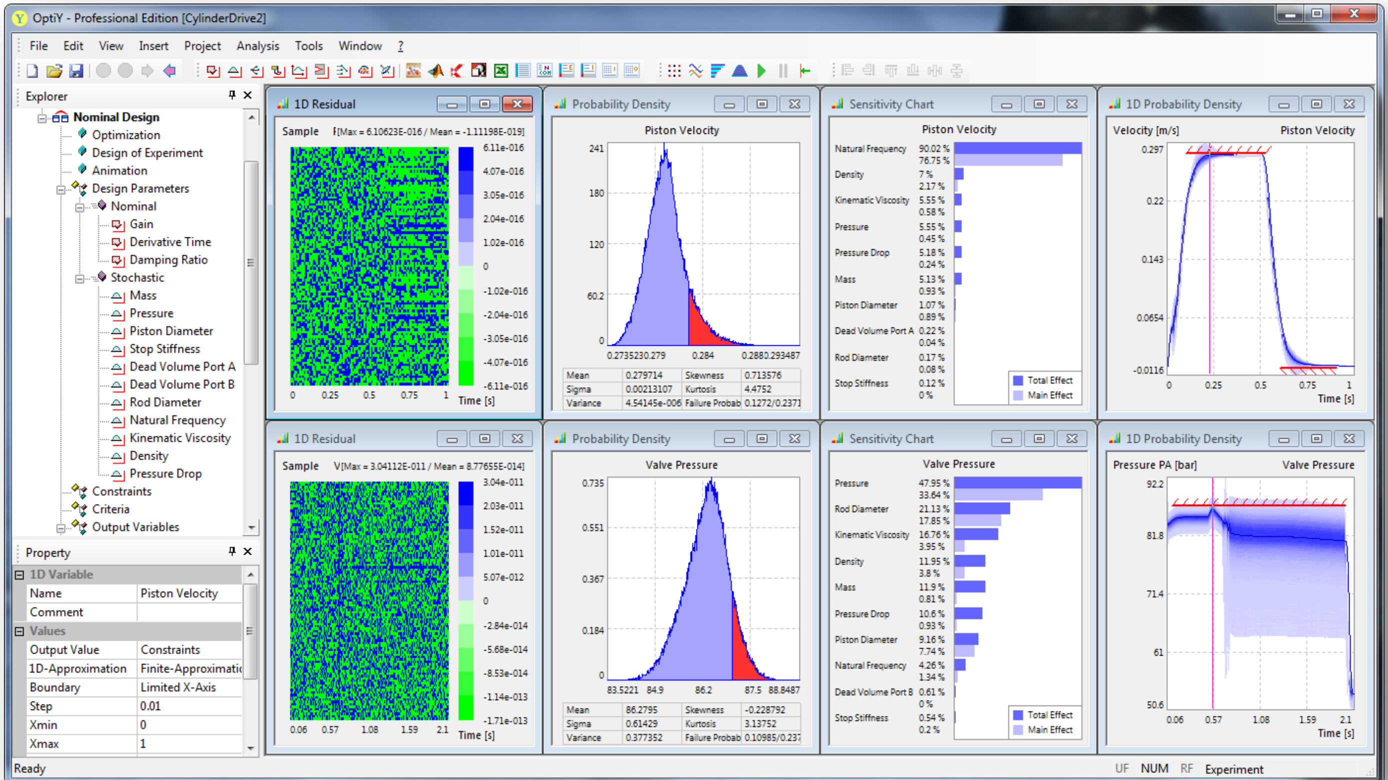
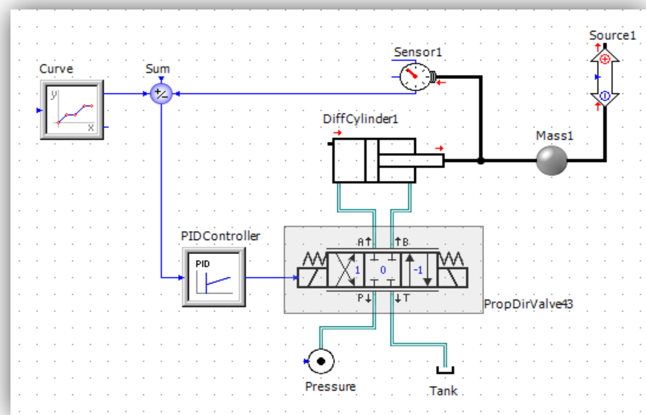
Robust Design of a Hydraulic Cylinder Drive



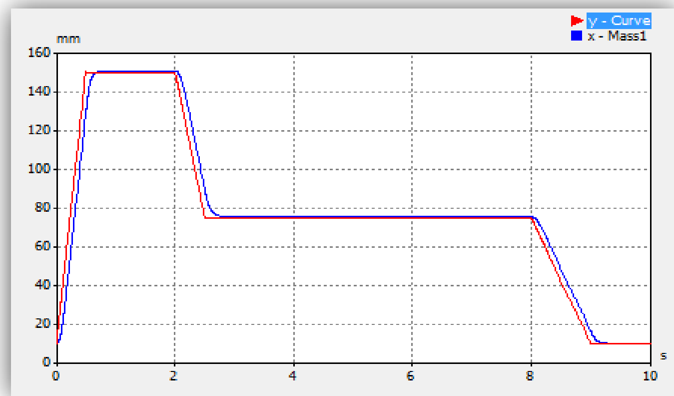
OptiY GmbH - Germany

www.optiy.eu

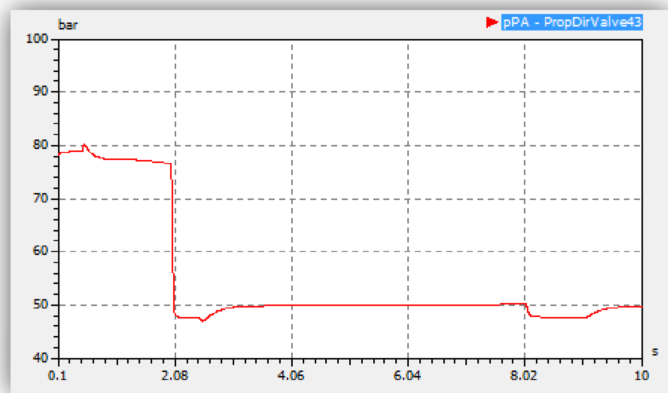
Dynamical Simulation of the Controlled Cylinder Drive



