Sensor reduction in down-hole linear permanent magnet machines

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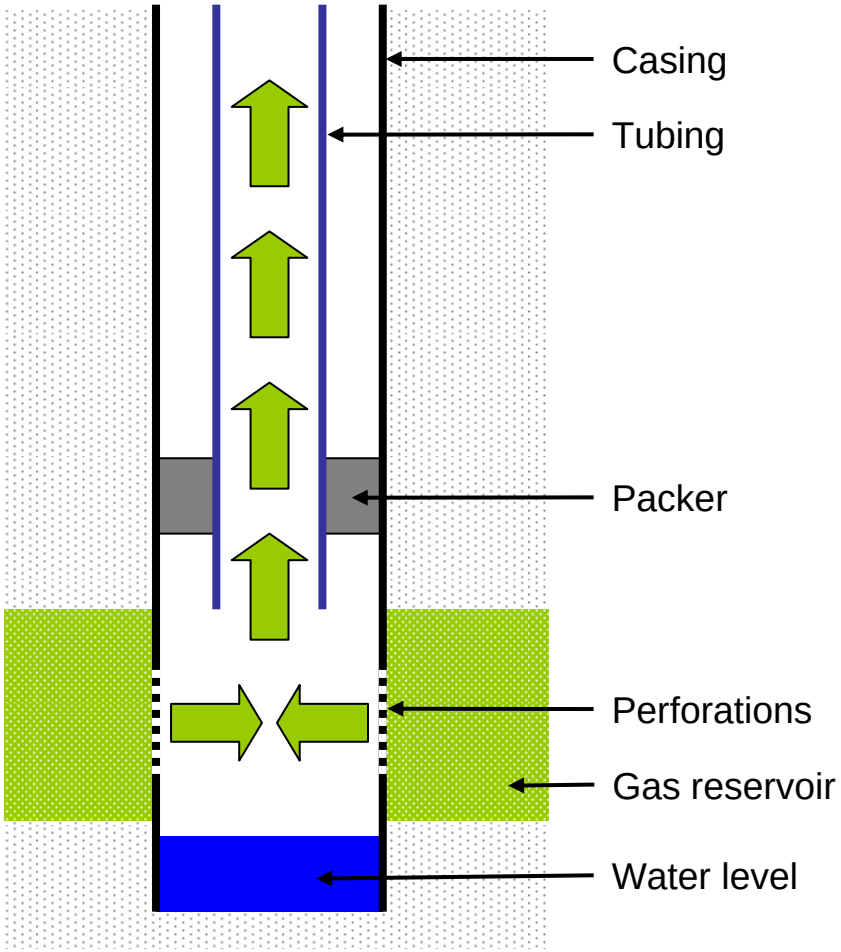
Introduction

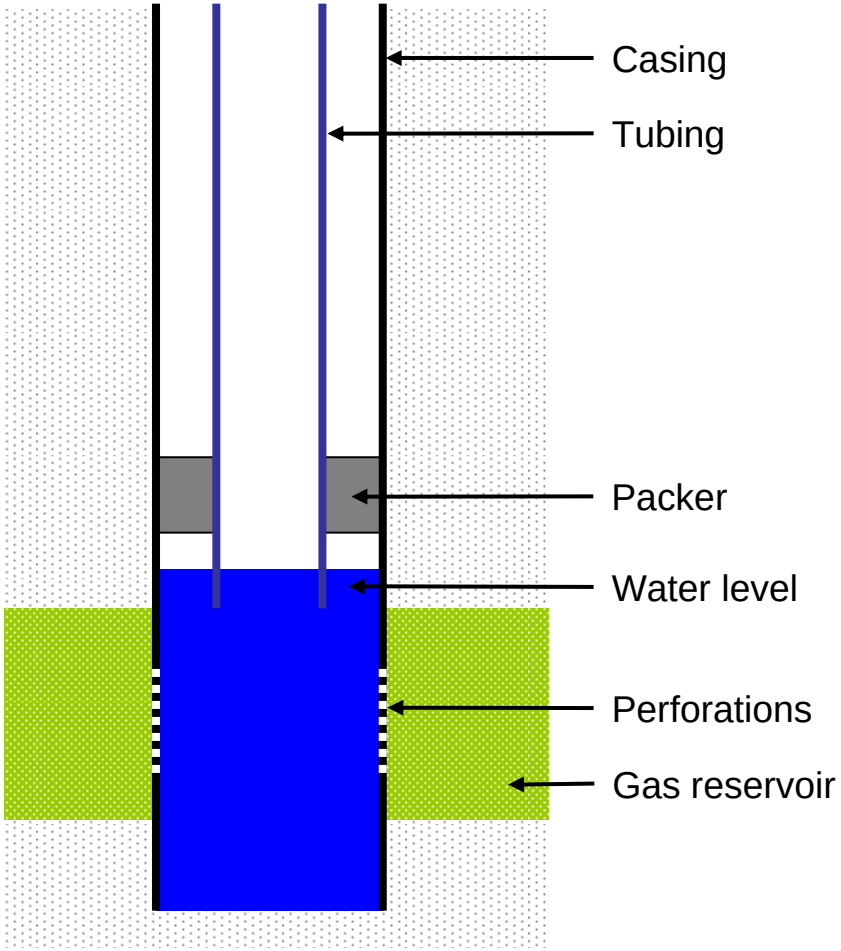
- Gas well deliquification
- Linear permanent magnet motor
- Variable-speed drive
- Position sensing
- Sensor reduction techniques
- The problem

