Detection and Diagnosis of Plant-wide Oscillations using the Spectral Envelope Method

Hailei Jiang , M.A.A. Shoukat Choudhury, and Sirish L. Shah

Computer and Process Control group
Department of Chemical and Materials Engineering
University of Alberta

Outline

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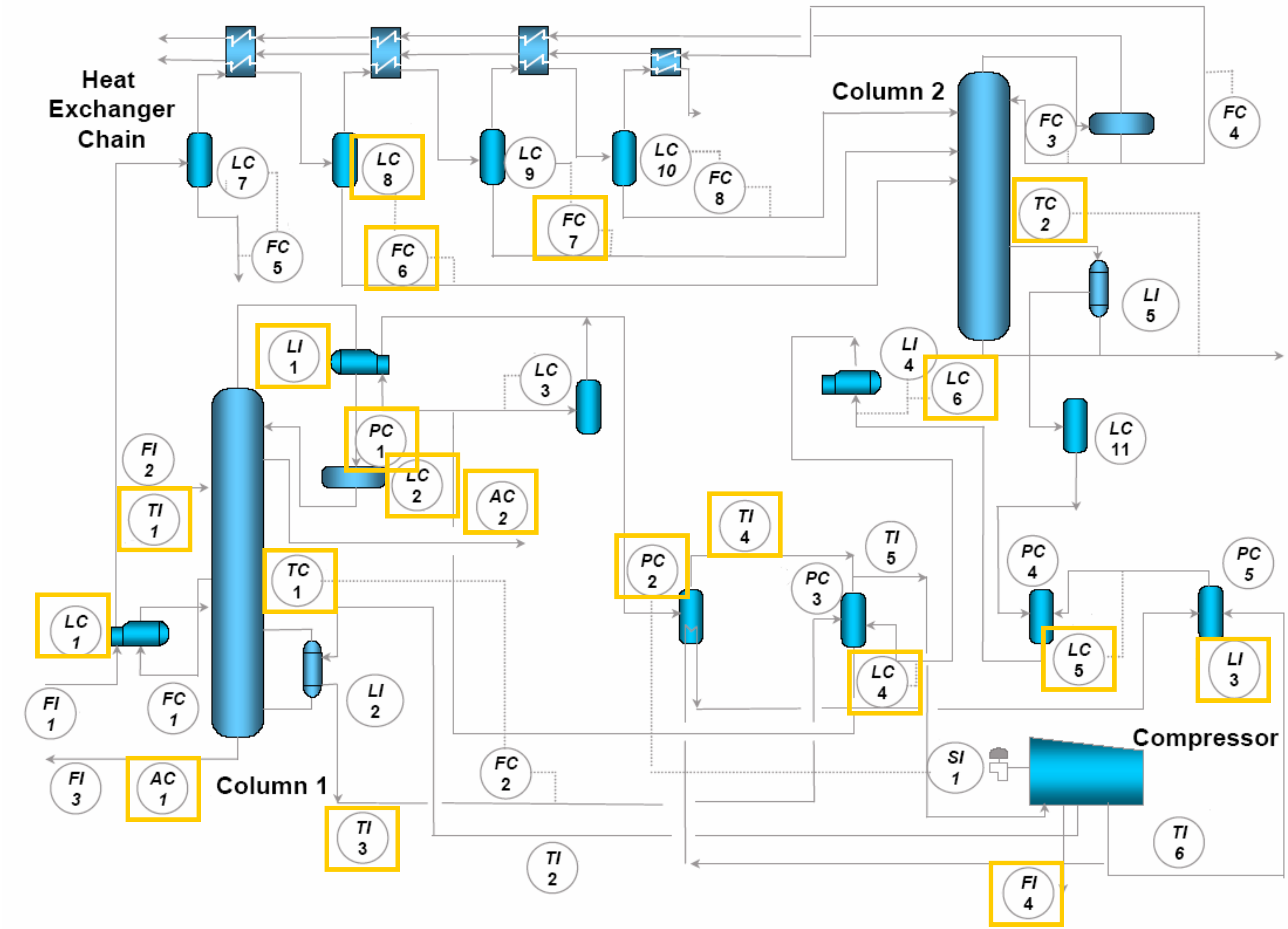
- Spectral Envelop Method and its use in Oscillation Detection & Variable Categorization
- Application to industrial data
- Conclusion
- Acknowledgement

Motivation

Motivation

- Oscillations are common in many processes, whose effects propagate to many units and thus may impact the overall process performance.
- For reasons of Safety and Profitability, it is important to detect and diagnose the plant-wide oscillation.

Industrial Example



Objective

- Detect oscillations in the process variables.
- Categorize the variables that have similar oscillations.
- Deliver useful information on the potential root-cause(s)

Spectral Envelop Method

and its use in

Oscillation Detection & Variable Categorization

Preliminaries

- Assume $\mathbf{X}(t) = \begin{bmatrix} \mathbf{x}_1(t) \\ \mathbf{x}_2(t) \\ \vdots \\ \mathbf{x}_m(t) \end{bmatrix}$ is an m dimensional, vector-valued time series, for $-\infty < t < \infty$.