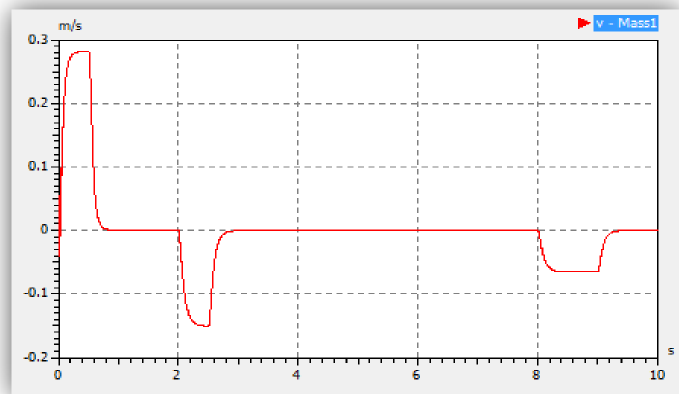
Network Model in SimulationX



Piston Displacement

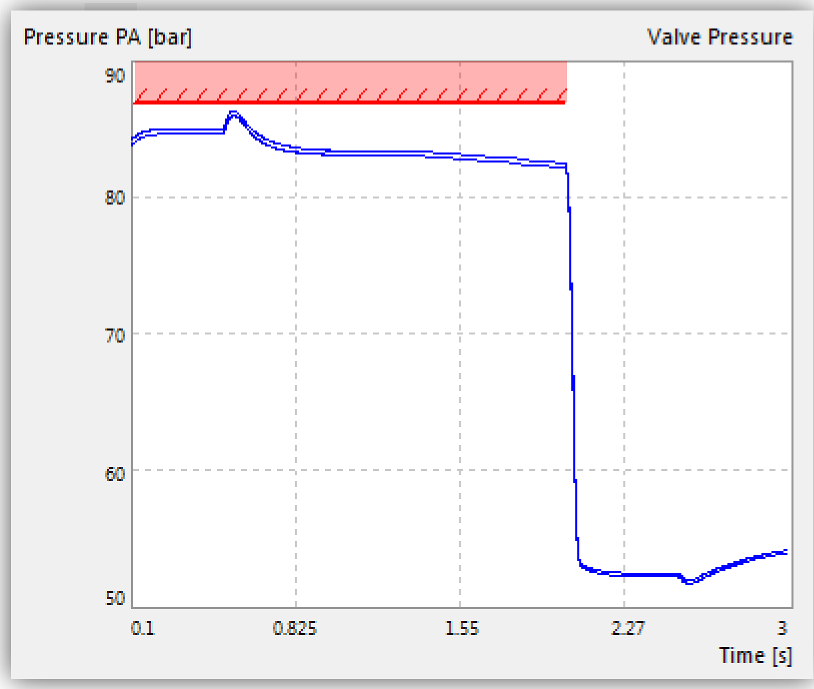


Valve Pressure



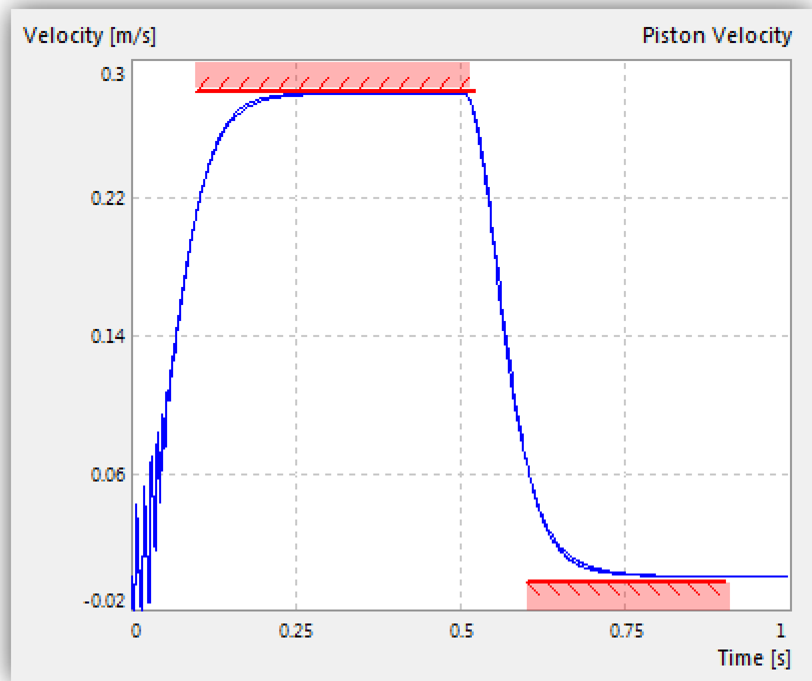
Piston Velocity

Design Specifications = Constraints



Valve Pressure P

P < 87 bar in range [0.1; 2.0] s

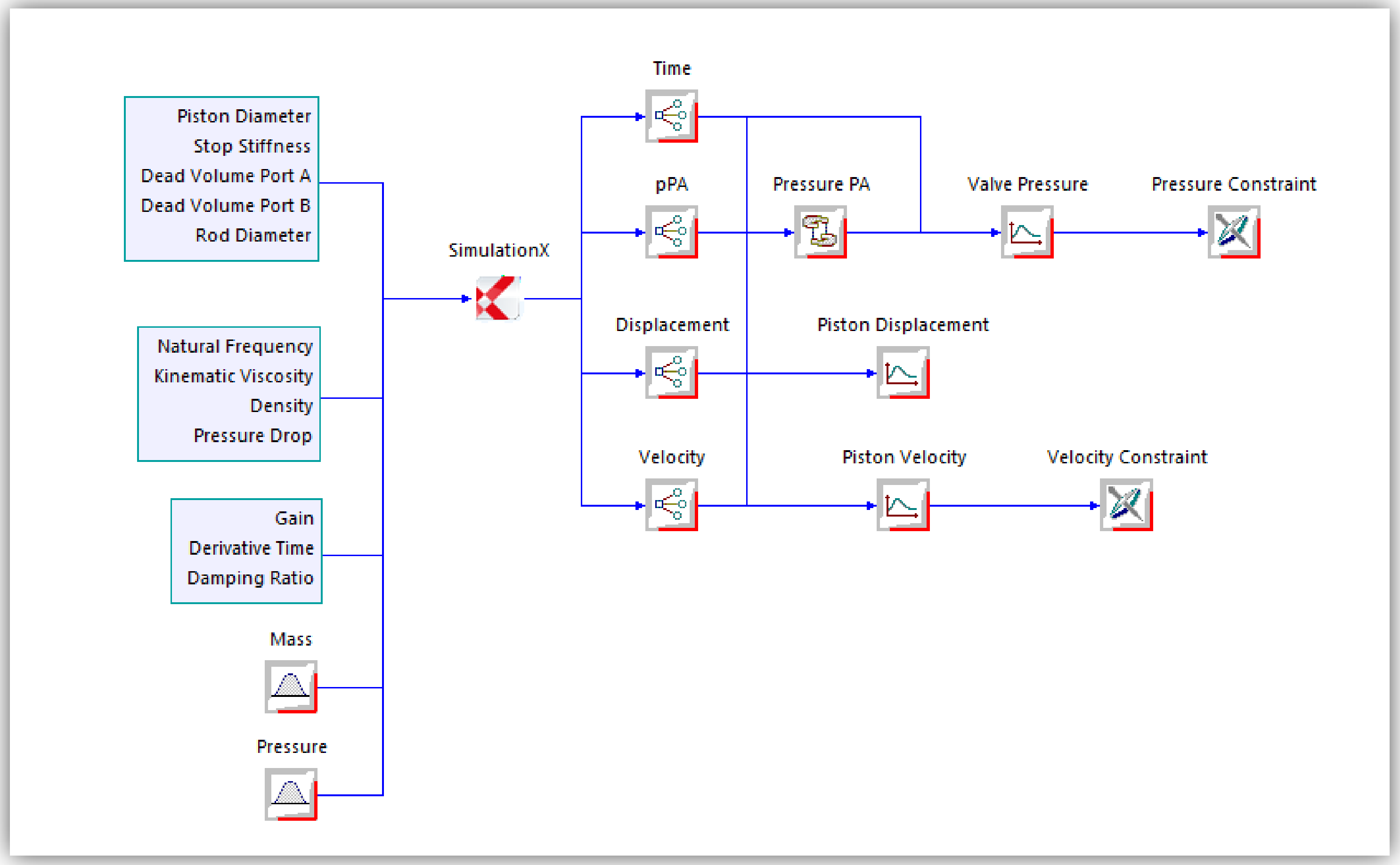


Piston Velocity v

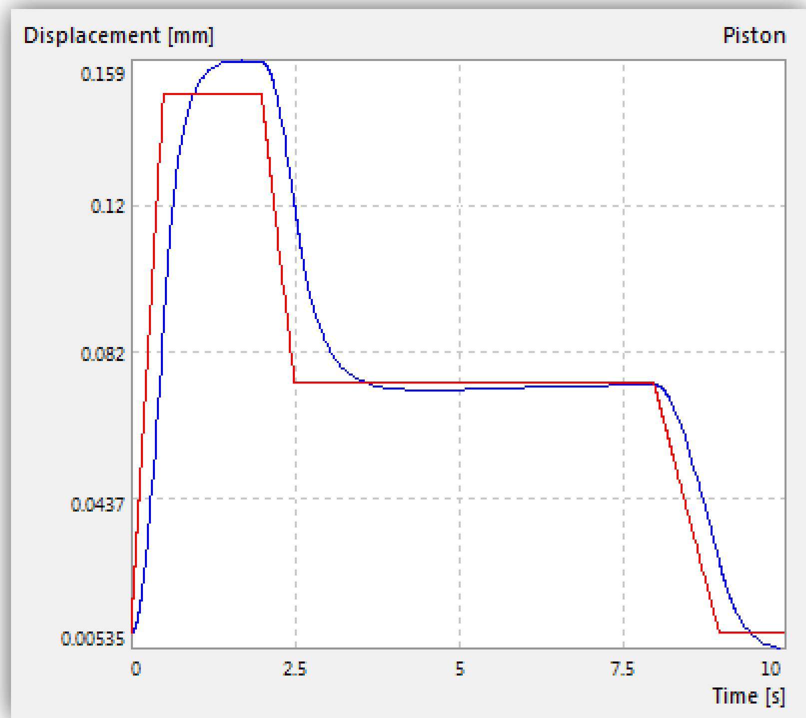
v < 0.282 m/s in range [0.1; 0.52] s

v >-0.003 m/s in range [0.6; 0.90] s

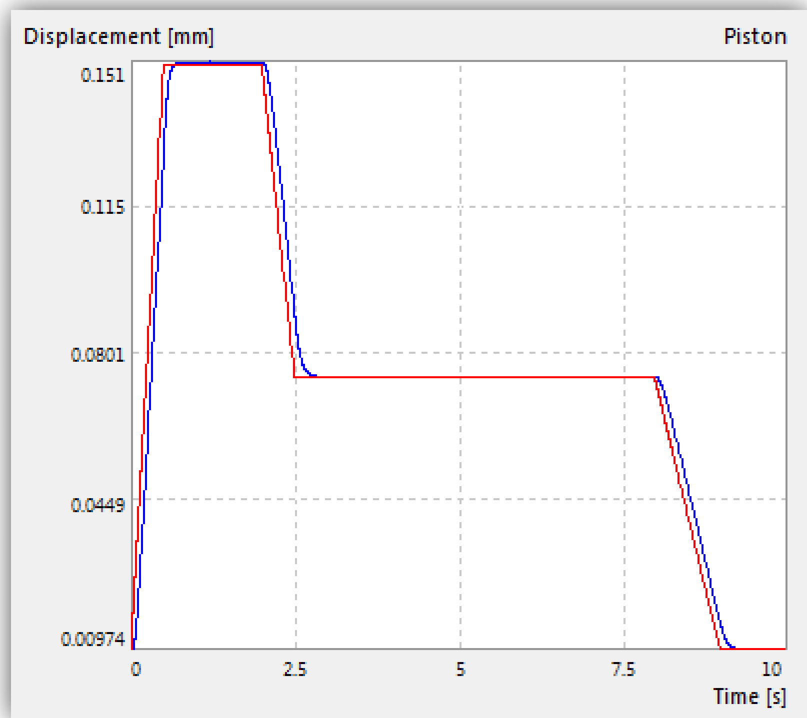
Process Work Flow



PID-Control Parameter Identification through Optimization



