





Willpower to Empower Generations

No.3 - March 2015

EDITORIAL

"We are what we repeatedly do; excellence, then, is not an act, but a habit."

Dear Customers, Partners and Professionals,

Not relying on previous success, MAPNA Group is striving towards sustainable excellence by perpetual broadening and adding variety to the range of products and services it provides in Energy sector. This 3rd issue introduces a few rather recent accomplishments and the added value they suggest for existing and prospective customers.

The first essay in this issue unveils the state of the art upgrading package for E-class MGT-70 machines. Extreme effort has been made to achieve the most one can possibly get from a heavy duty machine, adhering to the E-class cost requirements and tolerable maintenance expenses and downtimes. The added value for the customers adopting this new package alone or in combination with previously offered upgrades have been also discussed.

Gas turbine governor features that affect the machine-grid dynamic interactions have drawn quite a lot of attention to themselves. In the second essay, the specific governor details that dynamically affect machine-grid interactions have been captured, a subsequent thorough investigation has been accomplished, and the results have been pointed out in some detail.

A brief account of our approach towards life time assessment and life time extension for gas turbine components, based upon their duty cycle and operation history, has been provided in the third essay. New evaluation techniques are however, being developed in this field all the time, and an ongoing effort is made to keep up with the most recent advances in the relevant technologies.

Near-shape forging of Ti-based, Al-based and super alloy blades to be used in compressor or turbine sections of gas turbines is another break-through in our manufacturing lines outlined in the article number four. Given the high ordering lead times for these items, the decisive role of having such a technology at the group's disposal locally, is crystal clear in handling major outages. In particular, advances made in subsequent precise machining of forged variable guide vanes, has also been presented in article five.

Design and manufacture of customized dynos to test the produced gas turbines rather than using already developed ones by other manufacturers was a well-planned development program during the past few years. The results of this endeavour and the features enabling our dynamometers to simulate heavy duty cycles in our test cells is brought out in some detail in the 6th essay.

As the last but not the least article, a portable precision grinding unit recently manufactured to restore accuracy in our milling machines has been introduced. It was the outcome of a campaign to meet the strict quality criteria set for our manufacturing lines.

This issue of Technical Review is based upon the information meticulously compiled by engineers, active in technology development at TUGA and MAVADKARAN, in different technical disciplines, whose invaluable sharing is hereby appreciated.

Respectfully,

Mohammad Owliya, PhD

M.Ocoliych

Vice President for Engineering and R&D MAPNA Turbine Company (TUGA) - March 2015



Touching the Extreme of Performance in E-Class Gas Turbines ; New Turbine Section Upgrade for MGT-70	4
Scrutinizing Governor Features to Model GT-Grid	10
Life Drediction and Extension for Cap Turking	
Components	16
Al, Ti and Ni-based Super-alloy Forging; a Breakthrough in Turbine Blade Manufacturing	22
Variable Guide Vane Precise Machining; Another	30
Customized Durgersenters for Testing	
Mechanical Drives in Harsh Duty Cycles	35
Precision Grinding of Taper Seats; Do It Onsite to Restore Accuracy in Milling Machines with No Hassles!	41

Contributors to this Issue:

Saeid Rashidi Shahab Ajami Mohsen Asgari Eshagh Abbasi Mojtaba Nikroo Hossein Balaghi Arash Keshavarz Kianoosh Radfar Amir Poursamad Javid Mirahmadi Alireza Zarrabian Hossein Salemkar Ahmad Razzaghi Mehrdad Vahebi Hossein BadrRezaei Reihaneh Banihabib Ehsan Farokhmanesh Ebrahim Mohammadi MohammadReza Shirzadi Mohammad Cheraghzadeh



. Touching the Extreme of Performance in E-Class Gas Turbines ; New Turbine Section Upgrade for MGT-70

Introduction

During the past years, various R&D projects have been launched in MAPNA Group, in order to continually improve the performance, remove weak spots, and increase the reliability and availability of MGT-70 heavy-duty gas turbine. Successful upgrade experience of the turbine section in MGT-70(1) and MGT-70(2) versions were some examples of such ongoing improvements. As a major step forward, a new turbine section upgrade is introduced here as "tMAP3D", which can be combined to form a new version of the machine together with the compressor upgrade package outlined in the second issue of this Technical Review (October 2014). The newly introduced compressor and turbine sections, realize our ambitions to reach the extreme performance of such E-class gas turbine.

Our advances in design and modeling of aerodynamics, cooling and heat transfer, as well as sealing technologies, have paved the way towards an optimized, highly efficient gas path design, named tMAP3D. It includes 3D optimized airfoils, optimized cooling systems, and enhanced seals for all vanes and blades. Furthermore, using more advanced materials and coatings has also provided room to operate the hot gas path components in a more severe condition with higher temperature levels.

The redesign process aimed to increase power and efficiency, while maintaining the targeted life of the components for better reliability and availability. Further, the E-class design concepts were maintained in order to stay within E-class production and maintenance costs, and to avoid imposing any further limits on fuels at the same time. Moreover, considering the numerous operating machines in this fleet, together with the fact that the turbine vanes and blades have to be replaced during standard major outages, the new upgraded turbine section was designed to be available as a retrofit. The redesign process started with aerodynamic optimization of vanes and blades outer profiles. Then, the cooling system of vanes and blades were adapted and redesigned to match the new profiles and to improve the cooling performance. Finally, some secondary air system components were changed to match the new cooling system, and also, seals were modified to minimize leakages.