- Denote $g(t, \boldsymbol{\beta})$ as a linear combination of the variables of $\mathbf{X}(t)$:

$$g(t, \boldsymbol{\beta}) = \begin{bmatrix} \beta_1 & \beta_2 & \cdots & \beta_m \end{bmatrix} \begin{bmatrix} \mathbf{x}_1(t) \\ \mathbf{x}_2(t) \\ \vdots \\ \mathbf{x}_m(t) \end{bmatrix} = \boldsymbol{\beta}^T \mathbf{X}(t) \quad \textit{with} \ \boldsymbol{\beta} = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_m \end{bmatrix}$$

Preliminaries (con't)

- Denote the covariance of $\mathbf{X}(t)$ as:

$$\mathbf{V}_{\mathbf{X}} = Cov(\mathbf{X}(t))$$

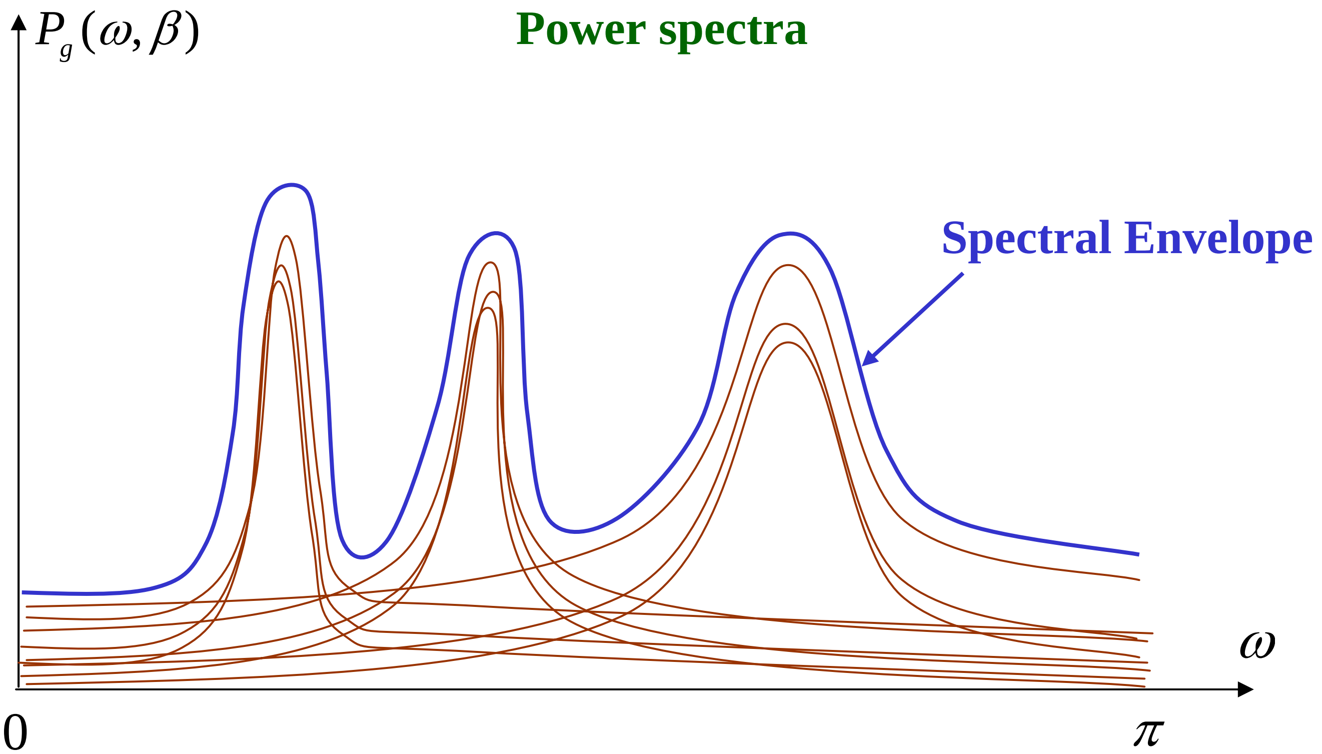
- The variance of $g(t, \boldsymbol{\beta})$ can be expressed as:

$$V_g(\boldsymbol{\beta}) = \boldsymbol{\beta}^T \mathbf{V}_{\mathbf{X}} \boldsymbol{\beta}$$

What is a Spectral Envelope?

- With the constraint that $V_g(\boldsymbol{\beta}) = \boldsymbol{\beta}^T \mathbf{V_X} \boldsymbol{\beta} = \mathbf{1}$

  then $g(t, \boldsymbol{\beta})$ is unit-variance.



