

Calibration Workshop

Modelon Innovate

Oct 11, 2024



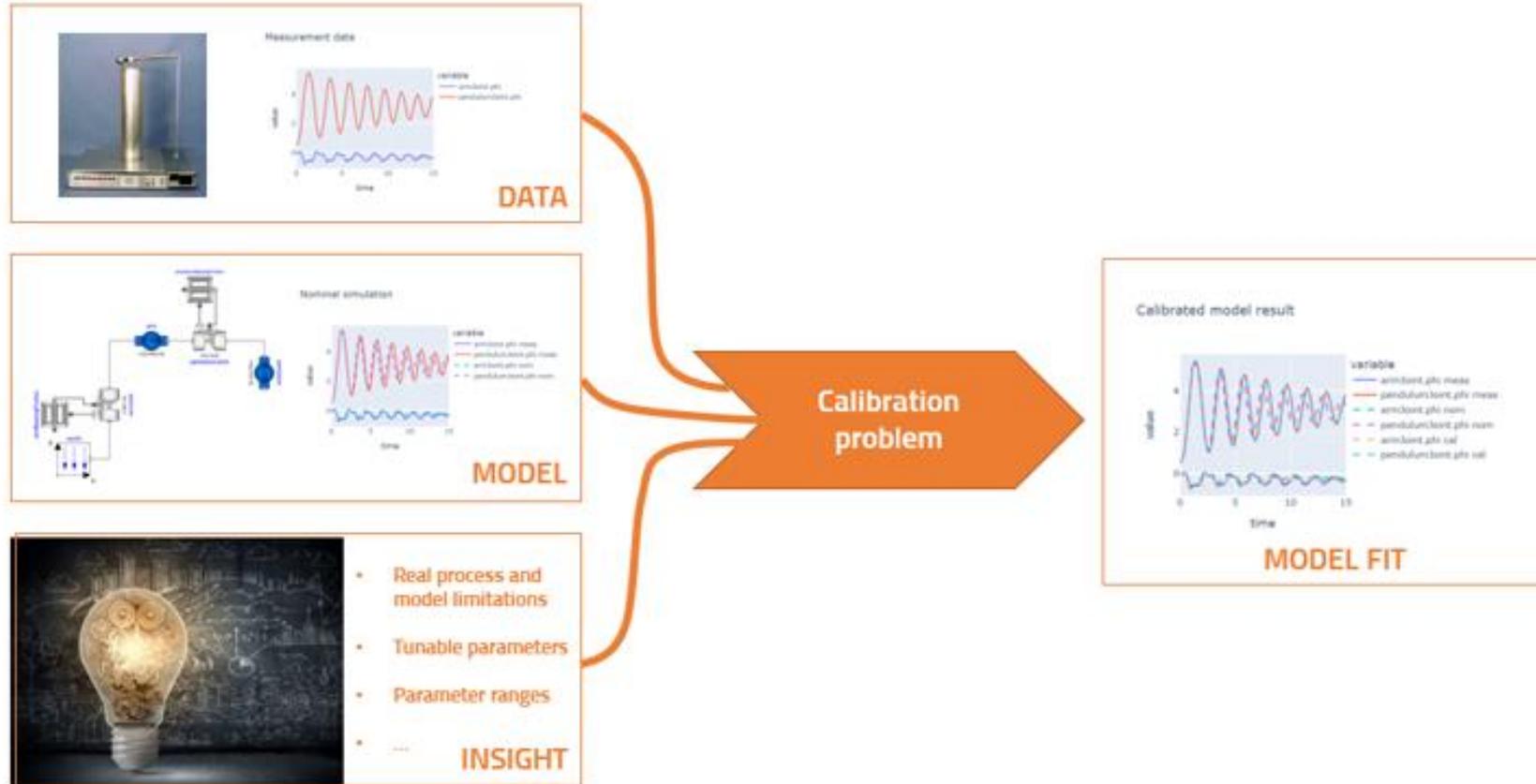
Introduction



Calibration 1.0 Library
Part of Modelon's 2024.2 Release

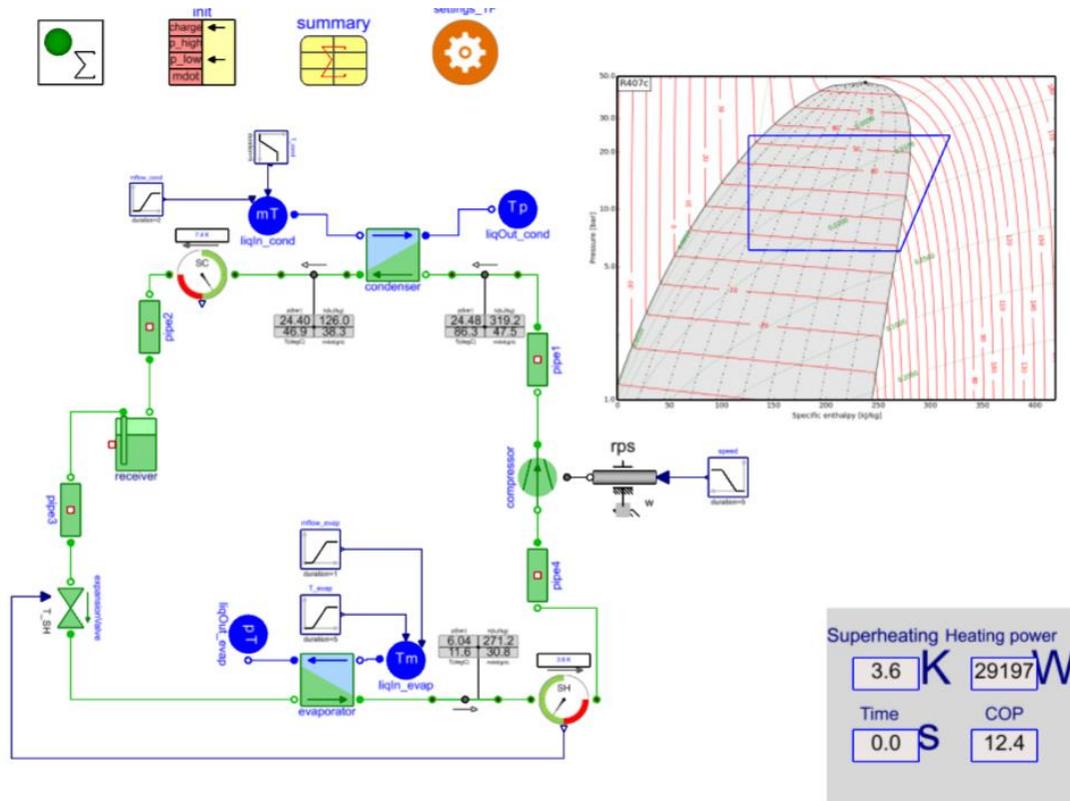
- Designed to facilitate parameter calibration of Modelica models within Modelon Impact
- Optimization problem that finds the set of parameters that minimize the difference between reference values and the model output
- Currently in beta-stage and subject to change

End-to-end workflows



