ITN ENERGY-SMARTOPS WORKSHOP "Optimization to provide energy savings by better integration of operations across the process-mechanical-electrical interfaces", LADENBURG, GERMANY, 22-24 Oct 2013.

Energy-SmartOps

Integrated Control and Operation of Process, Rotating Machinery and Electrical Equipment

Control systems for centrifugal compressors with an emphasis on CO_2 compression

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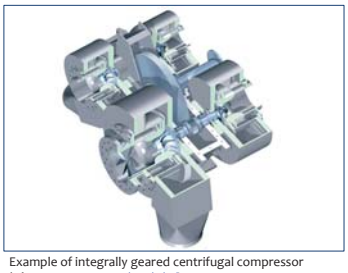
Problem statement

Control of compressor
- Performance control
- Antisurge control

Performance control
- Control of pressure or flow rate
- Standard feedback PI controller
- Limited integration with antisurge control

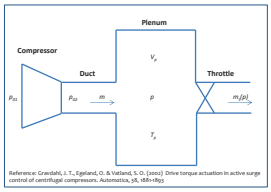
Margins for improvement
- Faster response
- Integrated solution for overall control stability
- Energy saving

Methodology
- Modelling
- Dynamic simulation
- Comparison with plant data or literature



Example of integrally geared centrifugal compressor
(reference: www.siemens.com/entry/cc/en/)

Model of a generic compressor



Reference: Gravdahl, J. T., Egeland, O. & Vatland, S. O. (2002) 'Drive torque actuation in active surge control of centrifugal compressors.' Automatica, 38, 1881-1893

$$\frac{dp}{dt} = \frac{a^2_{01}}{V_p}(m - m_t(p)) \quad (1)$$

$$\frac{dm}{dt} = \frac{A_1}{L_c}(\Psi_c(\omega, m)p_{01} - p) \quad (2)$$

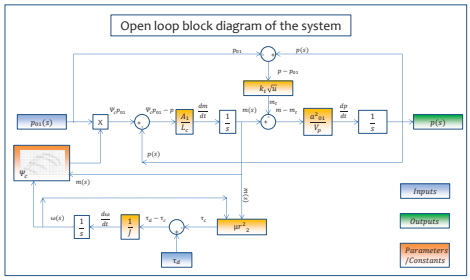
$$\frac{d\omega}{dt} = \frac{1}{J}(\tau_d - \tau_c) \quad (3)$$

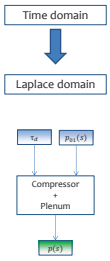
$$m_t(p) = k_t\sqrt{p - p_{01}} \quad (4)$$

$$\tau_c = \mu r^2_2 \omega m \quad (5)$$

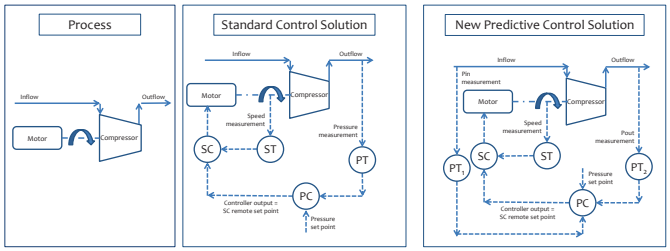
$$\Psi_c(\omega, m) = \frac{p_{02}}{p_{01}} \quad (6)$$

where p is the plenum pressure, m is the compressor mass flow, ω is the rotational velocity, A_1 is the throughflow area, L_c is the duct length, V_p is the plenum volume, p_{01} and a_{01} are the inlet pressure and sonic velocity at ambient conditions, $m_t(p)$ is the throttle flow, J is the total inertia of the system, τ_d is the drive torque, τ_c is the compressor load torque, Ψ_c is the compressor characteristic, k_t is the throttle parameter, r_2 is the impeller radius, μ is a function of Stanitz slip factor (Gravdahl et al., 2002)

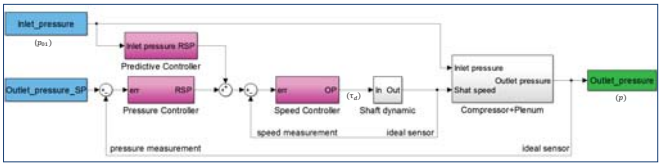




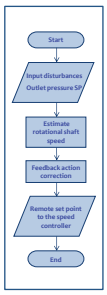
Control system implementation



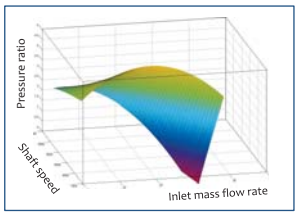
Closed loop block diagram for the Predictive Control Solution



How the predictive controller works

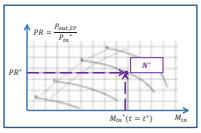


Compressor pressure ratio as a function of inlet mass flow rate and shaft speed

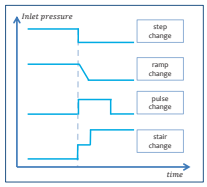


In two dimensions

At time $t = t^*$ the predictive controller determines the shaft speed N^* according to the instant value of inlet pressure and flow rate (respectively $P_{in}{}^*$ and $M_{in}{}^*$)



Evaluation of the controller performance



Comparison between standard control solution and new predictive control solution

Evaluation via testing: range of disturbance magnitudes and dynamics

Definition of three performance indexes

- **EI** energy consumption index (kWh)
- **CPI** controller performance index: closeness to SP over time (%)
- **CI** cost index: suitable for CCS (carbon capture and storage) applications, it takes into account the power consumption but also the cost of carbon dioxide emission in case of low outlet pressure (£h^{-1})

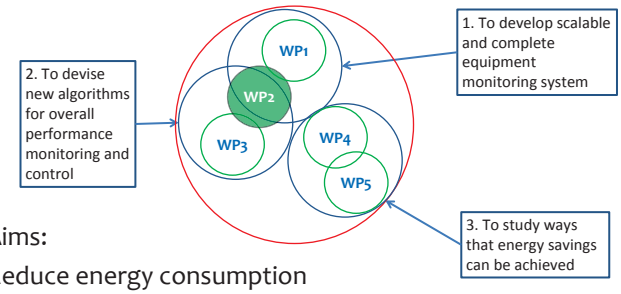
Conclusions and future work

- ✓ Modelling of the compressor
- ✓ Modelling of the typical pressure controller
- ✓ Definition and modelling of the new predictive control solution
- ❑ Testing of process disturbances
- ❑ Definition of a trade-off between delivered pressure and energy consumption (optimisation)
- ❑ Integration with antisurge controller

My project in Energy SmartOps

Energy SmartOps: energy savings from smart operation

WP2: integrated automation for energy saving



Aims:

Reduce energy consumption

Increase overall stability of the system

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