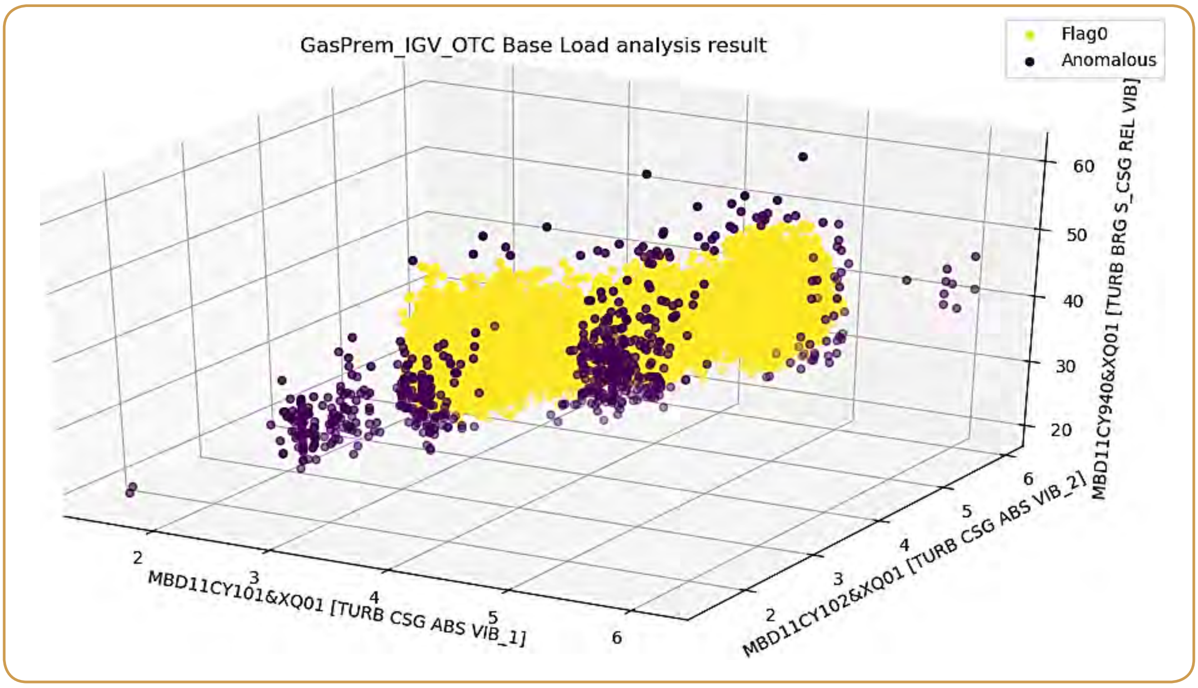

Fig 4. 3-D representation of the MGT-40 gas turbine measured vibration values

The benefits of having an ICMS system in place includes but is not limited to the following:

- Fault detection, prediction and prevention
- Fact finding and faulty parts identification
- Communication with expert teams to seek advice, technical information and practical solutions to any problem encountered

Inspection Reports

Gas turbine and auxiliary systems inspection reports aim at optimization of preventive maintenance planning and repairs. So, in addition to technical inspection support services, inspection reports based on observations made during inspection intervals and the performance data acquired are provided to the client. The required data could also be obtained through the mobile application of the MAPNA MIND platform. Obtained data is analyzed by a team of experts and delivered to the client in the form of inspection technical reports.

The Bottom Line

MAPNA Turbine have been implementing product monitoring schemes since 2013. While monitoring their entire fleet of gas and steam turbines and auxiliary equipment, they have also launched an online monitoring campaign of both local and remote types, based on MAPNA MIND platform for several of their products including the first manufactured MGT-40 gas turbine installed at Zahedan power plant, south east of Iran.

The main goals of product monitoring projects carried out are as follows:

- **Remote Support:** A communication channel established between the plant operators and our highly skilled technical staff via the MAPNA MIND Center to provide remote technical services and supports of all sorts such as tuning up the machine for optimized performance or reduced emissions as well as troubleshooting services.
- **Preventive Maintenance:** Diagnostic services would be provided utilizing state-of-the-art trends and technologies to enable proactive intervention to prevent potential damages and unplanned outages.
- **Risk Mitigation:** Improved performance, reliability, availability and maintainability via utilization of advanced analytics to identify root causes of the problems encountered and avoiding unplanned outages.
- **Outage Reduction:** Technical supports provided on a 24/7 basis makes it possible to apply MAPNA Turbine's extensive knowledge and expertise on resolving any technical problem encountered and hence minimizing the forced outages as much as possible.
- **Fact-based Decision Making:** Enriched databases accumulated over the years enable MAPNA Turbine engineers and experts to quickly assess key performance indicators and provide most appropriate suggestions, recommendations and corrective actions needed to be taken either for performance improvement or to resolve any issue encountered.