Heat pump HX calibration 101

- VaporCycle.Experiments.HeatPump



Heat pump HX calibration 101: HX as set of pipes

- Gas, vapor or fluid in a pipe...
 - Pressure loss along the pipe
 - Exchanges heat over walls
- Basic model example:
 - Pressure drop – need to guess “friction factor”:

$$\frac{\Delta p}{L} = \boxed{f_D} \cdot \frac{\rho}{2} \cdot \frac{\langle v \rangle^2}{D_H},$$

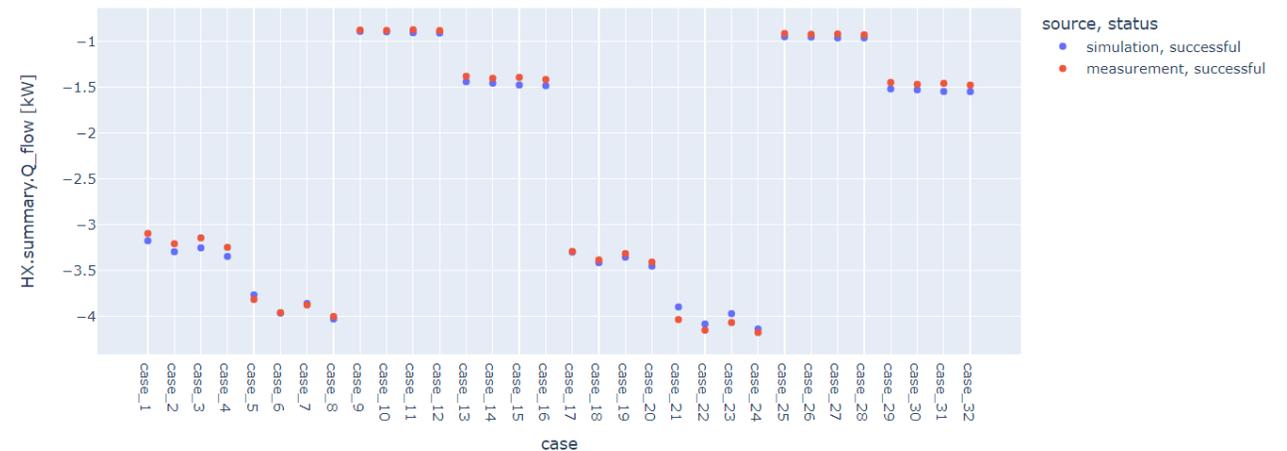
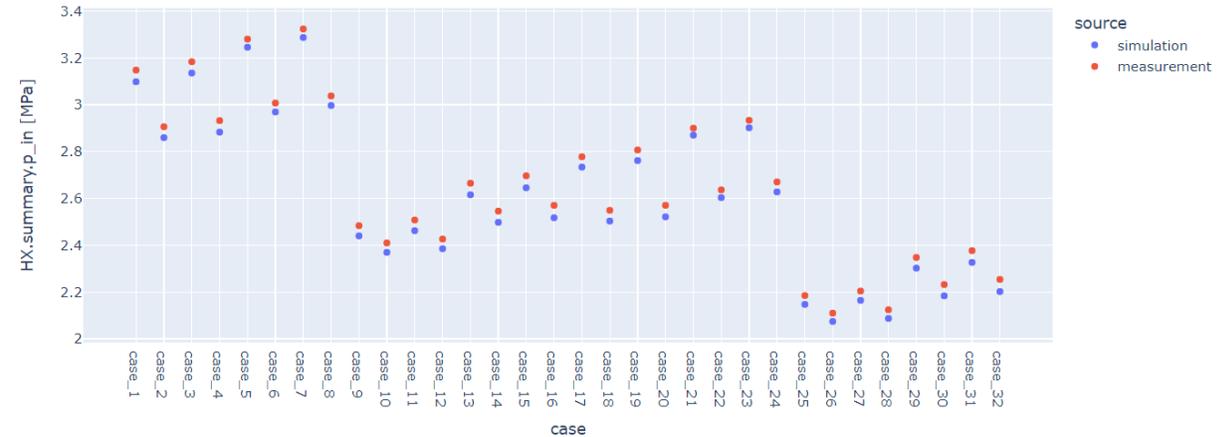
- Heat transfer – need to guess “heat transfer coefficient”