Piston Displacement before Optimization



Piston Displacement after Optimization

Parameters

Gain	GP:	19.995	-
Derivative Time	TdD:	0.015801	s
Damping Ratio	TiI:	0.97974	s

www.optiy.eu

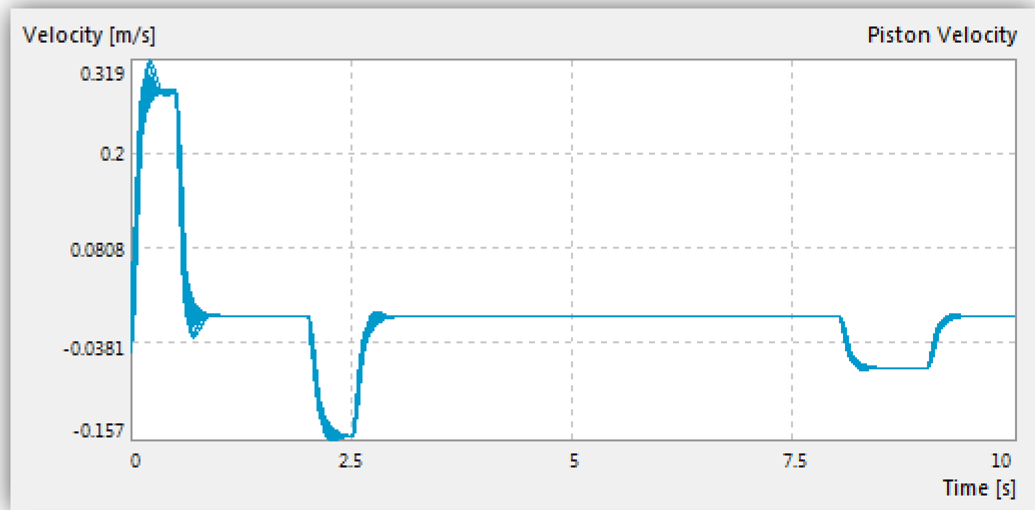
Robustness Evaluation of Nominal Design

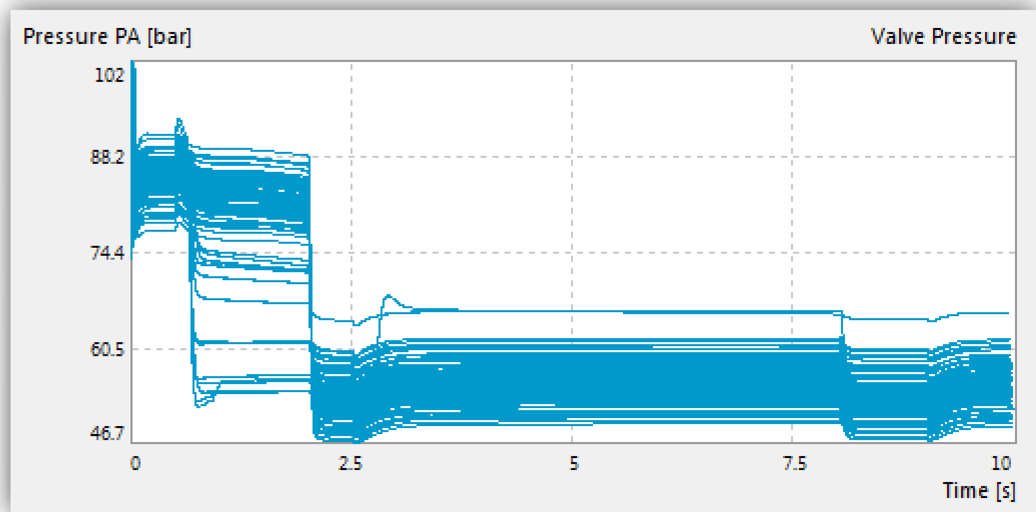
Design Parameters

Name	Nom...	Tolera...	Unit
Mass	100	4	kg
Pressure	100	4	bar
Piston Diameter	50	1	mm
Stop Stiffness	50	4	kN/mm
Dead Volume Port A	50	4	cm^3
Dead Volume Port B	50	4	cm^3
Rod Diameter	36	1	mm
Natural Frequency	10	5	Hz
Kinematic Viscosity	41	2	mm^2/s
Density	0.89	0.01	g/cm^3
Pressure Drop	35	4	bar