2

Thermal-Assisted Turning of Tungsten Carbide by PCD Cutting Tools

Introduction

With the rapid growth in the energy industry, material demands have changed machining methods and new innovations are being introduced in the machining process. Tungsten carbide cutting tools and especially forming cutting tools are essential in the production of different workpieces of power turbines at MAPNA Turbine. Due to the growing number of projects and products, there is an increasing need to manufacture cutting tools with special forms. Currently, grinding, as the common material removal process for tungsten carbide material, is in use at the company. Hard machining, as a suitable substitute for grinding, can considerably reduce the required time to manufacture cutting tools and consequently the cost of manufacturing. Hard turning process has benefited from the advances in machine technology, especially in the power and rigidity of CNC turning centers and the advent of new cutting materials like Poly-crystalline Diamond (PCD). Synthetic diamonds are the main components of PCD and CBN cutting tools. Technological innovations are applied in the development of synthetic diamonds for industrial applications such as metal-cutting tools, wire drawing, polishing and rock drilling. The mechanical properties of tungsten carbide such as high hardness and brittleness, higher cutting temperature and cutting forces have posed many challenges to the machinability of this material and hence it is considered highly difficult to cut such tools. The brittleness and hardness of tungsten carbide makes it difficult to be machined using the conventional techniques and they could inflict damage to the surface of the material. Thermal-assisted machining has recently emerged as a potential method to reduce the problem of hardness and brittleness while machining hard materials to attain high material removal rates. The thermal softening feature of a heat source is used to improve the machinability of such materials. Heating causes reduction of the hardness and brittleness of the workpiece, thereby lowering the forces required to cut the material. There are some experiences examining possibility, benefits and impacts of thermal-assisted hard turning of tungsten carbide. This work focuses on the experimental trials on the possibility of machining tungsten carbide with conventional and non-conventional thermal-assisted turning by PCD tools.

Theory & Method

During the last decade, hard turning has been increasingly used for industrial applications, including machining reinforced composites, ceramics and hard steels. PCBN (Polycrystalline Cubic Boron Nitride) cutting tools commonly used for hardened steels and cast iron turning and milling applications especially for power engines' components due to their high hardness and chemical composition stability at high temperatures [1]. PCD tools are very effective in high-volume machining of aluminum parts for applications such as engine pads or transmission covers. It can also be used in hard turning applications on tungsten carbide material. Diamond tools appear to be an option for turning tungsten carbide since they have a suitable toughness together with a very high hot hardness and wear resistance.

Texturing on the rake face of the PCD tool and machining in dry conditions as a potential method can be used to reduce the friction coefficient in ultra-precision machining of tungsten carbide (WC) [2]. Due to the low friction coefficient of the patterned tool, less heat is generated in the tool-workpiece interface which improves the tool life. The linear patterns parallel and perpendicular to the cutting direction were fabricated on the rake face of the Nano-PCD tool in a focused ion beam process. The experimental result illustrated that the friction coefficient of the perpendicular patterned tool decreased by 10%.

PCD tools are applied in machining tungsten carbide using different unconventional methods to enhance the tool life and surface quality and increase material removal rates. Commercial PCD tools were used in machining sintered tungsten carbide by applying the ultrasonic elliptical vibration cutting method which resulted in minimum Ra of 0.036 mm in a length of 1257 mm[3].

Laser-assisted machining has attracted the attention of industries in machining hard materials such as tungsten carbide. In this method, a high-powered laser locally heats the workpiece prior to the cutting tools operation on the surface of the material. As a result of the temperature rise, the yield strength of the brittle material decreases to below its ultimate tensile strength changing the material deformation behavior from brittle to ductile. Laser-assisted machining also reduces the tool wear and the cost of machining by reducing the machine operating hours per part[4]. Machinability during conventional and laser-assisted turning of silicon carbide particulate aluminum metal matrix composite, cemented carbide material and technical ceramics (Si_3N_4) were tested[5]. According to the investigations carried out, the use of laser-assisted turning to cut materials showed that laser heating of the machined surface causes significant improvement in the turning process, including reduction in tool wear and improvement of surface roughness indicators.

In this work, in order to decrease the tungsten carbide hardness and brittleness and increase the PCD cutting tools' life, the surface of the material is gradually heated by using oxygen-acetylene torch on the surface of the material to 900°C. With increase in the temperature of the K10 tungsten carbide to 800°C, the hardness is expected to be decreased by more than 55% [6].

It is to be noted that, the temperature range of 800-1190°C is deemed to be the initial stage of the grain growth, so at these temperatures neither grain dislocation nor microstructure rearrangement is likely to occur [7].

Experiments & Results

In this work the turning is performed using two conventional and non-conventional thermal-assisted turning methods in longitudinal and profile cutting states according to the schematic illustrated in Fig. 1. The sample used for the turning test is a cylindrical piece of tungsten carbide with the diameter of 40 mm and the length of 100 mm and the commercial grade of K10 with the composition and characteristics listed in Table 1.

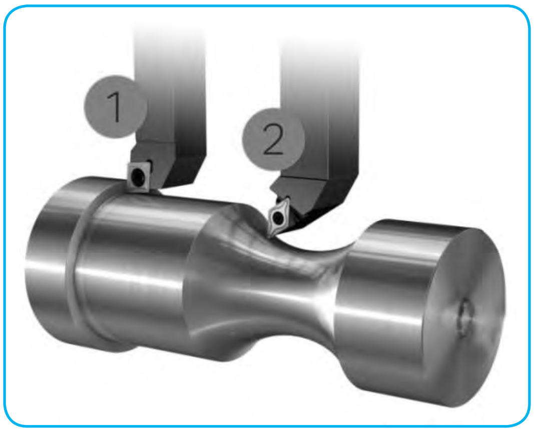

Fig. 1 – Longitudinal (1) and profile (2) turning schematics

Table 1 – Tungsten carbide sample composition and characteristics

Classification ISO-Range	WC %	Co %	Particle Size µm	Density g/cm³	Hardness Rockwell
K10	95	6	1.0	14.8	91.8

The conventional test is performed with the PCD C form inserts for longitudinal turning at the cutting speed of 40 mm/min (the spindle speed of 400 RPM) and the depth of cut of 0.2 mm in dry conditions according to Fig. 2.

