

The image features a close-up of two hands, one resting on the other, with a decorative graphic overlay of overlapping triangles in teal and orange. The text 'MATLAB EXPO 2018 KOREA' is positioned on the right side of the image.

MATLAB EXPO 2018
KOREA

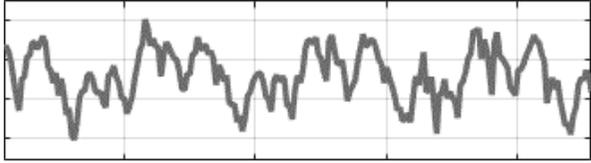
MATLAB EXPO 2018

[Track 3] 물리모델 시뮬레이션을 활용한 고장 예측

김종헌 부장



ฉันต้องการความช่วยเหลือ.



Segítségre van szükségem.

انا بحاجة الى مساعدة.

Necesito ayuda.

Мне нужна помощь.

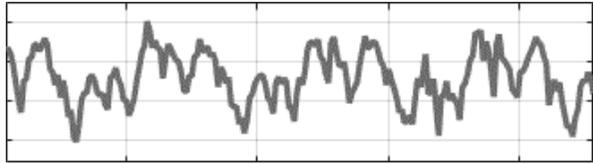
Ich brauche Hilfe.

I need help.

J'ai besoin d'aide.

Χρειάζομαι βοήθεια.

ฉันต้องการความช่วยเหลือ.



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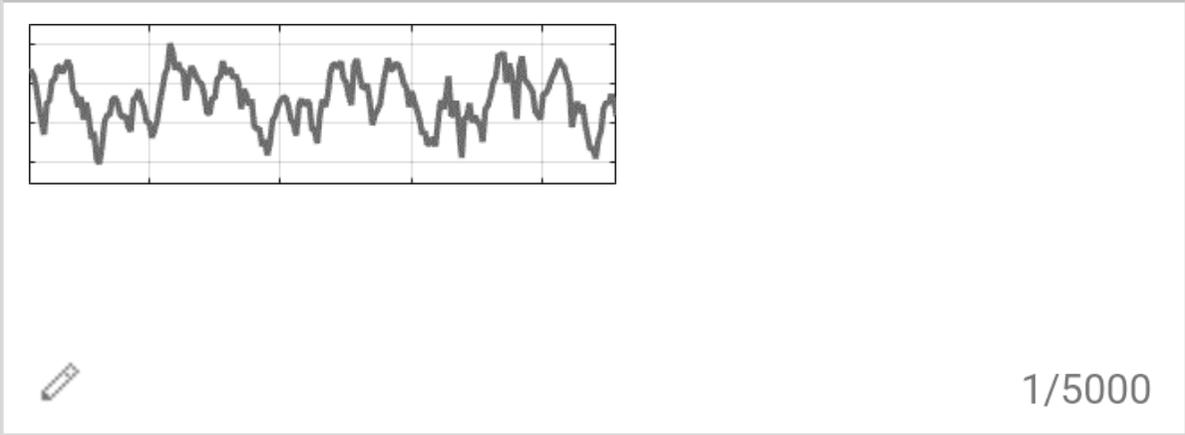


English Spanish French Pump - detected ▼



English Russian Greek ▼

Translate



I need help.

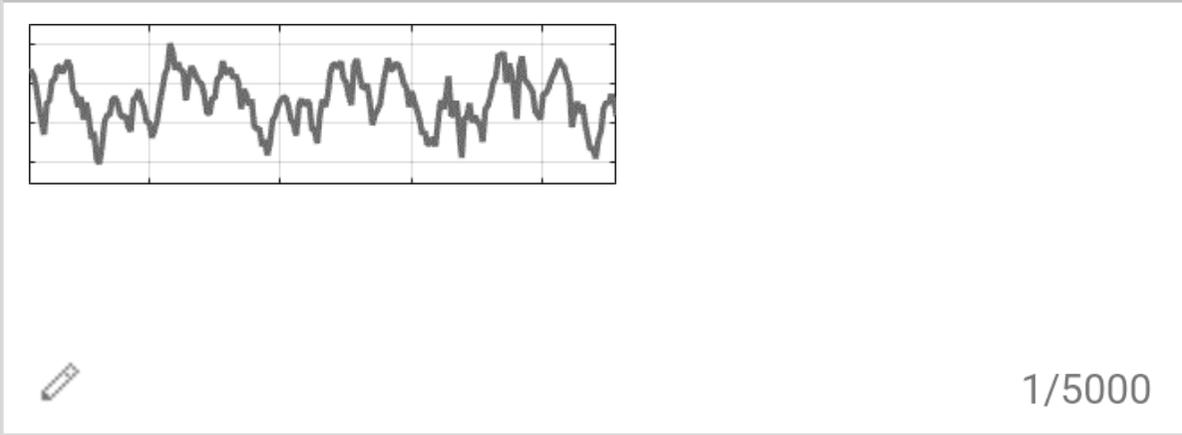


English Spanish French Pump - detected ▾



English Russian Greek ▾

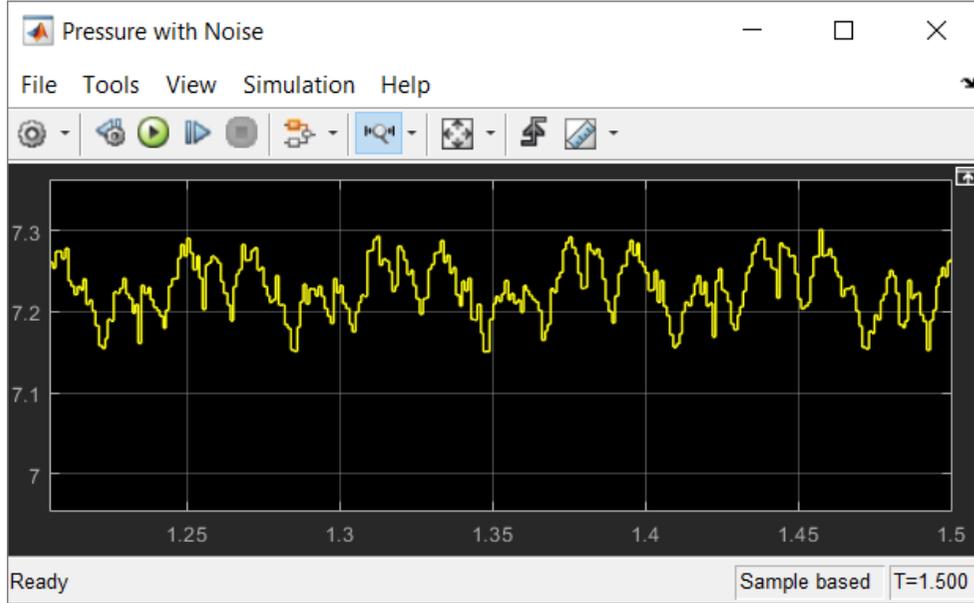
Translate



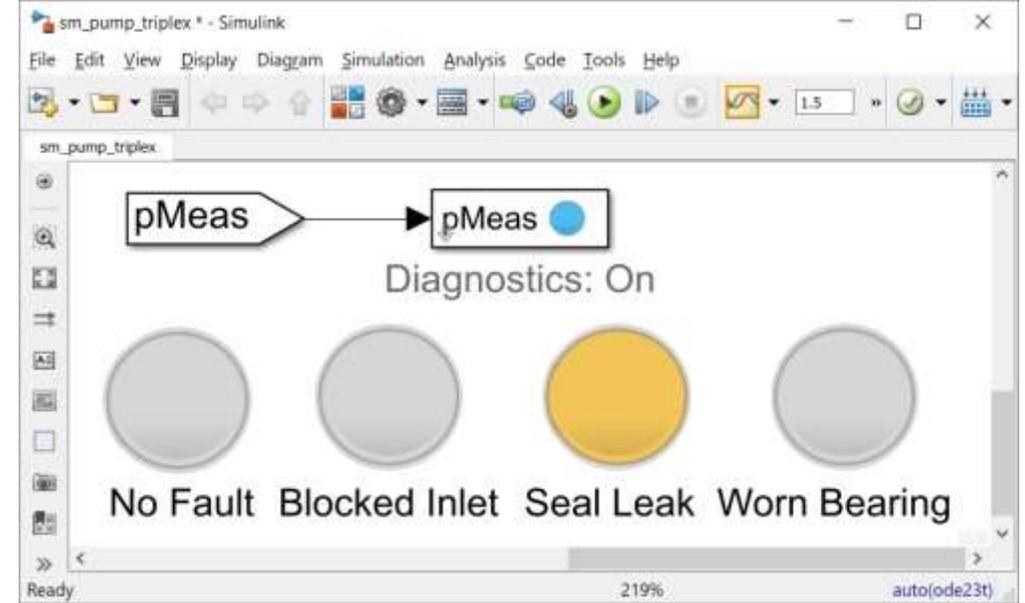
I need help. One of my seals is leaking. I will shut down your line in 5 days 

Prevent system downtime

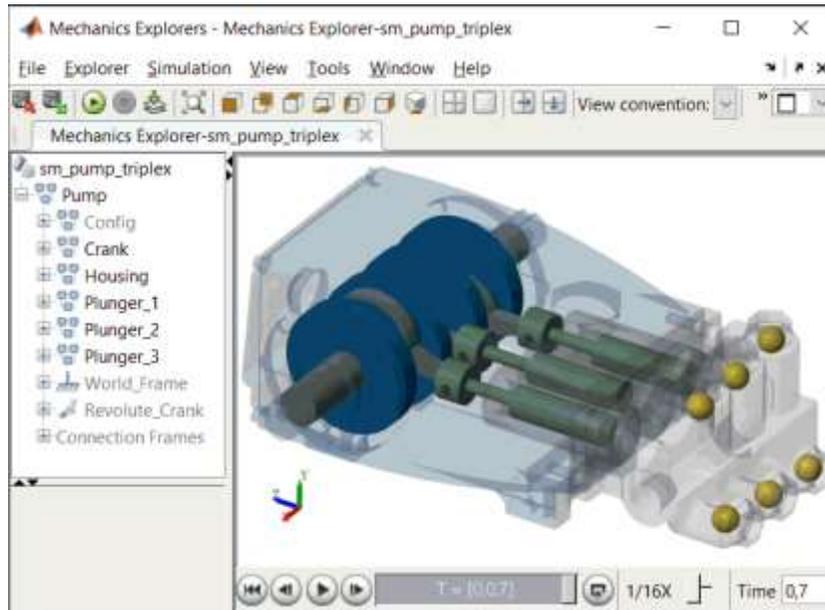
by sending sensor data



to a predictive maintenance algorithm



created
using a
Digital
Twin



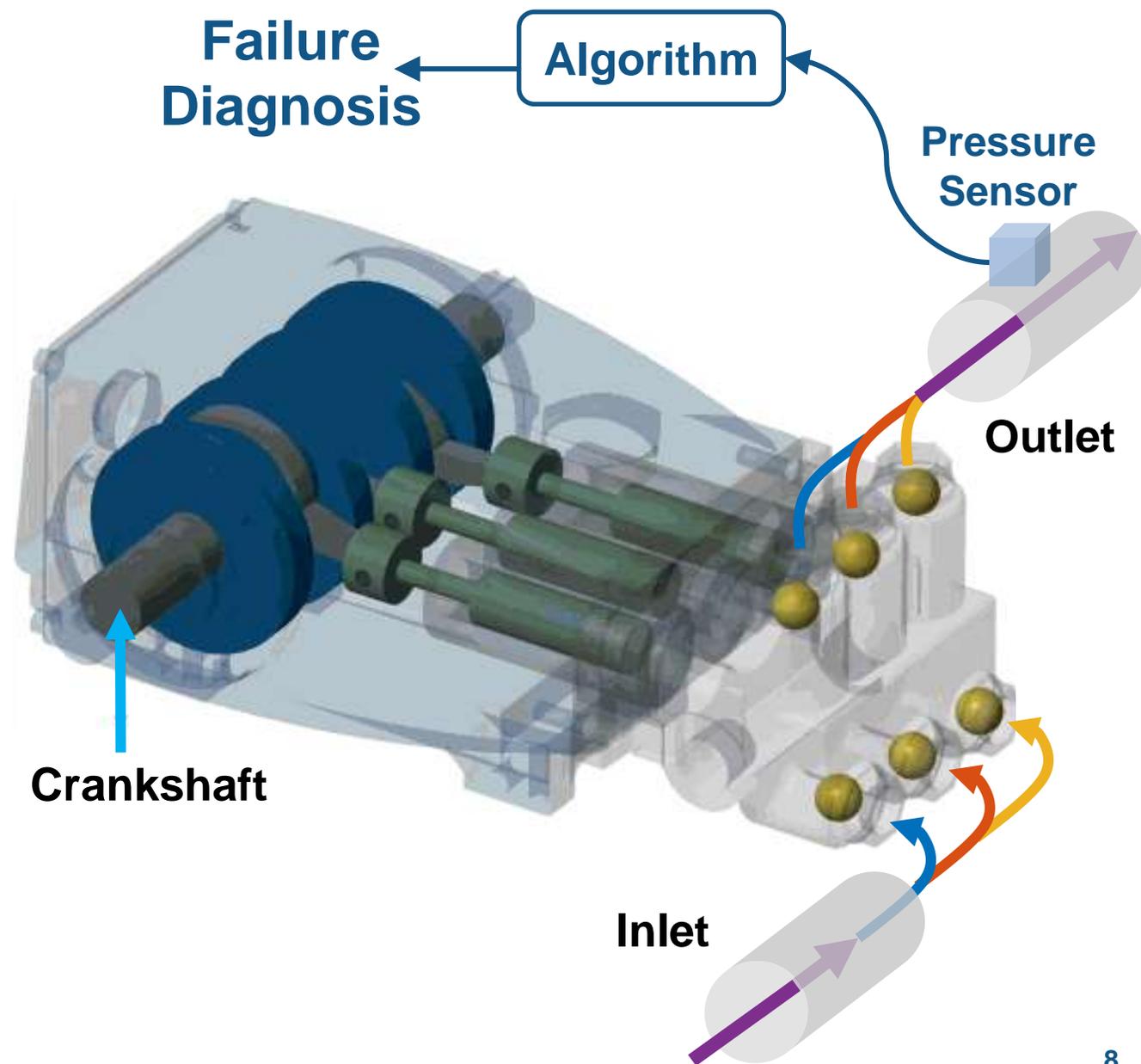
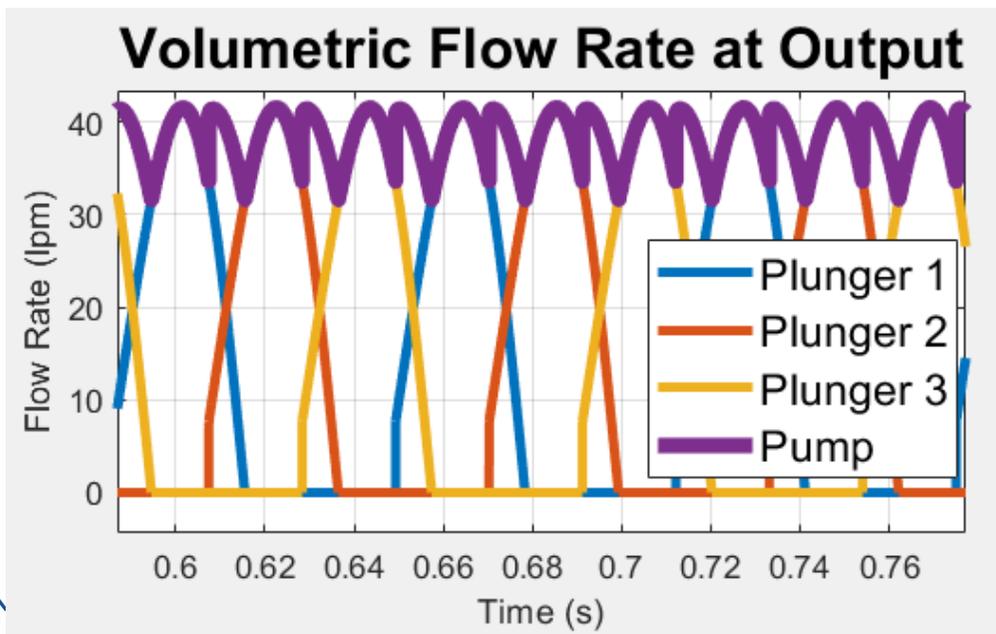
Model 1.18