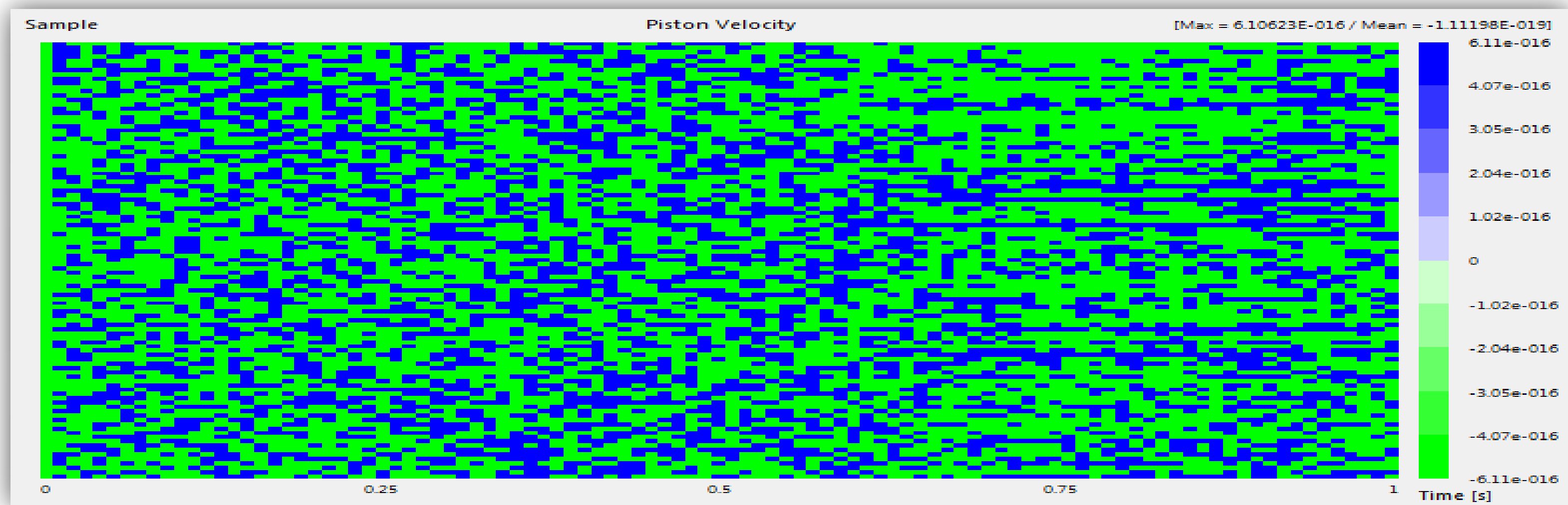
Parameter and Process Uncertainties for Nominal Design

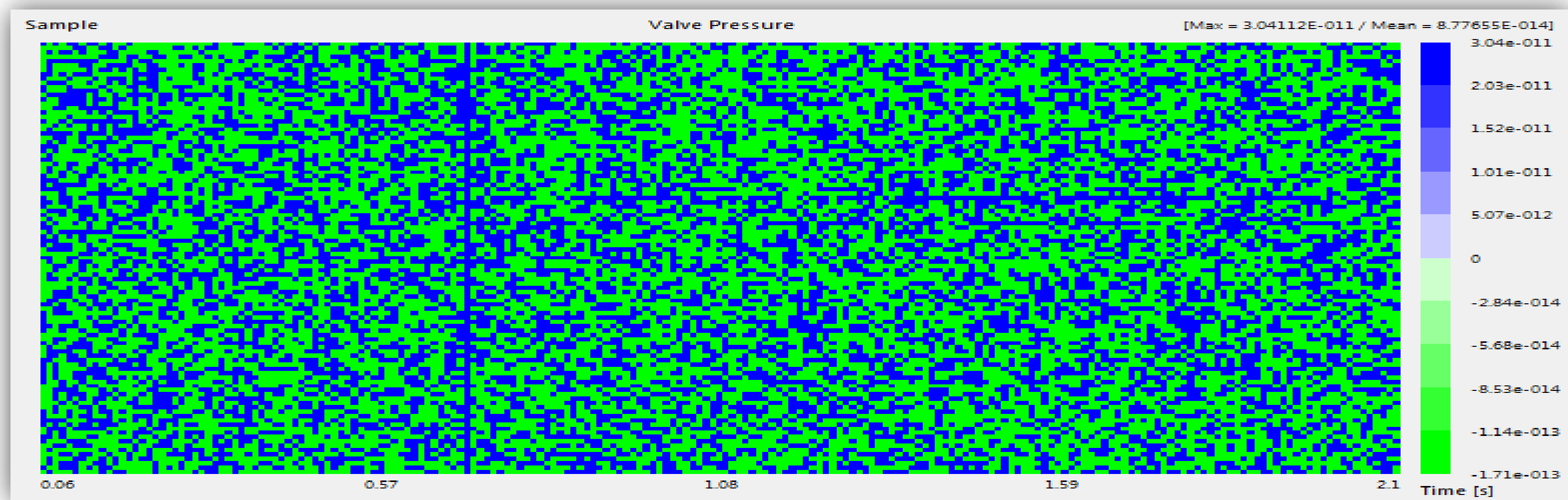
Design of Experiment
100 Model Calculations





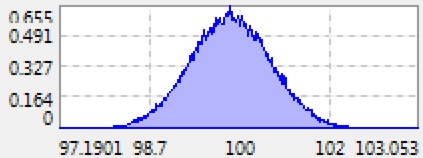
Residual Plot for 1D-Meta-Models





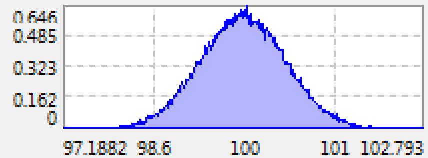
Design and Process Uncertainties

Mass



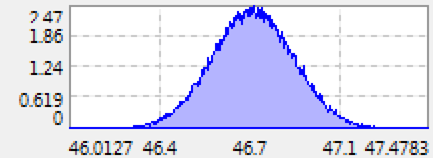
Mean	99.9992	Skewness	-0.00750092
Sigma	0.664907	Kurtosis	2.9839
Variance	0.442101		

Pressure



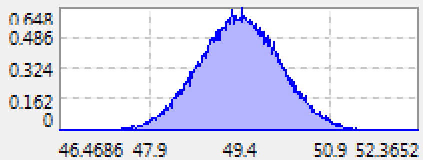
Mean	99.9991	Skewness	0.0124019
Sigma	0.667636	Kurtosis	3.00035
Variance	0.445738		