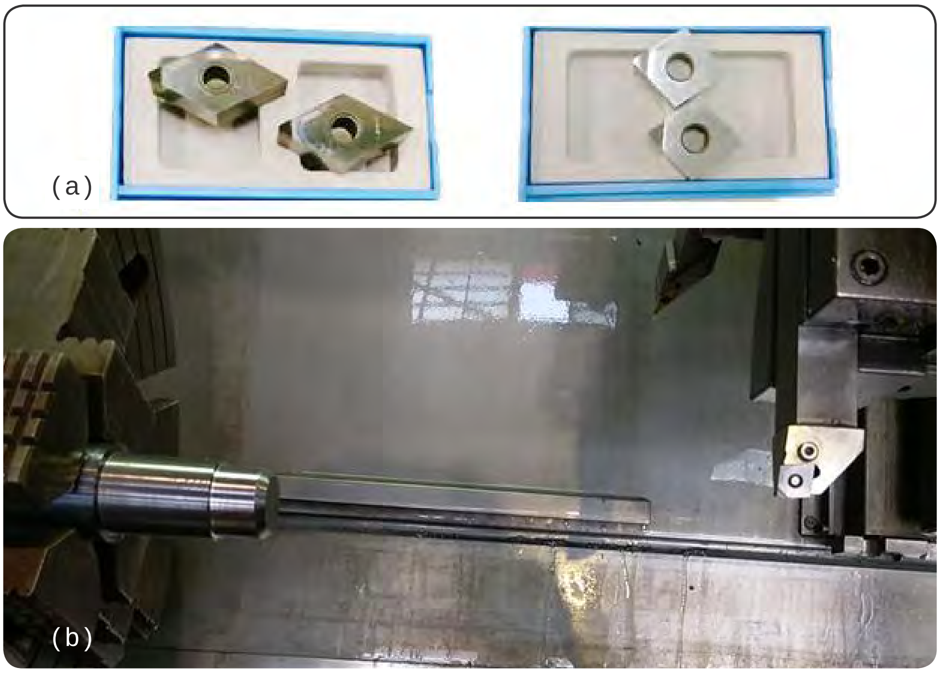

Fig. 2 – C and D type PCD inserts (a); Conventional turning set up (b)

The chips were in the form of tungsten carbide powder. After 850 mm of longitudinal turning operation with a C type insert, the crater and fracture wear on the PCD tip insert were observed. Profile turning test was also performed with a D type insert, where, because of tungsten carbide brittleness, the material removal didn't occur and the cutting tool's force in the radial direction caused breaking and separation of tungsten carbide pieces.

The thermal-assisted turning tests were performed with the same cutting tools, cutting speeds and cutting parameters of a conventional turning. After 1100 mm of longitudinal turning, a wear on the tip of the cutting insert was observed which was considerably less than that in the conventional turning. The profile turning was also performed with a D type insert and unlike the conventional turning, the operation was done without breaking the carbide material. Fig. 3 presents the thermal-assisted turning operation and the workpiece after operation. A comparison was made between the tools wear in the conventional and thermal-assisted turning respectively. The amount of wear in the thermal-assisted operation is 0.3 mm while in the conventional turning process it is 1.5 mm.

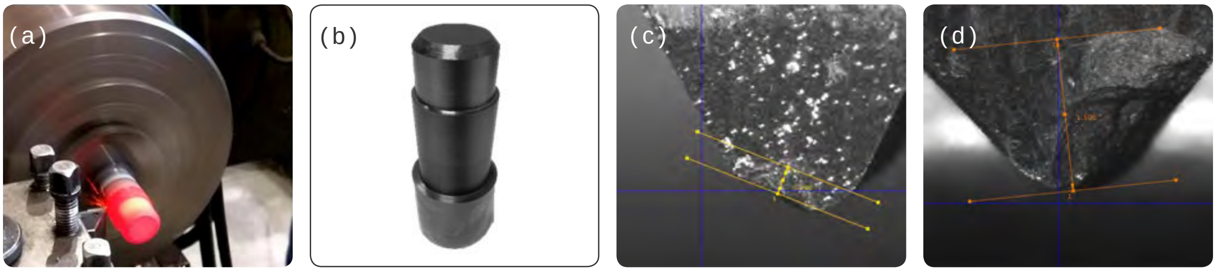

Fig. 3 – Thermal assisted turning operation with PCD insert (a),tungsten carbide workpiece after thermal assisted turning process (b), PCD insert wear after thermal assisted longitudinal turning (c), PCD insert wear following conventional longitudinal turning (d)

Concluding Remarks

The conventional and thermal-assisted turning of K10 tungsten carbide, which is a hard material to cut and is one of the main materials of solid cutting tools, were performed with the PCD cutting inserts. Due to the positive effects of heat on the hardness and brittleness reduction of tungsten carbide, the wear of the PCD insert decreases. These tests illustrate that by applying a hybrid turning process like using an induction heat source on the surface of the carbide material and using the PCD cutting tools, high levels of material removal is achievable. Furthermore, this process could be considered as a cost-effective and time-saving alternative for the grinding process of cutting tools at MAPNA Turbine.

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3

Residual Life Estimation of MGT-70 Gas Turbine Compressor Blades

Introduction

Gas turbines compressor blades are one of the most critical components in gas turbines. In the case of their failure, the power generation in the plant will be interrupted and could lead to a massive economic loss. Therefore, TUGA needs to ensure reliability, availability, and safe operation of MGT-70 gas turbines. Some numerical analyses and experimental tests were designed to estimate the residual life of MGT-70 critical components such as compressor blades beyond their nominal design life of approximately 100K EOH, in Lifetime Extension (LTE) projects.

