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TURBOMACHINERY LABORATORY TEXAS A&M UNIVERSITY RESEARCH PROGRESS ON ANNULAR GAS SEALS

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Dara W. Childs
Turbomachinery Laboratory
Texas A&M University
College Station, Texas

ACCOMPLISHMENTS

* Tested 3 helically-grooved seals and compared results to MTI code SPIRALG
* Tested a smooth annular seal at 6 eccentricity ratios (0 → 0.5)
* Transferred test apparatus to a new facility. Testing should resume in December 1993.

REMAINING TESTS

* Test 2 long honeycomb seals; L/D = 1/2, 1
* Test a short labyrinth or honeycomb seal with and without a reduced inlet cavity.

C-4

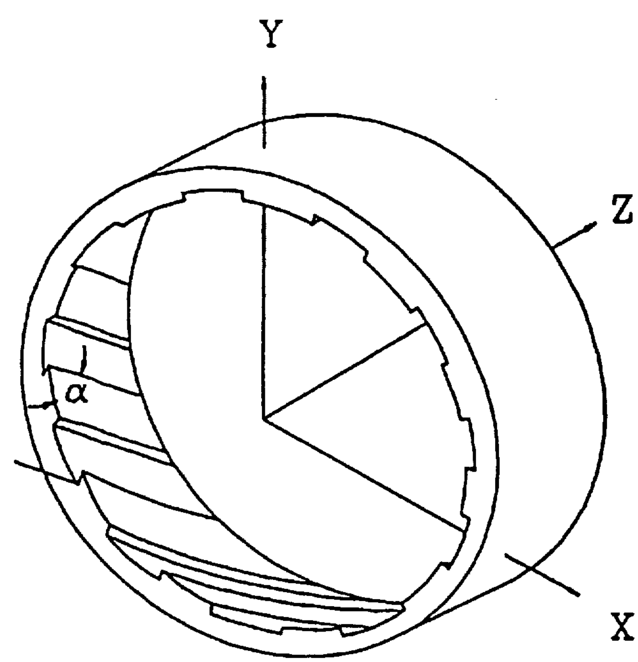
INTRODUCTION

HELICALLY GROOVED ANNULAR GAS SEAL

- Reduce leakage from high to low pressure side

- Cylindrical seal with groove pattern along face

- α, angle between direction of grooves and rotational velocity



Helically grooved seal

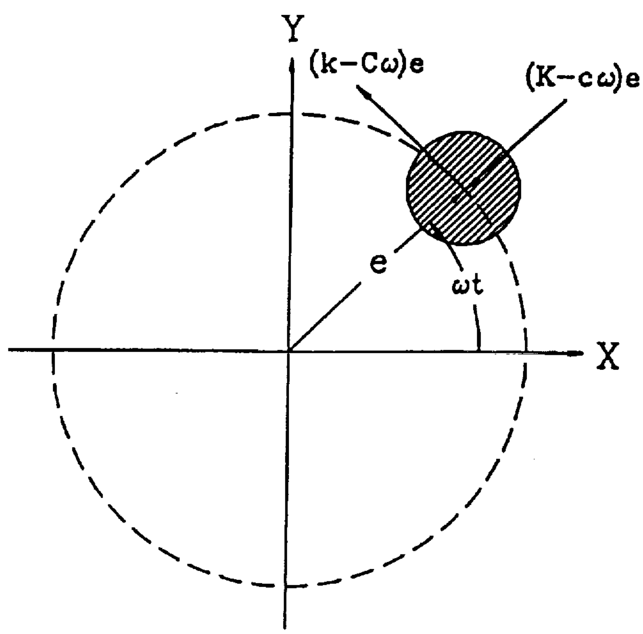
INTRODUCTION

ANNULAR GAS SEAL MODEL

- Annular gas seal exhibiting small motion about a centered position

$$-\begin{Bmatrix} F_x \\ F_y \end{Bmatrix} = \begin{bmatrix} K & k \\ -k & K \end{bmatrix} \begin{Bmatrix} X \\ Y \end{Bmatrix} + \begin{bmatrix} C & c \\ -c & C \end{bmatrix} \begin{Bmatrix} \dot{X} \\ \dot{Y} \end{Bmatrix}$$