Definition of Spectral Envelop

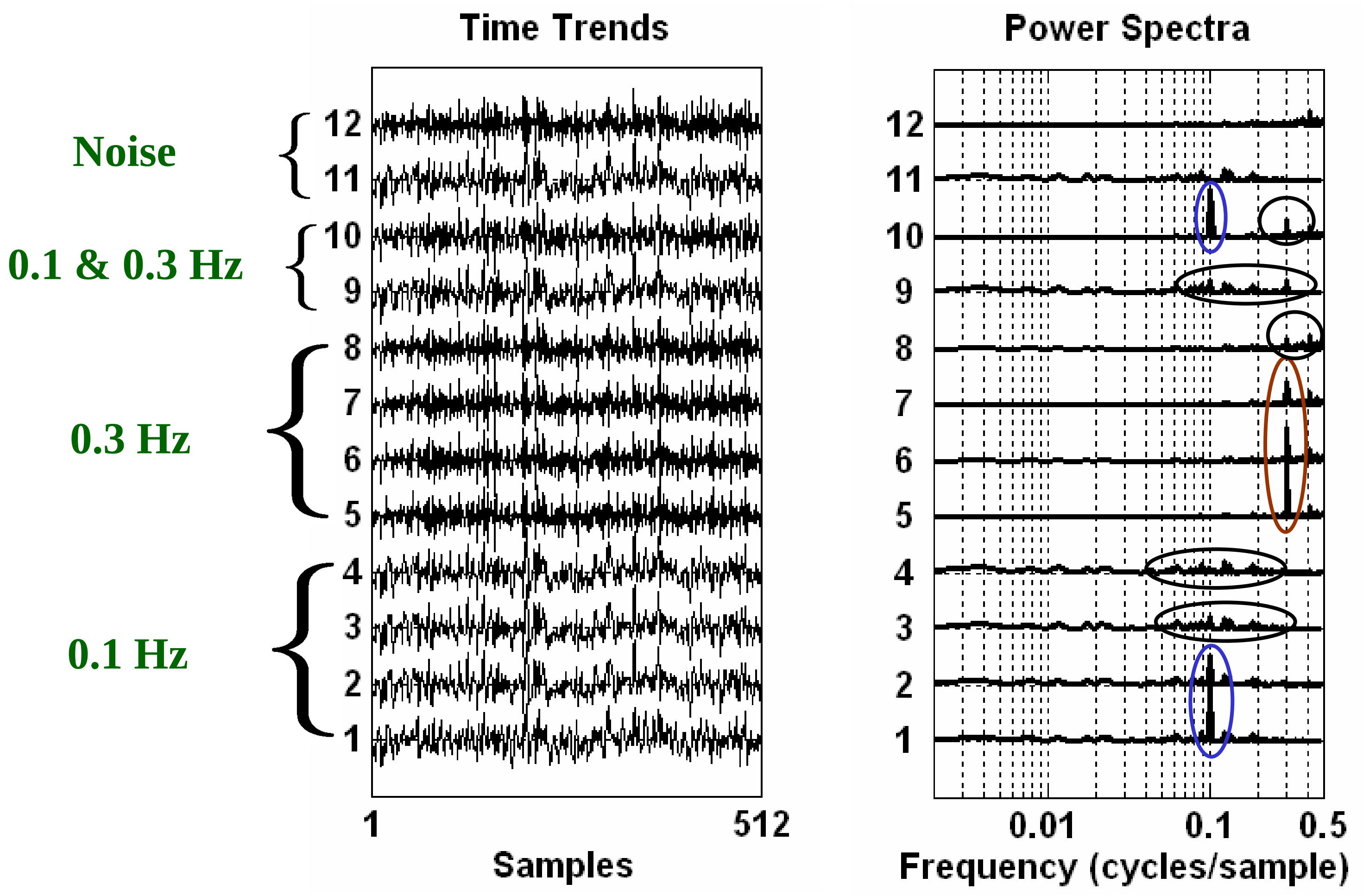
- The Spectral Envelope of $X(t)$ is defined to be

$$\lambda(\omega) = \sup \{Power\ of\ the\ scaled\ series\ at\ frequency\ \omega\}$$

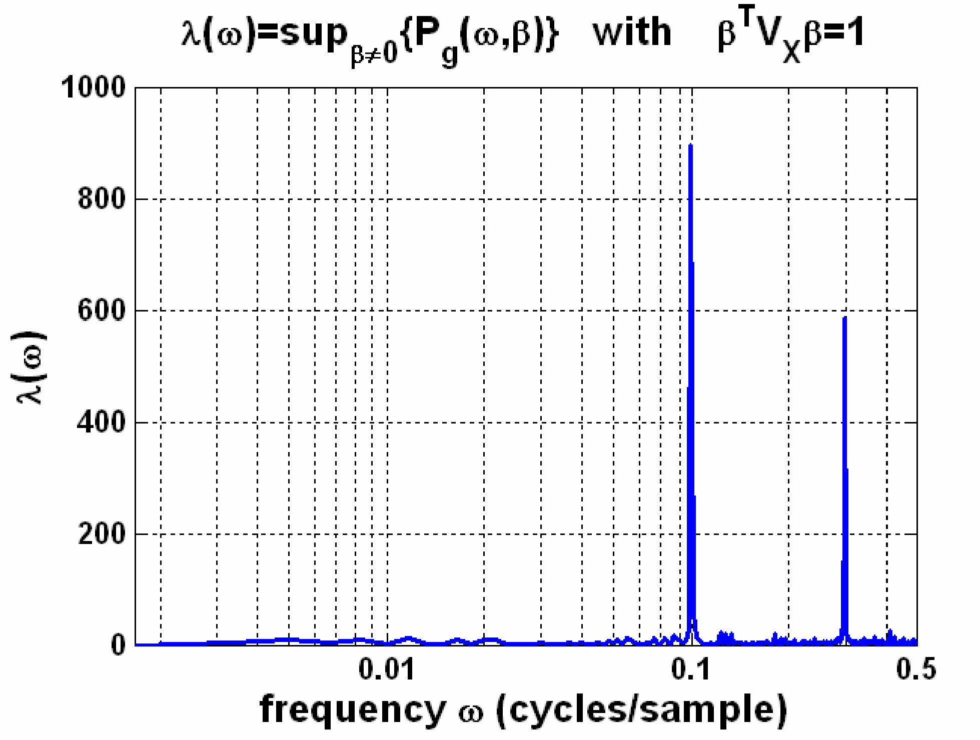
$$= \sup_{\boldsymbol{\beta} \neq 0} \{P_g(\omega, \boldsymbol{\beta})\} \quad with \quad \boldsymbol{\beta}^T \mathbf{V}_{\mathbf{X}} \boldsymbol{\beta} = 1$$