Gas well deliquification (1)



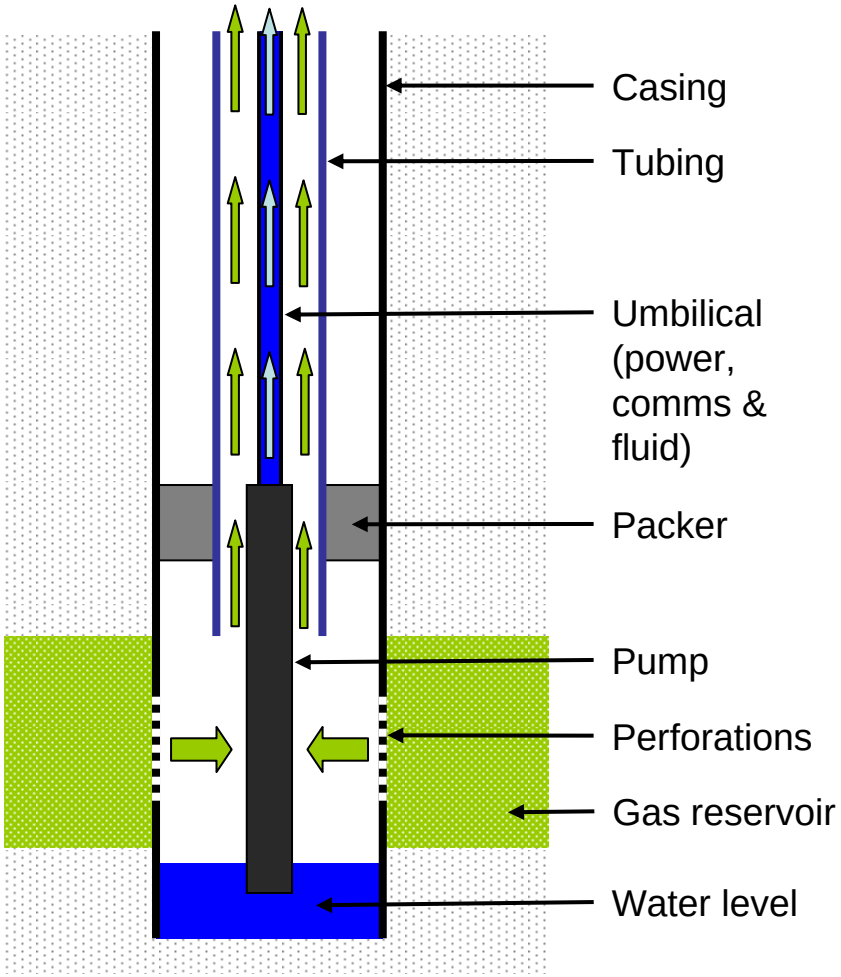
- In a new well, the velocity is high enough for the gas flow to carry liquid to the surface.
- Any fluid build-up in the bottom of the well remains below the casing perforations.
- The well produces a high volume of gas per day.