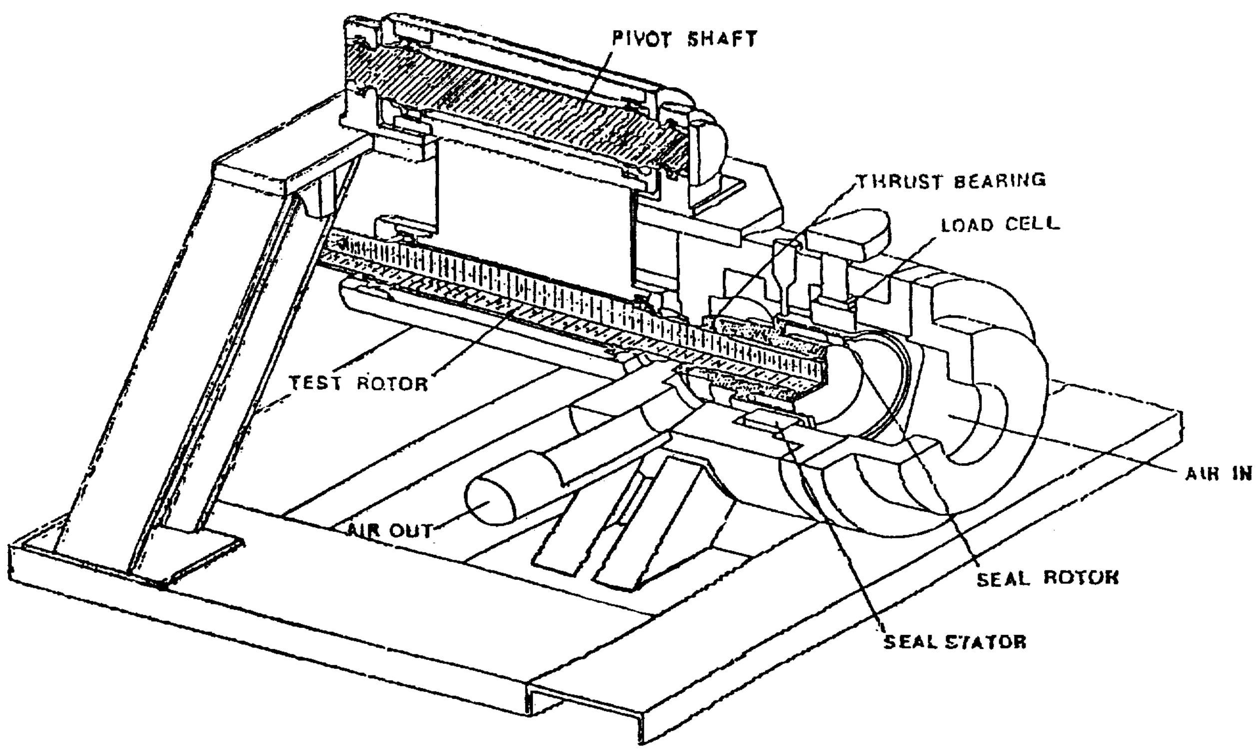
- Rotordynamic force components acting on a rotor



Forces on a whirling rotor

TEST APPARATUS

- Rotor shaft / Pivot shaft arrangement
- Horizontal excitation through shaker head arrangement
- Load cell / Accelerometer arrangement
- Cross sectional view



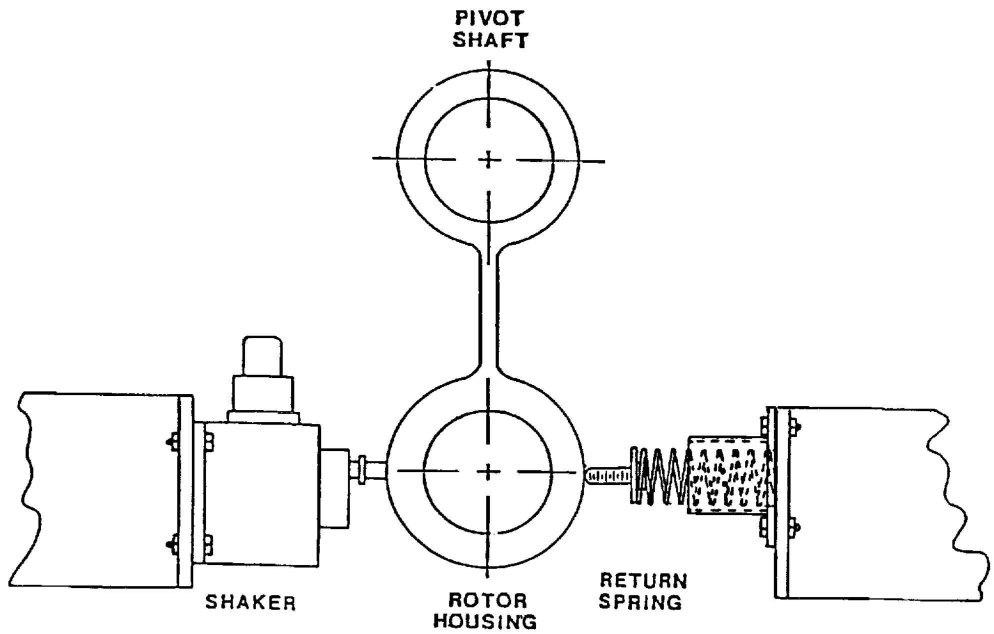
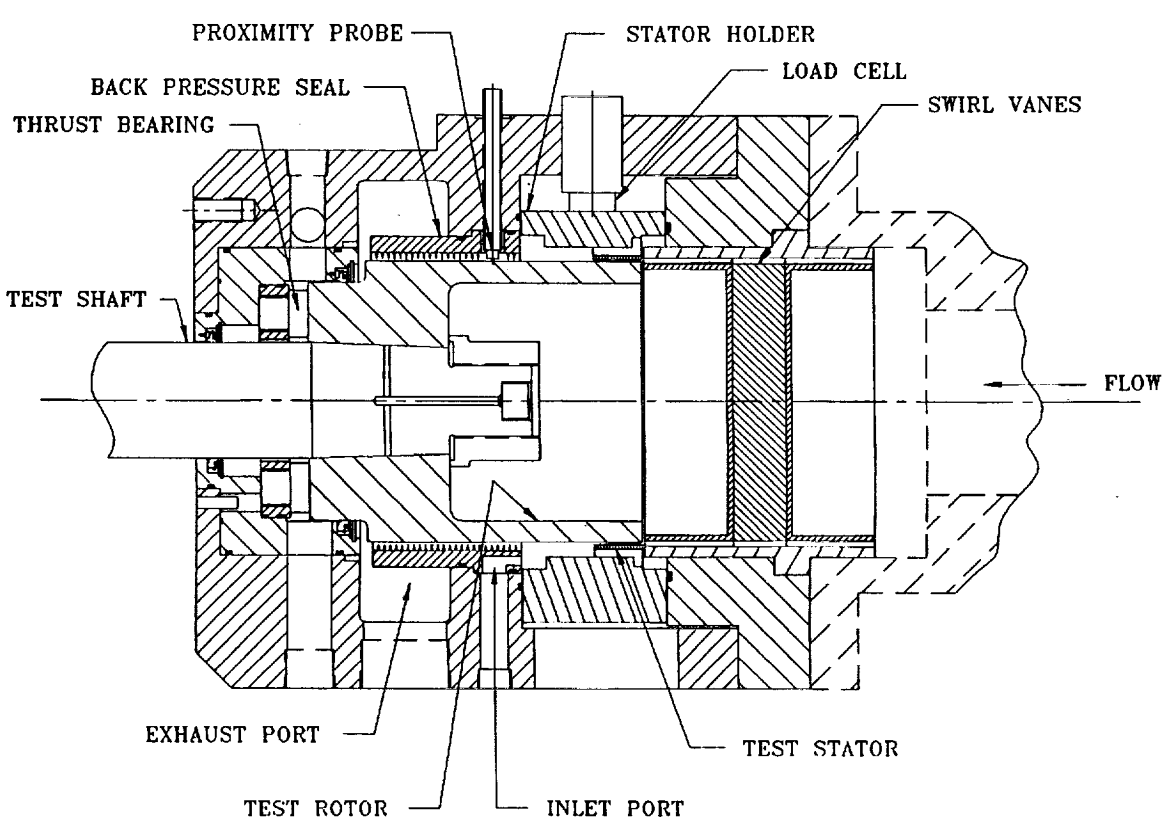


