A Thermo-Gas-Dynamic Model for the Bifurcation Analysis of Refrigerant-Lubricated Gas Foil Bearing Rotor Systems

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- High-speed rotor supported by gasdynamic lubrication wedge
- Oil-free machinery offers high energy efficiency and low wear
- System optimized by using refrigerant as lubricating fluid

**Refrigerant** R-245fa

\[
\begin{align*}
\text{Cubic Peng–Robinson equation of state (PR EoS)} \\
\text{Reg. PR EoS} \quad \text{by algebraic solution}
\end{align*}
\]

**Non-Ideal Gases**

\[
\begin{align*}
\Delta H_{\text{reg}}(T) & = \Delta H_{\text{reg}}(T_0) + \sum \Delta H_i(T) \\
\Delta S_{\text{reg}}(T) & = \Delta S_{\text{reg}}(T_0) + \sum \Delta S_i(T)
\end{align*}
\]

**Nonlinear ODE system**

\[
\begin{align*}
\dot{\mathbf{r}}(t) & = \mathbf{F}(\mathbf{r}(t), t) \\
\mathbf{r}(0) & = \mathbf{r}_0
\end{align*}
\]

**Simultaneous subproblem solution by means of collective state vector**

\[
\begin{align*}
\mathbf{r} & = \begin{bmatrix} \mathbf{r}_1 & \mathbf{r}_2 & \cdots & \mathbf{r}_n \end{bmatrix}^T
\end{align*}
\]

**Application: Vapor-Compression Refrigeration**

- Fluid film thickness
- Reynolds equation
- Energy equation

\[
\begin{align*}
\dot{H}(r, t) & = 1 - \mathbf{Q}(r, t) - \mathbf{s}(r, t) \\
\mathbf{Q}(r, t) & = \mathbf{Q}(r, t) - \mathbf{s}(r, t)
\end{align*}
\]

**Challenges: Self-Excited Vibrations**

- Stationary operating points tend to become unstable at elevated rotational speeds
- Occurrence of self-excited rotor vibrations with large amplitudes (fluid whirl)
- Vibrations calmed down by deliberately introduced friction

**System Analysis**

- Triangular spring–mass–rod arrangement with superposed elastic beam model
- Elasto-plastic bristle friction

\[
\begin{align*}
\tau_r(t) & = \mathbf{F}(\mathbf{r}(t), t) \\
\mathbf{r}(0) & = \mathbf{r}_0
\end{align*}
\]

**Results and Conclusions**

- Stable stationary operation under two-phase flow conditions
- Detailed investigation of stick–slip transitions in foil contacts
- Bifurcation diagram giving insights into coexisting solutions