Technical Review

MAPNA TURBINE ENGINEERING & MANUFACTURING CO. (TUGA)

No.2 - October 2014

Our Willpower, to Empower Generations

TUGA MAPNA GROUP

EDITORIAL

Dear Customers, Partners and Professionals,

We are pleased to present the second issue of this biannual Technical Review, to share the latest developments and achievements in our products and technology.

In this issue, firstly, a new manoeuvrability enhancement, enabling way faster loading/unloading of MGT-70 with minimal modifications on operating machines has been introduced. The innovation extends our MGTboost-70 series of after-market products on the MGT-70 machine.

In the second essay, an account of a thorough re-design in compressor blading is provided. The subsequent up-ratings as a result of this redesign both separately and along with other proposed items of upgrading package are discussed.

Advances we have made in A-Z manufacturing of different turbines have led to innovations in tools and techniques that could give leverage to one-of-the-type manufacture. This paves our way in making prototypes, as well as in service market, when we go to competitors' machines. The following two articles fall in this category.

The third essay deals with a new package developed in-house to generate blade 3D models right from the air-foil point clouds of relevant 2D drawings. This is used to provide 3D models of blades for CNC machines for own fleet products and is equally good for any new set of blades and vanes to be manufactured for customers' various operating machines.

An exciting success story in overcoming a serious manufacturing problem has been given in the fourth essay. Specific form-tools have been developed to cut fir grooves and fir-tree blade roots and prove that nothing is considered a hassle when there is a will to move toward excellence.

Finally, the last essay in this issue is a report of our successful manufacturing and testing of the newly developed helical turbine meter. Being the first in its range, it has shown magnificent results in terms of repeatability, linearity and accuracy, as verified in international accredited verification labs.

This issue of Technical Review is based upon the information provided by our experts in different fields, active in technology development of MAPNA Turbine Company, whose invaluable sharing is hereby appreciated.

Respectfully,

M.Owliya

Mohammad Owliya, PhD

Vice President for Engineering and R&D

MAPNA Turbine Company (TUGA) - October 2014

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1. Load/Unload your MGT-70 Faster

Introduction

MGTboost-70 platform is a series of developed technologies by MAPNA Group for the installed-base units to boost operational flexibility, reliability, and energy efficiency of the machine. MGTboost-70.4 is a new one in the series, enabling faster loading/ unloading of MGT-70 machine.

Compressor of the machine has an adjustable inlet guide vane row which obviously adjusts the air flow to the gas turbine. At a constant fuel flow, the turbine outlet temperature (exhaust gas temperature) decreases when the inlet guide vanes are opened and vice versa. By increasing or decreasing the fuel flow and the air flow at the same time, the turbine exhaust temperature can be held constant.

Intended task for the compressor inlet guide vane controller, as shown in Fig.1, is to regulate the exhaust gas temperature in partial load range by adjusting inlet guide vanes.

In the event of very fast changes in fuel mass flow, e.g. if the gas turbine operates in frequency control or in cases that there is a need to quickly increase or decrease load to a certain value, the compressor mass flow and the fuel mass flow must be kept at a certain ratio at all times, so that:

- The thermal stress remains lower than a certain value,
- Stability range of the premix burners is maintained, and
- A safe margin from the compressor surge limit is guaranteed.

This demonstrates how highly dependent the rate of loading and unloading of gas turbine is on operation speed of the inlet guide vane (IGV) mechanism. With the latest developments on control system of MGT-70 machines, the maximum speed of current IGV actuators was achieved which resulted in 6 times higher loading and unloading rate.

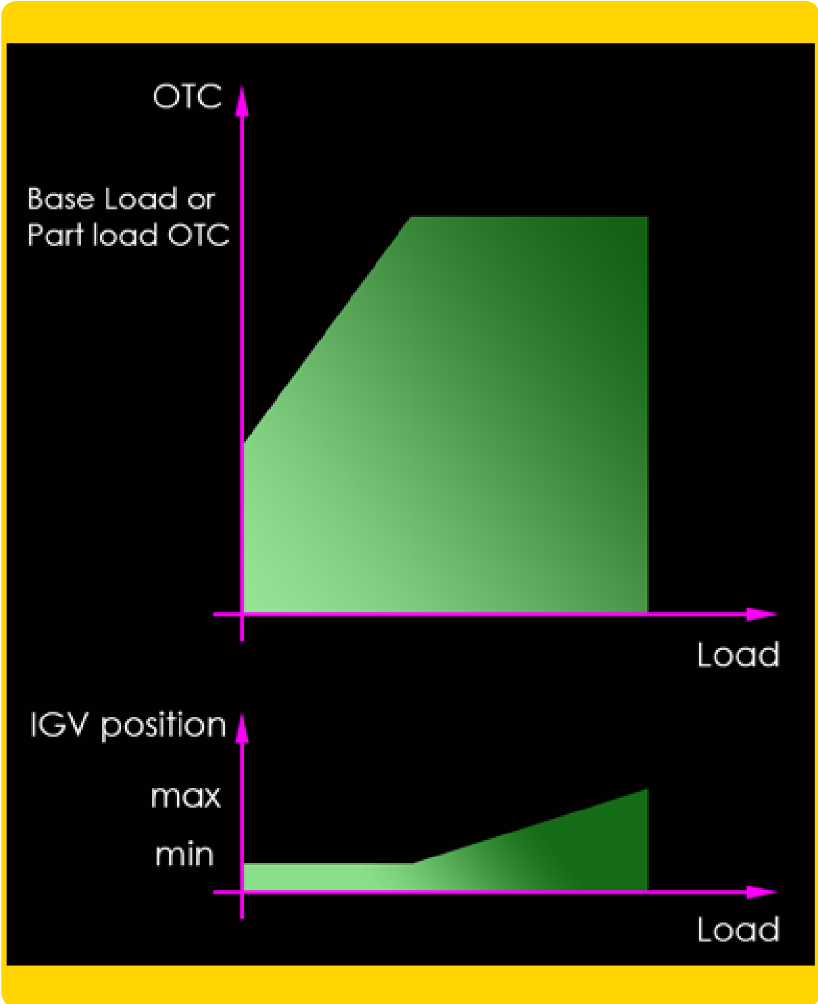


Fig.1- Turbine Outlet Temperature vs. Load with relevant IGV position

Available options for IGV mechanism of MGT-70

At the moment, there are two different IGV actuators available for commercialized MGT-70 gas turbines:

1) Standard Motorized Worm Gear Actuator

This actuator normally travels its full span (from fully closed to fully open position and vise versa) in about 150 seconds and enables the engine to undergo a maximum loading gradient of 30MW/min.

2) Servo-electric Power Screw Actuator

This type of actuator which is mainly used in gas turbines operated in frequency control of electrical grids is able to travel its full span within 12 seconds and therefore secures a maximum loading rate of 6MW/seconds for the engine.

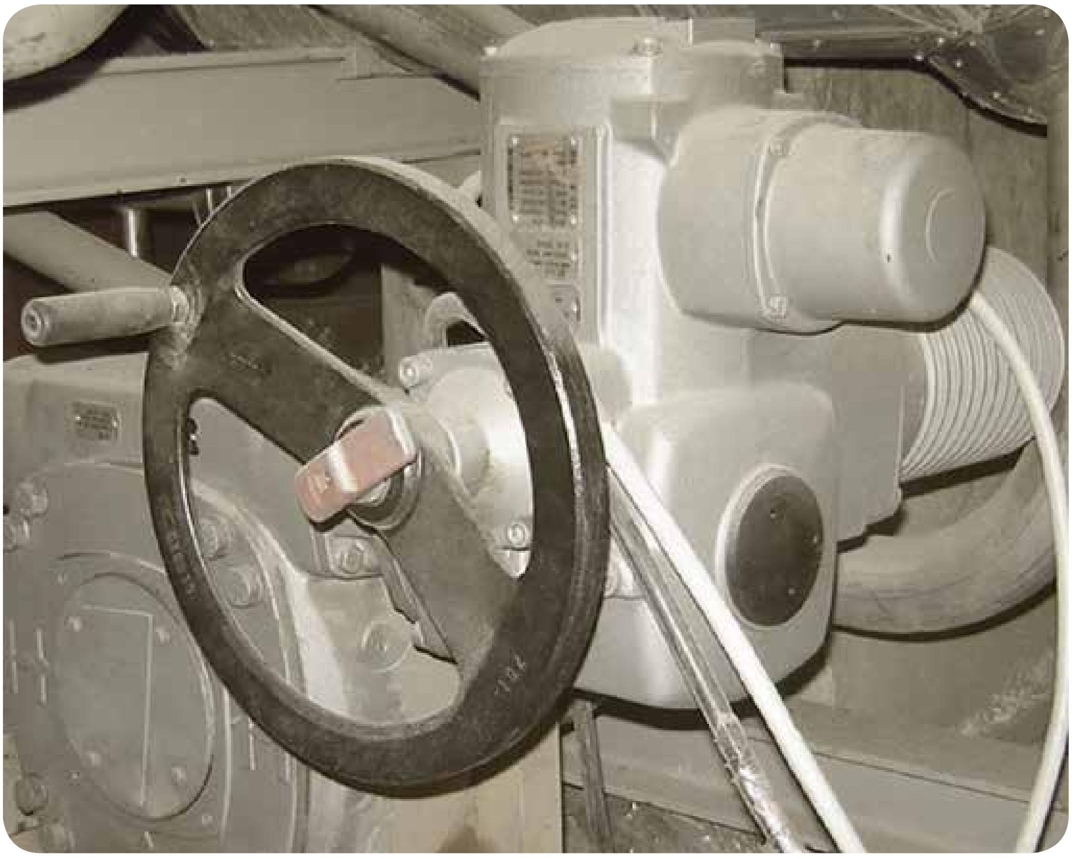


Fig.2- Motorized worm gear IGV actuator

Fig.3- Servo-electric power screw IGV actuator

How to increase loading gradients with a standard actuator?