Piston Diameter



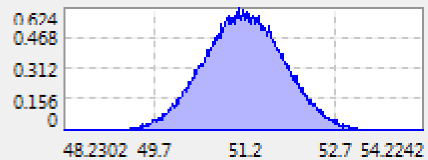
Mean	46.7655	Skewness	0.00635831
Sigma	0.167211	Kurtosis	2.9995
Variance	0.0279594		

Stop Stiffness



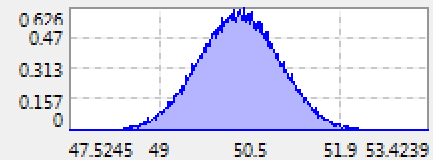
Mean	49.4441	Skewness	-0.0112785
Sigma	0.665226	Kurtosis	2.97764
Variance	0.442526		

Dead Volume Port A



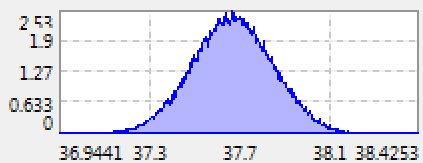
Mean	51.2454	Skewness	-0.00300127
Sigma	0.667047	Kurtosis	3.00093
Variance	0.444951		

Dead Volume Port B



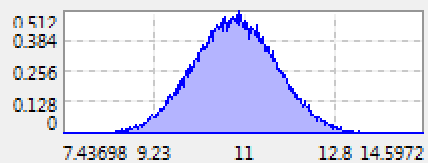
Mean	50.3283	Skewness	-0.00266783
Sigma	0.667145	Kurtosis	3.0076
Variance	0.445083		

Rod Diameter



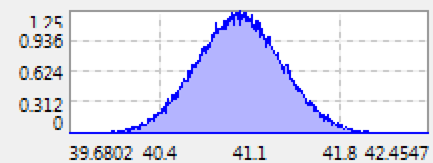
Mean	37.6633	Skewness	0.00211408
Sigma	0.167268	Kurtosis	2.98827
Variance	0.0279786		

Natural Frequency



Mean	10.8618	Skewness	0.00148864
Sigma	0.833224	Kurtosis	3.01093
Variance	0.694263		

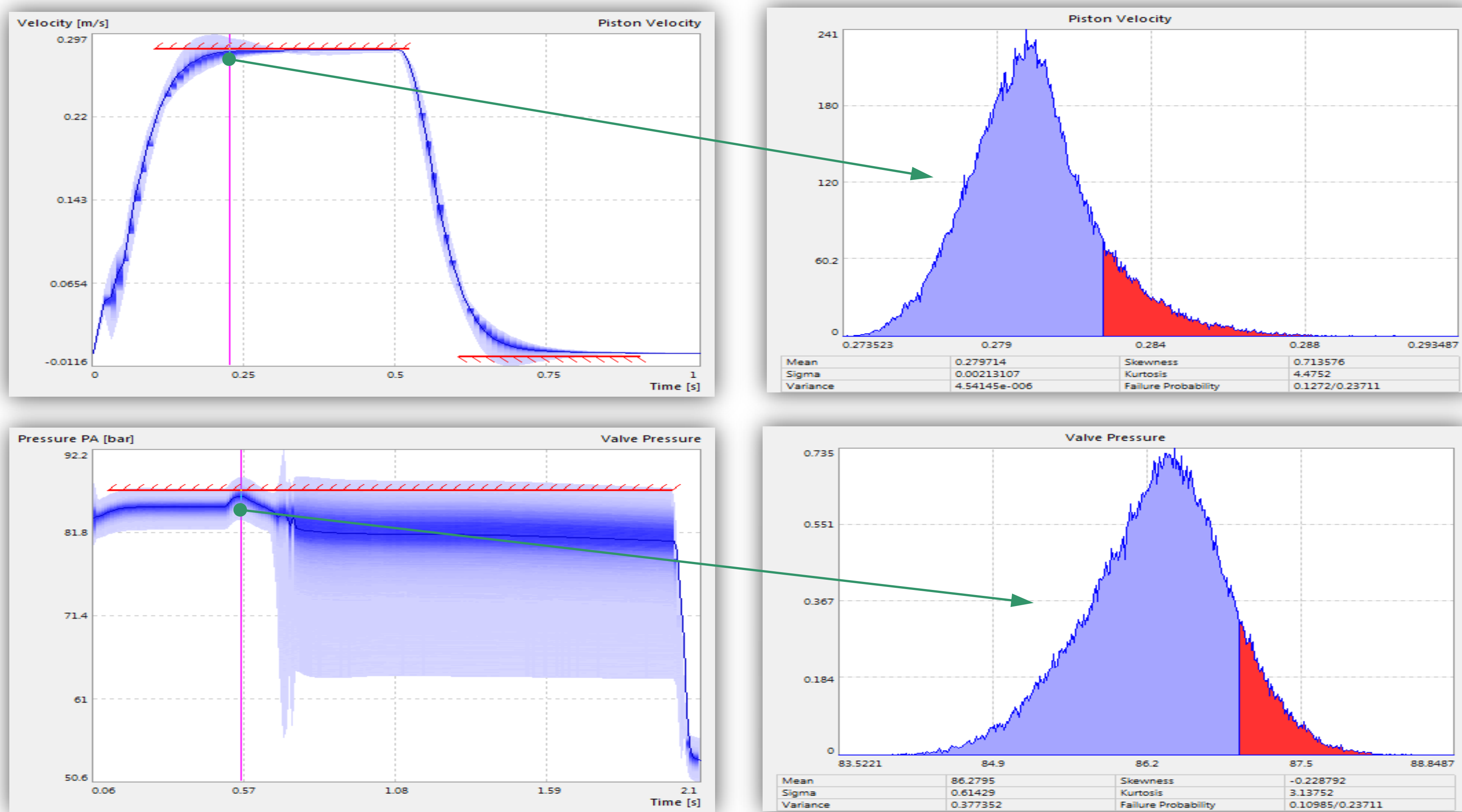
Kinematic Viscosity



Mean	41.0009	Skewness	0.00785149
Sigma	0.334002	Kurtosis	3.00662
Variance	0.111557		

