

# PROGRESS WITH THE INDUSTRIAL ACTUATOR REAL DATA BENCHMARK STUDY

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- What was done?
- What faults?
- Human factor fault
- Data file structure
- Added value
- End remarks

**DAMADICS Workshop**

**ROBUST METHODS IN FAULT  
DIAGNOSIS**

**HULL**

**January 25, 2002**

# What was done?

Concise progress report between September and December 2001

- 19 successful artificial fault simulation sessions in sugar factory Lublin
- Upgrading factory equipment with the instruments necessary to perform demanded experiments
- Installing the SCADA system suited for Damadics purposes
- Acquiring the 32 process data between October 29 and November 22, 2001 (sampling time 1s)
- Post processing the data to achieve transferable data files.
- Identifying records from faulty states
- Fault specification
- Publishing the data in the internet <http://diag.mchtr.pw.edu.pl/damadics>

# What faults were introduced?

## Control valve faults

- $f_1$  - valve clogging
- $f_2$  - valve or valve seat sedimentation
- $f_3$  - valve or valve seat erosion
- $f_4$  - increase of valve or bushing friction
- $f_5$  - external leakage (leaky bushing, covers)
- $f_6$  - internal leakage (valve tightness)
- $f_7$  - medium evaporation or critical flow

## Pneumatic servo-motor faults

- $f_8$  - twisted servomotor's rod
- $f_9$  - servomotor's housing or terminals tightness
- $f_{10}$  - servomotor's diaphragm perforation
- $f_{11}$  - servomotor's spring fault

## Positioner faults

- $f_{12}$  - electropneumatic transducer fault
- $f_{13}$  - rod displacement sensor fault
- $f_{14}$  - pressure sensor fault
- $f_{15}$  - positioner spring fault



2001

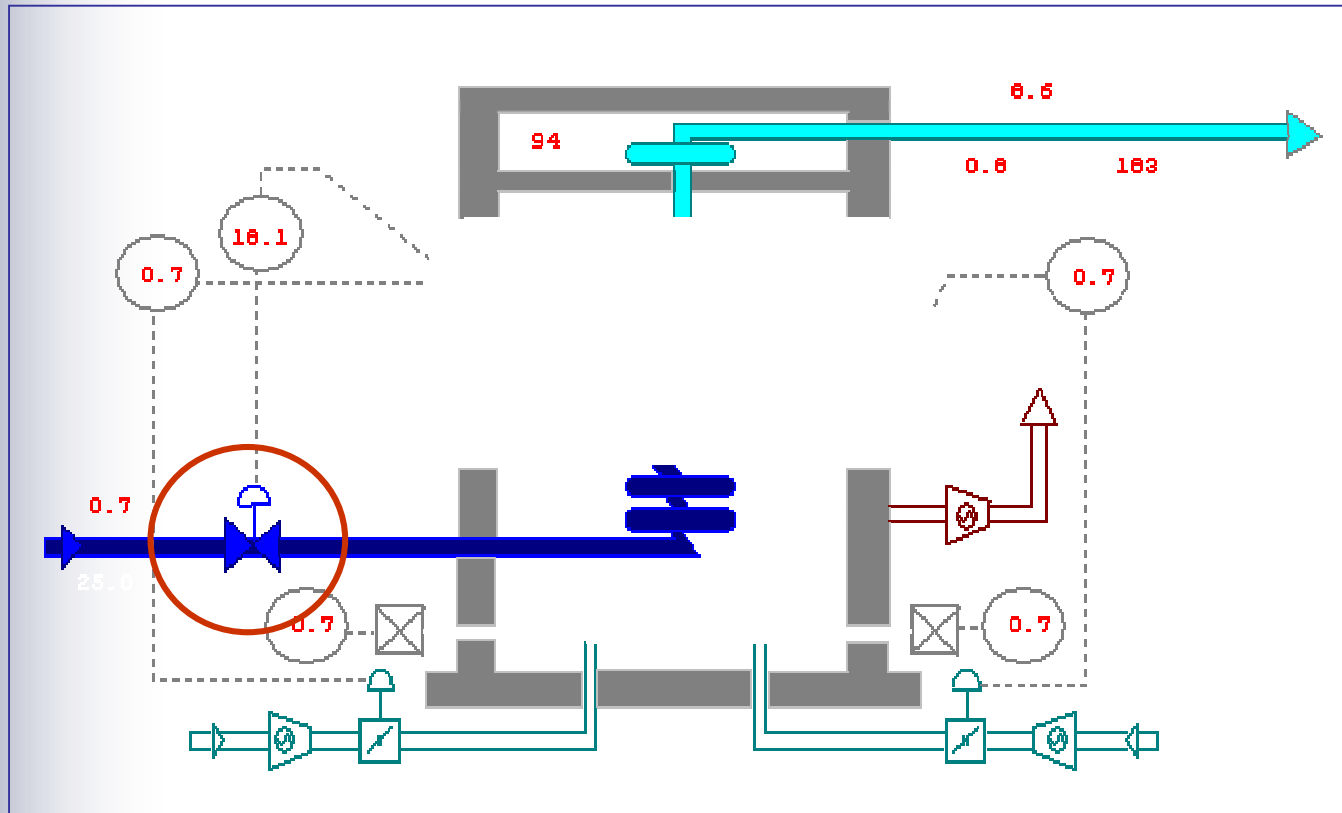
## General faults/external faults

- $f_{16}$  - positioner supply pressure drop
- $f_{17}$  - unexpected pressure change across the valve
- $f_{18}$  - fully or partly opened bypass valves
- $f_{19}$  - flow rate sensor fault

# Steam boiler

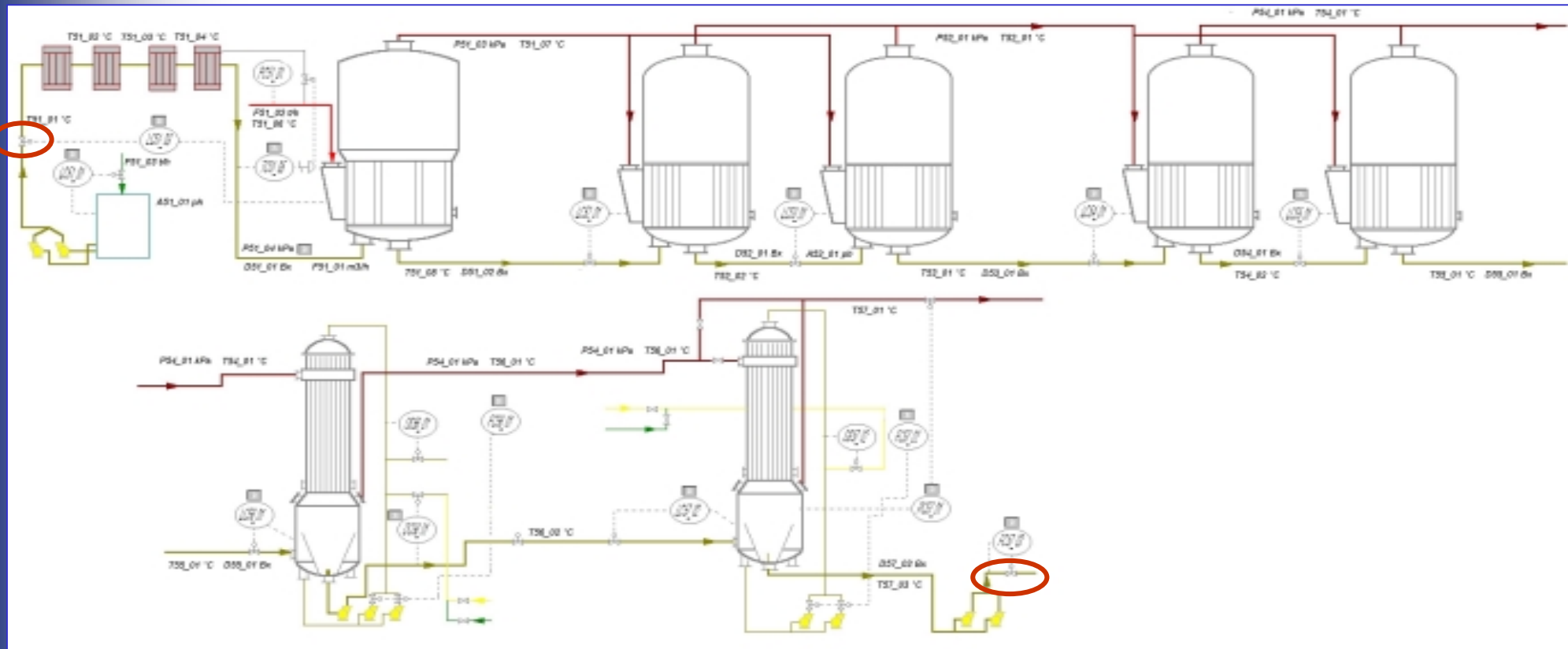
(synoptic overview)

## Water level control loop



Control loop tag: LC74\_20

# Evaporation station



Thin juice level control loop in the first section of evaporation station :

LC51\_03

Thick juice flow control loop at the outlet of the fifth section of evaporation station :

FC57\_03

# Data files structure

## Principles

- Each data file contains data acquired from one day.
- Data are structured in a form of a matrix (86400 rows x 33 columns) of real numbers.
- First column contains time stamp (number of seconds passing from hour 0:00:00).
- Columns are related to the process variables while rows are corresponding to the time stamps.
- *NaN* string represents dummy data in the case of data lack (if any)

# Data files structure

Time stamp

P2

F1

X1

P1

T1

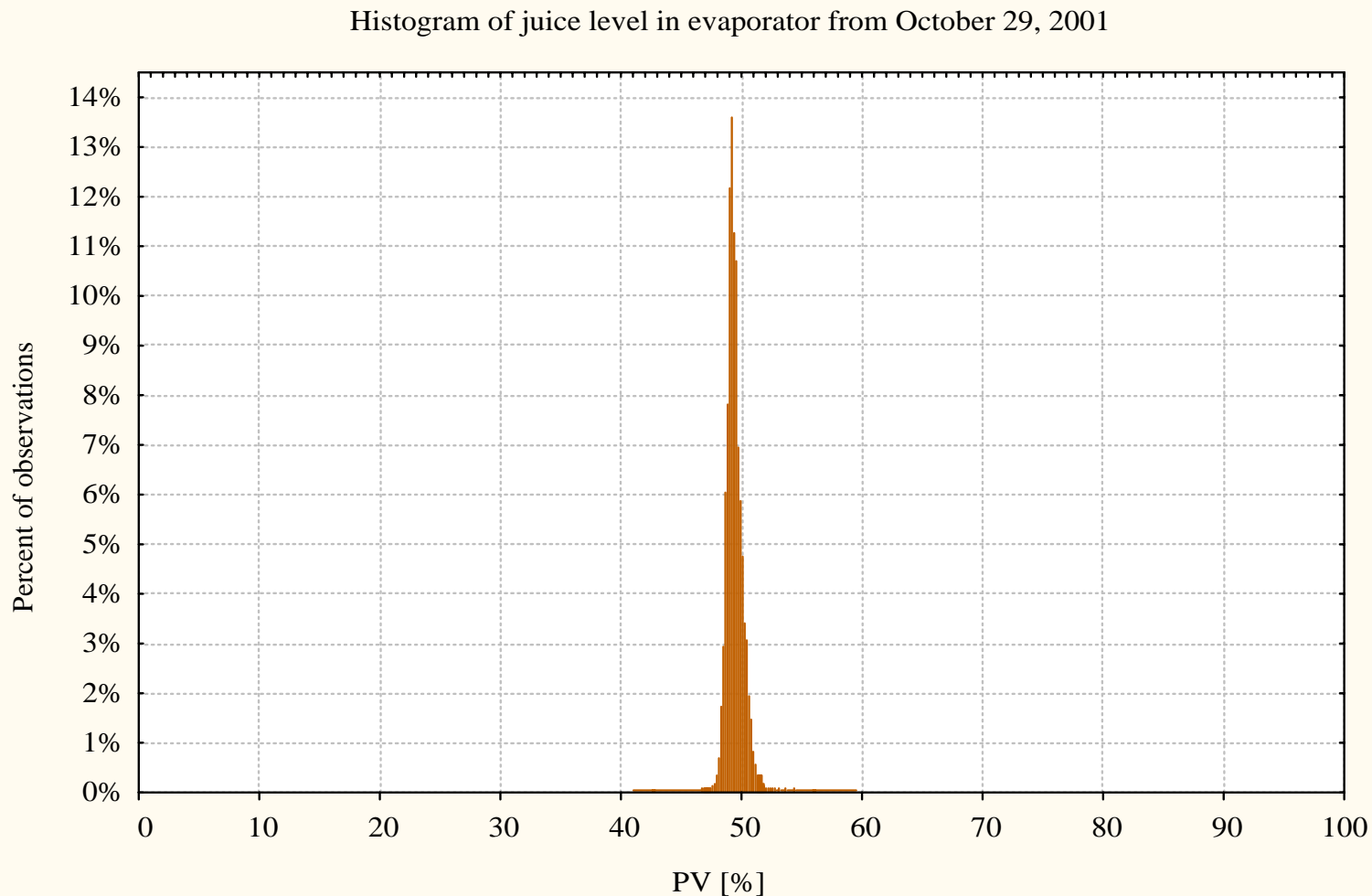
CV1

PV1

	Z0F1	Z0F2	Z0F3	Z0F4	Z0F5	Z0F6	Z0F7	Z0F8	Z0F9	Z0F10	Z0F11	Z0F12	Z0F13	Z0F14
1	0.000	636.900	393.400	96.200	371.200	33.700	30.900	48.100	130.700	134.300	13.300	21.000	70.000	280.70
2	1.000	647.400	378.500	96.200	365.300	33.900	32.500	47.800	130.700	134.300	13.300	21.200	69.600	280.70
3	2.000	649.100	378.300	96.200	360.800	33.300	32.700	47.500	130.700	134.300	13.300	21.200	70.800	280.70
4	3.000	649.100	387.800	96.200	359.100	33.100	32.600	47.300	130.700	134.300	13.300	21.200	69.900	280.90
5	4.000	640.800	384.600	96.200	359.600	32.700	33.600	47.700	130.700	134.300	13.300	21.100	69.700	281.20
6	5.000	634.900	389.000	96.200	361.500	33.500	32.500	47.500	130.700	134.300	13.300	21.100	70.700	280.90
7	6.000	636.900	388.500	96.200	365.300	32.900	31.100	47.800	130.700	134.300	13.300	21.100	70.300	281.30
8	7.000	639.800	380.700	96.200	365.400	33.600	32.200	47.900	130.700	134.300	13.300	21.100	68.900	281.20
9	8.000	638.600	381.900	96.200	365.400	34.000	32.800	48.400	130.700	134.300	13.300	21.100	70.200	281.10
10	9.000	648.800	374.400	96.200	361.400	34.700	33.300	48.200	130.700	134.300	13.300	21.100	70.200	281.20
11	10.000	652.500	367.300	96.200	356.300	34.000	33.300	47.400	130.700	134.300	13.300	21.100	70.100	281.20
12	11.000	656.400	380.000	96.200	353.400	32.900	34.800	46.800	130.700	134.300	13.300	21.200	68.900	281.10
13	12.000	647.400	374.600	96.200	353.400	32.000	32.700	46.700	130.700	134.300	13.300	21.100	70.400	281.00
14	13.000	643.700	388.800	96.100	355.900	32.100	33.100	47.100	130.700	134.300	13.300	21.100	69.500	281.50
15	14.000	637.100	381.900	96.200	360.900	32.500	31.700	46.800	130.700	134.300	13.300	21.000	70.800	281.30
16	15.000	629.100	383.900	96.200	365.300	32.100	31.800	46.900	130.700	134.300	13.300	20.900	70.500	281.50
17	16.000	632.200	389.700	96.200	368.400	31.800	31.300	46.500	130.700	134.300	13.300	20.900	70.000	281.40
18	17.000	624.200	397.300	96.200	371.100	31.600	31.600	46.900	130.700	134.300	13.300	21.100	69.200	281.50
19	18.000	627.100	391.200	96.200	372.400	32.000	30.600	46.700	130.700	134.300	13.300	21.100	70.200	281.10
20	19.000	632.200	392.700	96.200	373.500	31.700	31.900	46.700	130.700	134.300	13.300	21.100	70.200	281.40
21	20.000	630.800	391.500	96.200	373.300	31.900	30.600	46.700	130.700	134.300	13.300	21.000	69.900	281.80
22	21.000	630.800	396.800	96.100	373.100	31.600	32.300	46.800	130.700	134.300	13.300	20.900	69.700	281.50
23	22.000	628.100	397.100	96.200	372.800	32.200	31.400	46.800	130.700	134.300	13.300	20.900	70.600	281.60
24	23.000	630.300	396.800	96.200	372.300	31.900	30.800	46.700	130.700	134.300	13.300	21.000	69.600	281.60
25	24.000	630.500	392.900	96.200	372.400	32.200	32.200	47.000	130.700	134.300	13.300	21.100	69.500	281.70
26	25.000	627.800	386.600	96.200	371.900	31.900	30.600	46.600	130.700	134.300	13.300	21.200	71.000	281.50
27	26.000	632.200	387.300	96.200	371.900	31.900	32.300	46.900	130.700	134.300	13.300	21.300	70.300	281.50
28	27.000	627.600	392.200	96.200	372.300	31.800	30.700	46.800	130.700	134.300	13.300	21.300	68.600	281.90
29	28.000	624.900	393.200	96.200	372.900	31.800	32.500	46.900	130.700	134.300	13.300	21.500	69.200	281.80