Implementation of LTE does not only significantly reduce the operating risks of the unit, but also decreases potential downtime due to unscheduled outages or additional maintenance. Gas turbine components are exposed to failures caused by temperature or static and dynamic loadings like creep, low-cycle fatigue (LCF) and high-cycle fatigue (HCF), erosion, high temperature oxidation, hot corrosion as well as mechanical stress and wear. Each type of stress causes characteristic damages which can occur individually or in combination with others. Part failures due to the initiation and propagation of fatigue cracks emanating from manufacturing process (e.g. Non-metallic inclusions) and service defects (e.g. corrosion pits, foreign object damage, or material degradation), are the fundamental damage mechanisms of compressor blades. Several investigations have been carried out on failure analysis of compressor blades. Fatigue fracture of the these blades was studied by Lourenco et al. [1], Silveira et al. [2], Witek [3], and Kirthan et al. [4]. Fatigue Life prediction methods have also been reviewed by Santecchia et al. [5].

In this article, the residual life of MGT-70 compressor blades (after 100 K EOH operation) was calculated based on the "Damage Tolerance Method". This method determines the growth rate of undetectable cracks in critical locations along with estimating the failure time. It is necessary to investigate the effect of compressor blades operating factors on crack growth rate and to develop crack propagation models using the fracture mechanics criteria.

Methodology

Fatigue is a failure mechanism of material caused by cyclic loading and results in crack and structural damage in the parts. Fatigue is a function of load, average stress, stress ratio, surface conditions, component size, temperature, and frequency. Fatigue damage occurs in both the elastic and plastic regions. At high temperatures, fatigue is affected by creep damage mechanisms. Other factors such as oxidation, waveform, metallurgical aspects including aging and phase changes, affect the extent of damage. Different approaches are used to estimate the engineering structures life, and Damage Tolerance Method is one of them. Damage tolerance, or safety by inspection, was introduced as a design philosophy in the 1970s and developed as an improvement on the fail-safe principle for the structural deterioration. The damage tolerance approach is based on the determination of crack development process while cracks (due to fatigue and corrosion) propagate in the structure. A key element is the development of a comprehensive inspection program to detect cracks before they can affect the safety parameter. Damage tolerant structures are designed to sustain cracks without catastrophic failure until the damage is detected in scheduled inspections and the damaged part is repaired or replaced, afterwards. In order to fully understand damage tolerance principles, comprehension of some subjects, mostly related to Fatigue and Fracture Mechanics are desired.

Fracture mechanics is mainly concerned with the study of crack propagation in materials. Fracture mechanics is the analysis of cracks to find out whether they are safe enough (do not grow) or otherwise, they are liable to propagate and cause failure. Therefore, it is possible to achieve the safe operation of a structure through damage tolerance analysis. It should be noted that an initial damage located in the most critical area, in the most critical quantity, and in the most critical direction (according to the load applied) is assumed for the structure. Damage tolerance is estimated over several steps including the following:

1. Determination of the most critical point in terms of stress concentration (crack initiation and propagation is easier at these locations)
2. Definition of the initial damage (length, direction, shape and quantity)
3. Required Material properties such as fracture toughness, Paris law constants, etc.

Crack growth determination will enable one to compute the number of cycles required for the structure to possess a crack with a prescribed dimension, inspection procedure preparation, determination of the inspection threshold and interval. The inspection charts can be made through taking the above-mentioned steps

Testing & Analysis

Compressor blades are made of two different types of martensitic stainless steel. In order to investigate the stresses induced on the blades during operation and to determine the critical points, stress analysis was performed on the compressor blades in various rotational speeds. Afterwards, two critical stages (for each material) pertaining the most stress are determined. Subsequently, the amplitude of alternating stress and the amount of mean stress in each stage were determined through a standard method. Fig. 1 shows stress distribution in one of the critical compressor blades.

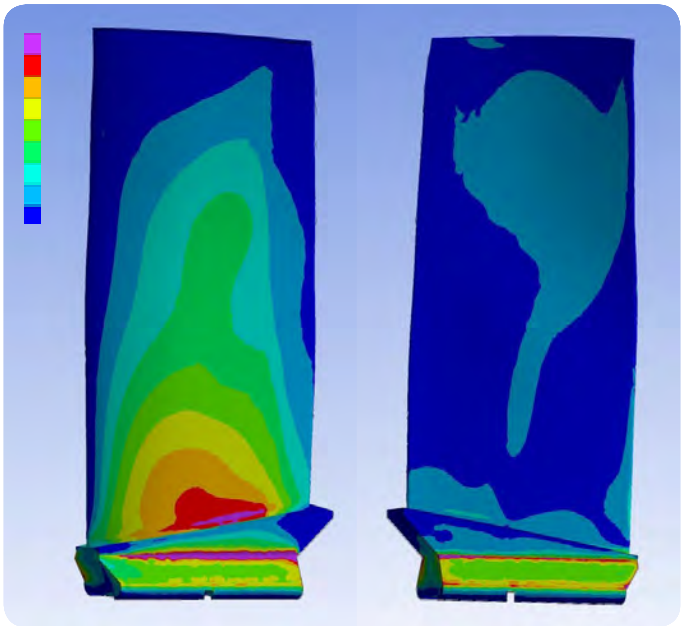

Fig. 1 – Stress distribution in one of the critical compressor blades on suction side (Left) and pressure side (Right)

In the next step, fracture mechanics analyses were performed in two stages of critical blades to determine crack tip constraints in the presence of edge and surface cracks with different lengths. This analysis was also carried out on CT fracture toughness test specimens with different thicknesses and lengths of cracks. An example of the model prepared in one of the stages is shown in Fig. 2.

