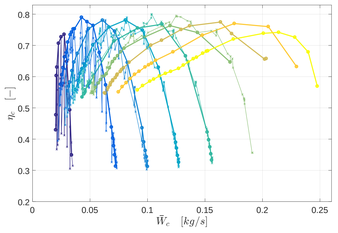
Control-Oriented Compressor Model with Adiabatic Efficiency Extrapolation

Xavier Llamas and Lars Eriksson

Introduction



In a combustion engine installation, compressor operation is not adiabatic. Nevertheless, knowing the true adiabatic performance of the compressor is important, since the heat transfer characteristics of the gas stand are not the same as in the combustion engine. A way to identify heat transfer in a measured compressor map is to use the rule that the different speed lines should collapse into a single line in the $\lambda_{Euler} - \phi_2$ plane, unless there is heat transfer affecting the efficiency measurements.

$$\lambda_{\text{Euler}} = 1 - \frac{c_s}{U_2} + \phi_2 \tan \beta_2$$

Compressor Model

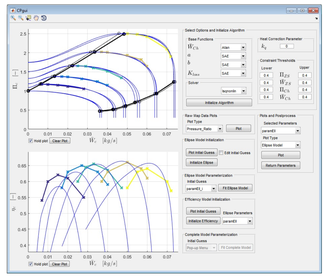
The complete compressor model consists of a submodel to compute the mass flow, and another submodel to compute the efficiency. The compressor mass flow is modeled with the Ellipse model.

$$\left(\frac{\bar{W}_c - \bar{W}_{ZS}}{\bar{W}_{Ch} - \bar{W}_{ZS}}\right)^{CUR} + \left(\frac{\Pi_c - \Pi_{Ch}}{\Pi_{ZS} - \Pi_{Ch}}\right)^{CUR} = 1$$

The efficiency is modeled using the knowledge of the speed lines shape in the $\lambda - \phi_1$ plane to define suitable base functions for $a(\bar{N}_{c,n})$ and $b(\bar{N}_{c,n})$.

$$\eta_c = \frac{c_p T_{01}\left[\Pi_c^{\frac{\gamma-1}{\gamma}} - 1\right]}{\Delta h_{act}}, \qquad \Delta h_{act} = \left(1 + \frac{c_{21}\rho_{01} D_2^3 \pi \bar{N}_c}{60 \bar{W}_c}\right)\left(b(\bar{N}_{c,n}) - a(\bar{N}_{c,n})\bar{W}_c\right)$$

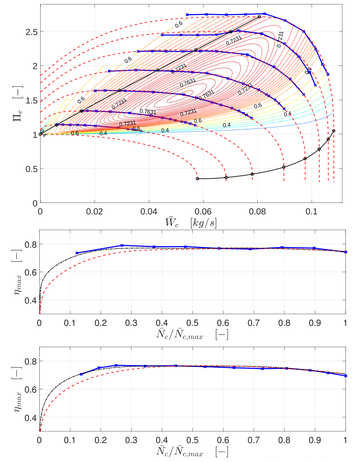
Parameterization with LiU CPgui Package



The parameterization of the model is not trivial because of the asymptotic behavior of the compressor map close to the surge and choke areas as well as the interdependence of the efficiency and mass flow models. A tailored Total Least-Squares (TLS) algorithm is developed to solve the parameterization problem for any automotive compressor map. The algorithm is implemented in a Matlab GUI and released as free software for anyone to use it with any compressor map. Furthermore, a compressor heat transfer correction method is also implemented in the package to help the user analyze and correct the map if necessary.

Model Results

The model errors are below 0.85% in each dimension for uncorrected maps, in particular the fit is better, below 0.78%, when the heat transfer is corrected. This shows that the model is very flexible, since it can cope with the heat corrected maps which have higher efficiency values at the lower speeds, and at the same time it adapts with a similar accuracy to the uncorrected maps.



The model extrapolation to low load is analyzed by parameterizing two special maps measured with almost adiabatic conditions, that have speed lines under 30% of the maximum compressor speed. The modeled efficiency is able to adjust to the high measured values when the compressor speed is low, as would be expected in a compressor measured without heat transfer effects.

Conclusions

- Control-oriented compressor model capable to extrapolate to the low load area.
- 21 parameters, estimated together using standard SAE compressor maps.
- Model errors for more than 230 maps under 1 % with good efficiency extrapolation with and without heat transfer.
- TLS algorithm implemented in a Matlab GUI and openly released as: LiU CPgui.

LINKÖPING UNIVERSITY
DEPT. OF ELECTRICAL ENGINEERING