COMPRESSOR REBUNDLE TO INCREASE LNG PRODUCTION

Antonio Pelagotti
Baker Hughes, a GE company

The economic crisis has impacted the development of new LNG plants in the recent years. A good opportunity to increase actual LNG production is to rebundle existing compressors. Some successful study has already been applied on some LNG plant in Middle East, Australia, West Africa where the machinery has been upgraded with limited impact on the plant layout.

The rebundle projects starts with actual data analysis followed by an engineering study on various opportunities that ends with the recommendation on best solution.

The compressor re bundle and upgrades can involve impeller selection for higher efficiency or operating range or include also casing for a large flow increase or higher pressure desired.

The paper will discuss various opportunities including case studies of compressor rebundle.
1 INTRODUCTION

Compressor rebundle can be required by Original Equipment Manufacturer (OEM) or by End User after looking to the difference between actual compressor operation and the expected one. Plants are designed considering multiple margin on process or equipment and this can sometime lead to an off-design operation. OEM can leverage Remote Fleet Data, Customer data, assess the off-design operating condition and start a conceptual study of possible upgrades.

Typical Compressor off-design operations are
- New process requirements… different Pressure, Gas composition, Flow, Temperatures.
- More power available from the driver
- Modifications to other equipment
- Design margins

Compressor upgrade is typically done by changing the internal (impeller and diaphragm) increasing the performances and usually the efficiency, flow and/or head.

New aerodynamics state-of-art can increase efficiency up to 10% reducing power absorption and save energy. This additional power can be used to increase head and flow maximizing the production keeping the same driver.

New internals can be designed to allow up to 50% more flow depending from compressor size.

Figure 1 - Actual conditions may cause low efficiency or operability... Compressor re-bundle helps optimize plant operation....
Compressor upgrades typically involve just the internal, in order to re-use the casing, without changing the external process piping loop or foundation, but sometimes the upgrade can also replace the complete unit or sometimes the complete train. The choice is made by looking at real operating conditions respect to the original curve. If the new point falls well beyond the actual performance curves the modification suggested is the compressor replacement.

An example of debottleneck analysis is the compressor operated close to choke condition.

Although the operating envelope is very large the compressor is operated at its maximum flow. What is typical in this region typically is a drop in efficiency as it is close to the end of curve.
The operating range can be recalibrated with a new stages selection recentering the average operating point at efficiency peak.

With the new operating envelope the compressor will use more mass flow and will absorb more power from the gas turbine that should also be upgraded.

Compressor rebundle may involve:

- New state of art impeller design…increase efficiency, enlarge operating range, reduce external diameter
- Diffusers … vaned or high diffuser ratio vaneless … increase efficiency
- Volute …. From constant to variable , including guided vanes… increase performances
- Side Streams … From constant to variable … increase performances
- Seals…clearance reduction…increase efficiency
- Gas Turbine Upgrade….more power

In case of compressor or train replacement a new casing can be provided to reduce external diameter, reduce bearing span and/or increase design pressure.

2 Case Studies
2.1 AUSTRALIA LNG

The Australia LNG project was expected to become one of the fastest developed LNG projects. In order to achieve such target the design is based on the previous train 4 and 5. The degree of “carbon-copy” was maximized to capture scheduled and cost advantages.

The liquefaction unit uses the Propane pre-cooled/mixed refrigerant (C3/MR) technology with the following train arrangement

GE Frame 7 + LPMR + MP/HPMR + Helper Motor
GE Frame 7+ PR + Helper Motor

Preferences was given to modification that improved performance but needed minimum or no changes to layout or existing equipment dimensions

The train layout was unchanged and the LPMR compressor was replaced with a larger capacity one and the PR compressor was designed brand new minimizing nozzle changes to keep piping layout.

The PR impellers were designed to minimize risk of lack of performances during the final test but chosen among the latest developed impeller family to achieve state-of-art performances.

First impeller was characterized by high impeller inlet relative mach number and a dedicated model test was foreseen to avoid any further surprise during full scale test.

Second, third and fourth impeller were chosen from another LNG project and scaled to fit new casing. The fifth is the lower critical.

The risk of lack of performance during the string test was minimized by taking the approach of scaling from previously proven impellers and verifying the new one with model test. Four out of five impeller were already proven one year before acceptance test.