$$Q = \boxed{U} \times Ar \times \frac{\Delta T(B) - \Delta T(A)}{\ln\left(\frac{\Delta T(B)}{\Delta T(A)}\right)}$$

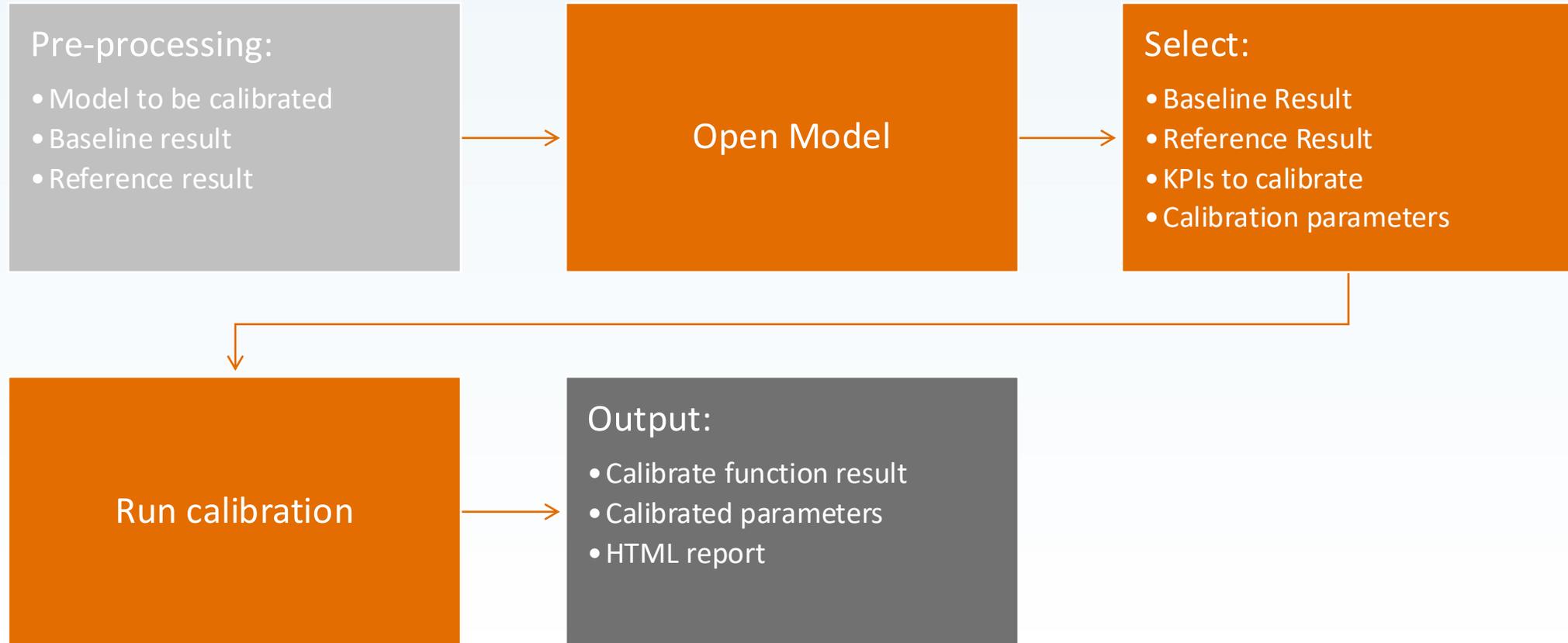


Heat pump HX calibration 101:

- Input: approximated heat transfer and friction coefficients
- Measurements are done for a set of different Operating Conditions
 - Temperatures inside/outside
 - Desired cooling (or heating) effect
- Calibration: find correction factors so that model and experiments agree



Workflow overview



Model to be calibrated

- **Definition:**

- The model to be calibrated, i.e., the model to be executed with the calibrate function.

- **Generation:**

- Model authoring is done using regular Modelon Impact features.
- If reference result comes from a high-fidelity simulation, then it is recommended to have the same test bench model with a replaceable component in both cases.

Baseline Result

Definition:

Baseline Result is a single case result that defines the analysis to be calibrated, that is:

- Custom-function (dynamic, steady-state, other custom)
- Custom-function parameters (e.g., start time, stop time)
- Model parameterization (modifiers)
 - not recommended, these should be stored in the model
- Simulation settings, etc.