Aerodynamic Optimization

The aerodynamic optimization of the turbine flow path, including all vanes and blades profiles, was accomplished utilizing state of the art 3D aerodynamic design and optimization approaches, developed in MAPNA Group.

First, high-fidelity CFD models of the reference turbine flow path were set up. After performing numerous Design of Experiments (DOE) analyses, appropriate details were considered in the model, including inlet and exhaust effects, cooling, sealing, and leakage flows, Thermal Barrier Coating (TBC) layer effect, end-wall fillets of all vanes and blades, and so forth. These models were validated and improved using extended performance test results. Then, aerodynamic redesign and optimization of the turbine was performed utilizing up-to-date CFD-based optimization approaches.

Aerodynamic optimization of the turbine was accomplished in three steps. At the first step, the expansion line of the turbine was redesigned, to get a more uniformly distributed stage drops between all stages, leading to a better aerodynamic performance. At the second step, radial distribution of flow parameters was optimized. Finally, at the third step, blade profiles were optimized to obtain a velocity distribution along blade suction and pressure surfaces which minimizes the profile loss. In the new design, not only 2D profile loss of blades and vanes is reduced, but also a considerable amount of effort has been made to reduce 3D loss mechanisms, including tip leakage loss and secondary loss associated with the turning of the boundary layer near the end-wall regions.

As a result of removing rigorous stage drops together with profile optimization, the surface shocks are removed in the upgraded vanes and blades. Besides, flow separations are eliminated due to optimized re-profiling and correction of inappropriate incidence angles. Finally, thanks to 3D aerodynamic optimization, the total pressure loss due to tip leakage and secondary flows are minimized in the new turbine (Figure 1).



Figure 1 - Aerodynamic performance improvement with tMAP3D upgrade in turbine section



Cooling System Improvement

The new outer profiles required new internal cooling system for cooled vanes and blades. The target of cooling system redesign was to minimize the cooling air mass flow, while reaching a uniform temperature distribution and avoiding some maximum temperature limits, and to maintain the targeted life of the components.

Utilizing advanced up-to-date heat transfer modeling techniques, high-fidelity models were established to predict heat transfer, temperature distribution, and peak metal temperature in turbine vanes and blades (Figure 2). These models were used to evaluate the performance of cooling system during design iterations.



Figure 2 - Temperature distribution of cooled vanes and blades

The cooling systems of vanes and blades in all previous versions of MGT-70 were confined to internal cooling. In the new design, this concept is still in place, i.e. no film cooling was added, in order to maintain the production costs for the E-class machines, and also, to maintain fuel flexibility of the gas turbine.

In vane 1, impingement cooling is the major cooling method together with pins in the midchord region and pin-fins near the trailing edge. The impingement holes and pins size and distribution were modified. The pin-fin arrangement was also altered in terms of number, diameter and distribution. Moreover, the trailing edge cut-back was replaced with a new pressure side cut-back which allows a reduction in trailing edge thickness to reduce vane total pressure loss. Blade 1 uses serpentine cooling passages with rib-turbulators along the path and pin-fins near the trailing edge. The shape, size and arrangement of ribs and pin-fins were modified and pressure side cut-back was implemented. For vane 2, impingement cooling was maintained, with modified impingement holes. Pin-fins were also added near the trailing edge, and the trailing edge ejection holes were modified. Radial cooling bores were kept in blade 2, but the number, size and diameter of the bores were changed. For vane 3, the simple cavity was redesigned with some ribs and fins added to the cooling system. Some trailing edge ejection holes were also added to cool the trailing edge (Figure 3). Considering the fact that the Turbine Inlet Temperature (TIT) has increased to 1090 °C in the latest versions of MGT-70, together with the effect of redistribution of stage loadings, most vanes and blades are exposed to more rigorous hot gas path condition in the upgraded turbine. However, better cooling design with improved cooling effectiveness, more advanced super-alloys with higher thermo-mechanical resistance, and enhanced coatings has resulted in reduced total fraction of coolant mass flow, while maintaining or even enhancing vanes and blades lives. The reduction of total coolant flow, decreases the amount of air extracted from compressor and allows more air to be combusted and produce power, resulting in improved performance of the gas turbine.



Figure 3 - Cooling system redesign for tMAP3D upgrade

Secondary Air System Components and Seals modifications

Some components of the Secondary Air System (SAS), and seals have had to be modified due to the changes applied in the flow path and the vanes and blades cooling systems. The SAS provides the cooling and sealing air needed to keep metal temperature of components in hot gas section and combustion chamber, below the maximum allowable, and to avoid hot gas ingestion.

Extensive 1D network models and detailed 3D CFD models of SAS circuits and components were developed. These models were iteratively used during the aerodynamic and cooling system redesign of vanes and blades to ensure the efficient delivery of enough cooling and sealing flows and to minimize leakage air. In order to conform to retrofitability concept, only those SAS and seal elements that could be replaced or modified during standard major outages, were made subject to change.

The baffle plates in the third cavity of vane carrier were modified to guide the cooling air to the new vane 3. The seal ring of the third vane was also modified to regulate the sealing air flow in the rim cavity. Furthermore, all seal plates between vane segments and between seal ring segments were replaced with new enhanced seals in order to reduce the leakage flow (Figure 4).