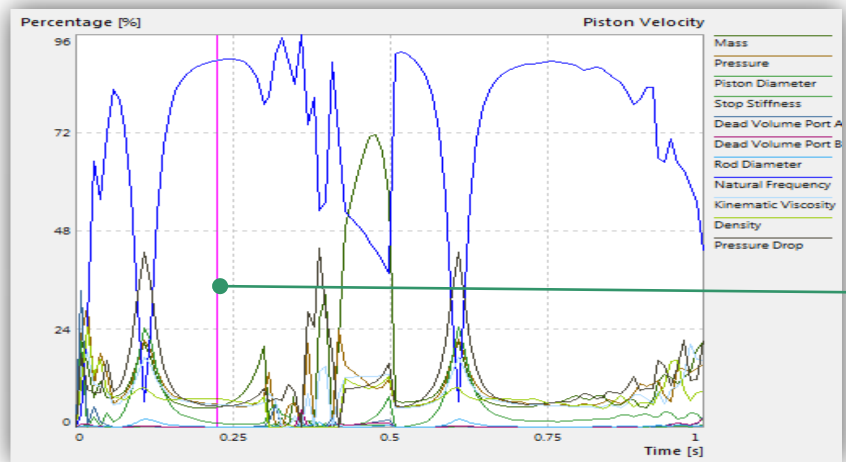
100.000 Samples

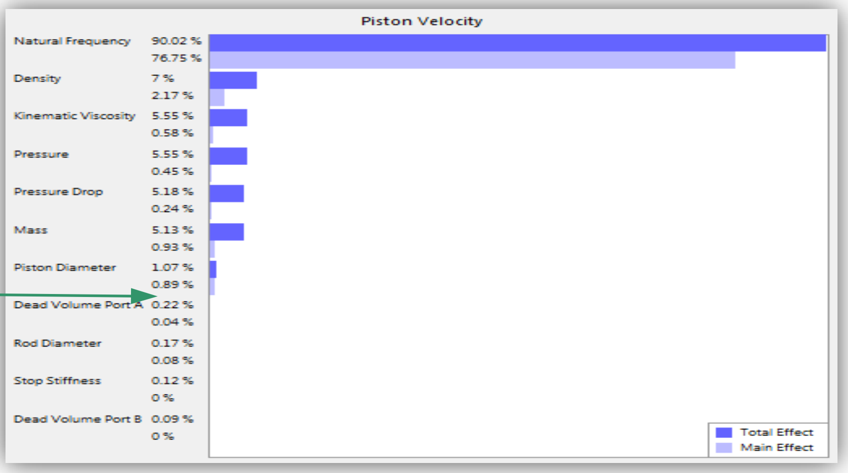
Probabilistic Simulation of Nominal Design