Generation:

- Execute experiment for model to be calibrated with desired settings and default values of calibration parameters

Assumptions:

- Calibration parameters are independent and settable on the model

Reference Result

Definition:

The **Reference Result** is a (Multi-Case) experiment result that contains the desired model output at a number of different operating conditions.

Generation:

The reference result can be generated by either:

- Executing an experiment (typically with a model of higher fidelity)
- Uploading data as result via the **Reference file loader** app

Assumptions:

- Operating conditions for each case are set via experiment modifiers (parameterization object)
- Variable names in the reference result matches their counterparts in the model to be calibrated

Generate Reference Result

Options:

1. Load CondenserCalibrationData from the library's Resource folder, using the custom function 'Generate Reference Results'
2. Use 'Reference file loader' App to load calibration data from local drive

The screenshot shows a software interface with two tabs: 'Analysis' and 'Modifications'. Under 'Analysis', there are three icons: 'Dynamic' (a waveform), 'Steady State' (a target symbol), and 'Custom' (a wrench icon). Below these is a dropdown menu with the text 'Calibration. Generate Reference Results'. Under 'Modifications', there is a field for 'file_uri' with the value 'modelica://Calibration/Resources/CondenserCalibrationData.csv' and icons for delete and edit. Below that is a field for 'baseline_experiment' with a dropdown menu showing 'Baseline Result'.

The screenshot shows a software menu with a grid icon, a gear icon, and a question mark icon. The menu items are: EXCEL ADD-IN, Add-in manifest file, Download template, Open template, WORKSPACE MANAGEMENT, Project Explorer, Workspace Configuration, CALIBRATION, Reference file loader, FUELSYSTEM, Tank Pre-Processing App, TOOLS - ADVANCED, JupyterLab, Server Management, VS Code in browser.

Reference Result Generation: Reference file loader App

Step 1: Select baseline result

- To be able to deduce what content is parameters and what is KPIs (reference output), a compiled model is needed.

Step 2: Upload measurement file

- Mapping of data to reference result based on baseline result.

Step 3: Generate reference result

- Identify Label column
- Click button to generate the reference result.

Calibration: Reference file loader

1. Setup 2. Upload 3. Export

Choose a Result for Calibration

Select a result from the model that you want to calibrate.

Important Considerations

- The result should be from the experiment that is to be calibrated to ensure accurate matching with the uploaded data file.
- The selected result will be used in the next step to identify parameters and variables from the uploaded data file.

Workspace: TankCalibration

Model: Calibration.Examples.CoupledClutches

Experiment:

Calibration: Reference file loader

1. Setup 2. Upload 3. Export

Upload a Local Data File

Upload a local data file with reference values.

Supported File Formats

- .xlsx - The first tab will be used for data import.
- .csv

The data names in the uploaded file must match the corresponding parameters and variables in the model.

Loaded CoupledClutchesCalibrationData.csv

Matching measurement file content to experiment data...

Matched Parameters:

clutch_control_1
clutch_control_3
clutch_control_2

Matched Reference Output:

33.w
34.w
31.w
32.w

Following variables could not be matched:

Case

Calibration: Reference file loader

1. Setup 2. Upload 3. Export

Generate a Reference Result

Click **Generate Reference** to generate a reference result using the uploaded data file from the previous tab.

Labeling Experiment Cases

Use the **Label** field to name the experiment cases after a specific data label.

Label column: Reference 'Reference 1' generated.

Reference Result Generation: File format

- Variable names + Label column in first row
- Values for cases in rows
- Operating conditions and reference output mixed – will be deduced by model.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Tests	init.m_flow_air	init.T_air	init.dT_air	init.phi	init.p_in_air	init.p_out_air	dp	init.m_flow	T_in	T_out	HX.summary.p_in	init.p_out	init.h_in	HX.summary.h_out	init.h_out	init.p_in	HX.summary.Q_flow	
2	1	0,2	320	20	0,6	103000	101300	42,61057	0,035	80,37193758	73,14674356	2321953,671	2270000	438960,5755	317984,553	317984,6	2321954	-4234,161	
3	2	0,2	320	20	0,6	103000	101300	42,68692	0,04	80,72119216	73,14674356	2342587,78	2270000	438960,5755	330377,2203	330377,2	2342588	-4343,334	
4	3	0,2	320	20	0,6	103000	101300	42,74268	0,045	81,06899286	73,14674356	2363155,222	2270000	438960,5755	340463,1483	340463,1	2363155	-4432,384	
5	4	0,2	320	20	0,6	103000	101300	42,79968	0,05	81,56032743	73,14674356	2392241,429	2270000	438960,5755	348276,3243	348276,3	2392241	-4534,213	
6	5	0,2	320	20	0,6	103000	101300	42,69356	0,035	80,26117146	72,80567234	2414989,39	2370000	436308,3333	308999,5132	308999,5	2414989	-4455,809	
7	6	0,2	320	20	0,6	103000	101300	42,82154	0,04	80,57545914	75,11394189	2433042,433	2370000	436308,3333	320927,8373	320927,8	2433042	-4615,22	
8	7	0,2	320	20	0,6	103000	101300	42,89117	0,045	80,93805672	75,11394189	2453891,539	2370000	436308,3333	331544,0816	331544,1	2453892	-4714,391	
9	8	0,2	320	20	0,6	103000	101300	42,94914	0,05	81,35578534	75,11394189	2477938,289	2370000	436308,3333	340154,4093	340154,4	2477938	-4807,696	
10	9	0,2	320	20	0,6	103000	101300	42,72789	0,035	80,13726099	68,14216899	2507636,984	2470000	433369,0694	300542,0092	300542	2507637	-4648,947	
11	10	0,2	320	20	0,6	103000	101300	42,91518	0,04	80,46888177	74,45689343	2526102,498	2470000	433369,0694	311893,6063	311893,6	2526102	-4859,019	
12	11	0,2	320	20	0,6	103000	101300	43,02298	0,045	80,84434584	77,01791884	2547034,787	2470000	433369,0694	322479,4372	322479,4	2547035	-4990,033	
13	12	0,2	320	20	0,6	103000	101300	43,08853	0,05	81,16267247	77,01791884	2564802,791	2470000	433369,0694	331773,9909	331774	2564803	-5079,754	
14	13	0,2	320	20	0,6	103000	101300	42,68184	0,035	80,03708757	64,2424624	2601992,102	2570000	430038,0161	293822,6959	293822,7	2601992	-4767,536	
15	14	0,2	320	20	0,6	103000	101300	42,93262	0,04	80,31865217	70,33979825	2617125,278	2570000	430038,0161	304260,7861	304260,8	2617125	-5031,089	
16	15	0,2	320	20	0,6	103000	101300	43,10543	0,045	80,62399871	75,68012002	2633555,598	2570000	430038,0161	314011,4158	314011,4	2633556	-5221,197	
17	16	0,2	320	20	0,6	103000	101300	43,21429	0,05	81,00341418	78,86781558	2654000,137	2570000	430038,0161	322972,1773	322972,2	2654000	-5353,202	

