Fifteen Years of Field Experience in LNG Expander Technology

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The modern natural gas liquefaction process is based upon the Linde-Hampson Cycle, independently patented in 1895 by C. von Linde and W. Hampson.
In three steps, the process compresses, cools, expands the gas to a lower temperature. This triple step process is repeated until the gas condenses.
Linde-Hampson Air Liquefaction Cycle from 1895
Originally Compression was achieved by a piston compressor Cooling by a heat exchanger Expansion by a Joule-Thomson Valve
First improvements in operation and efficiency:

**Rotary Gas Compressors**

and

**Rotary Gas Expanders**

replaced piston compressors and gas expansion valves
Subsequent improvements in operation and efficiency:
Since 1994
Liquefied Gas Expanders replace Joule-Thomson Liquid Expansion Valves
Henri Paradowski proposed in December 1979 the use of “a cryogenic hydraulic turbine” to improve the efficiency of the liquefaction process. US Patent 4,334,902
It took 15 years from the idea in 1979 to the first installation of a cryogenic hydraulic turbine in 1994 at an LNG Liquefaction Plant in Kansas/USA. It took another 4 years to install the second one 1998 in Malaysia.
Early design of an LNG expander with air cooled induction generator, shaft seal and coupling installed in Malaysia 1998.
Early design of an MR Propane Mixed Refrigerant expander and an LNG expander installed side by side 1999 in Nigeria
Improved Design

The cryogenic expander operates on variable speed, and is entirely submerged in LNG with no dynamic rotating shaft seals, no coupling between expander and generator, and no thrust bearing, due to a field proven thrust balancing device.
Improved Design with variable speed submerged generator
Performance Characteristic of Variable Speed Expanders
First variable speed LNG expander at the LNG test stand in Sparks, Nevada, before shipping to an LNG liquefaction plant in Oman in 1999
Typical Installation Schematic for an LNG Expander
Variable speed LNG expander installed in 2002 in Malaysia
Complete Assembly of an LNG Expander with Downward Flow Design
Complete Assembly of an LNG Expander with Upward Flow Design
Conventional Single-Phase versus Two-Phase LNG Expander
Euler Turbine Equation Applied for Two-Phase Expanders

The Euler Turbine Equation states that the generated torque $T$ of rotating turbine runners is equal to the difference of the angular momentum $L_1$ at the inlet and $L_2$ at the outlet.

$$T = L_1 - L_2$$
The angular momentum $L$ is the product of mass flow $\dot{m}$ per time, the tangential velocity $c$ of the fluid and the radial distance $r$ to the center of rotation.

$L = \dot{m} c r$
There are three typical cases for the generated torque $T$:

**Case A:** The outlet and inlet momentum $L_2$ and $L_1$ are both positive

**Case B:** The outlet momentum is equal to zero

**Case C:** The outlet momentum $L_2$ is negative and the inlet momentum $L_1$ is positive
\[ T_A = \dot{m}(c_1 r_1 - c_2 r_2) \]

\[ T_B = \dot{m}(c_1 r_1) \]

\[ T_C = \dot{m}(c_1 r_1 + c_2 r_2) \]
The torque in case C is always larger than the torque in the cases B and A

\[ T_C > T_B > T_A \]

The hydraulic efficiency \( \eta \) in case B is always larger than the hydraulic efficiency in the cases A and C

\[ \eta_B > [\eta_A; \eta_C] \]

\[ \eta = \frac{\text{Hydraulic Power Out}}{\text{Hydraulic Power In}} \]
The hydraulic efficiency $\eta$ in case B is at the maximum value, because there is no remaining angular momentum at the outlet and the rotational kinetic energy of the fluid at the outlet is zero.

The generated torque in case C is larger than in case A or case B due to the negative angular momentum at the outlet.

The hydraulic efficiency in case C is smaller than in case B due to the remaining angular momentum at the outlet and the remaining rotational kinetic energy of the fluid at the outlet.
The equation for the mechanical expansion power of two-phase fluids

The specific volume \( v \) of saturated fluids is a function of the specific enthalpy \( h \) and the pressure \( p \)

\[ v = v[h, p] \]
The theoretical maximum differential specific enthalpy $dh$ is described by the following differential equation

\[
\frac{dh}{dp} = v[h, p]
\]

The maximum mechanical power output $P$ is the product of the mass flow $\dot{m}$ and the specific enthalpy difference $\Delta h$ between inlet and outlet

\[
P = \dot{m} \Delta h
\]
Cross Section of the Two-Phase LNG Expander
Hydraulic Assembly for Two-Phase Expansion applying Case C of the Euler Turbine Equation
Installation of the Very First Two-Phase LNG Expander in Poland 2001
Two-Phase LNG Expanders at the Manufacturing Plant
Combined single and two-phase LNG Expanders in tandem configuration. To optimize the power generation, different rotational speeds for the higher density single-phase and for the lower density two-phase LNG are recommended.
Installation of the Tandem Configuration in Poland in 2009
Thank You

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