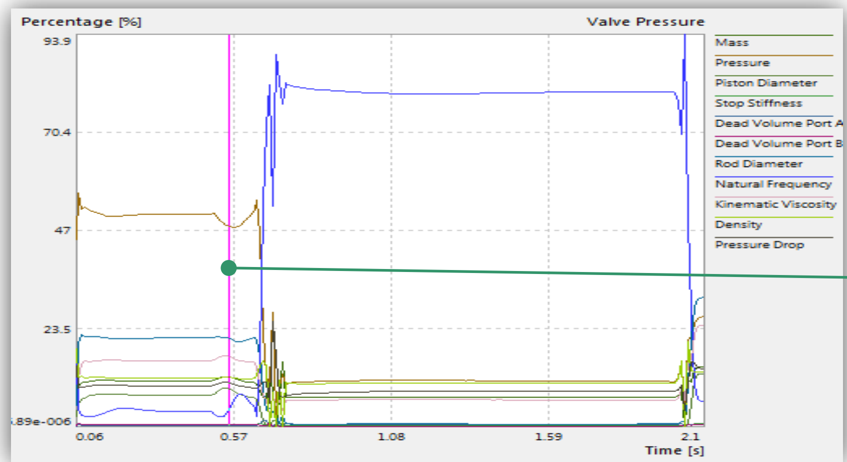


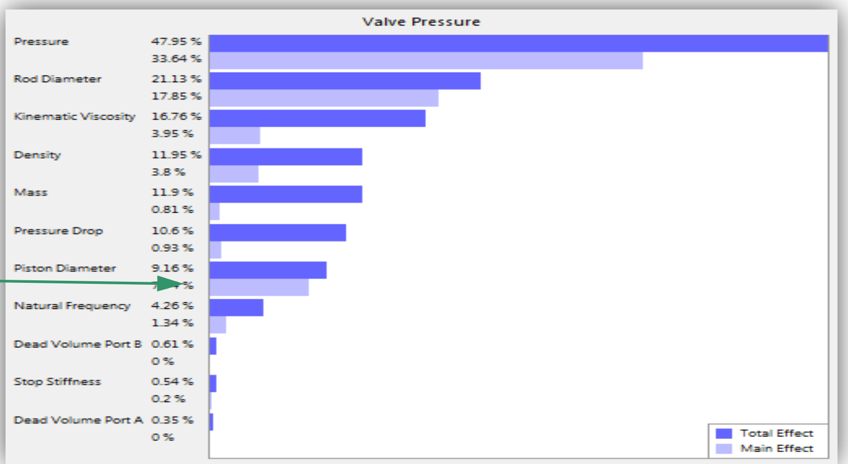
Failure Probability = 23.71%

Sensitivity Analysis of Nominal Design

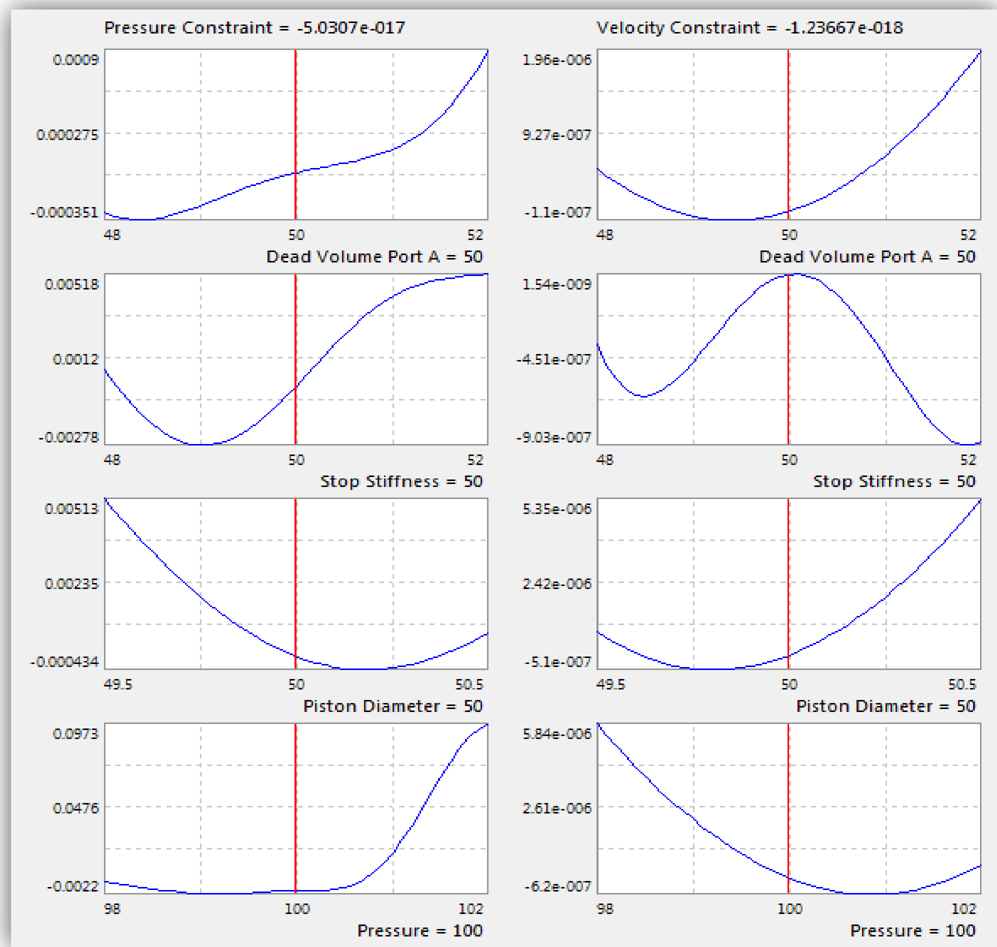


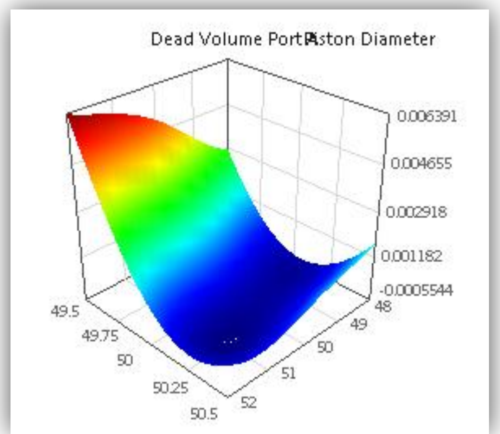


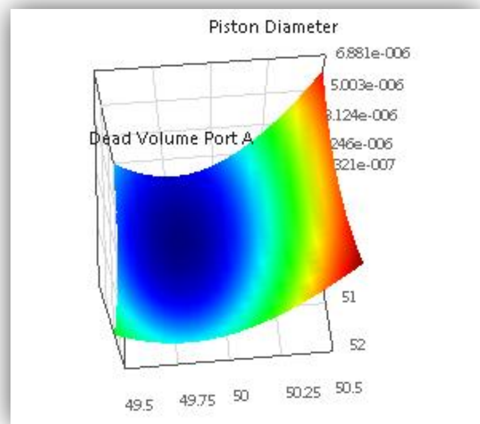




Meta Models of the Cylinder Drive

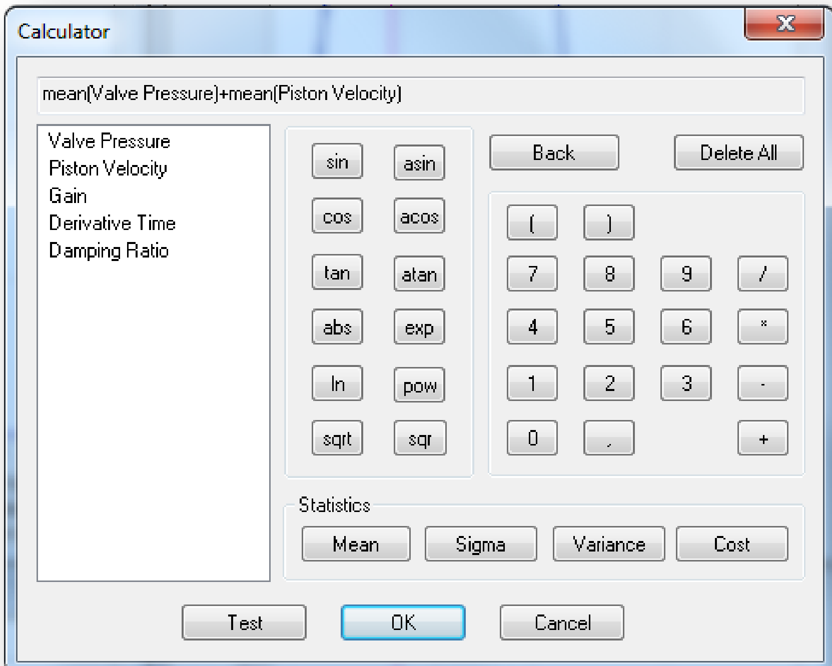




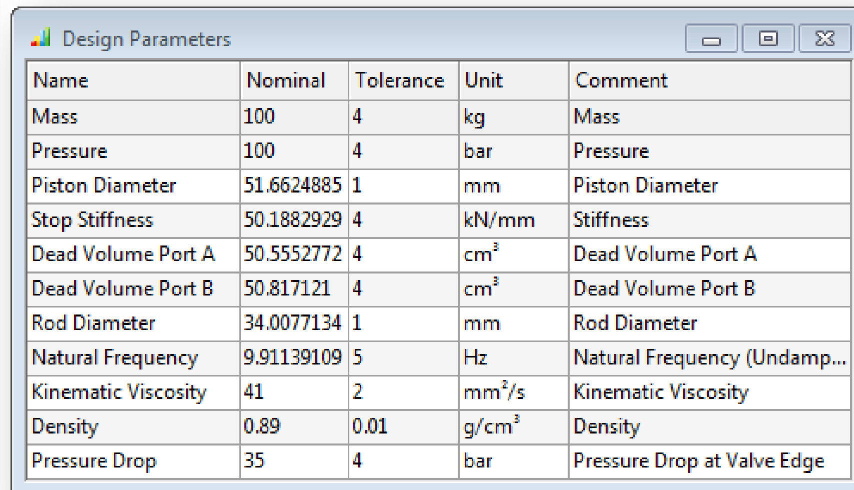


www.optiy.eu

Robust Design Optimization



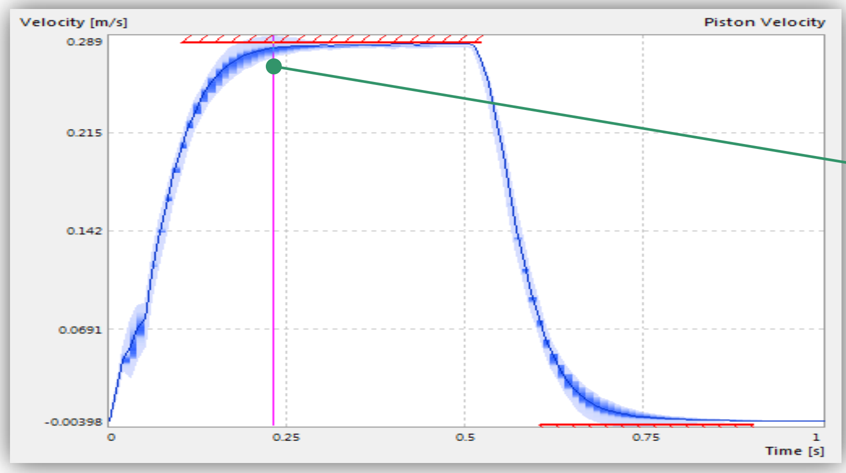
Design Objective for the Virtual Robust Optimization Process

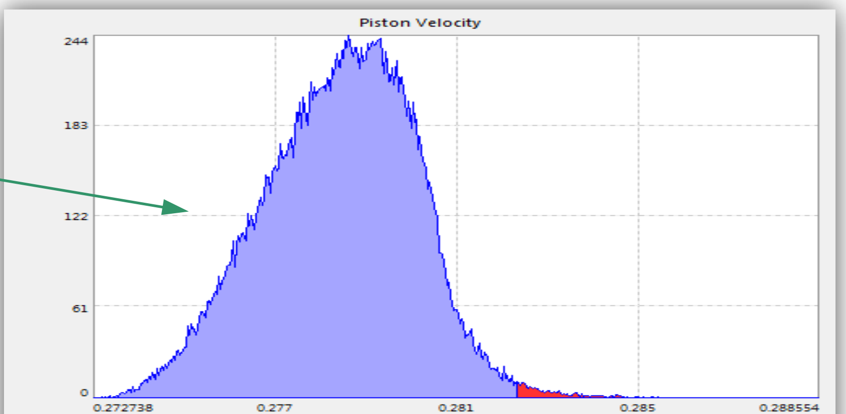


Name	Nominal	Tolerance	Unit	Comment
Mass	100	4	kg	Mass
Pressure	100	4	bar	Pressure
Piston Diameter	51.6624885	1	mm	Piston Diameter
Stop Stiffness	50.1882929	4	kN/mm	Stiffness
Dead Volume Port A	50.5552772	4	cm^3	Dead Volume Port A
Dead Volume Port B	50.817121	4	cm^3	Dead Volume Port B
Rod Diameter	34.0077134	1	mm	Rod Diameter
Natural Frequency	9.91139109	5	Hz	Natural Frequency (Undamp...
Kinematic Viscosity	41	2	mm^2/s	Kinematic Viscosity
Density	0.89	0.01	g/cm^3	Density
Pressure Drop	35	4	bar	Pressure Drop at Valve Edge