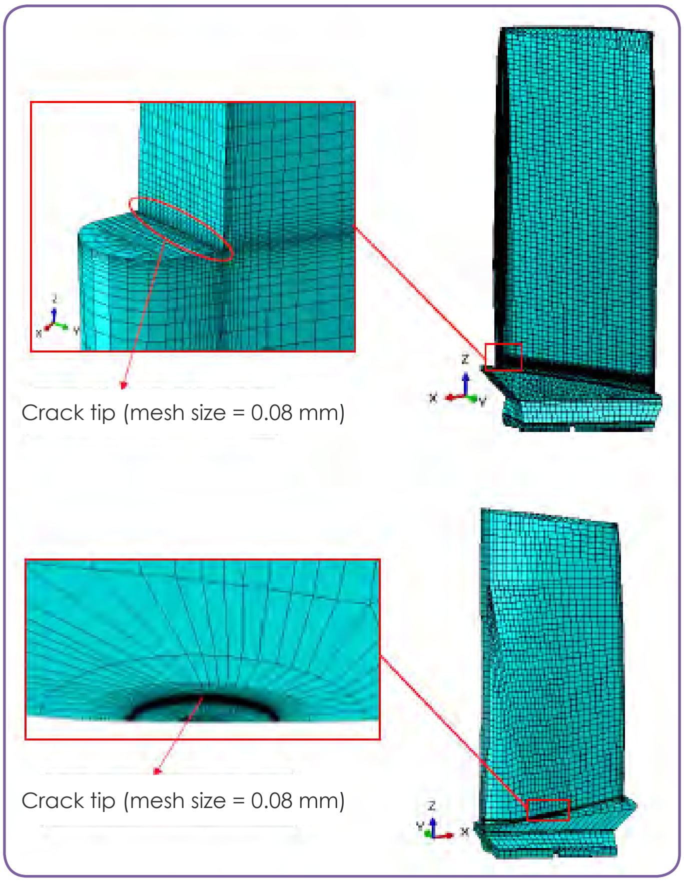

Fig. 2 – FEM Model of one of the blades with surface crack

In order to evaluate the accuracy of finite element calculations in computing the J integral and crack tip constraint, the results of finite element calculations were compared with the analytical solution results of a sample which is geometrically similar to the vanes.

Different experimental tests were performed on the blade material as well. Firstly, since the comparison of raw block, new blade and used blade material was required in terms of chemical compositions, relevant tests were performed according to ASTM E 406-81 standard. Secondly, to measure the fracture energy of new and used blades, impact test specimens were prepared and impact test was performed on the samples based on ASTM E23 standard. Thirdly, to determine and compare the mechanical properties of new and used materials at ambient and high temperatures, tensile test specimens were prepared in accordance to ASTM E8 standard and tensile testing was performed. It should be noted that the extracted parameters from the tensile test were yield stress, tensile stress, fracture strain and the ratio of tensile stress to yield stress. Mechanical properties of two critical stages for the new and ex-service blades are shown in Table 1.

Table 1 – Mechanical properties of the new and ex-service critical stages blades with different materials

Component	Impact J	Yield Strength MPa	Tensile Strength MPa	Elongation %
New Blade (High Temperature Stage)	60-70	640-680	875	14-16
Ex-Service Blade (High Temperature Stage)	18-24	680-720	885-890	12-13
New Blade (Low Temperature Stage)	146-154	800-850	1016-1045	18-20
Ex-Service Blade (Low Temperature Stage)	157-165	820-850	978-998	13-15

Fourthly, fracture tests were performed to determine the fracture toughness of the used blades based on ASTM E1820 standard. The fatigue testing machine is also depicted in Fig. 3.

A test specimen made from one of the blades is shown in Fig. 4. This test was performed at ambient temperature and at high temperature. Fig. 5 shows the failure mode of one of the test specimens. Fracture toughness results are shown in Table 2.

Fig. 3 – The fatigue testing machine

Fig. 4 – The fracture toughness test specimen

Fig. 5 – Broken fracture toughness test specimen

Table 2 – Fracture toughness results of new and ex-service critical stages blades with different materials

Component	Temperature °C	K_c / K_{max}
New Blade (High Temperature Stage)	340	0.946
Ex-Service Blade (High Temperature Stage)	340	0.946
New Blade (Low Temperature Stage)	20	0.948
Ex-Service Blade (Low Temperature Stage)	20	0.923

Finally, fatigue crack growth tests were performed to extract the constant parameters of the Paris law and the fatigue crack growth rate in accordance with ASTM E647 standard. The tested specimens are of CT type.

After obtaining the required parameters through testing, the lifespan of two stages of critical blades is estimated due to the fatigue crack growth. At these stages, the number of fatigue cycles due to crack growth in a blade is estimated from an initial length to a final length considering information from the tests. At this step, the total number of fatigue cycles required for crack growth from the initial to the final length was estimated in a blade. Afterwards, the estimated cycle number was compared with that of an in-service blade. Therefore, safe operation hours of a blade (allowable to be in service) despite the presence of the crack were determined. It should be noted that in the aforementioned estimation, the effect of turbine start numbers was replaced with that of equivalent number of cycles.

Concluding Remarks

In this paper, residual life of MGT-70 compressor blades (after 100K EOH operation) was studied based on "Damage Tolerance Method". The purpose was to determine whether the cracked blades would hold out until the next scheduled inspections without catastrophic failure. Gas turbine compressor blades are exposed to stress caused by temperature or static and dynamic loadings that may lead to different failure modes. In this work, high cycle fatigue crack growth was studied. Different experimental trials were carried out on the blade materials. The data, especially the growth of fatigue cracks, makes it possible to estimate the life of two critical stages of blades. Finally, the total number of cycles obtained was compared with the scheduled inspection intervals.

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4

Running on Liquid Fuel; No More an Issue with MGT-40

Introduction

Soon after the introduction of MGT-40 gas turbine as a new product in MAPNA Turbine product portfolio and following successful testing of the product at Zahedan power plant, south east of Iran, the second phase of its development program was initiated.

On the agenda was provision of all required systems, parts and components making the dual fuel operation of the product possible and hence increasing its operability and applicability.

