Report of TE Control Model

Yue Ma

Overview:

The TE control model which is chosen for studying is *MultiLoop_mode1.mdl* which is a Simulink model of the control strategy described in "Decentralized control of the Tennessee Eastman Challenge Process", N. L. Ricker, J. Proc. Cont., Vol. 6, No. 4, pp. 205-221, 1996. It is set up to initialize and run with constant setpoints at the "Mode 1" operating condition.

Features:

Since this is a control system and it can prevent meeting constraints, this model can simulate for 72 hours. The original TE model in J. J. Downs can only simulate for 3 hours. This reversion model is the one which adds 20 controller to the original benchmark model.

There are 12 XMVs, 20+8 disturbances, 41 XMEAS in total. In the original benchmark system, XMVs are constant input which can be changed by ourselves. Since this model is a control system, the controllers will adjust the value of input, the XMVs become unstable outputs which shows us as figures. In the original version, there are only 20 disturbances. In this version, the author adds eight more disturbances. XMEAS are the outputs which can be used to analyze the changing in the system.

In this simulation model, there are one main system and one subsystem named TE plant. There are 12 setpoints showing in the main system which we can treat them as changeable inputs. Each setpoint is used in a controller. The controllers adjust XMVs so that the system is under control.

There are 28 disturbances which can be changed between 0 and 1. 0 means no disturbance and 1 means there is a disturbance. We can also input a number which lies between 0 and 1, but it will adjust to 0 or 1 depending on the nearest index value. Downs and Vogel provide 20 test disturbances. Some are step changes. Others have random character. Most are unmeasured, precluding feedforward compensation. They may occur individually or in combination. In this version, additional 8 random variation disturbances added to test the model. Through reading the code "temexd_mod.c", each disturbance has a complicated algorithm to calculate and it is better to not change the algorithm of disturbances. This model can be tested by changing values of setpoints and disturbance(0 or 1). The step changes of disturbances can also be realized, that is, we can decide when the faults happen by changing the simulation of the model. We can also combine two disturbances together or just use one disturbance.

Table 4. Continuous process measurements

Variable name	Variable number	Base case value	Units
A feed (stream 1)	XMEAS (1)	0.25052	kscmh
D feed (stream 2)	XMEAS (2)	3664.0	$kg\ h^{-1}$
E feed (stream 3)	XMEAS (3)	4509.3	$kg\ h^{-1}$
A and C feed (stream 4)	XMEAS (4)	9.3477	kscmh
Recycle flow (stream 8)	XMEAS (5)	26.902	kscmh
Reactor feed rate (stream 6)	XMEAS (6)	42.339	kscmh
Reactor pressure	XMEAS (7)	2705.0	kPa gauge
Reactor level	XMEAS (8)	75.000	%
Reactor temperature	XMEAS (9)	120.40	°C
Purge rate (stream 9)	XMEAS (10)	0.33712	kscmh
Product separator temperature	XMEAS (11)	80.109	°C
Product separator level	XMEAS (12)	50.000	%
Product separator pressure	XMEAS (13)	2633.7	kPa gauge
Product separator underflow (stream 10)	XMEAS (14)	25.160	$m^3\ h^{-1}$
Stripper level	XMEAS (15)	50.000	%
Stripper pressure	XMEAS (16)	3102.2	kPa gauge
Stripper underflow (stream 11)	XMEAS (17)	22.949	$m^3\ h^{-1}$
Stripper temperature	XMEAS (18)	65.731	°C
Stripper steam flow	XMEAS (19)	230.31	$kg\ h^{-1}$
Compressor work	XMEAS (20)	341.43	kW
Reactor cooling water outlet temperature	XMEAS (21)	94.599	°C

Table 5. Sampled process measurements

Reactor feed analysis (stream 6)

