ORC 2017 4th International Seminar on Organic Rankine Cycle Power Systems

# The study of dynamic process of ORC variable conditions based on control characteristics analysis

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# content





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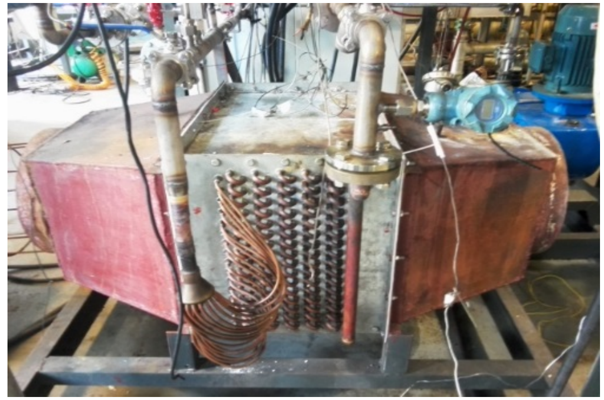
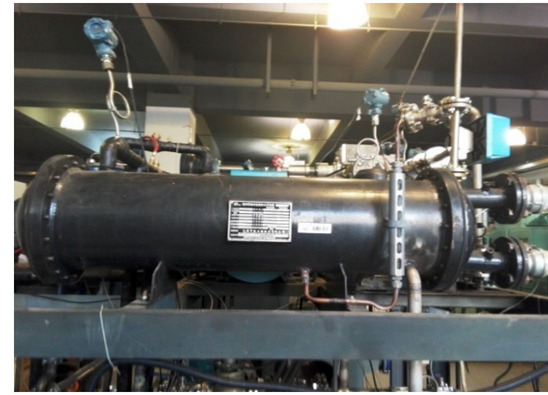
Scroll expander



