BHR Group

EXPERTS IN FLUID ENGINEERING

Pump Characteristics: What they don't necessarily teach you at university

Pump Centre

An Introduction to Pressure Surge Analysis

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Objectives

This presentation objectives are:

- Introduction to pressure surge analysis in pipelines:
  - Causes of surge events
  - Consequences of surge events in the pipeline integrity
  - Estimation of the magnitude of transient pressures
  - Presentation of amelioration measures for pressure surge events
- Improve understanding of the physics and risks of pressure surge events in pipelines.

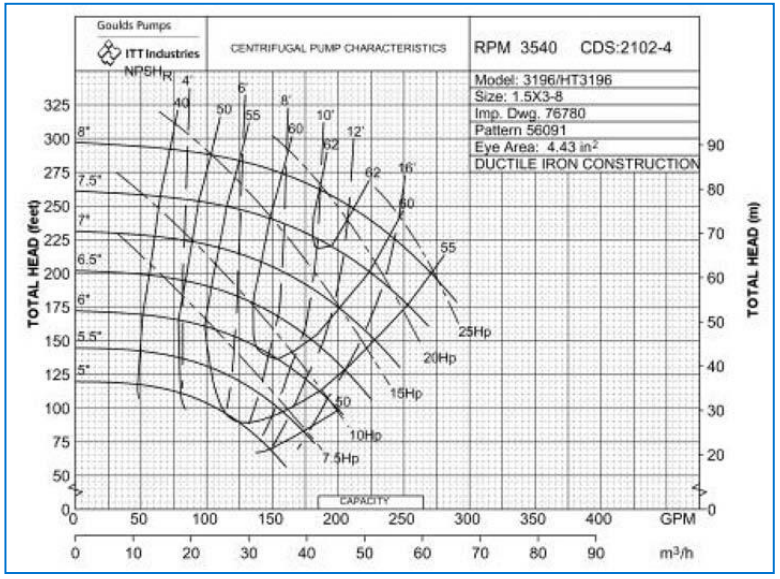
Presentation Outline

- Pressure Surge
  - Definitions
  - Causes
  - Effects
  - Methods of Analysis
- System Protection
  - Types of System Protection
  - Selection of the Process
- Modelling Software's
- Conclusions

Introduction: Pumping Systems

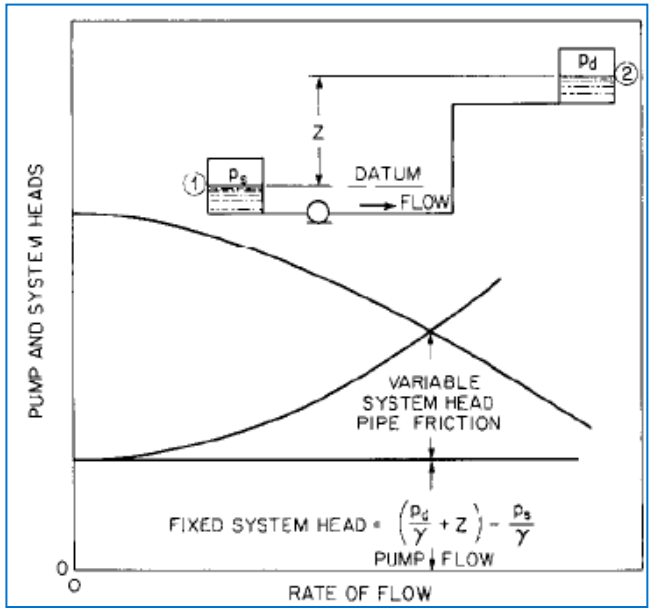
- Pump Characteristics Curves

(Diagram which describes the relationship between the head and the capacity of the pump using various size impellers).