Gas well deliquification (2)



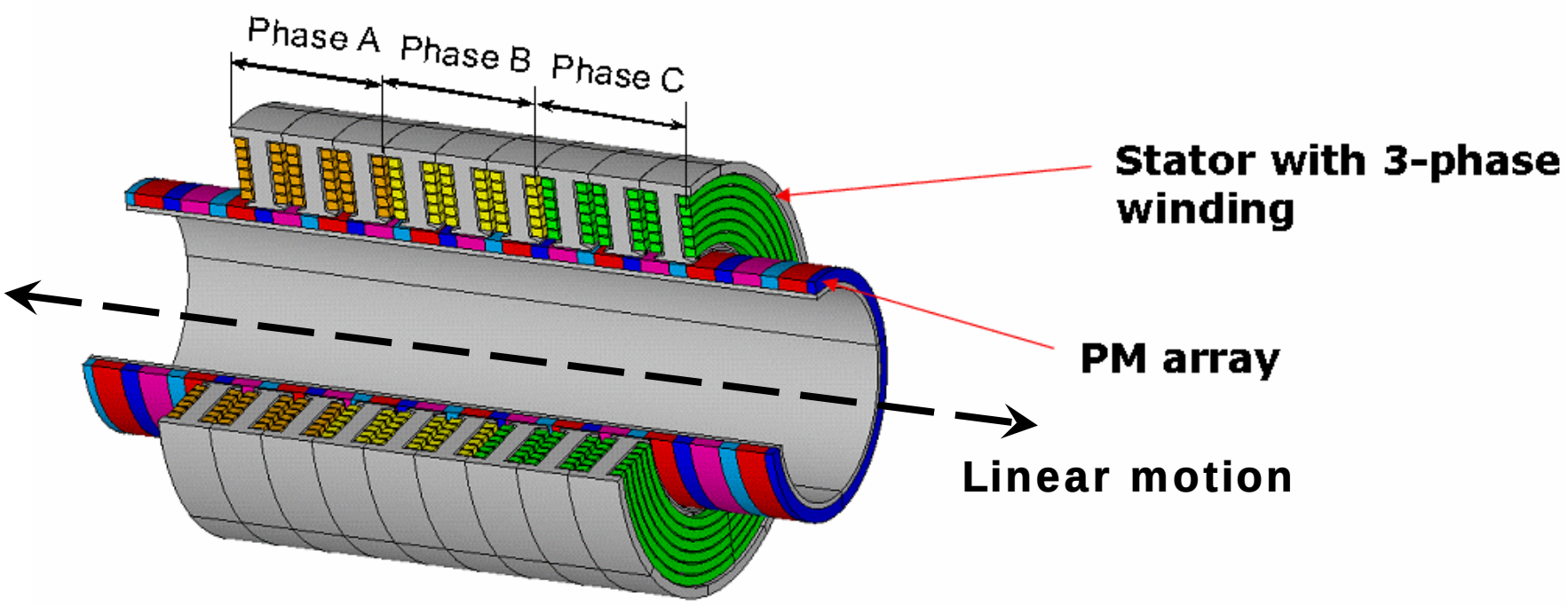
- Over time, the reservoir pressure falls resulting in a reduction in the gas flow rate.
- The gas velocity is no longer high enough to carry liquids to the surface, and so water collects in the bottom of the well.
- Gas production falls significantly or even stops completely.
- This will eventually lead to well abandonment.

Gas well deliquification (3)



- A down-hole pump is used to remove liquid from the bottom of the well.
- This reduces the fluid height and allows the gas to flow naturally to the surface.
- This extends the production life of the well and increases the total volume of gas recovered.
- However, the installation, maintenance and running costs of the pump must be offset against the value of the additional gas recovered.

