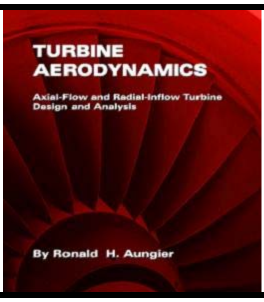
**TURBOMACHINERY
AERODYNAMICS
CONSULTING**

Industrial Compressor & Turbine Design, Performance Analysis, Application and Troubleshooting



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Instructions: This input data form supplies the geometry required for an axial-flow turbine aerodynamic performance analysis using program *AxTurb*. For multistage turbines, some sections will need to be supplied more than once.

Reference: Aungier, R. H., ***Turbine Aerodynamics: Axial-Flow and Radial-Inflow Turbine Design and Analysis*** (ASME Press, New York, 2006).

Program *AxTurb* considers two basic turbine stage configurations: diaphragm-disk or drum-rotor styles as shown on figures 1 and 2. A stage generally consists of a nozzle followed by a rotor, but special provision is available to consider a four-row Curtis stage. In that case, the third row is designated as a reversing row rather than as a nozzle. The analysis is conducted the same way in either case, but the performance of the four-row stage is summarized separately for purpose of evaluation.

The major difference in the input data required for the two types of construction is the blade row seal geometry required. The diaphragm disk style also requires definition of the disk axial gaps as well as the disk and shaft radii. It may include balance holes and disk seals as well. Reversing rows may be modeled as a diaphragm-disk style or with axial gap seals as shown on figure 3. Blades may be shrouded or unshrouded, although with diaphragm-disk construction, nozzles and reversing rows are really "shrouded" by definition.

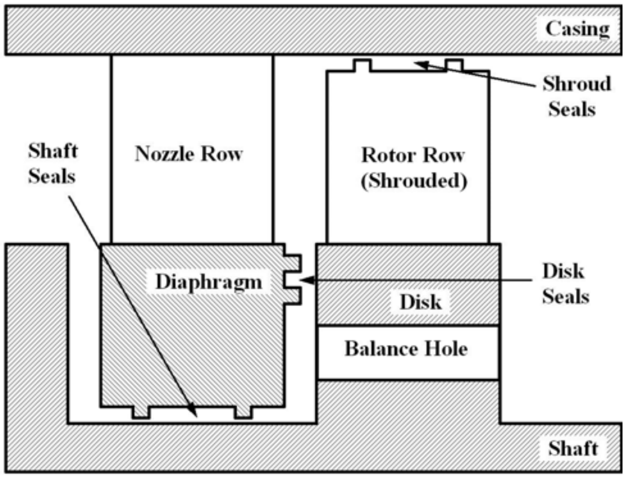

Figure 1: Diaphragm-Disk Construction

Program *AxTurb* can analyze single-stage and multistage turbines. Provision is made for an optional shaft seal downstream of the turbine. When it is to be included, the temperature and pressure downstream of the seal and the seal geometry must be supplied. In the case of the diaphragm-disk construction, consideration of the shaft seal of the first stage diaphragm (or inlet guide vane) is also optional and requires specification of the upstream pressure and temperature for seal leakage to be considered.