- The quantity $\lambda(\omega)$ represents the largest power (variance) that can be obtained at frequency ω for any unit-variance scaled series, which is a linear combination of the variables of $\mathbf{X}(t)$.

Simulation example

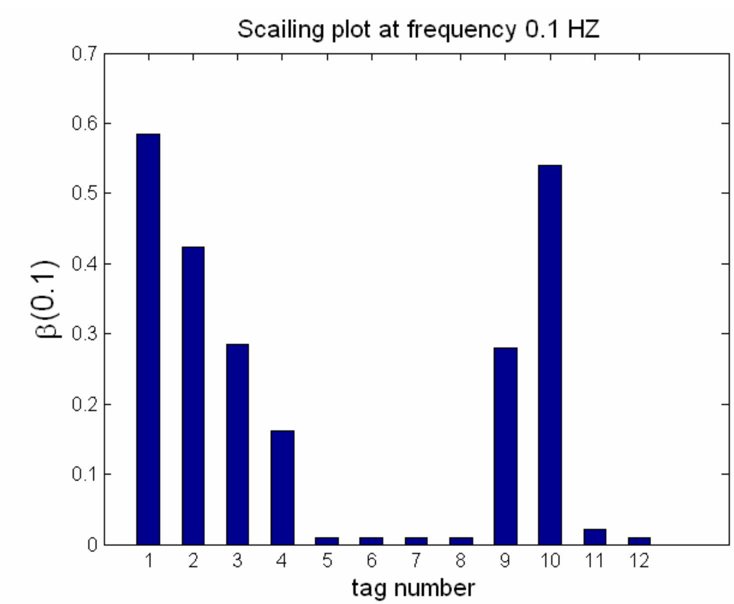


Spectral Envelope

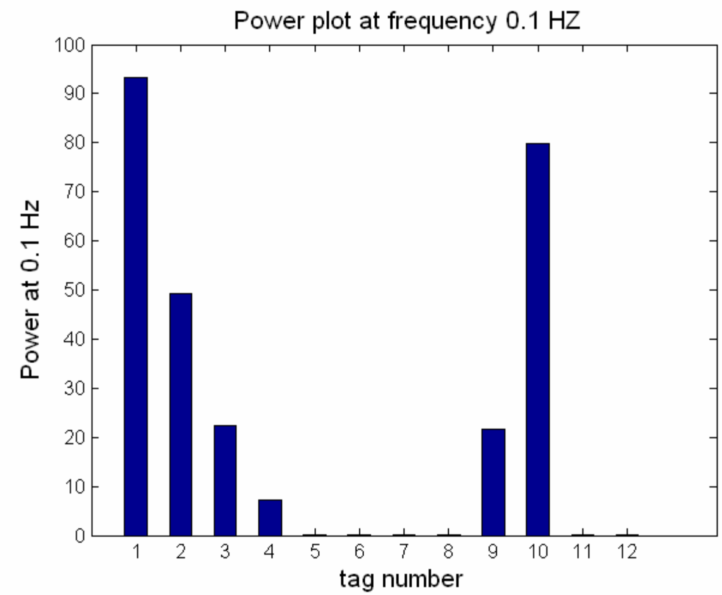


Spectral envelope can identify the oscillations at 0.1 and 0.3 Hz.