Finned tube evaporator



shell-and-tube cooler

Diaphragm metering pump

Cooling water pump

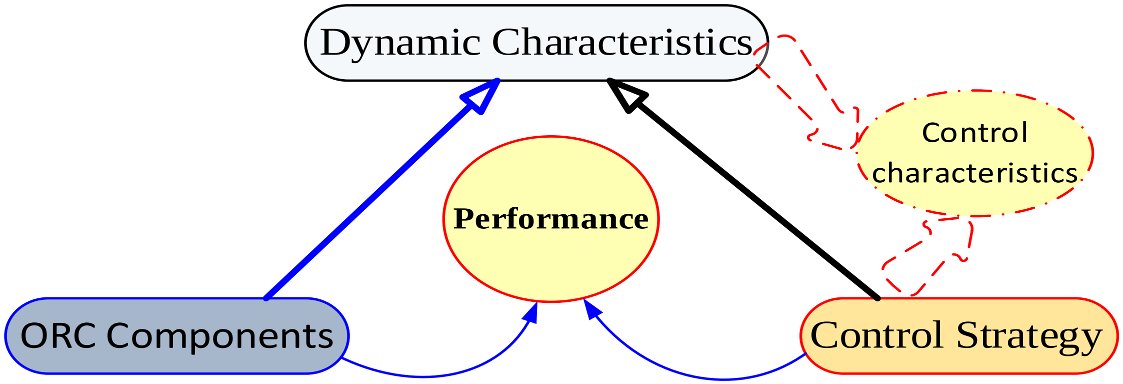
cooling tower

**Components of test rig of ORC system**



## 1. Introduction to control characteristics analysis of dynamic process

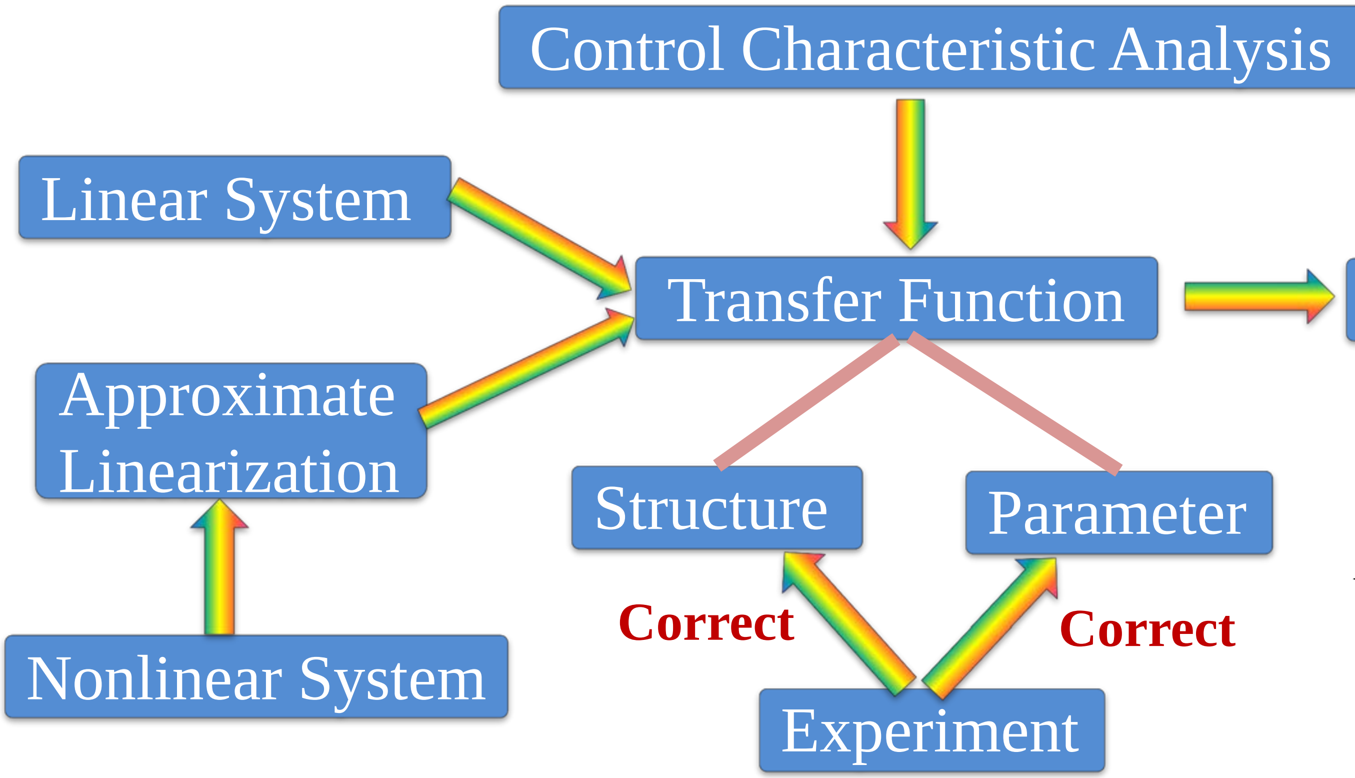
### Control characteristics of ORC

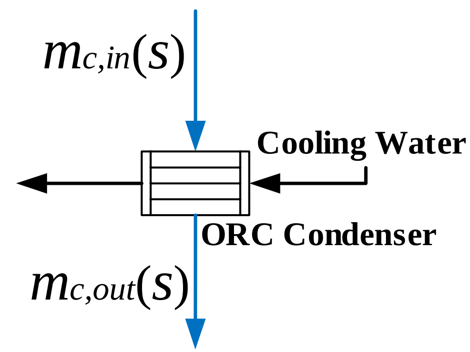



Control strategy
- Control variables
- Regulated variables
- Control algorithm
- Operation mode
  - Fixed pressure
  - Slide pressure