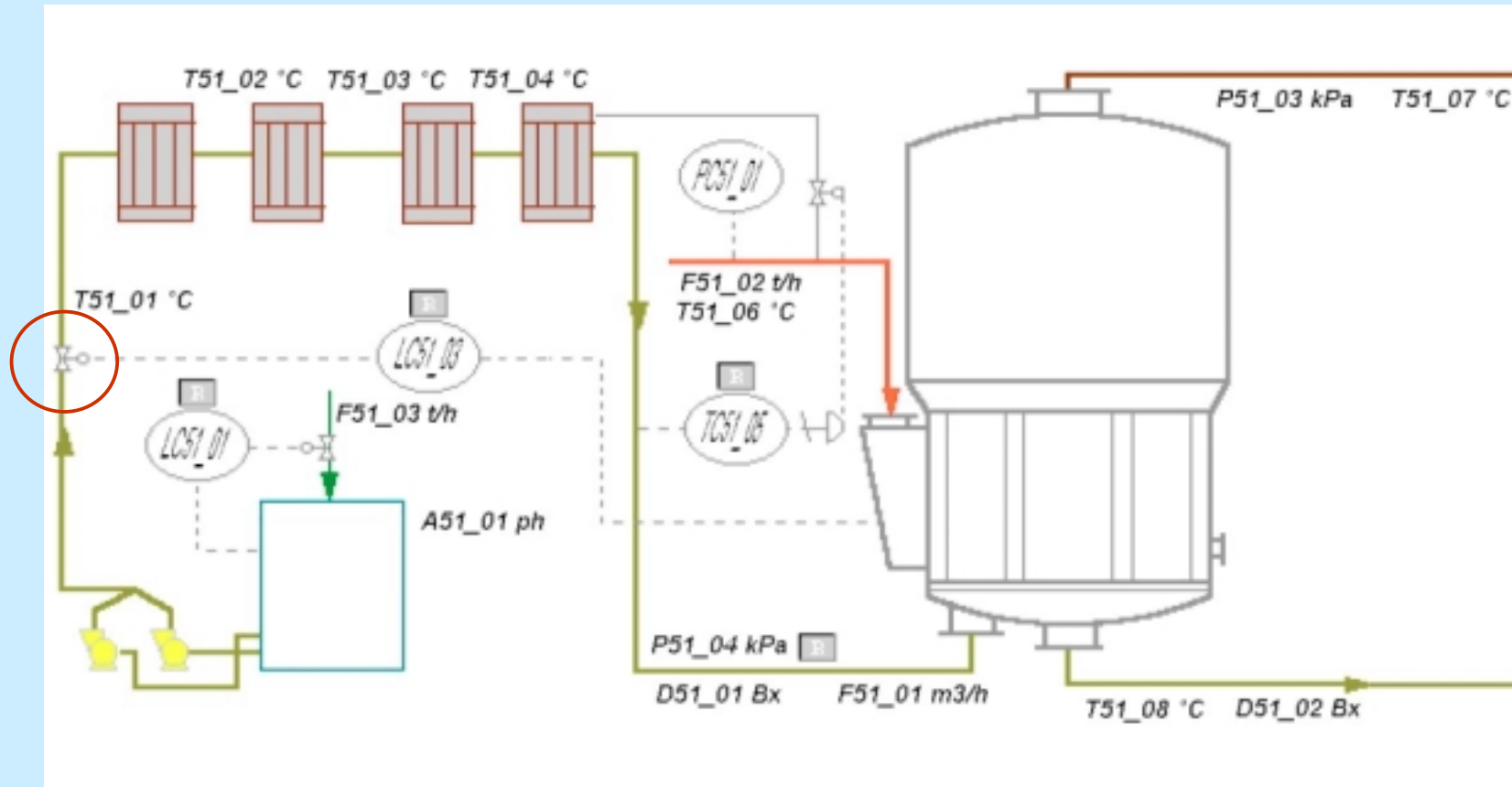
# Control loop quality statistic evaluation

(off-line diagnostics)



# Evaporator

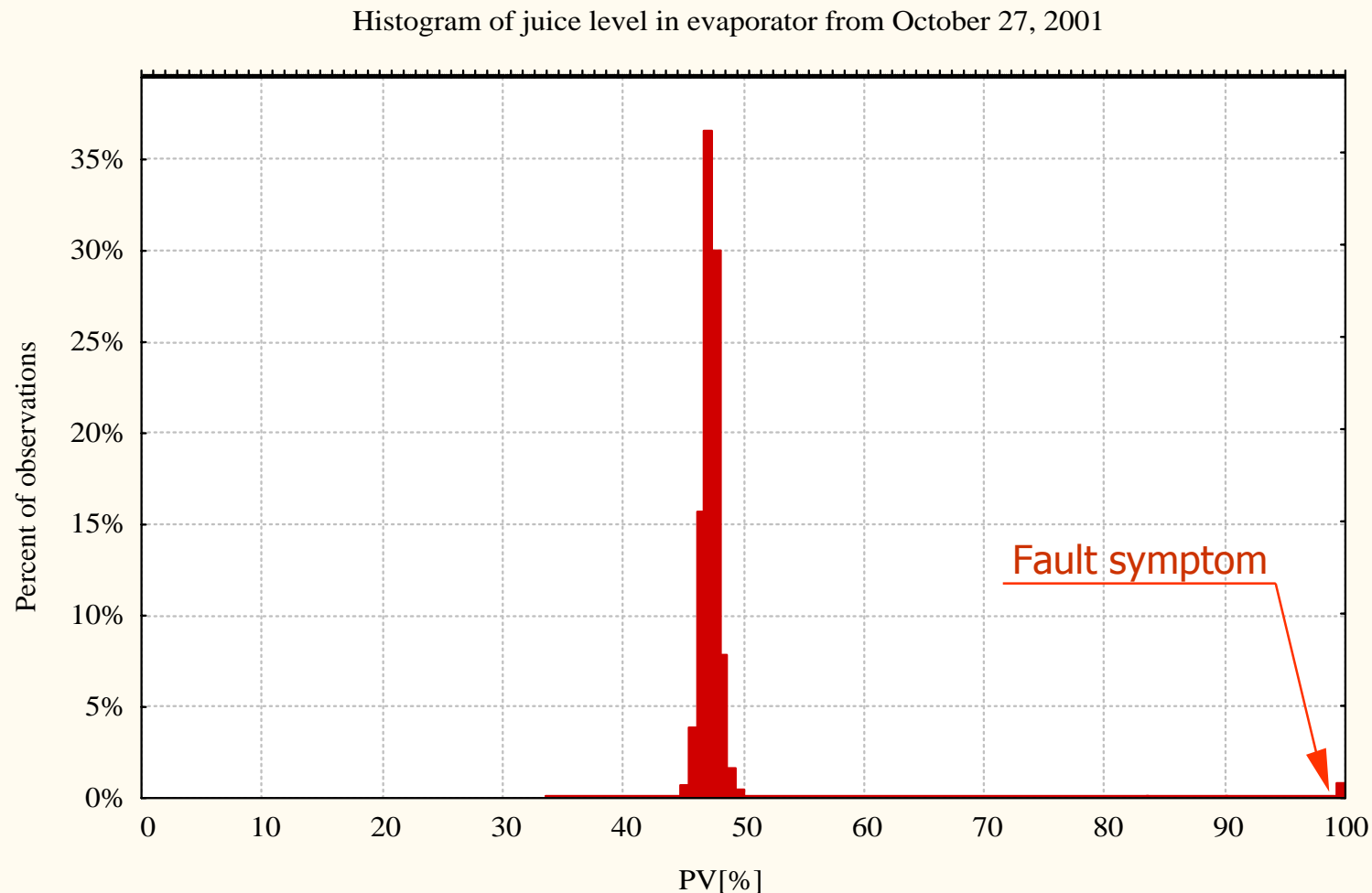
(I-st section)



Thin juice level control loop

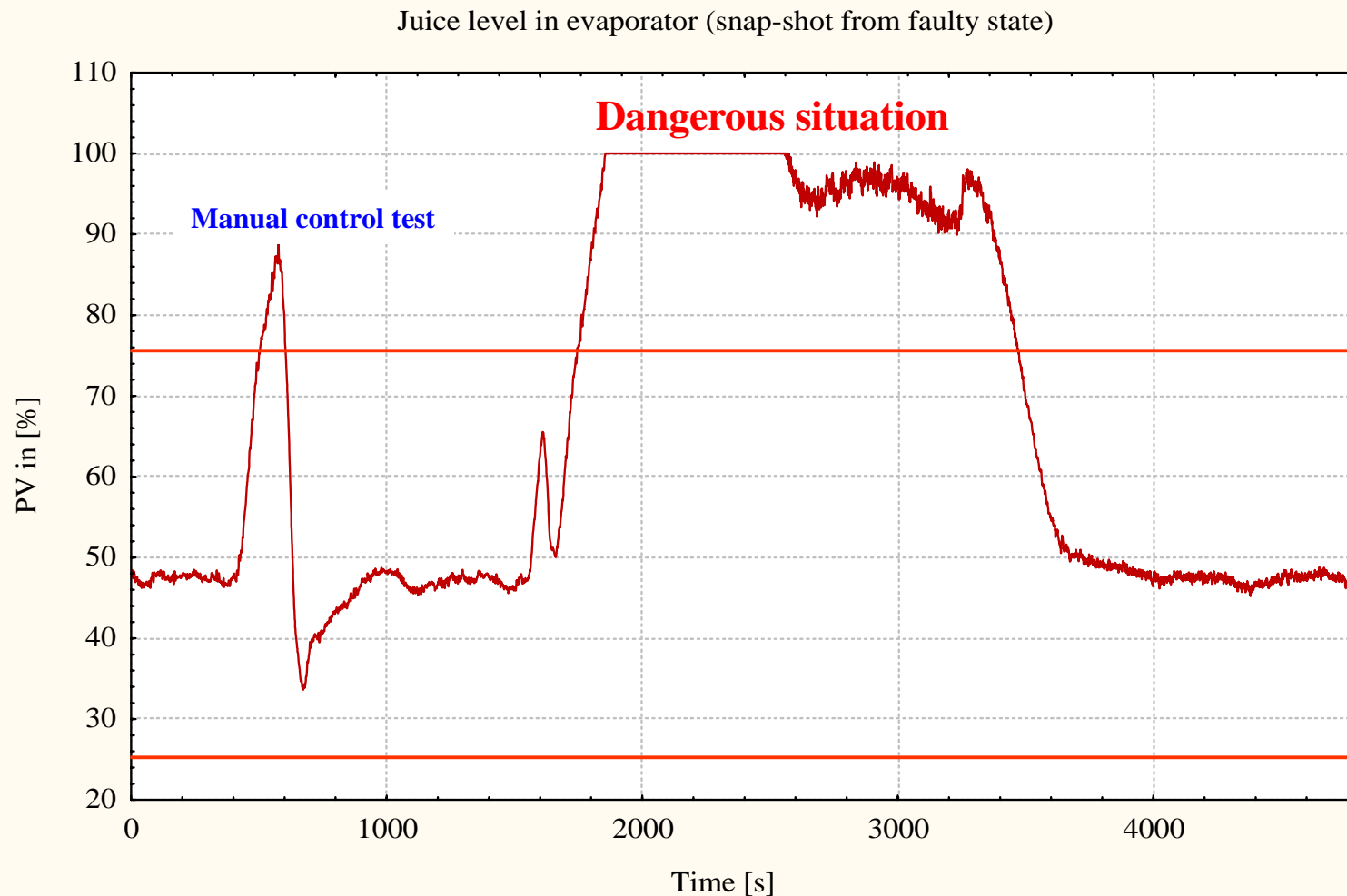
# Control loop quality statistic evaluation

(off-line diagnostics)

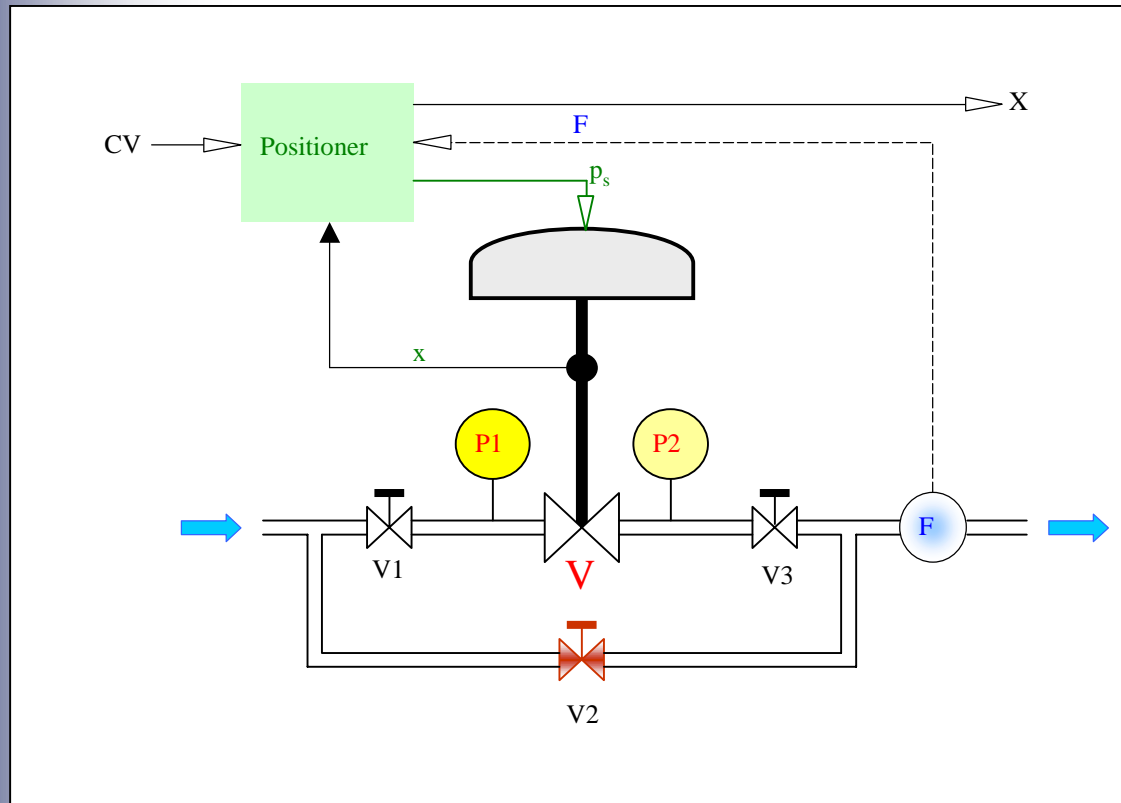


# Faulty situation vivisection

(human factor fault)