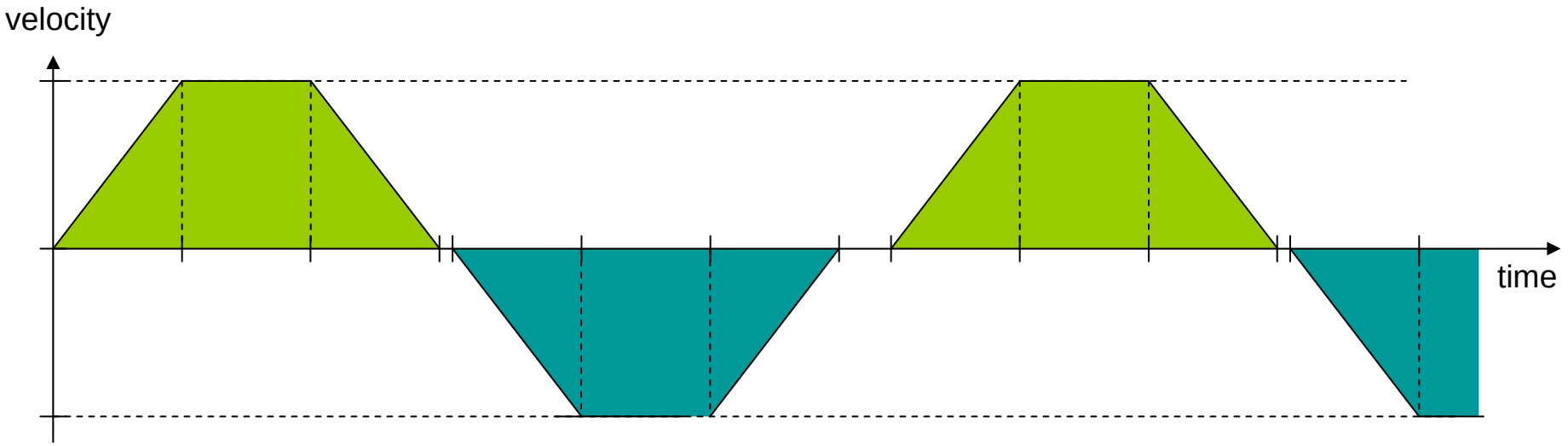
Linear permanent magnet motor



- The three phases (A, B, and C) are energised in turn to move the permanent magnet rod through the stator.
- The ABC windings are repeated multiple times to produce the required force.

Variable speed drive

- A variable speed drive (VSD) generates the ABC output waveforms to move the permanent magnet rod.
- The drive requires feedback from the motor to control the speed and position of the rod.
- For a linear motor, the motion must be programmed to move with a particular velocity profile:



Position sensing (1)

- In normal applications, the VSD requires accurate position sensing feedback to synchronize the generated waveforms with the position of the permanent magnets.
- Inaccurate position feedback causes the motor to deliver less force or draw excessive current (depending on the VSD limits).
- In extreme cases, the drive may lose control of the motor completely and either generate no movement, or a random movement when started.
- Position feedback can be either absolute or relative. Relative feedback devices tend to operate faster and can cope with highly dynamic applications.
- Many relative position sensors use an optical read head to provide movement sensitivity at the 20-30 micron range.

Position sensing (2)

- In the well environment, extreme temperature, pressure and vibration make optical devices impractical.
- Alternative position sensors exist, but are potentially less accurate or less responsive.
- However, any down-hole position sensor is a weak point in the overall design of the pumping system.
- If the position sensor, its control electronics, or its connection to the surface is lost, then motor control is impossible.
- However, changes in the position sensing over time due to thermal drift or physical wear may prevent motor control too.

Sensor reduction techniques

- A recent survey paper[1] has highlighted a number of possible sensor reduction techniques.
- Many of these techniques use mathematical models of the drive/motor behaviour to estimate speed and position based on alternative measurements.
- Measurements such as motor current and voltage can be obtained at the surface, and so avoid down-hole sensors.
- Possible techniques include:
  - Integration of the back EMF of the motor to give stator flux.
  - Observer-based approaches using a Kalman Filter, or Extended Kalman Filter.
  - High-frequency carrier signal injection.

The problem

- We require an investigation of the mathematical models used for sensor reduction that can:
  - work for a linear rather than rotary motor, and
  - cope with extremely long cable lengths.
- The model could be used to either improve or eliminate the down-hole position sensor.
- Ideally this model could be implemented without substantial modification of the VSD or motor.

References

[1] Singh, B., Singh, B. P., and Dwivedi, S. (2009). A review of sensor reduction techniques in permanent magnet synchronous motor drives. In *International Journal of Power and Energy Systems*, Vol. 29(1), pp 10-18. Acta Press.