Optimal Scalings at 0.1 Hz



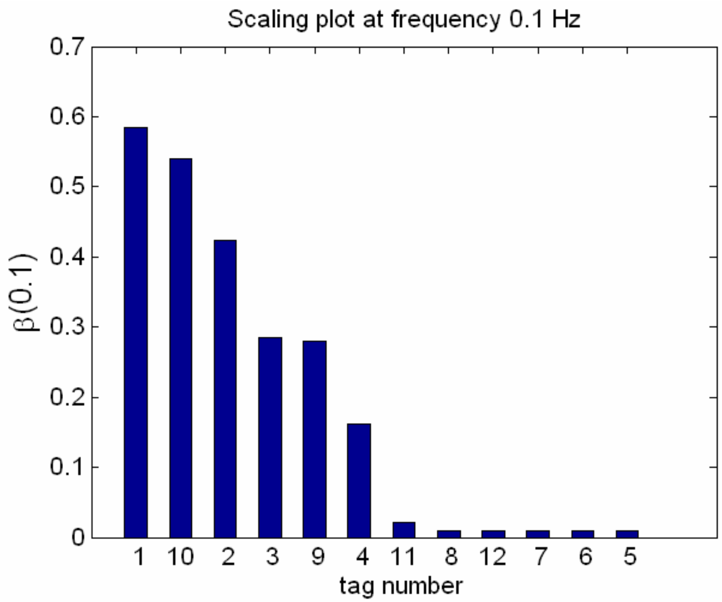
Magnitude of scaling for each variable



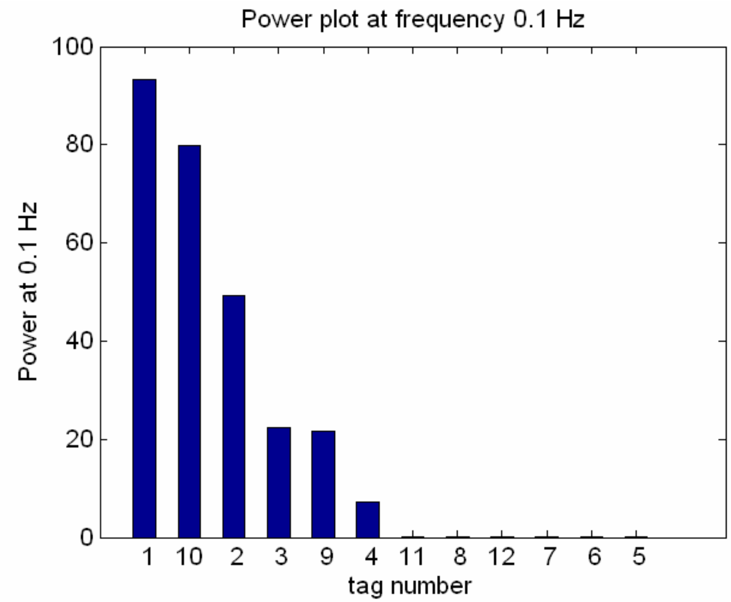
12	0.0093	0.0239
7	0.0092	0.0233
6	0.0089	0.0223
5	0.0088	0.0211

Power at 0.1 Hz for each variable

Scaling plot *VS* Power plot at 0.1Hz



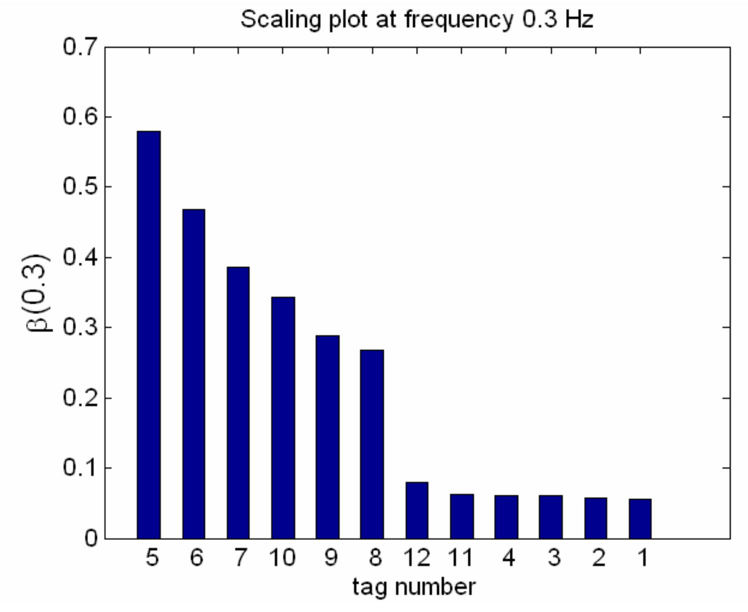
Scaling plot



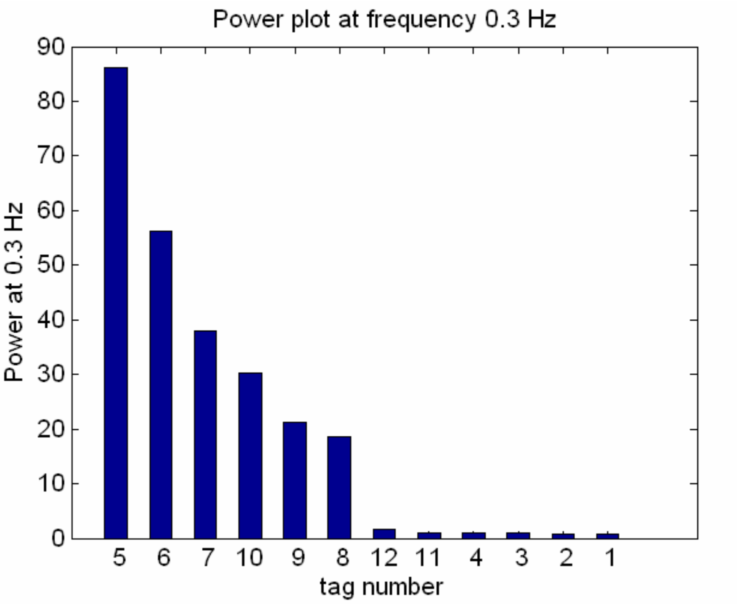
Power plot

Both plots can help us to categorize variables.

Scaling plot *VS* Power plot at 0.3Hz



Scaling plot



Power plot

Both plots can help us to categorize variables.