The main feature of standard MGT-70 in fast (30MW/min) loading mode is that the loading rate is achieved continuously from minimum load up to the engine base load. In other words, the maximum loading rate with fully closed IGV where no control on air flow exists has been extended to encompass the full load range of the machine (including IGV operating range). Therefore, although the standard IGV controller is designed in accordance with this loading gradient, the existing actuator can indeed operate much faster!

Tests show that the standard motorized IGV actuator is able to travel its full span at maximum speed within 25 seconds that is nearly 6 times faster than the usual travelling time. This means that theoretically we can control the exhaust temperature even with higher loading gradients. In order to implement this idea into the control system the following modifications and checks have been carried out:

- Tuning IGV position controller to a higher loading gradient
- Checking and fine tuning of IGV pre-controller
- Modifications on Load-speed controller
- Tuning the Compressor Pressure Gradient Controller according to a new loading gradient
- Tests and verifications on the engine model through MGTS-70.1 SIMULATOR
- Performing field test and final tuning of controllers

As a result, by dividing operating range of the machine into two separate regimes, the following maximum loading rates were achieved:

1) Outside operating range of IGV (that is from minimum load up to 50% Base load) the highest loading gradient remains 30MW/min which is limited by allowable thermal stress on hot parts of the machine.

2) In operating range of IGV (from 50% base load up to base load) maximum loading rate of 180MW/min which provides far more flexibility in frequency response and grid power demands.

Conclusion:

By taking advantage of the maximum performance of the existing equipment on standard MGT-70 machines and performing required modifications on the control system a much higher loading gradient of 180MW/min (6 times faster than standard models) was achieved in working range of IGV. Test results with 180MW/min have been presented in Fig.4 which shows even a narrower exhaust temperature variation (15°C) compared to that of old fast loading (20°C) which means even better control response at a way higher loading gradient.

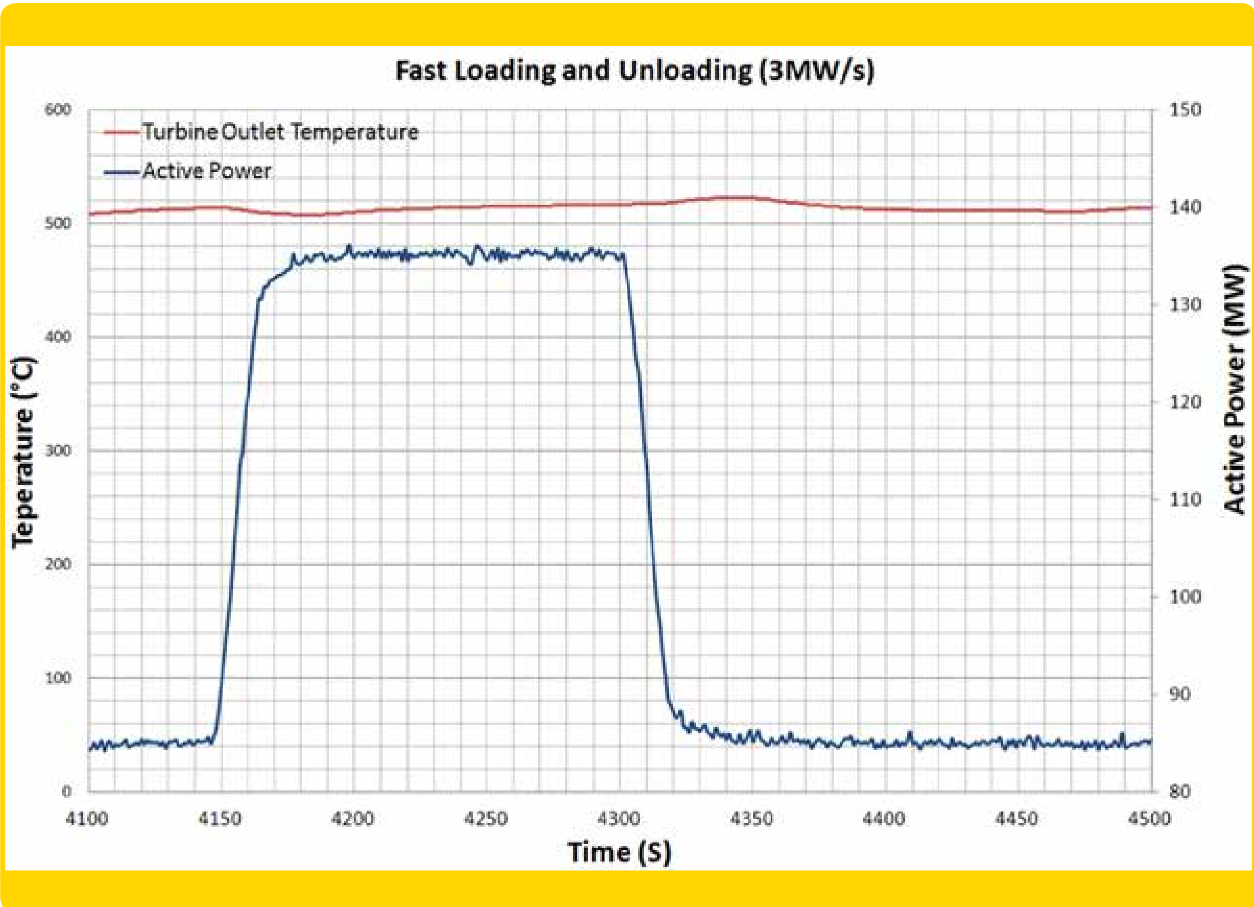


Fig.4- Test results with higher fast loading rate of 180MW/min

2. Compressor Mass Flow and Efficiency Increase

New Upgrade for MGT-70 Gas Turbines

Introduction

In recent decades uninterrupted effort has been made by OEM's and active companies in the field of power generation to present new products and/or coming up with improvement packages for the existing fleet. MAPNA Group, as one of the internationally active parties in energy sector, has also begun its campaign to expand its portfolio by developing new products as well as improving its current machines as a response to the ever-increasing energy demand and environmental concerns. MGT-70, being one of the dominant machines in service in the gas turbine fleet of IRAN and throughout the world, is a noteworthy machine to invest on, for improvement and optimization purposes. Thus, developing an upgrading package to unveil the 3rd version of MGT-70 was tackled at MAPNA Group with part of the package dealing with upgrading the compressor section to maximize the input air mass flow rate and compressor efficiency as a modern approach. This, in turn, will have a considerable impact on output power and cycle efficiency in both simple and combined cycles. Due to the positive impact on the efficiency, this improvement will decrease both fuel cost and pollutant emissions per energy output unit which brings about a considerable competitive advantage for both current and future users of the machine.

The Compressor Upgrade and the Advantages

Enhancing the mass flow rate and efficiency of the compressor section of the machine MGT-70 involved a 3D re-design of the first 4 stages of the compressor, CV15 and CV16. This involves both rotary and stationary blades and results in an improvement in total efficiency and net power output of the whole machine. As a separate upgrading module, this enhancement enables the customers to enjoy a higher power output with minimal changes in compressor blading for certain stages and adjustments in the control system.