Figure 4 - Secondary air system components and seals modifications for tMAP3D upgrade

Upgrade Scope and Customer Benefits

As mentioned earlier, the introduced upgrade in the turbine section is practical during standard major outages. The scope of delivery for the turbine section upgrade, tMAP3D, includes:

- New vanes and blades (with optimized aerodynamic and cooling), with new Ni-base material, enhanced bond coat, enhanced thermal barrier coating (TBC), internal aluminization
- New baffle plate for vane 3
- New seal ring for vane 3
- New seal plates for all vane segments
- New seal plates for all seal ring segments
- Control system adjustments

Depending on different selections of upgrade packages, and based on the version to be upgraded and site specific conditions, performance guarantee figures will be provided to the customers. For instance, for a full upgrade to MGT-70(3), including turbine (tMAP3D) and compressor (cMAP3D) modifications, the performance parameters are compared to MGT-70(1) and MGT-70(2) in Table 1.

Parameter	Unit	MGT-70(1)	MGT-70(2)	MGT-70(3)
Turbine inlet temperature (ISO 2314)	°C	1075	1090	1090
Turbine outlet temperature	°C	546	556	544
Turbine outlet mass flow	kg/s	535	535	555
Gross power output at generator terminal	[MW]	166	170	183
Gross efficiency at generator terminal	%	34.5	34.6	36

Table 1 – Performance data of MGT-70(3) compared to MGT-70(1) and (2) @ base load, ISO conditions, natural gas

Conclusion

The new turbine section upgrade, introduced here as tMAP3D, can be implemented separately, or together with other upgrade packages developed by MAPNA Group. It can be implemented on all previous versions of MGT-70 during standard major outages.

This would not have been achieved without painstaking efforts of a team of design engineers whose knowledge and professional skills, in a variety of fields, were deployed during this product development project.

2. Scrutinizing Governor Features to Model Gt-Grid Dynamics; a Field-Proven Success

Introduction

Due to substantial use of gas turbines and their highly dynamic behavior, they have a profound impact on electrical grid so that an accurate model of these turbines is demanded for grid behavior studies. Although control philosophies of various turbines are almost the same, there are some nuances in governor systems. As long as these details affect system response in extremely dynamic phenomena such as load rejection, they should be included in models. In this research, the governor system is subjected to careful scrutiny, and some special features such as back-tracing and feed-forward are discussed. Turbine performance is also modeled and a function is developed to calculate turbine exhaust gas temperature. The proposed governor-turbine model is validated by test results and a comparative analysis shows that back-tracing method prevents wind-up phenomenon and feed-forward method improves stability and response time.

Findings of this research led to a paper entitled "A Detailed Governor-Turbine Model for Heavy-Duty Gas Turbines with a Careful Scrutiny of Governor Features" published in the journal of *IEEE Transactions on Power Systems*.

Modeling

Governor of gas turbines carries out three main tasks; controlling load, frequency and turbine exhaust temperature. In addition, there are some subsidiary tasks such as controlling compressor output pressure gradient and compressor pressure ratio, which are to maintain machine operation within high availability and reliability area. The structure is a bumpless override control in which seven controllers are used (Figure 1).



Figure 1 - Structure of gas turbine governor

Turbine-governor model, shown in Figure 2-3, 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. Including power and temperature dynamics, this model represents the block diagram for a single-shaft gas turbine. It is applicable to speed range of 95-105 per cent of rated speed.



Figure 2 - Turbine-governor model (main loops in operation)



Figure 3 - Turbine model

Validation

Table1 shows specification of tested gas turbines at standard conditions established by International Standards Organization (ISO). These standards used by gas turbine industry are:

- Ambient temperature: 15°C
- Ambient pressure: 101.3 kPa
- Relative humidity: 60%

Electrical net power	P _{GT}	MW	162.5	
Nominal frequency	F	Hz	50	
Turbine speed	Ν	rpm	3000	
Simple cycle efficiency	η		34.4	
Compressor air mass flow	W _a	kg/s	525	
Primary operating fuel	Natural gas			
Fuel mass flow		kg/s	10.3	
Turbine exhaust temperature	TET	°C	535	

Table 1 – Gas turbine specifica	ations
---------------------------------	--------

Operating data were collected from DCS, and the sampling rate is 1 per second. Tests have included load increasing, base load operation, load rejection, synchronization and load decreasing in various plants with different atmospheric conditions, including ambient air pressure and temperature. Field validation was initially conducted in PAREHSAR power plant and the results were also equally verified in ALIABAD and FARS power plants. Tests were simulated by MATLAB™/ SIMULINK using the model shown in Figure 2-3. Results for one of the units are displayed in Figure 4.



Figure 4 - Comparison of measurement and simulated responses



The main controllers are also specified in various operation modes. As can be seen, the derived model represents governor-turbine behavior with a high degree of accuracy since power and temperature are accurate to within 5 percent.

Figure 5 shows speed simulation after load rejection. Due to considerable difference between power set point and generated power at base load, speed overshoot will be considerable and cause over-speed and trip unless the back tracing method is used.

Feed-forward in the IGV controller is also used to improve IGV controller response delay in fast loading. Figure 6 compares both cases with and without feed-forward to evaluate its impact. It can be seen that rate of loading is limited unless the feed-forward method is used.



