# A Simulink Library of cryogenic components to generate control schemes for large refrigerators

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The aim of this work is to describe a generic methodology to model cryogenic plants and to synthesize control strategies for those witch are submitted to variable

#### Simulink Library

#### heat loads.



#### Subsystem Construction



### **Operational point finder**

Further refine the o						
	perating point	search				
Inputs						
# PortName	Known	Value	Min	Max	]	
1 CV155_cmd		20.6323	0	100		
2 CV158_cmd		45.5986	0	100		
3 NCR22_cmd	<b>v</b>	0	-Inf	Inf		
4 CV157_cmd		95	0	100		
5 Tc_cust		4.7000	-Inf	Inf		
6 Mc_cust	$\checkmark$	0.0250	-Inf	Inf		
7 Mh_cust	$\checkmark$	0.0250	-Inf	Inf		
8 Ph_bt	V	16	-Inf	Inf		
9 Th_bt	<b>V</b>	8.5000	-Inf	Inf		
10 Pc_bt	$\checkmark$	1.1500	-Inf	Inf		
Outputs						
# PortName	Known	Value	Min	Max	 ]	
1 TTB230_mes		6.5610	-Inf	Inf		
2 LTB131_mes		80	50	80		
3 TTB108_mes		4.7054	-Inf	Inf		
4 PTB206_mes		15.9793	-Inf	Inf		
5 TTB232_mes		4.4927	-Inf	Inf		
		1.1655	-Inf	Inf		
6 PTB218_mes						

JT cycle / SBT

Obtaining the model of the refrigerator for simulation and control purposes

$$\dot{x} = f(x, u, w)$$

x: state (temp., press., etc.)u: manipulated variable (valve opening, ...)w: disturbances (boundary conditions)

## Linear approximation



Obtaining the linear approximation of the model

 $\dot{x} = f(x, u, w) \Rightarrow \dot{x} = A\tilde{x} + B\tilde{u} + F\tilde{w}$ 

Finding the constrained  
operating point of the machine 
$$\frac{df(x, u, w)}{dt} = 0 \qquad A = \frac{\partial f(x, u, w)}{\partial x} \Big|_{\substack{x=x_0 \\ u=u_0}}, B = \frac{\partial f(x, u, w)}{\partial u} \Big|_{\substack{x=x_0 \\ u=u_0}}$$





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#### Experimental results SBT Cold Box

Software to generate:

- Advanced contrôle scheme
- PID controllers



Plant:	•				Export Control
Linnou					Export control
PID MPC					
New Controller Controller	-				
Control Output/States P	arametrization Simul	lation			
onstraints Weights					
Import from Workspace					
U min = []	-	U max =	[]	<ul> <li>Slack variables = [</li> </ul>	-
dU min = [1]	-	dU max =	: 11	▼	
					Impor
Deline					
Control Derivatives					
Control Derivatives Name	Constrained	U min U n	max Soft	Slack Type	
Control Derivatives           Control         Derivatives           Name         1           CV155_cmd	Constrained	Umin Un -Inf	max Soft	Slack Type Inf Command 🚽	
Control Derivatives           Control         Derivatives           Name         1           CV155_cmd         2           CV158_cmd         2	Constrained	Umin Un -Inf -Inf	max Soft	Slack Type Inf Command - Inf Command -	
Control Derivatives           Control         Derivatives           1         CV155_cmd           2         CV158_cmd           3         NCR22_cmd           4         CV157_cmd	Constrained	Umin Un -Inf -Inf -Inf	max Soft	Slack     Type       Inf     Command       Inf     Command       Inf     Command       Inf     Command	
Control Derivatives           Control         Derivatives           1         CV155_cmd           2         CV158_cmd           3         NCR22_cmd           4         CV157_cmd           5         Tc cust	Constrained	Umin Un -Inf -Inf -Inf -Inf -Inf	max Soft	Slack     Type       Inf     Command       Inf     Command       Inf     Command       Inf     Command       Inf     Command       Inf     Command	
Control     Derivatives       1     CV155_cmd       2     CV158_cmd       3     NCR22_cmd       4     CV157_cmd       5     Tc_cust       6     Mc_cust	Constrained	Umin Un -Inf -Inf -Inf -Inf -Inf -Inf -Inf	max Soft	Slack       Type         Inf       Command       ✓         Inf       Disturbance       ✓         Inf       Command       ✓	
Control       Derivatives         I       CV155_cmd         2       CV158_cmd         3       NCR22_cmd         4       CV157_cmd         5       Tc_cust         6       Mc_cust         7       Mh_cust	Constrained	Umin Un -Inf -Inf -Inf -Inf -Inf -Inf -Inf -In	max Soft	Slack       Type         Inf       Command       ✓         Inf       Disturbance       ✓         Inf       Disturbance       ✓         Inf       Disturbance       ✓	
Control       Derivatives         1       CV155_cmd         2       CV155_cmd         3       NCR22_cmd         4       CV157_cmd         5       Tc_cust         6       Mc_cust         7       Mh_cust         8       Ph_bt	Constrained	Umin Un -Inf -Inf -Inf -Inf -Inf -Inf -Inf -In	max Soft	Slack       Type         Inf       Command       ✓         Inf       Disturbance       ✓         Inf       Disturbance       ✓         Inf       Disturbance       ✓         Inf       Command       ✓         Inf       Disturbance       ✓         Inf       Command       ✓	
Control       Derivatives         1       CV155_cmd         2       CV158_cmd         3       NCR22_cmd         4       CV157_cmd         5       Tc_cust         6       Mc_cust         7       Mh_cust         8       Ph_bt         9       Th_bt	Constrained	U min         U n           -Inf         -Inf	max Soft	Slack       Type         Inf       Command       ✓         Inf       Disturbance       ✓         Inf       Disturbance       ✓         Inf       Disturbance       ✓         Inf       Disturbance       ✓         Inf       Command       ✓	
ControlDerivatives1CV155_cmd2CV155_cmd3NCR22_cmd4CV157_cmd5Tc_cust6Mc_cust7Mh_cust8Ph_bt9Th_bt10Pc_bt	Constrained	U min         U n           -Inf         -Inf           -Inf         -Inf	max Soft Inf Inf Inf Inf Inf Inf Inf Inf Inf Inf	Slack       Type         Inf       Command          Inf       Disturbance          Inf       Disturbance          Inf       Disturbance          Inf       Command	
Control       Derivatives         1       CV155_cmd         2       CV155_cmd         3       NCR22_cmd         4       CV157_cmd         5       Tc_cust         6       Mc_cust         7       Mh_cust         8       Ph_bt         9       Th_bt         10       Pc_bt	Constrained	Umin Un -Inf -Inf -Inf -Inf -Inf -Inf -Inf -Inf -Inf -Inf -Inf -Inf -Inf -Inf -Inf	max Soft Inf Control	Slack       Type         Inf       Command          Inf       Disturbance          Inf       Disturbance          Inf       Disturbance          Inf       Command          Inf       Command          Inf       Command          Inf       Command          Inf       Command          Inf       Command	
Control       Derivatives         1       CV155_cmd         2       CV155_cmd         3       NCR22_cmd         4       CV157_cmd         5       Tc_cust         6       Mc_cust         7       Mh_cust         8       Ph_bt         9       Th_bt         10       Pc_bt	Constrained           Image: Constrained	U min         U n           -Inf         -Inf	max Soft	Slack       Type         Inf       Command         Inf       Command         Inf       Command         Inf       Command         Inf       Command         Inf       Command         Inf       Disturbance         Inf       Disturbance         Inf       Disturbance         Inf       Disturbance         Inf       Disturbance         Inf       Command	
Control       Derivatives         1       CV155_cmd         2       CV155_cmd         3       NCR22_cmd         4       CV157_cmd         5       Tc_cust         6       Mc_cust         7       Mh_cust         8       Ph_bt         9       Th_bt         10       Pc_bt	Constrained	U min         U n           -Inf         -Inf	max Soft	Slack       Type         Inf       Command       Inf         Inf       Disturbance       Inf         Inf       Disturbance       Inf         Inf       Command       Inf	
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#### **CERN Warm Compression Station**

# $\mathbf{C} \mathbf{L} \mathbf{V} \mathbf{V} \mathbf{V}$









Absorbed flow-rate looks

like the heat load

=>possible energy savings













Low pressure is spending less time below atm pressure thanks to the advanced controller

Measured variables are constrained as well as actuators : it provides operational safety

INSTITUT NANOSCIENCES ET CRYOGÉNIE

Niveau (%)