Application to industrial data

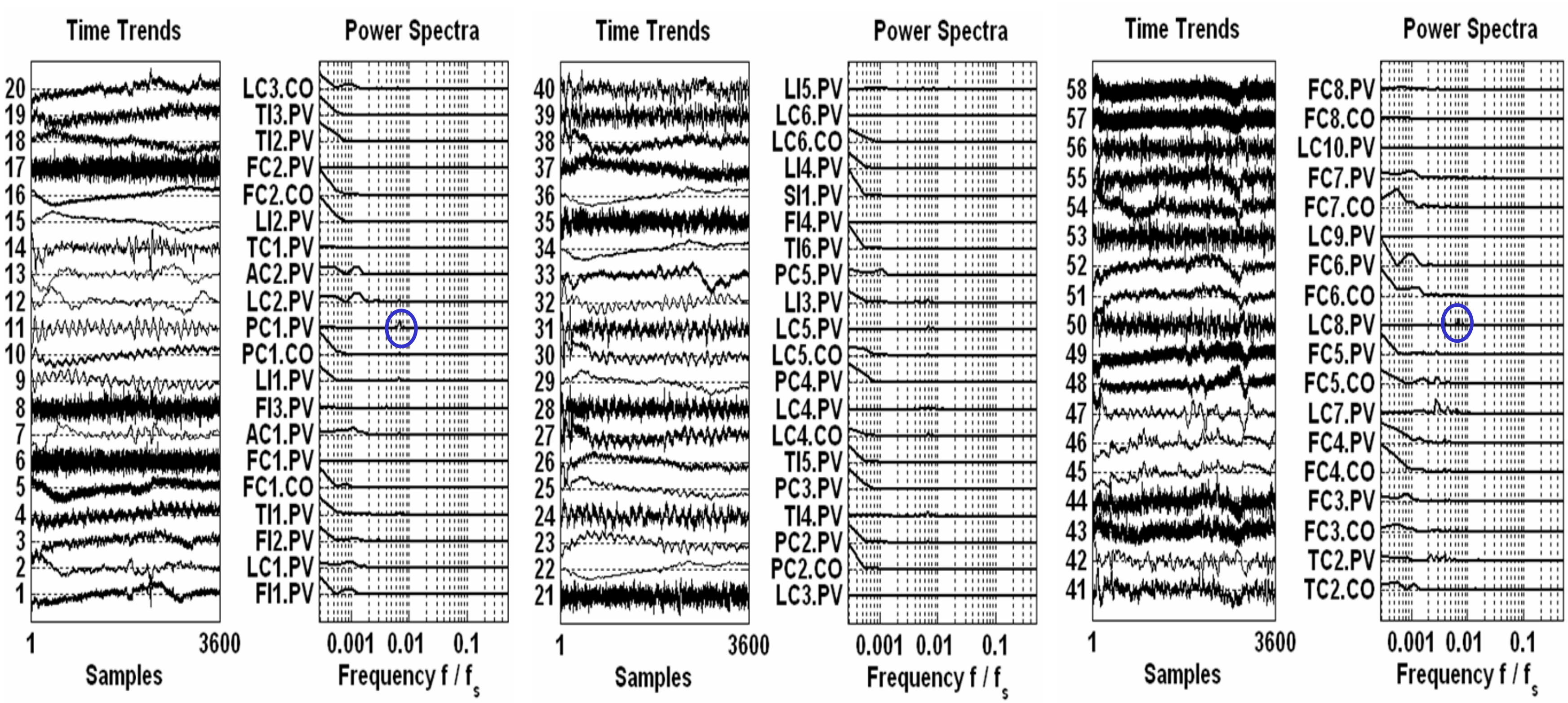
Distillation plant example

- Data from Mitsubishi Chemical Corporation
- 58 process variables from a distillation plant
- 3600 observations sampled at 1 min interval

Overview of the data

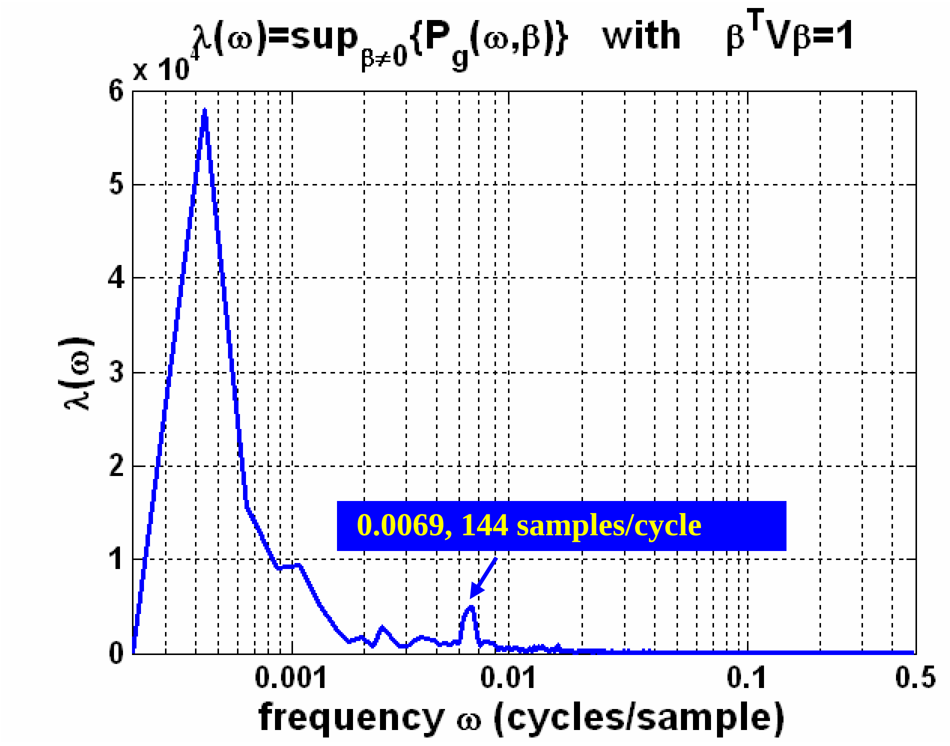
Interested in oscillations with period 2.5 hours