Figure 5 - Speed response (162 MW load rejection)



Figure 6 - Loading response (fast loading: 0-162 MW)

Conclusion

This research surveys the governor structure schematically. Moreover, a detailed governor model together with a turbine model is developed in which a new approach is used to calculate turbine exhaust temperature. The model is employed to simulate extreme dynamic phenomena such as load rejection from base load. The simulation results are validated by field measurements, obtained from a unit in commissioning test.

Governor features come into focus and the following points are illustrated:

1- The back-tracing method prevents wind-up phenomenon. Unless it is used, speed overshoot will be considerable and cause over-speed and trip.

2- Feed-forward method compensates IGV response delay with respect to power response. Unless it is used, temperature controller will be the dominant controller and limit load increasing rate in fast loading.

Introducing back-tracing and feed-forward techniques can substantially mitigate adverse dynamic effects: prevent unnecessary over-speed trips and sustain loading rate in fast loading regime, respectively. They can thus, provide power plant operators with a significant availability and reliability increase for their machines.

3. Life Prediction and Extension for Gas Turbine Components

Introduction

Different damage mechanisms are activated due to mechanical and thermal loads that are present during operation of a gas turbine. Levels of damage in turbine components are different. Based on the desian concepts, for a gas turbine, some formulas exist to calculate equivalent operating hours of the machine. At the end of this calculated time, some components are damaged so severely that it is not feasible to repair them and some others are not. After checks and probable repairs, the second aroup can be used for another certain period of time. The main idea of life time extension (LTE) of a gas turbine is to identify the components that can be used again and perform the required checks and repairs in a way that turbine continues its work for a longer period of time than the limited design life-time. The LTE measures are to assure high availability, reliability and safety of the machine for the extended life. A specific procedure is followed by Mapna Turbine Company for LTE. After identifying working regimes and conditions, damage mechanism in each component can be anticipated. In the next step, critical points of each component are listed (this can be done by inspections and finite element analysis), followed by damage tolerance analysis to estimate critical crack length in each critical point. At the end, based on these analyses, LTE procedure for the specific machine is issued. Each of these steps is explained in the following sections.

Operating Regimes and Working Conditions

Types of operating regimes (continuous base load to peak load duty) affect component life time.



Figure 1: Operational regimes and dominant failures for MGT-70 fleet experience

Thermal mechanical fatigue is the dominant failure for peaking and cycling machines, while creep, oxidation, and corrosion are the dominant failures for continuous duty machines.

	Design criteria and life expenditure effects							
	Yield strength, stiffness	Time Impacted Failures			Cyclic Impacted Failures			
Components		Oxidation, corrosion, erosion	Rubbing	Creep	TMF	LCF	HCF	Crack propagation
Turbine blades								
Compressor blades								
Combustion chamber, exhaust								
Rotor parts (exclude blades)								
Pressure casings								

Different damage mechanisms and Finding critical points in each component

Finite element (FE) analysis method is used to define the severity of probable damage mechanism in each component. To perform the FE analysis, temperature field in the component and material characteristics related to different damages are needed. Stress-strain curves at different temperature, creep and fatigue data and physical-mechanical properties are essential inputs in the FE analysis. Life at different points of component as a result of each damage mechanism is the output of the FE analysis which indicates the critical points very well. Special attention should be paid to these points during inspections.



Figure 2: Different damage mechanisms of MGT-70

(CR=CREEP, FOD=FOREIGN OBJECT DAMAGING, HC=HOT CORROSION, HCF=HIGH CYCLE FATIGUE, LCF= LOW CYCLE FATIGUGE, OX=OXIDATION, RB=RUBBING, RP=RUPTURE, TMF= THERMAL MECHANICAL FATIGUE)



Figure 3: FEM models of different components of the MGT-70 machine

To find critical points in each component, in-service monitoring, checks and inspections during overhauls and outages and computerized analysis can be helpful. Visual inspection, non-destructive tests and examinations, replication, dimensional checks, hardness test and localized sample taking are actions to be taken during an outage, to assess the components damage.



Figure 4: different methods of inspection [1&2]

Damage Tolerance Approach

Another set of computational analyses on the components of a turbine is the FE modeling based on damage tolerance concept. In this method, the smallest possible crack is inserted into the body, and during simulations, the crack grows until it reaches its critical length for different loading condition. Using this, it is possible to estimate the remaining life after detecting a crack in each component. Similar to the previous analysis, this approach needs material data such as creep crack growth rate, fatigue crack growth rate, and critical crack size in each condition.



Figure 5: Crack growth simulations in MGT-70 discs



Figure 6: ND tests to find cracks and other discontinuities [3]

Life Time Extension Procedure

The final result of the mentioned steps is a procedure including the following items:

- List of components whose lives can be extended
- Critical points for each component
- Tests and checks that should be done on each component
- Remaining life calculations for each component
- Remaining life for the gas turbine
- Special inspection and monitoring during extended life
- Notes and instructions to the operators of the machine during the extended life

List of References

- [1] http://en.wikipedia.org/wiki/Nondestructive_testing
- [2] Dogan B., "Sampling and Small Punch Testing in Power Generation Industry", 1st SSTT, 2010, Ostrava, Czech.
- [3] P. Ciorau, D. Macgillivray, R. Hanson, Recent Applications of Phased Array Inspection for Turbine Components and Welded Structures, The e-Journal of Nondestructive Testing, Oct 2004, Vol. 9 No.10

Al, Ti and Ni-Based Super-Alloy Forging, a Breakthrough in Turbine Blade Manufacturing

Introduction

Gas turbine blades are manufactured through precision vacuum casting, forging and finally, machining. Forged blades rather than cast ones are preferable due to the need for high toughness, flexibility and resistance against various failure modes resulting from harsh operation conditions such as excessive vibrations. That is why lots of blades in various gas turbines have been, and still are being, manufactured through forging. In MAPNA Group, a project was kicked off a few years ago by Mavadkaran, with the aim of producing forged blades of AI, Ti and Ni-based super-alloy materials. The project has recently led to developing the respective technology inside the Group.



