PRESENTATION OF COMPUTER CODE SPIRALI FOR INCOMPRESSIBLE, TURBULENT, 
PLANE AND SPIRAL GROOVED CYLINDRICAL AND FACE SEALS 

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OVERALL CAPABILITIES OF PROGRAM  

- Computes rotordynamic coefficients, flow and power loss for cylindrical and face seals  
- Treats turbulent and laminar, Couette and Poiseuille dominated flows  
- Fluid inertia effects included  
- Rotordynamic coefficients in 3 (face) or 4 (cylindrical) degrees of freedom  
- Includes effects of spiral grooves  
- User definable transverse film geometry including circular steps and grooves  
- Independent user definable friction factor models for rotor and stator  
- User definable loss coefficients for sudden expansions and contractions
Coordinate system for seal analysis.
Figure 1: Diagram showing high pressure at the top and low pressure at the bottom. The figure illustrates the principle of a face seal with inward pumping grooves.

- High pressure
- Low pressure
- Rotor motion
- Groove land
- Region 2 (grooved)
- Region 1 (ungrooved)

Face seal stator with inward pumping grooves
ASSUMPTIONS

• Incompressible and isothermal flow

• Film thickness small in comparison with other geometric parameters

• Bulk flow turbulence model

• Loss coefficients used to treat inertia effects at film discontinuities

• Axisymmetric primary flow with small perturbations theory used for transient and circumferential effects

• Narrow groove theory used for spiral grooves with inertia treated globally

• No cavitation

Parameters for characterizing quadratic film variation.
BULK FLOW EQUATIONS FOR TURBULENT FLOW

integrated momentum

\[ \rho_h \left( \frac{\partial u}{\partial t} + v \frac{\partial u}{\partial s} + u \frac{\partial u}{\partial \theta} + \frac{uv_l}{r} \right) = -\frac{h}{r} \frac{\partial p}{\partial \theta} + (\tau_b - \tau_a) \cdot \mathbf{I} \]

\[ \rho_h \left( \frac{\partial v}{\partial t} + v \frac{\partial v}{\partial s} + u \frac{\partial v}{\partial \theta} + \frac{u^2 l}{r} \right) = -\frac{h}{r} \frac{\partial p}{\partial \theta} + (\tau_b - \tau_a) \cdot \mathbf{J} \]

integrated continuity

\[ \frac{1}{r} \frac{\partial}{\partial s} \left( rvh \right) + \frac{1}{r} \frac{\partial}{\partial \theta} \left( uh \right) + \frac{\partial h}{\partial t} = 0 \]

Velocities and forces on a differential element in the \( \theta \) direction.
SHEAR STRESS AND FRICTION FACTOR RELATIONSHIPS

\[ \tau_a = \frac{1}{2} \rho |\bar{u} - \bar{u}_a| f_a\left( \frac{2h \rho |\bar{u} - \bar{u}_a|}{\mu} \right)(\bar{u} - \bar{u}_a) = \frac{1}{4} h R_a R_a f_a(R_a) (\bar{u} - \bar{u}_a), \]

\[ \tau_b = -\frac{1}{2} \rho |\bar{u} - \bar{u}_b| f_b\left( \frac{2h \rho |\bar{u} - \bar{u}_b|}{\mu} \right)(\bar{u} - \bar{u}_b) = -\frac{1}{4} h R_b R_b f_b(R_b) (\bar{u} - \bar{u}_b), \]

\[ R_a = 2h |\bar{u} - \bar{u}_a| \rho / \mu, \quad R_b = 2h |\bar{u} - \bar{u}_b| \rho / \mu. \]

\[ f_a(R_a) = n_o R_a^{m_o}, \quad f_b(R_b) = n_o R_b^{m_o}, \quad \text{Hirs - Blasius} \]

\[ f_{a,b} = 0.001375 \left[ 1 + \left( \frac{10^4 K_{a,b}}{h} + \frac{10^6}{R_{a,b}} \right)^{\frac{1}{3}} \right], \quad \text{Moody} \]

\[ p_j, \nu_j, h - \Delta h \quad \begin{array}{c} p, \nu, h \end{array} \quad \begin{array}{c} -\Delta h \end{array} \quad \text{s flow direction} \]

\[ p_j + \frac{1}{2} \rho v_j^2 = p + \frac{1}{2} \rho v^2 (1 + \xi) \quad \text{at} \quad s = s_j. \]

\[ \xi = \begin{cases} \zeta(R, \bar{h}, \bar{v}) & , \Delta \bar{h} < 0 \text{ (contraction)} \\ \left( 1 - \frac{\bar{h}}{\bar{h} - \Delta \bar{h}} \right)^2 & , \Delta \bar{h} \geq 0 \text{ (expansion)} \end{cases} \]
Schematic of spiral groove parameters, global and local pressures.