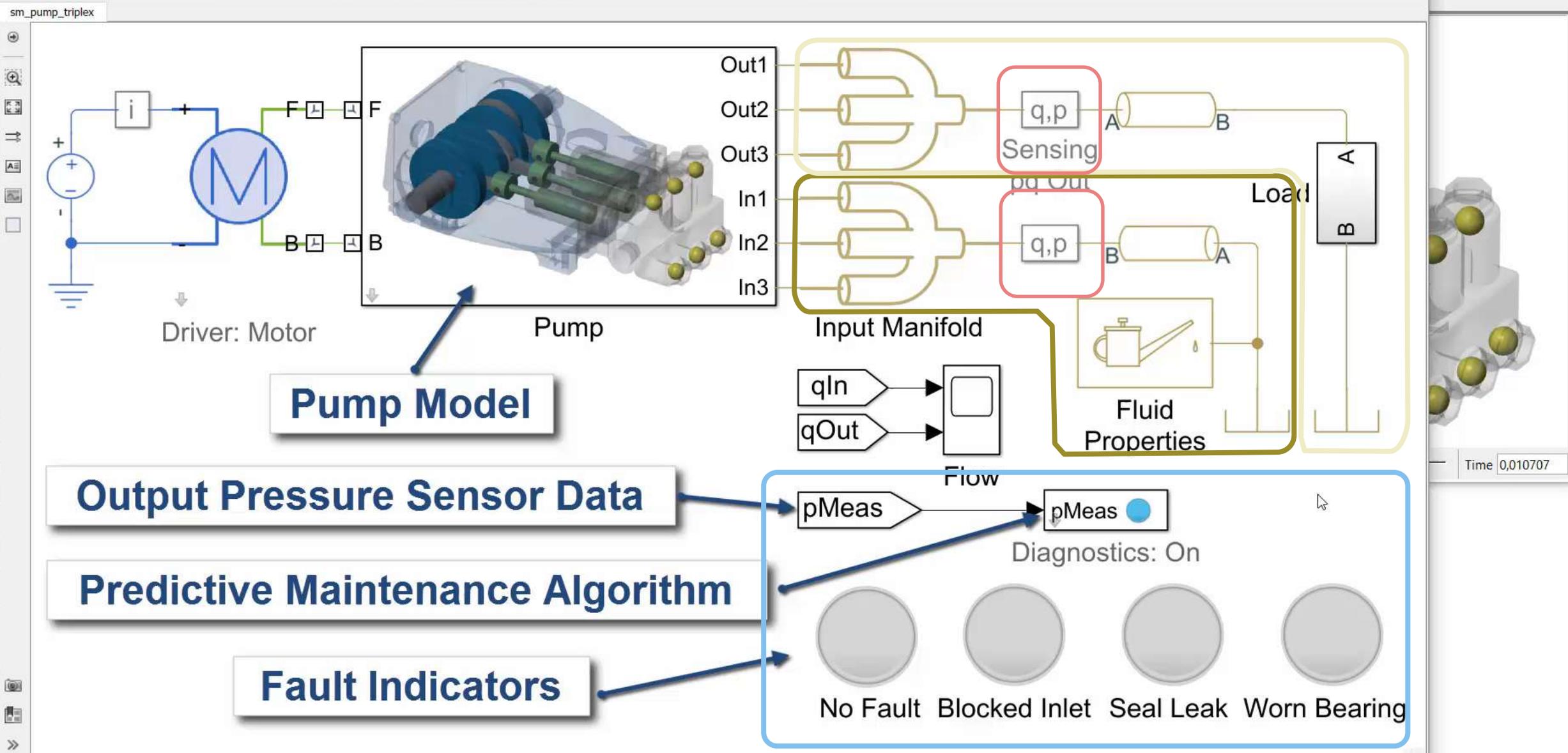
Block P1	88%		12%			
Block P1, Worn Bearing		100%				
Leak P1			100%			
Leak P1, Block P1	4%		96%			
Leak P1, Worn Bearing				100%		
Nominal					100%	
Worn Bearing						100%

and
machine
learning
in MATLAB

Triplex Pump

- Crankshaft drives three plungers
 - Each 120 degrees out of phase
 - One chamber always discharging
 - Smoother flow than single or duplex piston pumps





Pump Model

Output Pressure Sensor Data

Predictive Maintenance Algorithm

Fault Indicators

Flow

pMeas

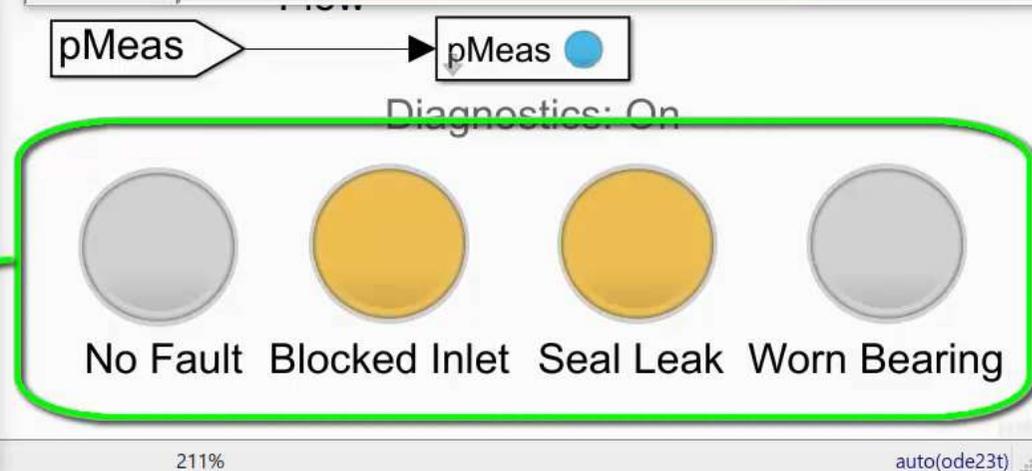
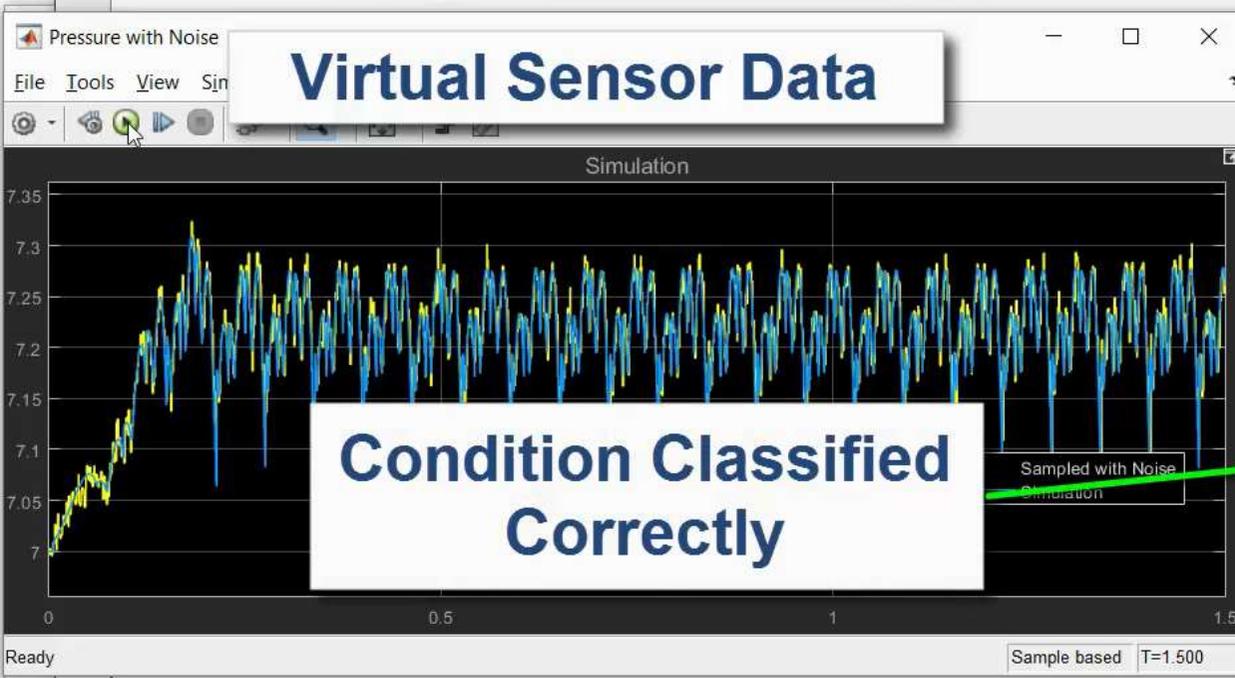
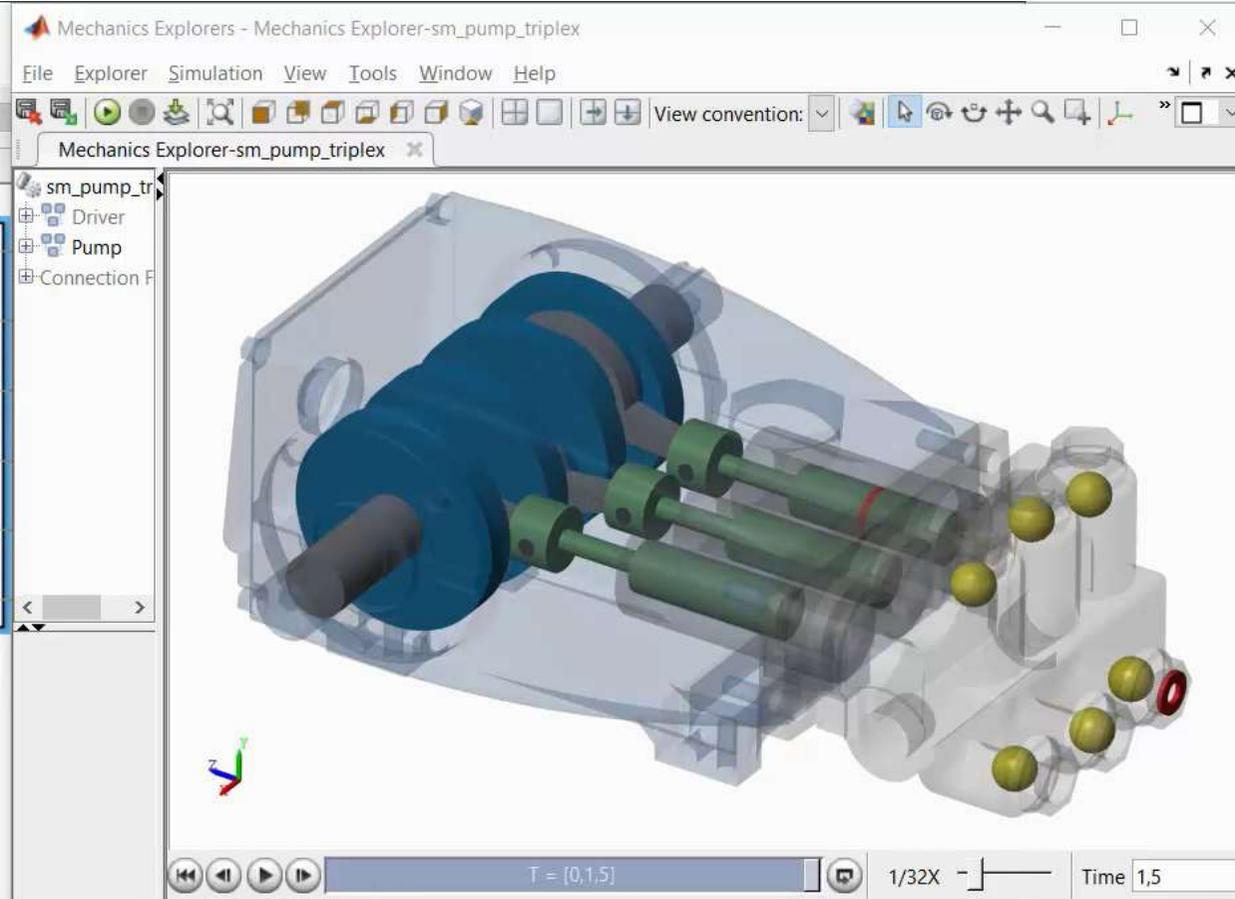
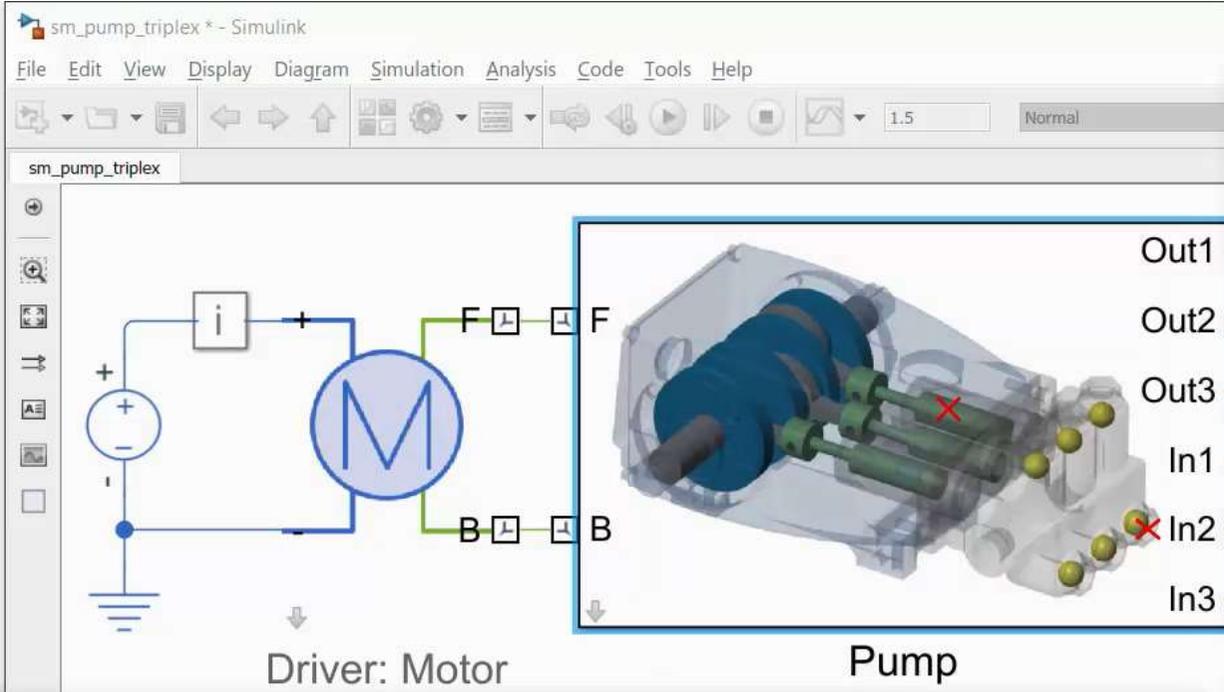
pMeas ●