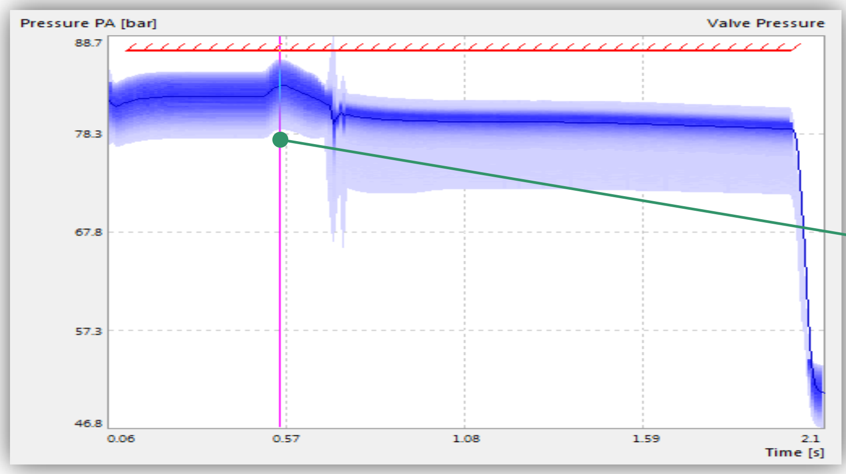
Design and Process Parameters of the Robust Design

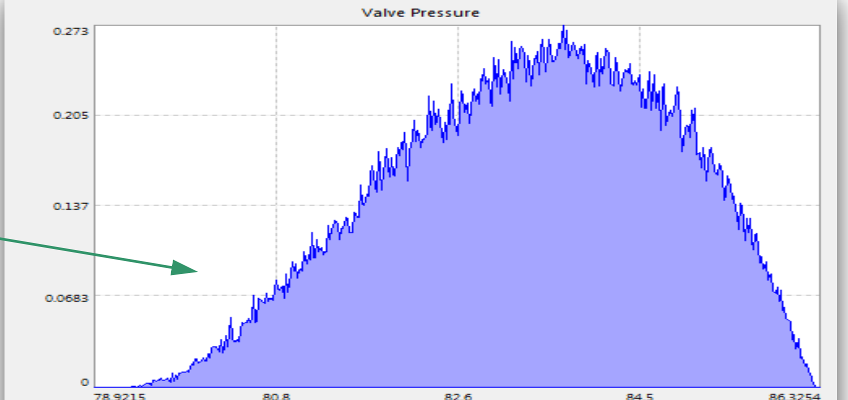
Robust Design Probability





Mean	0.278123	Skewness	-0.0776719
Sigma	0.00165716	Kurtosis	3.02686
Variance	2.74618e-006	Failure Probability	0.009/0.01081

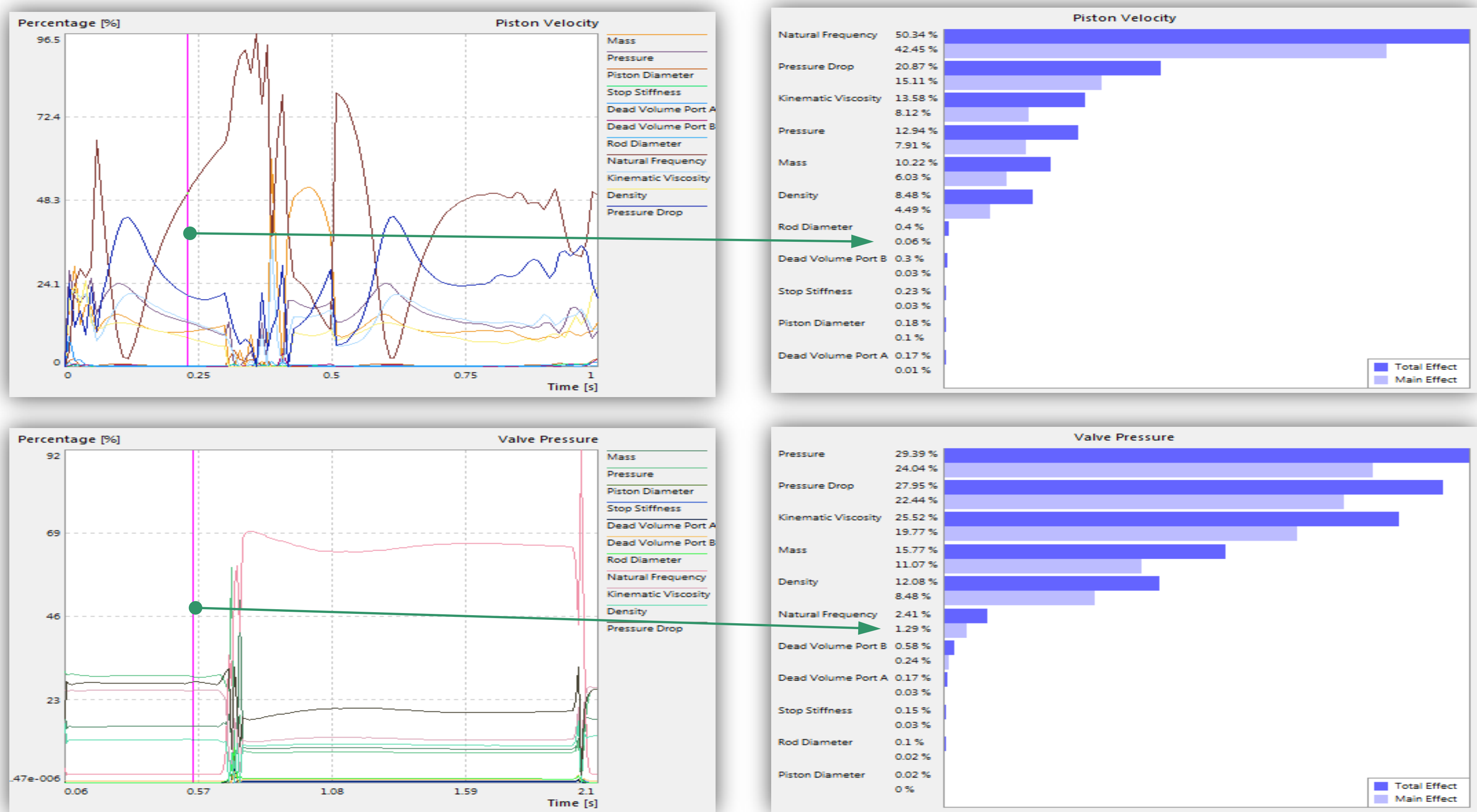




Mean	83.3738	Skewness	-0.241453
Sigma	1.41233	Kurtosis	2.3329
Variance	1.99467	Failure Probability	0/0.01081

Failure Probability = 1.08%

Robust Design Sensitivity



Conclusion

Nominal design using classical nominal simulation cannot warranty the reliability and quality of the products, because the nominal parameters are only one fix value.

Robust design is a power-full tool for design of reliable and quality product in the early design stage without any cost. It considers parameter uncertainties as stochastic distributions.

In the case of the hydraulic cylinder drive, the failure probability has been reduced from **23.71% to 1.08%** for the manufacturing process.

OptiY® is the leading software platform for robust design of all engineering fields using different commercial CAD/CAE-software or in-house codes.