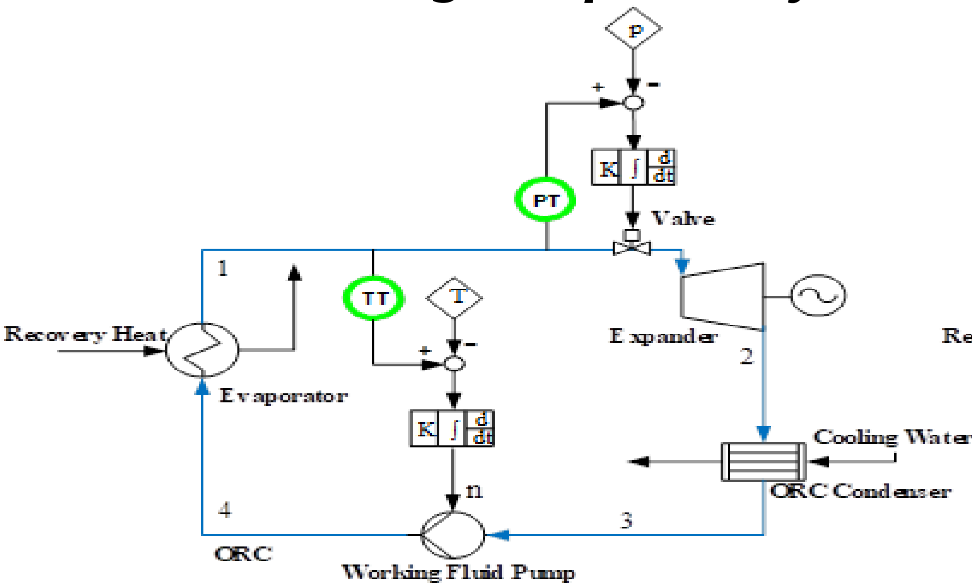


## Control characteristics analysis

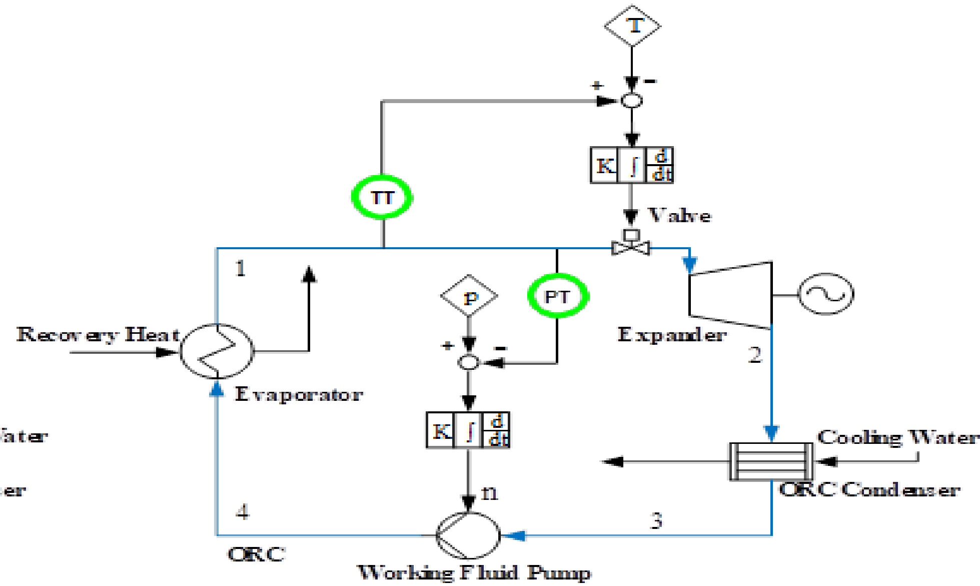


## 2. Control strategies of ORC system




(a) Control mode A




(b) Control mode B

| | Control mode A | | Control mode B | |
|---|---|---|---|---|
| | Pump Speed | Valve Opening | Pump Speed | Valve Opening |
| Evaporator Outlet Temperature | √ | | | √ |
| Expander Inlet Pressure | | √ | √ | |

## *Control mode and operation pressure*

### Fixed pressure operation

- Keeping operation pressure constant by controller adjustment

### Slide pressure operation

- Pressure changes freely without control action
- Pressure changes in accordance with setting curve by controller adjustment.