Figure 4. Excitation system.



TEST PARAMETERS

TEST POINTS

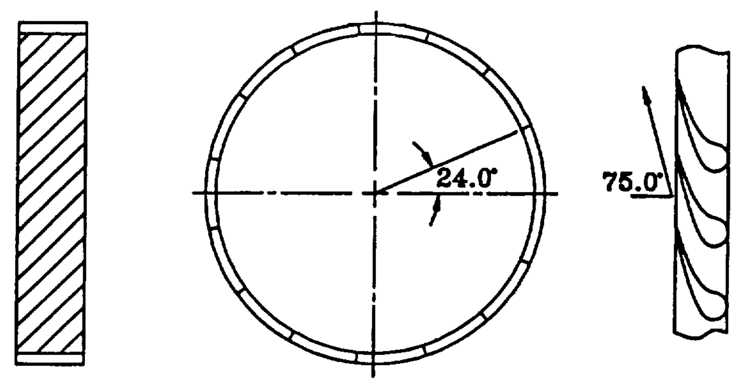
Rotor Speed (rpm) ω	Inlet Pressure (bar) P_r	Pressure Ratio (-) P_{ra}	Inlet Preswirl in the Direction of Rotor Rotation
1 - 5000	1 - 7.90	1 - 0.67	1 - None
2 - 12000	2 - 13.1	2 - 0.56	2 - Intermediate
3 - 16000		3 - 0.50	3 - High
		4 - 0.45	

- 100 Hp electric motor with belt drive and pulley system
- Only two inlet pressures obtainable
- Pressure ratio controlled through back pressure seal and exhaust ports

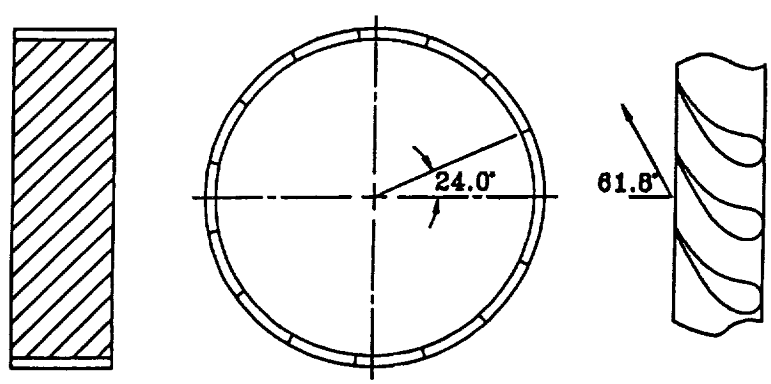
TEST PARAMETERS

- Preswirl guide vanes

- Intermediate swirl provides half exit tangential velocity as maximum swirl



MAXIMUM SWIRL VANES EXIT ANGLE



INTERMEDIATE SWIRL VANES EXIT ANGLE

- Exit velocity / Inlet tangential velocity

$$V_{EX} = \frac{\dot{Q}}{N_B\, A_{EX}}$$

$$V_{\theta 0} = V_{EX} SIN\beta$$

EXPERIMENTAL RESULTS

- Direct stiffness
- Cross-coupled stiffness
- Direct damping
- Whirl frequency ratio
- Leakage