# Artificial fault generation (bypass valve leakage )



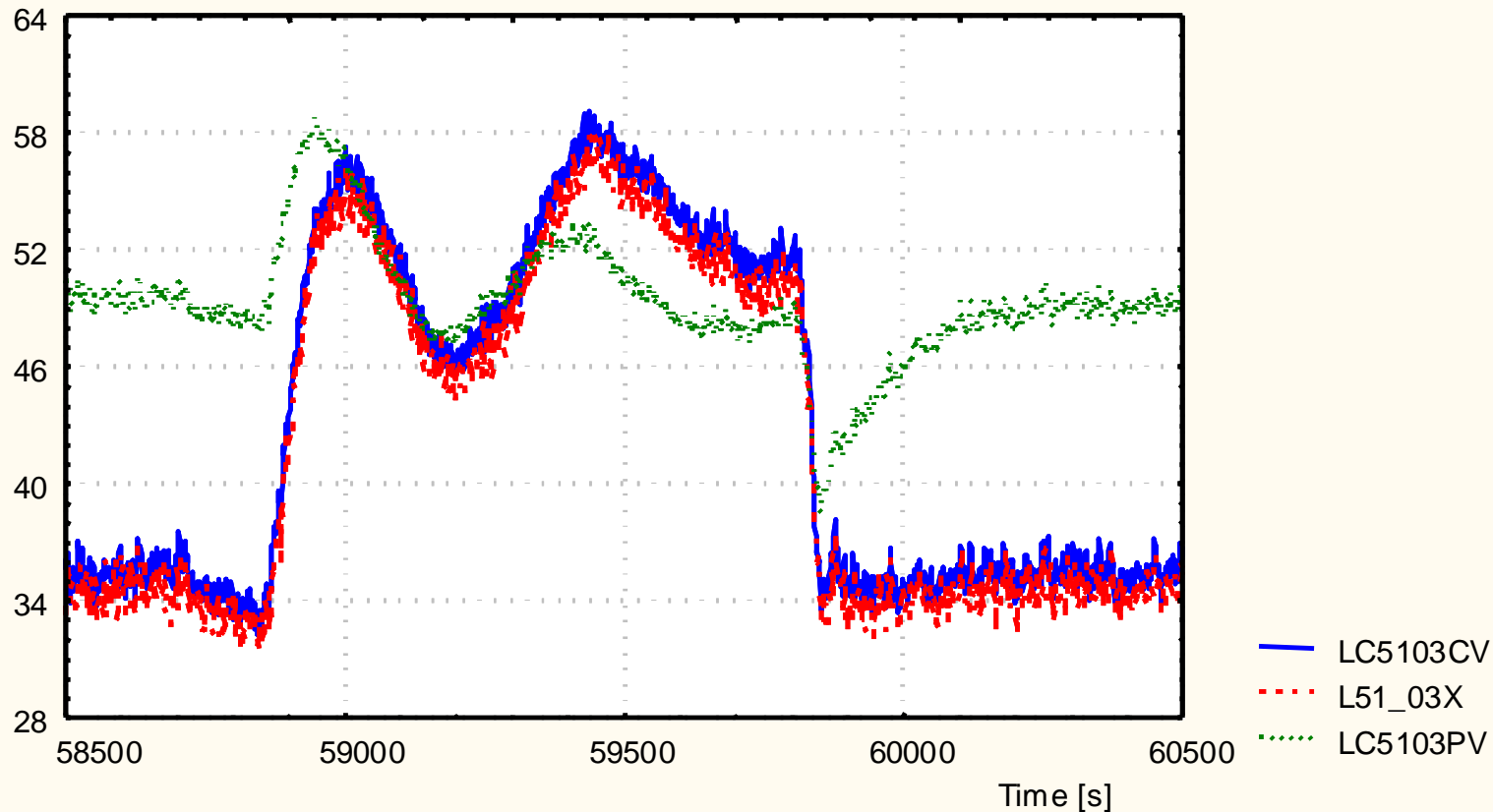
## Scenario:

1. Partly opening the V2 bypass valve.  
(Valve internal and external leakage simulation)

# Artificial fault generation

*Fault **f18** - partly opened bypass valve on Actuator 1*

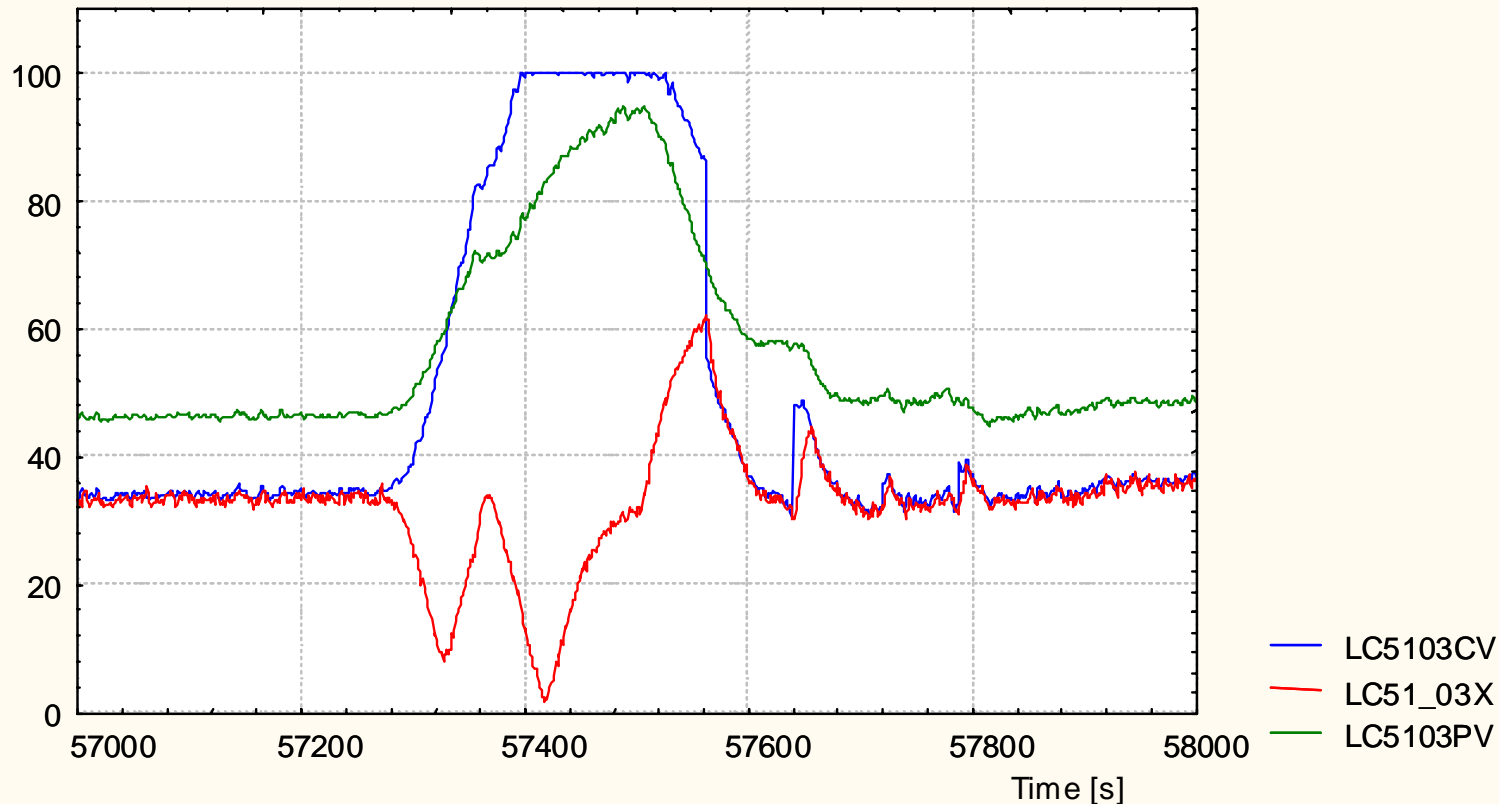
**Fault:** partly opened bypass valve on actuator 1 (**f18**)  
**Plant:** evaporator I stage  
**Date:** October 30, 2001  
**Duration:** 58800 (valve opening) – 59800 (valve closing) s



# Artificial fault generation

*Fault **f16** – positioner supply pressure drop on Actuator 1*

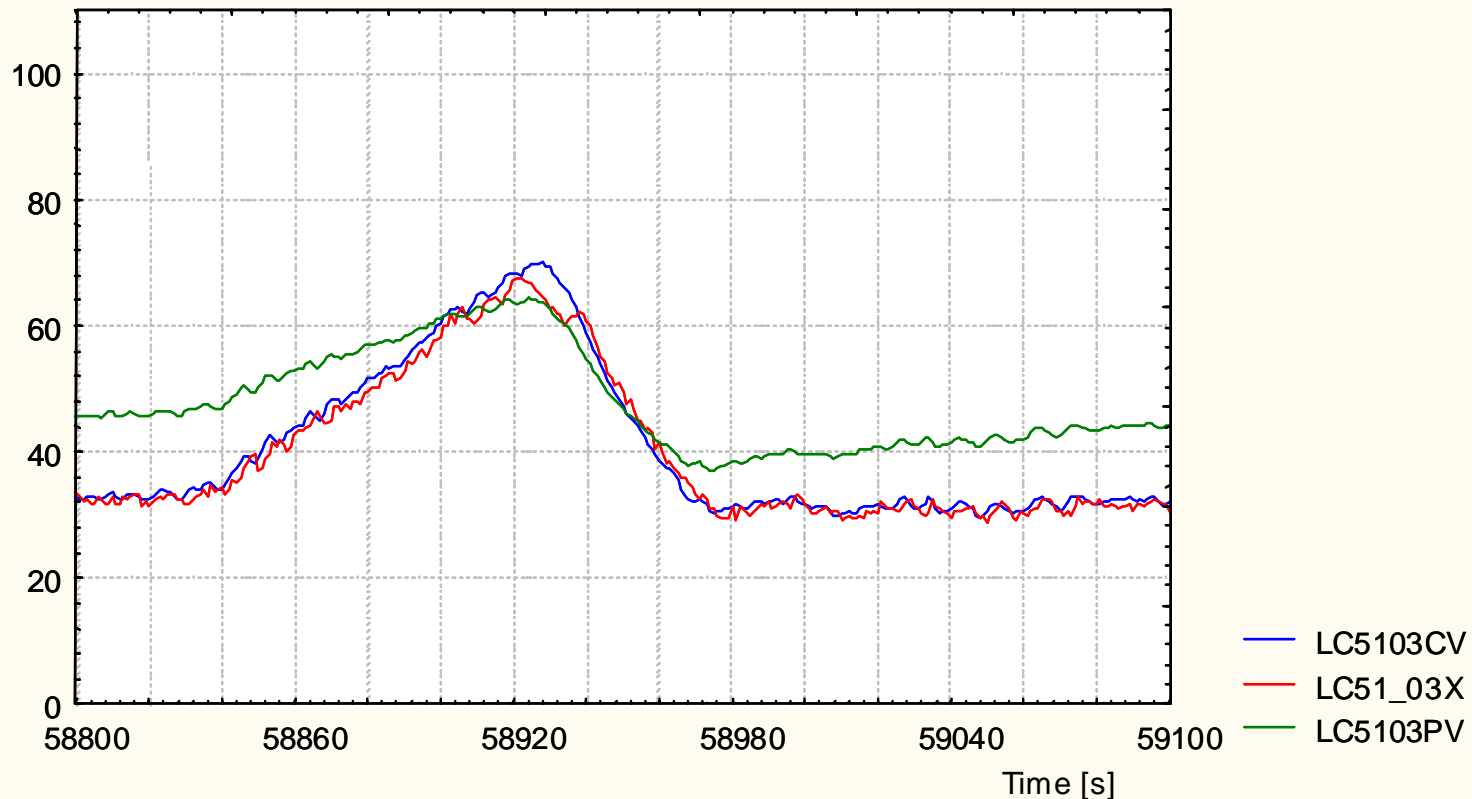
**Fault:** positioner supply pressure drop on Actuator 1 (**f16**)  
**Plant:** evaporator I stage  
**Date:** November 9, 2001  
**Duration:** 57275 (pressure drop) – 57550 (pressure ok) s



