APPLICATION OF TRIZ METHODOLOGY TO GAS TURBINE DESIGN TO COST IN GE OIL&GAS

AUTHOR: ANGELA SERRA GAS TURBINE COST CONFIGURATION GE OIL & GAS – TURBOMACHINERY SOLUTIONS (TMS)

Abstract

The purpose of the project carried out was to find design to cost opportunities on Gas Turbines. The aim was to improve product efficiency, reliability and availability, while minimizing impact on product cost and simplifying production process. The paper reviews how the TRIZ methodology has been applied to specific case study (Low Pressure Turbine Rotor and Exhaust Diffuser), finding productivity opportunities, followed by a discussion of the DTC strategies that commonly used in GE Oil & Gas and pros/cons of using this tools for specific problem solving. The comparison will involve Should Cost, VaVe, 3P and, of course, TRIZ.

Introduction: Gas Turbine value

Historically in the oil & gas industry segment, the main values recognized by customers to gas turbine were product availability and reliability followed by efficiency. Until this segment structure was favorable and demand was high, the margin was big enough for oil companies and their suppliers. Oil companies were mainly focused on keeping historically "rich" standards that were driving high project cost. Lastly, the demand went down, oil lost more than 50% value (see Figure 1 Crude Oil Price (ref.: http://www.nasdaq.com/markets/crude-oil.aspx?timeframe=3y)) causing margin erosion for Oil Companies, this quickly translated in much higher sensitivity to product cost (see Michael Porter, "The competitive advantage", 2011, page 16).

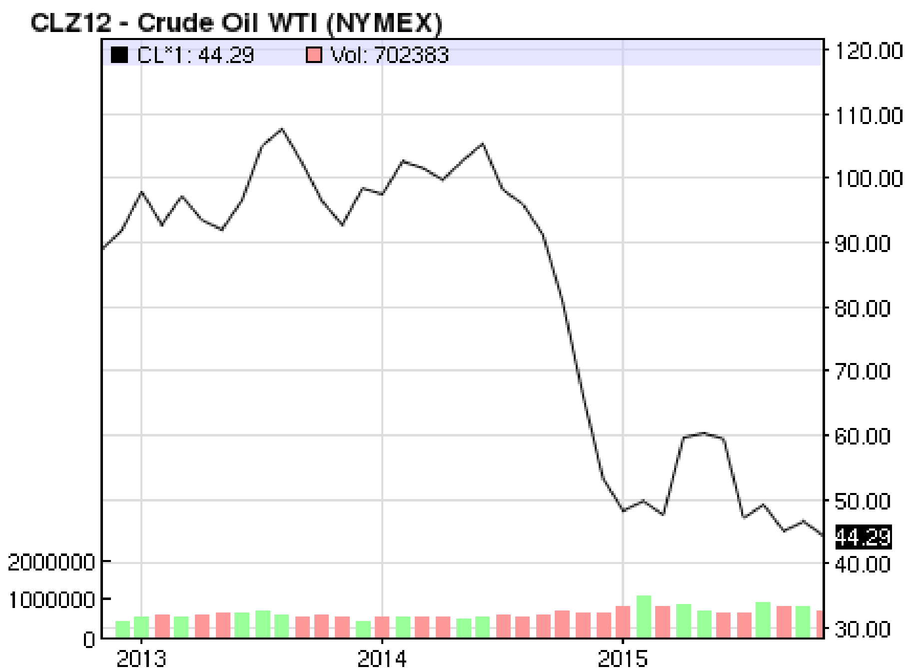

Figure 1 Crude Oil Price (ref.: http://www.nasdaq.com/markets/crude-oil.aspx?timeframe=3y)

Customers are increasingly asking also Gas Turbine producers to provide lower cost units without discounting on quality or performances, as it can be seen in the Figure 2 Capex and Opex Cost index (ref. IHS energy) are going down since beginning of 2015.

