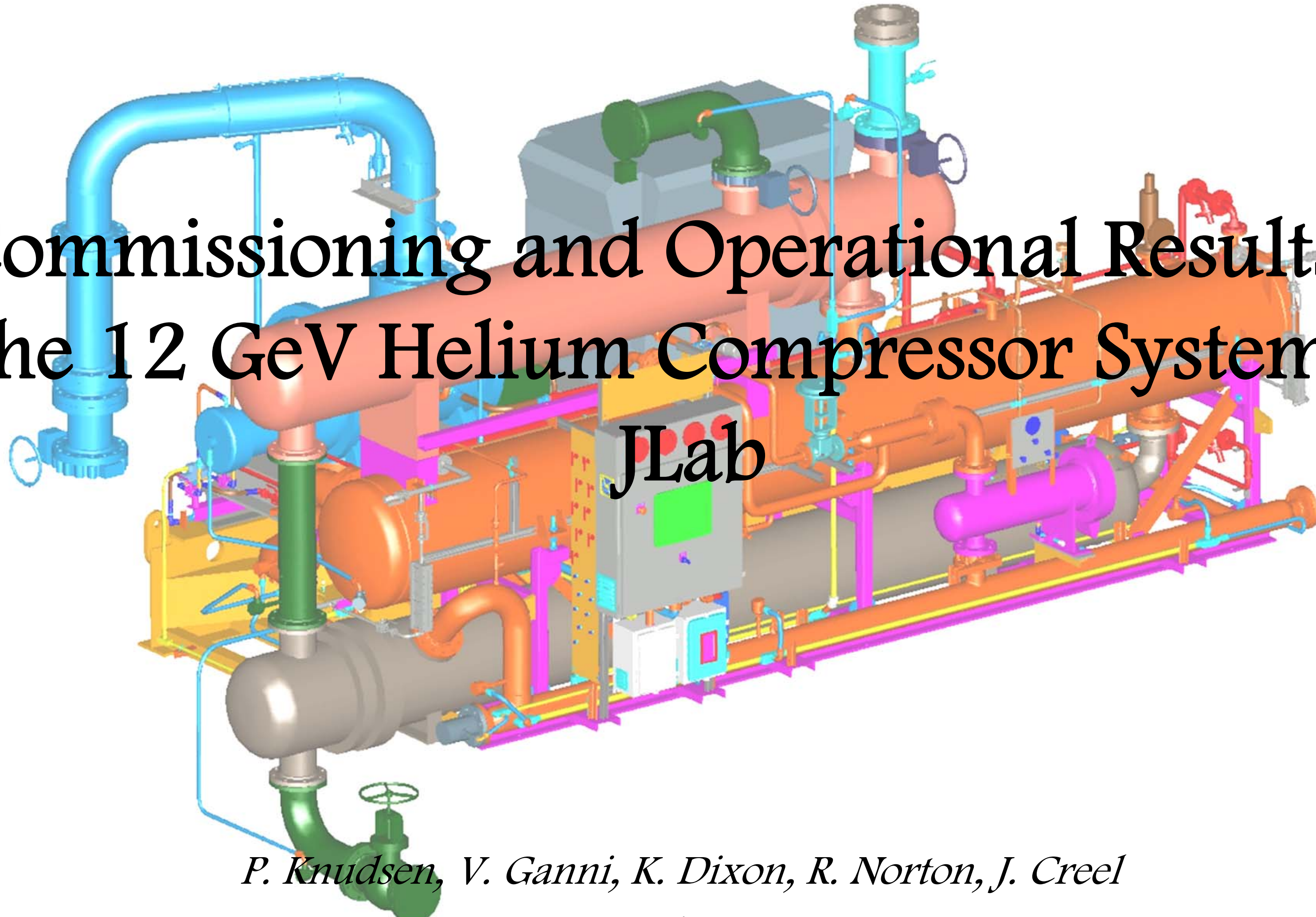
Commissioning and Operational Results of the 12 GeV Helium Compressor System at JLab



