GE OIL &GAS TURBOCOMPRESSOR TRAINS ON FIRST FLOATING LNG PLANT

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ABSTRACT

As new technology frontier in LNG production, the construction of the first Floating LNG Plant has started off the coast of West Australia. The FLNG vessel will be around 500 m long and will weigh 600,000 tons circa and will produce more than 3.5 Mtpa of LNG for more than 20 years.

For this LNG application, the customer has selected the steam turbine as driver for the large compressors, since in the project priority has been given to the reliability, safety and maintenance aspects.

GE Oil &Gas is providing the two larger trains, i.e. PMR and the MR turbo-compressor, on which a tailored design have been applied in order to fulfill the challenging requirements and limitations of the offshore application.

For the two 60 MW steam turbines, the design has been completely reviewed in order to comply with the strictly weight requirements. In addition, deeper analysis and investigations have been performed in order to satisfy the safety restrictions required for board installation. Finally, the effects of the movements of the vessel and related loads transmitted in different cyclones conditions have been simulated and the related rotor dynamics behavior verified.

This paper will present the turbo-compressor trains design challenges, optimizations and deeper analysis developed in order to guarantee all the peculiarities deriving from the floating LNG application.

1 INTRODUCTION

The most common arrangement studied for FLNG is the SINGLE COMPRESSOR TRAIN that means that any liquefaction service is done by one compressor and it’s driven by one single driver. This single compressor train can become a single liquefaction train in case of SMR or N2 refrigeration cycle.
Centrifugal compressors for barges are typically barrel type because of the easiness of installation and maintenance. The solution preferred is the direct drive removing the use of a gearbox that increases the weight and dimension and the consumption.

The compressor for FLNG must be developed in order to accomplish simple and light solution and efforts must be concentrated in:

- Bearing span minimized
- Casing weight reduction with dedicated design
- CC bundle cartridge type (crane limitation)
- Dedicated FEA on CC casings and on Baseplate to allow high nozzle loads
- Motion & acceleration study for Rotordynamics robustness even in extreme ambient condition
- Easiness of maintenance, robustness, compactness

Figure 3 – Large barrel bundle removal

FLNG compressor can also leverage the advantage on other OEM design features such as high head impellers. This kind of impeller has an high head coefficient that means high pressure ratio (up to 15% more) with the same external diameter. In this way the overall pressure ratio can be achieved by one impeller less with a lower external diameter reducing bearing span and the casing inner diameter. The solution is therefore more compact, shorter and lighter.

Another important feature for compressor for FLNG is the possibility to change field during the life of the barge. This means that the compressor may change its operating point according to different gas composition or different ambient temperature.

Figure 4 – FLNG operation at different gas fields
Figure 5 – IGV flexibility

The compressor must be therefore design for large operability range in such a way to not reduce performance by shifting to another gas fields. Inlet guide vanes can help in the operability of the compressor because they can help to keep a large operating range even with a fixed speed driver (see Figure 3). The solution in this case is a simple and cheap electric motor directly coupled with a compressor with IGVs at the suction.
The main CTQ to select rotating equipment for a large FLNG project are robustness, maintenance and compactness that should be accomplished all at the same time.

2 PRELUDE FLOATING LNG

Prelude Floating LNG is a project started in 2007 after the discovery by Shell of a large field off the northern Australian coast. Due to the distance from the coast Shell decided to go for a Floating solution that may duplicate for other following project. The Prelude barge will be designed by Technip and built by Samsun Heavy Industries in Korea and will be impressive: 488m long, 74m wide, 600000 t weight.

The barge will mainly produce 3.6 MTPY LNG plus other minor gas production.

The main refrigerant service will be accomplished by the Shell liquefaction process and will be done by high speed/high power steam turbine rated 60MW@5000rpm for both refrigerant loops PMR and MR.

2.1 PMR and MR Compressors

Large Centrifugal compressors in the onshore LNG facilities are typically horizontally split while for FLNG the best choice is the barrel one. The main reason is the maintenance: the bundle can slide from the casing and disassembled and inspected. On the contrary, in case of an horizontally split casing, additional vertical space is needed for compressor opening increasing the overall height of the barge with impact on the piping loop and on allowable force and moments.