- System Characteristics

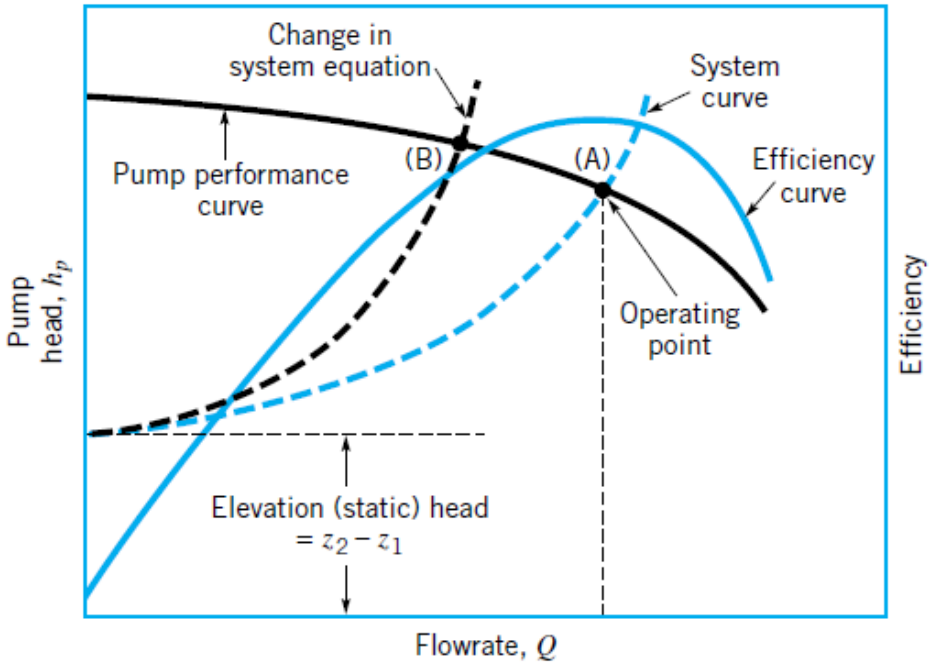
(Takes into account the fixed system head and the resistance of flow of the liquid through the system components)



Introduction: Pumping Systems

- Operating Point

(Point of intersection of the pump curve and system curve. The head and the flow rate corresponding to the operating point is the steady state head and flow rate).



Introduction: Pumping Systems

But if something wrong happens, such as sudden power failure that causes all pumps to stop simultaneously (typically the worst transient case scenario) and the system is not properly protected against transients

The system integrity may be at risk

Burst water main: Brazil

Burst water main: Australia

Pressure Surge: Definitions

- ***Pressure Surge.*** Is a pressure wave caused by a sudden change in water velocity.
- ***Waves speed***. The speed at which pressure waves travel through the fluid.
- ***Joukowsky equation***. Fundamental relationship relating pressure change with velocity change and acoustic velocity.
- ***Pipeline Period.*** Time for a pressure wave to travel the length of the pipe and come back.
- ***Head.*** Pressure measured as height of fluid (10 m head of water is roughly 1 atmosphere)

Pressure Surge: Causes

Hydraulic transients occur at flow changes in pressurised conduits and this is due to, for example:

- Star and stop of pumps, especially stop due to power failure
- Valve operation (shut-off valves)
- Check valve closure
- Air pockets in pipelines, especially ay pump start
- Air release
- Pipeline Filling
- Etc.

Pressure Surge: Effects

The effects of the pressure surge range from:

- Slight change in pressure and velocity

TO

- High pressure or vacuum along the pipelines causing:
  - Failure of fittings
  - Burst pipes
  - Pump Damage

Pressure Surge: Effects

The magnitude of the transient pressure peak depends on many factor. For example:

- Pipeline Profile
- Pipeline Length
- Pipeline Configuration
- Pipe material and dimensions
- Pump Moment of Inertia
- Filling around the pipeline
- Rate of change of the flow
- Protective measures applied
- Etc.

Pressure Surge: Analysis

The most important parameters to estimate the magnitude of transient pressures are:

1. Velocity change in time, Δv
2. Acoustic wave speed, c
3. Pipe period, T
4. Joukowsky pressure, Δp
5. Elevation profile

Pressure Surge: Analysis

Because of the compressibility of water and the elasticity of pipes, pressure waves will then propagate in the pipe

- The **acoustic wave speed** formula is expressed as:

$$a = \frac{\sqrt{\frac{K}{\rho}}}{\sqrt{1 + \frac{KD}{Ee}}}$$

- a = Velocity of pressure wave
- K = Bulk modulus of fluid
- ρ = Liquid mass density
- D = Inside diameter of the pipe
- E = Young's elastic modulus of the pipe wall
- e = Wall thickness

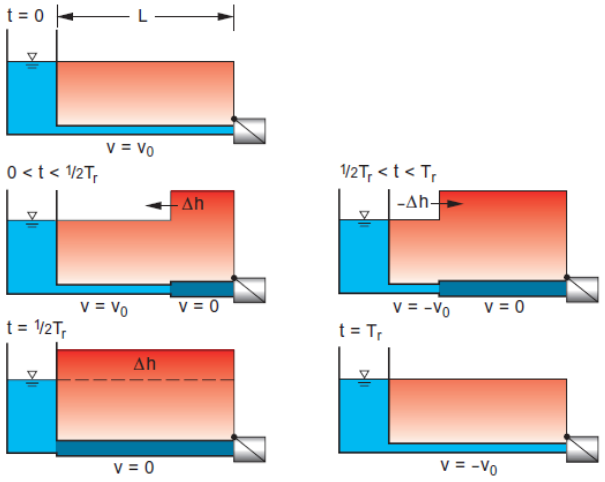
Pressure Surge: Analysis

The pipe period T is defined as the time required for a pressure wave to travel from its source of origin through the system and back to its source.