Component	Variable number	Base case value	Units	Sampling frequency = 0.1 h Dead time = 0.1 h
A	XMEAS (23)	32.188	mol%	
B	XMEAS (24)	8.8933	mol%	
C	XMEAS (25)	26.383	mol%	
D	XMEAS (26)	6.8820	mol%	
E	XMEAS (27)	18.776	mol%	
F	XMEAS (28)	1.6567	mol%	

Purge gas analysis (stream 9)

Component	Variable number	Base case value	Units	Sampling frequency = 0.1 h Dead time = 0.1 h
A	XMEAS (29)	32.958	mol%	
B	XMEAS (30)	13.823	mol%	
C	XMEAS (31)	23.978	mol%	
D	XMEAS (32)	1.2565	mol%	
E	XMEAS (33)	18.579	mol%	
F	XMEAS (34)	2.2633	mol%	
G	XMEAS (35)	4.8436	mol%	
H	XMEAS (36)	2.2986	mol%	

Product analysis (stream 11)

Component	Variable number	Base case value	Units	Sampling frequency = 0.25 h Dead time = 0.25 h
D	XMEAS (37)	0.01787	mol%	
E	XMEAS (38)	0.83570	mol%	
F	XMEAS (39)	0.09858	mol%	
G	XMEAS (40)	53.724	mol%	
H	XMEAS (41)	43.828	mol%	

The analyzer sampling frequency is how often the analyzer takes a sample of the stream. The dead time is the time between when a sample is taken and when the analysis is complete. For an analyzer with a sampling frequency of 0.1 h and a dead time of 0.1 h, a new measurement is available every 0.1 h and the measurement is 0.1 h old.

Changing Disturbances:

Table 8. Process disturbances

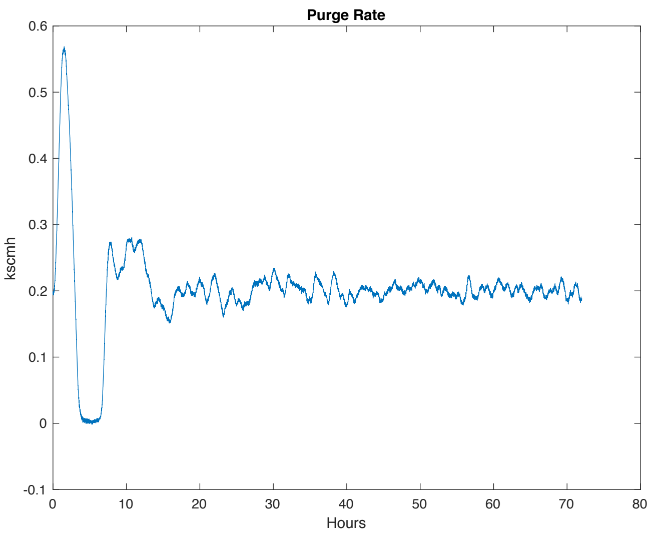
Variable number	Process variable	Type
IDV (1)	A/C feed ratio, B composition constant (stream 4)	Step
IDV (2)	B composition, A/C ratio constant (stream 4)	Step
IDV (3)	D feed temperature (stream 2)	Step
IDV (4)	Reactor cooling water inlet temperature	Step
IDV (5)	Condenser cooling water inlet temperature	Step
IDV (6)	A feed loss (stream 1)	Step
IDV (7)	C header pressure loss—reduced availability (stream 4)	Step
IDV (8)	A, B, C feed composition (stream 4)	Random variation
IDV (9)	D feed temperature (stream 2)	Random variation
IDV (10)	C feed temperature (stream 4)	Random variation
IDV (11)	Reactor cooling water inlet temperature	Random variation
IDV (12)	Condenser cooling water inlet temperature	Random variation
IDV (13)	Reaction kinetics	Slow drift
IDV (14)	Reactor cooling water valve	Sticking
IDV (15)	Condensor cooling water valve	Sticking
IDV (16)	Unknown	Unknown
IDV (17)	Unknown	Unknown
IDV (18)	Unknown	Unknown
IDV (19)	Unknown	Unknown
IDV (20)	Unknown	Unknown