Final PR compressor features are:

- Long bearing span 5100mm
- Bearing Span / Shaft Diameter > 10.4
- High Logarithmic Decrement > 0.3
The trains are equipped with a low pressure axial MR compressor of AN200 type. For the high flow rates requested for the Australia design, the an200 machine would require to operate at the limit of its capability. It was decided to select for the Australia train the AN 250 type axial compressor which has a wider operating range. AN additional advantage is that at the operating points the AN250 efficiency is 56% higher than an200.
This gain in available power margin and the additional margin in the safe operating envelope have increased the flexibility in the MR train operation.
The MPHP MR unit was unchanged.
All the three compressors were installed without impacting piping loop or plant foundation.
Australia LNG is in successful operation since many years.

2.2 Southeast Asia LNG
A plant in Southeast Asia is configured with as MS6001B that drives a Propane compressor with a steam turbine as helper and a Mixed Refrigerant train with an MS7001EA as driver.
Customer asked for higher mass flow through the Propane compressor to increase LNG production without changing the compressor casing
The Flow increase was about 20% in mass that led to a fast velocity at the flanges higher than 40 m/s and a Impeller peripheral Mach greater than 1.25

![Figure 6 – C3 train configuration](image)

Because of higher mass flow, the Gas turbine should deliver 4% more power and the steam turbine upgraded of about 50% in power. The end user decided to rebundle to compressor to meet new operating condition
The main features of the installed compressor were:
- Old plenum aerodynamics…loss coefficient =2
- Old High Mach impellers geometry … reduced efficiency less than 0.8
- Tangential side streams
- Low diffusion ratios 1.4
- Constant section discharge volute loss coefficient =1.5

The new design has upgraded all the feature above (newly developed impeller, variable section volute, higher diffuser ratio, radial side streams) increasing efficiency of about 4% with a final LNG production increased about 7%. The compressor was upgraded without new product but just using existing technology developed for more recent project.
2.3 C3MR LNG project upgrade

One of the most common processes used for LNG production is the C3 MR. There are at least seven trains with such configuration. The evolution of the train started from Australia with MS5002 as driver, then the MS7001 EA and the MS6001B were introduced. This LNG liquefaction configuration is done by two trains: one with LPMR and MP/HP MR and the other with C3 in single casing.

![Figure 8 - C3 operating condition and possible rebundle](image-url)
2.3.1 Propane Compressor
Looking to actual process data since 2007 it was noted that the compressor installed was mostly operated between design and max flow, in a region were efficiency was not optimized. The average calculated efficiency was 75%.

The C3 compressor can be upgraded with state-of-art components increasing overall efficiency such as new impeller. New diaphragm, suction and discharge volute.

![Flow coefficient variation and new rotor picture](image1)

*Figure 9 – Flow coefficient variation and new rotor picture*

© 2019 Baker Hughes, a GE company, LLC – All rights reserved.

The C3 could be upgraded by changing the internals and introducing more “modern” impeller (mixed flow).

OEM had developed an high flow coefficient impeller family to increase efficiency and operating range at high flow high Mach number. In Figure 9 it’s shown the effect of the introduction of this family on flow coefficient:

- Lower impeller diameter

![OLD vs NEW PR COMPRESSOR](image2)

*Figure 10 - OLD vs NEW PR COMPRESSOR*

© 2019 Baker Hughes, a GE company, LLC – All rights reserved.
Revamping the existing compressor using the referenced bundle design, allows an expected power saving of 6.4MW (about 9.3%) vs original design.

2.3.2 MP/HP Mixed refrigerant

Some trains in different countries are equipped with a compressor that takes care of MP/HP MR duties in a back to back configuration. Typically, this compressor is on the same shaft line of the LPMR.

Historical data have been analyzed finding room for bundle optimization; the compressor is operated at high flow for most part of the hours in a portion were efficiency is lower than operating at middle of the curve.

OEM has therefore re-design the bundle trying to keep same casing, introducing state-of-art impeller and increasing efficiency by a new operating range more centered.

The modification is impacting only the colored parts in figure 11 leaving unchanged head flanges (and also bearing and dry gas seal) and casing (and flange’s position without need of piping realignment).

The new bundle is guaranteeing same flow with a better efficiency with an average power saving of about 4% for one year.

2.3.3 Axial Compressor for Low Pressure Mixed Refrigerant.

Also the axial type LPMR compressor can be upgraded.
Axial compressors are much more complex than centrifugal due to aeromechanics interaction between statoric and rotoric blades. Axial compressor cannot be designed on custom needs but can only be scaled geometrically up and down.

One way to slightly increase the flow of an axial compressor is to install and additional stage upstream without changing the downstream ones.

The new stage must be deeply tested to assess correctly the mechanical behavior and blade frequencies with wheel box test and ping test as a minimum.