(about 150 samples/cycle, or 1/150 = 0.0067)



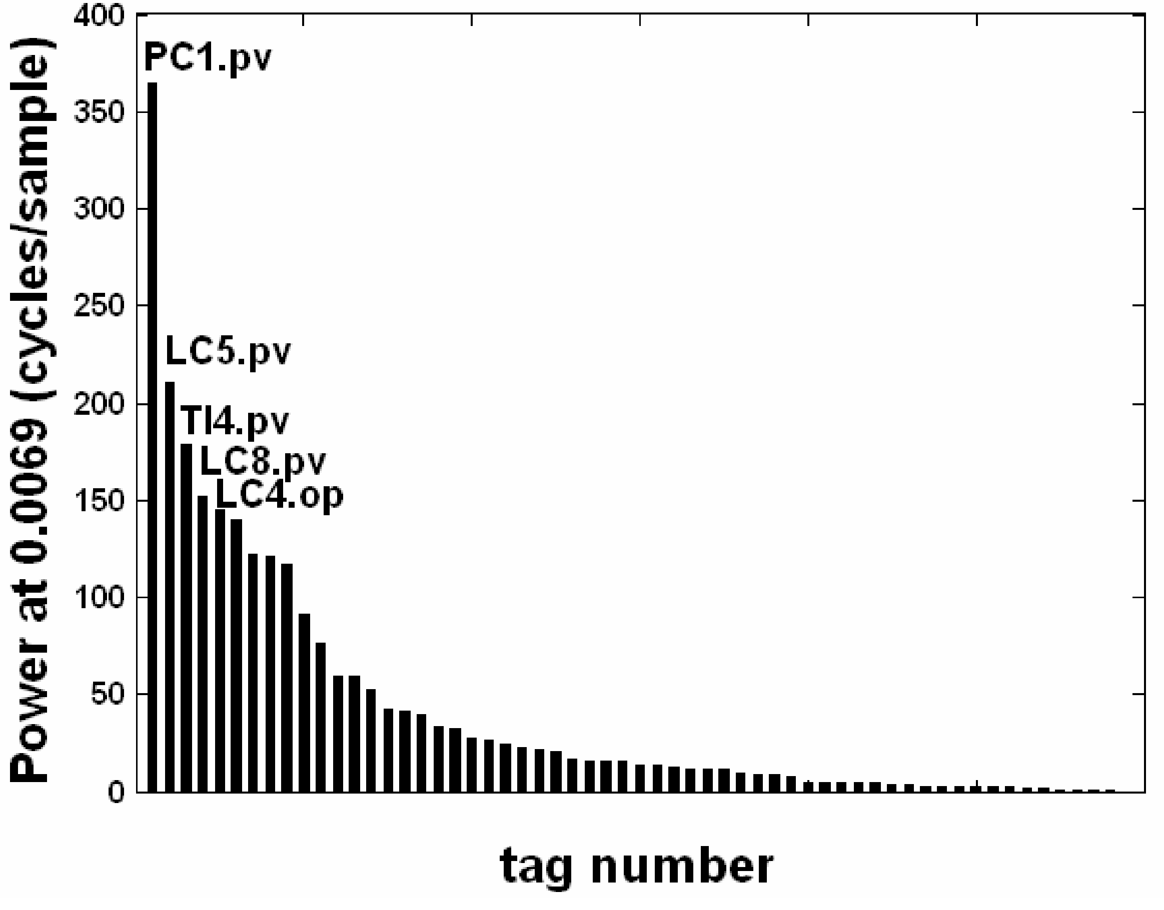
tag 1- 20 **tag 21- 40** **tag 41- 58**

Spectral Envelope



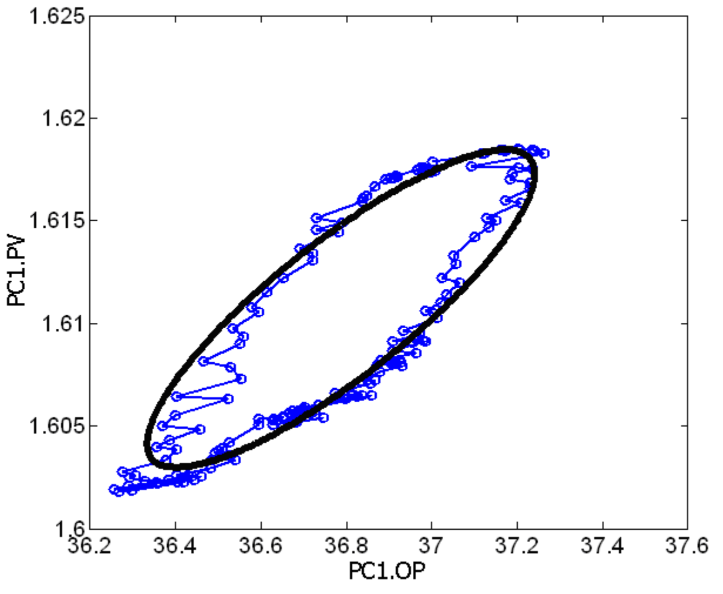
Spectral envelope detect the oscillation of concern with a period of 144 samples/cycle.