Diagnostics: On

No Fault Blocked Inlet Seal Leak Worn Bearing



Time 0,010707

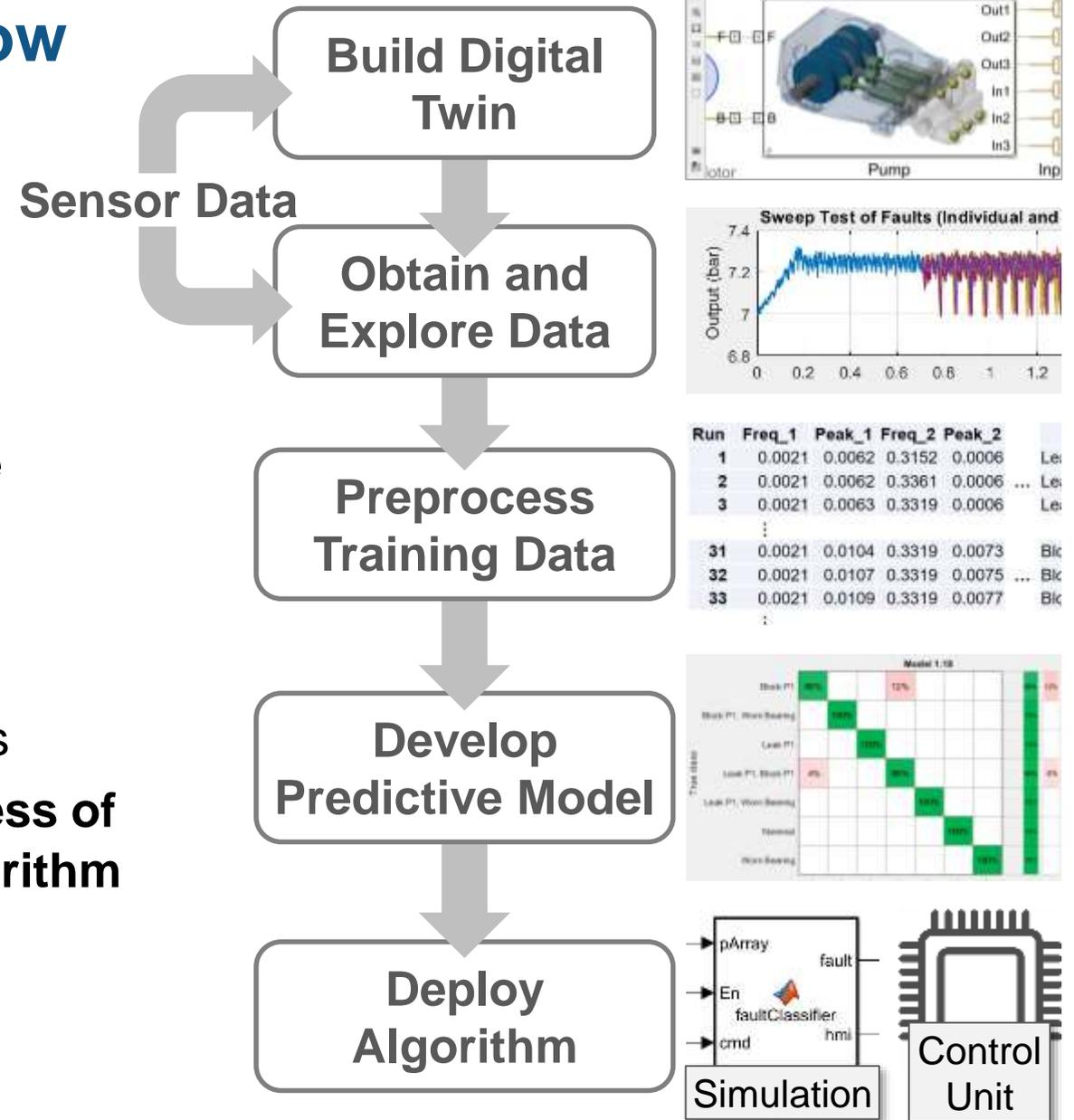


Agenda

- Predictive Maintenance Workflow
- Build a Digital Twin
 - Model physical system
 - Tune using measured data
- Create Predictive Model
 - Model component failure
 - Generate training data
 - Select and train classification model
- Deploy Fault Diagnostics Algorithm

Predictive Maintenance Workflow

- Sensor data isn't always available
 - Failure conditions difficult to reproduce
 - Time consuming or costly to generate**Solution: Build digital twin and generate sensor data using simulation**
- Developing algorithm is complex
 - Requires complex concepts and analysis**Solution: Use MATLAB to simplify process of developing and deploying algorithm**



Baker Hughes Develops Predictive Maintenance Software for Gas and Oil Extraction Equipment Using Data Analytics and Machine Learning

Challenge

Develop a predictive maintenance system to reduce pump equipment costs and downtime

Solution

Use MATLAB to analyze nearly one terabyte of data and create a neural network that can predict machine failures before they occur

Results

- Savings of more than \$10 million projected
- Development time reduced tenfold
- Multiple types of data easily accessed



Truck with positive displacement pump.

“MATLAB gave us the ability to convert previously unreadable data into a usable format; automate filtering, spectral analysis, and transform steps for multiple trucks and regions; and ultimately, apply machine learning techniques in real time to predict the ideal time to perform maintenance.”

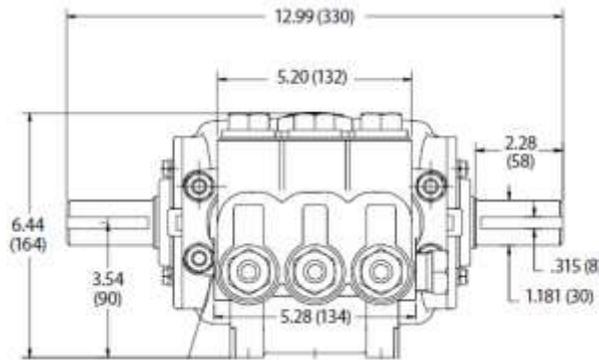
- Gulshan Singh, Baker Hughes

Agenda

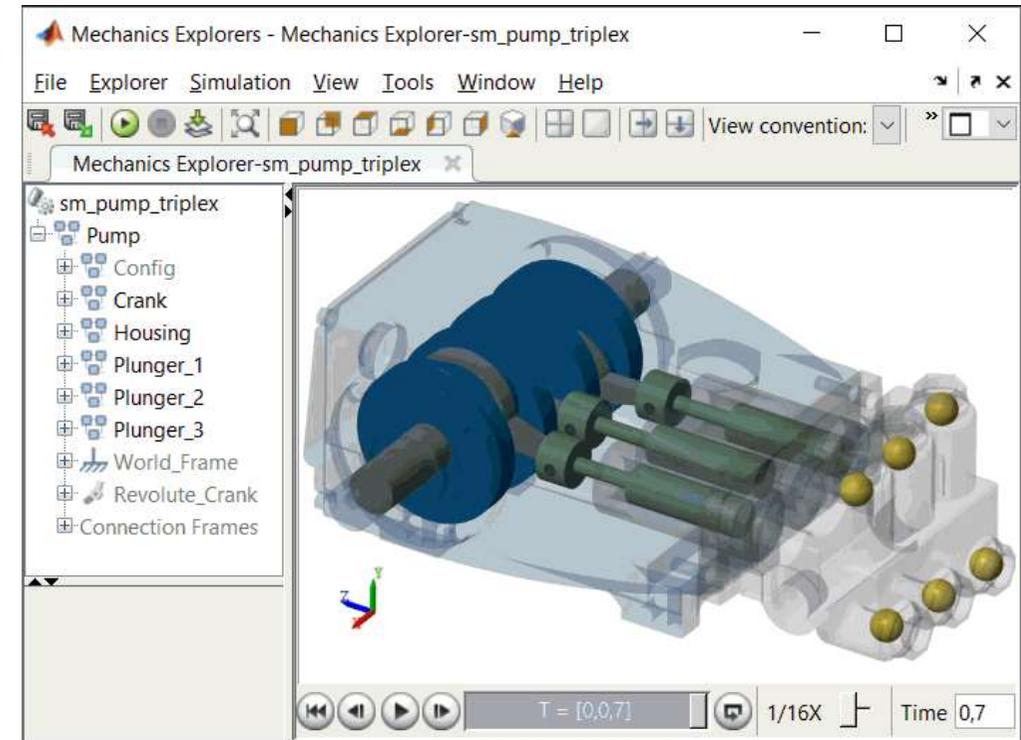
- Predictive Maintenance Workflow
- Build a Digital Twin
 - Model physical system
 - Simulate component failure
- Create Predictive Model
 - Obtain and explore data
 - Preprocess training data
 - Select and train classification model
- Deploy Fault Diagnostics Algorithm

Build Digital Twin of Hydraulic Pump

System:

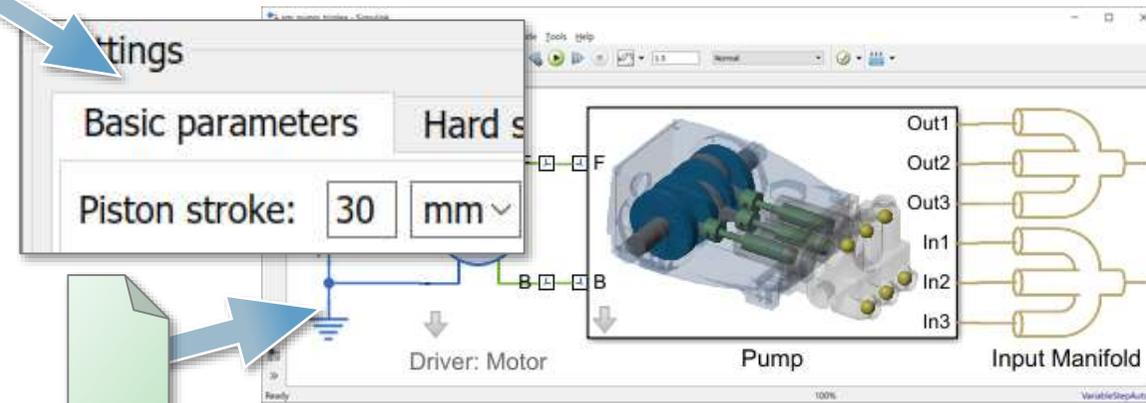


COMMON SPECIFICATIONS	U.S.	Metric
Bore	0.945"	24 mm
Stroke	1.18"	30 mm
Crankcase Capacity	42 oz.	1.26 l
Shaft Diameter	1.181"	30 mm