So, significant modifications on the fuel delivery, burning and control systems of the MGT-40 gas turbine, as well as the auxiliary systems and equipment were planned and pursued diligently to accomplish the task. A large number of technical documents of all sorts were generated for this purpose.

Engineering Overview

The development of a fuel nozzle for injection of the liquid fuel into the combustion chamber as well as the ancillary systems and equipment providing controlled delivery of the liquid fuel to the fuel nozzles, and atomizing and purge air systems required for dual fuel operation of the MGT-40 gas turbine were among the main project objectives. More detailed information is provided in subsequent sections.

Fuel Nozzle Set

Due to some restrictions in the space available for placement of the combustion chambers on the MGT-40 gas turbine, it was deemed necessary to only modify the fuel nozzles and leave the combustion casing, liner and transition pieces unchanged. Furthermore, different nature and dynamics of the gas and liquid fuels made it necessary to have a distinct liquid fuel injection path since it was impossible to take advantage of a single path for both applications. The liquid fuel injection path was incorporated into the inner ring of the fuel nozzle. The corresponding fuel and atomizing air paths were also designed accordingly on the newly developed fuel nozzle. A 3D representation along with a longitudinal cross-section of the developed fuel nozzle model is shown in Fig. 1.

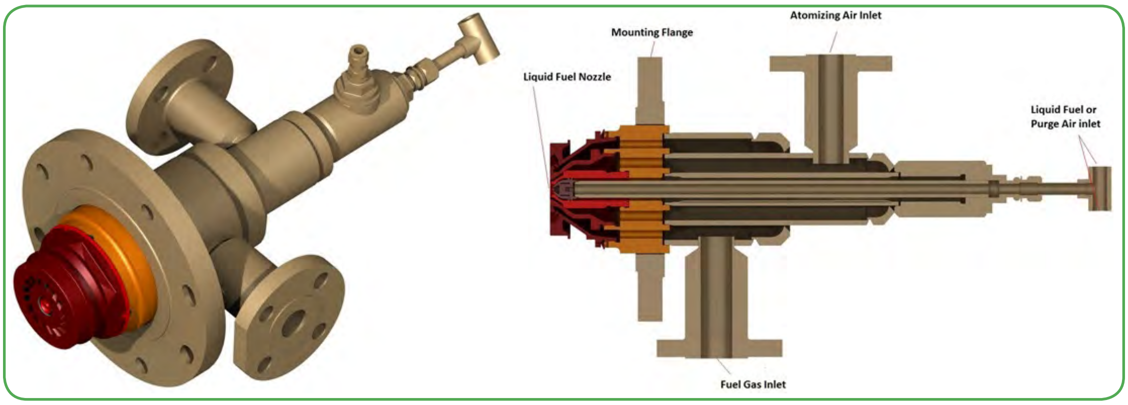

Fig. 1 – 3D model (left) and longitudinal cross-section (right) of the fuel nozzle set for dual fuel gas turbine

The developed fuel nozzle is to be assembled on the combustion chamber casing of the gas turbine via a flanged connection, as shown in Fig. 2.

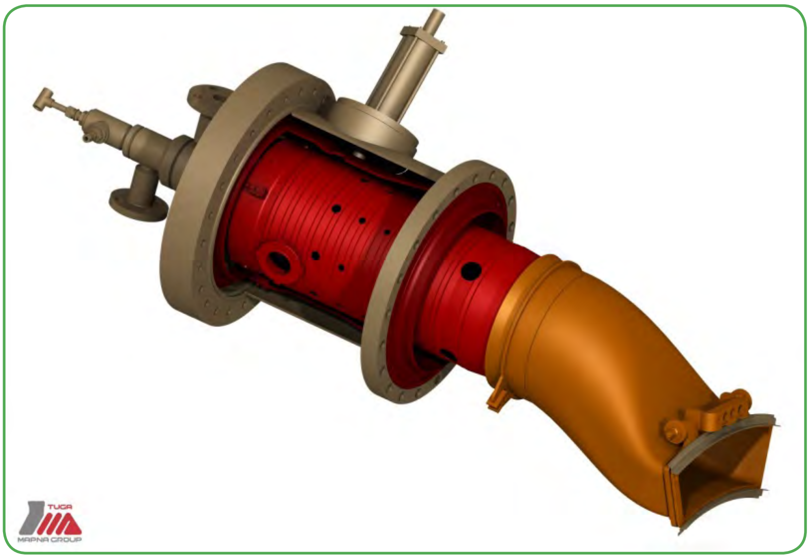

Fig. 2 – 3D model of the entire combustion chamber set of the dual fuel MGT-40 gas turbine

Liquid Fuel auxiliaries

The main purpose of this system is to deliver the liquid fuel to combustion chambers. A simple process flow diagram of the liquid fuel auxiliary system for MGT-40 gas turbine in compliance with the corresponding API standard requirements, is presented in Fig. 3.

As shown in Fig. 3, the liquid fuel skid is equipped with a safety shut-off valve at the entrance of the liquid fuel pipeline to the gas turbine skid. To increase the liquid fuel pressure to required level, a mechanically driven pump is connected to the accessory gearbox of the gas turbine. The pump is driven via either gas turbine or the starting motor as is the case with lubrication oil pump, hydraulic system and atomizing air compressor. Fuel flow control is accomplished via a control valve located on a bypass line to the pump taking some of the outlet flow to the inlet of the pump and eventually controlling the outlet flow going forward to the turbine. There are ten combustion chambers with the MGT-40 gas turbine which are needed to be equally fuel-fed and hence a flow divider comprising ten arrays of gears is used. The fuel flow divider serves as a positive displacement pump which provides a fixed amount of fuel for each combustion chamber. There are also fuel filtration measures in place and instrumentation installed including a pressure switch signaling a drain valve to open and hence shutting down the unit in case of a low pressure fuel flow event as well as pressure gauges allowing the operator to monitor fuel flow pressure in each combustion chamber.