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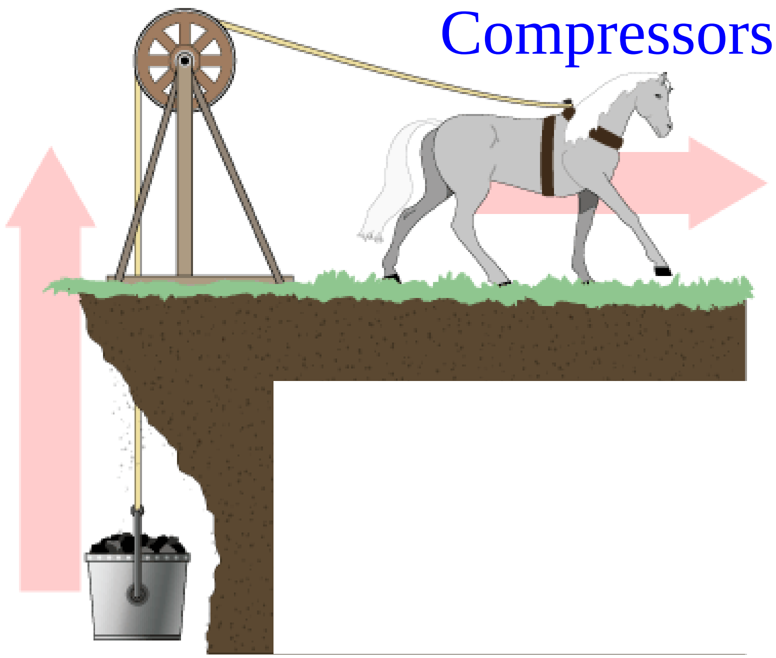
Cryogenics Group

Background

- The compressor system is often considered
- An off-the-shelf, commercially available sub-system,
- Not worth the same level of consideration as compared to the cold box…however, *it should!*...since it,
  - Provides the cold box the “potential energy” (exergy) and,
  - *At least half* of the input power is lost in the compressor system



Background

- *And, where do all the mega-watts go?…*
- Our environment via the evaporative cooling towers!

Background

- Helium refrigeration systems are very power intensive processes (and are usually more efficient the larger the system)
  - Large 4.5-K helium refrigeration system
    - Inverse COP ~250 W/W
  - Large 2-K helium refrigeration system
    - Inverse COP ~750 to 950 W/W
- *System design of the anticipated loads is an estimate*
- It is therefore of great importance to design the cryogenic system with considerable flexibility, balanced with cost and good efficiency for the primary operating mode(s)

Background

- The internal (Jlab) development of 12 GeV compressor system was brought about by:
  (1) A key motivating factor
    - Having to deal with the inevitable load variances and,
    - An awareness of the inherent energy intensiveness of these systems
    - Was 'birthed' at the SSCL, with several refinements and applications (to existing systems) occurring at JLab

Background

(2) Observations of existing compressor systems

- Have had the benefit of operating screw compressors used in helium refrigerators, for the past 35 years, encompassing a wide range of
  - Sizes (100 to ~2000 kW)
  - Compressor manufacturers
  - Skid packagers
- This provided a broad range of experience

Background

(3) Fortuitous opportunity

- Provided by NASA Johnson Space Center's (JSC) request to the JLab Cryogenics Group to design and specify a 12 kW 20-K helium refrigeration system for the James Webb program which was pivotal
- *The development of the 12 GeV compressor system would not have been possible without the courageous support of the NASA-JSC project team*
- This refrigeration system provided a demonstration of new wide range compressor design concept which afforded an acceptable level of risk to the JLab 12 GeV project