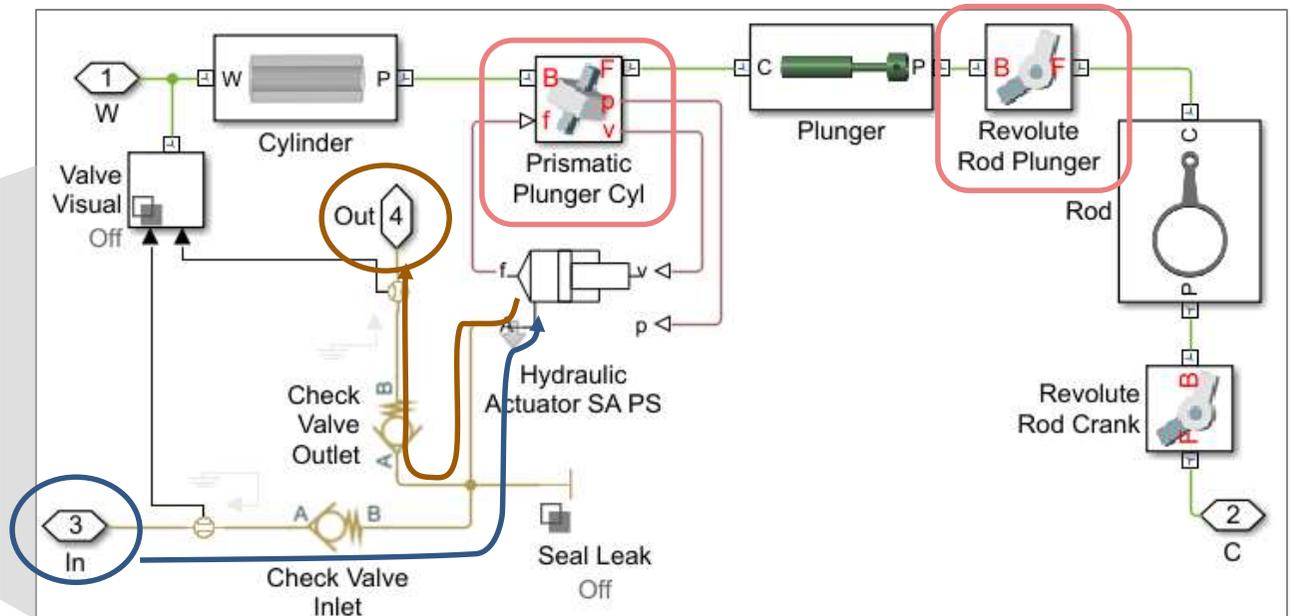
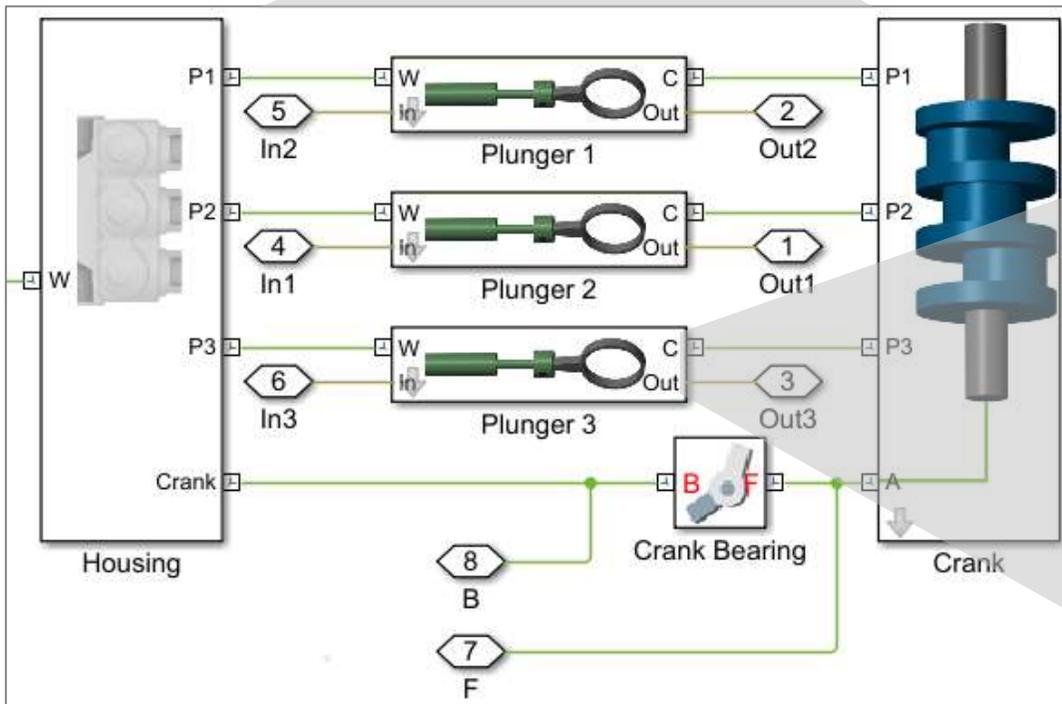
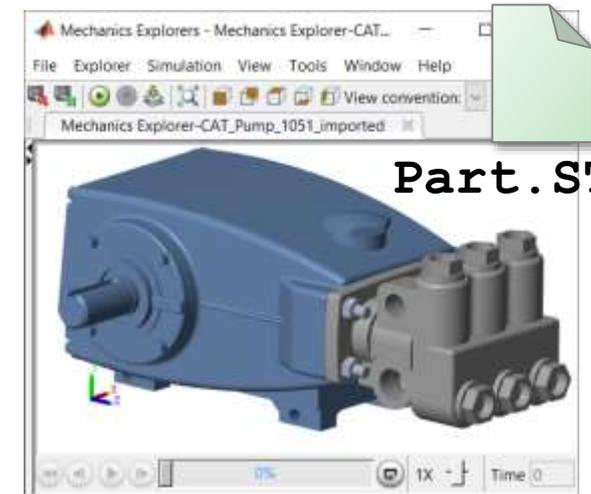
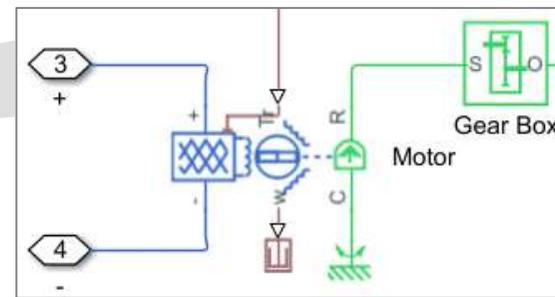
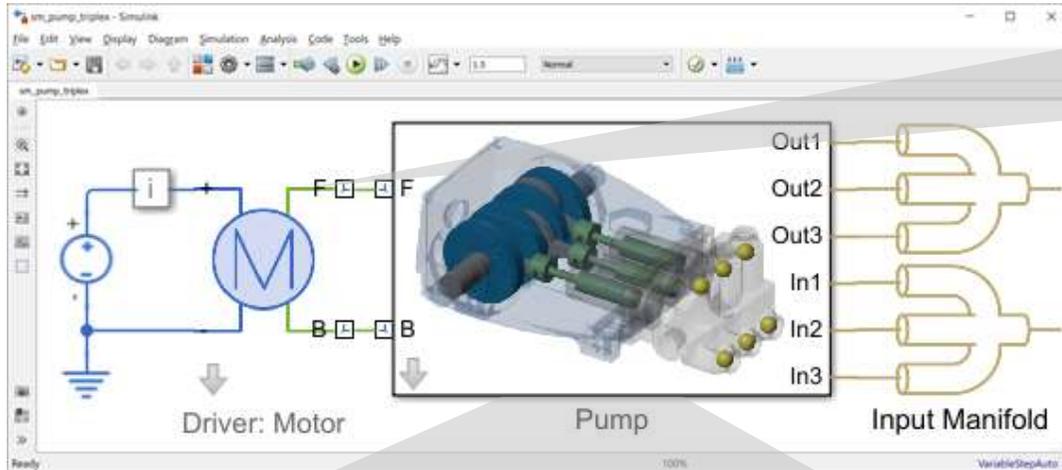


Challenge: Data needed for predictive maintenance workflow is not available

Solution: Use [Simscape](#) to build virtual model of pump, including mechanical, hydraulic and electronic components

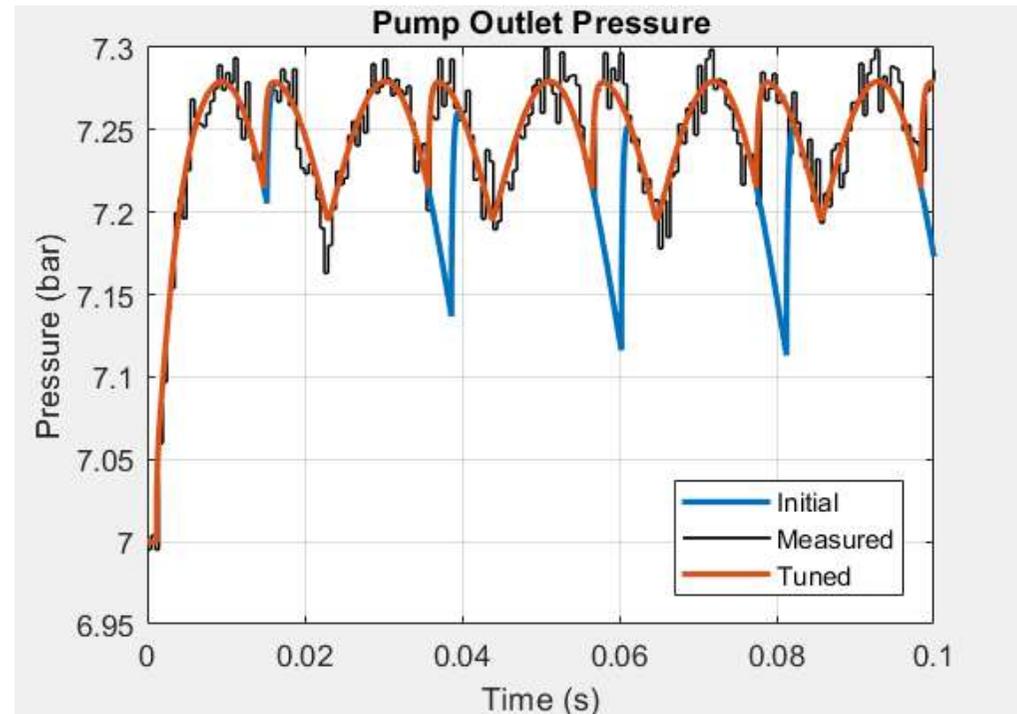
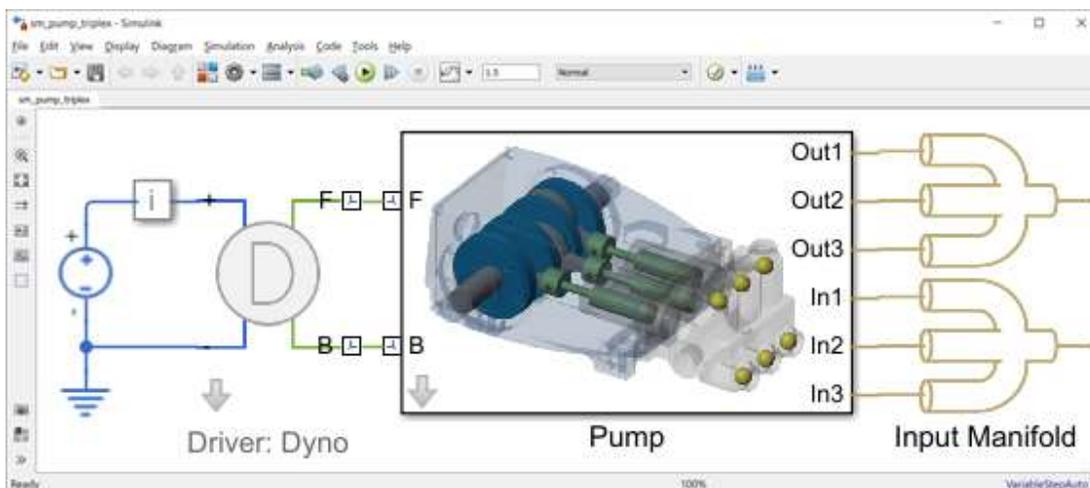


Simscape Model



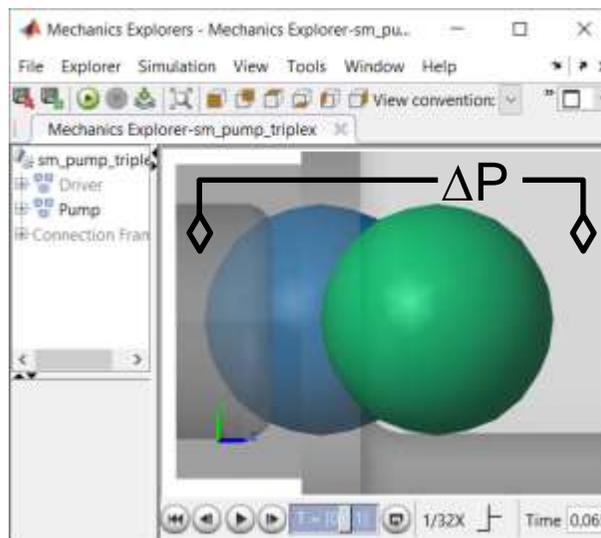
Estimate Parameters Using Measured Data

Model:

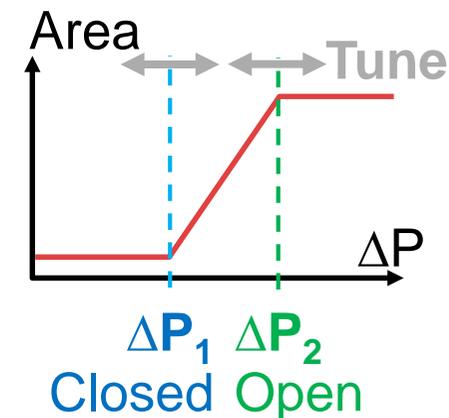


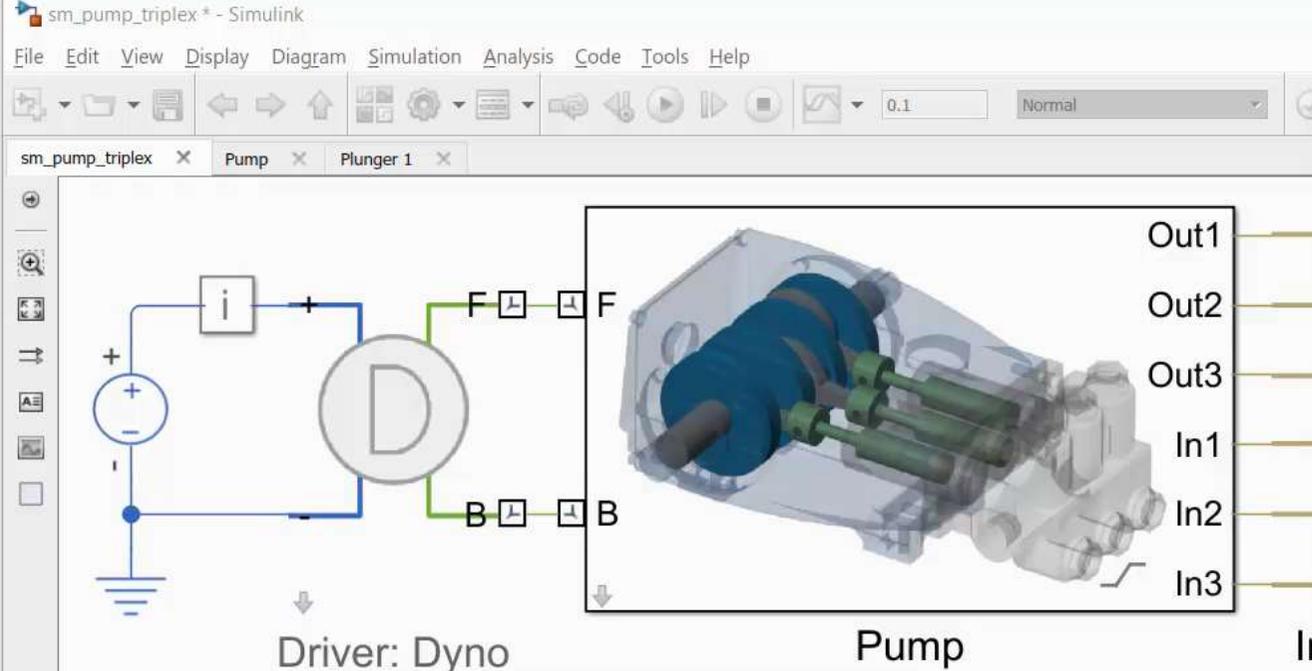
Challenge: Simulation results do not match behavior of real system

Solution: Use [Simulink Design Optimization](#) to automatically tune model parameters



Check Valve Characteristic





Estimation Progress Report

Iteration	F-count	Exp (Minimize)
0	1	
0	1	
1	3	
2	5	
3	7	
4	9	
5	11	

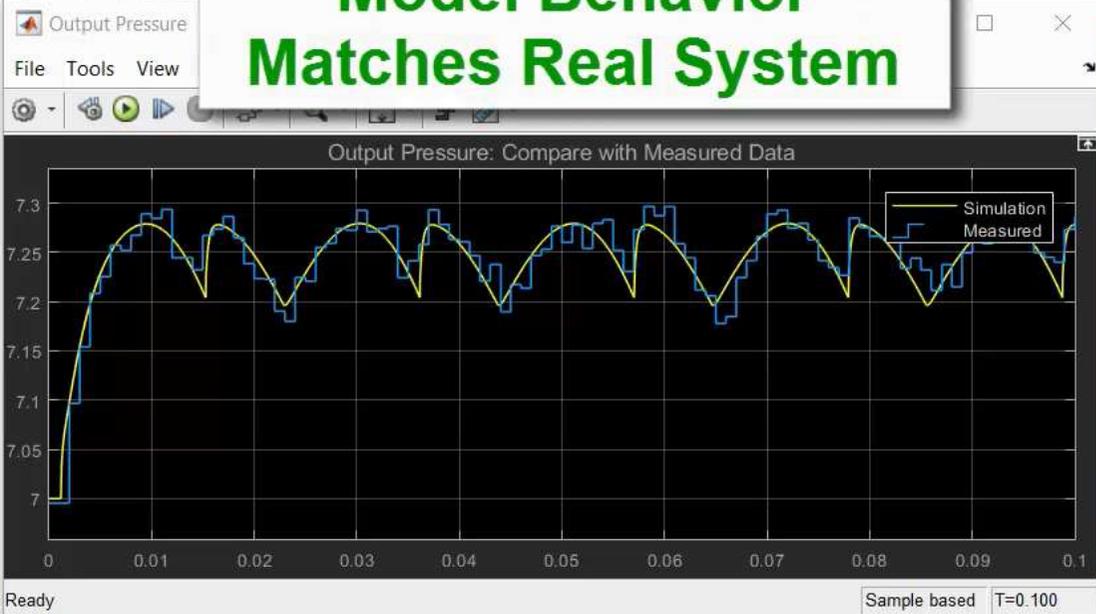
Optimization started 03-Jan-2018 18:11:59

The 'fminsearch' optimization method can not be used to optimize parameters with lower and upper bounds. The specified bounds will be ignored.

Phase two: Minimizing objective...

Model Behavior Matches Real System

Evolution of Parameter Values During Estimation

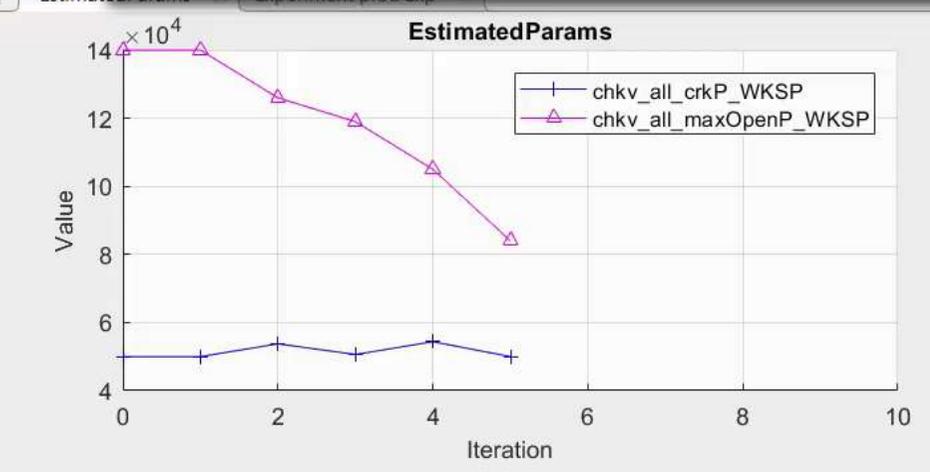


Parameter Estimation - sm_pump_triplex - Esti

PARAMETER ESTIMATION VALIDATION

Data Browser

- Parameters
 - chkv_all_crkP_WKSP
 - chkv_all_maxOpenP_WKSP
- Experiments
 - Exp
- Results
 - EstimatedParams
- Preview
 - Parameter values:
 - chkv_all_crkP_WKSP = 50000
 - chkv_all_maxOpenP_WKSP = 1.4e+05

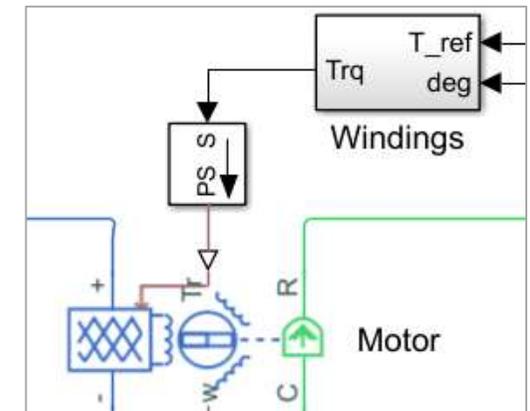
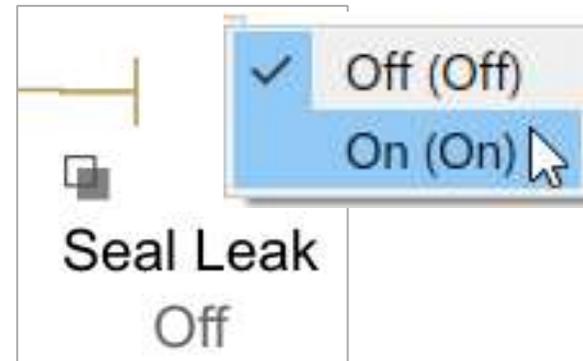
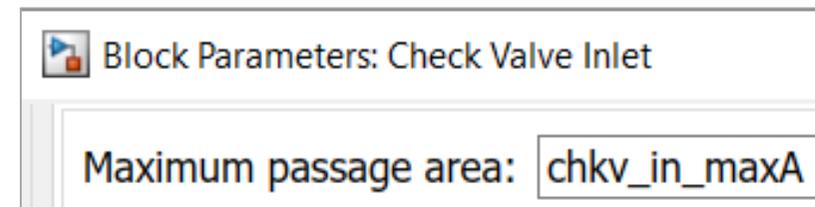
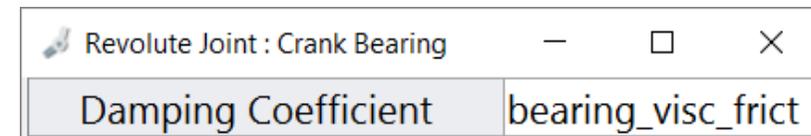
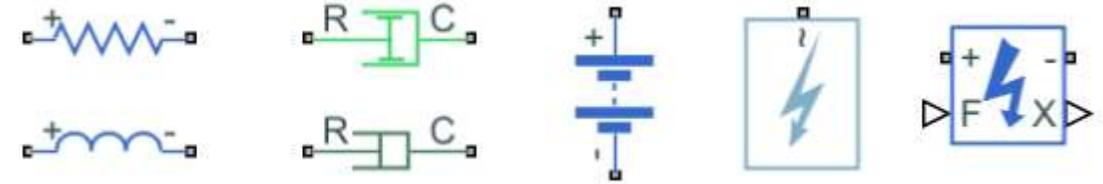


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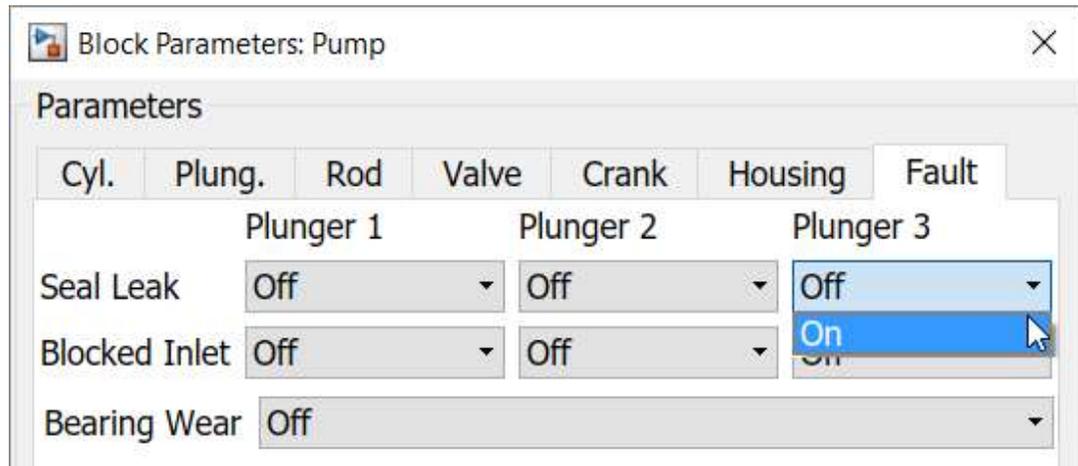
Model Component Failure

- Generic faults in many components
 - Short circuit, open circuit, friction, fade, etc.
 - Trigger based on time or conditions
- Adjust parameter values
 - Worn bearing adds friction
 - Blocked inlet has reduced passage area
- Adjust network
 - Seal leakage adds flow path
- Custom effects in Simulink
 - Broken winding applies no torque for 1/3 of every revolution