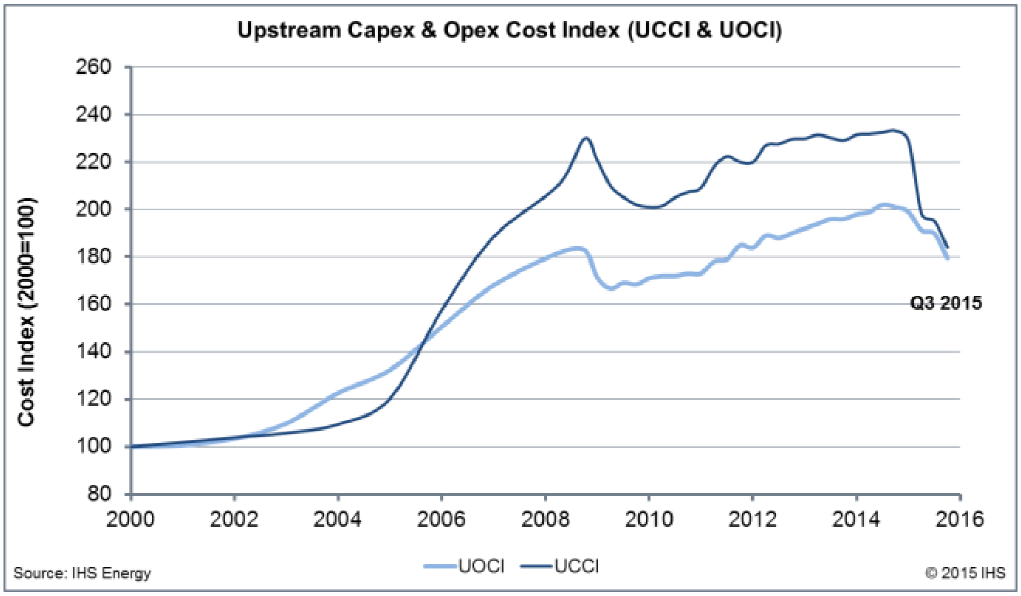

Figure 2 Capex and Opex Cost index (ref. IHS energy)

Traditionally Design To Cost has been a very important activity in GE Oil & Gas, it was commonly achieved using the 3P approach; this method was applied during product industrialization phase. Usually, when asked to reduce product cost, designers are focused on removing or simplifying design features in a gradual way, introducing lower cost materials and manufacturing processes that could assure same or better quality of previous design. This way of operating leads to an incremental productivity, but increasing engineering effort, a lower Return of Investment (ROI) is accomplished. In order to find new ways to reduce components cost it was carried out a pilot to apply TRIZ methodology to Gas Turbine components design to cost.

In this paper the author, after a short description of Design to Cost methodologies currently used in GE, is going to expose a practical application of TRIZ methodology, in order to stimulate the use of structured tools to achieve cost out results and to find a practical method to decide in which case it is worth to apply TRIZ or alternative methodology.

Design to Cost methodologies

Main design to cost tools used in GE Oil & Gas are Should Cost, 3P (Production, Preparation, Process), VaVe and TRIZ.

A method extensively applied is Should Cost (SC). This is a methodology used by the Designer to identify the cost drivers associated with the design features and to drive the design options selection towards minimum cost solutions. Should cost is based on the detailed analysis of the manufacturing process and the calculation of the duration and costs (labor and materials) associated to each single operation. Several SC tools are currently used in GE Oil&Gas TMS Engineering (home grown configurators, commercial and customized software, cost matrixes etc.) normally based on large and well validated databases of most typical manufacturing processes and materials. Optimum batch size and manufacturing location are also considered. Initially SC was introduced in O&G as an additional tool to support commercials negotiation with suppliers; generally it brought 10% minimum saving pushing the prices down towards the calculated entitlement; during the negotiation phase Should Cost is used to sustain technical discussion and cost alignment with the manufacturing company. Lately in Ge we started to use also Should Cost as a Design to Cost tool, we are also starting to introduce into the New Process Introduction (NPI) steps as a support to economic feasibility of new projects.

The 3P methodology has been widely applied to Gas Turbine industrialization; the project execution involves a huge team (up to thirty people) from all the functions: Engineering, Sourcing, Manufacturing, Product Leadership, and Logistic. They meet weekly, or two days per week for few months; main focus is to study in details production process in order to attack wastes (“MUDA” in Japanese) the “Kaizen” methodology is applied. A specific application of this methodology brought to ~ 20% costs saving respect to prototype cost, and 15% Lead Time reduction. This approach is really useful for those products not mature; especially when the Supply Chain is not optimized.

Alternative cost out tool is VaVe (Value Analysis Value Engineering); it applies to complex system and is based on the estimation of the value customers give to the different functions that the system is providing. Value is the ratio of function to cost; value can be improved by either enhancing the function or reducing the cost. The project team is composed by personnel from manufacturing, finance, quality, marketing, and engineering. The team need to be as small as possible to give possibility to take decisions on the project options, since one of the first steps of this method is to brainstorm on alternative ways the same function can be achieved, list all of them and then analyze to see if any of the proposal can be a lower cost or higher performance. Typical savings range from 15 to 35% for most projects.