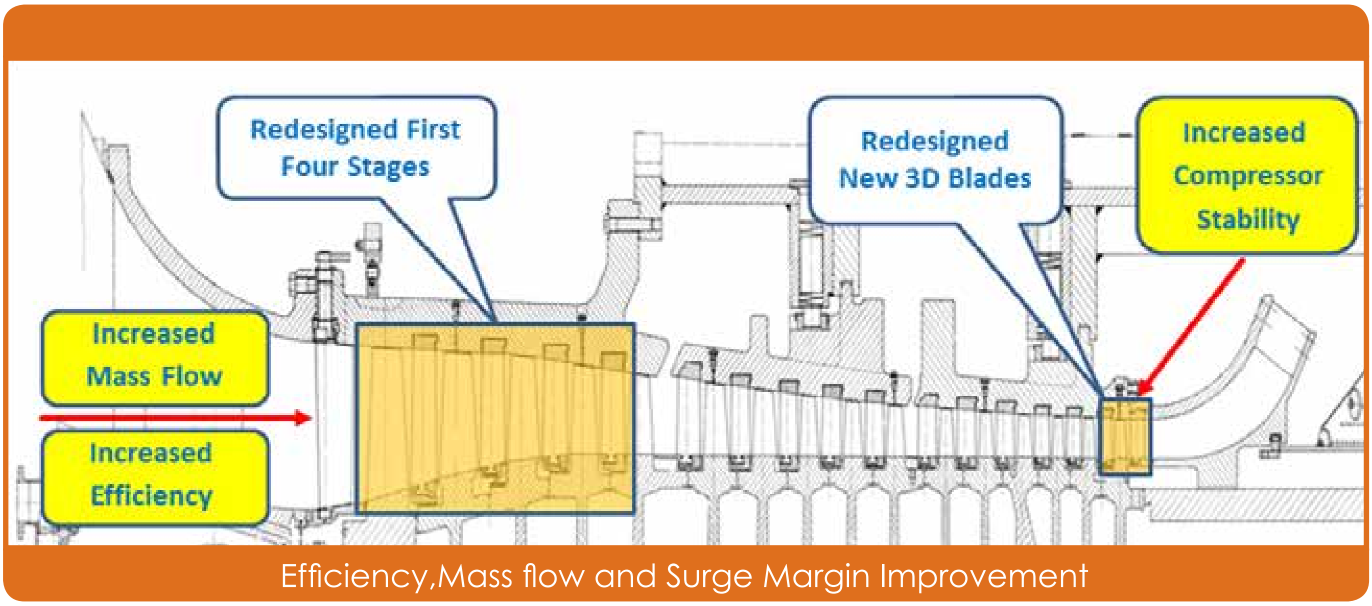


Fig.1- Cross section of MGT-70 (3) gas turbine compressor

Technical approach

The re-design and testing of the relevant rows of the compressor were implemented making use of state-of-the-art practices in the area of aerodynamic design and optimization. First, making effective use of the most up-to-date approaches, design and optimization were carried out in mean radius and then, to minimize the aerodynamic losses, 2D and 3D design and optimization were deployed. The result was coming up with blades and vanes with the highest possible efficiency and reliability along with an increase in mass flow rate. Another merit of the proposed package is the improvement in materials, which in addition to aerodynamic and mechanical design optimization has brought about a considerable rise in reliability, availability and design life of the compressor.

In this compressor upgrading module, use has been made of redesigning the compression line in the first rows. Based on this, a new load distribution taking into account the new mass flow and targeted efficiency was developed and subsequently optimized. The optimization enables us to achieve a higher efficiency in the redesigned rows compared with the initial compressor. Airfoils in the relevant rows have been developed taking use of the latest optimization algorithms; i.e. a combination of genetic algorithm, neural network and Design of Experience (DOE) approaches. This has resulted in a remarkable increase in stability margin and a considerable decrease in losses in both design and off-design regimes.

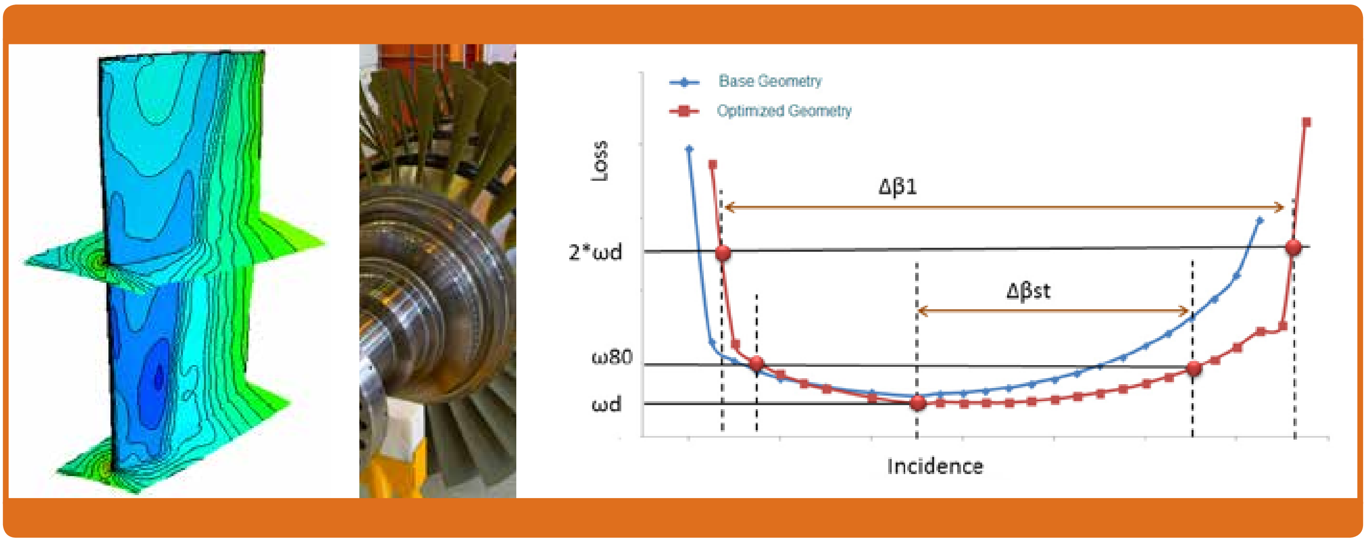


Fig.2 - 3D blade Design / 2D Airfoil Optimization and Characteristic

Customer benefits and scope of changes

The advantages of using such an upgrading module which can be implemented with minimal cost and asset downtime are:

- More than 3% increase in gas turbine power output in simple cycle
- More than 0.4% increase in the machine's overall efficiency as a result of the enhancement in isentropic efficiency of the compressor
- Improvement of power output and efficiency in combined cycle
- A wider stability margin in higher inlet temperatures for compressor and machine performance

It is noteworthy that the compressor upgrade package is only one of the innovative upgrade packages proposed by MAPNA Group for optimizing MGT-70 and developing the 3rd version of the machine. The modifications included in compressor upgrade package are as follows:

- Replacing the first 4 stages of the compressor by blades and vanes optimized according to the state-of-the-art practices
- Altering the materials of the first 4 stages of the blading to those with a higher resistance to erosion, corrosion and mechanical stress.
- Adjusting the control system to accommodate the new compressor design
- Replacing the 15th and 16th row of the compressor vanes and altering the blade material for them

The compressor upgrading can be implemented on various versions of MGT-70 as a separate module or combined with other modules of the upgrade package proposed by MAPNA Group. A remarkable advantage of this module in comparison with former similar mass flow rate increase proposals is that there is an increase in compressor efficiency along with the mass flow increase. This has come about thanks to deploying the latest knowledge in design and optimization of axial compressors in MAPNA Group.

3. Too Long a Path from Airfoil Point Clouds to Blade 3D Model? Voila! It's done at a click here!

Introduction

In blade manufacturing, to develop machining programs for the airfoils, 3D models of the blades should be developed first. Blade manufacturing drawings include two parts: blade root and airfoils. For the rather complicated forms of the airfoils coordinates of the airfoil points (point clouds) are usually given in a table. These clouds, developed out of design and fluid flow analysis software need to be transferred to a computer aided design and modeling software to generate the 3D model of the airfoil. An intermediate program was developed to supersede the manual input of airfoil data so as to not only rule out human error, but also considerably boost the speed of the blade modeling process.

Need to intermediate automatic blade modeling software

Blade root dimensions and views are produced, like any other ordinary drawing, through standard symbols and using normal drawing practices. As for the rather complicated airfoil surface, a parametric view of the cross section is normally presented in a selected coordinates system and the values of the parameters are given for a few sections in a table. Thus, points clouds made up of plenty of points shaping the 3D airfoil of the blades are produced.

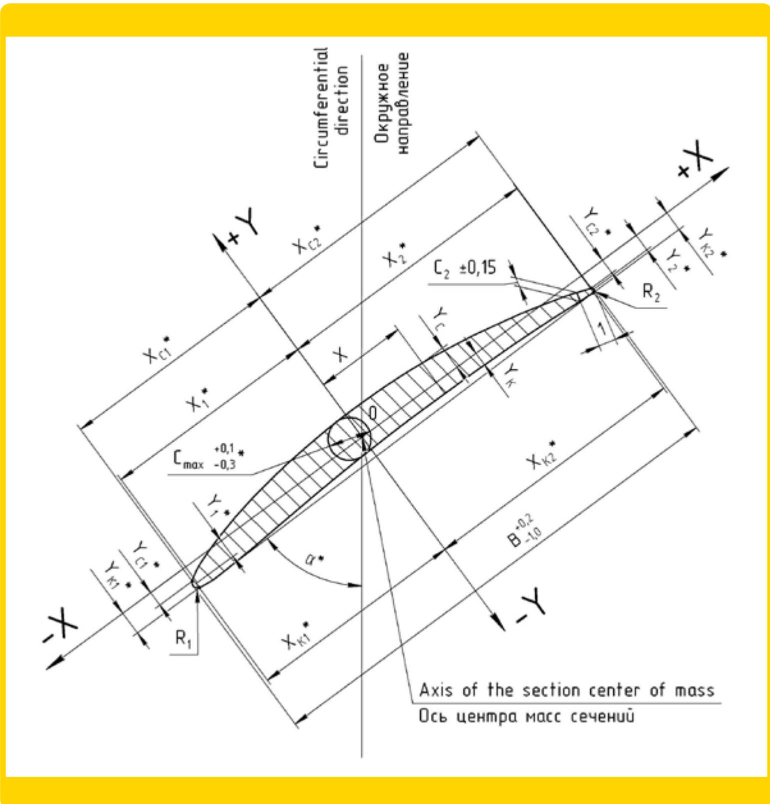
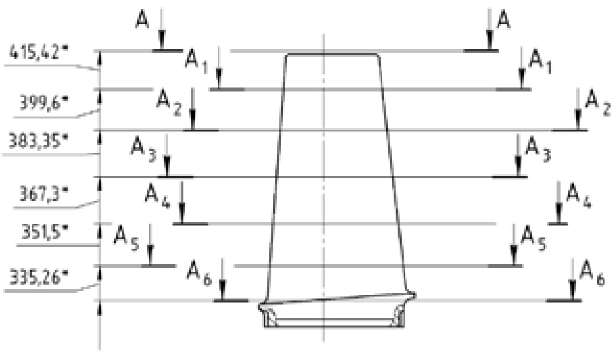