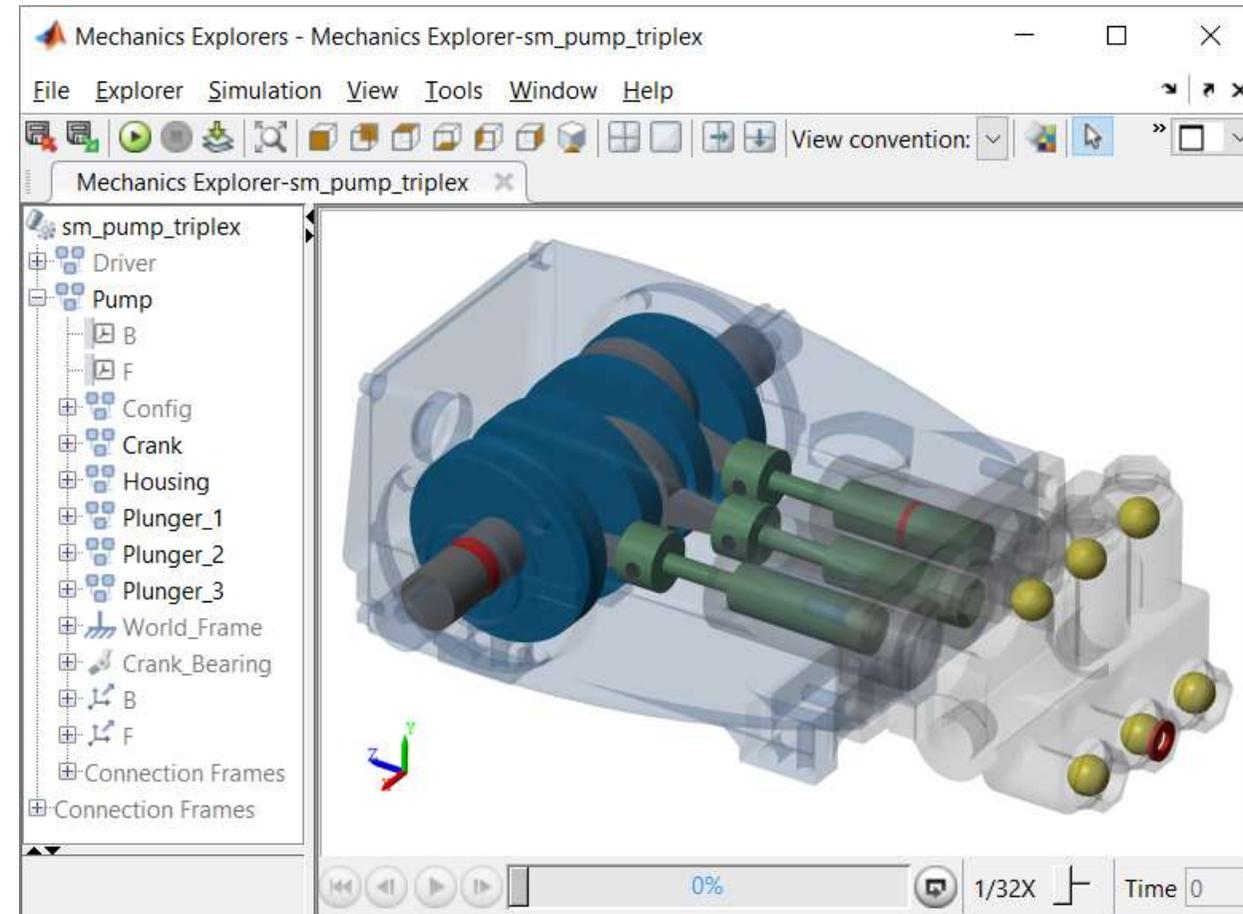
Model Component Failure

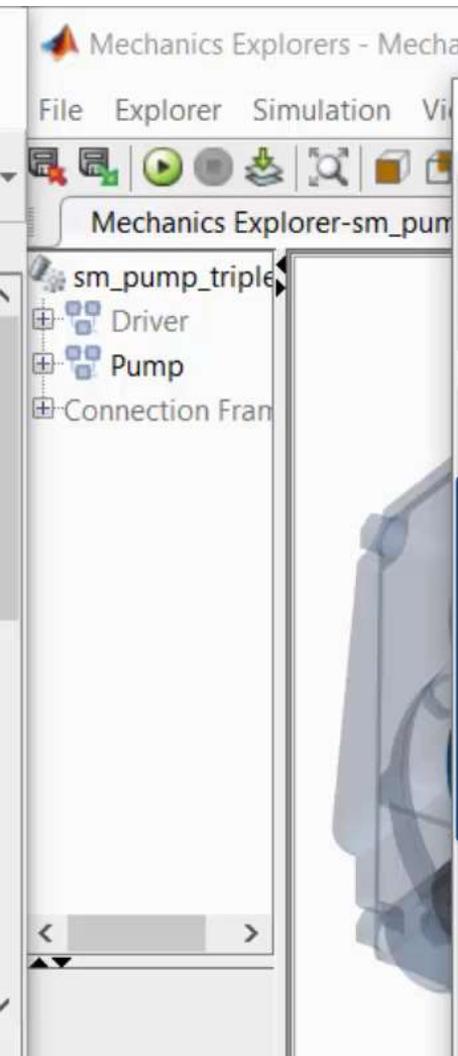
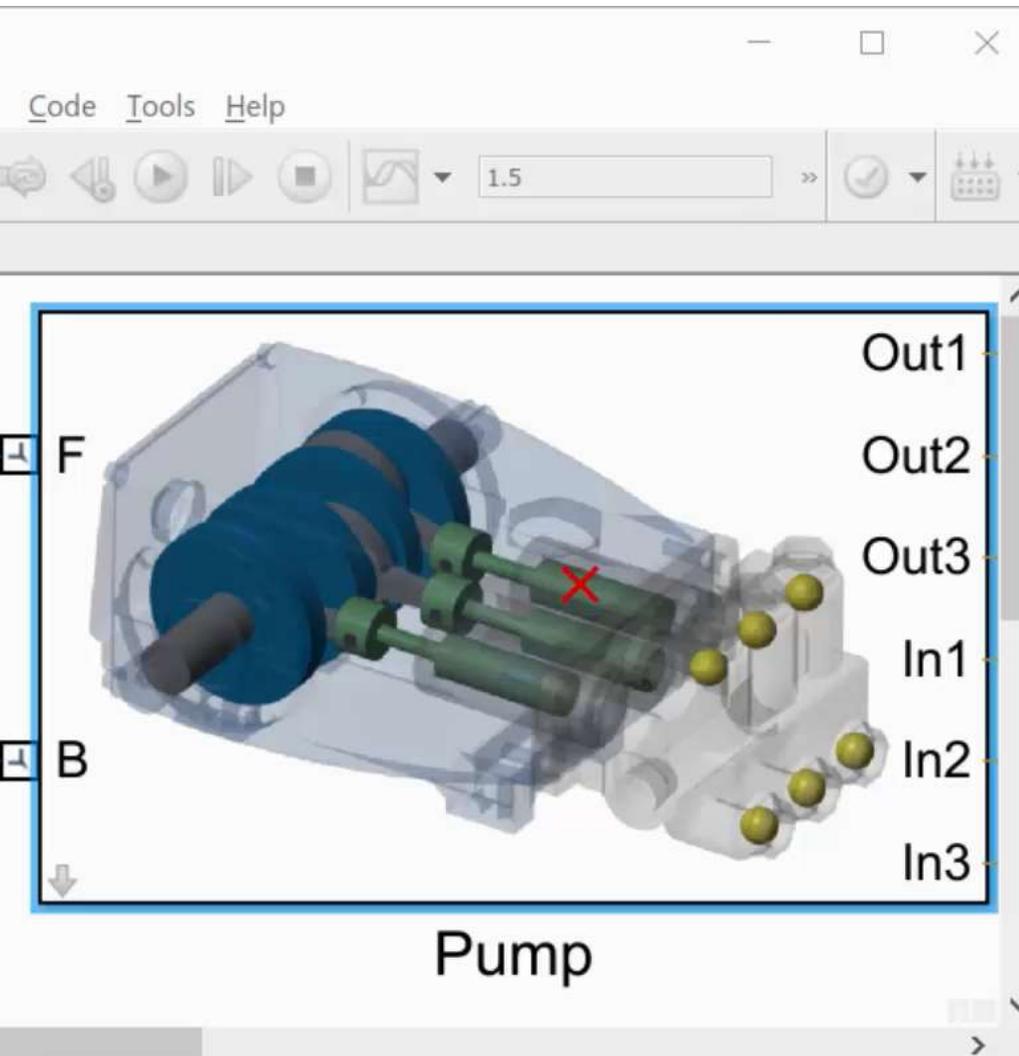
- Enable from UI or MATLAB



```
fx >> sm_pump_triplex_config_model...  
      ('sm_pump_triplex', 'Seal Leak', 'Off', 1);
```

- Visual indication of fault





Block Parameters: Pump

Triplex Pump with Faults (mask)

Models a triplex pump. Three hydraulic plungers are connected to a crankshaft. Hydraulic faults can be enabled on the Faults tab.

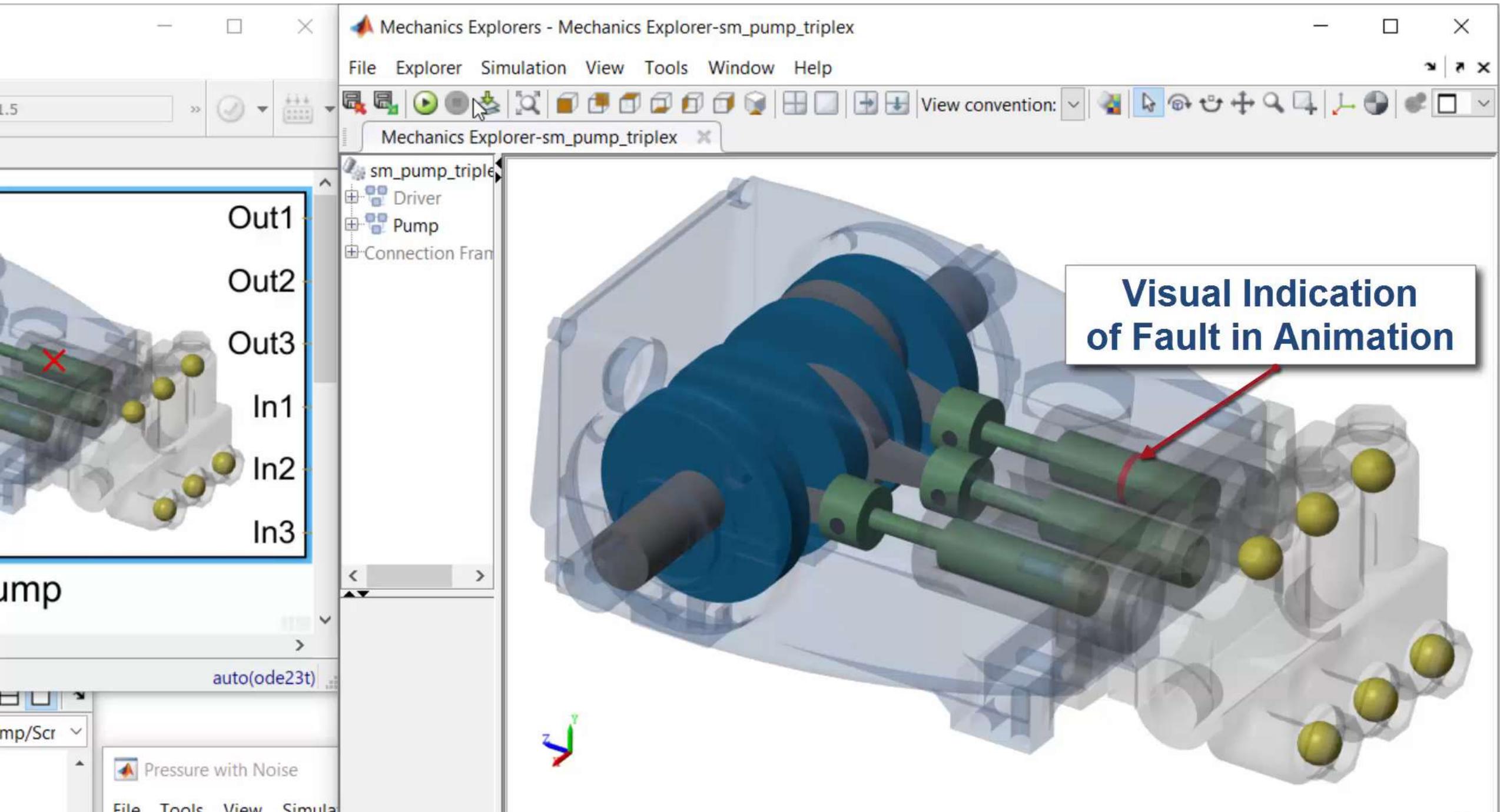
Configure Faults in Dialog Box

Parameters

	Cyl.	Plung.	Rod	Valve	Crank	Housing	Fault	
		Plunger 1		Plunger 2		Plunger 3		
Seal Leak		On		Off		Off		
Plunger 1 Leak Area (m ²)		P_Par.Check_Valve.In.Max_Area*0.03						
Blocked Inlet		Off		Off		Off		
Bearing Wear		Off						

- ▶ Seal Leak Visualization
- ▶ Blocked Line Visualization
- ▶ Bearing Fault Visualization