Process Description

Parameters like mechanical properties and metallurgical specifications, dimensional accuracy and manufacturing cost are of utmost importance in forging ags turbine blades. The airfoil geometry, its variable thickness along and across the blade and its twist and curvature, makes its forging a highly complicated process. To achieve forged blades with targeted mechanical specifications and required dimensional accuracy at a reasonable cost, substituting numerical simulation methods for more common trial and error procedures is a must. To do so, gathering thorough and inclusive data on process variables like boundary conditions, material flow parameters, strain and its rate, and important transition temperatures is the prerequisite. Achieving these pieces of information is possible through numerical simulation, thermo-mechanical simulation and a physical modelling based upon experimental data.

Blade materials are intrinsically of high strength in high temperatures and resistant against creep; so, manufacturing them through forming is hardly possible. As Al, Ti and Nibased alloys are the most important materials used in the industry, the research was mainly based upon extracting their parameters and forming variables.

Primary thermo-mechanical production technologies such as rolling and extrusion are deployed to produce the preforms, and secondary methods like open-die and closeddie (impression-die) forging are then used to produce geometrically complicated components with optimum micro-structure. Improving the existing technologies, appropriate die design, etc. results in an improvement in product quality and/or reduced manufacturing costs. Making use of high-tech equipment to inclusively and accurately control the process parameters is a decisive segment in manufacturing such products. So, an accurate understanding of the procedure methods and deployed materials and equipment are main items to guarantee success for the process using simulation strategies.

In forging process for the aforementioned materials, due to their particular mechanical properties and unique specifications, coming up with forged pieces requiring minimal subsequent machining is highly significant and that's why control and optimization of the process parameters are given special attention.

Hot die forging and Isothermal forging are unique techniques initially developed in aerospace industries. Using both methods, both Net-Shape and Near Net-Shape



components can be manufactured. Both techniques make use of the advantage of proximity of the die temperature to that of the billet. In conventional forging, the piece is kept in a temperature higher than that required for phase transition (solution) while the die is heated to reach a temperature of 95° C to 425° C. In conventional forging the dies are made of steel alloys. In isothermal forging the die temperature should be same as or close to that of the billet which is 760° C to 980° C for Titanium and 980° C to 1200° C for Ni-based super-alloys. In hot die forging, the die temperature is 110° C to 220° C lower than that of the billet. Both techniques can be made use of to forge pieces that are impossible or hard to produce through conventional forging. Both techniques enjoy a lesser initial ingot volume and subsequent machining and homogeneity of microstructure and specifications.

In isothermal forging the die and the forged piece temperatures are kept identical or close to each other during the entire process. The in-process temperature gradient inside the piece is negligible. The forging makes use of hydraulic presses to control the forming rate. If the strain rate is low, the production efficiency decreases, in particular, when a few forging stages are required to reduce row material consumption. Slow deformation in a rather tight temperature interval leads to lower flowing stress and deformation induced heat and in some cases (for certain materials), super-plastic deformation is enabled. Adopting this technique results in producing Net-Shape or Near-Net-Shape piece and substantially reduces the required subsequent machining.

Taking into account the abovementioned natural advantages of the Near Net-Shape forging, materials like Ni-based super-alloys, Ti alloys and Al alloys are mostly forged using isothermal technique to cut back on row material consumption.

To develop the required technology for isothermal forging of Ti and Al alloys, the company, Mavadkaran, designed and manufactured a hydraulic press with such an ability. This press is currently used in isothermal forging process with the following specifications:

• Free fall velocity of 85 mm/s

• Adjustable forming speed, constant or depending on the intended profile, in an interval of 0.02~50 mm/s,

• Adjustable forming stroke

• Ability to save and display process variables such as speed and pressure during the forming process

• Maximum capacity of 600 Tons

Achievements

The main achievements of the project include:

- Identification and parameter control of thermodynamic behavior of the materials
- Specifying characteristics equations for material flow in various temperatures
- Identification of the optimum temperature and material strain rate conditions to accomplish the thermo-mechanical process
- Development of numerical methods to specify parting lines in forging dies of various gas turbine blade types
- Development of a model to quantify flash (excessive material squeezing out of die cavities) in forging process of gas turbine blades
- Physical simulation of the thermo-mechanical stages of the process and their parameters
- Development of process plan for blade forging
- Specifying the type and capacity of the required presses
- Identification of appropriate lubricants
- Specifying process control plan and quality control plan for the forged pieces



Figure 1: Hydraulic Press at Mavadkaran





Figure 2: Identification and control of thermo-mechanical behavior of materials



Figure 3: Simulation of temperature and stress distribution during forging process



Figure 4: Simulation of material flow streamlines during successive stages of forming



Figure 5: Simulation of successive forming stages





Figure 6: Some forging equipment pieces (presses and dies)



Figure 7: Some stages of manufacturing



Figure 8: Some manufactured forgings



Figure 9: Micro-structure analysis of the pieces in different stages of forging as an item of product quality control plan



5. Variable Guide Vane Precise Machining; Another Milestone Towards Excellence

Introduction

To control flow rate and prevent compressor surge and stall during start-up of gas turbines, the few first stationary vanes are provided with an adjusting mechanism enabling them to rotate around their own axis and control the axil flow rate of the inlet air. The first row of such vanes are called (variable) inlet guide vanes or (V)IGVs and the others are simply called variable guide vanes (VGVs). For the sake of brevity and simplicity, we call them all variable guide vanes or VGVs hereafter in this text.