Fig.1- Parametric view of blade airfoil

Table 1- Airfoil points coordinates table



Profiles Сечения	A-A	A_1-A_1	A_2-A_2	A_3-A_3	A_4-A_4	A_5-A_5	A_6-A_6
X_1*	-26,820	-27,433	-27,747	-27,859	-27,851	-27,760	-27,538
Y_1*	-8,990	-6,431	-4,438	-2,669	-0,885	1,034	3,228
R_1	0,449	0,563	0,683	0,814	0,954	1,099	1,245
X_{C1}*	-27,094	-27,736	-28,139	-28,201	-28,195	-28,349	-28,065
Y_{C1}*	-8,634	-5,956	-3,878	-1,930	0,004	1,961	4,356
X_{K1}*	-26,764	-27,440	-27,751	-28,003	-28,133	-28,013	-28,040
Y_{K1}*	-9,435	-6,994	-5,122	-3,350	-1,797	-0,035	2,088
X	Y_C	Y_C	Y_C	Y_C	Y_C	Y_C	Y_C
-28,00	-	-	-3,785	-1,829	0,094	2,150	4,385
-27,50	-	-5,808	-3,459	-1,567	0,339	2,375	4,606
-27,00	-8,567	-5,502	-3,166	-1,320	0,572	2,588	4,807
-26,50	-8,205	-5,210	-2,904	-1,088	0,791	2,789	5,012
-26,00	-7,868	-4,935	-2,670	-0,867	0,993	2,971	5,197
-25,50	-7,544	-4,679	-2,450	-0,655	1,184	3,142	5,367
-25,00	-7,239	-4,433	-2,239	-0,451	1,366	3,303	5,526
-24,00	-6,663	-3,962	-1,835	-0,070	1,705	3,600	5,810
-21,00	-5,111	-2,695	-0,766	0,869	2,521	4,285	6,415
[illegible]	[illegible]	1,615	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

To develop the airfoil machining program, a 3D model should be provided first, so coordinates data entry from the drawing tables into modeling software needs to be carried out to develop the model of aerodynamic surface of the blades. These 3D models are required for proof analysis of the machine performance, development of manufacturing jigs and fixtures, developing CNC programs, and simulating blade machining process.

Due to huge number of points whose coordinates are given in blade drawings (averagely 800 points per drawing) and number of stages of the gas turbine, data entry from the drawings into CAD software takes a lot of time and involves a high risk of error. If only one could come up with some intermediate software package to automatically introduce the drawing tables into CAD software to build the 3D model, in addition to a huge improvement in accuracy and uniformity of the models, the time needed to accomplish the 3D modeling could be considerably decreased from a few days to less than one hour.

Intermediate package development phases

- An investigation on existing packages for converting PDF files to MS-Excel ones and possibility of correctly converting drawing data to figures readily accessible in MS-Excel format
- Developing a pattern in MS-Excel to accommodate all the airfoil data provided in various blade drawings of the industrial gas turbine
- Creating an Excel add-in in MS-Visual Basic environment to read the data introduced in MS-Excel and provide a connection between Excel and CATIA 3D modeling software, and then successfully transfer the data to CATIA and subsequently execute the internal commands of CATIA to develop the 3D model
- Manual modeling of a few completely different blades using different methods in CATIA to select the best possible approach
- Programming in MS-Visual Basic to enable automatic execution of internal commands in CATIA to transfer the data from MS-Excel and build the 3D model thereafter
- Programming to create 3 different approaches to make use of drawing dimensions and define the constraints to draw the airfoil sections in the software; and providing the user with the ability to select and convert to any of the 3 constraining options in the package

The way the package works

Creates a standard format to transfer data from drawings into MS-Excel

Toolbar in MS-Excel

Fig.2- Establishing connection with modeling software

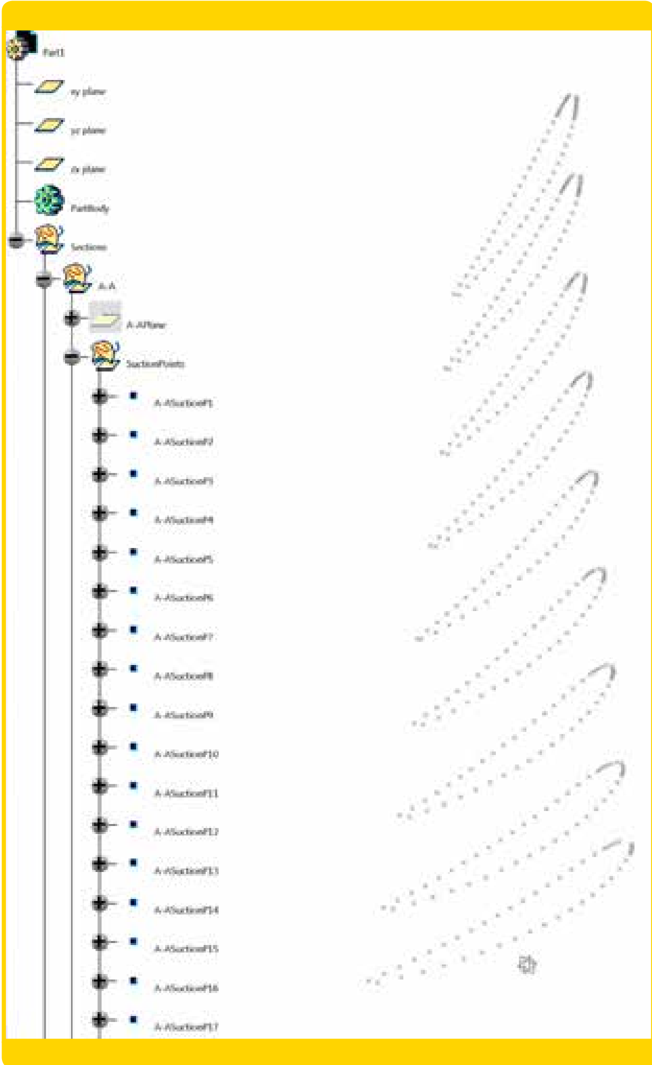


Fig.3- Creating the points clouds in modeling software using the coordinates in the MS Excel file

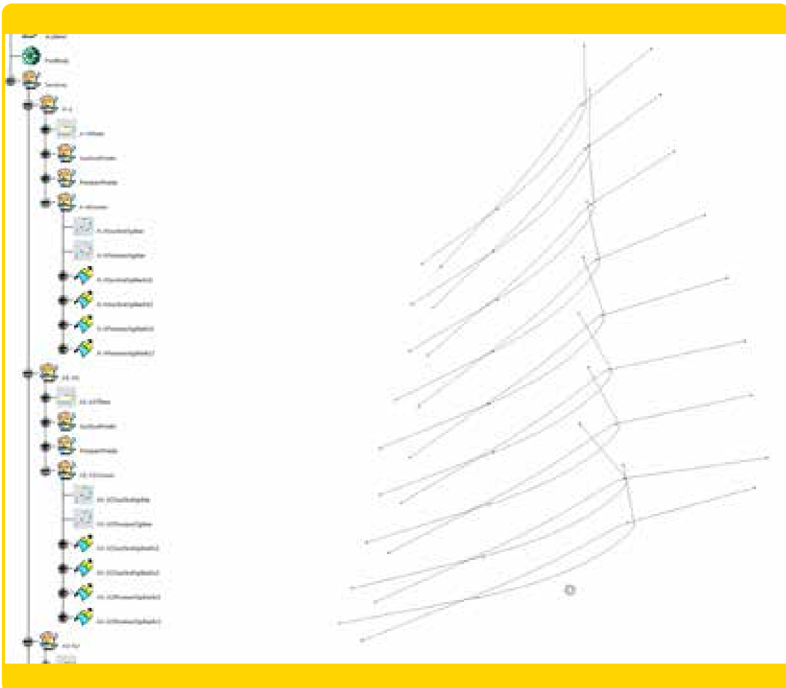
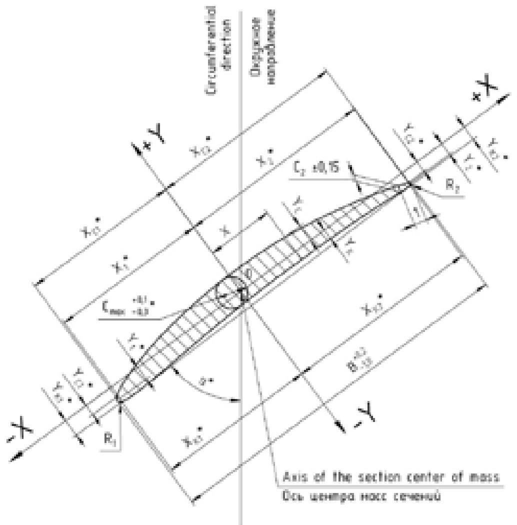


Fig.4- Continuing the curves on each side for each section

The points given in drawings are only used to draw pressure and suction side curves. For leading and trailing edges in each section, geometric features of two circular arcs are given. Each of these arcs should be drawn tangent to the suction and pressure side curves. In addition to radii and coordinates of the center for each arc, the distance between the peaks of the arcs and the tolerance for each dimension is given. Furthermore, coordinates of the intersections of these arcs with each curve are also given in each drawing.