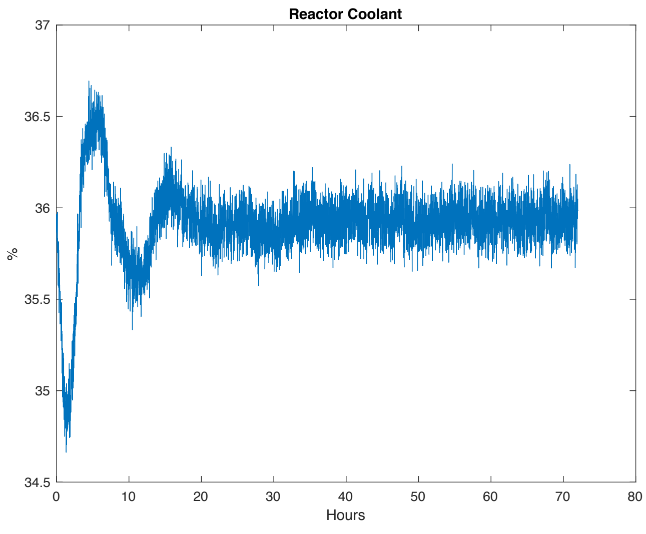
Disturbances 14–20 should be used in conjunction with another disturbance from this table or a setpoint change. To realize the full effect of these disturbances, we suggest a simulation time of 24–48 h.

Since this is a complicated chemical process, when a disturbance happens, it will definitely affect the whole system. However, some outputs have significant jump or bent, some outputs almost remain the same after adding the disturbance.

The following paragraphs record conditions of applying single disturbances.

Disturbance 1: Step disturbance happens at 1 hour. The outputs that don't have apparently change are XMV5, 9, 12, and XMEAS19, 32, 37, 39, 40, 41. Other outputs all have big influence under this disturbance.