Background

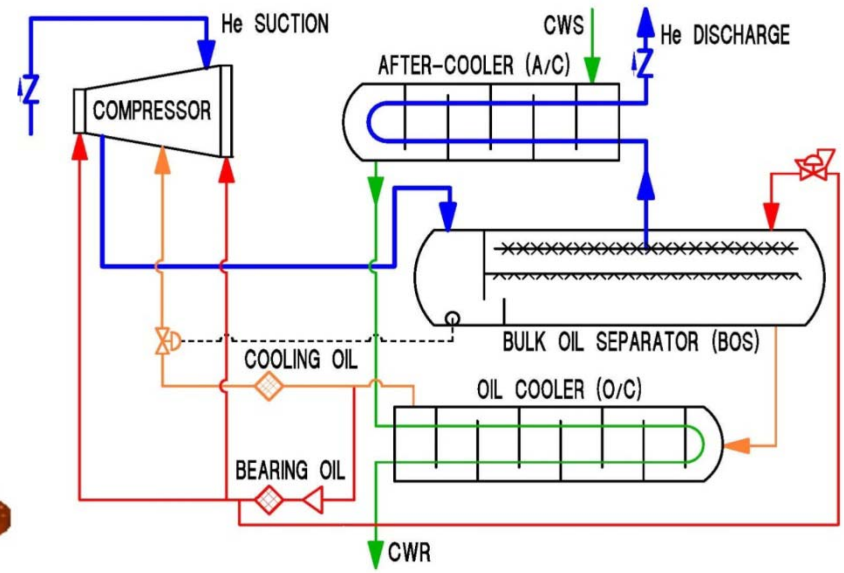
- Compressor skids are completely designed by JLab and 'built-to-print' by industry (skid specifications below, previously presented)

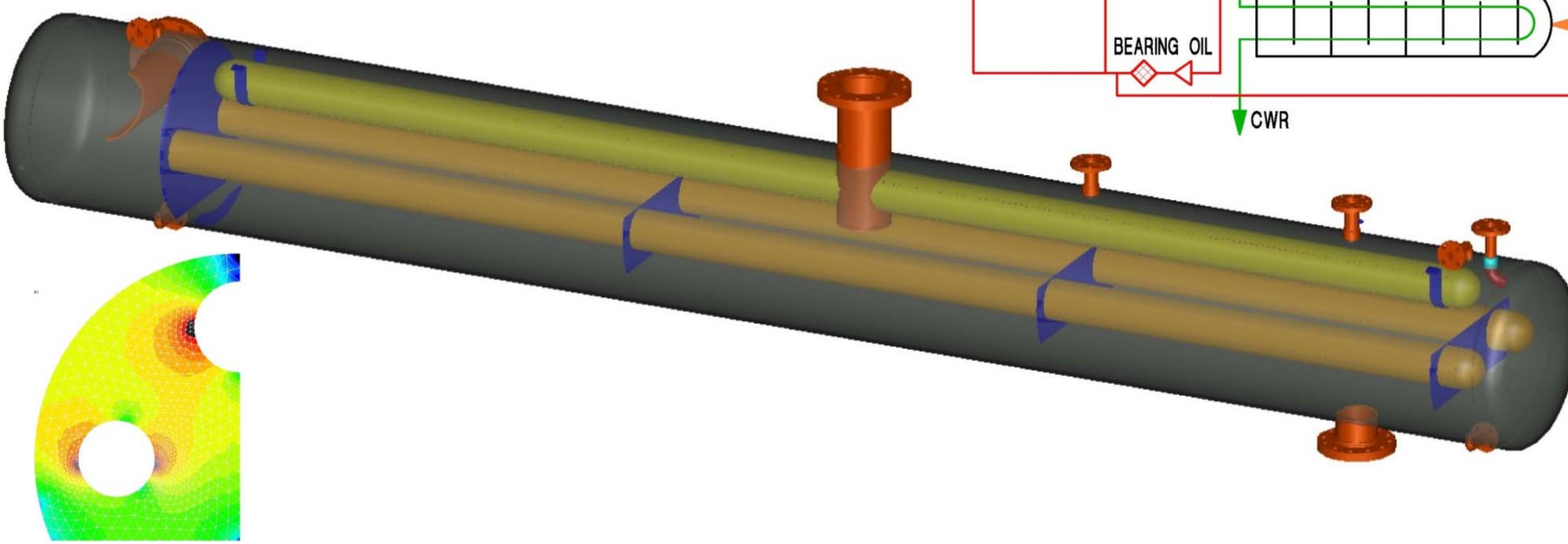
Stage		Units	HP	MP	LP	*Notes*
No. Units			1	1	3	
Compressor			Howden WLViH 321/193 (Variable Volume)	Howden WLVi 321/165 (Variable Volume)	Howden WLVi 321/193 (Variable Volume)	
Displacement		[m³/s]	1.774	1.577	1.774	*(a)*
Motor Rating		[kW]	1864	671	671	*(b)*
Motor Service Factor			1.15	1.15	1.15	
Weight (Est.)		[t]	30	22	20	*(c)*
Oil Charge (Est.)		[ℓ]	1400	1100	1000	
Water Flow (Est.)		[ℓ/s]	61	23	21	*(d)*
Oil Cooler	Type		AEU: Shell (Oil, 1 pass) & Tube (Water, 2 pass)			
	Duty	[kW]	1671	617	617	
	(UA)	[kW/K]	77.6	29.4	31.2	*(e)*
Helium After-Cooler	Type		AEU: Shell (Water, 1 pass) & Tube (Helium, 2 pass)			
	Duty	[kW]	448	184	105	
	(UA)	[kW/K]	20.4	8.44	4.66	*(e)*
Oil Pump Motor		[kW]	5.59	3.73	3.73	
Rotor Oil Injection Filter		[μm abs.]	8	8	8	*(f)*
Bearing Oil Injection Filter		[μm abs.]	8	8	8	*(f)*
Helium Pressure Rating		[barg]	22.4	12.1	12.1	
Oil Pressure Rating		[barg]	26.5	15.5	15.5	