Power plot at 0.0069 (144 samples/cycle)



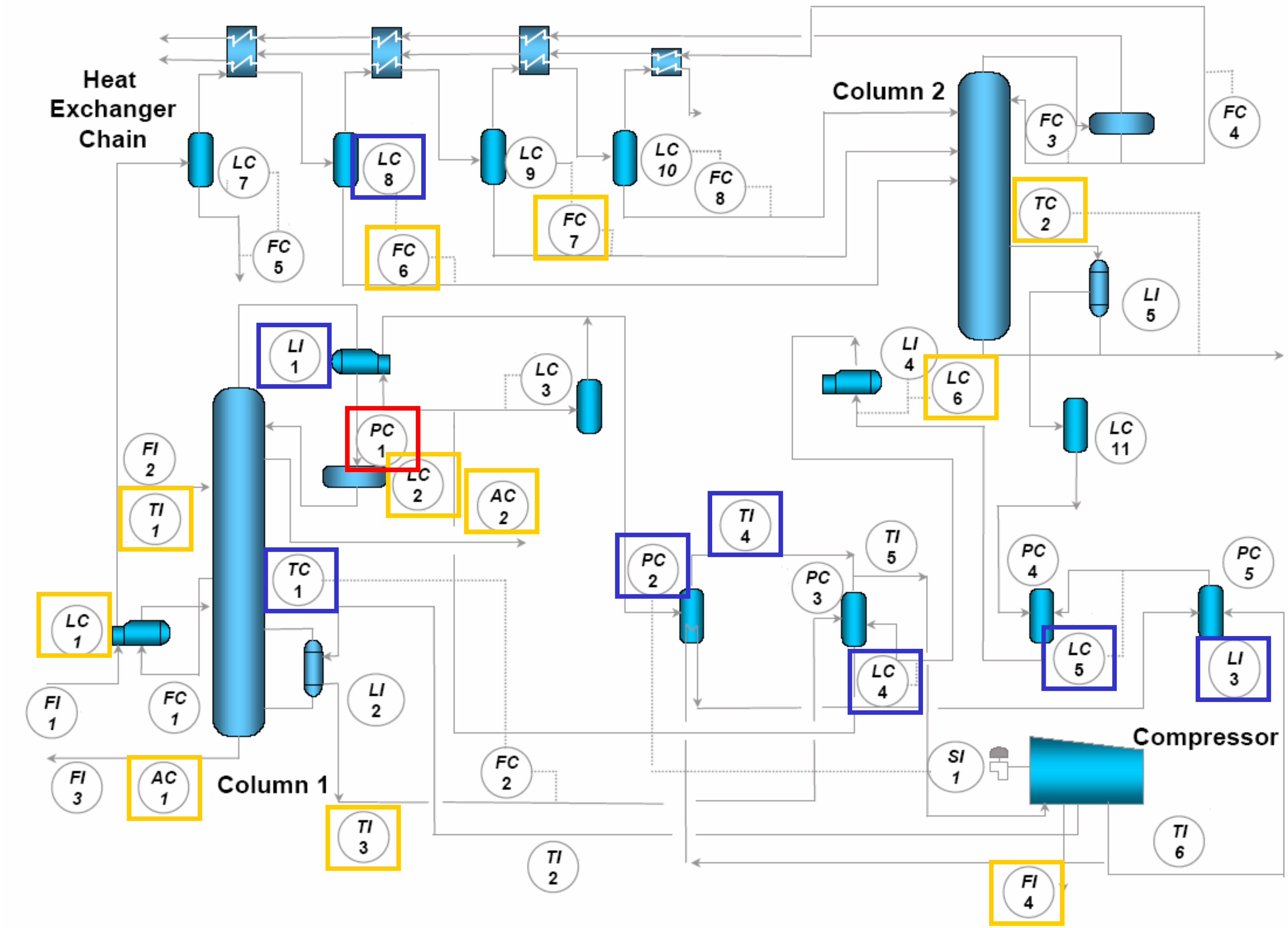
Power plot

pv-op plot



1. This plot shows a pattern of valve stiction.
2. Simple closed-loop plant test had confirmed that the valve really has stiction problem.
3. Further plant test and maintenance has been scheduled during the next plant shutdown.

Root cause Diagnosis



Conclusion

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- Spectral Envelop (SE) method has been successfully applied to industrial data to identify the oscillation frequencies and categorize the variables that have the same oscillations.

- Scaling plot and power plot provide useful information on the root-cause of oscillations.

Acknowledgement

Acknowledgement

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Thank you!