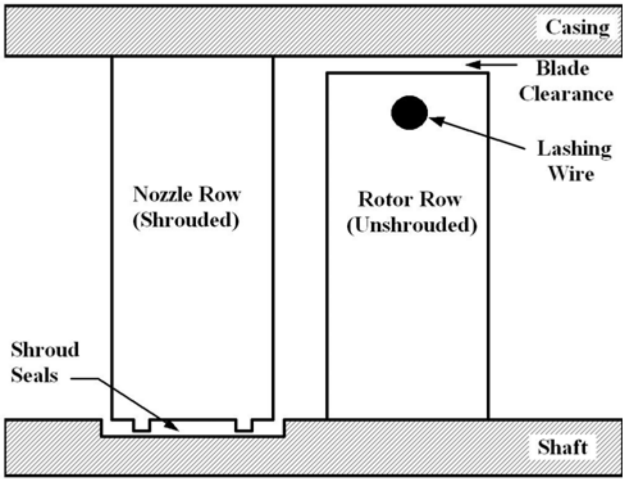

Figure 2: Drum-Rotor Construction

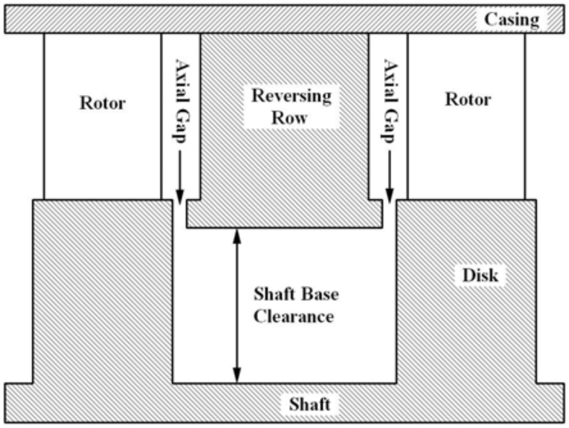

Figure 3: Reversing Row with Axial Gap Seals

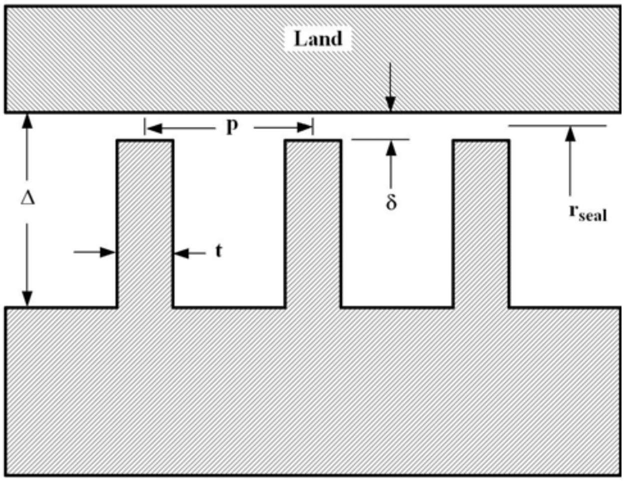

Figure 4: labyrinth Seal Geometry

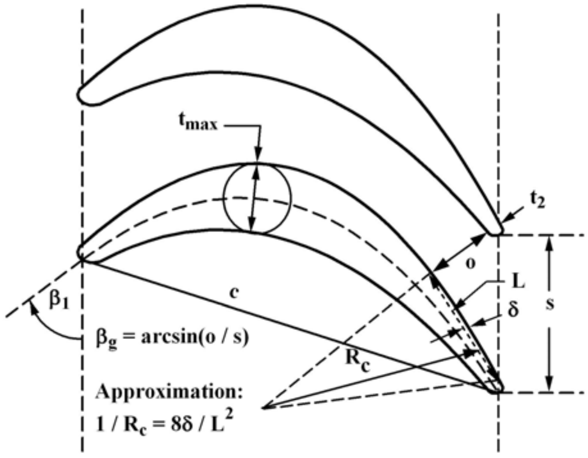

Figure 5: Blade Section Geometry Nomenclature

The basic components recognized by the program are vaneless passages, nozzle rows, rotor rows, reversing rows and guide vanes. The last component simply allows for stationary vanes that are not included in the logical definition of a stage. Exhaust diffusers are not analyzed specifically, but an exhaust loss coefficient can be included to account for a diffuser's influence on performance. An exhaust loss does not affect the analysis directly. Rather, it identifies the fraction of the discharge velocity pressure ($P_{total} – P_{static}$) that is lost in the diffuser to arrive at a turbine discharge pressure and the efficiency associated with it. A turbine performance analysis is conducted for either an assigned mass flow rate (applicable only if no blade rows are choked) or an assigned discharge static pressure. In the latter case, the discharge static pressure is associated with the last computing station in the turbine, i.e., it is not influenced by an assigned exhaust loss. In other words, an exhaust loss coefficient will result in an estimate of the influence of an exhaust diffuser for the conditions analyzed, but it is not used to define the operating conditions that are analyzed. The program also accepts a specification for the total pressure ratio across an inlet governor valve (specify 1.0 if no inlet governor valve is to be considered).