# Artificial fault generation

*Fault **f18** – partly opened bypass valve on Actuator 1*

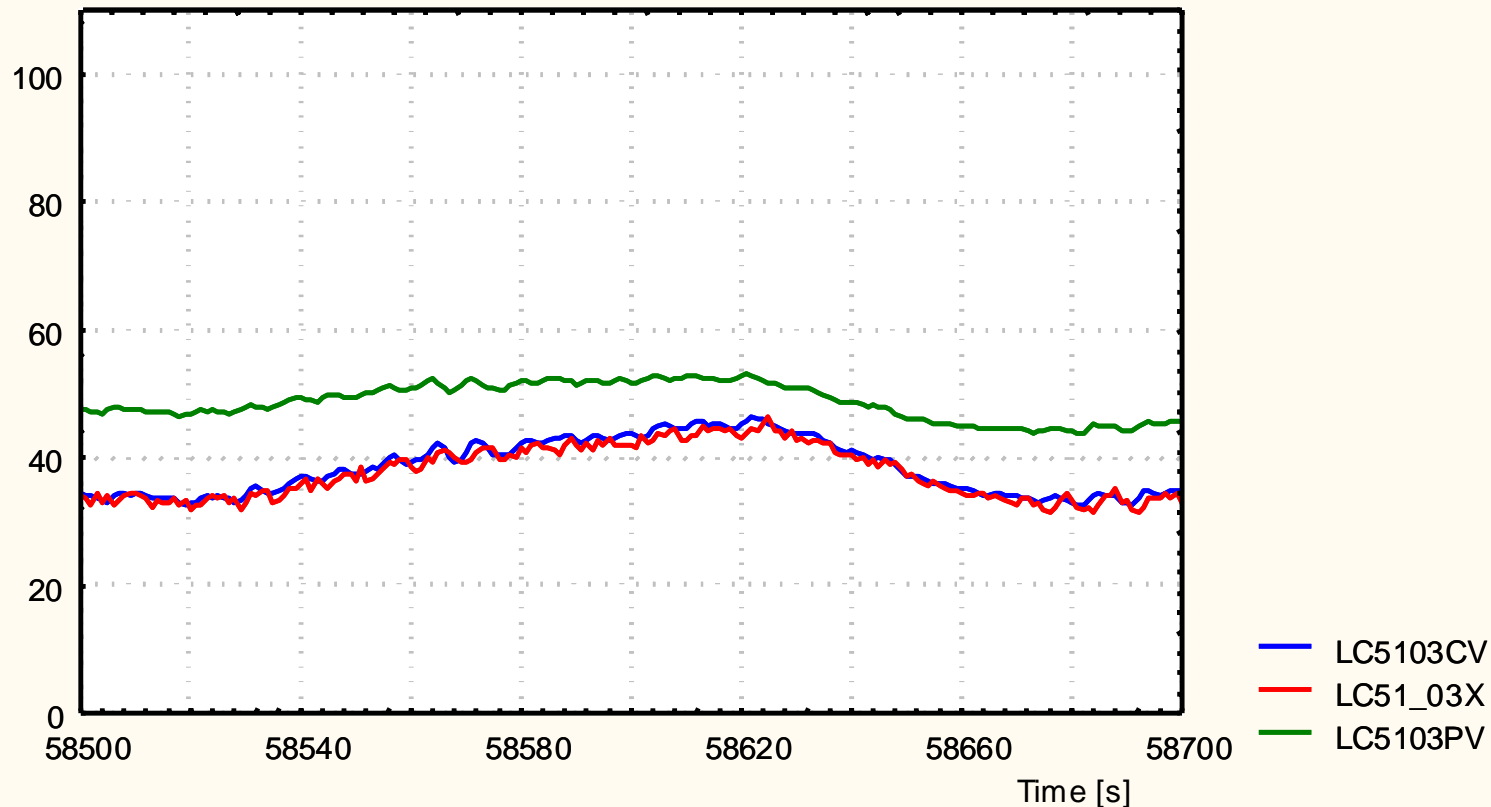
**Fault:** partly opened bypass valve on actuator 1 (**f18**)  
**Plant:** evaporator I stage  
**Date:** November 9, 2001  
**Duration:** 58830 (valve opening) – 5930 (valve closing) s



# Artificial fault generation

*Fault **f18** – partly opened bypass valve on Actuator 1*

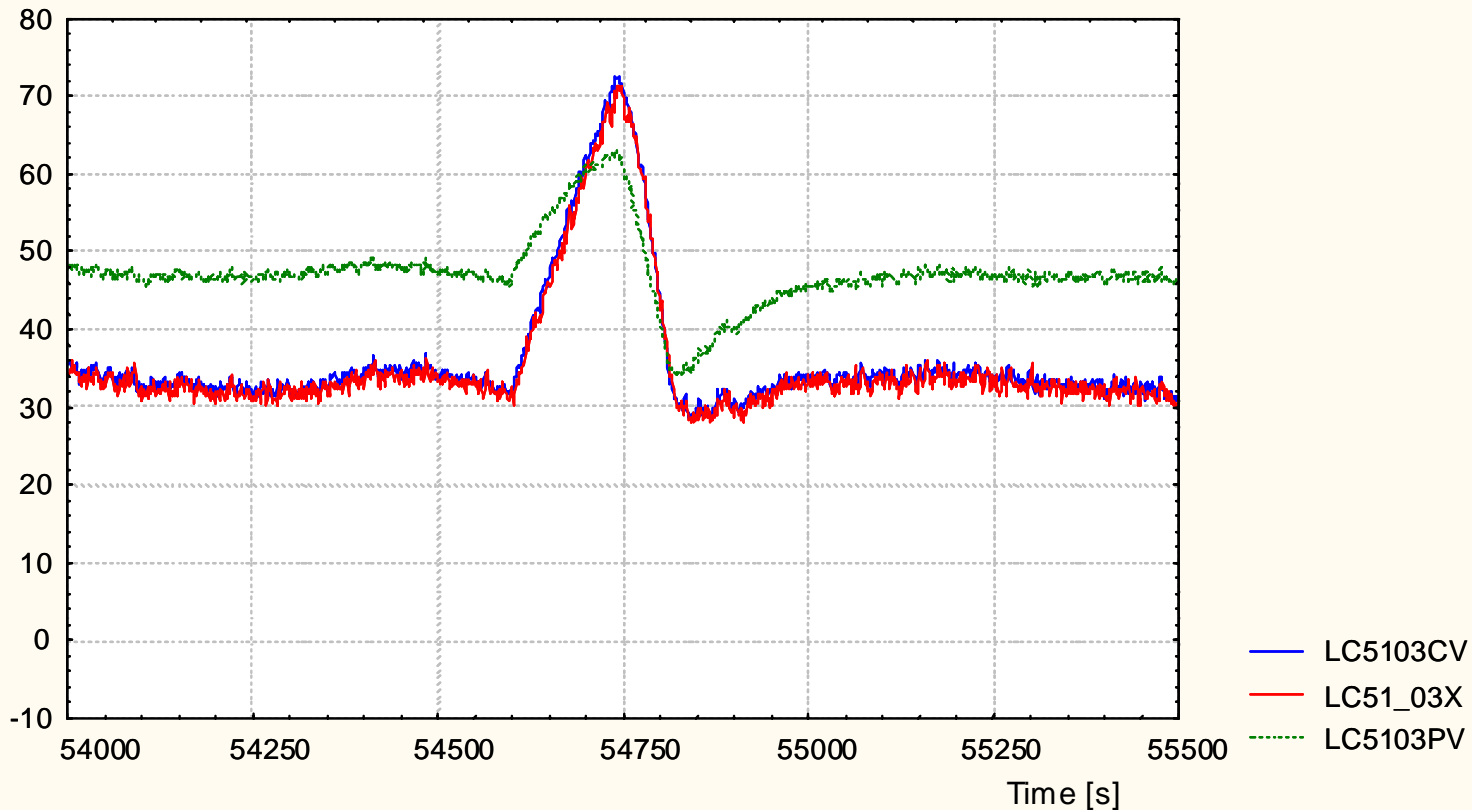
**Fault:** partly opened bypass valve on actuator 1 (**f18**)  
**Plant:** evaporator I stage  
**Date:** November 9, 2001  
**Duration:** 58520 (valve opening) – 58625 (valve closing) s



# Artificial fault generation

*Fault **f18** – partly opened bypass valve on Actuator 1*

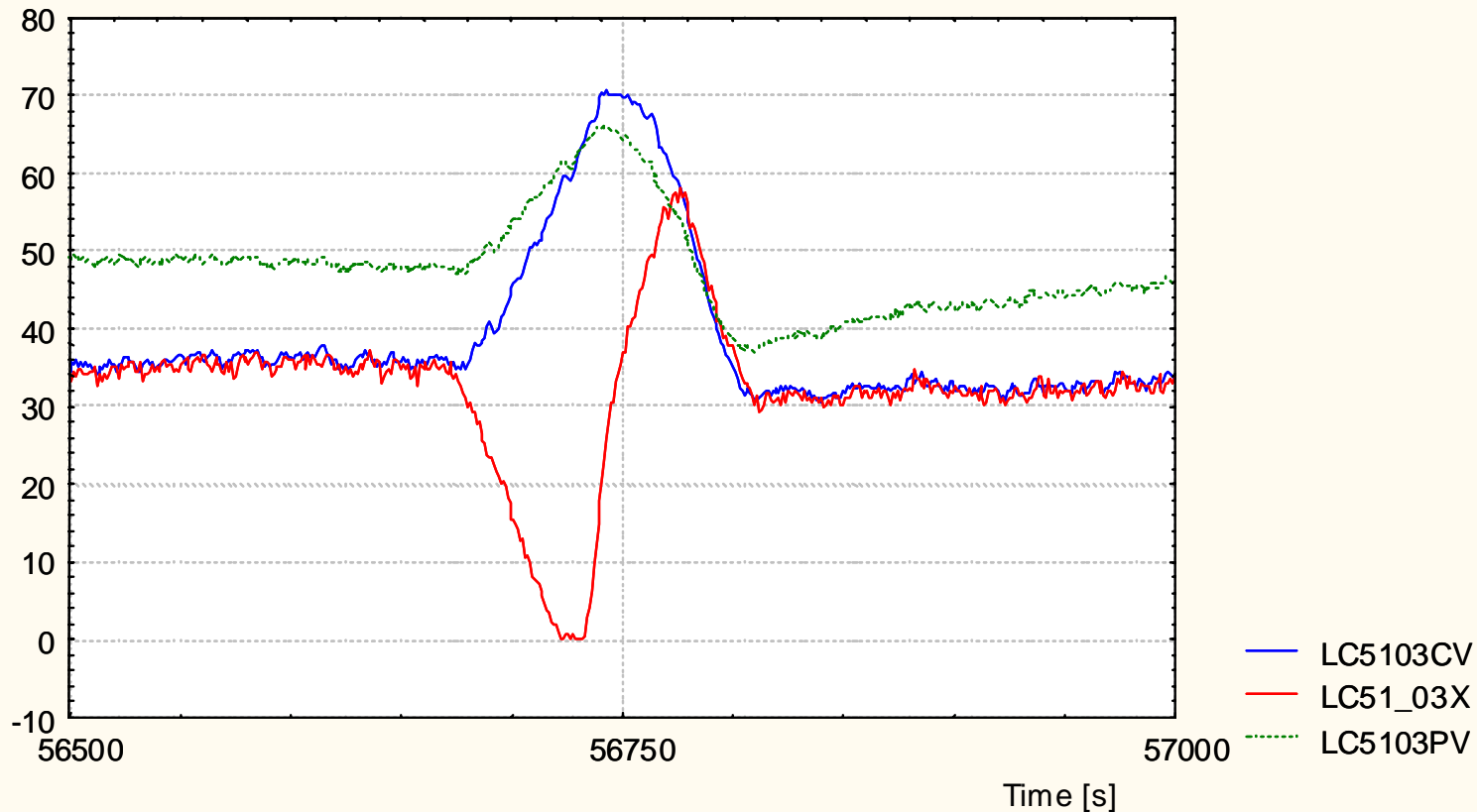
**Fault:** partly opened bypass valve on actuator 1 (**f18**)  
**Plant:** evaporator I stage  
**Date:** November 17, 2001  
**Duration:** 54600 (valve opening) – 54700 (valve closing) s



# Artificial fault generation

*Fault **f16** – positioner supply pressure drop on Actuator 1*

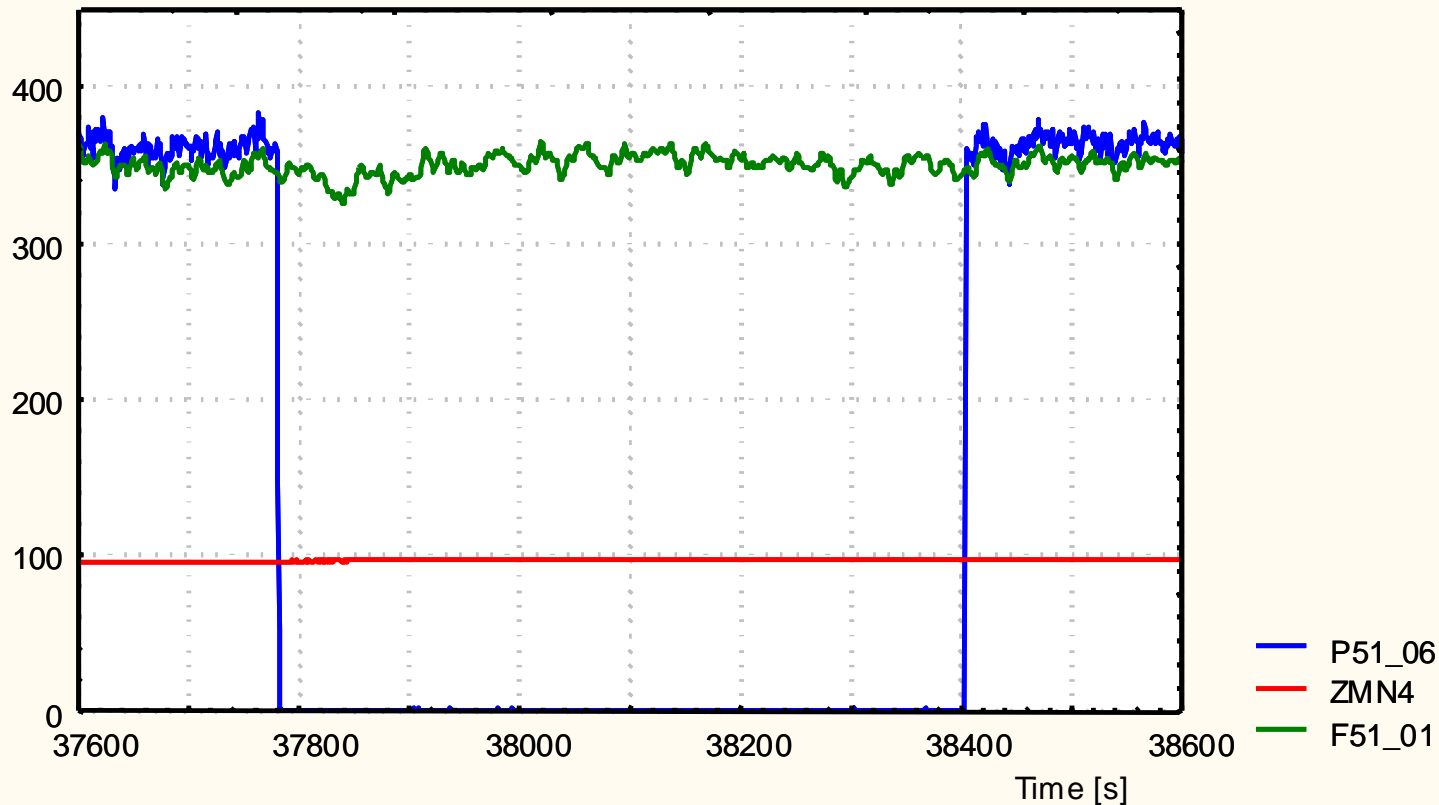
**Fault:** positioner supply pressure drop on actuator 1 (**f16**)  
**Plant:** evaporator I stage  
**Date:** November 17, 2001  
**Duration:** 56670 (pressure drop) – 56770 (pressure ok) s



# Artificial fault generation

*Fault **f17** – Unexpected pressure drop across the valve in Actuator 1*

**Fault:** Unexpected pressure drop across the valve in Actuator 1 (**f17**)  
**Plant:** evaporator I stage  
**Date:** November 20, 2001  
**Duration:** 37780 (pressure measurement off) – 38400 (pressure measurement on ) s



