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.

MARIE CURIE ACTIONS

Energy-SmartOps

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

"Aerodynamic Impact of Fouling in Centrifugal Compressors"

Maria Esperanza Barrera-Medrano (ESR-F)
Mechanical Engineering Department, Thermofluids Division. Imperial College London

Fouling Phenomena

Fouling is the **build-up of material** inside the compressor, normally on the **stationary components.**

Common causes:

- Airborne salt
- Industrial pollution
- Internal oil leaks
- Coal, dust ingested

Fouling produces:

- **Changes** blade shape
- **Increase** in **surface** roughness
- **Distortion** of **flow aerodynamics**

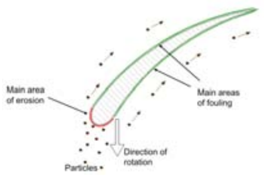

Figure 1. Compressor blade.

Main Consequences

- **Reduction in flow capacity**
- **Reduction in pressure ratio and efficiency**
- **Reduction in surge margin**
- Stage degradation has a **cumulative effect,** making successive stages operate further away from their design point

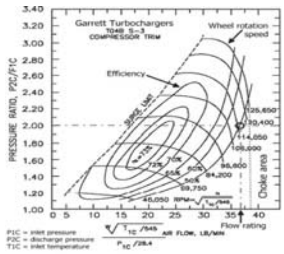

Figure 2. Compressor performance map example.

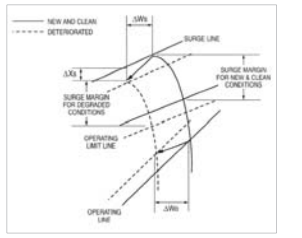

Figure 3. Compressor performance map deterioration.

Research Aim

To construct a 1D, meanline, reduced order model for Centrifugal Compressors under Different Levels of Fouling

This model should allow:

- To convert a clean, standard compressor performance map on to the equivalent map when the compressor operates with different inlet gas conditions.
- To detect if fouling, erosion or other loss mechanisms are occurring in the compressor, as its performance influence.

Methodology Proposed

Compressor performance map generation under different levels of fouling [1].

Normalized method based on four nondimensional parameters at the design point to characterize the compressor performance:

- Flow coefficient, $\boldsymbol{\phi} = {}^{\dot{V}}/_{u_2 D_2^2}$
- Tip-speed Mach number, $\boldsymbol{M} = {}^{u_2}/_{a_1}$
- Work coefficient, $\boldsymbol{\lambda} = {}^{\Delta h}/_{u_2^2}$
- Efficiency, $\boldsymbol{\eta}$

$\dot{V}$ = Volume flow rate (m^3/s)
u_2 = Impeller blade tip speed (m/s)
D_2 = Impeller tip diameter (m)
a_1 = Inlet speed of sound (m/s)
Δh = Specific enthalpy variation (J/Kg)

Goal: To calculate the values of two dependent variables (η, λ) for specific values of independent variables (ϕ, M):

$$\boldsymbol{\eta}, \boldsymbol{\lambda} = \mathrm{f}\,(\boldsymbol{\phi}, \boldsymbol{M})$$

[1] M. Casey, C. Robinson, 2013. "A Method to Estimate the Performance Map of a Centrifugal Compressor Stage". ASME Journal of Turbomachinery, 135, p.021034

Methodology Proposed

- **Variation** of **Efficiency** with **Flow** are based on: $\dfrac{\boldsymbol{\eta}}{\boldsymbol{\eta_p}} = \boldsymbol{f}\left(\boldsymbol{M}, \dfrac{\boldsymbol{\phi}}{\boldsymbol{\phi_C}}\right)$

Flows below the peak efficiency point $(\boldsymbol{\phi} < \boldsymbol{\phi_p})$	Flows above the peak efficiency point $(\boldsymbol{\phi} > \boldsymbol{\phi_p})$
$\dfrac{\eta}{\eta_p} = \left[1 - \left(1 - \dfrac{\phi/\phi_C}{\phi_p/\phi_C}\right)^D\right]^{1/D}$	$\dfrac{\eta}{\eta_p} = (1-G) + G\left[1 - \left(\dfrac{\frac{\phi}{\phi_C} - \frac{\phi_p}{\phi_C}}{1 - \frac{\phi_p}{\phi_C}}\right)^H\right]^{1/H}$

D, G and **H** are parameters that describe the stage characteristics

- **Variation** of **Work Input Coefficient** with **Flow** and **Tip-speed Mach number** based on:

$$\lambda_{Euler} = \frac{c_{u2}}{u_2} = 1 - \frac{c_s}{u_2} + \phi_2 tan\beta_2'$$

$\boldsymbol{\lambda_{Euler}}$ in terms of **Inlet Flow Coefficient**

$$\lambda_{Euler} = 1 - \frac{c_s}{u_2} + \frac{\phi D_2}{b_2 \pi} \frac{tan\beta_2'}{[1 + (\gamma - 1)\gamma_d \lambda M^2]^{\frac{1}{n_d - 1}}}$$

c_{u2} = Abs. velocity circum. comp.(out, m/s)
c_s = Slip velocity (m/s)
ϕ_2 = Impeller outlet flow coefficient
β_2' = Impeller blade back-sweep angle (°)
γ = Isentropic exponent
γ_d = Degree of reaction
n_d = Polytropic exponent, design point
b_2 = Impeller outlet width (m)

Figure 4. MHI Centrifugal Compressor that will be tested.

Future Work

- Experimental quantification of the performance deterioration due to fouling phenomena by experimental tests carried out on a centrifugal compressor.
- Quantification of the performance deterioration due to fouling by a validated performance prediction tool based on the methodology proposed.
- Understanding the impact of fouling and process for the deterioration of performance.
- This will enable energy savings by an estimation of cleaning schedules, replacement and load sharing.

Supervisor: Prof. Ricardo Martinez-Botas
Mechanical Engineering Department, Thermofluids Division.
Imperial College London

Imperial College London

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