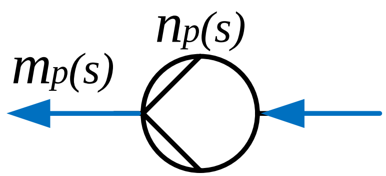
# 3. Dynamic response model based on control characteristics

## 3.1 Dynamic Response Characteristic of ORC Components

### working fluid pump:

Mass flow change passing through pump to pump speed variation

$$W_p(s) = \frac{m_p(s)}{n_p(s)} = K_1$$

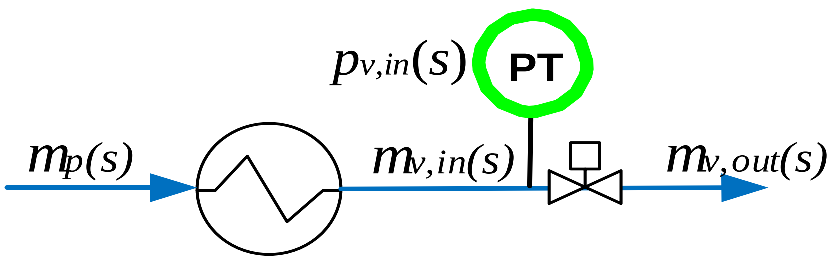



Working fluid pump obey proportional law

### evaporator

Pressure before expander inlet valve to pump mass flow change

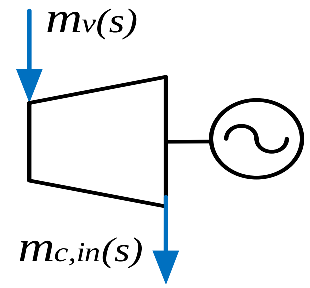
$$W_{ev}(s) = \frac{p_{v,in}(s)}{m_p(s)} = \frac{1}{1+T_1 s}\frac{K_2}{s}$$



## scroll expander

Condenser inlet mass flow to mass flow variation through expander inlet valve

$$W_{ex}(s) = \frac{m_{c,in}(s)}{m_v(s)} = \frac{1}{1 + T_4 s}$$

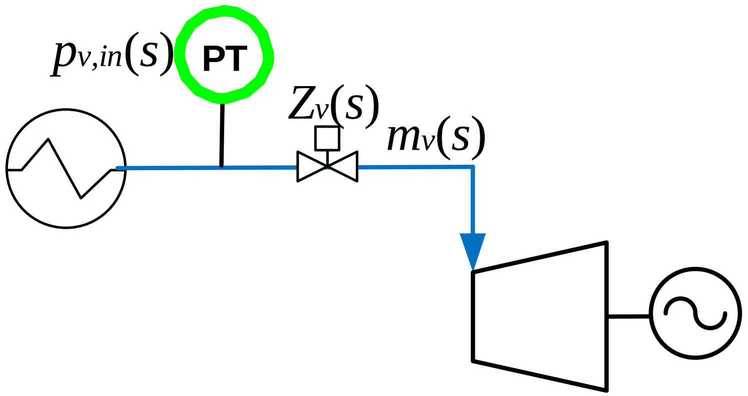



## control valve of expander inlet

$$W_v(s) = \frac{m_v(s)}{Z_v(s)} = K_3$$

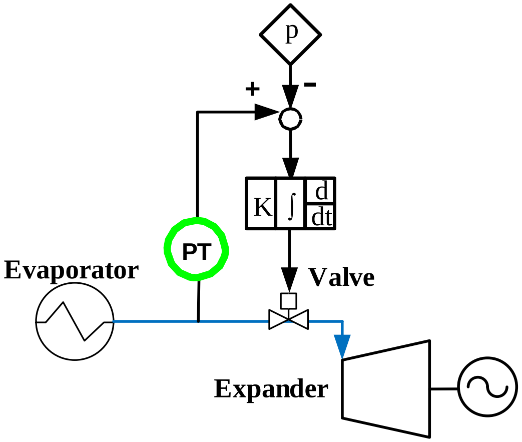
$$W_{v,pTm}(s) = \frac{m_v(s)}{p_{v,in}(s)} = \frac{K_4}{1 + T_2 s} e^{-\tau_1 s}$$

$$W_{v,mTp}(s) = \frac{p_{v,in}(s)}{m_v(s)} = -K_5 + \frac{1}{1 + T_3 s} \frac{-K_6}{s}$$