- Uncertainty analysis using Kline-McClinktock

EXPERIMENTAL RESULTS

LEAKAGE CHARACTERISTICS

- Mass flow rate determined using turbine flow meter, temperature and pressure measurements
- Flow coefficient determined

$$\lambda = \frac{\dfrac{\dot{m}}{2\pi R_0}}{C_r\sqrt{\dfrac{P_i^2 - P_e^2}{R_g T}}}$$

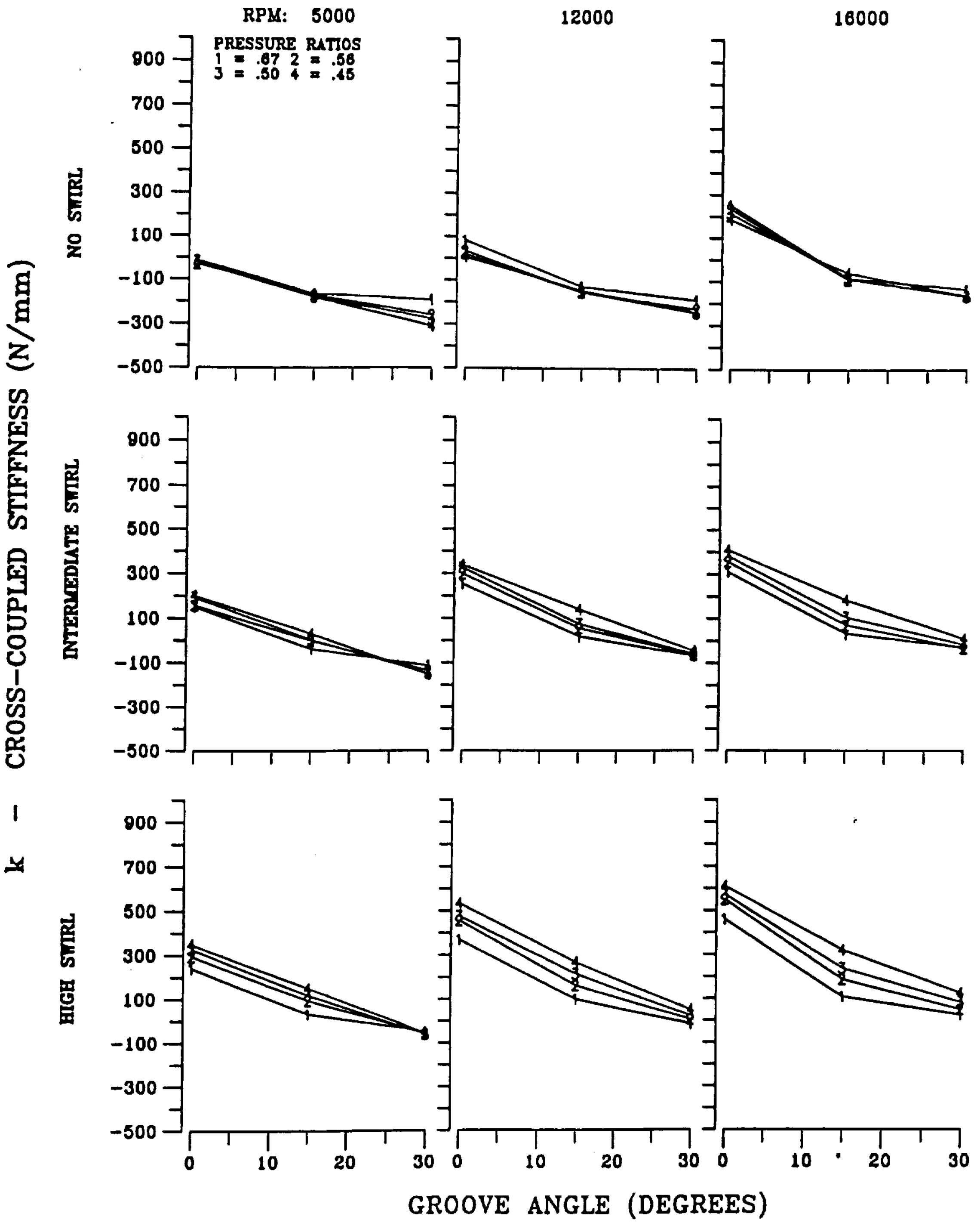
GAS SEAL THEORY

- Analysis based on Smalley (1972)