Developing and carrying out an appropriate manufacturing method results in meeting all design objectives including, but not limited to: ruling out jamming or unwanted clearance and vibration of VGVs during operation and thereby extending life time of the guide vane adjusting actuators and accessories, and total reliability of the final product.

What Make VGVs Unique

Figure 1 shows where VGVs are installed in a typical gas turbine. Their angle is adjusted using some external mechanism according to performance requirements. This feature makes VGVs stand out from other stationary vanes; since other vanes are fixed on both root and tip side with no swiveling maneuverability while VGVs have shafts and bearings on each end enabling them to swivel around the vanes' axis and adjust the air attack angle (Figure 4).

To accomplish their mission, VGVs need to have tight run-outs in coaxial shafts of both ends and furthermore, their airfoil position relative to the axis of rotation is equally significant and must be within an accurately set geometric tolerance. These additional requirements along with the intrinsic features to be considered while machining airfoils, renders the manufacturing technology more distinct and complicated for VGVs compared with that for other compressor blades and vanes.



Figure 1: Assembly of variable (inlet) guide vanes

In-house VGV Manufacture

VGVs used to be supplied in finished and ready-for-assembly form, as there was no such technology developed at TUGA; but things changed during manufacturing phase of MGT-30 machine and provisions were made to take the required steps to manufacture these vanes taking their different geometry and manufacturing technology into account.

For the near-shape forged pieces (figure 2), in addition to metallurgical structure and strength requirements, special attention has been paid to dimensions, stock material and forging tolerances to provide sufficient room for the upcoming machining and manufacturing stages.

The required manufacturing method and technology was developed taking the inhouse knowledge, equipment and machinery into account at the lowest possible cost. Mass production was launched when test and verification phases were accomplished. The VGVs are manufactured in 4 steps in our procedure. They were all carried out on all 3 VGVs of MGT-30 machine and can be readily extended to manufacture VGVs of any other machine.



Figure 2: As forged material

Axis Machining

At this step, a rough machining is done on the both ends of the forged piece to provide the upcoming stages with appropriate machining reference points. One of the big challenges in the way of manufacturing these vanes, making a huge difference between their manufacturing procedure and that for their non-variable counterparts, is their rather big size along with tight tolerances on both ends. Thus, even the slightest asymmetric bending or torsional clamping stresses will lead to distortion of the seemingly well-machined clamped vanes after releasing the clamps and the end shaft run-outs might end up far out of tolerance. On the other hand, failing to secure the piece in clamps firmly enough will result in vibration to avoid which, machining forces should be reduced through decreasing the cutting speed which can in turn, highly extend the manufacturing time.

To overcome this challenge, machining forces and the required clamping force were calculated and taking features of the available 4-axis machines, a special fixture was designed and manufactured. This fixture holds the forged piece without applying any asymmetric forces to enable the material cutting to take place on a 4-axis milling machine with the work piece in a fixed and definite position.

To achieve the run-out tolerance on shaft ends of vanes, which is the most important design feature of the piece, both ends are machined at the same time. As a result, regarding the way the piece is secured in the fixture, an accurate reference position is achieved for the next machining stage.

This machining is done making use of general cutting tools with no need to special cutters. The machining program for this stage was also developed making use of CAD/CAM softwares.



Figure 3: Milling end shafts

Airfoil Machining

After securing the piece in a special fixture, making use of the created reference in the previous step, we machine the airfoil of the VGV. During 5-axis airfoil machining, effort should be made to minimize the machining forces on the piece to avoid its bending. This was accomplished by fully deploying the existing knowhow at TUGA using utilities of RCS software and the high-tech machining process simulating system. To cut the costs and improve the process efficiency, all tools were chosen from available standard tool sets and only one special cutting tool required for airfoil surface finishing of all 3 VGVs in MGT-30 machine was designed and manufactured.



Figure 4: Final vane after airfoil finishing



Grinding

Dimensional tolerances and high surface quality, requires another grinding on both end shafts of VGVs taking reference from certain features in the previous stage (airfoil machining). This will provide the shafts with free rotation inside the relevant bushings in VGV casings and stator inner rings.

Again, an accurately designed fixture is required to provide precise clamping and adjustability and subsequently enable the demanding job of grinding on vane shafts. Figure 5 shows dimensions for one of the VGVs and the tight tolerances on both ends of the vane.



Figure 5: Grinding process on both end shafts of VGVs

Conclusion

Developing the required technology to manufacture VGVs, not only completed the added value chain in manufacturing compressor blades and vanes by TUGA for MGT-70 and MGT-30 machines, but also provided the company with another competitive advantage in the service market to fulfil the needs of customers with a short lead time and at a highly reasonable cost.