The compressor volume flow can increase by 10-15% with minimum impact on the mechanical behavior and new rotor can also be fitted inside the existing casing.

The main advantage of a new row upstream are:

- +16% design flow (AN200 vs AN200+)
- +12% max flow (from 240k to 270k m3/h .. safety limits)
- IGV more closed on average for same operation … more conservative operation … beneficial for VSV life
- Higher efficiency for same operation (+3 efficiency points)

3 C3MR rebundle simulation

We can now apply all the above-mentioned modification to simulate possible advantages for power saving.
### Table 1 – C3MR power saving with compressor upgrades

<table>
<thead>
<tr>
<th>MR TRAIN</th>
<th>ORIGINAL DataSheet</th>
<th>NEW DataSheet</th>
<th>PR</th>
<th>ORIGINAL DataSheet</th>
<th>NEW DataSheet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POWER [kW]</td>
<td>POWER [kW]</td>
<td></td>
<td>POWER [kW]</td>
<td>POWER [kW]</td>
</tr>
<tr>
<td>ORIGINAL</td>
<td>45,57</td>
<td>48,525</td>
<td></td>
<td>35,28</td>
<td>37,648</td>
</tr>
<tr>
<td>UPGRADED</td>
<td>44,864</td>
<td>47,339</td>
<td></td>
<td>33,642</td>
<td>35,644</td>
</tr>
<tr>
<td>EXPECTED SAVING</td>
<td>-1.5%</td>
<td>-2.4%</td>
<td></td>
<td>EXPECTED SAVING</td>
<td>-4.6%</td>
</tr>
</tbody>
</table>
| EXPECTED SAVING | -2.9%          | -3.7%        |    | -9.4%              | N.A.          

#### 4 Seals

Most of the compressors installed worldwide are using statoric seals at impeller in aluminum. The clearance between stator and rotor is designed to avoid contact allowing a certain leakage coming back from the impeller discharge. A contact will deform the seal permanently increasing the gap and reducing the compressor efficiency.

New thermoplastic seals allow the contact between stator and rotor without deformation. The clearance can be reduced to increase the stage and the overall compressor efficiency from 0.5 to 2 points depending from flow coefficient.

Geometry is the same, so the thermoplastic seals can easily replace existing aluminum seals during compressor maintenance.

![Thermoplastic seals](https://example.com/thermoplastic_seals.jpg)

**Figure 14 – Thermoplastic seals**

© 2019 Baker Hughes, a GE company, LLC – All rights reserved.

Standard material can reach 150°C maintaining mechanical properties, while to reach higher temperature (>180°C) more expensive material must be selected.

#### 5 Digital Outages

The Oil and Gas industry is entering in a new digital era. New technologies, tools and faster communication technologies are now mature to be used during site operation.

These new technologies are including 3D scanning, Virtual Reality or Digital Tools.
3D scan can be used to record the 3D layout of a plant to assess the position of the equipment and optimize the sequences of activities during maintenance such as installation of lighter crane, EV circulation, parts handling. The 3D scan can be also utilized to study new way of process piping removal and handling avoiding more intrusive operation such as enclosure removal or gas turbine inlet handling.

Virtual Reality is more useful to help Field Engineer (FE) to prepare themselves to perform the outage minimizing dangerous operation or unnecessary activities at site learning by simulation in a real environment. Next to the virtual reality there are the video field procedure (VFP). Paper manuals are being more and more dismissed to introduce electronic copies. In addition, short movies are created to show assembly and disassembly procedure to help FE to work in a safer and productive way.

Field Engineer can also be equipped with state-of-art tools such as smart helmet or Bluetooth gage. For the first, the field engineer is equipped with a portable Cam that can film what's happening on the deck and transmit to a dedicated technical office where another engineer can suggest actions from remote to optimize the time of the outage.

The Bluetooth gage is a modern tool capable of measuring optically the clearances and record them digitally without the need of mechanical tools.

All the above technologies can improve the outage activities reducing time and cost, improving health, safety and quality results.

5 Conclusion
Compressor OEM are continuously evolving the equipment design; the evolution is in all areas such as aerodynamics, mechanics and rotordynamics and is implemented during the design of new plant.
End users can access to these technologies to upgrade their equipment producing more LNG with same plant. Compressor rebundle is including outages operation; new technologies can help end user to optimize the outages reducing the time to do it, increasing LNG production.

References


17. Pelagotti A., Mariotti G., Cortese C. GE Oil and Gas Turbo-Compressor Trains on First Floating LNG Plant LNG17 2013 Houston, U.S.A