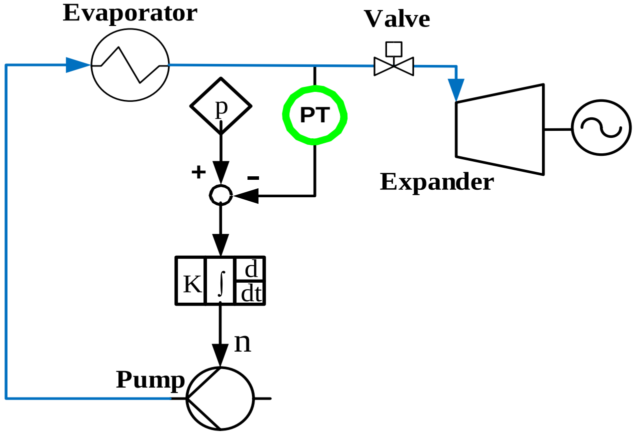
## 3. 2 Transfer function of controller

Controller of entrance pressure of expander inlet valve by regulating valve opening in mode A




$$G_v(s) = K_7 + \frac{1}{T_5 s} \qquad (PI\ CONTOLLER)$$

Valve inlet pressure is controlled by regulating working fluid pump speed in mode B




$$G_p(s) = -K_8 + \frac{-1}{T_6 s} \qquad (PI\ CONTOLLER)$$



# 4 Result and discussion

## 4.1 Dynamic model of control mode A with slide pressure operation

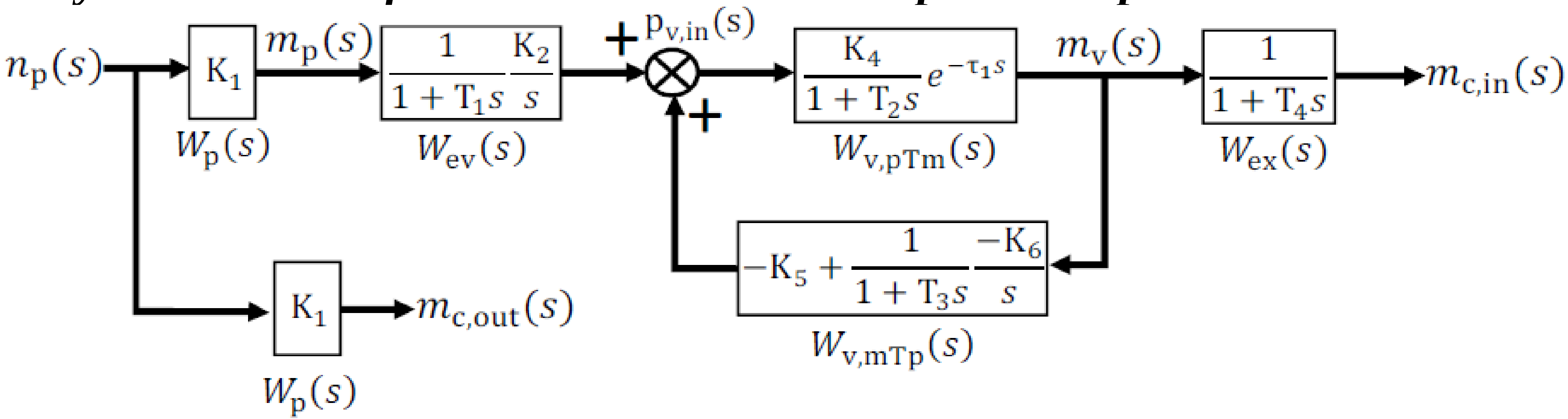



**Fig. 2. Dynamic response model of control mode A with slide pressure operation.**

**Transfer function between pump speed change and condenser inlet mass flow**

$$W_{p,cin}(s)=\frac{m_{c,in}(s)}{n_p(s)}=W_p(s)W_{ev}(s)\frac{W_{v,pTm}(s)}{1-W_{v,pTm}(s)W_{v,mTp}(s)}W_{ex}(s)$$