Flow diagram for overall logic used in computations
(CASE 1) Cylindrical seal with grooves, laminar, no press, grad.

&INPUTS
TITLE = 'Cylindrical seal with grooves, laminar, no press, grad.'
IFACE = 0
ISIUN = 0
IGROT = 0
NOI = 2
IFLOW = 1
RO = 1.0000E+00
EL = 5.0000E-01
C = 1.0000E-03
RPM = 5.0000E+04
RPMO = 2.5000E+04
RPMD = 0.0000E+00
PLEG = 0.0000E+00
PRIG = 0.0000E+00
FZD = 0.0000E+00
VISC = 3.0000E-08
DENS = 0.0000E+00
EMA = -2.5000E-01
ENA = 7.9100E-02
EMB = -2.5000E-01
ENB = 7.9100E-02
HTAP = 0.0000E+00
HBRL = 0.0000E+00
TOLH = 1.0000E-04
TOLV = 1.0000E-05
DUT = 1.0000E-06
IHOME = 0
NITH = 10
NITV = 30
NREG = 2
NRSUB = 50
ELFR = 5.0000E-01
ALPI = 5.0000E-01
BETI = 2.5000E+01
DELT = 2.0000E-03
ZET = 0.0000E+00

Cylindrical seal, Inertia neglected

Length, Diameter, Clearance = 5.0000E-01, 2.0000E+00, 1.0000E-03 (in)
Rotor, Swirl and Dist. Speeds = 5.0000E+04, 2.5000E+04, 0.0000E+00 (rpm)
Pressure at start, end Axial Boundaries = 0.0000E+00, 0.0000E+00 (psi)
Viscosity = 3.0000E-08 (psi-sec), Density = 0.0000E+00 (lb-sec/in^4)
Error Code = 0, Iterations in Primary Flow = 2
Flow = 1.1506E+00 (in^3/sec)
Torque = 4.3909E-01 (in-lb), Film Power Loss = 3.4835E-01 (hp)
Axial Reynolds Number = 0.0000E+00
Circ. Reynolds Numbers for Rotor at Seal Ends = 0.0000E+00, 0.0000E+00

Dynamic Coefficients (Force Unit / Disp. Unit)

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<th>DISP.</th>
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<th>y (IN)</th>
<th>phi (RAD)</th>
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Comparison with results published by D. W. Childs (1983)

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<td>( A_{xx} ) (kg)</td>
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DEFINITIONS OF COEFFICIENTS

Overall Seal Discharge Coefficient

\[
C_d = \frac{\Delta P}{\frac{1}{2} \rho V^2}
\]

Radial Force Coefficient

\[-f_r = K + c_0 \omega - M_0 \omega^2 = K_{ef} - M_{ef} \omega^2\]

Tangential Force Coefficient

\[-f_\theta = C_\omega - k = C_{ef} \omega\]
TITLE = 'Childs, Nolan & Kilgore Stator 1, 25% swirl, 1000 RPM'
IFACE = 0 ISIUN = 1
IGROT = 0 NOI = 0 IFLOW = 0
RO = 5.0800E-02 EL = 5.0800E-02 C = 3.5600E-04
RPM = 1.0000E+03 RPMO = 2.5000E+02 RPMD = 0.0000E+00
PLEG = 0.25000E+06 PRIG = 0.00000E+00 FZD = 0.00000E+00
VISC = 1.5400E-04 DENS = 1.5700E+03
EMA = -2.5000E-01 ENA = 7.9100E-02
EMB = -2.5000E-01 ENB = 7.9100E-02
HTAP = 0.00000E+00 HBRL = 0.00000E+00
TOLH = 1.0000E-04 TOLV = 1.0000E-05 DUT = 1.0000E-06
IHOME = 0 NITH = 10 NITV = 30
NREG = 19
NRSUB = 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
ALPI = 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1.
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ZET = 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

Dimensionless axial flow rates

RPM

Exp.

1000
4000
7200

ΔP (bar)
Extraction of effective stiffness and added mass

Tangential force coefficients
Radial force coefficients

Comparison between $K$ and $K_{el}$ at various rotating speeds
Comparison between $C - k/\omega$ and $C_{\text{ef}}$ at various rotating speeds

Effect of circumferential inertia on pressure disturbance
Effect of local pressure discontinuities on predicted axial flow rates