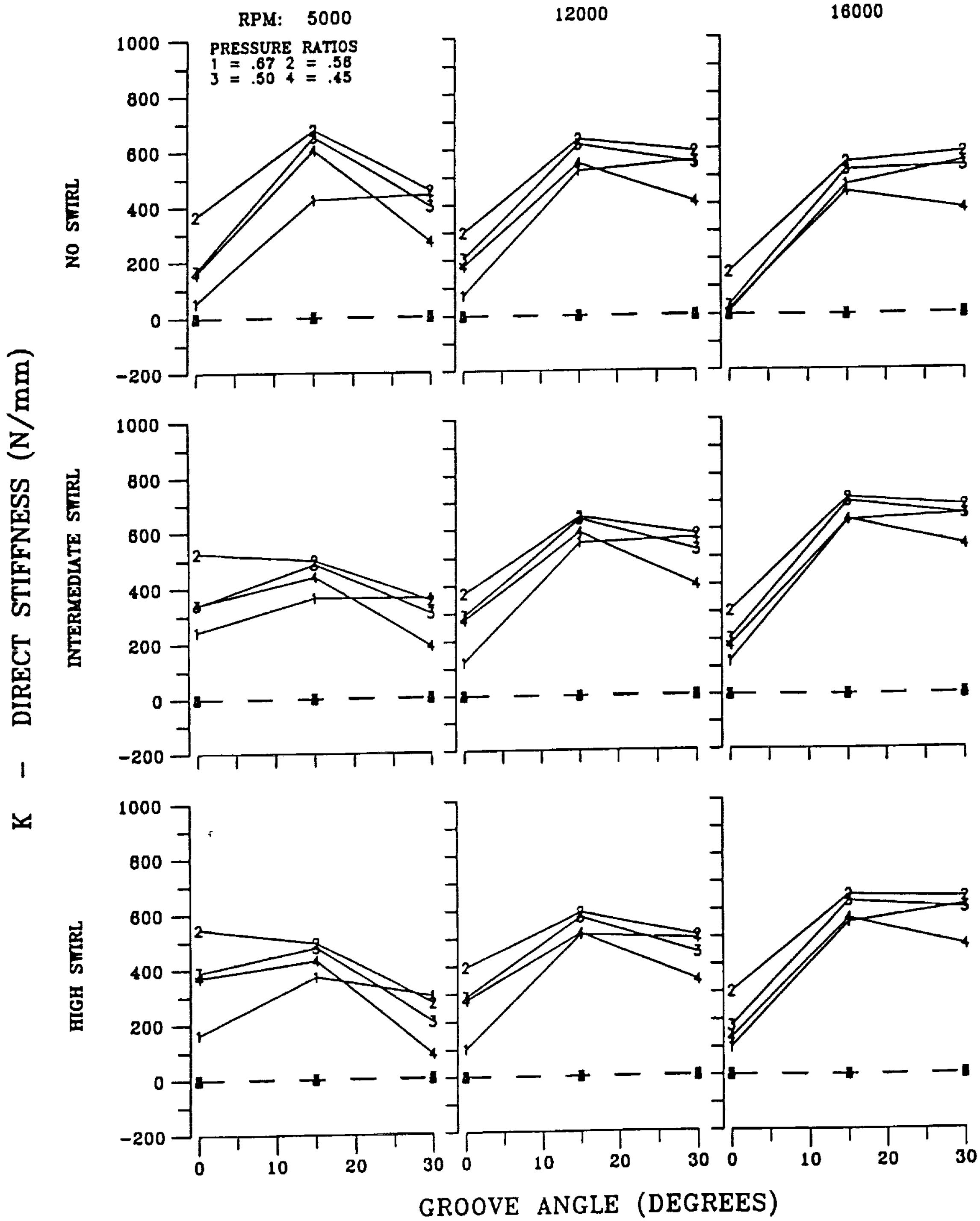
- Theory
  - Compressible form of Reynold's equation
  - Narrow groove theory with pressure distribution

- Major assumptions
  - Laminar flow
  - No inertial effects
  - Large number of grooves
  - Ideal, adiabatic gas