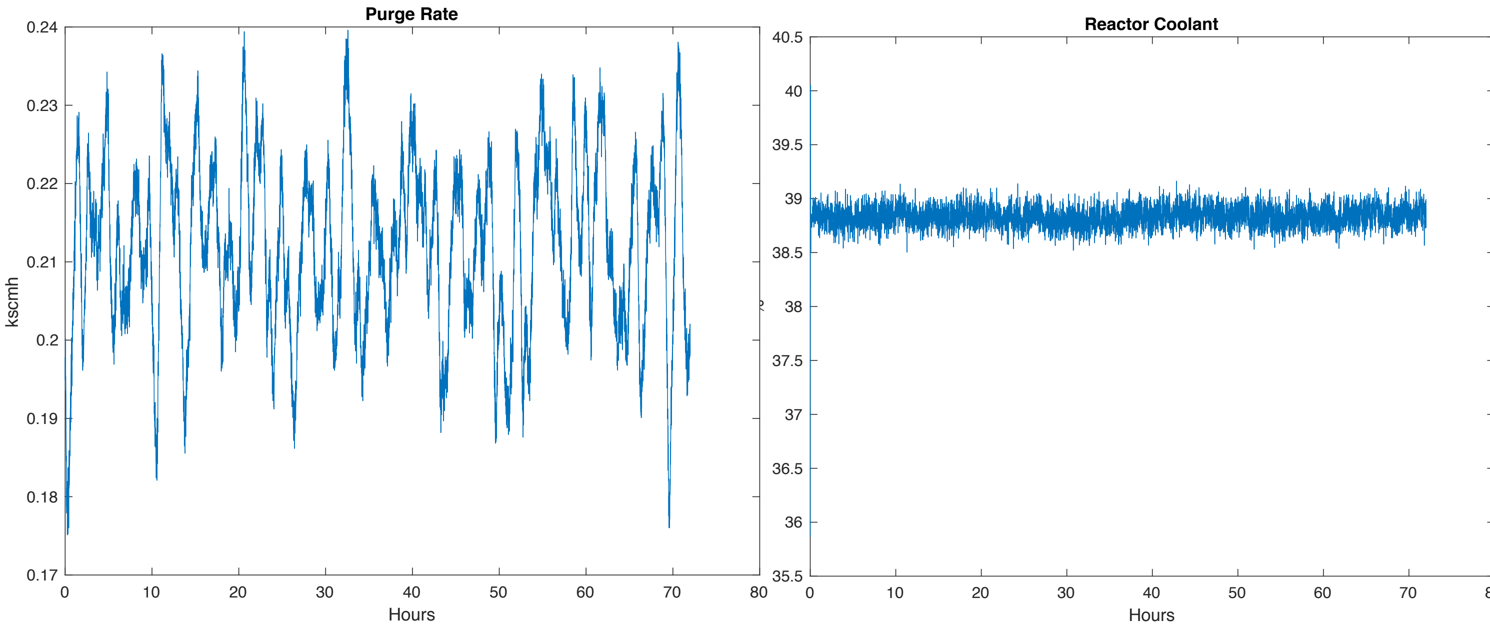




Disturbance 2: Step disturbance happens in the beginning of the simulation. The outputs that don't have apparently change are XMV5, 9, 10, 11, 12 and XMEAS8, 9, 20, 25, 31, 32, 37, 40, 41.

Disturbance 3: Step disturbance happens at 35 hours. XMV1 has an upward curve and XMV2 has a downward curve. Other outputs don't have a significant jump.

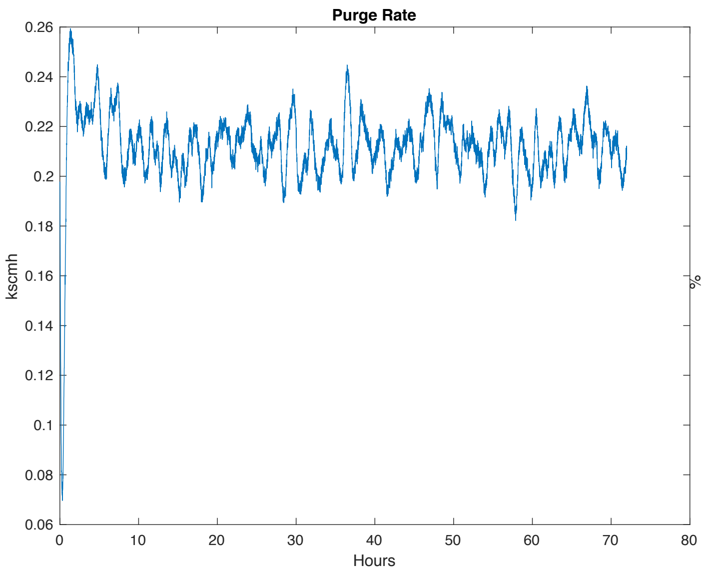
Disturbance 4:Step disturbance happens at the beginning of the reaction. XMEAS 9 and XMEAS 21 jump downwards suddenly.