Figure 4 illustrates the basic seal geometry employed for shrouded blades and the turbine exhaust-end seal. The fin thickness, t, pitch, p, clearance, δ, and gap radius, r, are required as well as the number of fins. The base clearance, Δ, is also required. This is required to compute the windage loss for rotor rows. In the case of no seal fins, it also is used to compute the leakage flow. In the case of the vertical disk seals (figure 1), the radii before and after the seal are specified and the program will calculate the seal pitch.

Figure 5 illustrates the blade-section geometry to be supplied for the various blade rows in the turbine. Program *AxTurb* is a hub-to-shroud type analysis, which requires blade geometry at a series of radii sufficient to cover the range from hub to shroud and to provide for reasonable accuracy for interpolation of the data for any radius in that range. Typically, data for about five constant-radius sections is sufficient. The data required are: blade inlet camberline angle, β_1, the blade gauging angle, β_g, the chord, c, the maximum thickness, t_{max}, the trailing edge thickness, t_2, and the suction surface curvature, $1 / R_C$, downstream of the throat, where R_C is the surface radius of curvature. Figure 5 defines β_g and provides an approximation for $1 / R_C$ that is sometimes useful.

Partial admission turbines require specification of the fractional arc of admission (i.e., the total active arc) and the number of separate active arcs comprising the total active for all stationary blade rows. In some partial admission applications, a portion of the rotor blades are shielded on the downstream side to prevent recirculation of flow into the inactive blade passages. This is specified as a fractional shielding relative to the total 360-degree arc).

Sections I through IX summarize the input geometry specifications required for a performance analysis with program *AxTurb*. Supply specifications for the components applicable to your case only. For multistage turbines copy as many blade row specification forms as you need to supply geometry for all blade rows.

I. Specify The Units Used For These Specifications.

Length: ______________ Temperature: ______________ Pressure: ______________

II. Basic Turbine Specifications:

These specifications permit including an inlet control valve pressure drop and an exhaust loss coefficient to permit an estimate of an exhaust diffuser influence on overall performance. Omit these specifications if not needed.

Turbine Inlet Governor Valve Total Pressure Ratio: ------ ____________

Turbine Exhaust Loss Coefficient ----------------------- ____________

III. Turbine Upstream Seal Leakage (Diaphragm-Disk Construction Only):

Check Option: ☐ Ignore Seal Leakage

☐ Use Computed Data At First Station As Seal Upstream Conditions

☐ Specify Seal Upstream Pressure & Temperature

Upstream Pressure: ------ ______________

Upstream Temperature: --- ______________

IV. Turbine Downstream (Exhaust Seal) Leakage

Check Option: ☐ Ignore Seal Leakage

☐ Use Following Exhaust Seal Specifications:

Downstream Pressure: ------- ____________

Downstream Temperature: ---- ____________

Seal Clearance: ------------ ____________

Number of Seal Fins: ------- ____________

Seal Pitch: ---------------- ____________

Seal Point Thickness: ------ ____________

Seal Radius: --------------- ____________

V. Turbine Computing Stations And End-Wall Geometry

Specify the end-wall geometry for all computing stations in the following table (copy it if you need more stations than the table provides). Stations should be specified before and after all blade rows to provide accurate flow data into and out of the blade row (i.e., two stations between blade rows are recommended). Additional stations can be specified as considered appropriate. However, there is little benefit from specifying more than one station upstream of the first blade row nor more than one station after the last blade row. The analysis at stations with no blade row upstream is totally inviscid flow analysis, which has virtually no effect on performance unless the station is immediately upstream of a blade row. Specify the blade row type that is upstream of each station. Choices are; None, Nozzle, Rotor, Reversing Row, or Guide Vane. Geometry data required are the hub axial coordinate, Z_H, hub radius, R_H, shroud axial coordinate, Z_S, and shroud radius, R_S (the origin for the axial coordinates is arbitrary). The coordinates define quasi-normals (lines approximately normal to the two end-walls. Usually, simple radial lines are sufficient ($Z_H = Z_S$), but more general orientation can be used for highly curved end-walls, etc.

For multistage turbines, the specific blade row data (sections VI through IX) specify the sequence number in which the specific blade row appears in the turbine (i.e., Nozzle 1, Nozzle 2, etc.). These sequence numbers and the blade row locations defined in the following table are used by program *AxTurb* to locate the blades in the proper position within the turbine. **See instructions and warnings on editing this template at the beginning of this document.**

Z_H	R_H	Z_S	R_S	**Upstream Blade Row**

VI. Nozzle Blade Row Geometry:

The nozzle row geometry required varies with the type (diaphragm-disk, drum rotor, shrouded or unshrouded). Supply only the geometry applicable to this specific nozzle row type.

Check Type: ☐ Diaphragm-Disk Type

☐ Unshrouded Drum-Rotor Type

☐ Shrouded Drum-Rotor Type

Nozzle Row Number (In Sequence of Location in Turbine) -- ____________

Number Of blades: -- ____________

Fractional Arc of Admission (If Partial Admission) ------ ____________

Number of Admission Arcs (If Partial Admission) --------- ____________

Shaft Seal Base Clearance, Δ, or Blade Clearance -------- ____________

Average rms Surface Finish (x 10^{-6}) ---------------------- ____________

Number of Shaft Seal Fins, NSHFT (0 If None) ------------ ____________

Shaft Seal Pitch (If NSHFT > 0) ------------------------- ____________

Shaft Seal Gap Radius (If NSHFT > 0) -------------------- ____________

Shaft Seal Fin Thickness (If NSHFT > 0) ----------------- ____________

Shaft Seal clearance (If NSHFT > 0) --------------------- ____________

Number of Disk Seal Fins, NDSK (0 If None) -------------- ____________

Disk Seal Clearance (If NDSK > 0) ----------------------- ____________

Disk Seal Lower Radius (If NDSK > 0) -------------------- ____________

Disk Seal Upper Radius (If NDSK > 0) -------------------- ____________

Disk Seal Fin Thickness (If NDSK > 0) ------------------- ____________

Radius	β_1	β_g	**c**	t_{max}	t_2	$1/R_c$

VII. Rotor Blade Row Geometry:

The rotor row geometry required also varies with the type (diaphragm-disk, drum rotor, shrouded or unshrouded). Supply only the geometry applicable to this specific rotor row type.