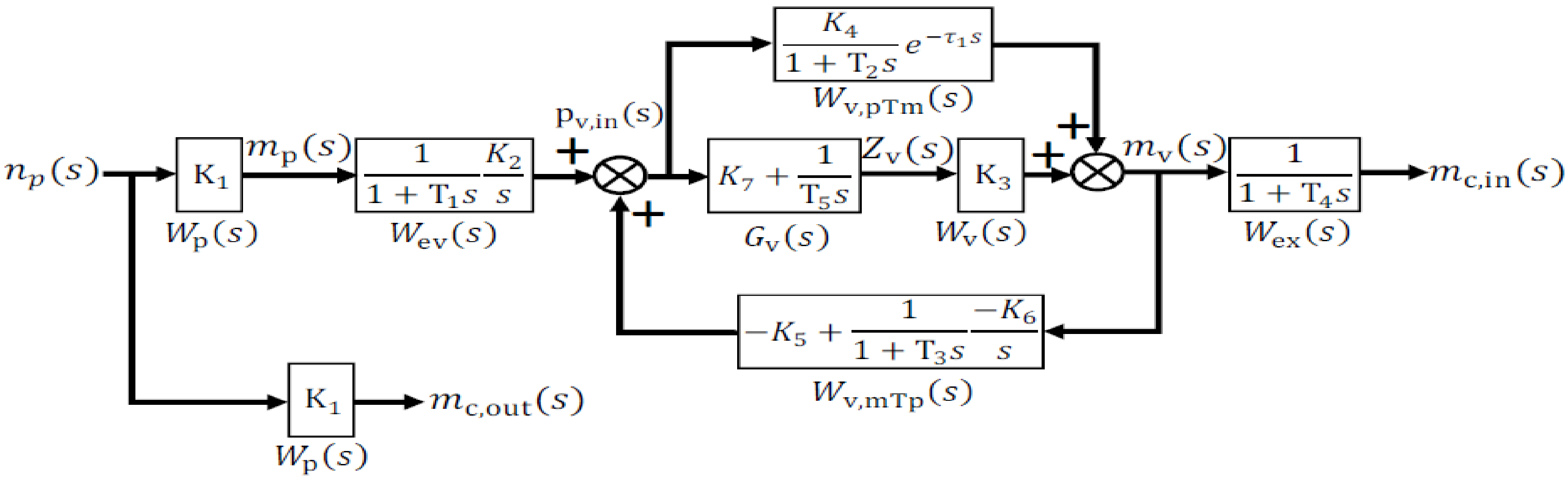
**Mass flow variation of condenser inlet and outlet**

$$\Delta m_{c,in}(t)=L^{-1}\left[n_p(s)W_p(s)W_{ev}(s)\frac{W_{v,pTm}(s)}{1-W_{v,pTm}(s)W_{v,mTp}(s)}W_{ex}(s)\right]$$