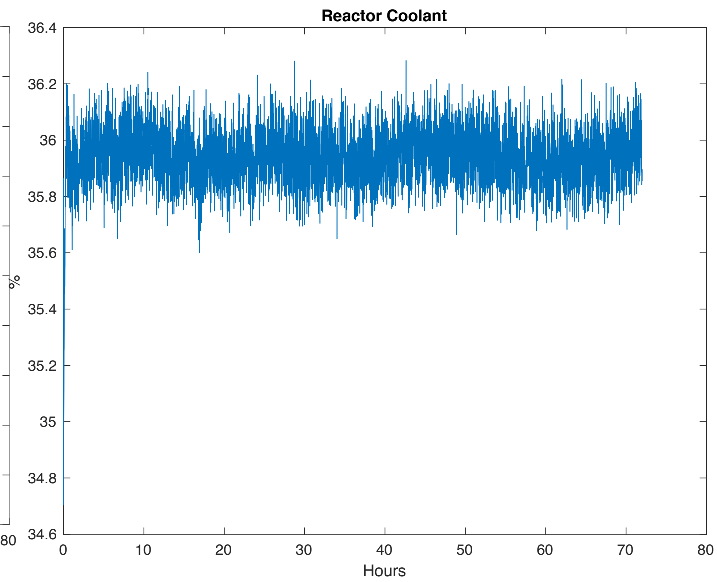


Disturbance 5: Step disturbance. XMV 1 goes up and XMV 2 goes down. There is no significant jump in XMEAS.

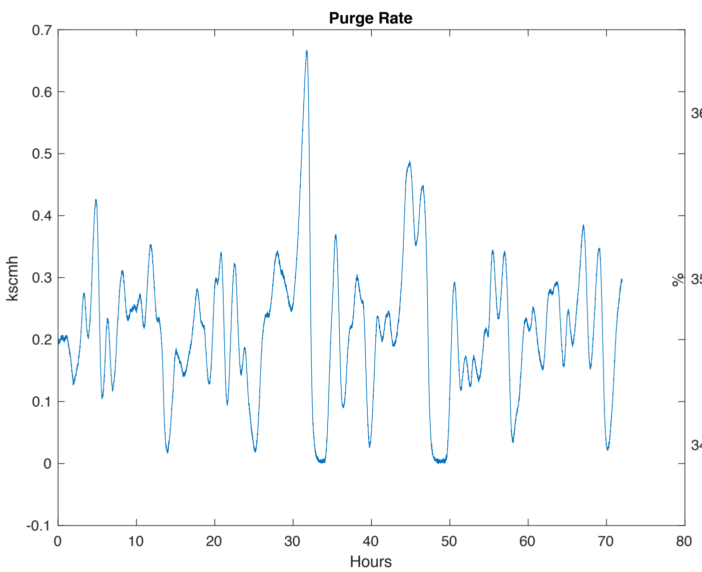
Disturbance 6: Step disturbance happens at the beginning of the process. The process meets constraints and shuts down at 7hrs. There are several outputs going up after adding the disturbance: XMV1, 2, 3, 6, 7, 11, and XMEAS 2, 3, 7, 10, 12, 13, 14, 16, 21, 25, 26, 27, 29, 31, 32, 33, 37, 38, 39, 40. Those going downwards are XMV5, 9, 10, and XMEAS 4, 5, 6, 11, 15, 17, 18, 20, 22, 23, 24, 28, 30, 34, 35, 36, 41.

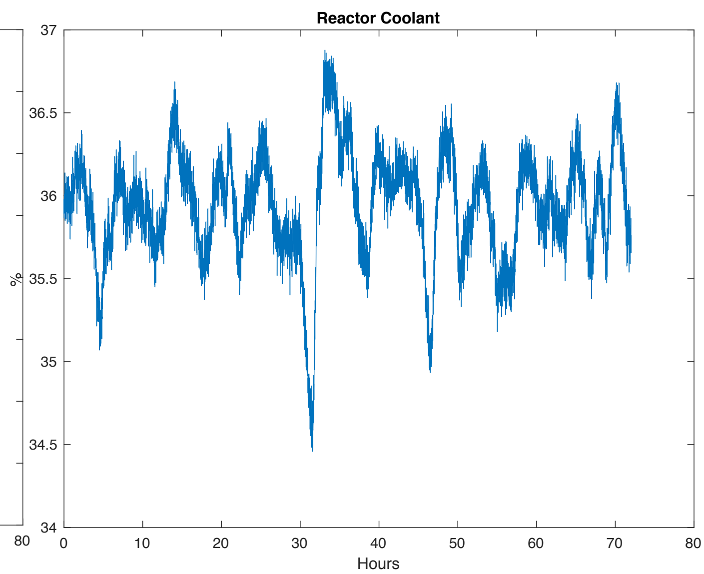
Disturbance 7: Step disturbance happens at the beginning of the process which make parts of outputs value decrease or increase suddenly. The outputs jumping upwards are XMV 4, 6, 10, and XMEAS 4, 7, 9, 13. The jumping down outputs are XMV8 and XMEAS18, 21, 38. Other outputs are also affected, but they don't have a significant jump.