- For a single pipeline with length L, the **time period** is:

$$Tr = \frac{2L}{a}$$

- Tr = Critical period
- L = Length of the pipe
- a = Velocity of pressure wave



Pressure Surge: Analysis

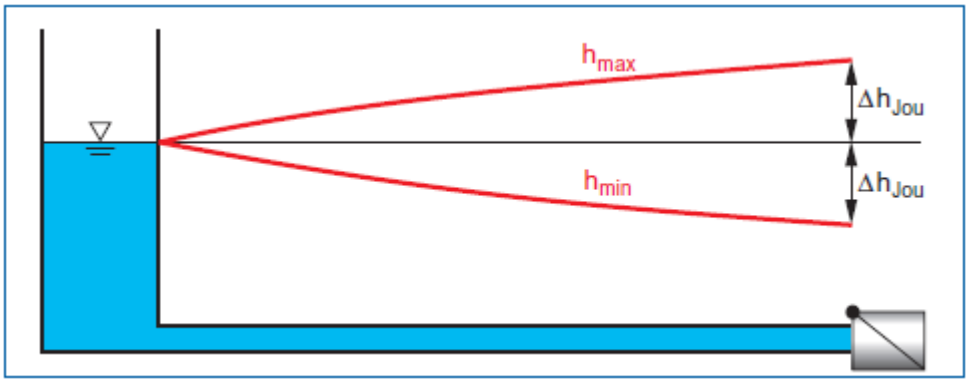
The Joukowsky's formula describes the pressure change (Δp) that results from a rapid change in velocity (ΔV).

- **Joukowsky's pressure** formula is expressed as:

$$\Delta p = -\rho a \Delta V$$

- The Joukowsky's **Head rise** (Δh) after a change of velocity is expresses as:

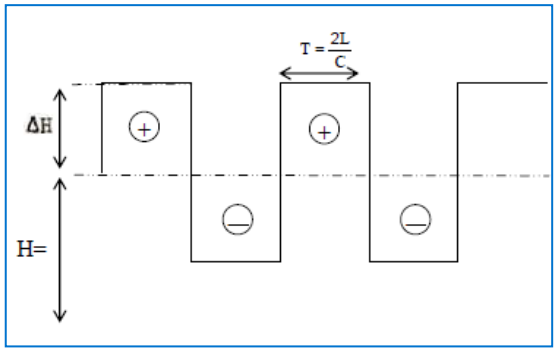
$$\Delta h = \frac{a.\Delta V}{g}$$

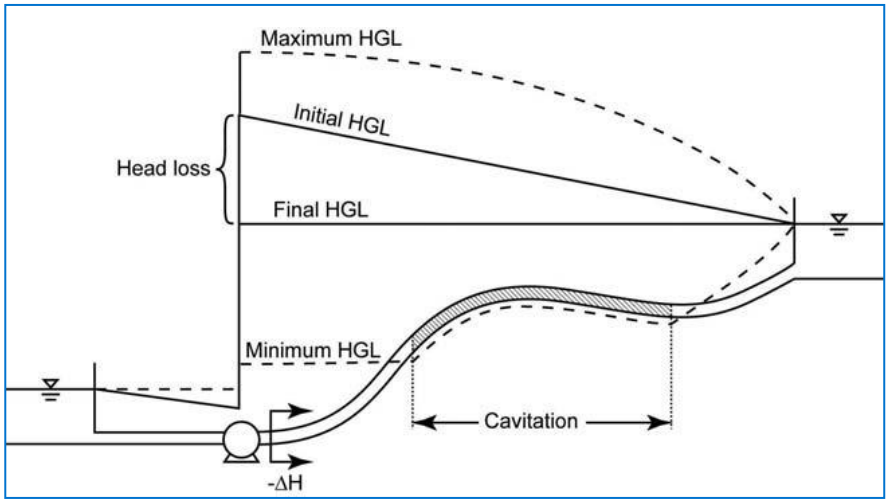


Pressure Surge: Analysis

The example shows the transient caused by pump shut down:

- Discharge side of the pump: The pressure decreases and a negative pressure wave begins to propagate toward the downstream reservoir.
- When the negative pressure wave reaches the high point in the pipe, the pressure can drop below atmospheric to reach vapour pressure.