The main compressors features are the following:

- Inlet Flange 40” PMR - 56” MR
- Speed 5000 rpm (for both)
- Power 60MW PMR – 58MW MR
- Largest Impeller 1165mm PMR – 1185MR
- Largest Flow coefficient 0.1290
- Highest Machine Mach Number 1.1

Both compressors have been designed for a smooth rotordynamic behavior showing a log dec greater than 0.2.

For the Prelude project additional efforts have been put on the design of the layout to reduce overall weight, compacting as much as possible the aerodynamic path inside a lower possible inner casing diameter. This has been accomplished by introducing solution developed for other project (such as power density) to the FLNG. The MR compressor has been studied to withstand the overall service in one casing in a back-to-back arrangement while typically this service is handled by at least two compressors. This has shortened further the train. The result is a compressor weight reduced by 20% than standard type for both services.
The casing has been also analyzed together with its baseplate with extensive use of Finite Elements tools. The baseplate is a three points type supported with rigid deck. The arrangement was analyze under multiple point of views including:

- Gravity
- Nozzles loads
- Vacuum load
- Operating torque

Figure 6 – Stability analysis for MR and PMR

Figure 7 – PMR train arrangement

Figure 8 – Baseplate FEM results
The results of the optimization were excellent:

- Vibration velocity within the limit
- Deck stiffness acts as absorption system due to the high mass and a relatively low deck stiffness
- Static deflection fully recoverable with the initial alignment procedure.
- Shaft misalignment within coupling capability
- Vacuum and nozzles as a secondary contribution to the overall displacement
- Stress level within the allowable values for material

Each compressor was then analyzed with highest nozzle loads that are foreseen by Shell that correspond to category 5 cyclone. These loads correspond to a NEMA factor much higher than the typical one that, in combination with the lightest casing, can impact the robustness of the project.

Extensive analyses were therefore carried out to check the compressor under multiple points of view. In particular

- the Von Mises stress was checked versus the allowable one to check the structural robustness (Figure 9)
- A Casing/Leg contact analysis performed to verify that no lifting of the casing from the support was happening (Figure 8)
— Checks were carried out at flange connection to avoid large misalignment between piping and compressor and gas leakage

— Checks were carried out at compressor head flange. The compressor is equipped with O-rings to grant perfect sealing between the head flange and the casing. When such high loads happen the casing can deform creating unrecoverable gap by the O-ring. Check on the relative displacement between casing and head flange must be carried out and found within o-ring capability without extrusion [Figure 10]

— Last but not least, a check was performed at the center of the dry gas seal location to verify that the shaft misalignment was within coupling capability.

![DGS housing](image)

**Figure 12 – Alignment check**

**Compressor test**

The PMR compressor has already overcome the MRT showing a smooth behavior

![PMR compressor MRT](image)

**Figure 13 – PMR compressor MRT**

### 2.2 PMR and MR Steam Turbine

The choice of steam for driving compressors was selected because it offers:

— Good reference in the marine environment
— simple operations and maintenance;
— use of low pressure fuel gas, which reduce the need for large end flash gas.
— large capability for different fuel gas composition
— avoids variable speed electric motor drivers or the use of fired machinery on a barge
The steam turbines for PMR and MR Compressors have a common design applied for both trains and are rated 60 MW each. These drivers have been submitted to stringent design reviews to comply with the Technip and Shell specifications as regards the weight, rotor dynamics and safety features required for on board installation.

The increased rotating speed of the whole train from the 3600rpm to 5000rpm has allowed a reduction in size and weights the steam turbines by 40%. Due to the new speed the enthalpy drop on each stages increased reducing the number of stages without impacting performances since the work coefficient remained the same.

The higher speed permitted to select a smaller size of low pressure blades and hence also a smaller size the exhaust casing. The reduced bearing span due to the increased speed has permitted a huge jump casing weight, and it has been further increased by the use of only one inlet flange leveraging a larger size available and proven in the standard.

The exhaust casing which is normally casted has been designed with fabricated steel to further reduce the weight, without affecting containment capability of loose objects. In fact reaction drum design guarantees a double shell protection since the statoric blades are installed in inner casings. The combination of the thickness of inner and external casing allows respecting design practice requirement of more than double in case of detachment of a last stage blade.
A test vehicle performed in 2004 demonstrated that low pressure stages are able to sustain severe condition like loss of vacuum or very low pressure. During the test vehicle instrumented low pressure blades were exposed to real operating condition and steam in order to evaluate both the performances and the static and dynamic stresses for different pressure level.