Table 2- Parametric drawing and geometry features of both leading and trailing edge arcs



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X	Y_c	Y_c	Y_c	Y_c	Y_c	Y_c	Y_c
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-27,00	-8,567	-5,502	-3,166	-1,320	0,572	2,588	4,807
-26,50	-8,205	-5,210	-2,904	-1,088	0,791	2,789	5,012
-26,00	-7,868	-4,935	-2,670	-0,867	0,993	2,971	5,197
-25,50	-7,544	-4,679	-2,450	-0,655	1,184	3,142	5,367
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

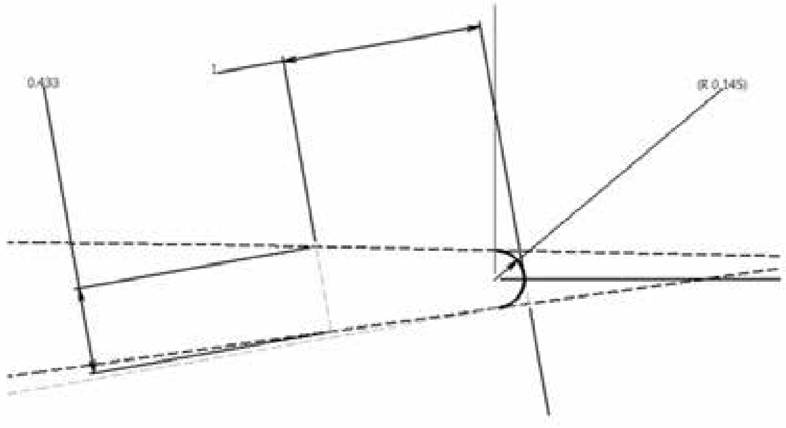


Fig.5-Sketch of edge arc

Given the within-tolerance deviations in the curve forming points, to draw them use is made of some other dimensions and constraints e.g. their being tangent to airfoil pressure and suction sides. Doing this may cause other dimensions (those not used in drawing the arcs) to fall out of tolerance. If this were the case, different dimensions and constraints would be used to draw the arcs and effort would be made to reach the best possible state of dimensions, within the drawing tolerance limits. To meet this, three approaches for using dimensions and constraints to draw the leading and trailing edge arcs of each section have been built in the software package.

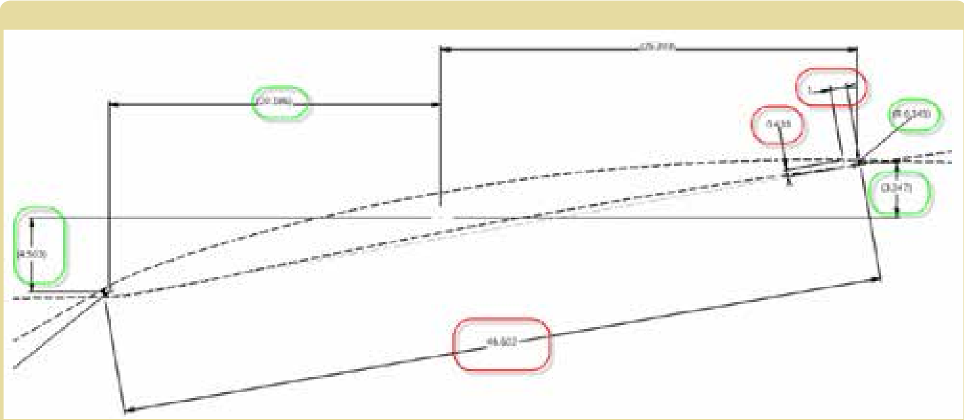


Fig.6- Fixed C1, C2 and B dimensions

Creating the 3D surface of the airfoil

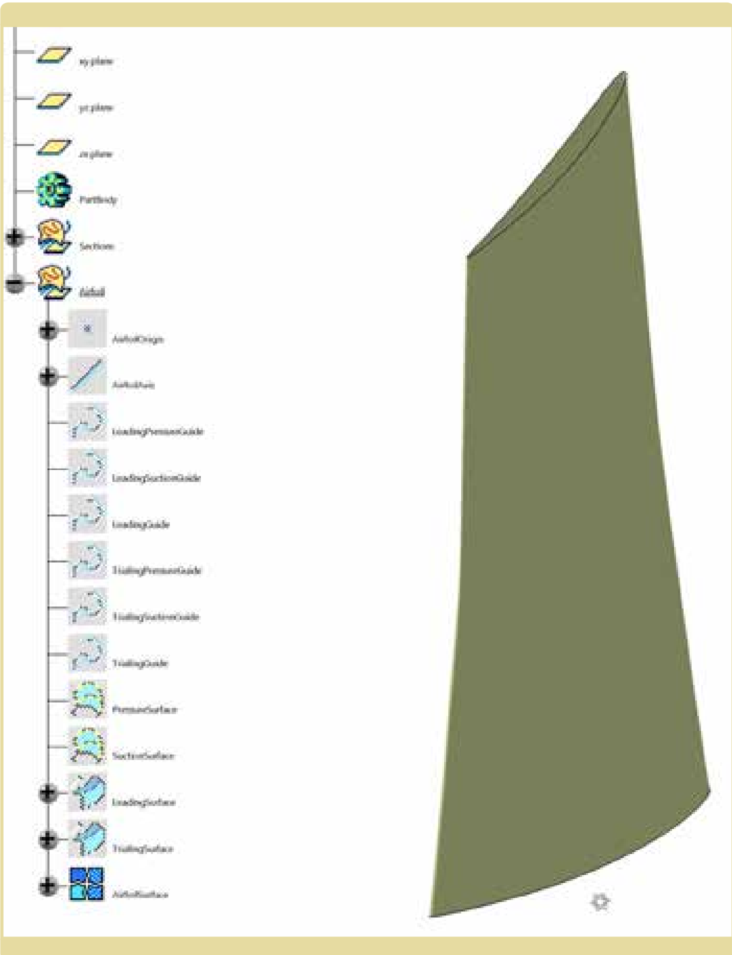


Fig.7- Multisection surface of airfoil

Creating the dimensional report from the 3D model

Given the approaches made use of to draw the arcs, some dimensions may fall out of tolerance. To verify this, all true dimensions are extracted from the set up 3D model in CATIA. All nominal dimensions and their tolerances are also added to the report from the original drawing and if any of the true dimensions happens to fall out of tolerance, this will be indicated by its containing cell's color turning to red in the table. In this way, the package user will be readily informed about the amount of deviation and the need to change the arc drawing approach as required. Also if there is an error in the drawing or the file whose data is taken out from the drawing, it can be readily detected.

After creating the 3D model, without a need to redrawing the model, it is feasible to change the constraining logic for drawing the arcs.

Table 3- Dimensional report of the model in MS-Excel

	A	B	C	D	E	F	G	H	I	J	K
1			A-A	A1-A1	A2-A2	A3-A3	A4-A4	A5-A5	A6-A6	A7-A7	A8-A8
2	X1	Drawing	20.211	19.703	19.015	18.300	17.724	17.653	17.623	17.540	17.418
3	0.000	Model	20.211	19.703	19.015	18.300	17.724	17.653	17.623	17.540	17.418
4	0.000	Deviation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5											
6	Y1	Drawing	4.512	3.858	3.044	2.198	1.361	0.518	0.384	1.390	2.280
7	0.000	Model	4.510	3.852	3.043	2.186	1.348	0.507	0.393	1.396	2.282
8	0.000	Deviation	-0.002	-0.006	-0.001	-0.012	-0.013	-0.011	0.009	0.006	0.002
9											
10	R1	Drawing	0.288	0.294	0.312	0.336	0.372	0.414	0.467	0.523	0.576
11	0.000	Model	0.291	0.297	0.311	0.325	0.354	0.386	0.445	0.496	0.586
12	0.000	Deviation	0.003	0.003	-0.001	-0.011	-0.018	-0.028	-0.022	-0.027	0.010
13											
14	X2	Drawing	25.287	24.627	23.719	22.750	21.927	21.674	21.417	21.010	20.544
15	0.000	Model	25.287	24.627	23.719	22.750	21.927	21.674	21.417	21.010	20.544
16	0.000	Deviation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17											
18	Y2	Drawing	3.345	2.349	1.130	0.125	1.395	2.793	4.292	5.942	7.375
19	0.000	Model	3.346	2.350	1.138	0.123	1.386	2.779	4.276	5.929	7.372
20	0.000	Deviation	0.001	0.001	0.008	-0.002	-0.009	-0.014	-0.016	-0.013	-0.003
21											
22	R2	Drawing	0.144	0.147	0.156	0.168	0.186	0.207	0.233	0.262	0.288
23	0.000	Model	0.147	0.147	0.166	0.169	0.177	0.224	0.250	0.270	0.288
24	0.000	Deviation	0.003	0.000	0.010	0.001	-0.009	0.017	0.017	0.008	0.000
25											
26	B	Drawing	46.603	45.204	43.405	41.607	40.209	40.013	40.019	40.026	40.035
27	0.400	Model	46.608	45.205	43.415	41.595	40.181	40.002	40.012	40.005	40.044
28	-0.400	[illegible]	0.005	0.001	0.010	-0.012	-0.028	-0.011	-0.007	-0.021	0.009

Conclusion

a- Transforming the drawing data into 3D model more quickly and more accurately

b- Quick verification as for the best approach to use drawing data to build the model

c- Quick report provided for other dimensions in 3D models to ease the comparison with drawing tolerances

d- The package can be used in blade design and analysis to provide the designer with a quick feedback to serve design verification purposes

e- Providing the company with a uniform blade modelling approach

4. Tool Manufacturing Turbine Manufacturer! We Pull out all the Stops!

Introduction

In most gas turbines, rotors are composed of turbine/compressor disks and a number of hollow or solid shafts connected together. Each disk, in particular, accommodates normally one row of blades. While operating, various forces including drag and lift of the working fluid, centrifugal force and those produced by temperature gradient along and across the blades are applied on each set of blades. These forces are transferred to the disks through the grooves securing the blades onto them. The constraining grooves are thus of utmost importance and criticality in designing the disks in both compressor and turbine sections.