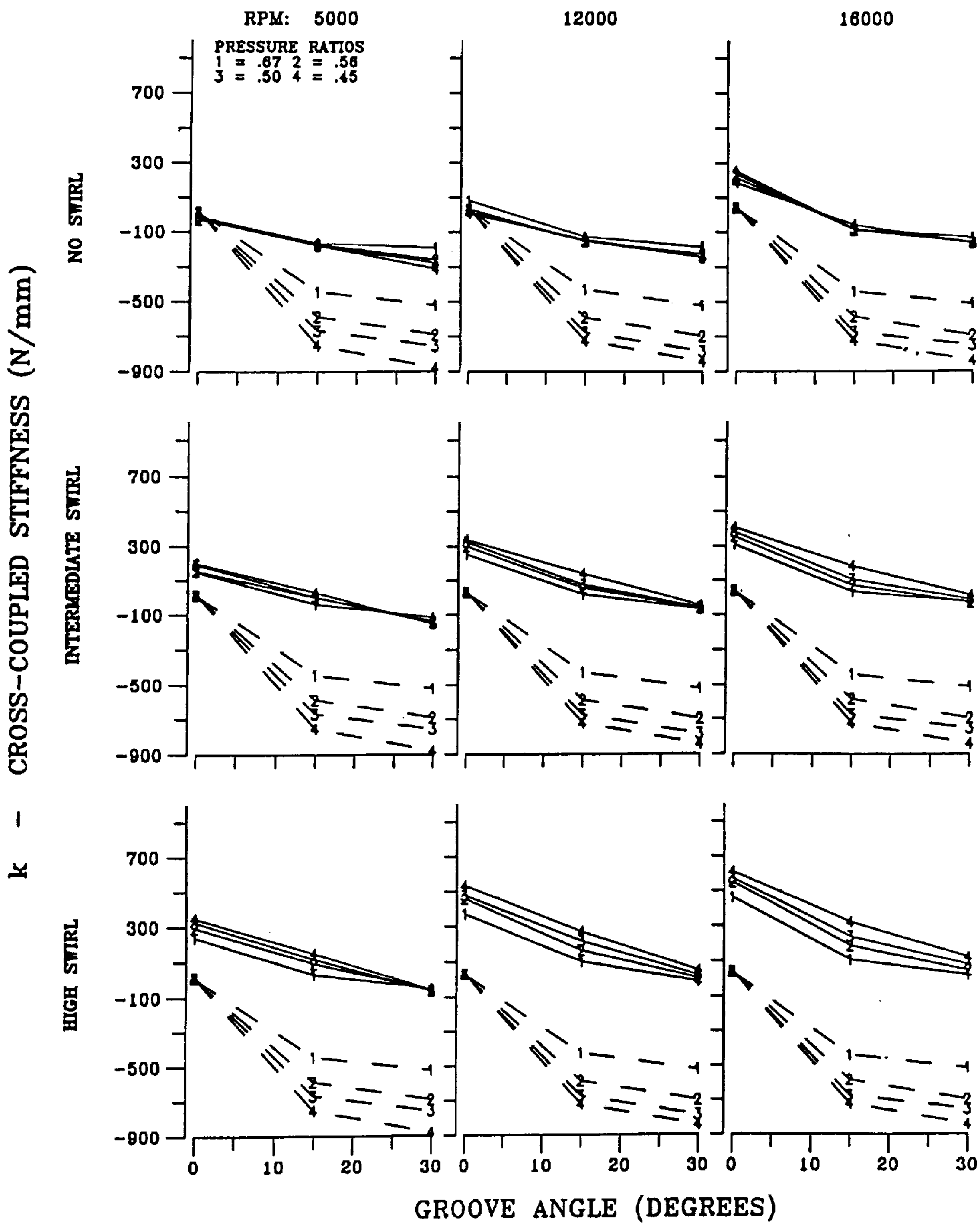
- Major SPIRALG inputs
  - Seal geometry
  - Shaft speed
  - Inlet and exit pressure
  - Viscosity of working fluid
  - Groove angle
  - User specifications



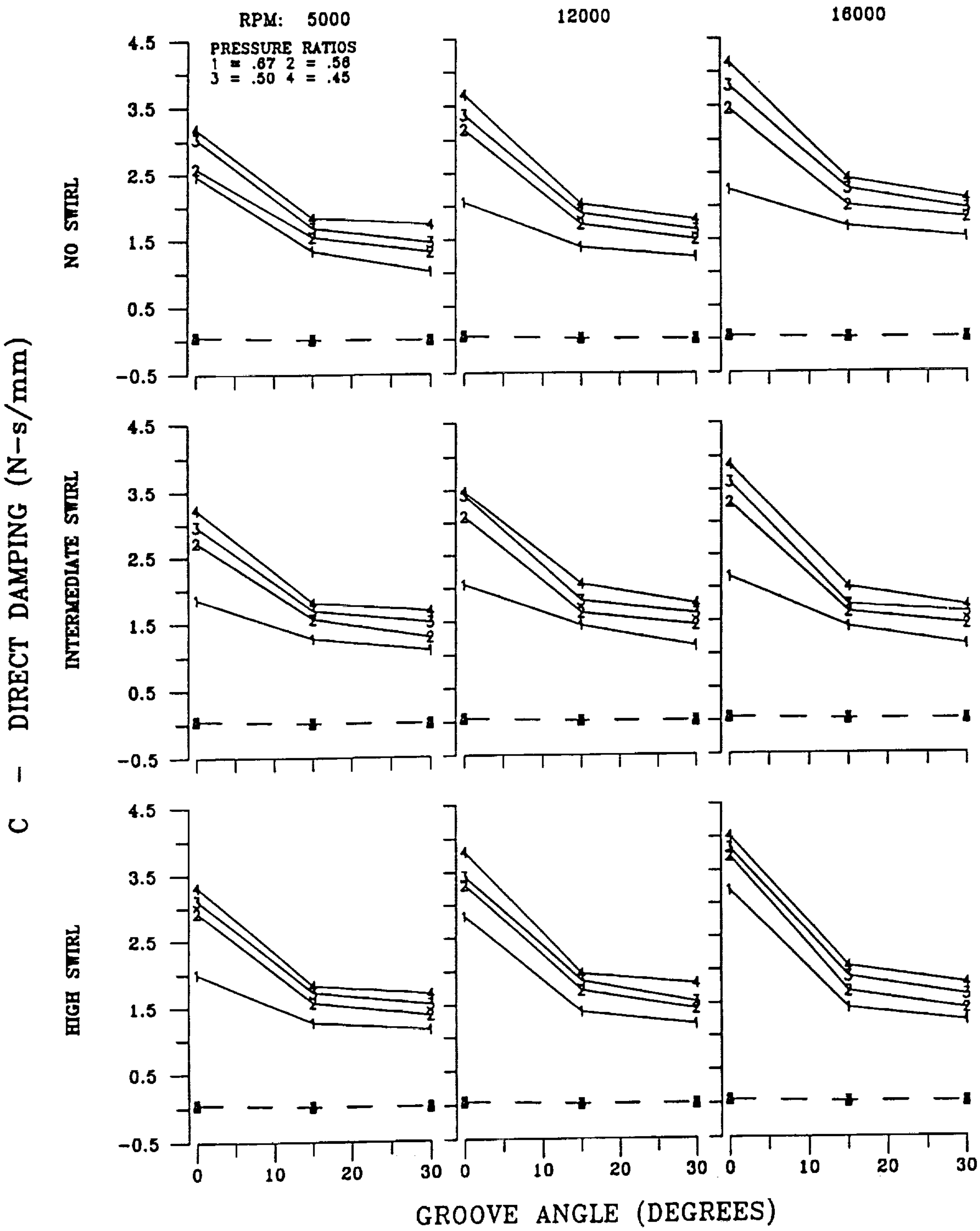
Cross-coupled stiffness, k, as a function of groove angle for C_r=0.229 and P_r=7.9 bar