System Protections: Types

The system protection can be divided in different groups:

- System Modification Solutions:
  - Use of stronger pipework
  - Reroute pipeline
  - Change of pipe material to one with a lower modulus (i.e. thermoplastic pipe materials)
  - Increase the pipe diameter to reduce velocity
  - Increase pump inertia
  - By-pass Lines

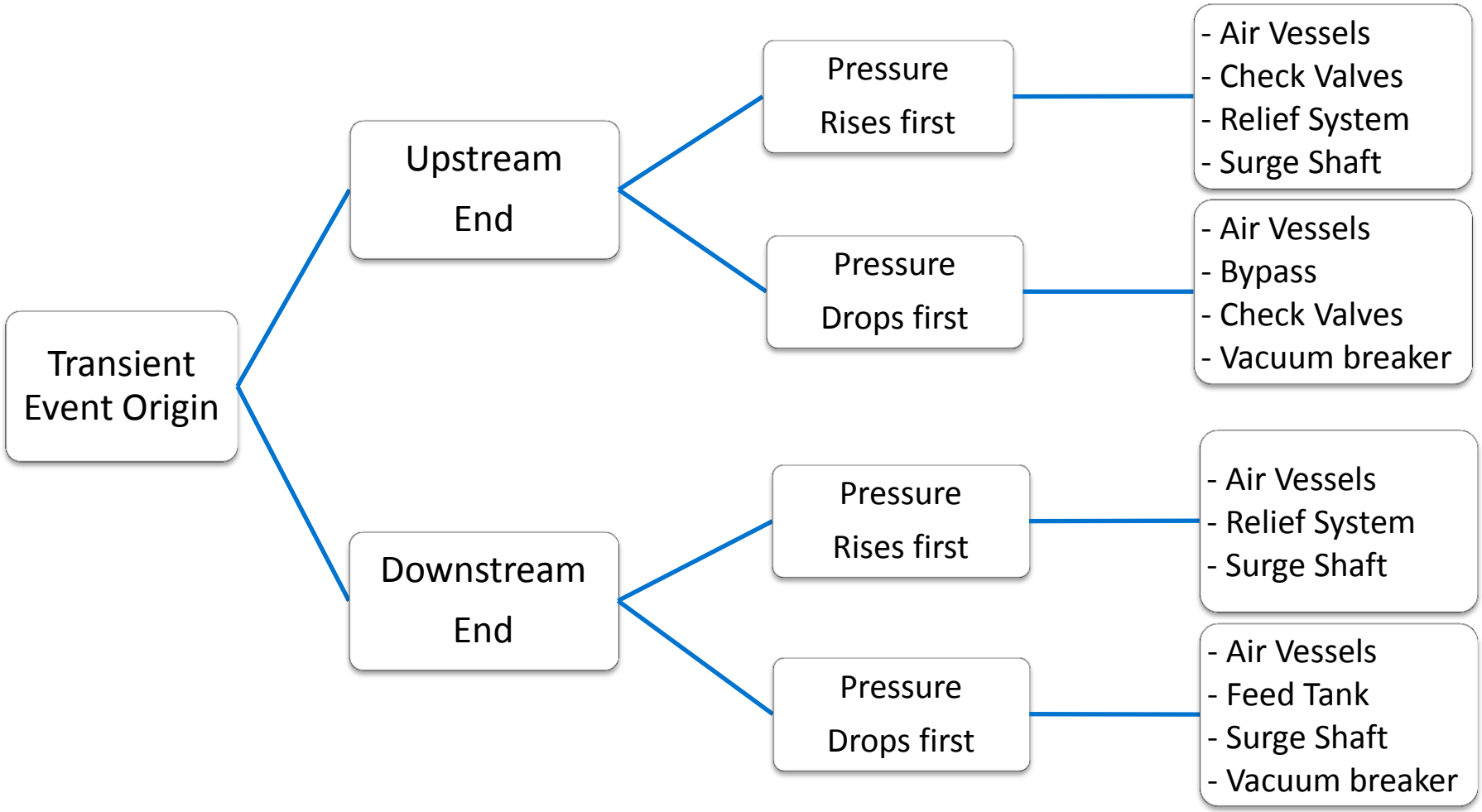
System Protections: Types

- Active protection (devices used to actively protect the systems against the effects of pressure surge during pipeline normal operation):
  - Variable speed pumping
  - Soft starters
  - Slow closing and opening valves