Notes: *(a)* at 59.17 Hz; *(b)* Westinghouse 4160 V; *(c)* Metric tonnes; *(d)* At 8.3 K temperature difference; *(e)* (UA) is the net thermal rating; *(f)* 98% efficiency

Commissioning and Operational Envelope

- Two key compressor skid features that allow a wide range of operation
  - Bulk oil removal design
  - Oil management





Commissioning and Operational Envelope

- Range of conditions tested during commissioning

Compressor Stage	Suction Pressure [bar]	Discharge Pressure [bar]	Pressure Ratio	BVR [(a)]
LP Stage	1.06	3.55 to 6.08	3.33 to 5.71	2.2 to 3.2
MP Stage	1.06 to 3.04	3.55 to 6.08	2.00 to 3.33	2.2 to 3.2
HP Stage [(c)]	1.07 to 5.47	13.37 to 18.75	3.00 to 16.98	2.2 to 5.0 [(b)]

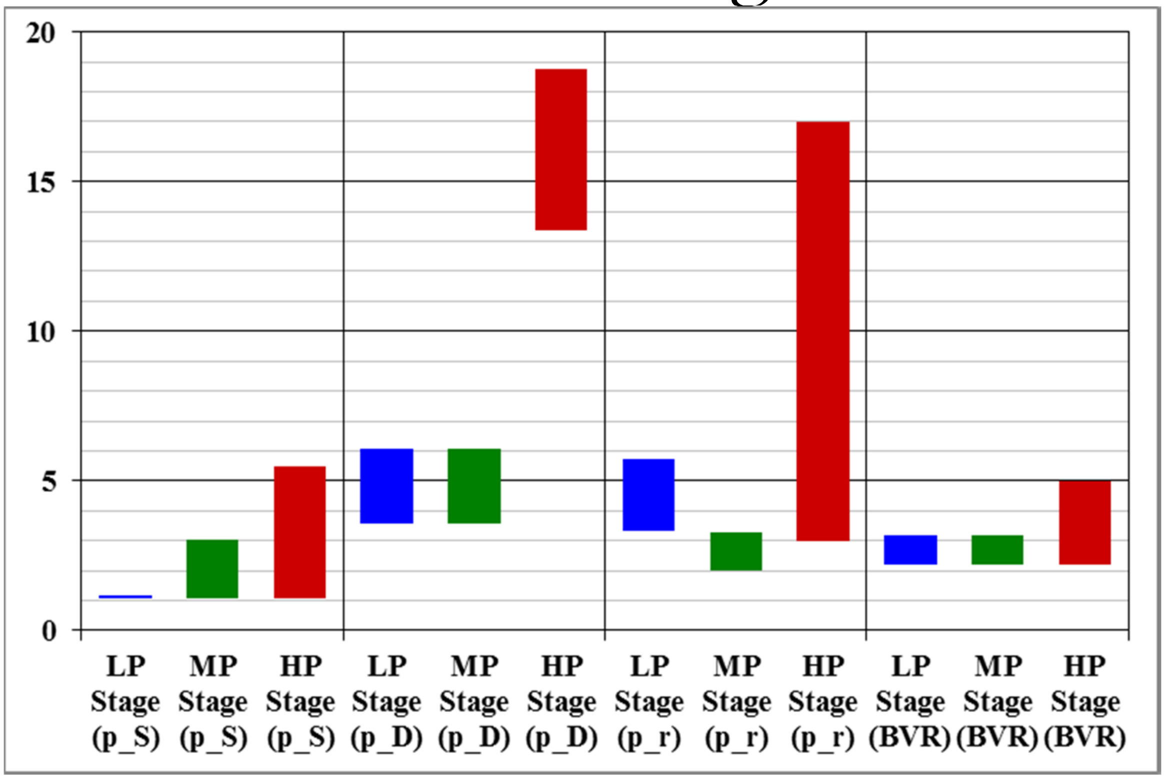
[(a)] BVR increments were 0.2