Normally, the grooves are of dovetail form in compressor section disks, unless the blades are relatively too heavy, for which, fir-groove forms are also made use of in some designs. The blades are both radially and axially secured, using caulks or locking plates/keys in compressor side. In turbine side, however, an adroitly calculated radial blade-groove clearance is introduced taking into account relative thermal expansion between the blades and disks. Thus in turbine section, the introduced stresses onto the blade roots and disk grooves have convinced the engineers to make use of fir-groove forms.

Naturally, these fir-grooves are significant from manufacturing point of view as well. The dimensional and geometric tolerances are usually tight and the surface smoothness is meticulously controlled to undermine any crack initiation and propagation probabilities.

Fig. 1- Disk grooves in turbine and compressor disks

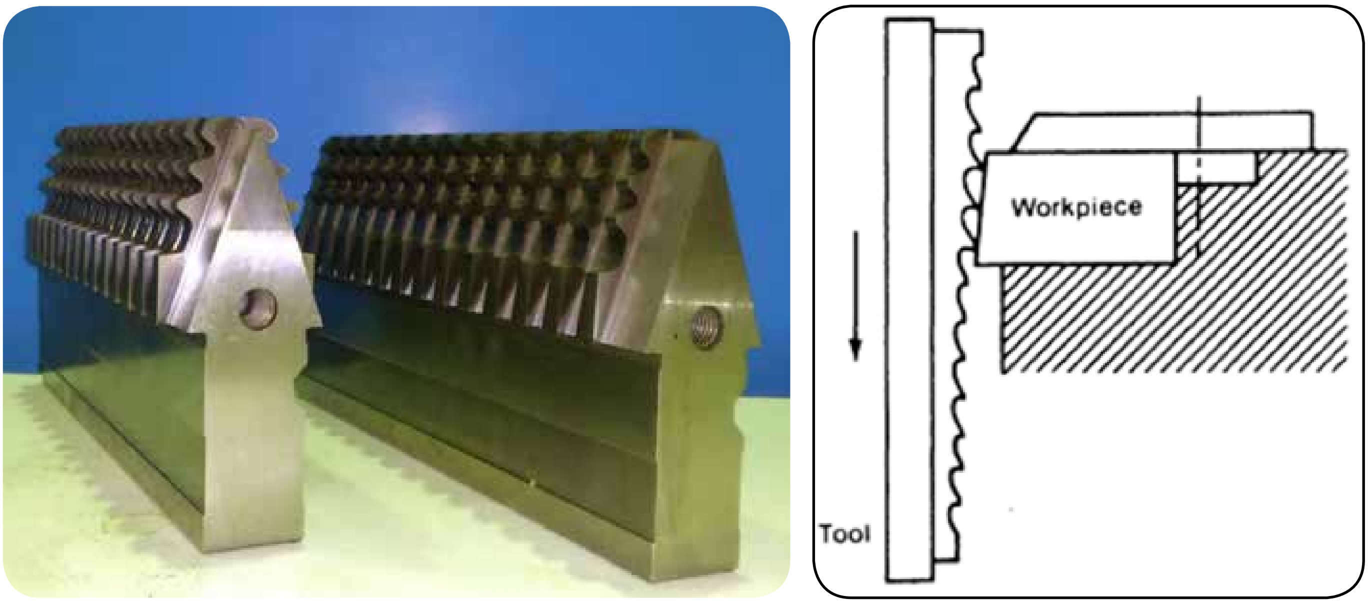


Fig. 2- Broaching process

Problem description

Broaching is the conventional machining method to create these forms on disks: The work-piece is held on the broaching machine's table and a set of cutting tools take turns to cut the form, as shown in figure 2

Designing and manufacturing broaching tools is a lengthy and expensive procedure, although once tool design is done, broaching is deemed to be the most economical method to cut the grooves. To align with the company's new approach to expand the portfolio and attend the newly opened service market, milling method was selected for the grooves to meet the following goals:

1- Manufacturing prototypes

2- Refurbishment and manufacturing disks of other brands of turbines during their major overhaul

According to the initial investigations, the specific milling tools for cutting the fir-grooves are highly complicated, exclusively handled by few prominent tool manufacturers in the world. On the other hand, placing orders to get such tools designed and manufactured overseas would be a time-consuming procedure that might adversely increase the lead times and impair our competitive advantage. So, relying on our previous experience in the area of sharpening the fir-groove forming tools and making dovetail milling tools, a strategic decision was made to appoint a multifunctional team of to acquire and apply the required knowledge to design and make such milling tools.

Fig.3- Tool making and sharpening specific machine

An account of the previous experience

Our first experience in the area of fir-groove forming tools was gained through sharpening fir-form tools used in manufacturing the rotor of MST-50C steam turbines. The sharpening only had to happen on the flutes of the tool. The tool design ruled out any change in its final profile after sharpening, so there was no need to follow a geometric pattern.

Our second experience goes back to sharpening of fir-form cutters used to produce blades of the Turbine MGT-30MD. Due to high technology and know-how made use of in producing sharpening drawings and the revenue that the tool makers enjoy through re-sharpening their sold form-cutters, these drawings are not provided along with the tools or only some general information on sharpening the tools is presented. Likewise; no information whatsoever on geometry of the tools was provided by the tool manufacturer in this case.

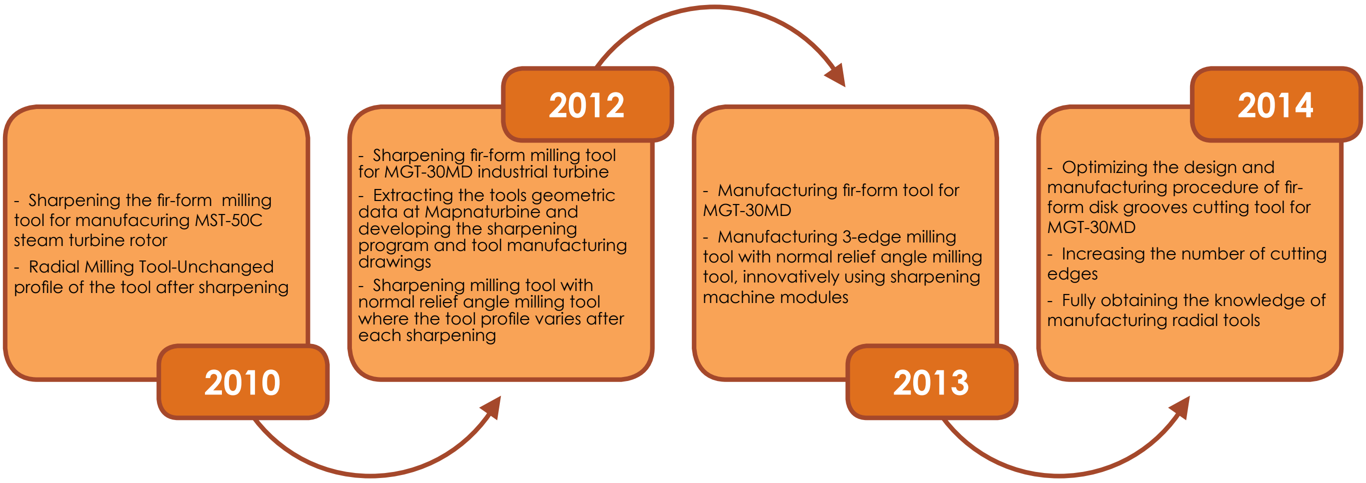


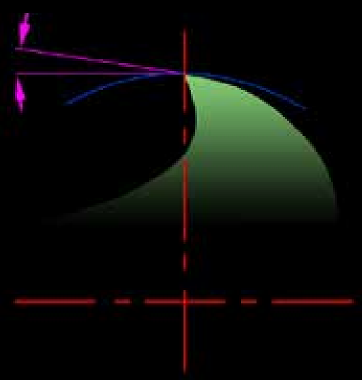
Fig. 4- Histogram of the development of the knowledge of manufacturing form cutting tools at MAPNA Turbine

A comparison between manufacturing methods of cutters

In milling operation, cutting edges are produced when a few angled faces meet, so that material removal from the work-piece to achieve the dimensional and geometric tolerances is accomplished. For finishing form tools, the machining features of the final piece have tight tolerances. Normally, 10 times tighter tolerances are applicable to the finishing milling tools to produce the targeted feature on the piece, taking into account the intrinsic errors in the milling machines.

Two methods of producing the main cutting edge are compared in table1.