Reference Result Generation: Model Execution

Generation:

- Any model can be used to generate a result to be used as reference result
- In practice, a test-bench model would be used where the component to be calibrated would be replaced (high fidelity -> low fidelity) between the reference result generation and the calibration.
 - Operating conditions and KPIs to calibrate are then naturally shared via the test-bench model

Open Model

Condenser
Calibration.Examples.Condenser

INFORMATION

PROPERTIES

COMPONENTS

EXPERIMENT

SIMULATIONS

- Baseline Result 10:52

Only show incomplete executions

CALCULATED VALUES

- Condenser
 - aggregateTwoPhaseProperties
 - aggregateTwoPhaseProperties1
 - airFlow
 - airPressure
 - airSink
 - airSource
 - airTemperature
 - CF_Friction_Air
 - CF_Friction_Wf
 - CF_HT_Air
 - CF_HT_Wf
 - coolingPower
 - dp_wf
 - HX
 - init

User input

Number of segments, air side	
Flow y	Flow z
1 X	1
Temp y	Temp z
1 X	1
Internal pass segmentation	
2	Flow direction
1	Orthogonal

Flow path two-phase fluid

Temperature

Vapor quality

185 Heat transfer, fluid to air [W]

Select Baseline Result (CASE)

Select:

- Baseline Result
- Reference Result
- KPIs to calibrate
- Calibration parameters

Analysis Modifications

Dynamic Steady State **Custom**

Calibration. Calibrate

xtol 0.01 ftol 0.01

max_iter 50 max_fail 0

output calibration

baseline_result Baseline Result Case 1

Select Reference Result

Select:

- Baseline Result
- Reference Result
- KPIs to calibrate
- Calibration parameters

- Can come from:
 - Result from any model
 - Result from uploaded measurement file

Assumptions:

- Variable names from results must coincide
- Operating conditions are saved in the parameterization object

The screenshot shows the 'Analysis' tab in the Modelon software. The 'Modifications' section is active, and the 'Custom' option is selected. The 'Calibration. Calibrate' dropdown menu is open, showing the following options:

- xtol: 0.01
- ftol: 0.01
- max_iter: 50
- max_fail: 0
- output: calibration
- baseline_result: Baseline Result
- reference_result: Reference 1

Arrows from the 'Select:' box point to the 'Baseline Result' and 'Reference 1' options in the dropdown menu.

Select KPIs to calibrate

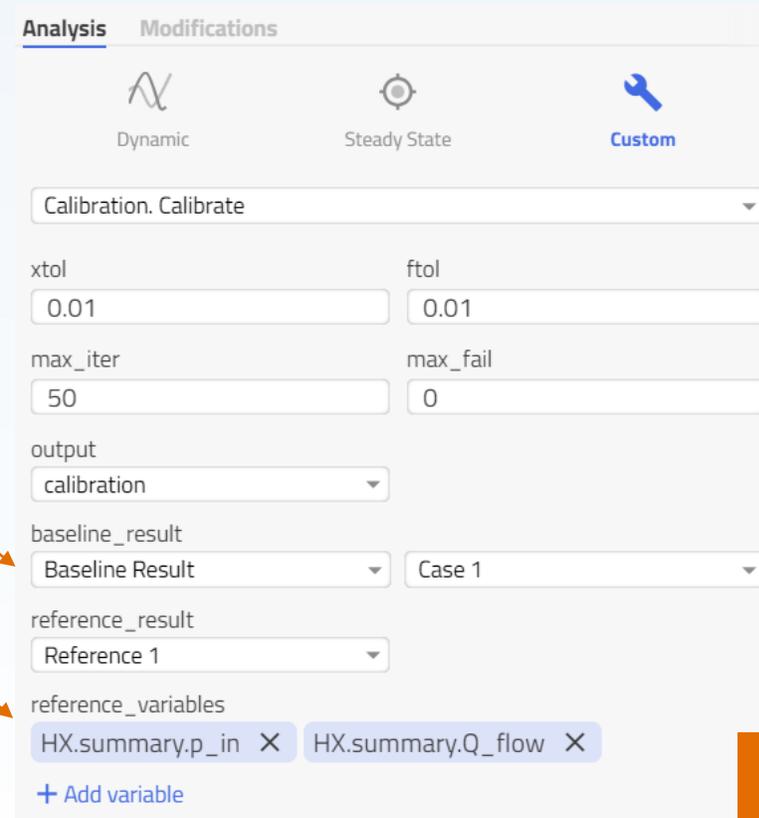
Select:

- Baseline Result
- Reference Result
- KPIs to calibrate
- Calibration parameters

- Via variable list custom function parameter
- **Assumptions:**
 - “Nominal” attribute in model is used to weight KPI output

Dependencies:

- User-friendly selection requires addition to experimentation app.



The screenshot shows the 'Analysis' tab in the Modelon software. The 'Custom' option is selected. The 'Calibration. Calibrate' dropdown is open, showing various parameters. The 'reference_variables' field contains two variables: 'HX.summary.p_in' and 'HX.summary.Q_flow'. The 'baseline_result' is set to 'Baseline Result' and the 'reference_result' is set to 'Reference 1'. The 'output' is set to 'calibration'. The 'xtol' is 0.01, 'ftol' is 0.01, 'max_iter' is 50, and 'max_fail' is 0.

Variables are filtered from the model

Select Calibration Parameters

Select:

- Baseline Result
- Reference Result
- KPIs to calibrate
- Calibration parameters

- Via variable list custom function parameter
- **Assumptions:**
 - “min” and “max” attribute in model are used to set bounds

Dependencies:

- Variable list custom function parameter
- User-friendly selection requires addition to experimentation app.

Analysis Modifications

Dynamic Steady State Custom

Calibration. Calibrate

xtol 0.01 ftol 0.01

max_iter 50 max_fail 0

output calibration

baseline_result Baseline Result Case 1

reference_result Reference 1

reference_variables HX.summary.p_in X HX.summary.Q_flow X

+ Add variable

calibration_parameters CF_Friction_Wf X CF_HT_Wf X

+ Add variable

Variables are filtered from the model

Select Calibration

Select:

- Baseline Result
- Reference Result
- KPIs to calibrate
- Calibration parameters

Analysis Modifications

Dynamic Steady State **Custom**

Calibration. Calibrate

xtol 0.01 ftol 0.01

max_iter 50 max_fail 0

output calibration

baseline_result Baseline Result Case 1

reference_result Reference 1

reference_variables HX.summary.p_in X HX.summary.Q_flow X

+ Add variable

calibration_parameters CF_Friction_Wf X CF_HT_Wf X

+ Add variable

Run calibrate function

The screenshot displays a mechanical simulation model with four joints (J1, J2, J3, J4) and three clutches (clutch1, clutch2, clutch3). The model is connected to a torque input and a fixed ground. The interface includes a 'calibrationInput' block, several 'const' blocks (const2, const3, const4), and a 'torque' block. Below the model, there is a 'k=0' block and a play button icon. The 'EXECUTION' section shows options for 'Dynamic', 'Steady State', 'Calibration-workflow.steady State With Derivatives', and 'Calibrationtoolbox. Calibrate'. The 'SIMULATIONS' section lists four simulation runs: 'Calibrated' (Feb 01 13:42), 'Baseline' (Feb 01 13:38), 'Result 12' (Feb 01 13:38), and 'BaseDef' (Jan 26 13:41).

Run baseline simulation for all cases

Run calibration

(run all operating points and calculate the objective function as the weighted sum of square errors for each iteration)

Run simulation with the calibrated parameters



Calibration function result

- Summary
- Calibrated cases
- Html-report accessible via Artifacts list

The screenshot displays a software interface with three main sections: SIMULATIONS, ARTIFACTS, and CALCULATED VALUES. The SIMULATIONS section is expanded to show a list of items, including 'Calibration Result' (Sep 26 11:33), 'Summary', 'Calibration case 1', 'Calibration case 2', 'Calibration case 3', 'Calibration case 4', 'Reference 1' (Sep 26 11:32), and 'Result 1' (Sep 26 11:32). A checkbox labeled 'Only show incomplete executions' is visible below the list. The ARTIFACTS section shows a single item, 'file.html'. The CALCULATED VALUES section includes a search filter box with the text 'Filter...' and a search icon.