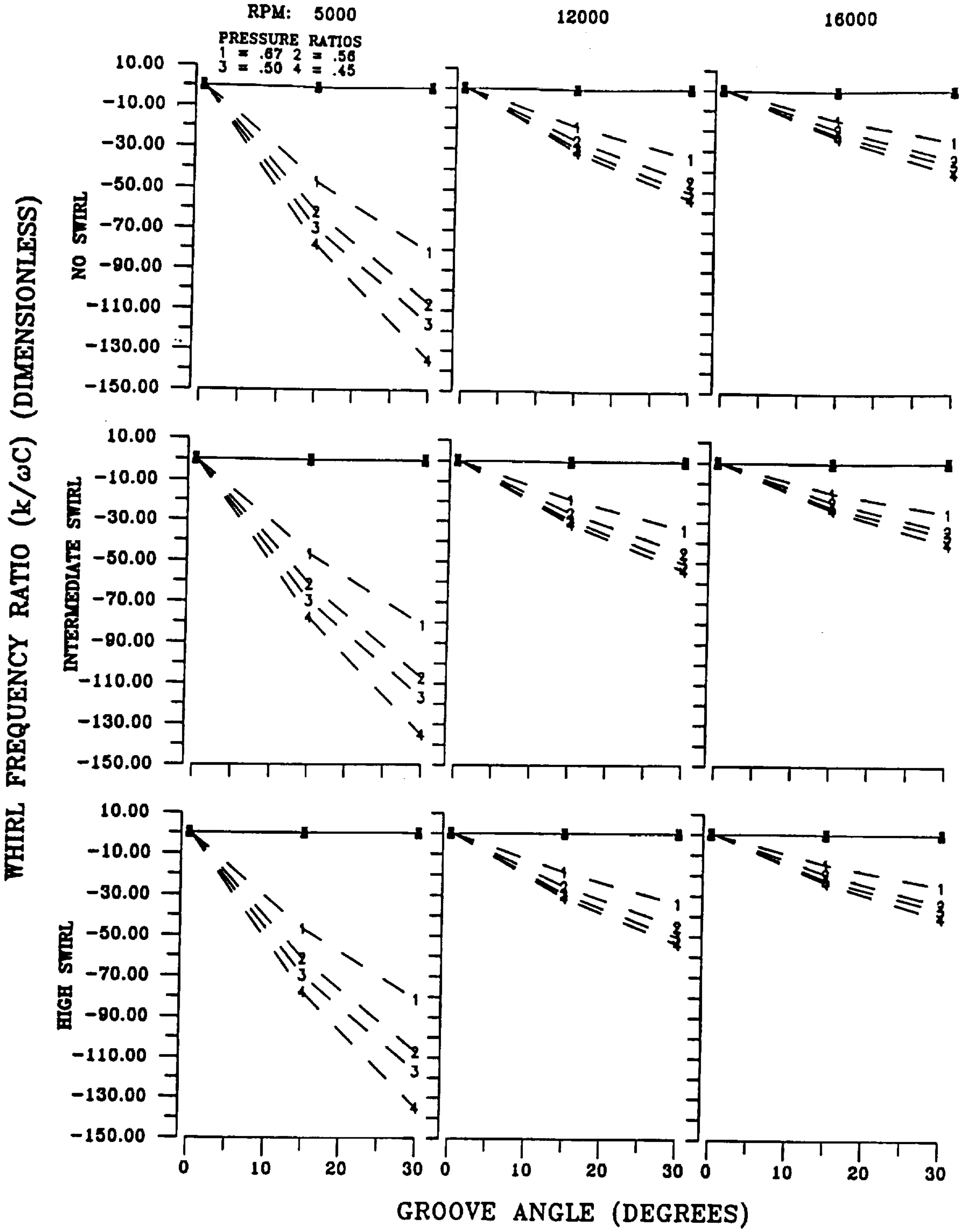
Experimental (solid) versus theoretical (dashed) results for direct stiffness, K, as a function of groove angle for C_r=0.305 mm and P_r=7.9 bar