6. Customized Dynamometers for Testing Mechanical Drives in Harsh Duty Cycles

Introduction

The typical method of testing a gas turbine is using a water brake dynamometer to simulate the load applied by driven equipment rather than connecting to the grid by a generator. MHD-30 and MHD-40 are hydraulic dynamometers developed by TUGA with different load capacities of 30 and 40 MW and maximum speed of 5500 rpm. These machines are manufactured for MGT-30 and MGT-40, two industrial drive products. The design is the same for both products and they only differ in the number of disks. The former has 4 and the latter has 6 disks. Both dynamometers can be coupled directly or via a gearbox, to driver machines.



Figure 1: MHD-30 dynamometer



Design Concept

MHD-30 and MHD-40 have a cavitation-free design and smooth disks for long service life with long service period. The machines are capable of absorbing maximum 30 MW or 40 MW respectively in a rotational speed of 3500 ~ 5500 rpm. At lower speeds, due to using T-rings, internal pressure can rise to as high as 30 bars.

The working media is water and thanks to viscous shear between disk and casing rather than turbulent vorticity, power is dissipated by water. Dissipated power transforms into heat energy and is given by water flow to atmosphere. The water inlet and outlet temperatures are 35°C and 60°C respectively. Required water flow for cooling is 40 m3/ hr MW.

Both exposed surfaces of disk and housing are smooth. Reaction torque due to frictional force applied on the casing, is calculated by the force sensed on the load cell, multiplied by radial distance (lever arm).



Figure 2: contour of velocity and temperature at maximum speed and full wet



Figure 3: Characteristics of MHD-40



Figure 4: internal pressure map

Rotor Configuration

In MHD-30, four smooth and approximately uniform-stress disks are pre-tensioned together by axial stud bolts connecting disks and two different stub shafts at both ends. Disks are of an inherently cavitation-free type; so, they make up a rugged equipment with long service life that can be used in continuously high power regimes. Another advantage of the smooth disks is operability in both directions. Rotor components are made of high strength alloy steel and disks are covered by inhibiting coating with enhanced resistance against erosion and oxidization.



Figure 5: MHD-30 Rotor stress analysis

Input torque is transmitted by splined coupling and by frictional torque through the rotor. Labyrinth seals are used on both sides of the rotor with replaceable components on the corresponding casing side to provide sufficiently tight clearance to minimize water leakage. Thrust collar is located at end side of the rotor.

The rotor has rigid behavior and is balanced at low speed in two planes as per ISO 1940-1 with a quality grade of G1. In order to isolate dynamometer rotor from other train components, a flexible coupling is used.



Figure 6: 3D rotor unbalance response

Radial bearings are of tilting pad type to minimize rotor instability due to their exceptional stiffness and damping characteristics. Active and inactive thrust bearings are springelement equalized babbitted pads to ensure equal load distribution on all of them. The oil grade is ISO VG32 supplied at 2 bar.

Two types of seals are used, labyrinth seals at the end of disks and oil floating graphite seal on both ends in order to prevent oil leak.



Figure 7: radial and thrust bearings

Casing Configuration

Casing includes pressure part in the middle and two bearing supports at each side, all horizontally split. Pressure casings are designed for 40 bar internal pressure acc. to Section VIII, Division 2 of the ASME code. Divided nuzzles for water supply and T-rings for reducing tangential velocity are attached to pressure casing. This component is made of carbon steel in separate parts with enhanced resistance by electroless coating to protect them against corrosion. Different stages are stacked onto each other by axial stud bolts. Casing roller bearing supports are located inside the bearing casing.



Figure 8: casing configuration and displacement due to internal pressure

7. Precision Grinding of Taper Seats; Do it Onsite to Restore Accuracy in Milling Machines with No Hassles!

Introduction

Tool run out (Figure 1) is a well-known deviation in cutting tools that greatly affects machining accuracy. For machine tools that are equipped with ISO 50-60 tool holders, run out deviation may arise from misalignment between tool axis and taper axis or from surface imperfections on taper seats (Figure 2). Axis eccentricity may be seen in assembly stage of new tool holding system, while surface imperfections mostly happen during operation time of machine tools. Run out deviations directly affect tool handling accuracy which may result in deviation of machined features, inadequate surface roughness or tools wear acceleration. High precision machining approach of MAPNA Turbine raised an urgent demand to address this problem on heavy duty milling machining centers. Hence, we started a campaign to find a solution to fix run out deviations of damaged taper seats. Attempts to outsource the high accuracy grinding services failed due to lack of experience or adequate instrumentation in subcontractors. Final decision was thus made to produce a new portable grinding machine in accordance with demanded strict quality criteria.



Figure 1: Schematic representation of tool run out [1]





Figure 2: Schematic illustration of tooling system inside a spindle [2]

Problem Description

Because of the strict quality acceptance criteria at TUGA, all newly installed machine tools perfectly pass run out tests (Figure 3). However, at some point during their service life, a number of them show unacceptable run out deviation of cutting tools. Root causes of such damages are cutting tool collision, surfaces imperfections and maltreats of automatic tool changers. The most tangible side effect of tool run out is to drill holes in bigger sizes than nominal tool diameter. In some cases the run out deviation was big enough to limit functionality of machine tool only to rough cuttings.



Figure 3: Spindle run out checking using a dial gage and test mandrel [3]

Details of the Solution

Common solution to the aforementioned problem is spindle disassembling in order to correct the taper by an internal grinding machine. It is a challenging task that entails a rather long machine downtime and involves the risk of damage on spindle precision parts like bearings and also misalignment due to inherent process inaccuracies. An alternative approach is onsite grinding of the spindles which isolates risk sources to yield the best possible results. In this case, bearings of the rotating spindle need to be perfect to generate stable rotational reference axis.