# Artificial fault generation

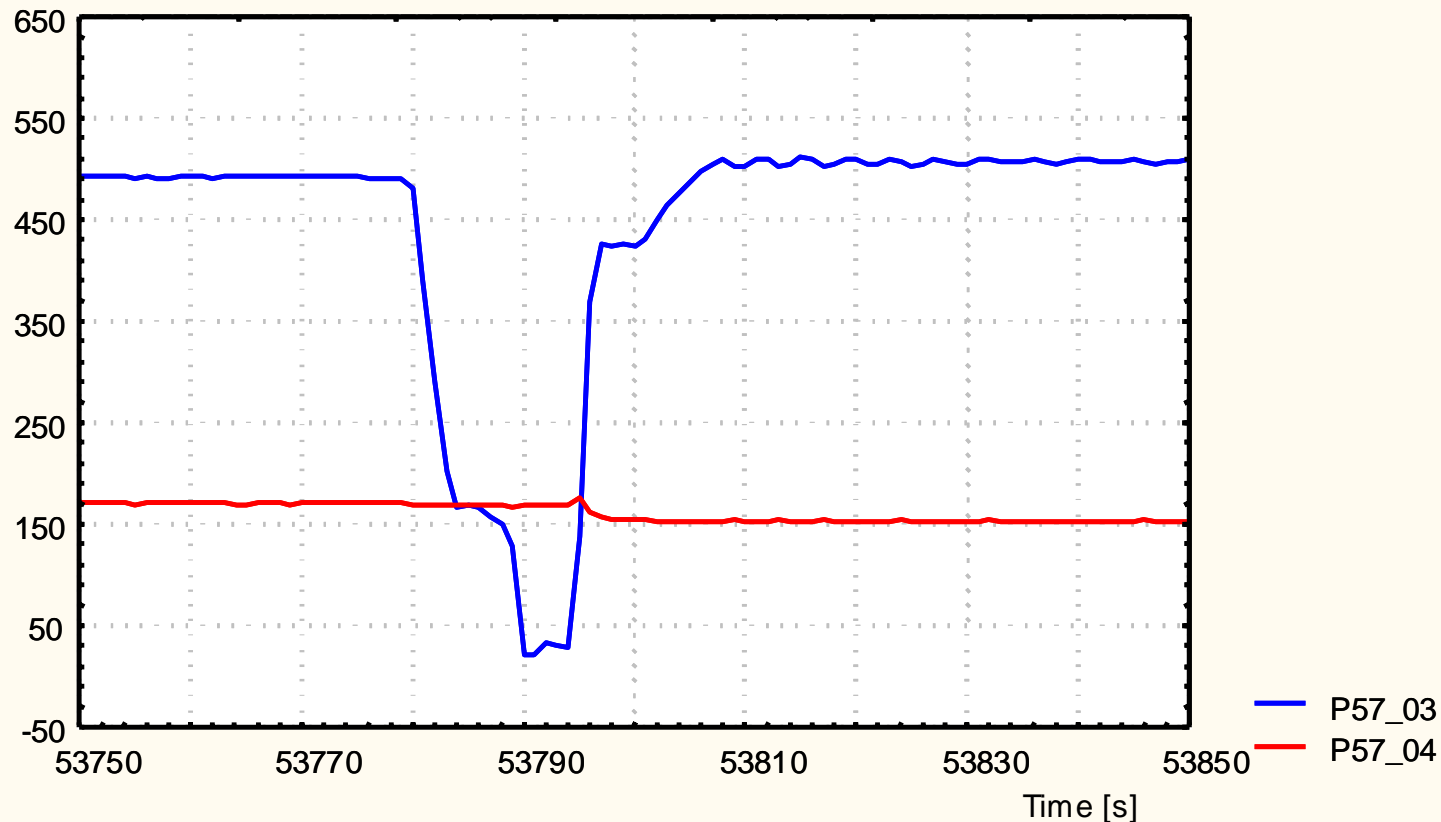
*Fault f17 – Unexpected pressure drop across the valve in Actuator 2*

**Fault:** Unexpected pressure drop across the valve in Actuator 2 (f17)

**Plant:** evaporation stage V

**Date:** November 17, 2001

**Duration:** 53780 (thick juice outflow pump switch off) – 53794 (thick juice outflow pump switch on) s



# Artificial fault generation

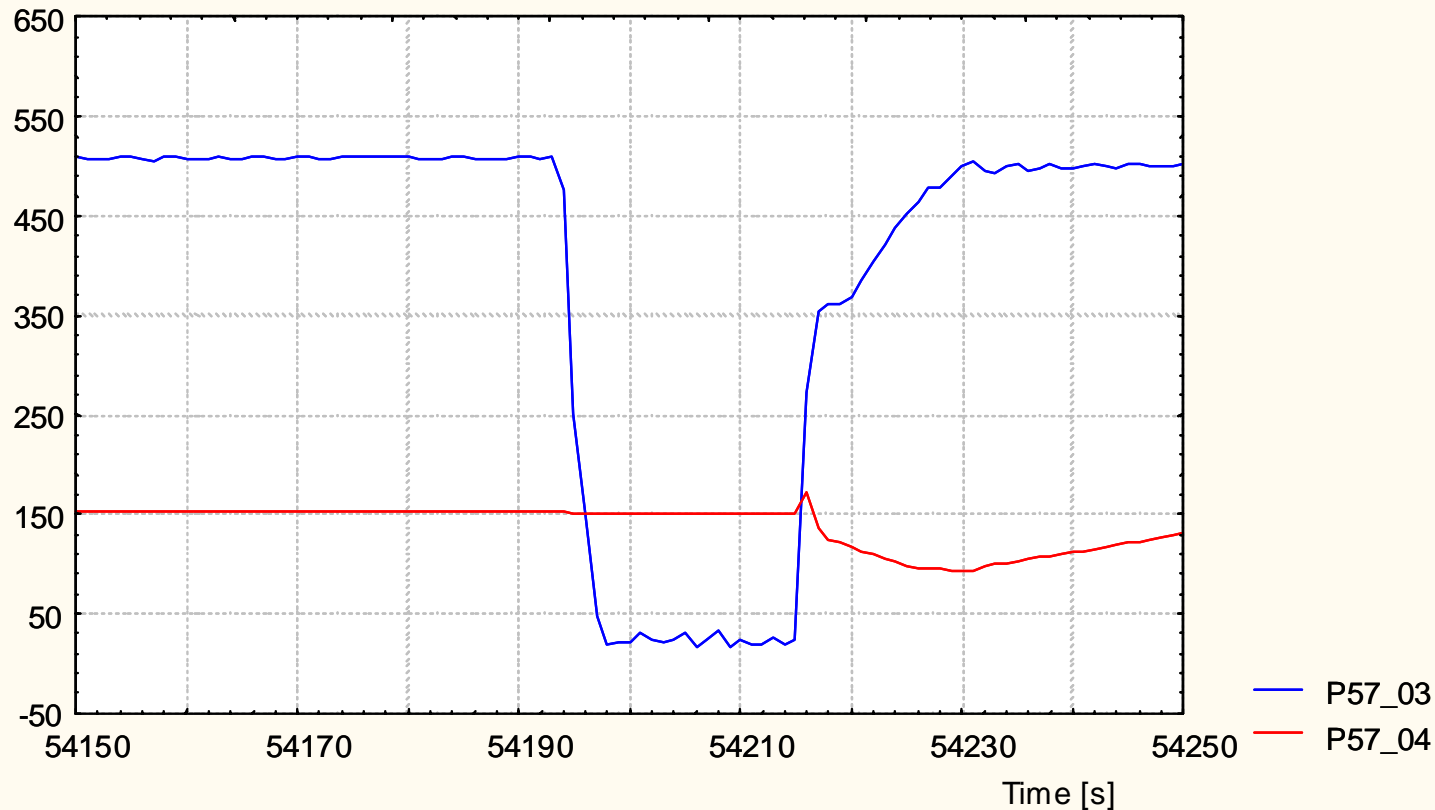
*Fault **f17** – Unexpected pressure drop across the valve in Actuator 2*

**Fault:** unexpected pressure drop across the valve in Actuator 2 (**f17**)

**Plant:** evaporation stage V

**Date:** November 17, 2001

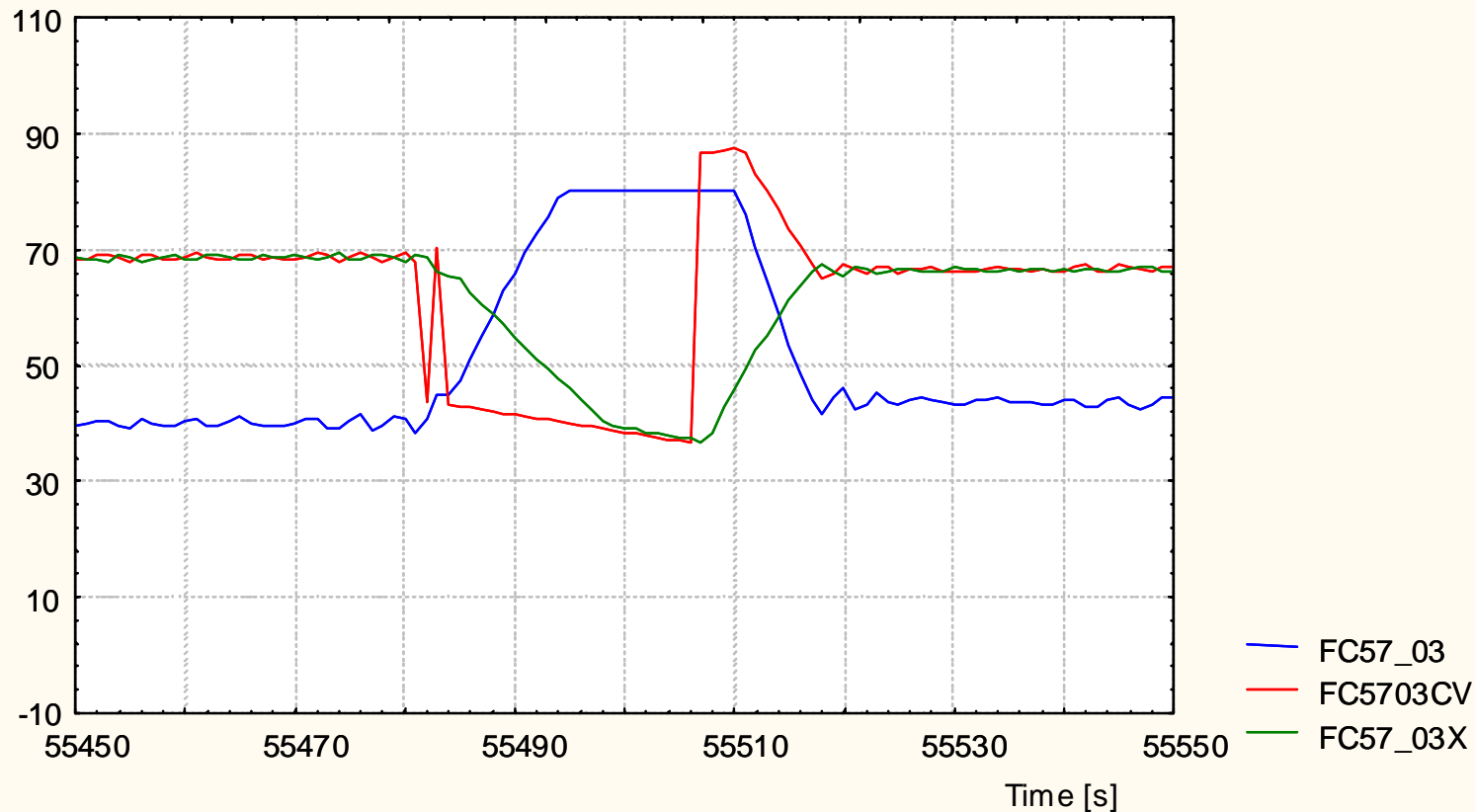
**Duration:** 54193 (thick juice outflow pump switch off) – 54215 (thick juice outflow pump switch on) s



# Artificial fault generation

## Fault *f19\** – Flow rate sensor fault in Actuator 2

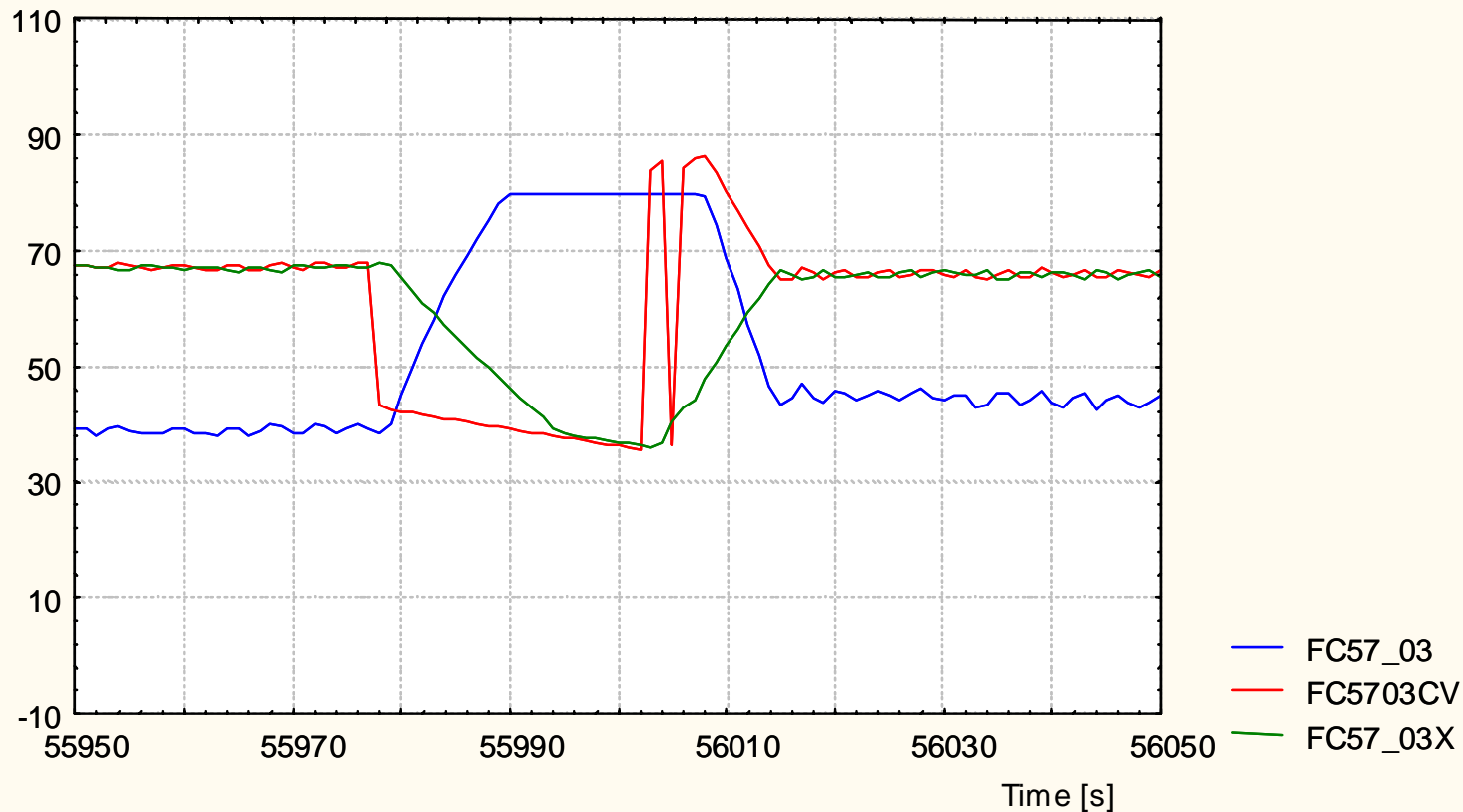
**Fault:** flow rate sensor fault in Actuator 2 (*f19*)  
**Plant:** evaporator stage V  
**Date:** November 17, 2001  
**Duration:** 55482 (sensor fault on) – 55517 (sensor fault off) s