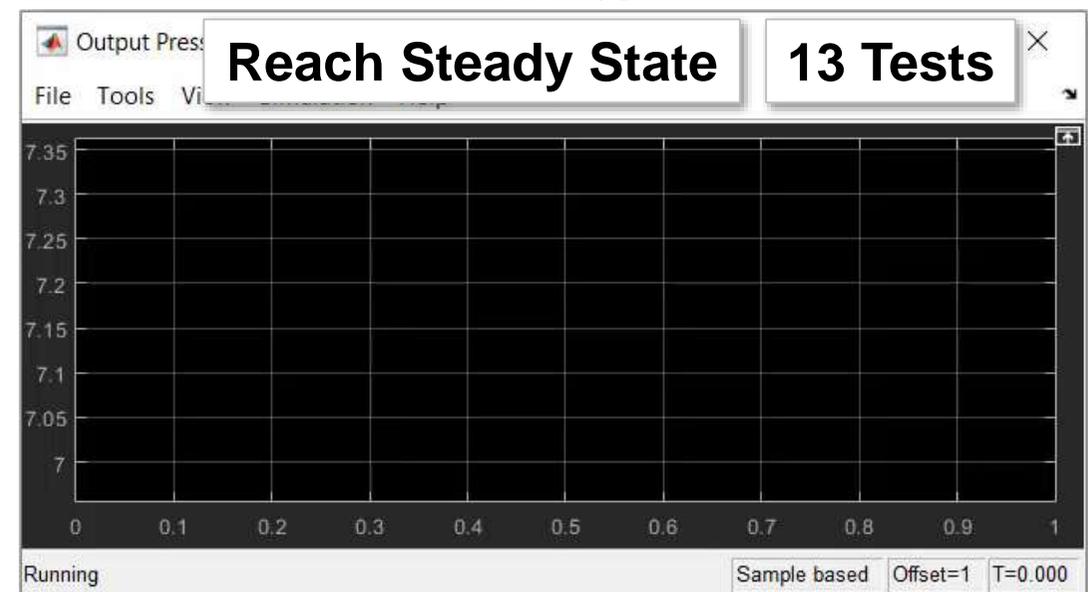
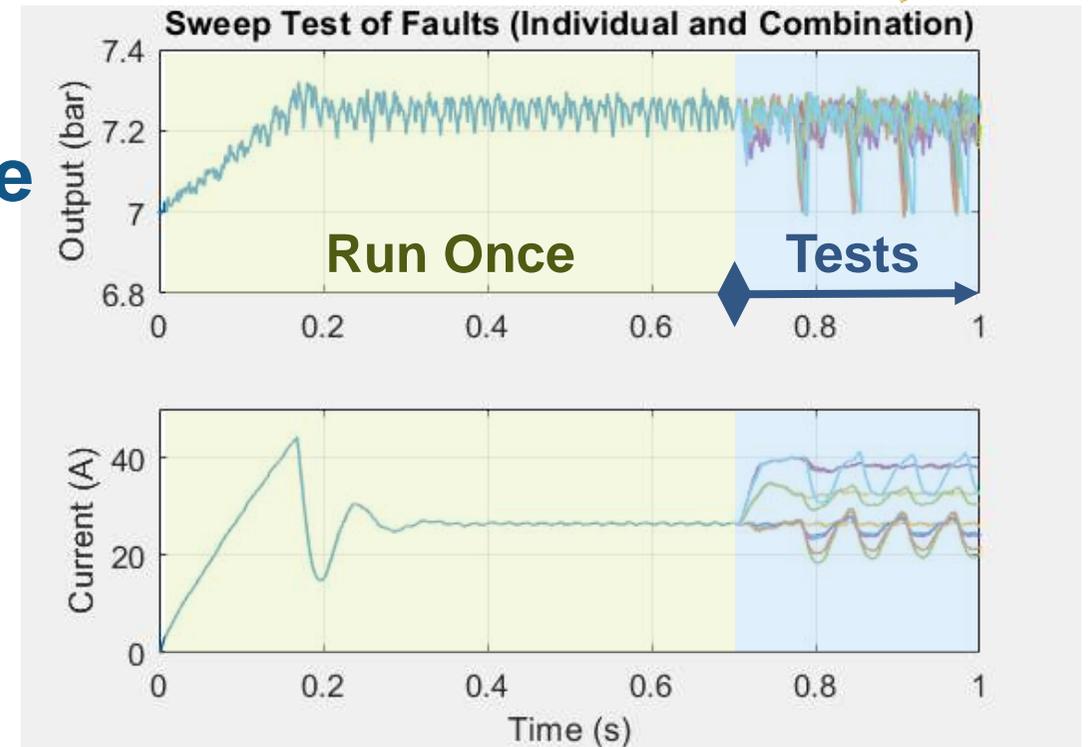




**Visual Indication
of Fault in Animation**

Quickly Create Sensor Data Using Parallel Computing and Initial State

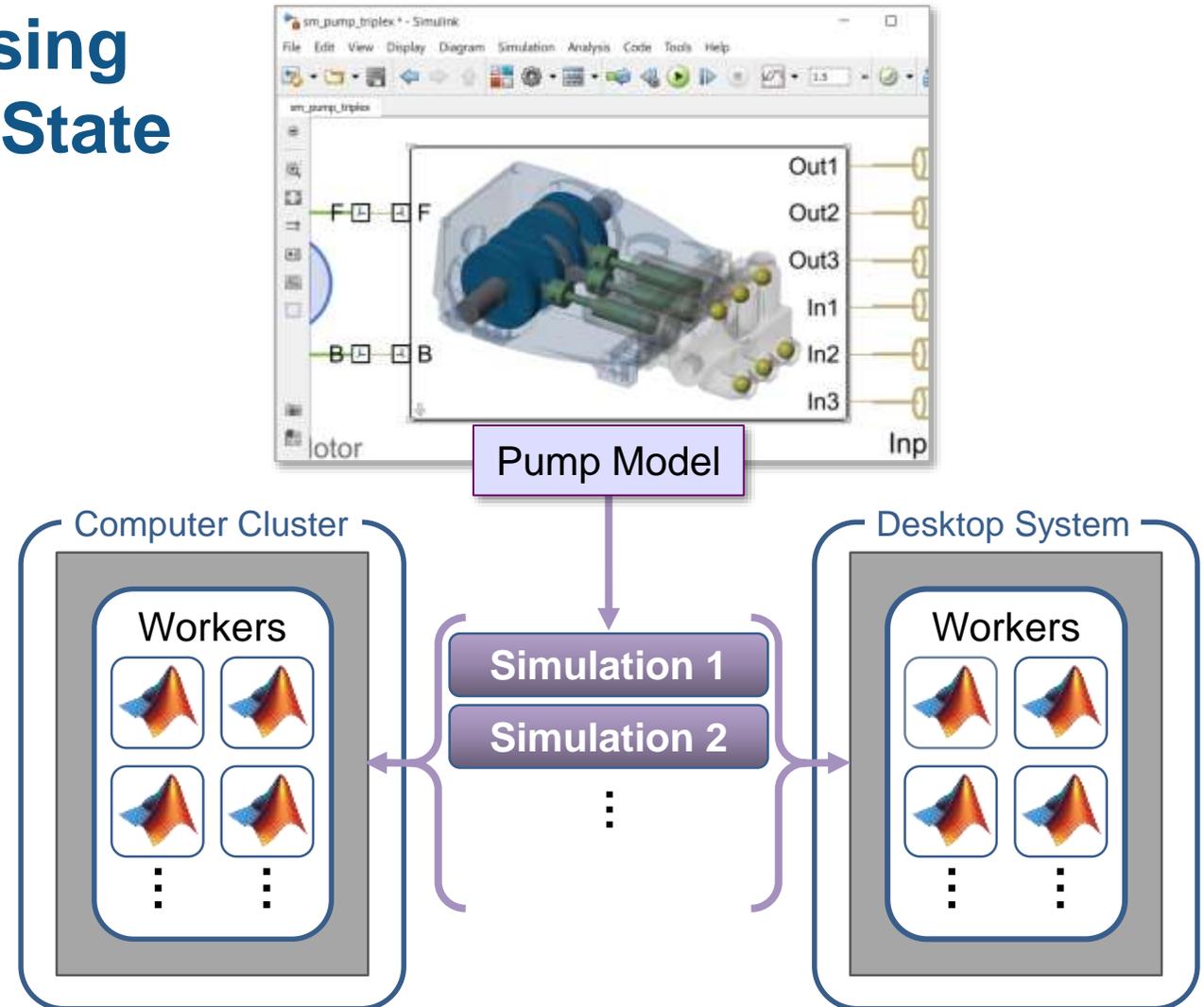
- Classification model requires data at various levels of failure for all fault combinations of interest
 - Many tests required
- Speed up tests
 - Start from steady state



Quickly Create Sensor Data Using Parallel Computing and Initial State

- Classification model requires data at various levels of failure for all fault combinations of interest
 - Many tests required
- Speed up tests
 - Start from steady state
 - Run tests in parallel

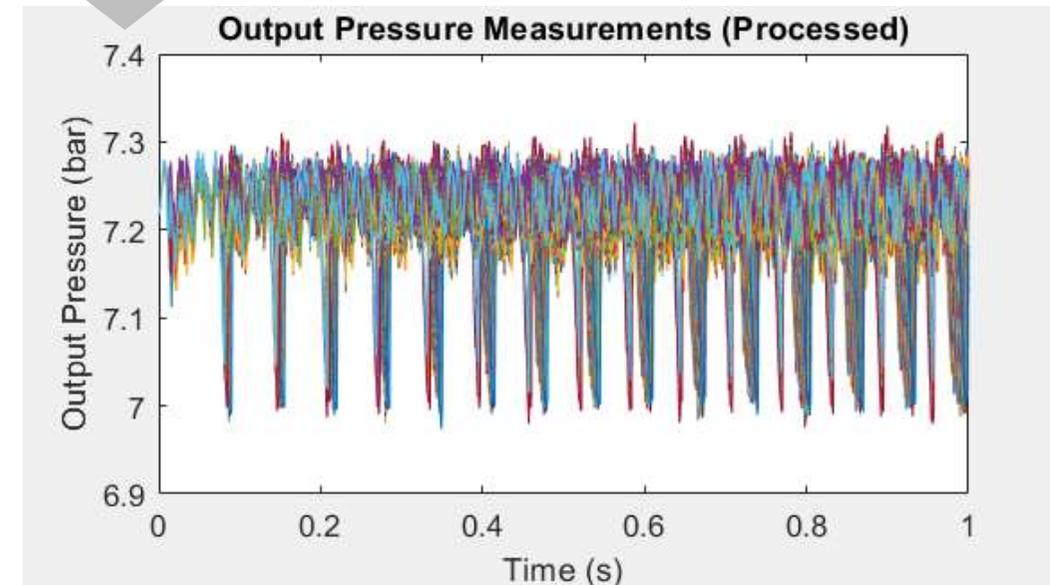
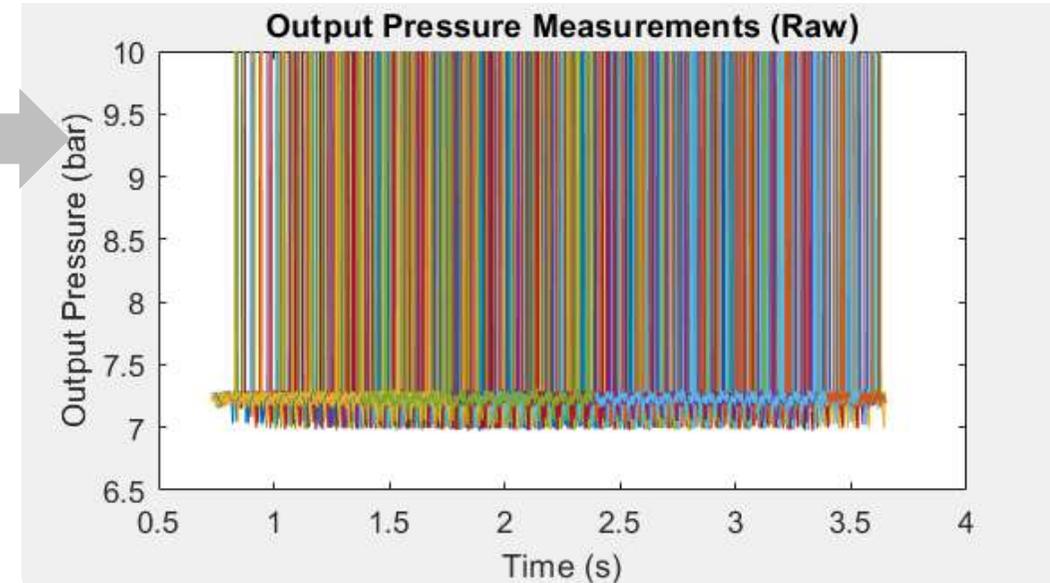
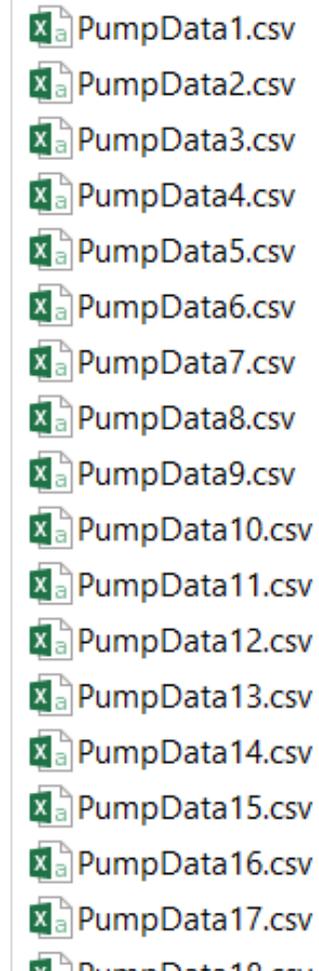
Distribute to multiple desktop workers or across a computing cluster



Running simulations in parallel speeds up your testing process.

