Risk optimisation of an automobile hydrogen system

Jean Meyer

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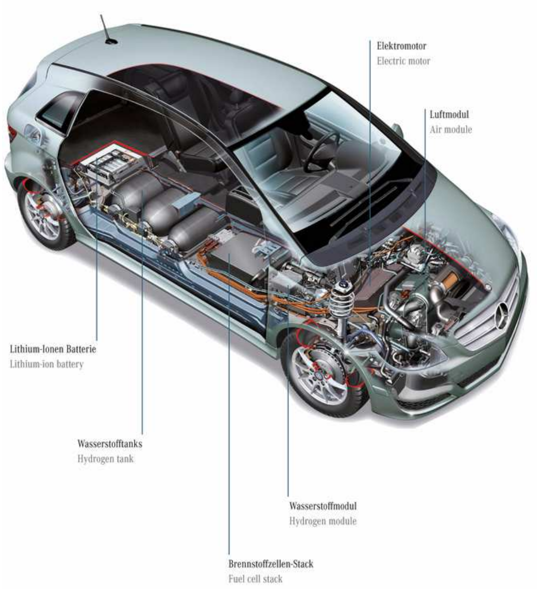
ICSAT

Background

H_2-cars and fossil fuel cars show significant differences with respect to the fuel system:

- handling of gaseous fuel vs. liquid fuel
- different components
- different system layout
- different system control

→ **different safety aspects!**

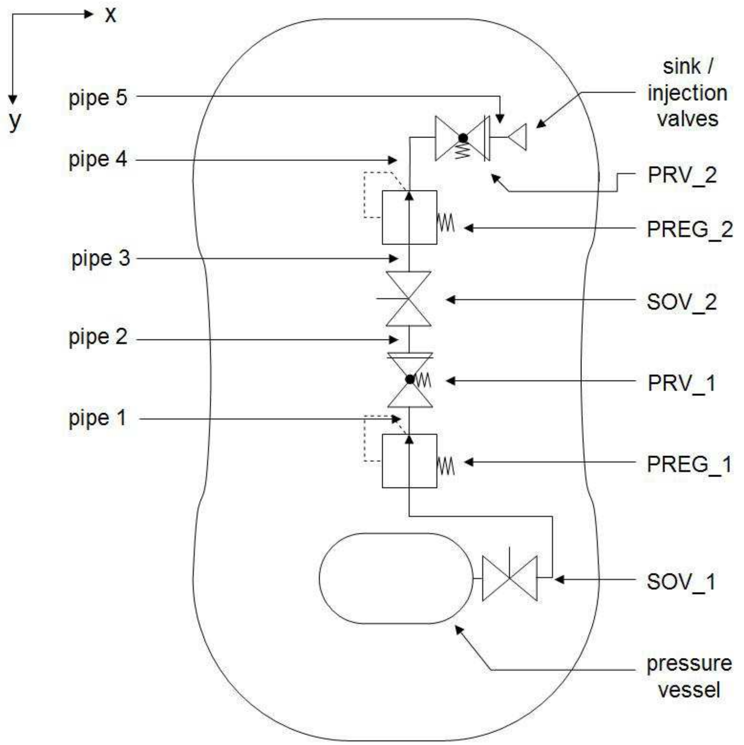


B-Class F-Cell
[Source: www.cleanenergypartnership.de]

Research Issue

How to design the hydrogen fuel system to make the car as safe as possible?

Risk optimisation



Simplified fuel system layout of a hydrogen powered car with ICE

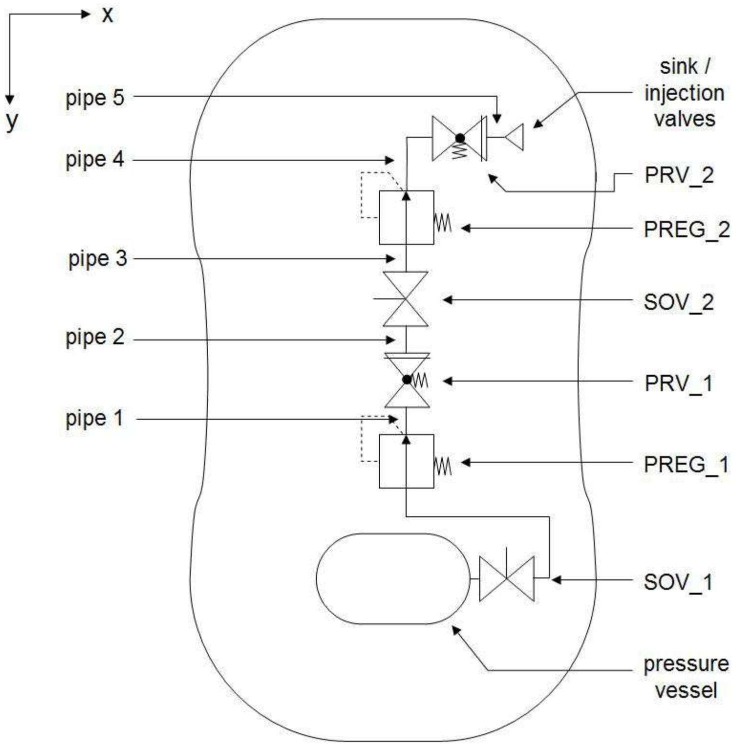
Basic assumptions

System layout:

- no venting system
- no refuelling system
- capacity: 4 kg H_2 @ p=350 bar

System operation:

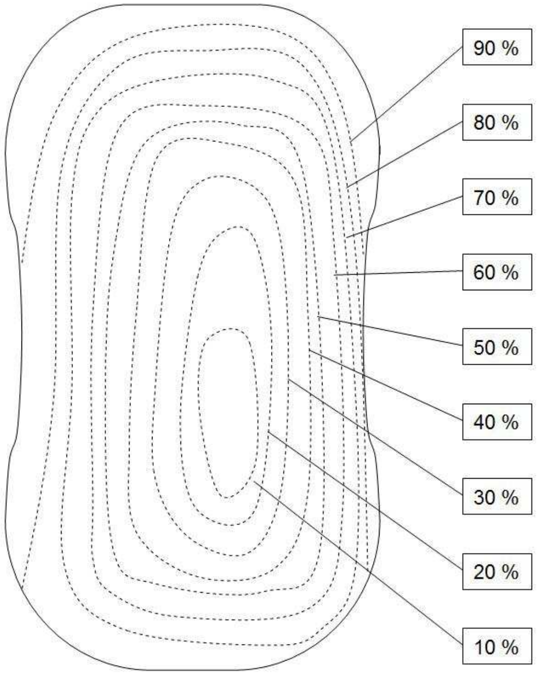
- minimum peak flow rate = 10 g/s
- 100% SOC → p_{vessel} = 350 bar
- minimum injection pressure = 5 bar
- SOVs are immediately shut after crash



Simplified fuel system layout of a hydrogen powered car with ICE

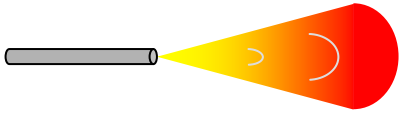
What is risk?

risk = **probability of occurrence** of a damage **x** negative **consequences** of a damage

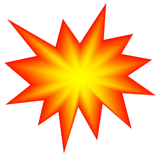


lethal injury due to:

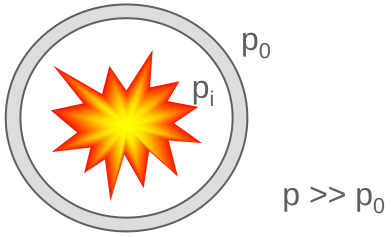
1. jet fire



2. flash fire



3. explosion



Implementation

Criteria for lethal injury:

- jet flame: area inside the cone of a jet flame
- flash-fire: area inside the flash-fire
- explosion: area surrounding explosion where $p_{peak} > 30$ kPa

risk = probability of occurrence x „lethal area“

Problem: „Lethal area“ is described by nonlinear functions

→ Risk optimisation with the help of a nonlinear optimisation approach
(e.g. „gradient descent method)!

Gradient descent method

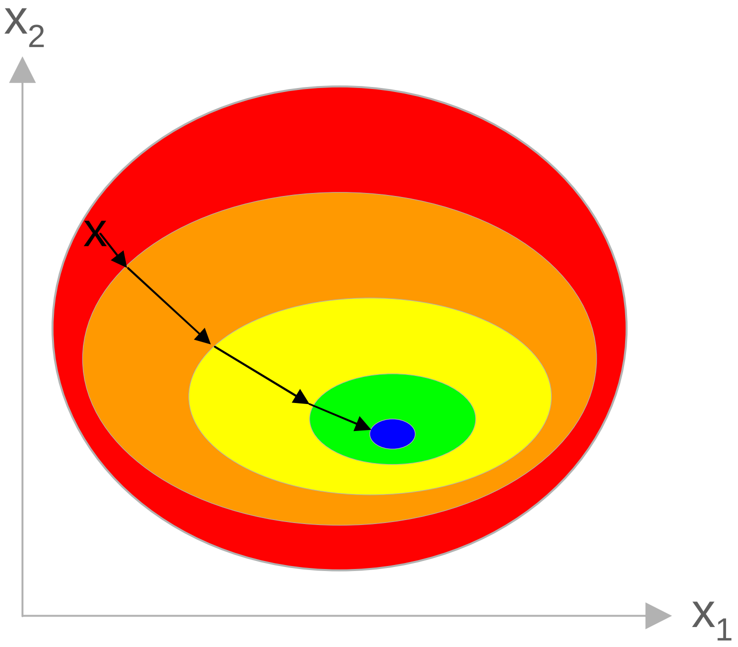
Iterative approach:

$$\boxed{x^{(i+1)} = x^{(i)} - \alpha^{(i)} \nabla f\left(x^{(i)}\right)}$$

$x^{(i)}$: iteration parameter x after i numbers of iteration

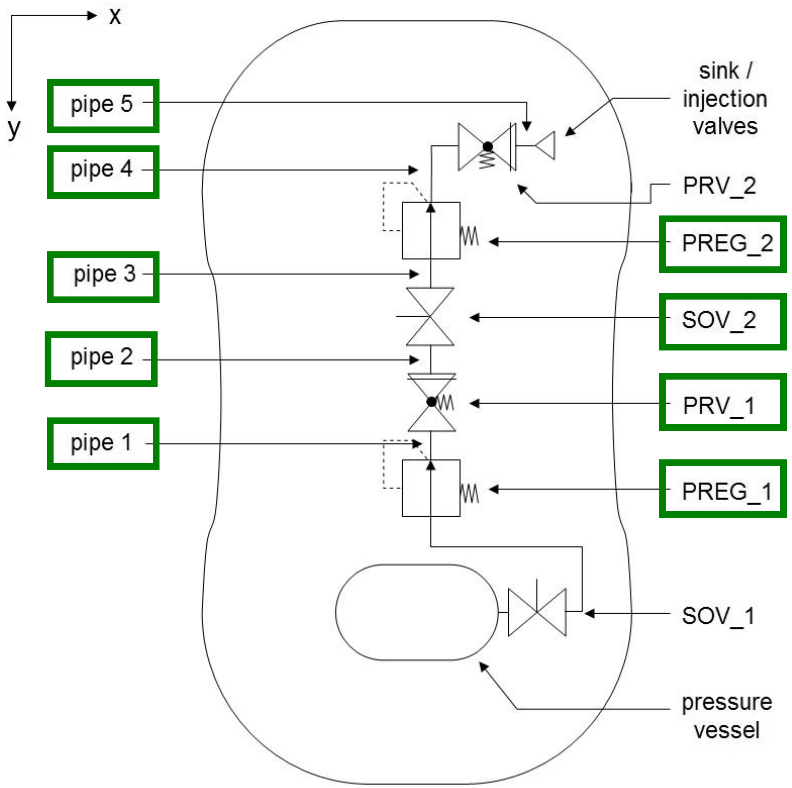
$\alpha^{(i)}$: step size

$\nabla f(x^{(i)})$: gradient of the function $f(x^{(i)})$



Visualisation of the gradient descent approach in terms of a two-dimensional minimisation problem

Variables and boundary conditions



component	variable parameter	unit	initial value	min. value	max. value
pipe 1	d	[mm]	8	4	10
pipe 2	d	[mm]	8	4	10
pipe 3	d	[mm]	8	4	10
pipe 4	d	[mm]	8	4	10
pipe 5	d	[mm]	8	4	10
PREG_1	p	[bar]	150	100	200
PREG_1	y**	[-]	0.58	0.56	0.62
PREG_2	p	[bar]	20	15	25
PREG_2	y**	[-]	0.23	0.22	0.25
PREG_2	x*	[-]	0.5	0.48	0.51
SOV_2	y**	[-]	0.38	0.33	0.42
PRV_1	y**	[-]	0.5	0.48	0.52

* Relative horizontal position with respect to car-width

** Relative vertical position with respect to car-length

Results and conclusion

component	variable parameter	unit	initial value	final value
pipe 1	d	[mm]	8	4.01
pipe 2	d	[mm]	8	4.05
pipe 3	d	[mm]	8	4.39
pipe 4	d	[mm]	8	4.47
pipe 5	d	[mm]	8	5.28
PREG_1	p	[bar]	150	112.75
PREG_1	y**	[-]	0.58	0.615
PREG_2	p	[bar]	20	15.72
PREG_2	y**	[-]	0.23	0.25
PREG_2	x*	[-]	0.5	0.506
SOV_2	y**	[-]	0.38	0.42
PRV_1	y**	[-]	0.5	0.52

* Relative horizontal position with respect to car-width

** Relative vertical position with respect to car-length

Outcomes:

- decrease of pipe diameters
- reduction of PREG exit pressures
- movement of components towards areas with lower probability of damage

Safety benefit:

- Overall risk reduction of (only) 2 % with respect to initial parameters
- Neglecting the risk associtated with the pressure vessel reveals a risk reduction of 84 %!

Summary and outlook

Main outcomes:

- Nonlinear optimisation methods are a useful tool to optimise the layout of hydrogen fuel systems
- The risk emanating from the downstream parts of a hydrogen fuel system (system without pressure vessel) can be reduced by more than 80 %

Future plans:

- Development of a software based tool that analyses the logical interaction of the system components and optimises the associated risk
  - → *Which components should be implemented?*
  - → *In which order should the components be arranged?*

Thank you for your attention !

Jean Meyer

jean.meyer@itd-in.de