Disturbance 8: Random variation disturbance, the faults happen all the time. But big faults happen at 30 hours and 40 hours. XMV5, 9, 11, 12 and XMEAS 9, 19 don't have significant change. For other outputs, we can see sudden slope change when disturbance happens.





Disturbance 9: Random variation disturbance.

Disturbance 10: Random variation disturbance. XMV5, 9, 10, 11, and 12 remain the same as before. XMEAS 10, 11, 15, 18, 20, 21 and 22 have significant wave change. The Other outputs have small changes, however it is not significant.

Disturbance 11: Random variation disturbance.

Disturbance 12: Random variation disturbance. XMV1, 2, and 3 have significant wave change. The other outputs all have small changes, but not significant.

Disturbance 13: Slow drift disturbance. XMV 5, 9, 12 and XMEAS 19 don't change. The other outputs all wave a lot and has significant difference after adding the disturbance.

Disturbance 14: Sticking. XMV 5, 9, 12 don't change. The other outputs all have change.

Disturbance 15: Sticking. XMV 5, 9, 12 don't change. The other outputs all have small wave change, but don't have significant change.

Disturbance 16: Unknown. XMV 5, 9, 12 don't change. The other outputs all have small wave change, but don't have significant change.

Disturbance 17: Unknown. Through the observation of output, XMV10 and XMEAS 21 have regular wave change. This disturbance should be step disturbance which happens on the reactor cooling water flow. XMEAS 7, 9, 10, 11, 13, 16, 18, 20, 21, 22 have significant wave change.

Disturbance 18: Unknown. XMEAS 7, 9, 10, 11, 13, 16, 18, 20, 21, 22 have significant regular wave change. Other outputs change slightly.

Disturbance 19: Unknown. XMV 5, 9, 12 don't change. Other outputs all changes.

Disturbance 20: Unknown. XMV 5, 9, 12 don't change. The other outputs all changes after adding the disturbance.

Disturbance 20~28 are added by the reversion of TE control system and they are not in the original TE model. They are 8 random variation disturbances.

Conclusion:

In this TE control model, we can adjust setpoints and disturbance value (0 or 1) to simulate the process. XMV and XMEAS are outputs. We can figure out when the faults happens through the figures of outputs.

References:

J. J. Downs and E. F. Vogel. A plant-wide industrial process control problem.

N. Lawrence Ricker. Decentralized control of the Tennessee Eastman Challenge Process

Andreas Bathelt* N. Lawrence Ricker** Mohieddline Jelali*** Revision of the Tennessee Eastman Process Model

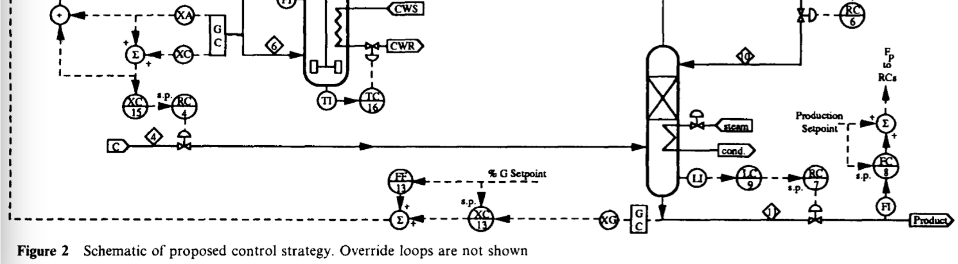


Figure 2 Schematic of proposed control strategy. Override loops are not shown