$$\Delta m_{c,out}(t)=L^{-1}[n_p(s)W_p(s)]$$

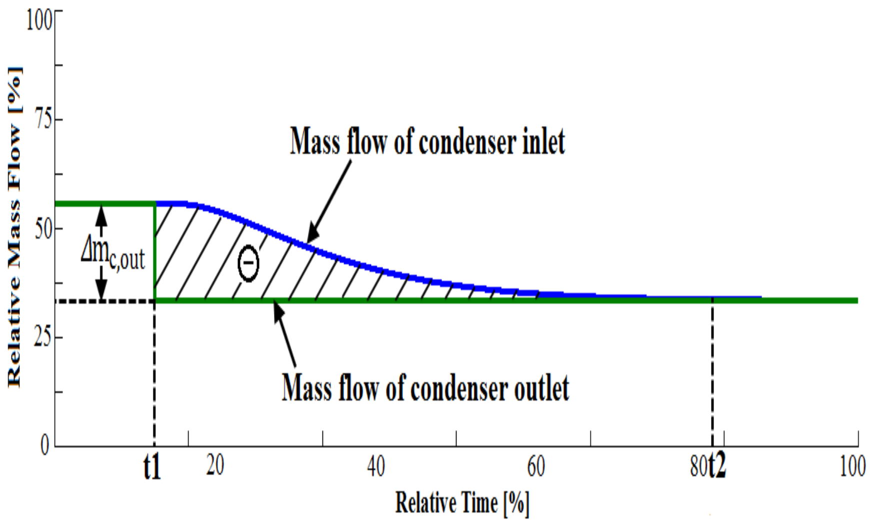


## *4.2 Control mode A with fixed pressure operation*

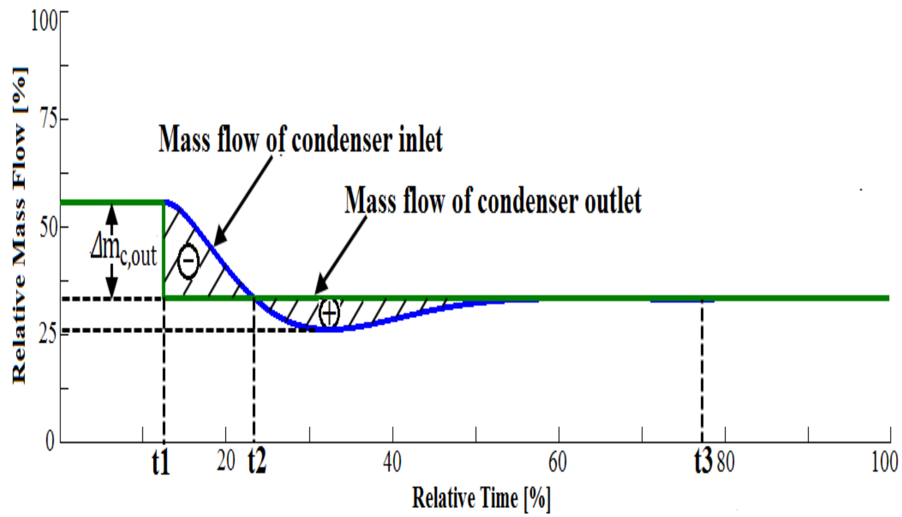



**Dynamic response model of control mode A with fixed pressure operation.**

## *4.3 Model Simulation of Control Mode A*



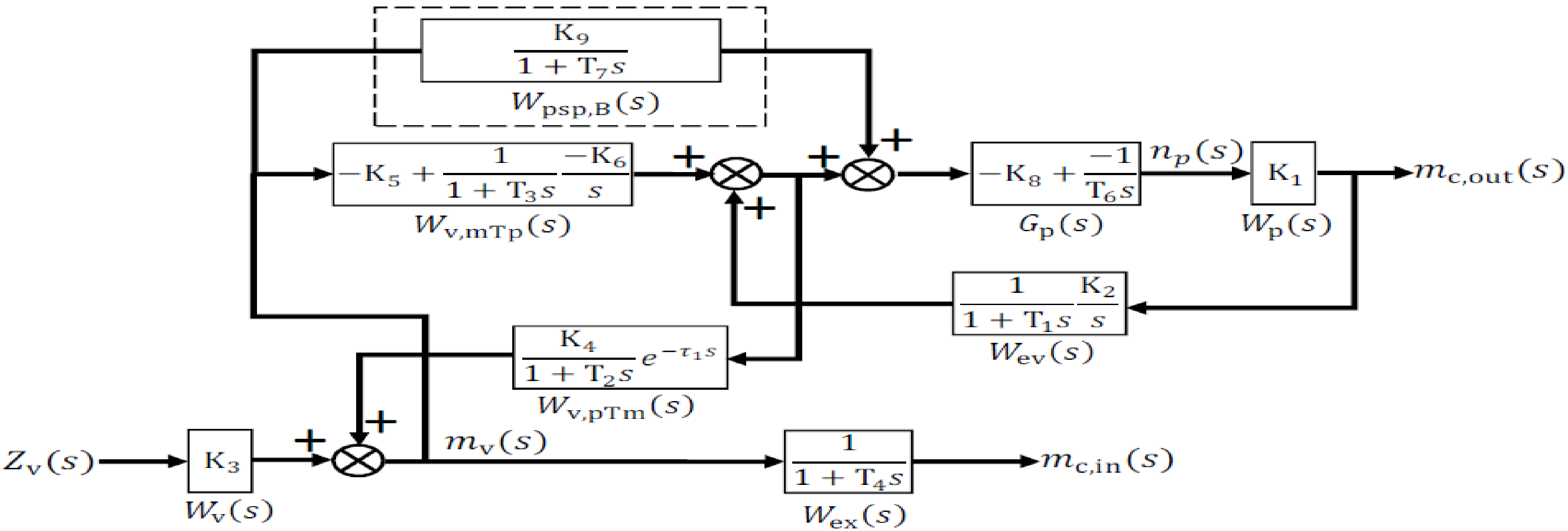

(a) Slide pressure operation.




(b) Fixed pressure operation.

**Mass flow change over time with mode A**

## 4.4 Dynamic Model of Control Mode B

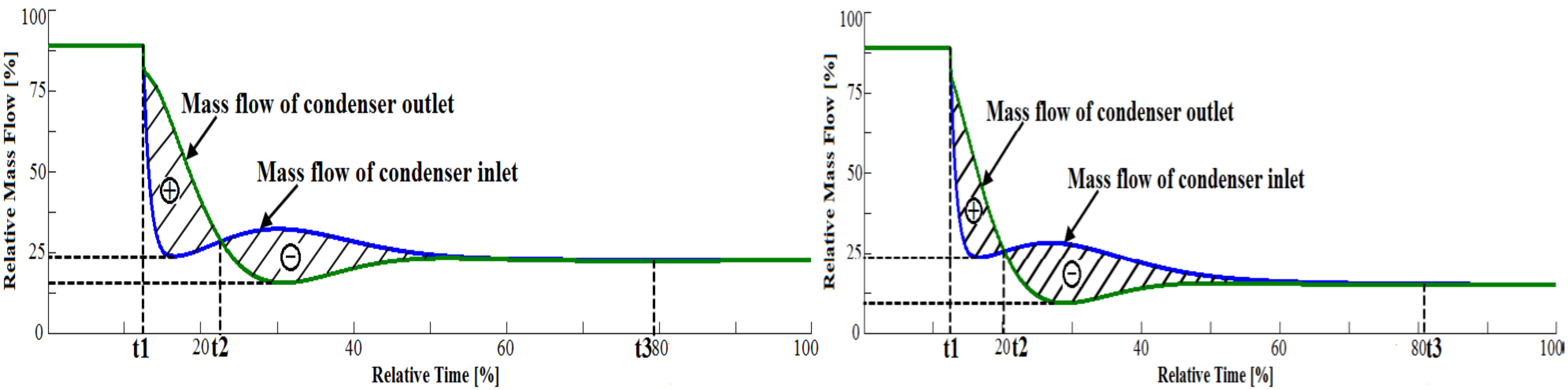



**Dynamic response model of control mode B (Including fixed and slide pressure operation)**

**Pressure set-point bias of slide pressure operation**

$$W_{psp,B}(s) = \frac{B_{psp}(s)}{m_v(s)} = \frac{K_9}{1+T_7 s}$$

# *4.7 Model Simulation (control mode B)*




(a) fixed pressure operation. (b) slide pressure operation.

**Mass flow change over time with mode B**

## *5. Conclusions*

- Control mode including regulated variables, control variables, control algorithm and parameters, influences the variation trends of parameters of dynamic process. But control mode has no effect on final stable state.

- The selection of fixed pressure or slide pressure operation affects the final steady state value and dynamic variation trend of parameters.

- the variation trends of mass flow can be controlled by changing control mode or operation pressure. So, the parameters change of variable conditions can be limited by control strategy.



# Q&A

# Thank you