# Artificial fault generation

*Fault **f19\*** – Flow rate sensor fault in Actuator 2*

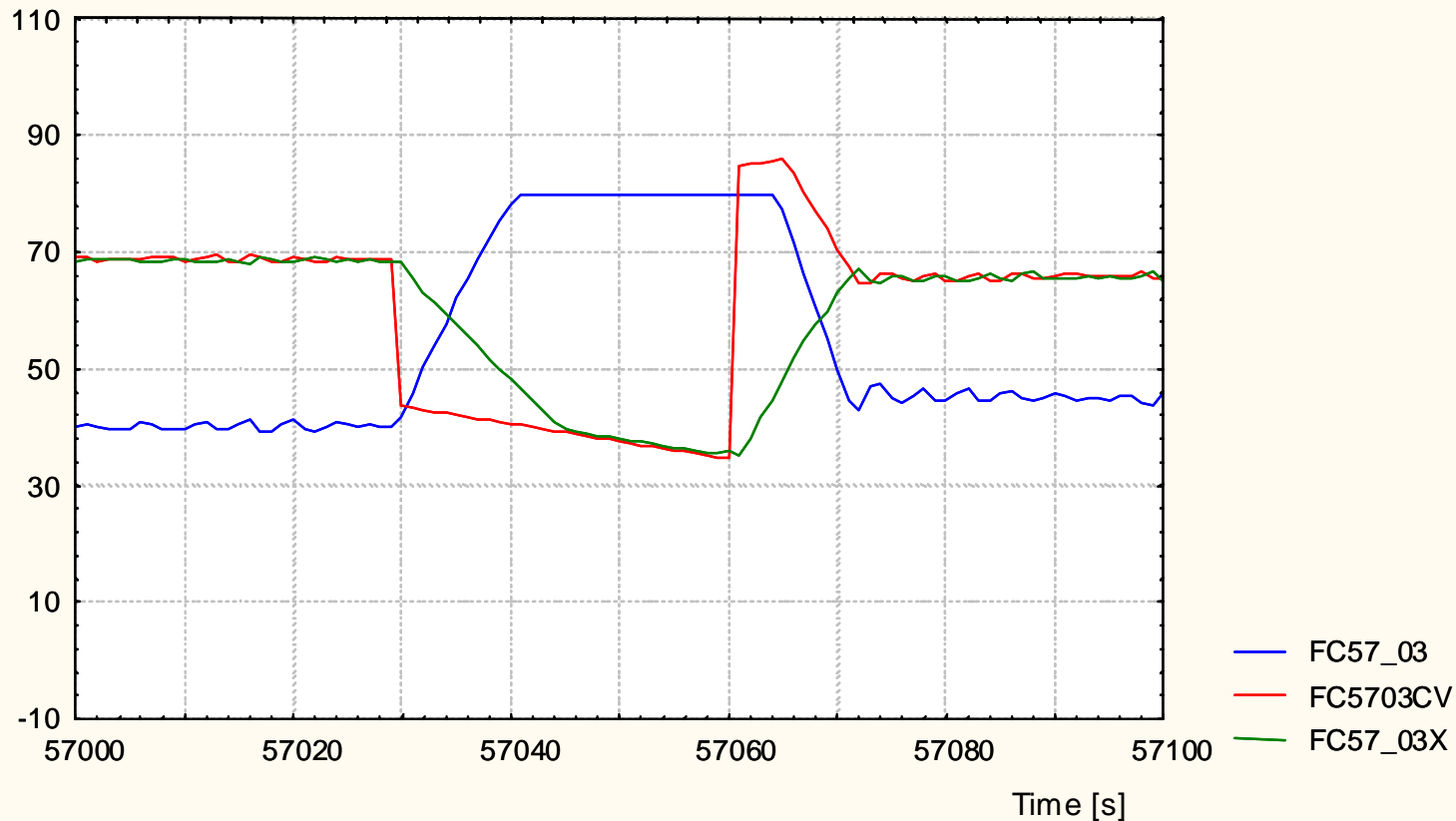
**Fault:** flow rate sensor fault in Actuator 2 (**f19**)  
**Plant:** evaporator stage V  
**Date:** November 17, 2001  
**Duration:** 55977 (sensor fault on) – 56015 (sensor fault off) s



# Artificial fault generation

*Fault **f19\*** – Flow rate sensor fault in Actuator 2*

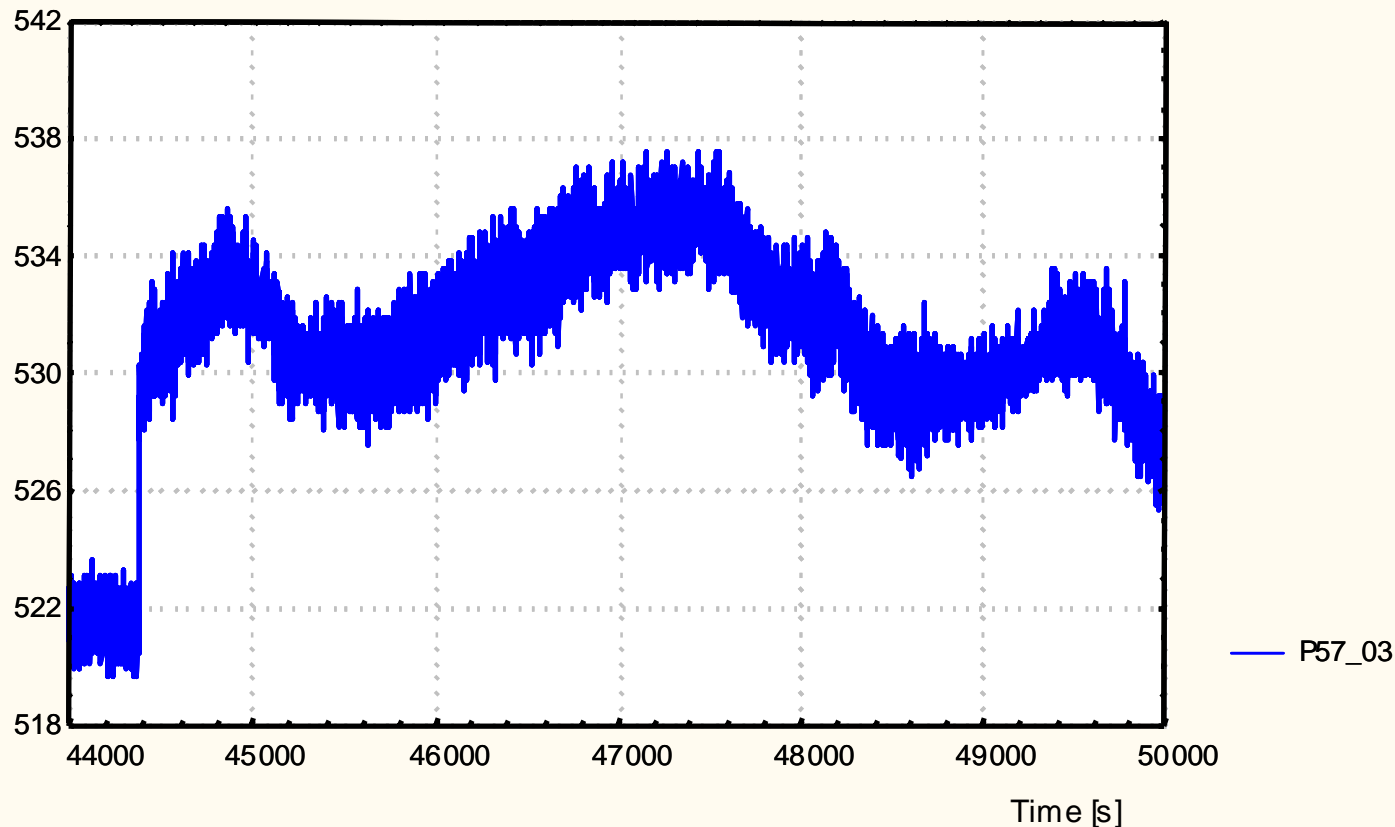
**Fault:** flow rate sensor fault in Actuator 2 (**f19**)  
**Plant:** evaporator stage V  
**Date:** November 17, 2001  
**Duration:** 57030 (sensor fault on) – 57072 (sensor fault off) s



# Artificial fault generation

*Fault **f17** – Unexpected pressure drop across the valve in Actuator 2*

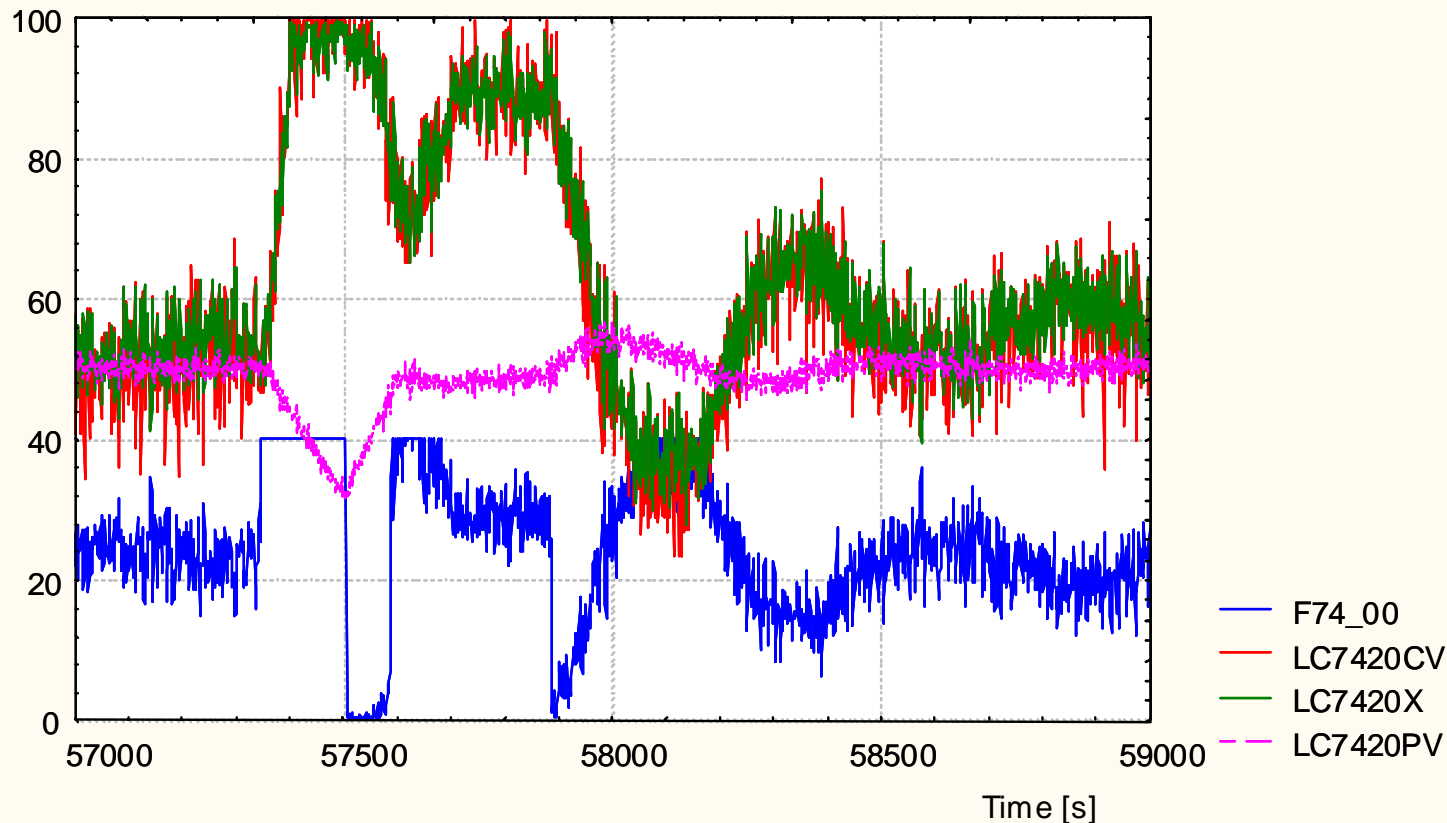
**Fault:** unexpected pressure drop across the valve in Actuator 2 (**f17**)  
**Plant:** evaporator stage V  
**Date:** November 20, 2001  
**Duration:** start at 44400 (added pressure offset on P57\_03)



# Artificial fault generation

*Fault **f18** - Partly opened bypass valve on actuator*

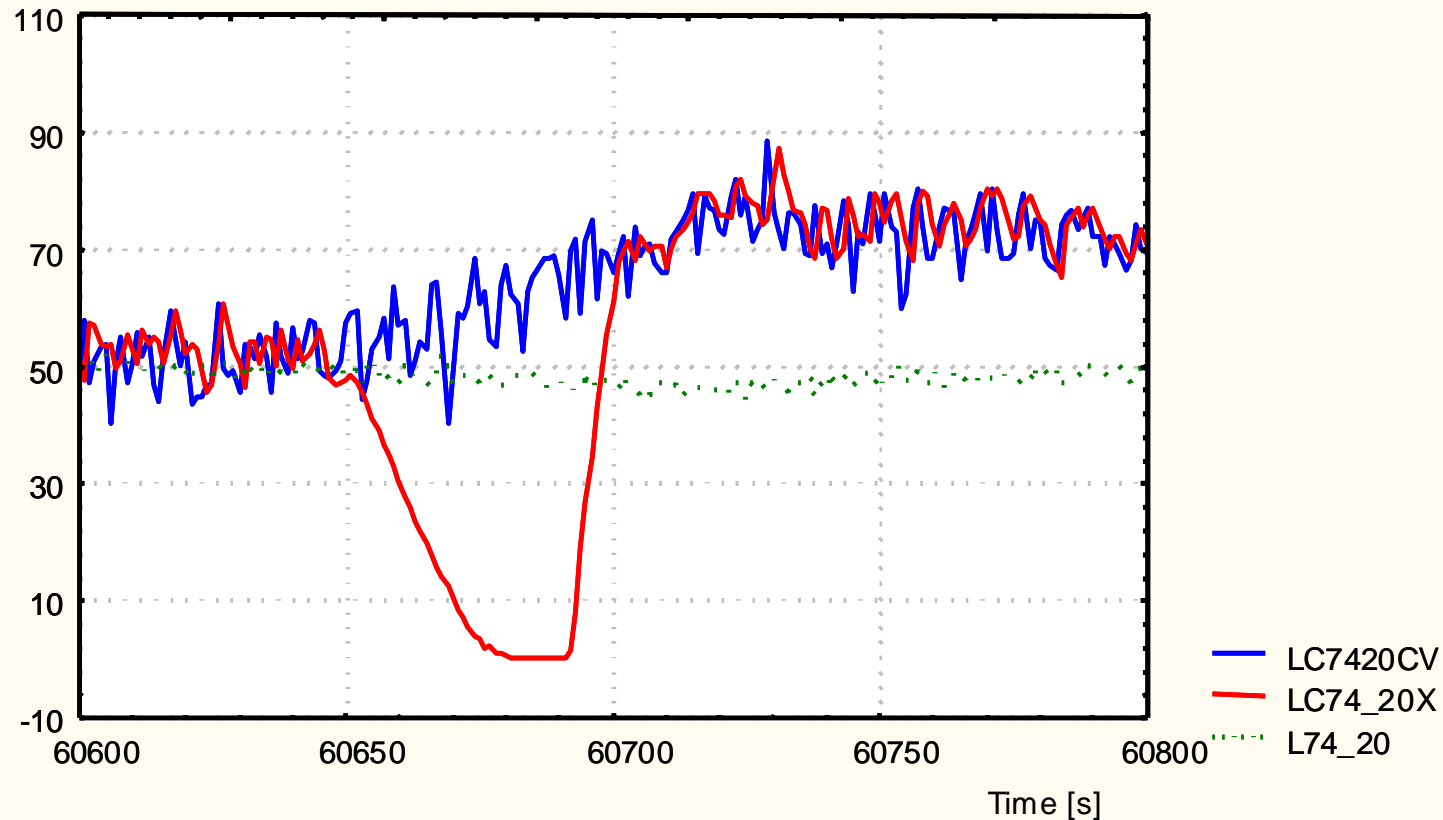
**Fault:** partly opened bypass valve on Actuator 3 (**f18**)  
**Plant:** steam boiler  
**Date:** October 30, 2001  
**Duration:** 57340 (valve opening) – 57890 (valve closing) s