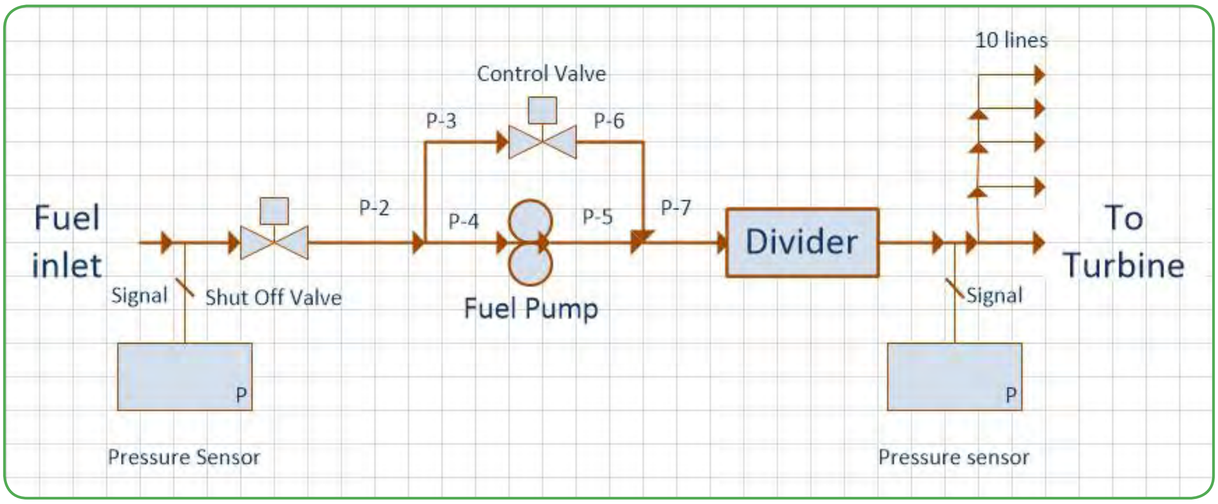

Fig. 3 – Process flow diagram of the liquid fuel ancillary system for dual fuel MGT-40

Atomizing Air System

Atomizing the liquid fuel to have a more efficient combustion and complete burning of the fuel has long been established as a common engineering practice within internal combustion engines. The atomizing air should have more pressure than the fuel and the air entering the combustion chamber, hence necessitating application of an air compressor. To make it possible to use a smaller size compressor, the atomizing air system is configured to be fed by the air extracted from the gas turbine compressor discharge, passing through an air cooler.

As mentioned earlier, the atomizing air compressor is driven by the gas turbine via an accessory gearbox. Since there is not enough pressure in the air at the compressor discharge at the start of gas turbine’s operation and during the ignition at rotational shaft speeds of around 1000 rpm, a compressor booster connected to the electric starting motor with constant rotational shaft speed of 3000 rpm is integrated into the atomizing air system.

A process flow diagram of the atomizing air system including major components and instrumentation is shown in Fig. 4.

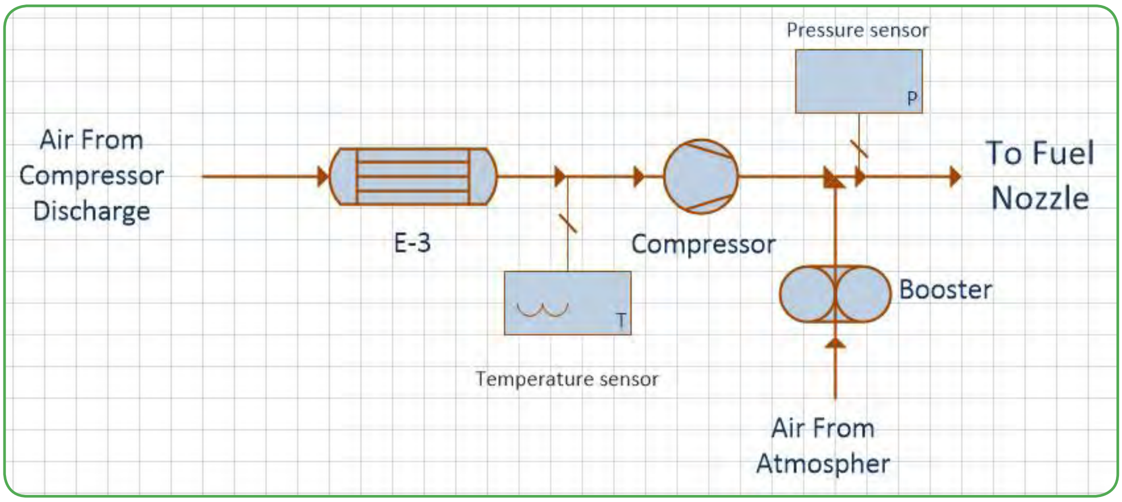

Fig. 4 – Process flow diagram of the atomizing air system for dual fuel MGT-40

Purge Air System

The air required for purge air system is arranged to be extracted from the gas turbine compressor discharge at the highest pressure. A control valve is also considered to control the flow of the air to the fuel nozzles. A simple process flow diagram of the purge air system including major components and instrumentation is represented in Fig. 5.