Obtain and Preprocess Data 181 Tests

- Challenges in processing data
 - Stored in many separate files
 - Noise or missed samples
 - Time vectors misaligned
- Use MATLAB to simplify task
 - Easy access to files
 - Simple commands to fix data
 - Efficient method to streamline computing process

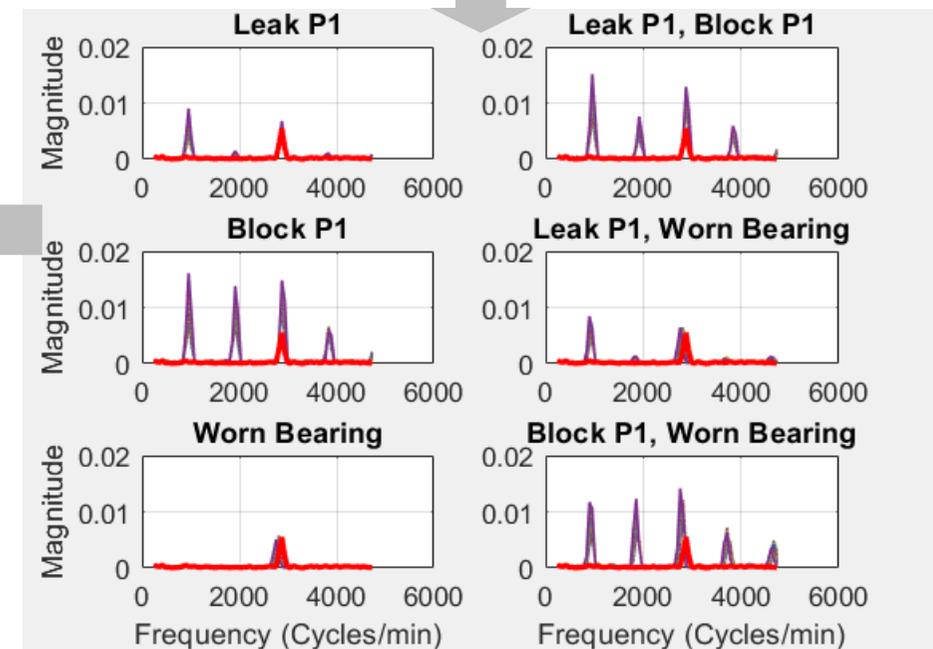
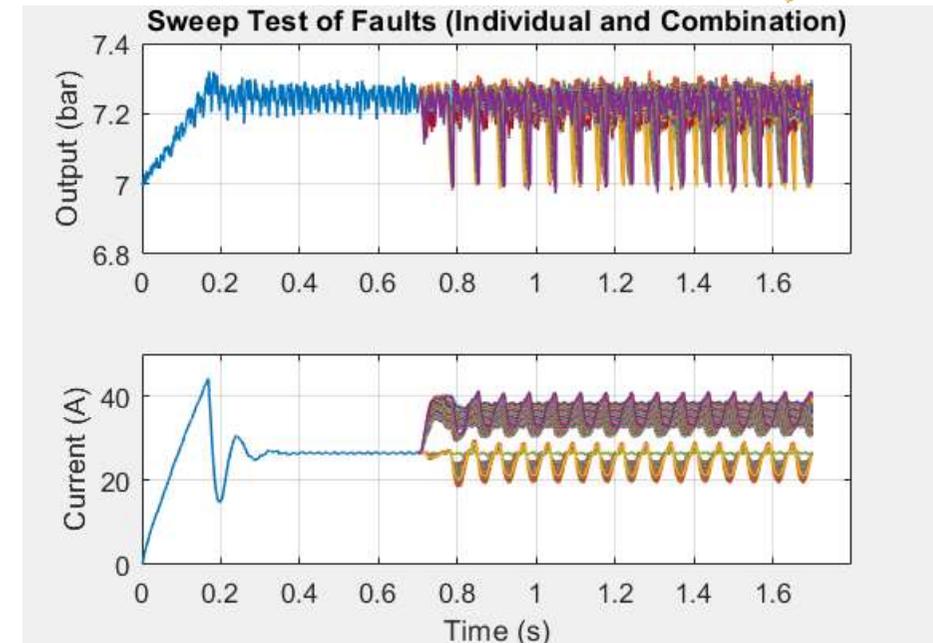


Extract Training Data from Sensor Measurements

- Perform FFT on results
 - Save frequencies, magnitudes, fault type

Classification Model Training Data

Run	Freq_1	Peak_1	Freq_2	Peak_2	Fault	
1	0.0021	0.0062	0.3152	0.0006	Leak_P1	
2	0.0021	0.0062	0.3361	0.0006	...	Leak_P1
3	0.0021	0.0063	0.3319	0.0006	Leak_P1	
⋮	⋮	⋮	⋮	⋮	⋮	
31	0.0021	0.0104	0.3319	0.0073	Block_P1	
32	0.0021	0.0107	0.3319	0.0075	...	Block_P1
33	0.0021	0.0109	0.3319	0.0077	Block_P1	
⋮	⋮	⋮	⋮	⋮	⋮	
91	0.0021	0.0092	0.3319	0.0042	Leak P1, Block P1	
92	0.0021	0.0095	0.3319	0.0044	...	Leak P1, Block P1
93	0.0021	0.0097	0.3319	0.0045	Leak P1, Block P1	
⋮	⋮	⋮	⋮	⋮	⋮	
MAT 181	0.0021	0.0055			Nominal	



Evaluate all Classification Models

- Train all models using training data and compare accuracy of each one
 - Trainings can run in parallel
- Multiple methods to assess accuracy

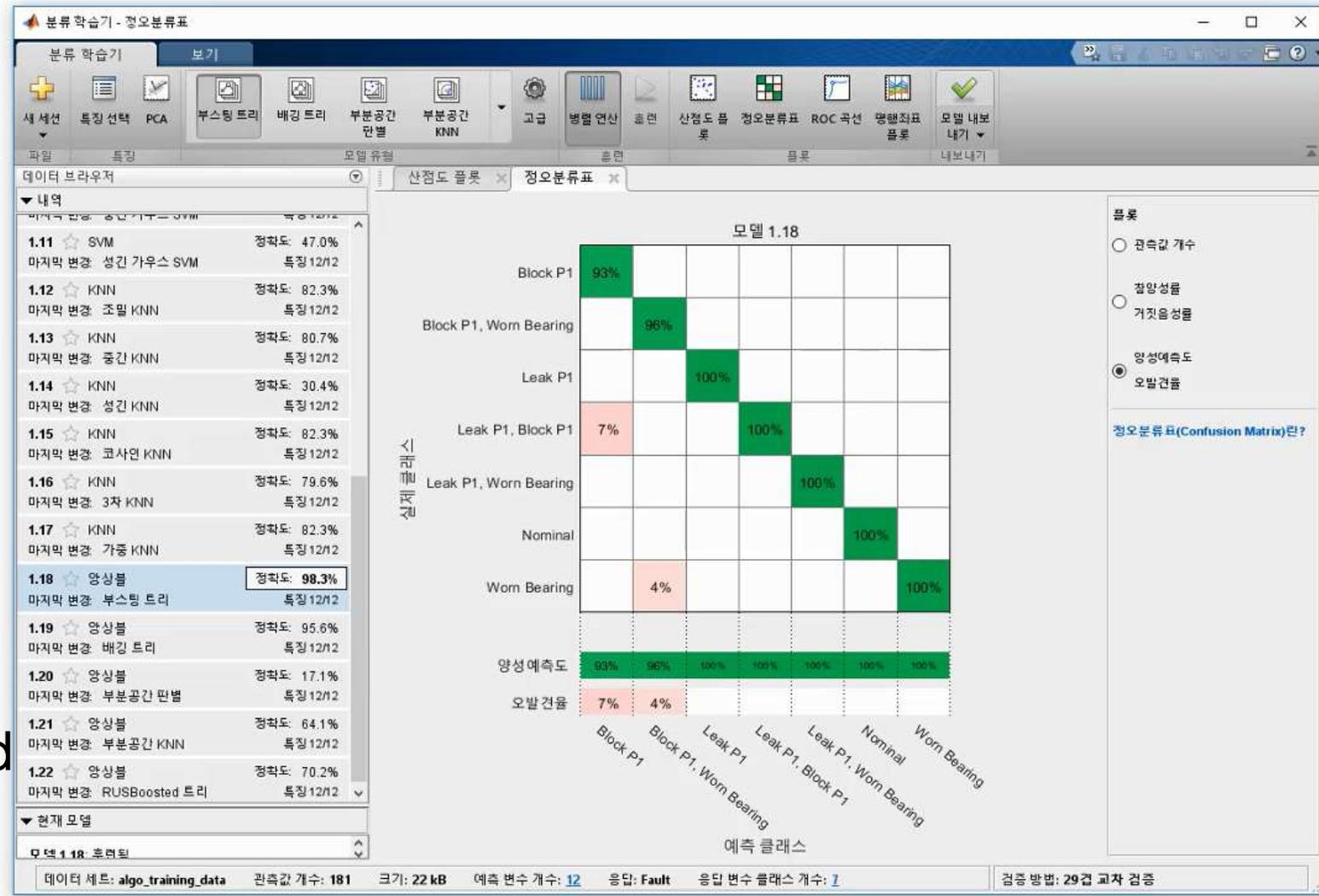
Run	Freq_1	Peak_1	Freq_2	Peak_2	
1	0.0021	0.0062	0.3152	0.0006	Le
2	0.0021	0.0062	0.3361	0.0006	... Le
3	0.0021	0.0063	0.3319	0.0006	Le
⋮					
31	0.0021	0.0104	0.3319	0.0073	Blo
32	0.0021	0.0107	0.3319	0.0075	... Blo
33	0.0021	0.0109	0.3319	0.0077	Blo
⋮					



Evaluate all Classification Models

- Train all models using training data and compare accuracy of each one
 - Trainings can run in parallel
- Multiple methods to assess accuracy
 - Matrix comparing prediction with actual conditions
 - Scatter plot, ROC Curve¹, Parallel Coordinates, etc.
- Process can be automated

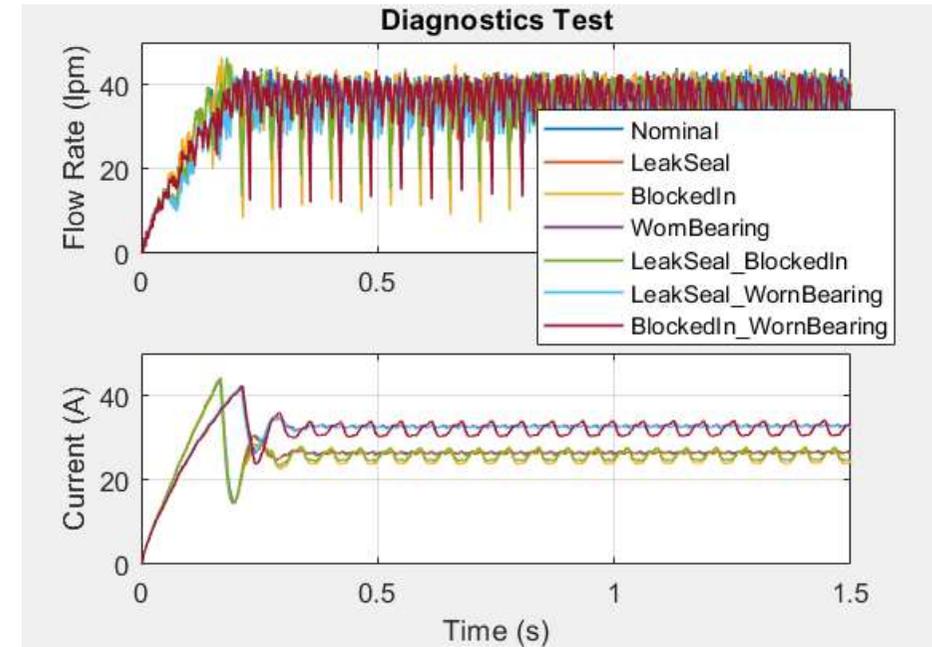
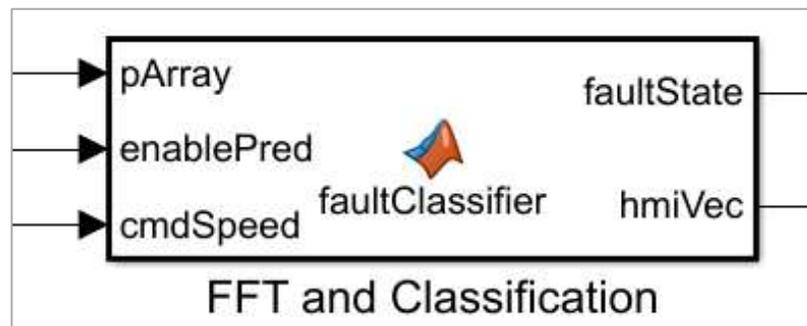
Generate Code
 Generate MATLAB code for training t



Test Algorithm in Simulation

- Connect trained algorithm to digital twin
 - Verify behavior on new scenarios before deploying in embedded code

Export Model  Export the currently selected model in the History list to the workspace to make predictions with new data



sm_pump_triplex - Simulink

File Edit View Display Diagram Simulation Analysis Code Tools Help

sm_pump_triplex:

pMeas → pMeas

Diagnostics: On

No Fault Blocked Inlet Seal Leak Worn Bearing

Ready 219% auto(ode23t)

Automate Entire Algorithm Development Process

- Test and update algorithm when any aspect of system changes
 - Environment: temperature, fluid, power source
 - Supplier: Seals, valves, tolerances, material
 - Design: Larger, smaller, new markets
- Improve algorithm with new data
 - Tune digital twin with field data, automatically update algorithm

<https://kr.mathworks.com/matlabcentral/fileexchange/?utf8=%E2%9C%93&term=tripler>