Finally, TRIZ is a structured methodology for problem solving; it was born in Soviet Union in 1946, it is based on an analysis of thousands of patents; the TRIZ founder Genrich Altshuller was able to classify the number of contradictions an inventor shall solve in “39 General Contradictions” and the way those were solved through “40 inventive Principles”. The result of this job is a Matrix that suggests which principles shall be used to solve specific contradictions.

In the next section I am going to better describe how TRIZ works and two specific case studies on which the method was successfully applied.

TRIZ

The TRIZ methodology comprises four stages (see Figure 3 TRIZ Process Map)

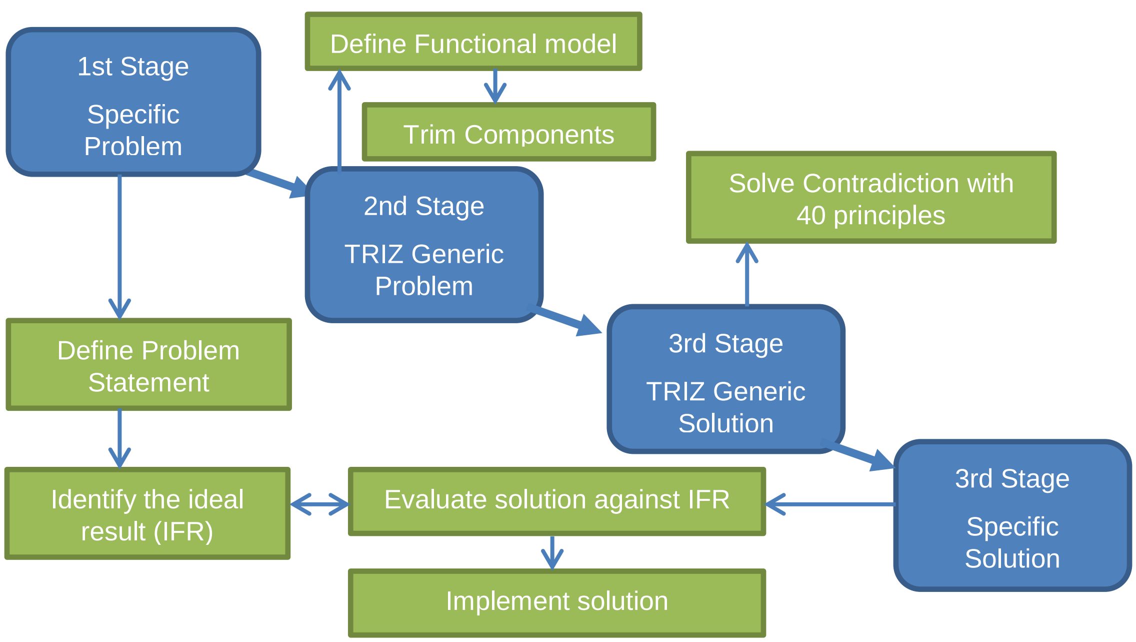

Figure 3 TRIZ Process Map

First stage is to clearly define the Problem Statement in order to highlight the real issue, then is needed to identify the Ideal Final Result (IFR) that solves the problem without harm and minimal changes to the system will be a criterion to define project success.

Second stage is to identify the TRIZ generic problem. It will be useful because not all the TRIZ tools are applicable to every kind of problem. Dedicated tools are available to support the Designers in building the component model. The tool will drive you through defining which functions are performed by the components, then to classify the functions defining if function itself is:

- harmful or helpful;
- basic, additional or auxiliaries;
- normal, insufficient or excessive;

The designers will also define how components interacts each other. Results are summarized in an interaction Matrix that will help identifying target component. In case of conflict, root cause analysis can be used to link the Target Disadvantage to its fundamental cause. The tool will also suggest which are the components you should think to trim since some other component can do the same function or the function that it is doing is harmful.

Third Stage is to apply the TRIZ tools to find a general solution to the problem. After the trimming of some component or function you can be in front of Engineering Contradictions (an action that results in an improvement of one parameter but in the worsening of another one) or Physical Contradictions (two opposite requirements the same parameter). The tool will propose you a systematic way to solve contradiction based on the identification of the 39 engineering parameters involved in the contradiction; the tool will propose one of 40 standard solutions called “inventive Principles”. Depending on the kind of problem you are facing there are different tools used in the TRIZ approach, this are those used in the specific cases we are going to discuss.

Fourth stage is the generic solution evaluation against the specific problem, it is needed to apply a practical solution to the specific problem, and then we will have the solution implementation.

Case Study 1 –Low Pressure Turbine Rotor

First pilot was applied on a Low Pressure Turbine Rotor of a Gas Turbine (see Figure 4 Gas Turbine components under evaluation); whole rotor assembly is complex and expensive, both in direct material cost and labor cost. In the past 3P was applied to the system, optimizing the lead time, manufacturing and mounting sequence, but still the Engineering team was asked to find additional saving opportunities.