[(b)] Not every BVR setting was used for each test point due to manufacturer maximum suction pressure limitations (for a given BVR)

[(c)] HP stage can be operated as a (swing) LP or MP stage; under these conditions the suction pressure can be as low as ~1.04 bar, the discharge pressure as high as ~18.7 bar, and the pressure ratio ~18

Commissioning and Operational Envelope

- Range of conditions tested during commissioning



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Commissioning and Operational Envelope

- Range of conditions operated since commissioning

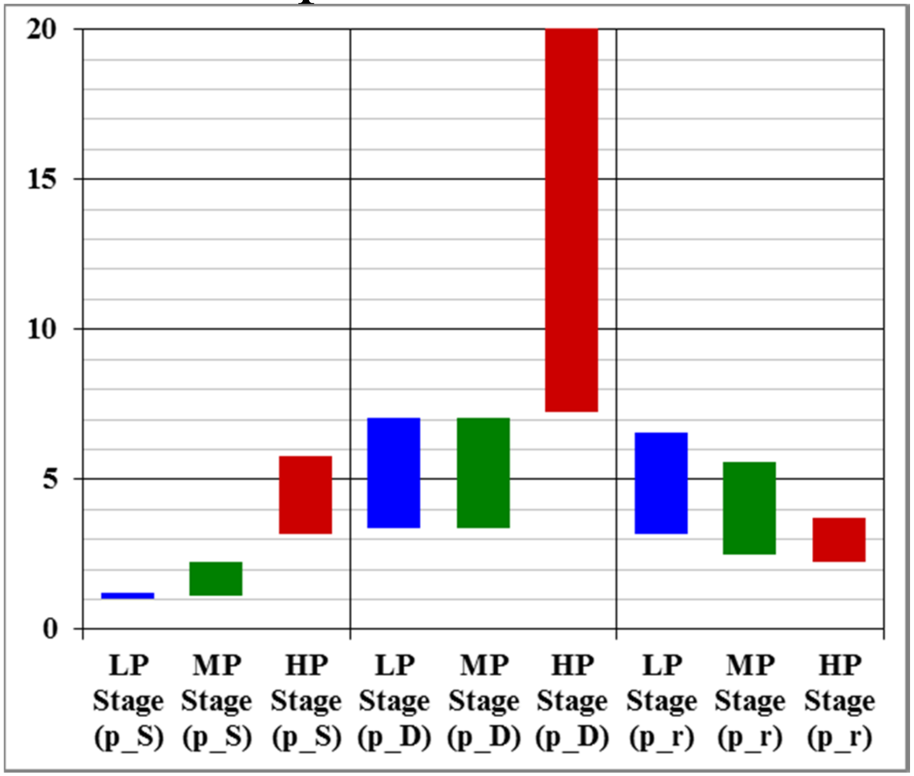
Compressor Stage	Suction Pressure [bar]	Discharge Pressure [bar]	Pressure Ratio
LP Stage	1.04 to 1.22	3.40 to 7.03	3.17 to 6.55
MP Stage	1.12 to 2.26	3.37 to 7.07	2.48 to 5.58
HP Stage [(c)]	3.19 to 5.78	7.25 to 20.04	2.27 to 3.70

(c) Same note as in table 3

LP BVR set to 2.4 for operation; MP and HP BVR set to 2.2 for operation

Commissioning and Operational Envelope

- Range of conditions operated since commissioning



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Minor Component Improvements

- Installation of a helium after-cooler (A/C) liquid level gauge
  - Modification utilized existing ports on the compressor A/C's and allows a local visual check to adjust the oil drain in order to minimize the helium bypass
- Modification of A/C oil drain line
  - Increased the size of the line (including check valve and needle valve) to prevent blockage from fabrication debris and incorporates o-ring seal unions to allow easy removal if necessary

Minor Component Improvements

- Elimination of HP stage super-feed injection flex-hose
  - Original flex-hose was a convoluted metal braided hose and developed a crack at the weld between the cuff and bellows
  - Line was replaced with hard-tubing to prevent fatigue of thin metal but allow adequate flexibility
- Oil pump VFD modification
  - Allowed the oil pump to ride through small power cycle interruptions.

Minor Component Improvements

- Ability to de-pressurize LP and MP stage suction lines
  - Helium discharge check valve will tend to leak at a greater rate than the helium suction check valve
  - Can result in a high initial gas charge in the LP and MP stages which can cause difficulties during a re-start
  - Connections were made to existing ports to de-pressurize the trapped volume of helium gas to reduce the starting torque.
- Heat shield between compressor PLC cabinet and the coolers and BOS
  - Although no know issues resulted from not having the shield, one was installed to protect local control system.

Minor Component Improvements

- Elimination of cooling oil control valve positioner
  - Valve supplies cooling oil to the super-feed port
  - Original positioner would stop functioning
  - Less critical on the LP and MP stages, but will cause a shut-down of the HP stage very quickly
  - Upgraded positioner developed a similar problem
  - These were replaced with an I/P

- *All of these have been incorporated into drawings for future skids, such as MSU-FRIB project*

Summary

- Present development is a culmination of many years of experience, observation, questioning and opportunities presented and taken
- 12 GeV compressor skid design has allowed a *very wide range of operation and a full implementation of the Floating Pressure Process*
- With ~15,000 hours of operation (by the beginning of the 2015 summer) this design has proven to be efficient, reliable and easily maintained

Further Development

- The energy intensiveness of ~250 W/W for 4.5-K refrigeration and ~750-950 W/W for 2-K refrigeration and,
- The fact that ***half of the input power*** is lost in the compression system warrants continued R&D

- Further work is planned to develop alternate BOS designs and investigate methods and processes to improve efficiency
  - Specifically in regards to:
    - Oil choice, oil injection temperature and oil injection method on the isothermal efficiency and,
    - Behavior of the helium-oil mix in the compression process and the effect of dissolved helium in the bulk oil flow.

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Thank you for your attention