Table 1- Comparison between Normal method and Radial method in making form milling tools

Tool Production Method	Normal Relief	Radial Relief
Picture		
Profile variation	After each regrinding critical dimensions change	After regrinding critical dimensions remained un-touched
Production	Require standard tool mak-ing grinding wheel	Require specially designed dressed grinding wheel

Making form milling tool to machine the fir-tree root of turbine disks

The project was outlined to design and make a specific tool from a Tungsten Carbide round bar at the beginning of 2012. Making best use of the previous experience, a plan comprising all stages of form milling of the grooves, from initial rough machining to final finishing, was developed. All calculations for tool geometry, outgoing chip recesses, cutting edge strength, feasibility of tool presetting to enable data entry into CNC machine tables, etc. were accomplished. The first 3-edge, helically form sample tool with a normal relief angle was designed and manufactured (fig. 5). Form deviation tolerance of the tool was verified to be better than 0.01mm on our presetting and measuring machine and it was introduced into the manufacturing line for final test.

Fig. 5- Draft design of the fir cutting tool and its manufacturing plan

Performance of the tool was verified after machining 3 grooves on a test block with the same material as original disks. The grooves were CMM-analyzed and their being inside the form tolerance band was proved.

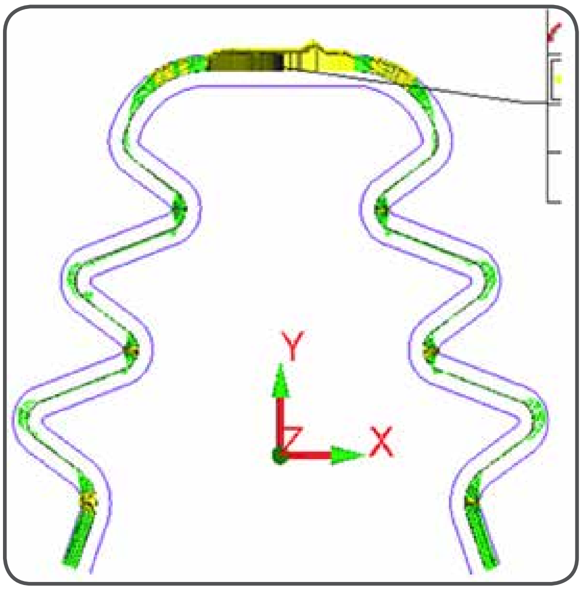


Fig. 6- Test Block cross section (the yellow color area has a wider tolerance, so the deviation is still allowable)

Part manufacturing through milling

After verification of the tool, the relevant quality control plan was drawn up for the disks machined by them and relevant machining constraints and fixtures were developed. To verify the whole process, a boring machine equipped with a rotating table was selected. After metrologically controlling the machine, the first disk was successfully machined under full supervision of the quality control dept.

Optimization

By successful manufacturing of the first disk, efforts were made to optimize the tool having the following goals in mind:

1- Reducing the tool manufacturing lead time
2- Reducing the work-piece manufacturing lead time

Given the natural advantages of radial form-tools, by making innovative use of control software modules of the tool making machine, alternative procedure was employed to accomplish the radial tool manufacturing.

To shorten the manufacturing time for the disks, specific tools to handle the rough machining were manufactured, 4-edge and 6-edge tools that increase the cutting speed by 50% were made and some research is being conducted on erosion-proof coatings to coat the main cutting edges of the tool in future. (fig. 7)

Fig. 7- Optimization trend of the tools to shorten the manufacturing time for the tool itself and the disks

Conclusion

Ability to manufacture fir-form milling tools is a reliable backup to fall back on, in both expanding own portfolio, and service providing for overhaul of gas turbine turbines of different manufacturers. Once there is a need to manufacture blades or disks during overhaul to replace the damaged parts, these tools can give MAPNA Turbine a huge competitive advantage in reducing the costs and downtime in service projects.

5. Helical Turbine Meters, Proven Engineering and Manufacturing Precision

Introduction

Due to their highly accurate and reliable flow measurement over a wide range of liquids, Helical Turbine Meters are considered strategic products in industry. Following technical and economical studies of the domestic market and along with the expansion of its portfolio, MAPNA Turbine (TUGA) undertook the development and manufacturing of HTM's.

MHTM-6 is the first in a series of helical turbine meters, with a linearity of ±0.15% and a repeatability of ±0.02% (Custody measurement).

Design

A design code was developed and subsequently modified, and validated by experimental results. Once the 3D geometry of all fixed and rotary components were specified and their materials were selected, detailed drawings were prepared for the manufacturing phase.

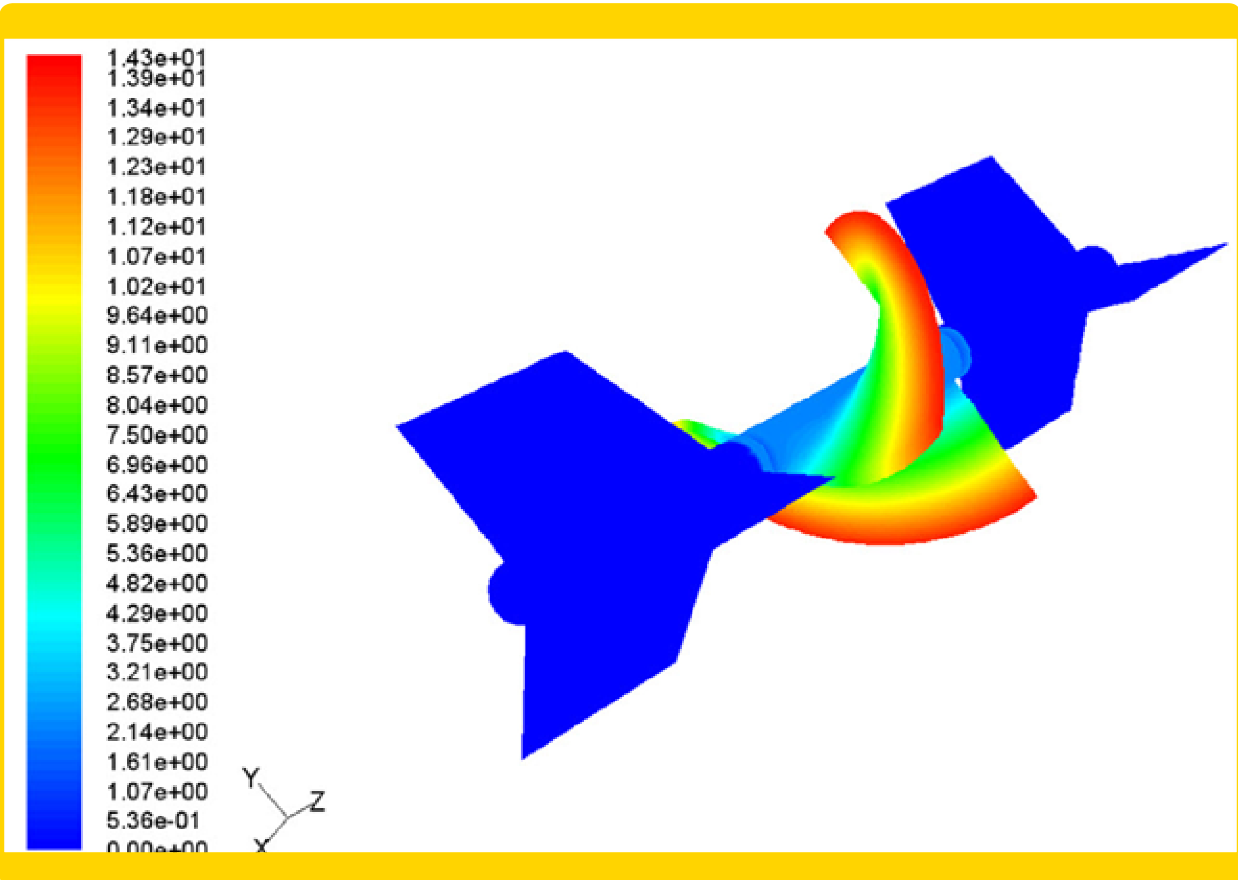


Fig. 1- Velocity contour on the surface of rotor and upstream/downstream of built-in flow straighteners

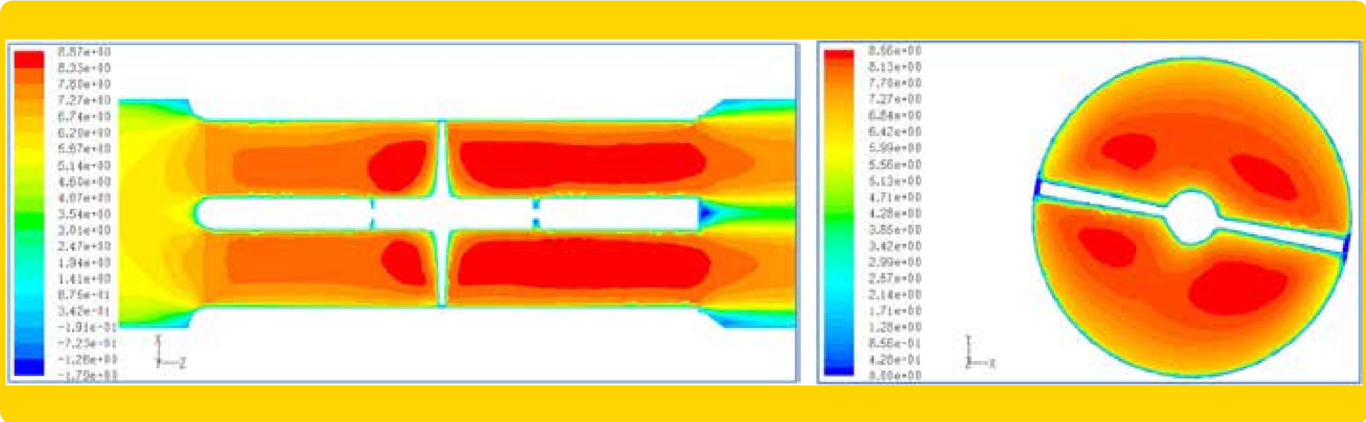


Fig. 2- Axial velocity contour inside turbine meter

Manufacturing

A prototype of this meter was made and then tested in a local calibration laboratory. The outcome showed that some modifications in the bearing tolerances, blade tip clearance and trailing edge angle of the blades were necessary. Modifications were introduced and the final product was fabricated.