System Protections: Types

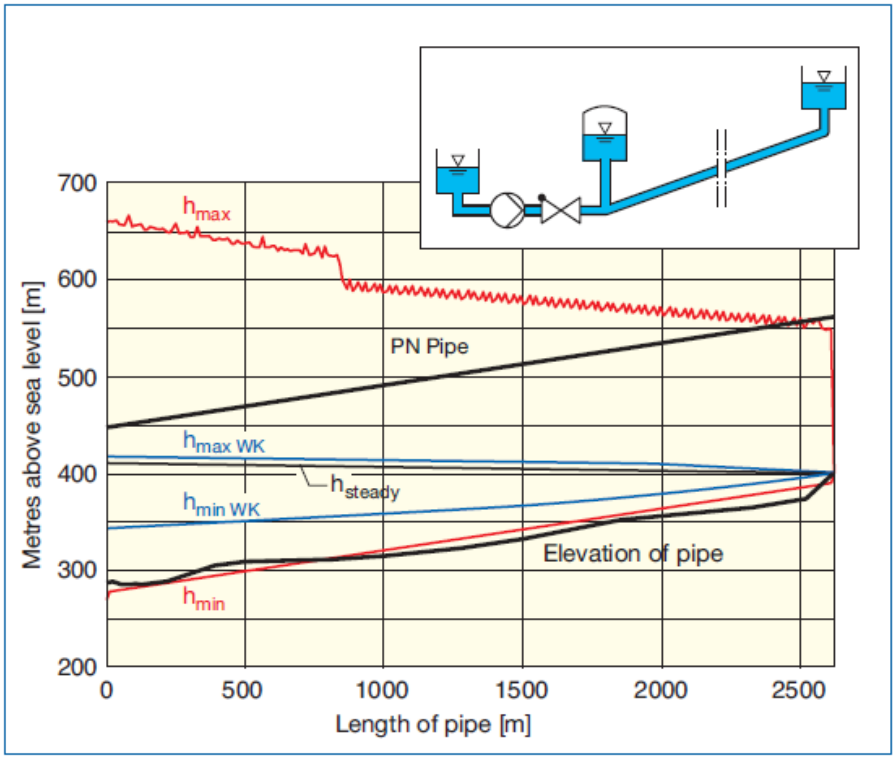
- Passive protection (Passive protection equipment operates without the need for additional power supply):
  - Air Vessels and Accumulators
  - Surge Shafts
  - Air Valves
  - Feed Tanks
  - Vacumm Breaking Valves
  - Pressure Relief Valves
  - Surge Anticipation Valves
  - Intermediate Check valves

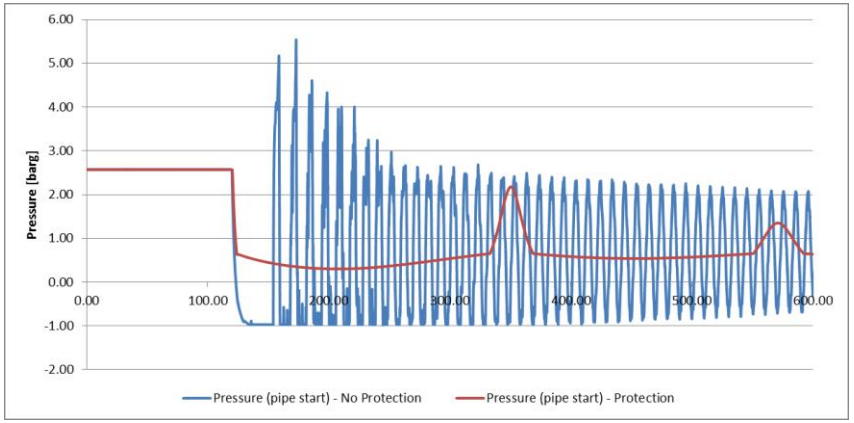
System Protections: Selection



System Protections: Example

The example shows the pressure envelope with and without an air vessel following pump trip





Modelling Software

- There are currently various software that help in this analysis
- Currently the most reliable models are the ones that use the Method of Characteristics, namely:
  - HyTran
  - Flowmaster
  - WANDA
  - Hammer
  - AFT Impulse

(With the Method of Characteristics if we know flow and pressure at A and B we can calculate the intermediate pressure).

Conclusions

- The phenomena that occur during the Hydraulic transients are very important since they can put in cause the system integrity.
- When the system is being designed should be taken into account the Pressure Surge Events and the corresponding mitigation devices
- By eliminating the risk of failure due to pressure surge in pipe systems, it is possible to attain the highest possible reliability of the systems.

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Thank you

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