The robustness is one of the most important CTQ of machines installed in the FLNG vessel. For this reason steam turbine components have been designed to sustain hurricane pitch & roll movements for both statoric parts, like casing and flanges, and rotating elements, like shaft and blades.

This OEM has evaluated the bearings stiffness and damping characteristics considering the influence of wave motion acceleration on support loads resultant: in this way it has been possible to calculate lateral behavior of the shaft in cyclonic condition and to determine how resonances and amplification factors are affected by dynamic loads.

Rotor dynamic calculations have demonstrated that vibrations induced by detachment of a low pressure blade will remain within the limits imposed by the rotor-stator clearances, due to the massive and stiffness rotor design associated with reaction steam turbine.

Also for the thrust bearing limit loading has been evaluated taking into consideration dynamic load associated to the wave motion on the axis of the machine, since the effect of acceleration can be up to 20% of the steam turbine thrust at the guaranteed condition.

![Diagram of wave motion acceleration on bearing loads resultant](image)

*Figure 16 – Influence of wave motion acceleration on bearing loads resultant*

The steam admission chest, usually vertically oriented, has been position horizontally due to the piping layout selected by Technip for barge space restrictions, continuing to guarantee proven reliability since all components were referenced by previous application.

Steam turbines will perform MRT in order to verify mechanical behavior after the assembly and then coupled with the compressor will be tested with steam at partial load. The compressors will perform also full load test at 60MW driven by a variable speed electric motor.
2.3 Turboexpanders

Floating LNG plant gas processing is equipped with a Turboexpanders model EC0401 rated for 5.5 MW at 11000 rpm, the unit is equipped with 200mm S2M SKF magnetic bearings.

The unit size is a well referenced frame among this OEM Turboexpanders; however considering the peculiarity of the application some design changes have been introduced mainly to improve the robustness of the unit.

The complete unit was designed using weld-less forgings milled from solid to provide higher strength and minimize defects.

Wheel material is open die disk forged aluminum 7050 from with a specific heat treatment to maximize its toughness. The use of HIRTH serration on shaft – wheel attachment contributes to minimize the stress level in the impeller.

Figure 17 – Last Stage Blade Failure unbalance analysis of vibration vs clearances

Figure 18 – Horizontal steam admission chest
Special attention was made to the flanged connection between the expander casing and the bearing housing. Typically this flange is the limiting point for nozzle allowable loads of the unit as it need to be quite tiny to minimize heat transfer between the cold expander casing and the warm bearing housing.

In FLNG Turboexpander, this OEM has introduced, outside the pressure containing part, a very stiff mating ring in NEMA G10 that allows to withstand severe nozzle loads imposed by this application as well as to avoid heat transfer.

The Turboexpander was calculated with state of the art numerical tools both to verify it’s mechanical design (FEM analysis) as well as to verify the performances (CFD).

The unit package was designed with the aim to provide excellent access for maintenance moreover some critical components like AMB wiring was improved by using redundant systems. The sealing of AMB cables from the pressurized casing is very important as any possible gas leak might migrate along the cables up to “not classified area”. Some OEM has introduced a double sealed AMB connector with intermediate bleed, extremely reliable thanks to its arrangement and the use of a mix of glass to metal and epoxy sealing.

The whole package is supported by “anti-vibration mount” (AVM) mainly to isolate the Turboexpander casing from any possible vibration from deck structure. The Turboexpander, in particular with active magnetic bearings, does not produce significant vibration signature however the bearing control system might react in case the bearing stator is subjected to an external stimulus. Considering the relatively light structure of the FLNG vessel deck and the presence of vibration sources (i.e. rotating machines), the AVM does filter high frequency vibrations that might impact AMB controller.
CONCLUSION

The paper has described the rotating equipment designed for the first large FLNG. Overall Turboexpander, Compressor and Steam Turbine have been designed with the aim to use very proven technology with some special feature specifically introduced for FLNG use.

BIBLIOGRAPHY