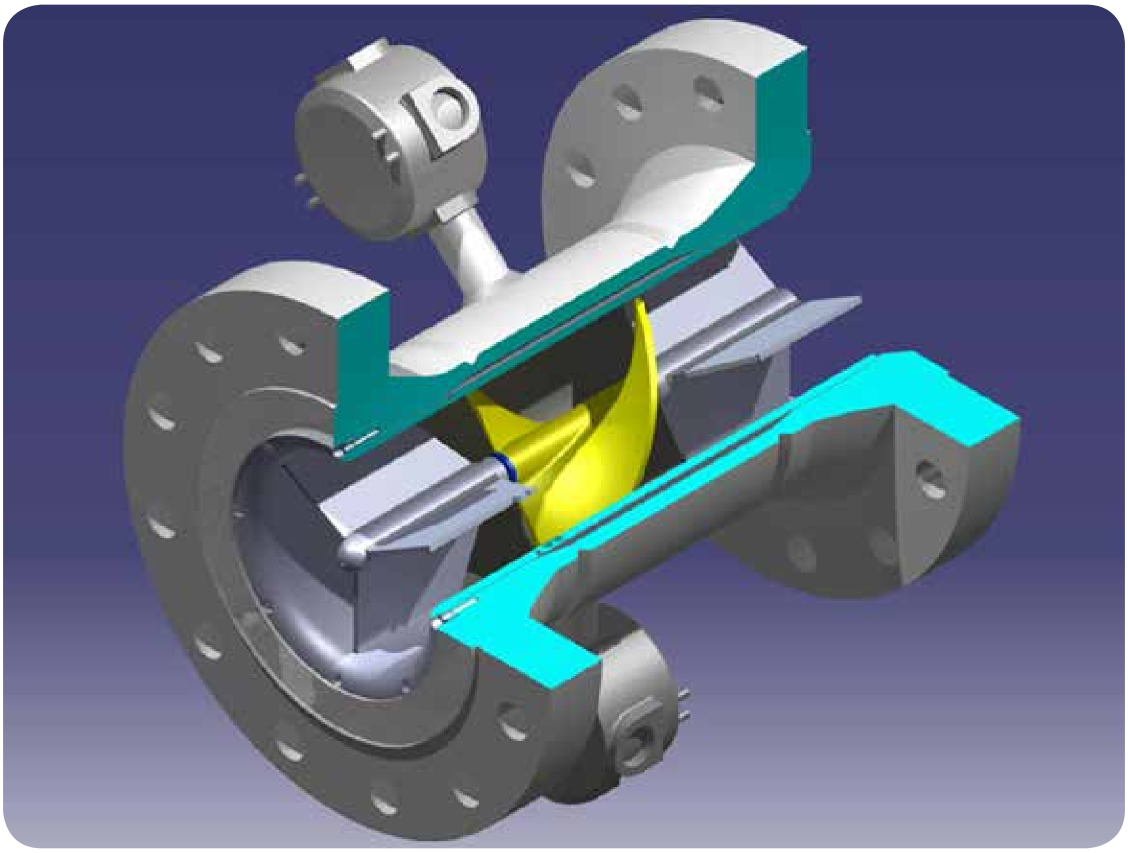


Fig. 3- Section view of the MHTM-6 in 3D model

Tests and Calibration

As the first calibration, water calibration was conducted in a calibration center in Netherlands. A complementary test was then carried out in France using three different hydrocarbon liquids. The table and diagram below illustrate the test results for the meter. Viscosity of each fluid is as per its mean value at operating conditions.

Table 1- results of the MHTM-6 calibration with different liquids

Fluid [Viscosity]	Points	Flow [m^3/h]	Repeatability [%]	Error [%]	Average MF	Max. Repeatability [%]	Linearity [%]
Water [1.01 cSt]	1-3	540	0.017	-0.23746	1.00238	0.017	± 0.342
	4-6	480	0.017	0.21046	0.9979		
	7-9	300	0.012	0.3425	0.99659		
	10-12	180	0.017	0.07256	0.99927		
	13-15	60	0.009	-0.3425	1.00344		
Gas-Oil [4.62 cSt]	1-3	600	0.01	0.181	0.99819	0.010	± 0.119
	4-6	500	0.005	0.166	0.99834		
	7-9	400	0.01	0.129	0.99871		
	10-12	300	0.004	0.098	0.99902		
	13-15	200	0.005	0.113	0.99887		
	16-18	70	0.01	0.02	0.99981		
	19-21	60	0.006	0.057	1.00057		
Light Crude Oil [12.18 cSt]	1-3	600	0.013	-0.011	1.00011	0.013	± 0.096
	4-6	500	0.011	0.027	0.99973		
	7-9	400	0	0.078	0.99922		
	10-12	300	0.005	0.1	0.999		
	13-15	200	0.006	0.047	0.99953		
	16-18	100	0.005	-0.091	1.00091		
Heavy Crude Oil [29.34 cSt]	1-3	600	0.009	-0.077	1.00077	0.010	± 0.153
	4-6	500	0.005	-0.061	1.00062		
	7-9	400	0.005	-0.069	1.00069		
	10-12	300	0.006	-0.112	1.00112		
	13-15	200	0.008	-0.216	1.00216		
	16-18	167	0.01	-0.368	1.00369		

Observations show that in comparison with water, the hydrocarbon tests have resulted in an even better repeatability and a far more satisfactory linearity in particular. This difference is deemed to be highly attributed to the lubricating nature of hydrocarbons which serves to diminish the friction torques of the bearings.

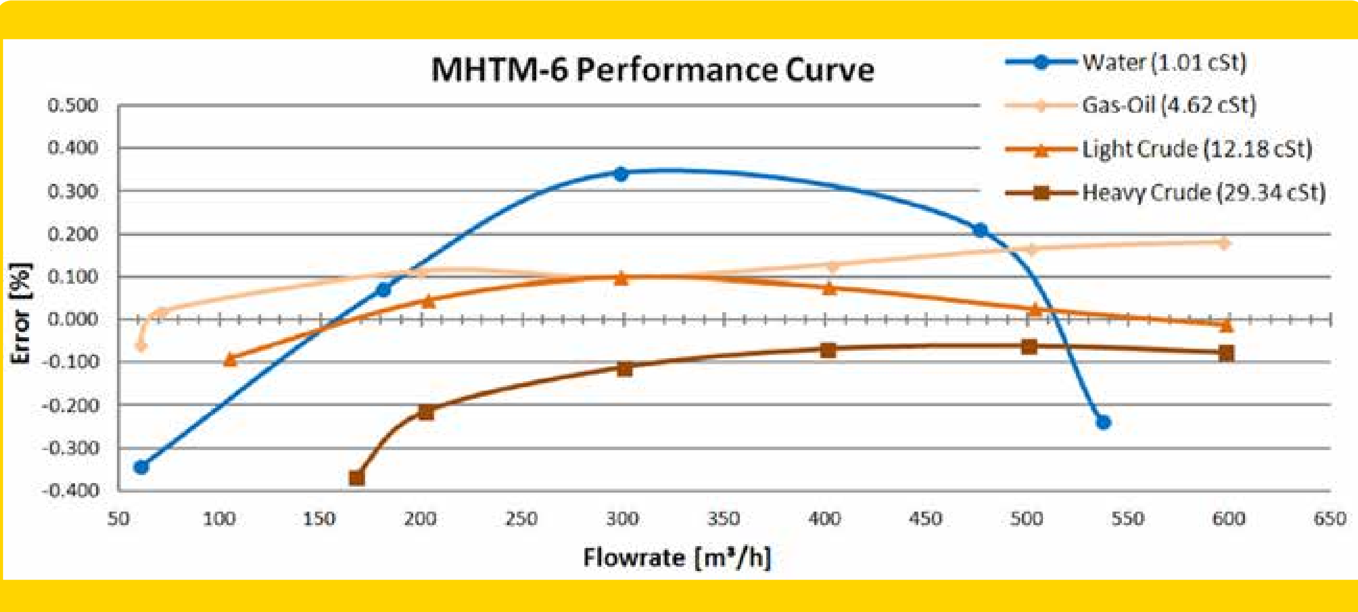


Fig. 4- performance curve of the MHTM-6 with different liquids and a unique k-factor

Conclusion

For the newly developed product MHTM-6, remarkable results have been achieved out of the tests in terms of repeatability and linearity, within the specified limits of ±0.02% and ±0.15% respectively. Since the calibration outcomes corroborated the precision of the design code, the next step is development of other meter sizes and conducting the specific durability tests.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