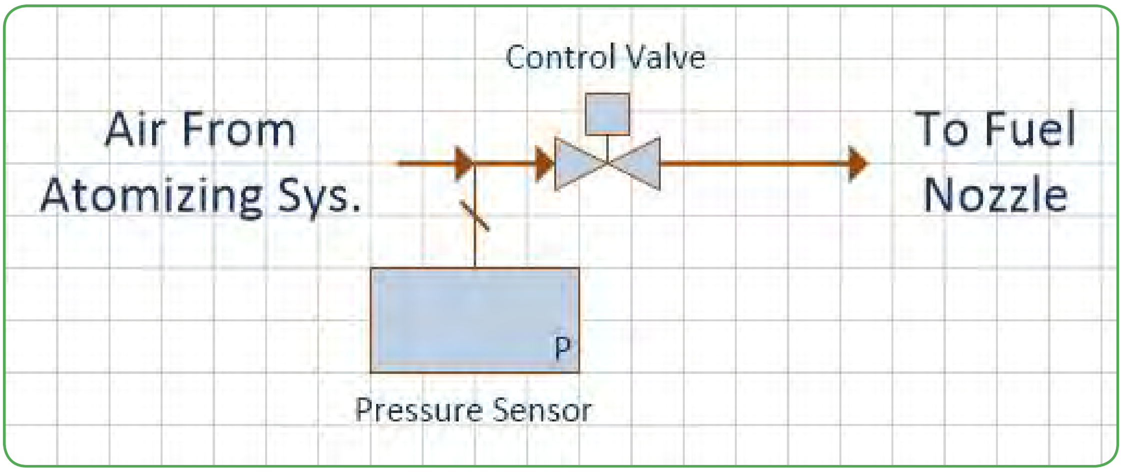

Fig. 5 – Process flow diagram of the purge air system for dual fuel MGT-40

Packaging of Auxiliary Systems on Gas Turbine Skid

The arrangement of the required auxiliary systems on the same gas turbine base frame of the single fuel MGT-40 gas turbine was another step of this project since all piping and electrical installations on the base frame had to be arranged and designed in a space-conscious fashion to accommodate new installations and equipment required for dual fuel operation of the gas turbine. Accessibility, easy maintenance, sturdiness of supports and fasteners as well as vibration minimization in rotary equipment were among the main criteria in developing the packaging scheme for dual fuel MGT-40 gas turbine. A 3D model of the packaging scheme tailored for the dual fuel MGT-40 gas turbine representing liquid fuel systems, equipment and accessories is shown in Fig. 6.

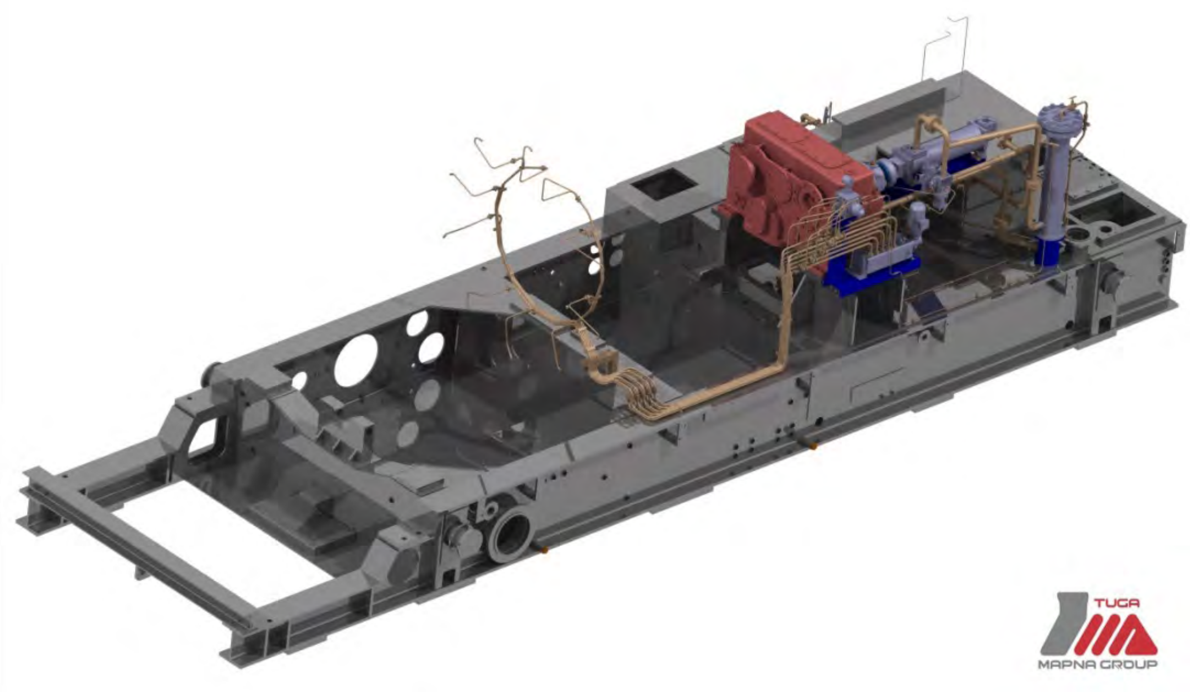

Fig. 6 – 3D model of the liquid fuel system components and accessories arrangement on the MGT-40 base frame

Control & Performance

Due to fundamental differences in starting sequence and operation of the GTE on gas and liquid fuels, the control system of the MGT-40 has gone through a thorough assessment-and revision to include all starting, operation and online fuel changeover control scenarios required for dual fuel application and performance of the MGT-40 unit.

The Bottom Line

A complete liquid fuel system comprising a fuel nozzle set as well as all required ancillary systems and equipment for dual fuel operation of the MGT-40 gas turbine was developed by MAPNA Turbine. This widens the applicability and operability of MGT-40 gas turbine and opens new markets for this product especially in places where natural gas resources are scarce or in large demand for other applications such as household heating during cold seasons.

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