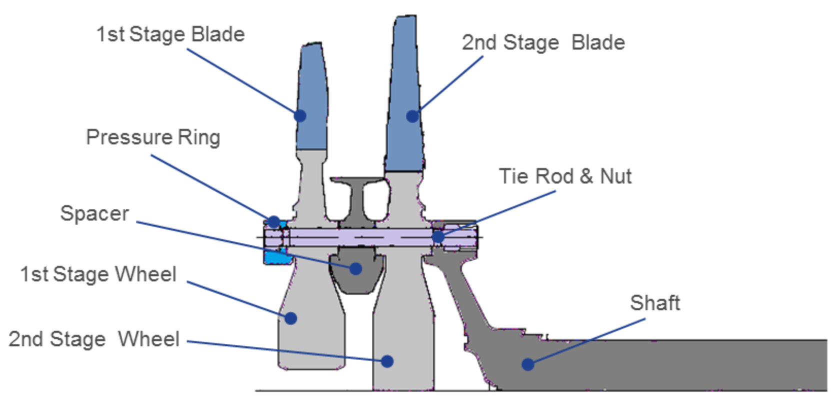

Figure 4 Gas Turbine components under evaluation

In the first step it was built the functional model, after reducing the System-Sub System components using the standard GE TRIZ tools; interaction Matrix and functional model where used in order to check the potential of trimming the functional model and harmful functions (Figure 5 Interaction Matrix).

Component Model | Interaction Matrix | Function Model | List Of Disadvantages

	Pressure ring	3dr stg disk	Tie rod	Nut	Personnel	4th stage disk	Shaft	Spacer	Lifting tool	Furnace	Cooling air
Pressure ring		+	+	+	+	-	-	-	+	-	+
3dr stg disk	+		+	-	+	-	-	+	+	+	+
Tie rod	+	+		+	+	+	+	-	-	-	+
Nut	+	-	+		+	-	+	-	-	-	+
Personnel	+	+	+	+		+	+	+	+	+	-
4th stage disk	-	-	+	-	+		+	+	+	+	+
Shaft	-	-	+	+	+	+		-	+	-	+
Spacer	-	+	-	-	+	+	-		+	-	+
Lifting tool	+	+	-	-	+	+	+	+		-	-
Furnace	-	+	-	-	+	+	-	-	-		-
Cooling air	+	+	+	+	-	+	+	+	-	-	

Figure 5 Interaction Matrix

The tool suggested trimming three components: pressure ring, spacer and furnace, but some engineering conflict needed solution. The team was put in front of the evidence that Pressure ring lost his initial function to distribute the tie rod pressure in the wheel, only remaining function was to center wheel on the table for assembly, this was an auxiliary function. The contradiction was coming from the risk to have Cost of Quality, generalized as “Manufacturing Precision” worsening, while improving overall cost, generalized as “Productivity” improving, The suggested Inventive Principles coming from this contradiction where: 18- Mechanical Vibration, 10- Preliminary Action, 32- Color Changes, 1- Segmentation. The team found a solution to take a preliminary action: the groove was moved to the Mounting Table and its manufacturing was simplified.

The team was not able to find a good alternative solution for trimming the spacer or the need to heat the components.

The team solved the conflict modifying the assembly table in a smart way. New assembly sequence was studied (see Figure 6 Assembly sequence of Low Pressure Rotor)