# Artificial fault generation

*Fault **f16** – Positioner supply pressure drop on Actuator 3*

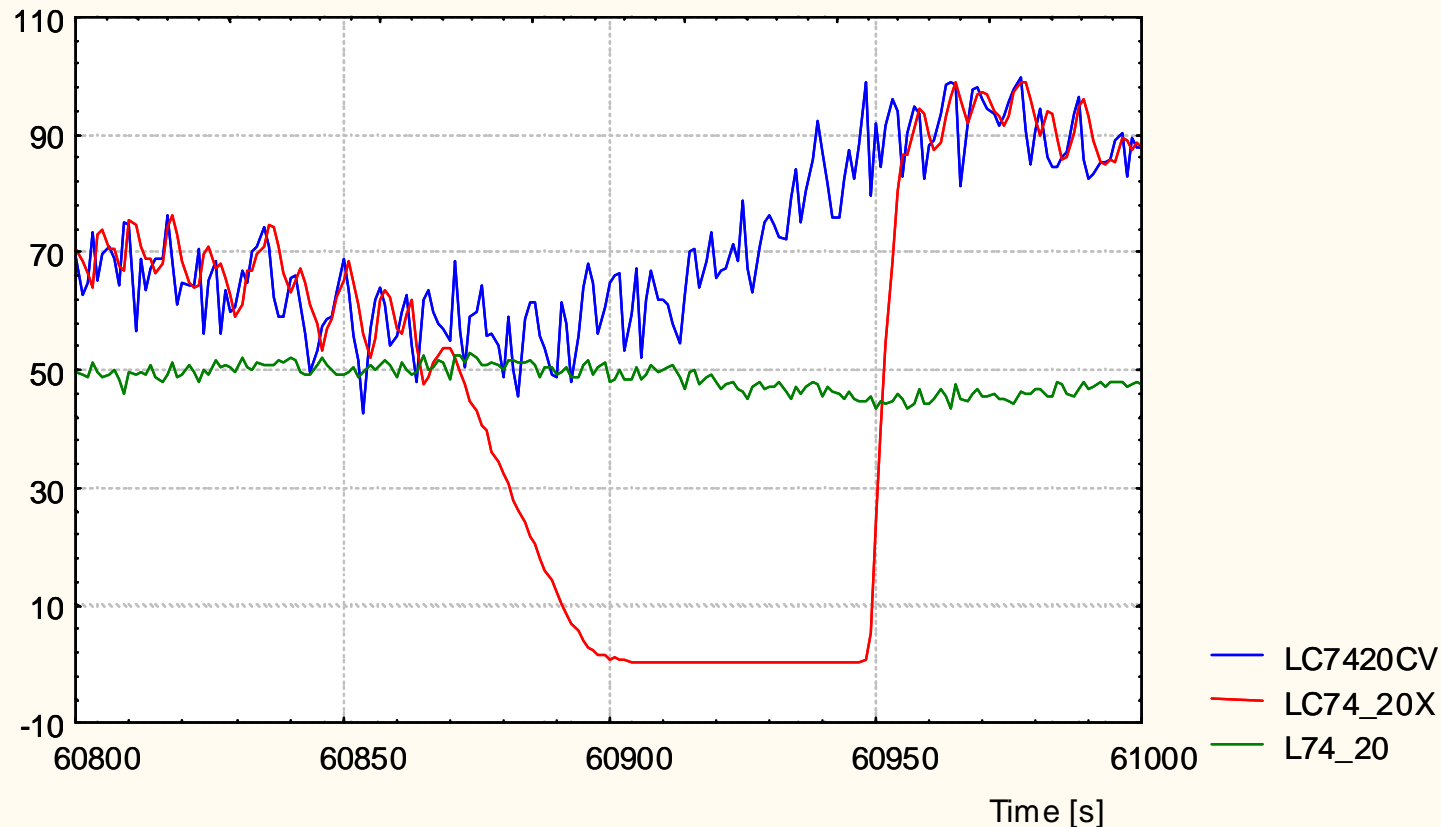
**Fault:** positioner supply pressure drop on Actuator 3 (**f16**)  
**Plant:** steam boiler  
**Date:** November 9, 2001  
**Duration:** 60650 (pressure drop) – 60700 (pressure ok) s



# Artificial fault generation

*Fault **f16** – Positioner supply pressure drop on Actuator 3*

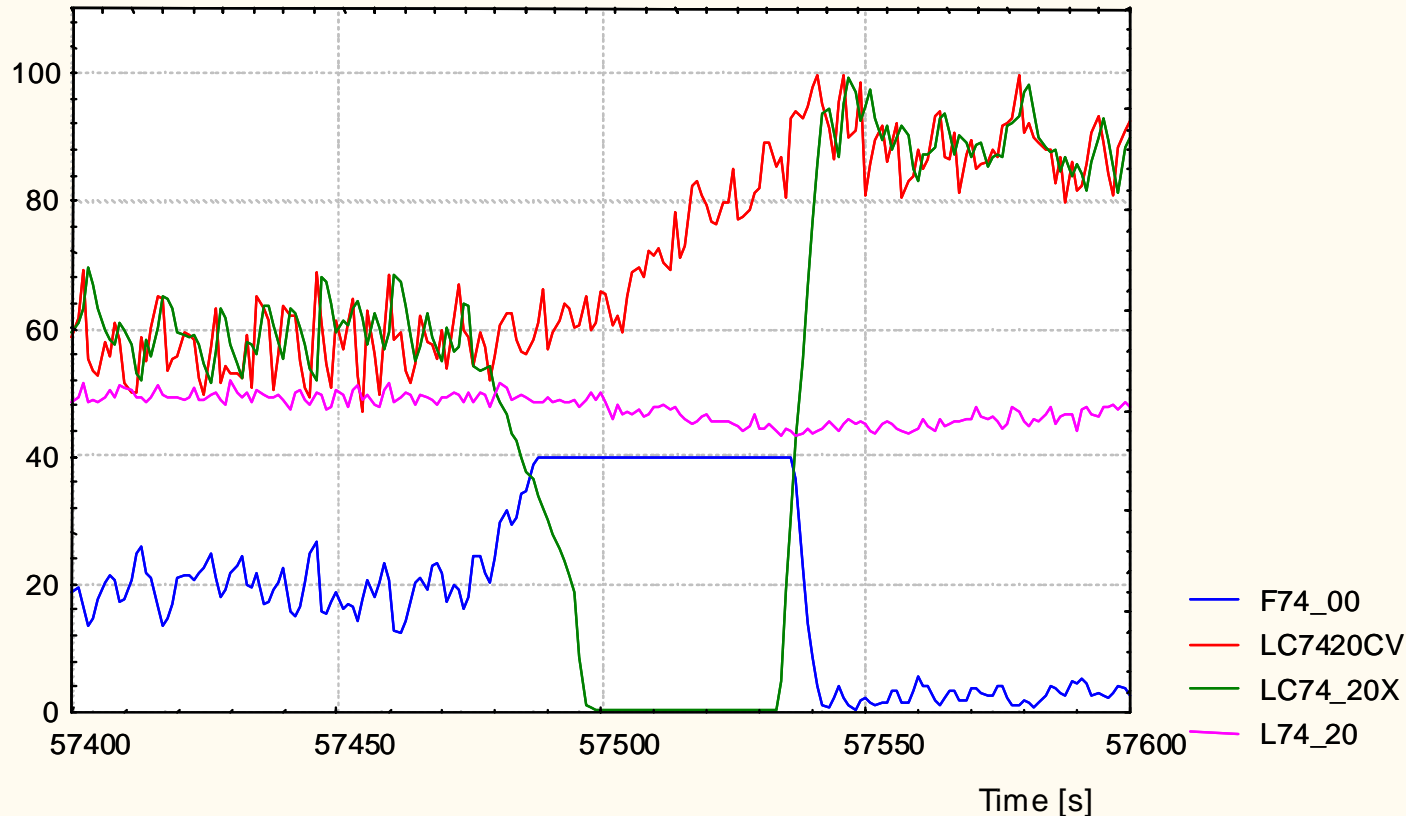
**Fault:** positioner supply pressure drop on Actuator 3 (**f16**)  
**Plant:** steam boiler  
**Date:** November 9, 2001  
**Duration:** 60870 (pressure drop) – 60960 (pressure ok) s



# Artificial fault generation

*Fault **f16** – Positioner supply pressure drop on Actuator 3*

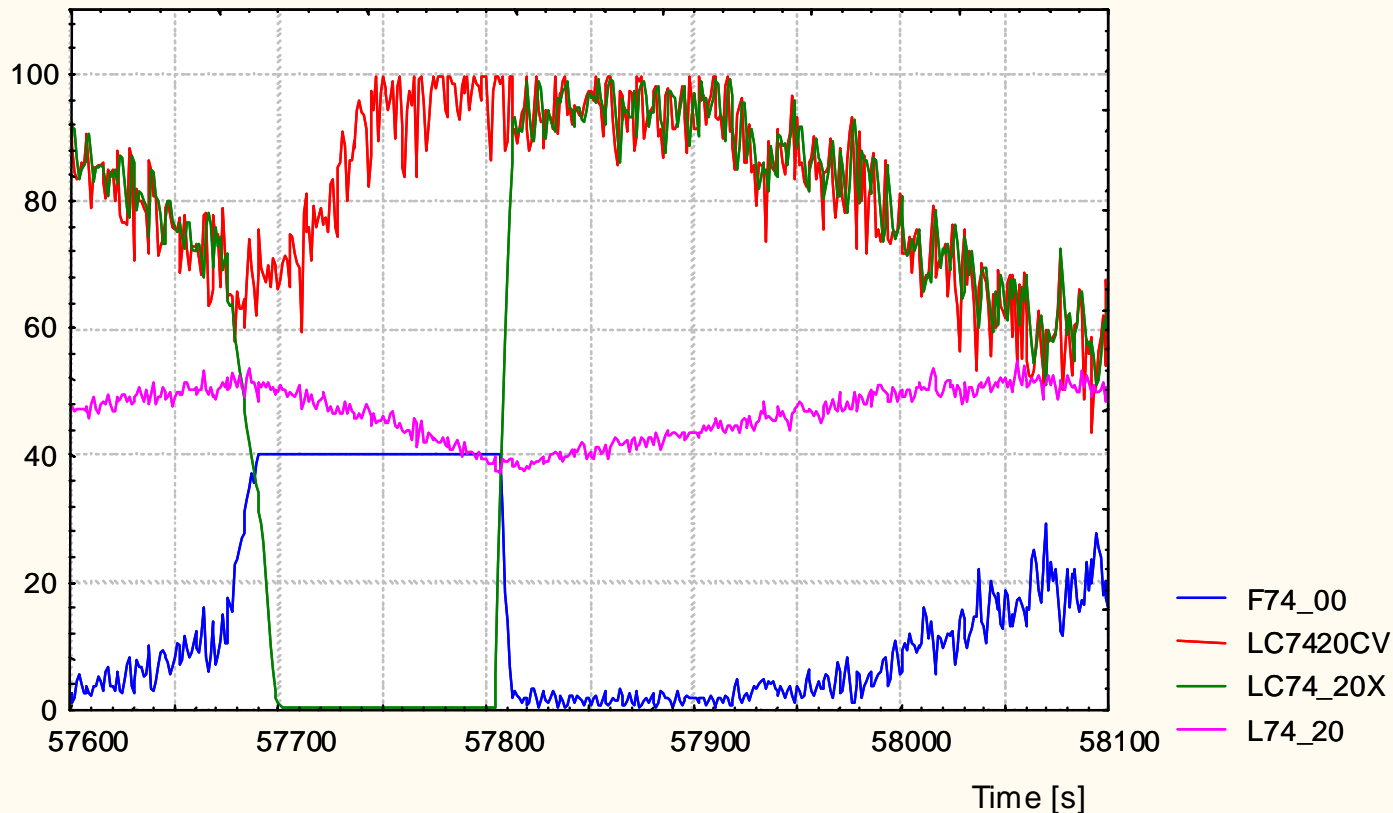
**Fault:** positioner supply pressure drop on Actuator 3 (**f16**)  
**Plant:** steam boiler  
**Date:** November 17, 2001  
**Duration:** 57475 (pressure drop) – 57530 (pressure ok) s



# Artificial fault generation

*Fault **f16** – Positioner supply pressure drop on Actuator 3*

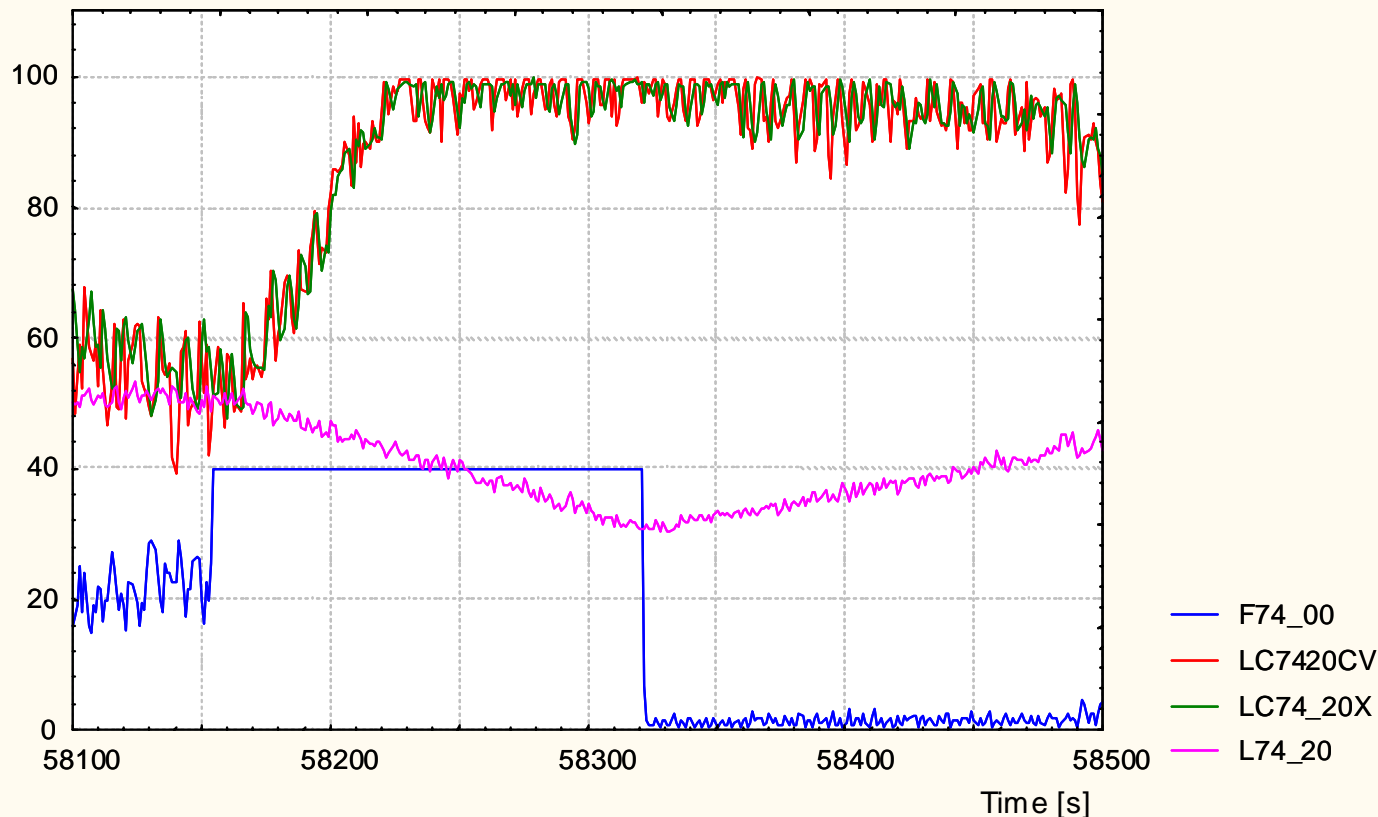
**Fault:** positioner supply pressure drop on Actuator 3 (**f16**)  
**Plant:** steam boiler  
**Date:** November 17, 2001  
**Duration:** 57675 (pressure drop) – 57800 (pressure ok) s



# Artificial fault generation

## Fault *f19* – Flow rate sensor fault in Actuator 3

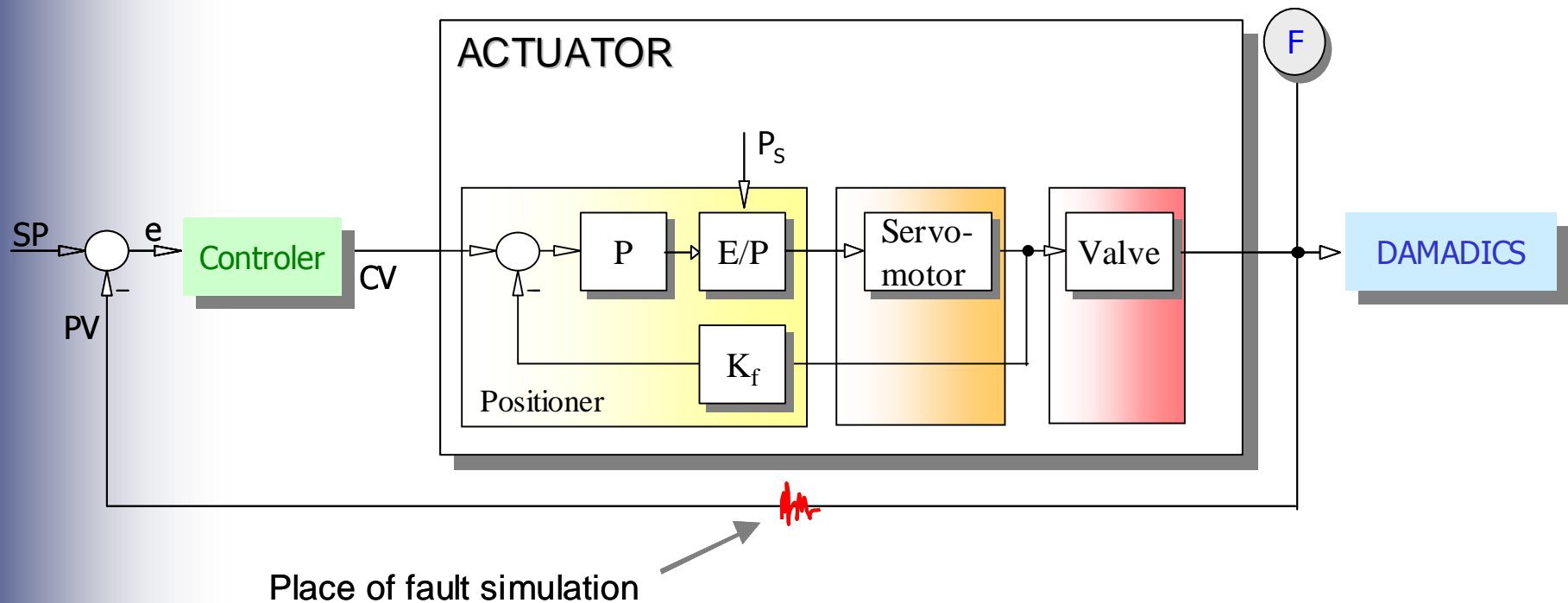
**Fault:** flow rate sensor fault in Actuator 3 (*f19*)  
**Plant:** steam boiler  
**Date:** November 17, 2001  
**Duration:** 58150 (sensor fault on) – 58325 (sensor fault off) s



# Artificial fault generation

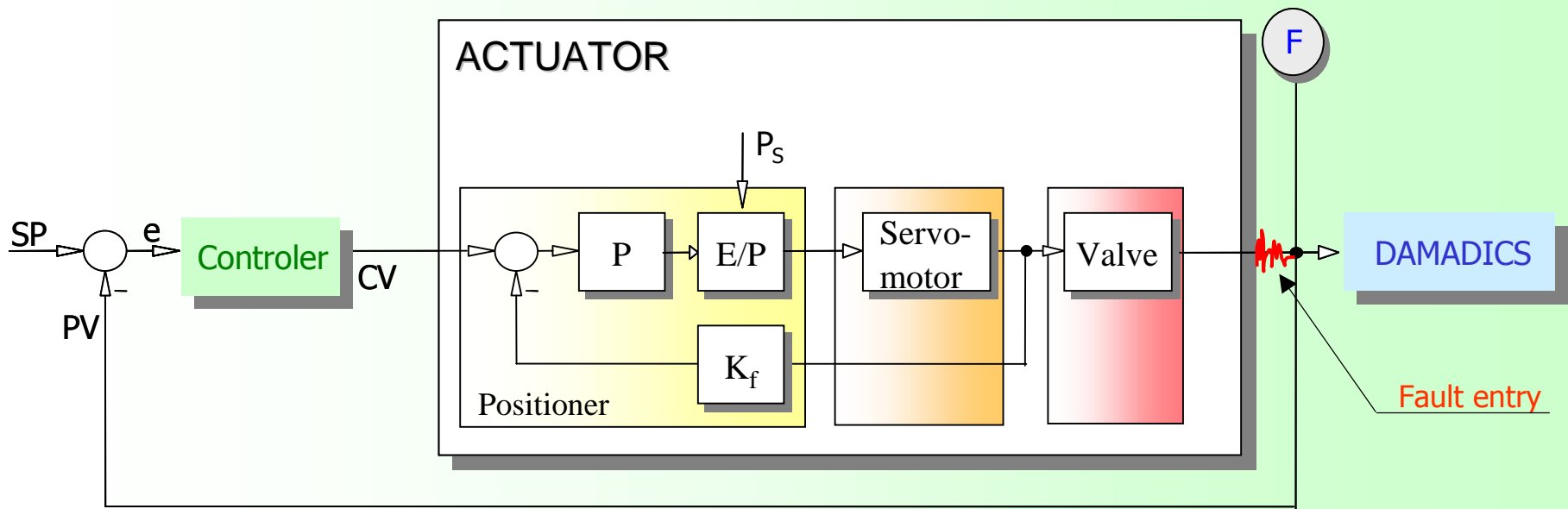
Remark to **f19\*** – Flow rate sensor fault in Actuator 2 (rather flow feedback fault)

Actuator 2 works in flow control loop. Please pay attention that the flow signal available in DAMADICS data file is fault free. The fault was introduced only in the feedback of control loop.



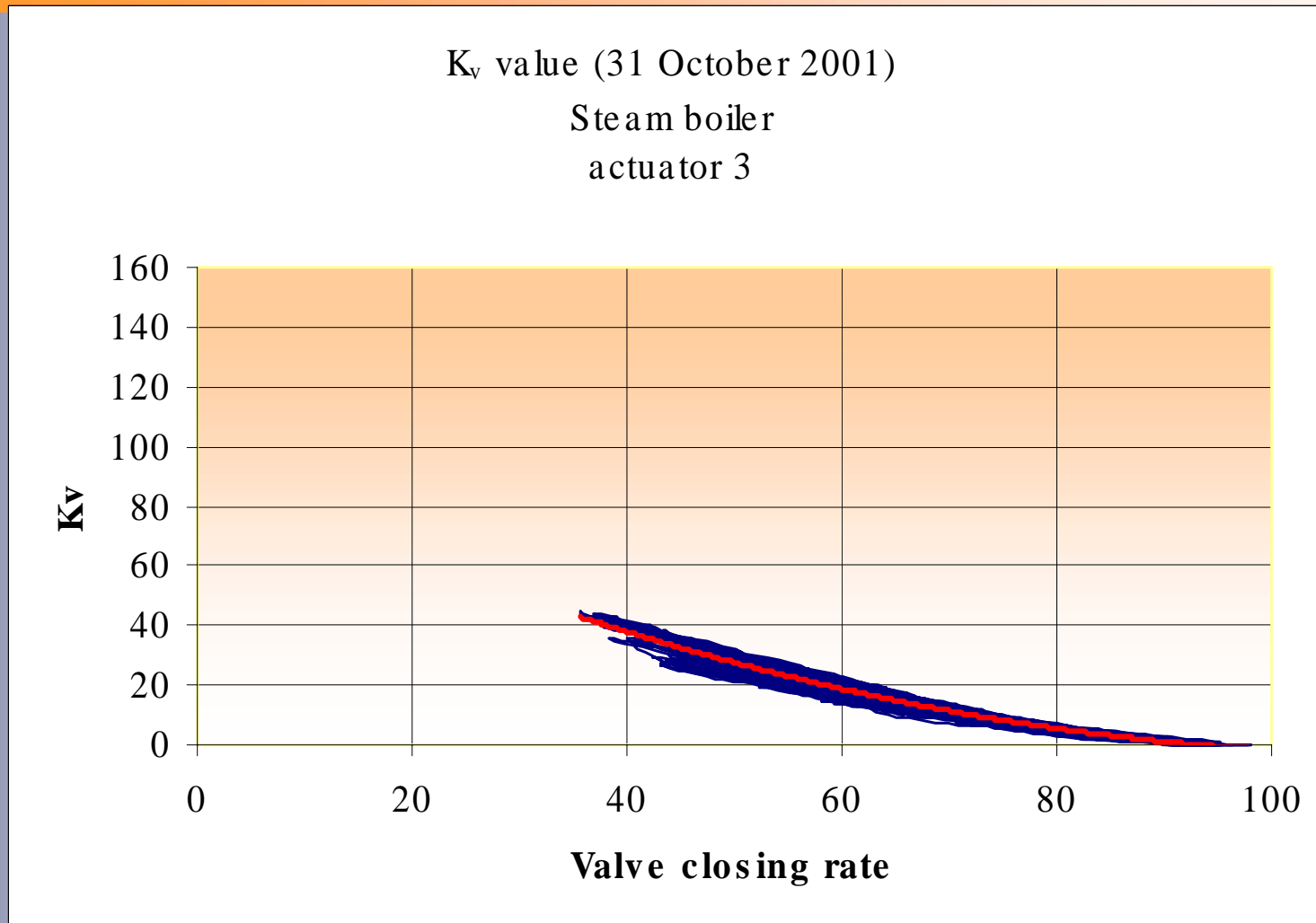
# Artificial fault generation

Remark to **f19** – Flow rate sensor fault in Actuator 3



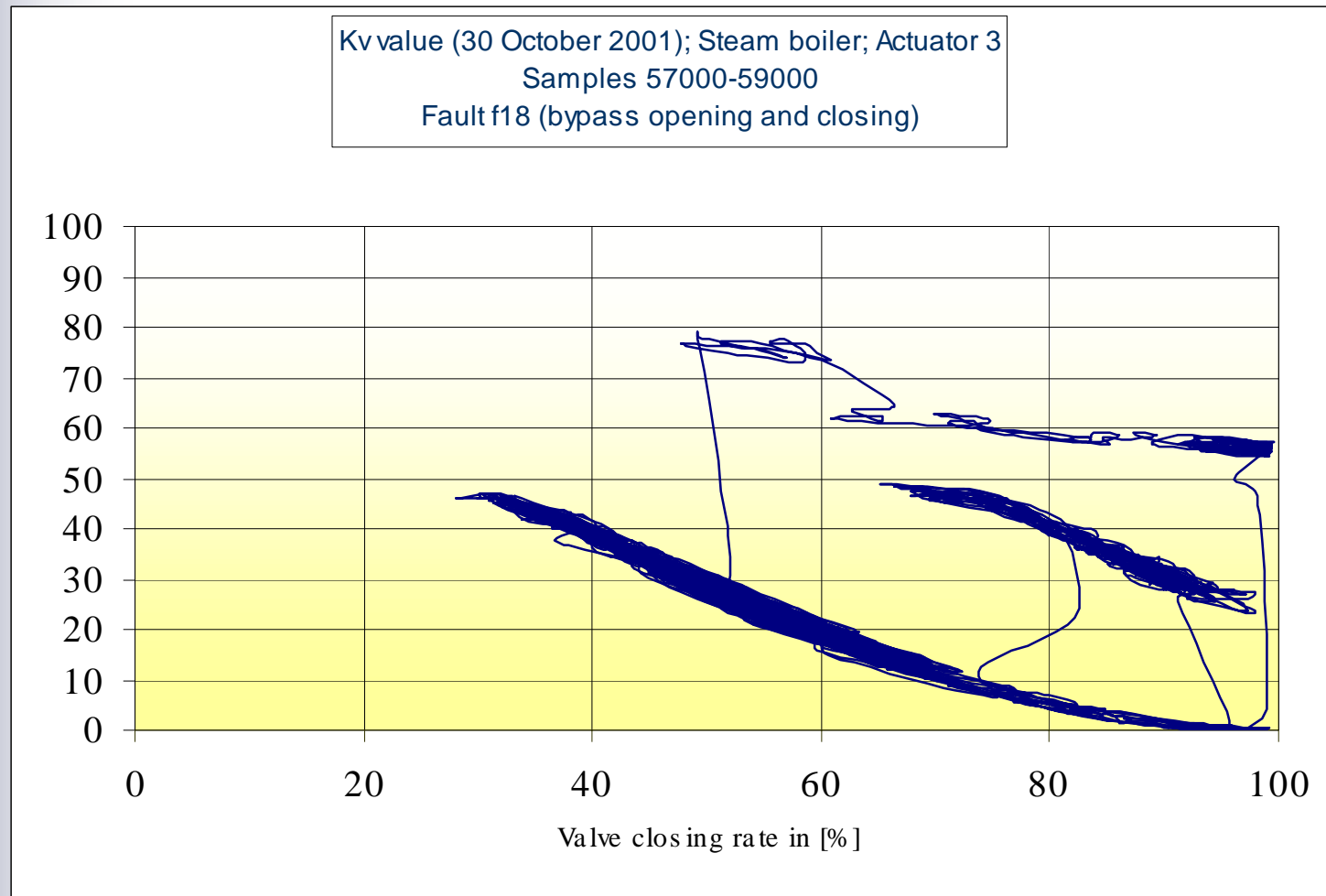
# Fault free state

(additional profits – Kv value identification)



# Faulty state

(Kv virtual change due to simulation of leakage )



# End remarks

The generation of hardware artificial faults can be dangerous for the process. Therefore not all known and identified faults can be simulated.

Data acquired from three actuators from sugar factory in autumn 2001 as well as detailed artificial fault specification are available from the web <http://diag.mchtr.pw.edu.pl/damadics>.

Experiments done are time and money expensive.