A precise rotational movement of the taper (provided by the spindle) coupled with a precision linear movement of high speed rotary grinding wheel (provided by the portable grinding unit) can generate a high quality conical surface. In this way, axis of symmetry for the newly generated surface exactly coincides with rotational axis of spindle which means minimum eccentricity in cutting tool.

Such portable grinding system should carry a number of characteristics as follows:

- High speed, accurate grinding spindle (at least 10,000 RPM with minimum possible run out)
- Linear reciprocating smooth movement with perfect straightness
- Minimum vibrations at high speeds and resonance-free structural design
- Thermal stability of spindle and wear-free linear sliders

Accordingly, final decision was made to design and produce a suitable portable grinding unit. During design, assembling and testing stages (Figure 4), technical concerns and successive modifications led to manufacturing our new portable grinding unit. Table 1 shows the main features while the final appearance is illustrated in Figure 5.



Figure 4: During production, A: Rotary part of base frame, B: Fixed part and linear pads, C: Initial assembly



Table	1_ Main	features	of	nortable	taner	arindina	unit
lable	1- <i>I</i> Main	leannes	OI	ponuble	laber	ginnaing	UTIII

ltem	Details
Main body	 Steel thick sheets, Formed, welded Slotted to help chip-coolant flow Carburized to protect against rust Lifting rings
Control system	 PLC Hand held control panel Electrical cabinet
Translational axis	 Precision Linear guide way with four wagons Hydraulic power pack Hydraulic cylinder Hydraulic valve assembly Feed velocity regulator valve Protection covers Travel adjusting system (in length and position)
Spindle	 High frequency inverter High speed electrical motor spindle (up to 18,000 RPM) Precision ceramic bearings
Orientation	 Possibility to horizontal and vertical set up and fine adjustment Very fine angular adjusting bolt and clamps for conical angle setting
Safety	 Appropriate emergency push bottoms Mechanical stopper of translational axis to increase the safety. Monitoring of the dresser arm position
Accessory	Single point dresser



Figure 5: Final product including: A- Grinding unit, B- Hydraulic power pack and C- electrical cabinet

Grinding Performance

After final assembly, taper grinding unit was tested. Geometric, kinematic and vibration tests showed such good results. The last step was to run a performance test i.e. carrying out a grinding test on real machine tool.

Three damaged horizontal boring machining centers were selected (in two horizontal and one vertical setup) for performance checking (Figure 6 & 7).

In case 1, the taper seat had experienced a crash and machining department used it only for facing and rough cuttings. Case 2 had been working since 13 years ago and its taper seat had been worn out in a course of normal application. Case 3 had experienced a hard crash and main shaft of the spindle had been reproduced and mounted slightly misaligned.

The average time of each grinding process was 3 hours with the results that are tabulated in Table 2. As seen in before-after situations, the unit accomplished onsite grinding task producing perfect results. Improvements are really surprising and even better than what reported by machine manufacturers on installation dates (Figure 8).

		Run o	ut test	Contact Ratio	Surface Quality	
		a) Spindle nose	b) At 300 mm			
Acceptable Values		0.010 mm	0.025 mm	More than 70%	Perfect Grinding Quality	
Case 1	Before	0.100 mm	0.300 mm	Really bad with local concentrations	Hardly Damaged	
After		0.001 mm	0.003 mm	More than 90%	Perfect	
Before 0.03 mm 0.10		0.100 mm	Almost 50 %	Slightly Damaged		
Case 2 After		0.001 mm	0.005 mm	More than 90%	Perfect	
Caro	Before	0.030 mm	0.060 mm	Almost 60 %	Locally damaged	
Cuse 3	After	0.003 mm	0.003 mm	More than 90%	Perfect	

Table 2- Results of three machine tool taper seat grinding





Figure 6: Grinding wheel running inside a taper seat



Figure 7: Taper grinding in vertical set up



Figure 8: Contact check: A-Before grinding, B: After first cut, C: Angle tuning and final cut

Conclusion

Run out deviation of milling cutting tools is a big concern for high quality machining processes. We found taper seat damages as the root cause for such deviations in milling machine tools. Onsite grinding strategy of taper seats led to design and production of our new portable taper grinding unit. During performance tests, it showed amazing improvements on damaged tapers which brought about best possible results in modifying run out deviation of cutting tools.

List of References

- [1] http://www.techniksusa.com/metal/holder_maintenance.htm
- [2] http://blog.cnccookbook.com/2014/06/11/ultimate-benchtop-cnc-mini-mill-part-7-spindle-drawbar-and-toolchanger
- [3] http://www.bigkaiser.com/products/accessories/dyna-test.html



Factory:

Fardis, Karaj - I.R.Iran. Post code: 31676-43594 Tel: +98 (26) 36630010 Fax: +98 (26) 36612734

Head Office:

231 Mirdamad Ave. Tehran - I.R.Iran. P.O.Box: 15875-5643 Tel: +98 (21) 22908581 Fax: +98 (21) 22908654

www.mapnaturbine.com tr@mapnaturbine.com



© MAPNA Group 2015 The technical and other data contained in this Technical Review is provided for information only and may not apply in all cases.`