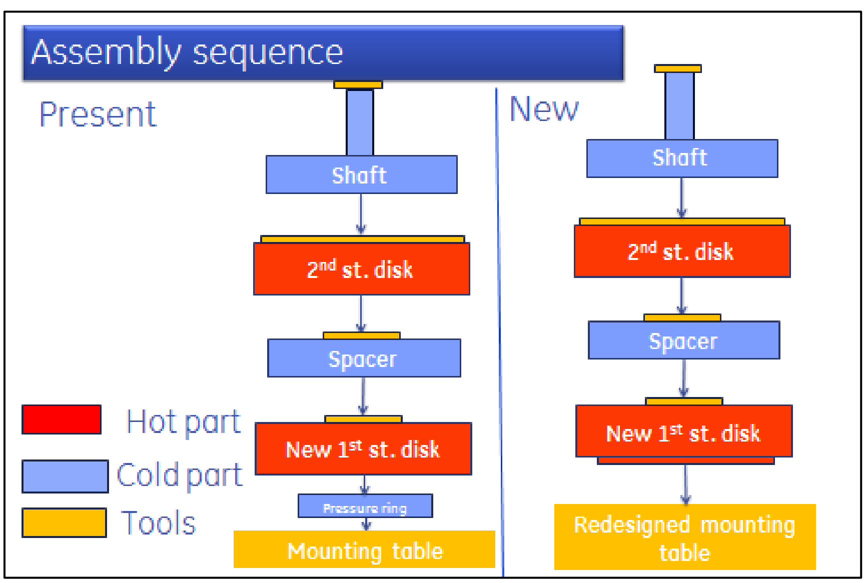

Figure 6 Assembly sequence of Low Pressure Rotor

In this case it was really useful to use the 40 principle matrix to solve the Conflicts; team was afraid about potential manufacturing quality losses due to this new design, being forced to think about the suggested inventing principle coming from the “40 principle matrix”, somehow, changed the Point of view, and a new solution was found.

Case Study 2 – Exhaust Diffuser

The Gas Turbine Exhaust diffuser is historically designed with turning vanes, this design assure a smooth rotation to the flow, contributing to overall Turbine efficiency (see Figure 7 Gas turbine external exhaust diffuser). Due to complex welding procedure and high temperature gradient during operation, a component was found with indications during inspection, there was no impact on product safety or performance, but it was needed a repair. In order to improve overall product performance and avoid future rework, the first corrective action established by Engineering Team was to increase residence time and temperature of Post Welding Heat Treatment (PWHT). This new temperature requested a different oven from the one available to the current supplier, so manufacturer needed to farm out the treatment increasing the final component cost around 10%.

Second pilot for TRIZ was applied to this component, to analyze the possibility to reshape the exhaust plenum, diffuser and optimize number of turning vanes to increase machine efficiency and bringing the cost back to the original one.

Gas turbine exhaust diffuser function is to turn the exhaust gas from axial to vertical direction; it is manufactured through a conic shape welded to a curved one ending with four turning vanes that assure a smooth transition of the flow. This component is very important since the overall gas turbine efficiency is directly linked to exhaust diffuser efficiency.

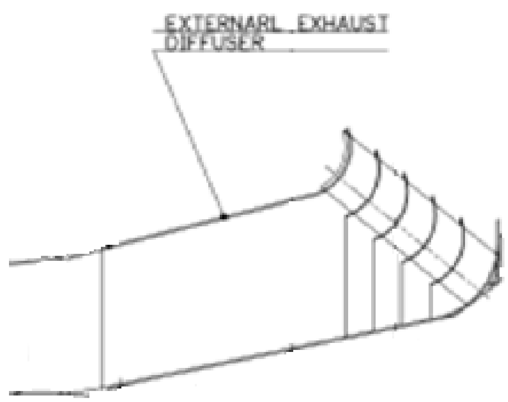

Figure 7 Gas turbine external exhaust diffuser

After standard GE TRIZ tools application, the primarily component suggested for trimming by the tool were struts and guide vanes

The contradiction was coming from the risk to have loss in performances due to the smaller exhaust area, generalized as “Area of a Stationary object” worsening, while improving diffuser footprint, generalized as “Length of a stationary object” improving, The suggested Inventive Principles coming from this contradiction where: 17- Another Dimension, 10- Preliminary Action, 7- Nesting Doll, 40- Composite Material. The team found a solution going to 17- Another Dimension and proposed a curved radial diffuser. This solution shall bring back the component cost to the original one also reducing reworks.

Conclusions

In the two Case Studies described, it was confirmed the benefit coming from TRIZ application. This structured approach has generated new ideas to solve engineering problems on systems already analyzed with different approach. It has been proven that TRIZ methodology is useful in case there are specific engineering contradictions, after schematization of the problem it is possible to trim components or processes and, using the 40 principle matrix, get ideas on how to solve the contradiction. It is a tool that gives the ability to think out of the box. In both the cases here analyzed another cost out methodology was already applied to the systems and there was still some improvement space.

A comparison between the tools is schematized in Table 1, to support in the decision about which tool can be used in different cases.

Tool	TRIZ	VaVe	3P	SC
Team	5-8	6-10	20-30	2
Effort	Medium	Medium	High	Low
Input	Problem to be solved	Details on system components design and cost	Details on system, components design and cost Manufacturing Process Plan	Detailed or reference design, Manufacturing Process Plan
Works for	System	System	Manufacturing Process	Component
Focus on	Problem to be solved	Value of Function	MUDA (Waste)	Ideal manufacturing process
Saving	Not focusing on saving	15-30%	20%	15%
When to use	Idea Generation	Idea Generation	Industrialization	Design decision / Supplier Negotiation

Table 1 Comparison between most popular tools used in GE Oil & Gas