SIMULATIONS	
Calibration Result	Sep 26 11:33
Summary	
Calibration case 1	
Calibration case 2	
Calibration case 3	
Calibration case 4	
Reference 1	Sep 26 11:32
Result 1	Sep 26 11:32

Only show incomplete executions

ARTIFACTS	
file.html	

CALCULATED VALUES

Filter... 🔍

Summary result

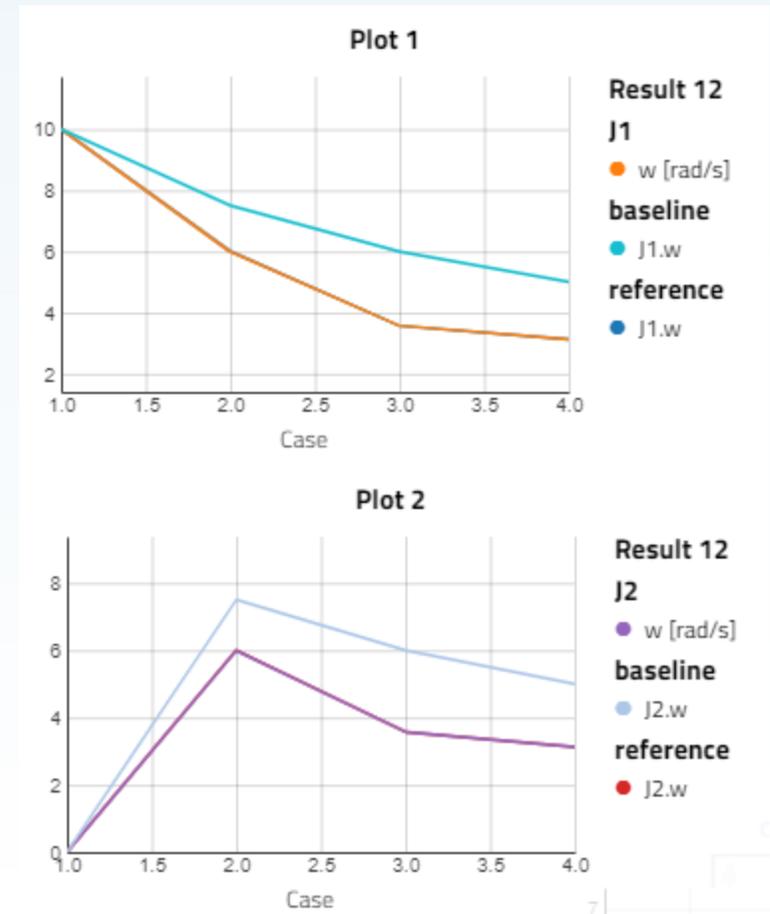
Baseline and reference results included for easy comparison

Top level variables and parameters correspond to the calibrated values.

CALCULATED VALUES

Filter...

- ▼ CoupledClutches
 - ▶ **baseline**
 - Case
 - clutch_control_1
 - clutch_control_2
 - clutch_control_3
 - ▶ J1
 - ▶ J2
 - ▶ J3
 - ▶ J4
- ▼ reference
 - clutch_control_1
 - clutch_control_2
 - clutch_control_3
 - ▼ J1
 - w
 - ▶ J2
 - ▶ J3
 - ▶ J4



HTML report

- Contains:
 - Comparison of KPIs between initial and final calibration parameter values.
- Accessed via Artifacts “preview” feature

The screenshot shows a software interface with two main sections: 'SIMULATIONS' and 'ARTIFACTS'. The 'SIMULATIONS' section lists several items, including 'Result 2' (11:33), 'Summary', and four 'Calibration case' entries. The 'ARTIFACTS' section shows a file named 'file.html' with a 'Preview' button.

Model calibration report for Calibration.Examples.CoupledClutches

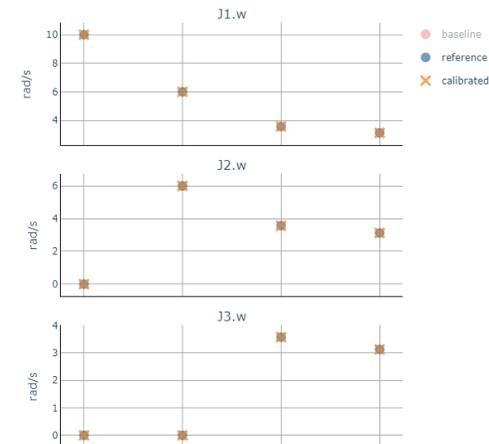
Thursday 26 September 2024

Calibration succesful

Iterations:67

Final objective function:2.230161918619843e-06

Reference variables comparison



Parameters

Baseline

	32.3	33.3	34.3
1.0	1.0	1.0	1.0

Calibrated

	32.3	33.3	34.3
2.0	3.4	1.2	

References

Error (Calibrated-reference values)

	31.w	32.w	33.w	34.w
Case				
1	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2	-3.00e-04	-3.00e-04	0.00e+00	-1.52e-15
3	6.61e-04	6.61e-04	6.61e-04	8.56e-16
4	1.36e-03	1.36e-03	1.36e-03	1.36e-03

Baseline values

	31.w	32.w	33.w	34.w
Case				
1	10.0	0.0	0.0	0.0
2	7.5	7.5	0.0	0.0
3	6.0	6.0	6.0	0.0
4	5.0	5.0	5.0	5.0

