Detection of Ammonia Slip Using NOx Sensor Signal Processing

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Need For NH3 Slip Detection

Illustration for Steady State NOx Conversion Efficiency

Sensor Measured Conversion Efficiency

Model Estimated $\eta$

Sensor Feedback $\eta$

Normalized NH3 Storage

No NH3 Slip Regime

NH3 Slip Regime $\text{NH3}>0$

Need method/s to correct NH3 storage estimate

$\theta_{\text{Est}}$

$\theta_{\text{NewEst?}}$

$\theta_{\text{NewEst?}}$

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Observed Response of the SCR System

- **Empty**
- **Light Load**
- **Critical Load**
- **Saturated**
- **Over Loaded**

**Excess Low Frequency Content**

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Components of NH3 Slip Detection Logic

Frequency Analysis
• By observing the frequency content of the upstream and downstream NOx signals, there is potential to detect presence of NH3 slip in the downstream signal.

Statistical Analysis
• By observing how well the downstream NOx signal moves relative to the upstream signal, it is possible to determine when there is a low likelihood of NH3 signal content within the downstream signal.

Steady State Analysis
• By observing the response of the downstream signal to intrusive upstream inputs, it is possible to detect NH3 slip.
Frequency Content of NOx Sensor Signals

Transient Cycle With Excessive NH3 Slip

- **Inlet Sensor**
  - Less high frequency content than inlet sensor

- **Outlet Sensor**
  - Less low frequency content than outlet sensor

Outlet NOx Sensor
Inlet NOx Sensor
Outlet NH3 FTIR

Less high frequency content then inlet sensor

Less low frequency content then outlet sensor
Statistical Correlation of Signals

Concatenated Transient Cycles

Emission (ppm)

(No NH3 Injection) (With NH3 Injection)

Correlation Metric

Time (sec)

High response means the outlet sensor’s movement is well correlated with the inlet sensor movement.
NH3 Slip Detection During Quasi-Steady Conditions

The response of the downstream NOx sensor is analyzed relative to the model prediction after an intrusive action has been taken.
Slip Detection Process Flow

Model prediction disagrees with feedback sensor

If steady state conditions, then check for obvious NH3 slip occurrence

If transient conditions, then check if there is likely no NH3 slip

If steady state conditions, then complete intrusive diagnostic

Check if transient conditions suggest there is NH3 slip

START

Steady State Analysis

False

Steady State Analysis

False

Statistical Analysis

False

Frequency Analysis

Slip Detected

Slip Detected

No Slip Detected

Set Slip Flag
Debouncing logic can help improve stability of detection.
For robust SCR control, it is useful to know the SCR outlet NOX & NH3 emissions such that the control model can be accurately corrected.

The current production NOx sensor is cross-sensitive to NH3. Therefore, it provides noisy feedback to the control algorithm.

Presented are some signal processing observations which can help to provide insight to the true nature of the exhaust downstream the catalyst. However, there is some inherent noise to these methods.

As future emission regulation become more stringent, the accuracy of the feedback sensor will become more important.

It is recommended that there be further development in a sensor that provides a combination of NOx and NH3 feedback.
THE END