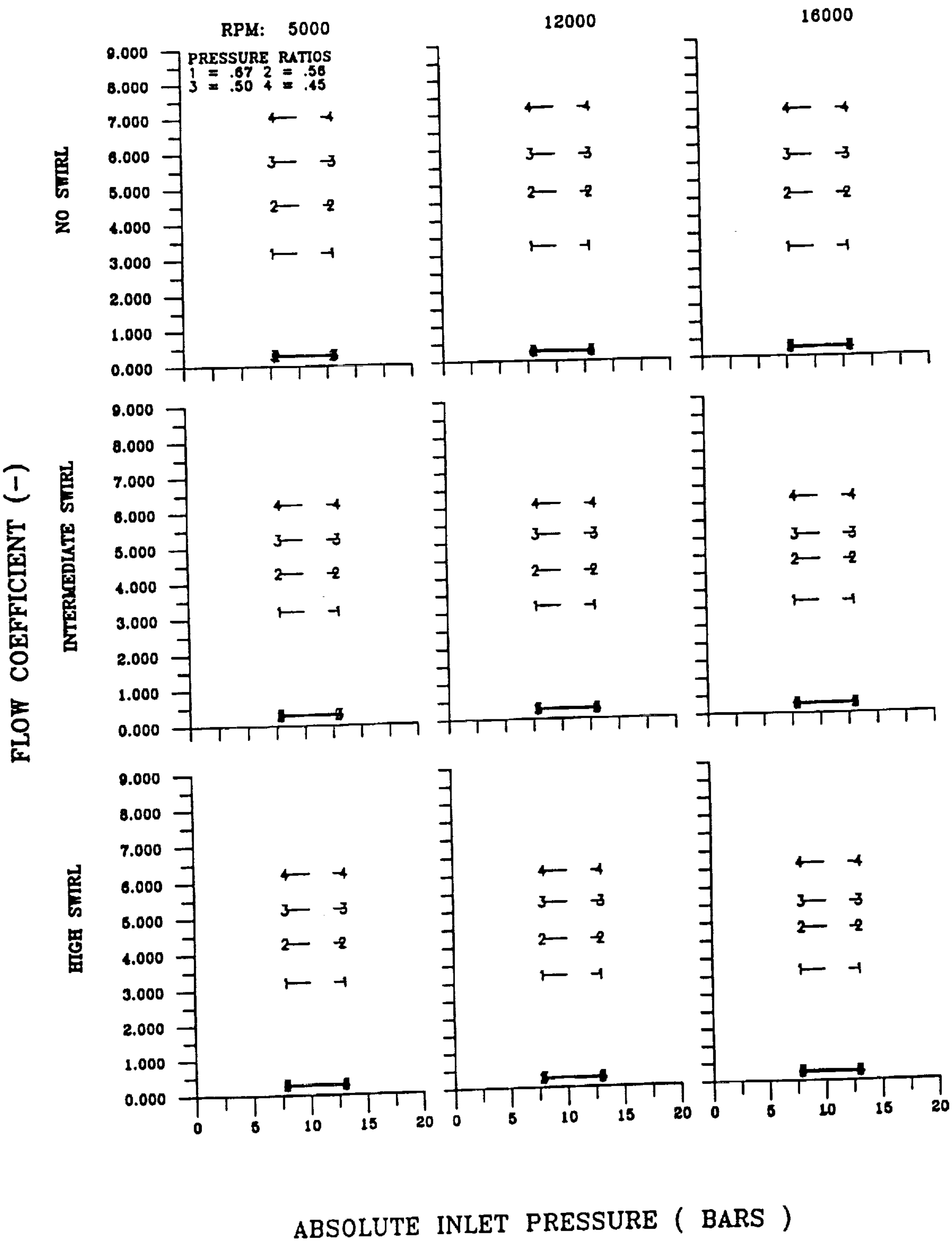
Experimental (solid) versus theoretical (dashed) results for cross-coupled stiffness, k, as a function of groove angle for C_r=0.229 mm and P_r=7.9 bar



Experimental (solid) versus theoretical (dashed) results for direct damping, C, as a function of groove angle for C_r=0.229 mm and P_r=7.9 bar



Experimental (solid) versus theoretical (dashed) results for whirl frequency ratio as a function of groove angle for C_r=0.229 mm and P_r=7.9 bar



Experimental (solid) versus theoretical (dashed) results for flow coefficient as a function of absolute inlet pressure for $\alpha=15^{\circ}$ and $C_r=0.305$ mm

CONCLUSIONS

* Helical-grooved seals provide a substantial reduction in cross-coupled stiffness coefficients. Negative k_{xy} values are obtained for no-swirl or low swirl cases.

* SPIRALG is completely unsuitable for the type of seal tested; namely, turbulent flow, wide grooves and lands, etc.

* A good analysis code is needed to guide the design of helically-grooved annular seals including groove and smooth sections.