Check Type: ☐ Unshrouded Diaphragm-Disk Type

☐ Shrouded Diaphragm-Disk Type

☐ Unshrouded Drum-Rotor Type

☐ Shrouded Drum-Rotor Type

Rotor Row Number (In Sequence Of Location In Turbine) ---- ____________

Number Of Blades --- ____________

Average rms Surface Finish (x 10^{-6}) --------------------- ____________

Number Of Balance Holes (if any, diaphragm disk type only) ____________

Balance Hole Diameter (if any, diaphragm disk type only) - ____________

Shroud Seal Base Clearance, Δ, or Blade Tip Clearance ---- ____________

Number of Lashing Wires (if any) ------------------------- ____________

Lashing Wire Diameter (if any) --------------------------- ____________

Number Of Tip Shroud Seals, NSL (0 if none) -------------- ____________

Shroud Seal Pitch, (if NSL > 0) -------------------------- ____________

Shroud Seal Gap Radius, (if NSL > 0) --------------------- ____________

Shroud Seal Fin Thickness, (if NSL > 0) ------------------ ____________

Shroud Seal Clearance, (if NSL > 0) ---------------------- ____________

Disk Axial Gap Width (diaphragm disk type only) ---------- ____________

Shaft Radius (diaphragm disk type only) ------------------ ____________

Fractional Shielding (if any, partial admission only) ---- ____________

Radius	β_1	β_g	**c**	t_{max}	t_2	$1/R_c$

VIII. Reversing Row Blade Row Geometry:

The reversing row geometry required ia quite similar to nozzle rows. Supply only the geometry applicable to this reversing row. When axial gap seals of figure 3 are used, the only seal specification is the axial gap clearance.

Check Type: ☐ Diaphragm-Disk Type With Diaphragm Shaft Seals

☐ Diaphragm-Disk Type With Axial Gap Seals (figure 3)

☐ Unshrouded Drum-Rotor Type

☐ Shrouded Drum-Rotor Type

Reversing Row Number (In Sequence Of Location In Turbine) ____________

Number Of blades -- ____________

Fractional Arc Of Admission (If Partial Admission) ------ ____________

Number Of Admission Arcs (If Partial Admission) --------- ____________

Shaft Seal Base Clearance, Δ, or Blade Clearance -------- ____________

Average rms Surface Finish (x 10^{-6}) --------------------- ____________

Number of Shaft Seal Fins, NSHFT (0 If None) ------------ ____________

Shaft Seal Pitch (If NSHFT > 0) ------------------------- ____________

Shaft Seal Gap Radius (If NSHFT > 0) -------------------- ____________

Shaft Seal Fin Thickness (If NSHFT > 0) ----------------- ____________

Shaft Seal (If NSHFT > 0) Or Axial Gap Seal Clearance --- ____________

Number Of Disk Seal Fins, NDSK (0 If None) -------------- ____________

Disk Seal Clearance (If NDSK > 0) ----------------------- ____________

Disk Seal Lower Radius (If NDSK > 0) -------------------- ____________

Disk Seal Upper Radius (If NDSK > 0) -------------------- ____________

Disk Seal Fin Thickness (If NDSK > 0) ------------------- ____________

Radius	β_1	β_g	**c**	t_{max}	t_2	$1/R_c$

IX. **Guide Vane Blade Row Geometry:**

The guide vane geometry is identical to nozzle row geometry. The guide vane designation simply allows the program to recognize that the blade row is not part of a logical stage so that stage performance data can be supplied.

Check Type: ☐ Diaphragm-Disk Type

☐ Unshrouded Drum-Rotor Type

☐ Shrouded Drum-Rotor Type

Guide Vane Number (In Sequence Of Location In Turbine) - ____________

Number Of blades: ------------------------------------- ____________

Fractional Arc Of Admission (If Partial Admission) ----- ____________

Number Of Admission Arcs (If Partial Admission) --------- ____________

Shaft Seal Base Clearance, Δ, or Blade Clearance -------- ____________

Average rms Surface Finish (x 10^{-6}) --------------------- ____________

Number of Shaft Seal Fins, NSHFT (0 If None) ----------- ____________

Shaft Seal Pitch (If NSHFT > 0) ------------------------ ____________

Shaft Seal Gap Radius (If NSHFT > 0) -------------------- ____________

Shaft Seal Fin Thickness (If NSHFT > 0) ---------------- ____________

Shaft Seal clearance (If NSHFT > 0) --------------------- ____________

Number Of Disk Seal Fins, NDSK (0 If None) ------------- ____________

Disk Seal Clearance (If NDSK > 0) ----------------------- ____________

Disk Seal Lower Radius (If NDSK > 0) -------------------- ____________

Disk Seal Upper Radius (If NDSK > 0) -------------------- ____________

Disk Seal Fin Thickness (If NDSK > 0) ------------------ ____________

Radius	β_1	β_g	**c**	t_{max}	t_2	$1/R_c$