Calibrated values

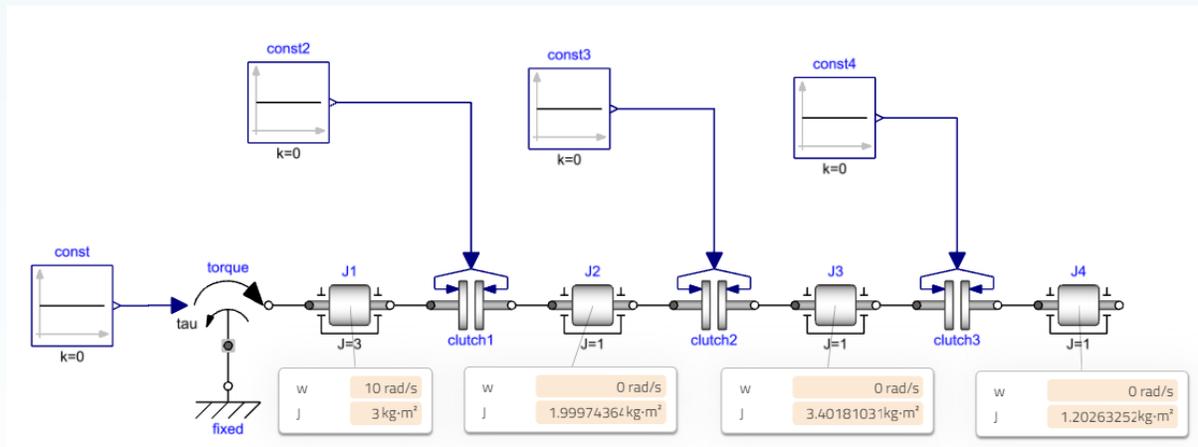
	31.w	32.w	33.w	34.w
Case				
1	10.00	0.00	0.00	0.00e+00
2	6.00	6.00	0.00	-8.86e-16
3	3.57	3.57	3.57	0.00e+00
4	3.12	3.12	3.12	3.12e+00

Operating conditions

	clutch_control_1	clutch_control_2	clutch_control_3
Case			
1	0.0	0.0	0.0
2	1.0	0.0	0.0
3	1.0	1.0	0.0
4	1.0	1.0	1.0

Demo:

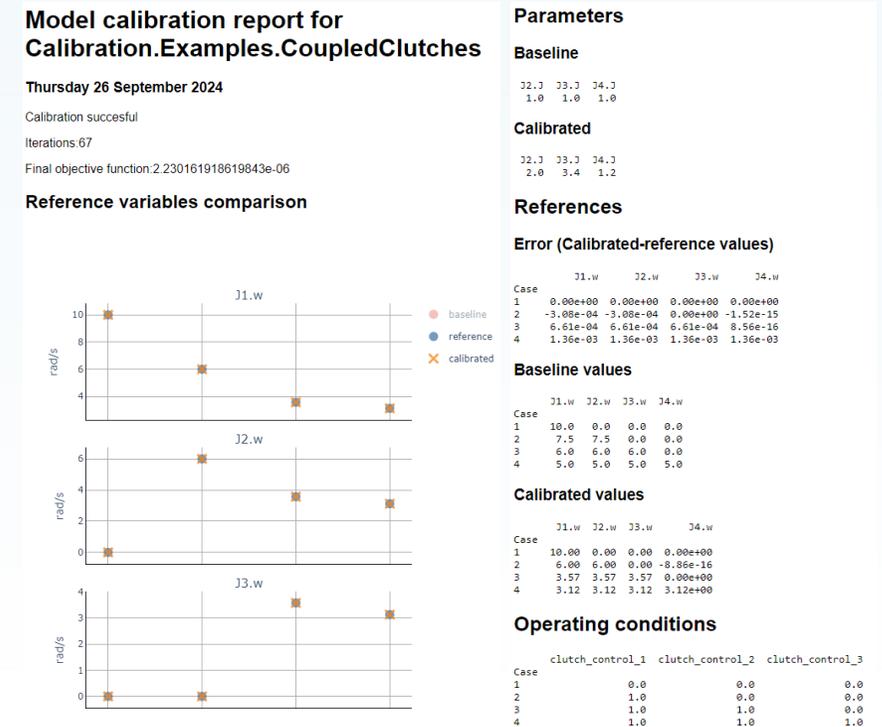
- Calibration.Examples.CoupledClutches



- Calibration data

	A	B	C	D	E	F	G	H
1	Case	clutch_control_1	clutch_control_2	clutch_control_3	J1.w	J2.w	J3.w	J4.w
2	1	0	0	0	10	0	0	0
3	2	1	0	0	0	6	6	-2.40E-15
4	3	1	1	0	3.571428571	3.571428571	3.5714286	8.56E-16
5	4	1	1	1	3.125	3.125	3.125	3.125

- Generated report



Hands-On

Part 1: Fin-and-Tube Heat Exchanger Calibration

- Calibrate friction and heat transfer coefficients with a series of operating conditions
- Help Center Tutorial: [Calibrate a model - Help Center \(modelon.com\)](https://help.modelon.com)



Part 2: Hydrogen Tank Dynamic Calibration

- Demonstrate another workflow using the Calibration library to calibrate parameters with dynamic experimental reference data
- Calibrate the heat transfer coefficients for a hydrogen storage tank to match experimental results of the pressure and temperature response to applied heat flux
- Published workspace: [Impact workspace: TankCalibrationWorkshop](https://help.modelon.com)
 - Find clickable links here: <https://help.modelon.com/latest/innovate/innovate2024/>

Feedback

We appreciate if you would take some time to fill out this form:

