CAPACITY IMPROVEMENT OF A LARGE, TWO STAGE DIAPHRAGM COMPRESSOR

GREGORY FRANTZ
DUPONT ENGINEERING

ROBERT EIZEMBER
DUPONT ENGINEERING

JOSE VAZQUEZ
BRG MACHINERY CONSULTING
Discussion Topics

1. Background & Compressor Details
2. Testing at Original Equipment Manufacturer (OEM) Facility
3. Initial Modifications
4. Gas Cavity Modifications
5. Summary
6. Conclusions
1a. Background

- Two stage diaphragm compressor is used to pressurize a process gas stream.
- As delivered, compressor produced less than 75% of the required flow rate at the specified suction and discharge conditions.
- **Improvement Goal: Increase capacity to deliver minimum required flow to the process.**
- An improvement effort was initiated. This presentation covers the improvements made to the compressor which resulted in a capacity increase to 98% of the design flow rate.
- The OEM was integral to this process and provided the engineering and shop time to implement the improvements.
1b. Compressor Details

- Two stage, hydraulically actuated diaphragm compressor.
- Single acting horizontal opposed design.
- 50 horsepower, belt drive @ 385 RPM.
- Discharge pressure up to 450 PSIG, 400 PSIG typical.
- Suction pressure up to 30 PSIG, 10 PSIG typical.
1c. Compressor Operation

- Reciprocating piston displaces hydraulic fluid behind diaphragm set.
- Metallic diaphragms displace gas in the “gas cavity” on the opposite side.
- Hydraulic “limiter” or “overpump valve” regulates peak hydraulic pressure and vents excess oil on each stroke of the compressor near top dead center.
- Compensating pump replenishes oil on each stroke near bottom dead center.
1) Suction valve open. Limiter & discharge valve closed.

2) Compression. Limiter, suction and discharge valves closed.

3) Discharge valve open. Limiter & suction valve closed.

4) Discharge. Pressure decreases due to:
   a) Piston moves slower as it approaches top dead center.
   b) Flow characteristics of the discharge valve.

5) Diaphragm contacts the gas cavity plate. Limiter valve opens. Discharge valve still open.

6) Maximum hydraulic pressure achieved. Limiter valve closed, discharge valve closed.
2a. Original Testing @ OEM

Original Equipment
Suction: 10 PSIG
Discharge: 310 PSIG

Stage 1 Hydraulic Pressure
Hydraulic Cavitation
Interstage Pressure
Discharge Pressure
Hydraulic Pressure

Stage 2 Hydraulic Pressure

Stage 1 Hydraulic Pressure

Interstage Pressure

Hydraulic Pressure

Stage 2 Hydraulic Pressure

Hydraulic Cavitation
2b. Original Testing @ OEM

Original Equipment
Suction: 10 PSIG
Discharge: 350 PSIG

Increased hydraulic pressure on stage 2 to eliminate hydraulic cavitation.

Stage 1 & 2 Hydraulic Pressure

Continued Hydraulic Cavitation
2c. Original Testing @ OEM

*Original Equipment*
*Suction: 10 PSIG*
*Discharge: 400 PSIG*

*Increased hydraulic pressure a second time on stage 2 to eliminate hydraulic cavitation.*

*Hydraulic Cavitation Eliminated*

**Stage 1 & 2 Hydraulic Pressure**
3a. Initial Modifications

• Modified the shape of the discharge ports from round to kidney shape.
  – Removed metal between every other hole.
  – No capacity improvement measured.
• Changed the type of suction and discharge valves to increase lift.
  – Design evaluated and modified by independent 3rd party.
  – No capacity improvement measured.
• Gas was not restricted in the check valves or in the valve porting.
  – Focused on gas cavity design.
  – *Modified compressor head to obtain gas cavity pressure measurement.*
3b. Initial Modification Results

Modified Check Valves
Kidney Shaped Porting
Suction: 15 PSIG
Discharge: 400 PSIG

Gas cavity pressure and hydraulic pressure do not deviate at discharge pressure!
3c. Initial Modification Results

- Gas was not able to exit compressor head.
  - Capacity loss calculated close to quantity of trapped gas.
  - Capacity increased w/ increased hydraulic pressure because more gas was forced from compressor.
  - Compressor is not designed to operate this way!
  - Needed to get the gas to the discharge check valves.

- Time to cut more metal . . .

<table>
<thead>
<tr>
<th>Actual Gas Cavity Pressure</th>
<th>Theoretical Gas Cavity Pressure</th>
<th>Trapped Gas</th>
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4a. Gas Cavity Modifications

- Step 1: Doubled width and depth on 12 original grooves in the gas cavity.
- Step 2: Doubled the number of grooves (24).
  - 14% stage 1 / 12% stage 2 dead volume increase over original.
- Step 3: Doubled the number of grooves on stage 1 again (48).
  - 34% stage 1 dead volume increase over original.

![Original 1st Stage](image1.jpg) ![Final 1st Stage](image2.jpg)
4b. Gas Cavity Modification Results

24 Grooves on Stage 1
24 Grooves on Stage 2
Suction: 15 PSIG
Discharge: 400 PSIG

Significant performance improvement on stage 2.
Modest performance improvement on stage 1.
4c. Gas Cavity Modification Results

48 Grooves on Stage 1
24 Grooves on Stage 2
Suction: 13 PSIG
Discharge: 380 PSIG

Additional improvement on stage 1. Modest detriment on stage 2 due to increased stage 1 capacity. Hydraulic pressure was decreased to lower rod forces.
5a. Summary

Comparison of the original stage 1 heads with the final head design incorporating all improvements.

Stage 1 P-V Diagram

Original Heads. Tested at OEM On Nitrogen

Chamber volume corrected for new dead volume

Modified Heads. Tested in the field On Nitrogen

Interstage Pressure

Suction Pressure

PSIG
5b. Summary

Comparison of the original stage 2 heads with the final head design incorporating all improvements.
6. Conclusions

• The root cause of the lack of capacity? The gas cavity profile restricted the ability of the gas to reach the discharge check valve.
  – Modifications to the grooves in the heads improved the ability of the compressor to discharge gas, greatly improving capacity.
  – Increases in the number and size of the grooves resulted in additional dead volume. This increase negatively impacted efficiency.
  – In this case the capacity gains far outweighed the efficiency loss.
  – This would not have worked had the compressor not been “oversized.”

• The most valuable measurement was the gas cavity pressure.
  – Provisions for this measurement are easy to incorporate when specifying and purchasing a new machine.
  – Modifications are more difficult to implement on existing equipment.

• The limiter pressure must be set correctly.
  – Pressure that is too low leads to hydraulic cavitation and poor performance.
  – Pressure that is too high can lead to excessive rod loads.
THANK YOU!!!

QUESTIONS?